

**ASME B31.3-2020**  
(Revision of ASME B31.3-2018)

# Process Piping

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**ASME Code for Pressure Piping, B31**

**AN INTERNATIONAL PIPING CODE®**



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**The American Society of  
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# FOREWORD

Responding to evident need and at the request of The American Society of Mechanical Engineers (ASME), the American Standards Association initiated Project B31 in March 1926, with ASME as sole administrative sponsor. The breadth of the field involved required that membership of the Sectional Committee be drawn from some 40 engineering societies, industries, government bureaus, institutes, and trade associations.

Initial publication in 1935 was as the American Tentative Standard Code for Pressure Piping. Revisions from 1942 through 1955 were published as American Standard Code for Pressure Piping, ASA B31.1. It was then decided to publish as separate documents the various industry Sections, beginning with ASA B31.8-1955, Gas Transmission and Distribution Piping Systems. The first Petroleum Refinery Piping Code Section was designated ASA B31.3-1959. ASA B31.3 revisions were published in 1962 and 1966.

In 1967–1969, the American Standards Association became first the United States of America Standards Institute, then the American National Standards Institute (ANSI). The Sectional Committee became American National Standards Committee B31 and the Code was renamed the American National Standard Code for Pressure Piping. The next B31.3 revision was designated ANSI B31.3-1973. Addenda were published through 1975.

A draft Code Section for Chemical Plant Piping, prepared by Section Committee B31.6, was ready for approval in 1974. It was decided, rather than have two closely related Code Sections, to merge the Section Committees and develop a joint Code Section, titled Chemical Plant and Petroleum Refinery Piping. The first edition was published as ANSI B31.3-1976.

In this Code, responsibility for piping design was conceptually integrated with that for the overall processing facility, with safeguarding recognized as an effective safety measure. Three categories of Fluid Service were identified, with a separate Chapter for Category M Fluid Service. Coverage for nonmetallic piping was introduced. New concepts were better defined in five Addenda, the fourth of which added Appendix M, a graphic aid to selection of the proper Fluid Service category.

The Standards Committee was reorganized in 1978 as a Committee operating under ASME procedures with ANSI accreditation. It is now the ASME Code for Pressure Piping, B31 Committee. Section committee structure remains essentially unchanged.

The second edition of Chemical Plant and Petroleum Refinery Piping was compiled from the 1976 Edition and its five Addenda, with nonmetal requirements editorially relocated to a separate Chapter. Its new designation was ANSI/ASME B31.3-1980.

Section Committee B31.10 had a draft Code for Cryogenic Piping ready for approval in 1981. Again, it was decided to merge the two Section Committees and develop a more inclusive Code with the same title. The work of consolidation was partially completed in the ANSI/ASME B31.3-1984 Edition.

Significant changes were made in Addenda to the 1984 Edition: integration of cryogenic requirements was completed; a new stand-alone Chapter on high-pressure piping was added; and coverage of fabrication, inspection, testing, and allowable stresses was reorganized. The new Edition was designated as ASME/ANSI B31.3-1987 Edition.

Addenda to the subsequent five Editions, published at 3-year intervals, were primarily used to keep the Code up to date. New Appendices were added, however, on requirements for bellows expansion joints, estimating service life, submittal of Inquiries, aluminum flanges, and quality control in the 1990, 1993, 1999, and 2002 Editions, all designated as ASME B31.3.

In a program to clarify the application of all Sections of the Code for Pressure Piping, changes were made in the Introduction and Scope statements of the 1996 Edition, and its title was changed to Process Piping.

Under direction of ASME Codes and Standards management, SI (metric) units of measurement were emphasized. With certain exceptions, SI units were listed first in the 1996 Edition and were designated as the standard. Instructions for conversion were given where SI units data were not available. U.S. Customary units also were given. By agreement, either system may have been used.

Beginning with the 2004 Edition, the publication cycle of ASME B31.3 was changed to biennial. Other changes made in the 2004 Edition included the introduction of the weld joint strength reduction factor,  $W$ , and the additions of Appendix P, Alternative Rules for Evaluating Stress Range, and Appendix S, Piping System Stress Analysis Examples.

Changes that were made to the 2006 and 2008 Editions of ASME B31.3 included the requirement that valves have blowout-proof stems and the addition of a definition for elevated temperature fluid service, respectively. The most significant change that was made to the 2010 Edition of ASME B31.3 was the addition of Chapter X, High Purity

Piping. In the 2012 Edition, Tables A-1M and A-2M were added to Appendix A that give allowable design values in SI units, and Appendix N, Application of ASME B31.3 Internationally, was also added.

For the 2016 Edition, the allowable design values in SI units as shown in Tables A-1M and A-2M were changed from for information only to values that may be used to meet the requirements of the Code.

In this Edition, SI units are given first, with U.S. Customary units in parentheses. Table K-1 in Appendix K is an exception, containing only U.S. Customary units. The allowable design values in Tables A-1 and A-2 are given in U.S. Customary units, and the SI values are given in Tables A-1M and A-2M. Either the U.S. Customary units or the SI units for these allowable design values may be used. Except for Tables A-1, A-1M, A-2, A-2M, C-1, C-1M, C-6, C-6M, and K-1, values in SI units are to be regarded as the standard, unless otherwise agreed between the contracting parties. Instructions are given in Table K-1 for converting tabular data in U.S. Customary units to appropriate SI units.

Interpretations, Code Cases, and errata to the B31.3 Code on Process Piping are published on the following ASME web page: <https://cstools.asme.org/csconnect/CommitteePages.cfm?Committee=N10020400>.

ASME B31.3-2020 was approved by the American National Standards Institute on September 29, 2020.



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## Code for Pressure Piping

(The following is the roster of the Committee at the time of approval of this Code.)

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# INTRODUCTION

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections, each an American National Standard, under the direction of ASME Committee B31, Code for Pressure Piping.

Rules for each Section reflect the kinds of piping installations considered during its development, as follows:

- B31.1 Power Piping: piping typically found in electric power generating stations, in industrial and institutional plants, geothermal heating systems, and central and district heating and cooling systems
- B31.3 Process Piping: piping typically found in petroleum refineries; onshore and offshore petroleum and natural gas production facilities; chemical, pharmaceutical, textile, paper, ore processing, semiconductor, and cryogenic plants; food and beverage processing facilities; and related processing plants and terminals
- B31.4 Pipeline Transportation Systems for Liquids and Slurries: piping transporting products that are predominately liquid between plants and terminals and within terminals, pumping, regulating, and metering stations
- B31.5 Refrigeration Piping and Heat Transfer Components: piping for refrigerants and secondary coolants
- B31.8 Gas Transmission and Distribution Piping Systems: piping transporting products that are predominately gas between sources and terminals, including compressor, regulating, and metering stations; gas gathering pipelines
- B31.9 Building Services Piping: piping typically found in industrial, institutional, commercial, and public buildings, and in multi-unit residences, which does not require the range of sizes, pressures, and temperatures covered in B31.1
- B31.12 Hydrogen Piping and Pipelines: piping in gaseous and liquid hydrogen service and pipelines in gaseous hydrogen service

This is the B31.3 Process Piping Code Section. Hereafter, in this Introduction and in the text of this Code Section B31.3, where the word *Code* is used without specific identification, it means this Code Section.

It is the owner's responsibility to select the Code Section that most nearly applies to a proposed piping installation. Factors to be considered by the owner include limitations of the Code Section; jurisdictional requirements; and the applicability of other codes and standards. All applicable requirements of the selected Code Section shall be met. For some installations, more than one Code Section may apply to different parts of the installation. The owner is also responsible for imposing requirements supplementary to those of the Code if necessary to assure safe piping for the proposed installation.

Certain piping within a facility may be subject to other codes and standards, including but not limited to

- ANSI Z223.1 National Fuel Gas Code: piping for fuel gas from the point of delivery to the connection of each fuel utilization device

- NFPA Fire Protection Standards: fire protection systems using water, carbon dioxide, halon, foam, dry chemicals, and wet chemicals

- NFPA 99 Health Care Facilities: medical and laboratory gas systems

- building and plumbing codes, as applicable, for potable hot and cold water, and for sewer and drain systems

The Code specifies engineering requirements deemed necessary for safe design and construction of pressure piping. While safety is the primary consideration, this factor alone will not necessarily govern the final specifications for any piping installation. The Code is not a design handbook. Many decisions that must be made to produce a sound piping installation are not specified in detail within this Code. The Code does not serve as a substitute for sound engineering judgments by the owner and the designer.

To the greatest possible extent, Code requirements for design are stated in terms of basic design principles and formulas. These are supplemented as necessary with specific requirements to ensure uniform application of principles and to guide selection and application of piping elements. The Code prohibits designs and practices known to be unsafe and contains warnings where caution, but not prohibition, is warranted.

This Code Section includes the following:

(a) references to acceptable material specifications and component standards, including dimensional requirements and pressure–temperature ratings

(b) requirements for design of components and assemblies, including piping supports

(c) requirements and data for evaluation and limitation of stresses, reactions, and movements associated with pressure, temperature changes, and other forces

(d) guidance and limitations on the selection and application of materials, components, and joining methods

(e) requirements for the fabrication, assembly, and erection of piping

(f) requirements for examination, inspection, and testing of piping

Either International System (SI, also known as metric) or U.S. Customary units may be used with this edition. Local customary units may also be used to demonstrate compliance with this Code. One system of units should be used consistently for requirements applying to a specific installation. The equations in this Code may be used with any consistent system of units. It is the responsibility of the organization performing calculations to ensure that a consistent system of units is used.

ASME Committee B31 is organized and operates under procedures of The American Society of Mechanical Engineers that have been accredited by the American National Standards Institute. The Committee is a continuing one, and keeps all Code Sections current with new developments in materials, construction, and industrial practice. New editions are published at intervals of 2 years.

Code users will note that paragraphs in the Code are not necessarily numbered consecutively. Such discontinuities result from following a common outline, insofar as practical, for all Code Sections. In this way, corresponding material is correspondingly numbered in most Code Sections, thus facilitating reference by those who have occasion to use more than one Section.

This edition of Code Section B31.3 is not retroactive. Normally, agreement is made between contracting parties to use a specific edition, considering requirements

of the authority having jurisdiction. When specified as the latest edition and when no edition is specified, the specific edition is the one issued at least 6 months prior to the original contract date for the first design activity.

Users of this Code are cautioned against making use of Code revisions without assurance that they are acceptable to the proper authorities in the jurisdiction where the piping is to be installed.

The B31 Committee has established an orderly procedure to consider requests for interpretation and revision of Code requirements. To receive consideration, such request must be in writing and must give full particulars in accordance with [Appendix Z](#).

The approved reply to an inquiry will be sent directly to the inquirer. In addition, the question and reply will be published as part of an Interpretation supplement.

A Case is the prescribed form of reply when study indicates that the Code wording needs clarification, or when the reply modifies existing requirements of the Code or grants permission to use new materials or alternative constructions. The Case will be published as part of a Case supplement.

Code Cases remain available for use until annulled by the ASME B31 Standards Committee.

A request for revision of the Code will be placed on the Committee's agenda. Further information or active participation on the part of the proponent may be requested during consideration of a proposed revision.

Materials ordinarily are listed in the stress tables only when sufficient usage in piping within the scope of the Code has been shown. Requests for listing shall include evidence of satisfactory usage and specific data to permit establishment of allowable stresses, maximum and minimum temperature limits, and other restrictions. Additional criteria can be found in the guidelines for addition of new materials in the ASME Boiler and Pressure Vessel Code, Section II. (To develop usage and gain experience, unlisted materials may be used in accordance with [para. 323.1.2](#).)

# ASME B31.3-2020

## SUMMARY OF CHANGES

Following approval by the ASME B31 Committee and ASME, and after public review, ASME B31.3-2020 was approved by the American National Standards Institute on September 29, 2020.

ASME B31.3-2020 includes the following changes identified by a margin note, **(20)**.

| <i>Page</i> | <i>Location</i> | <i>Change</i>                                                                                |
|-------------|-----------------|----------------------------------------------------------------------------------------------|
| xx          | Introduction    | After subpara. (f), paragraph added                                                          |
| 2           | 300.1.4         | Added, and subsequent paragraph redesignated                                                 |
| 10          | Table 300.4     | Appendix D deleted                                                                           |
| 12          | 301.3.2         | Title revised                                                                                |
| 12          | 301.3.3         | Title revised                                                                                |
| 12          | 301.3.4         | Title revised                                                                                |
| 13          | 302.2.4         | Revised                                                                                      |
| 14          | 302.2.5         | Last sentence deleted                                                                        |
| 16          | Table 302.3.3C  | General Note revised                                                                         |
| 19          | 302.3.6         | Subparagraph (a)(1) revised                                                                  |
| 24          | 304.3.1         | Subparagraphs (a) and (a)(2) revised                                                         |
| 31          | 304.5.2         | Subparagraph (b) revised                                                                     |
| 32          | 304.7.2         | Subparagraphs (b) and (c) revised                                                            |
| 34          | 306.5.2         | Revised                                                                                      |
| 34          | 307.1.2         | Last sentence deleted                                                                        |
| 36          | 311.2.2         | Subparagraph (d) revised                                                                     |
| 37          | 314.2.1         | Subparagraph (c) revised                                                                     |
| 40          | 319.3.4         | Subparagraph (b) revised                                                                     |
| 40          | 319.3.6         | Revised                                                                                      |
| 41          | 319.4.4         | (1) Subparagraphs (a) and (b) revised<br>(2) Subparagraph (c) and eqs. (19) and (20) deleted |
| 43          | 320.1           | Revised                                                                                      |
| 44          | 320.2           | (1) Revised<br>(2) Footnote 9 added                                                          |
| 49          | Table 323.2.2   | Items A-3(b) and B-3 revised                                                                 |
| 56          | Table 323.3.1   | (1) Items 4, A-5, and B-5 revised<br>(2) Note (4) deleted                                    |
| 60          | Table 326.1     | Revised in its entirety                                                                      |
| 66          | 328.5.2         | Revised in its entirety                                                                      |
| 66          | 328.5.4         | Subparagraphs (d), (e)(2), and (f) revised                                                   |
| 67          | Figure 328.5.2A | Title revised                                                                                |
| 67          | Figure 328.5.2B | Title revised                                                                                |
| 68          | Figure 328.5.2C | (1) Title revised<br>(2) Variable for nominal pipe wall thickness revised                    |

| <i>Page</i> | <i>Location</i> | <i>Change</i>                                                                                               |
|-------------|-----------------|-------------------------------------------------------------------------------------------------------------|
| 69          | 328.6           | Revised                                                                                                     |
| 71          | 330.1           | Last paragraph added                                                                                        |
| 73          | 331.1.1         | Subparagraph (a) revised                                                                                    |
| 73          | 331.1.3         | Subparagraph (b)(5)(-a) revised                                                                             |
| 74          | Table 331.1.1   | Note (7) revised                                                                                            |
| 73          | 331.1.6         | Subparagraph (c) revised                                                                                    |
| 75          | 331.2.6         | Revised                                                                                                     |
| 78          | 332.4           | Last sentence added                                                                                         |
| 90          | 344.6.2         | Subparagraph (a) revised                                                                                    |
| 103         | A321.5.1        | Subparagraph (a) revised                                                                                    |
| 103         | A321.5.2        | Revised in its entirety                                                                                     |
| 106         | A328.2.1        | Subparagraph (b)(6) revised                                                                                 |
| 107         | Table A326.1    | Standards ASTM D3309, ASTM D2310, ASTM D2447, ASTM D3309, and ASTM F1974 deleted                            |
| 109         | A328.2.5        | Nomenclature in subpara. (c)(1) revised                                                                     |
| 120         | M331            | Revised                                                                                                     |
| 124         | K300            | Revised in its entirety                                                                                     |
| 124         | K300.1          | K300.1.4 added, subsequent paragraphs redesignated, and cross-references updated                            |
| 125         | K302.3.1        | Subparagraphs (b) and (d) revised                                                                           |
| 126         | K302.3.2        | Subparagraphs (b), (c), and (d) revised                                                                     |
| 127         | K302.3.6        | Subparagraph (a) revised                                                                                    |
| 128         | K304.1.2        | Revised                                                                                                     |
| 128         | K304.1.3        | Revised                                                                                                     |
| 128         | K304.2.4        | Revised                                                                                                     |
| 129         | K304.7.2        | Subparagraph (c) revised                                                                                    |
| 130         | K304.7.3        | Revised                                                                                                     |
| 130         | K304.8.1        | First paragraph and footnote 6 revised                                                                      |
| 130         | K304.8.2        | Former subpara. (a) deleted, and subsequent subparagraphs revised and redesignated                          |
| 130         | K304.8.3        | Subparagraph (c) revised                                                                                    |
| 130         | K304.8.5        | First paragraph revised                                                                                     |
| 131         | K307            | Revised in its entirety                                                                                     |
| 132         | K314.2          | Subparagraph (b) revised                                                                                    |
| 133         | K317.2          | Title revised                                                                                               |
| 134         | K322.6.3        | (1) Subparagraphs (a) and (b) revised<br>(2) Subparagraph (c) deleted                                       |
| 135         | K323.2.2        | Revised in its entirety                                                                                     |
| 135         | K323.3.1        | Revised                                                                                                     |
| 135         | K323.3.4        | Revised in its entirety                                                                                     |
| 139         | Table K326.1    | (1) Standards under “Bolting” and “Metallic Fittings, Valves, and Flanges” revised<br>(2) Note (1)(c) added |
| 140         | K328            | Revised                                                                                                     |
| 140         | K328.1          | Revised in its entirety                                                                                     |



| <i>Page</i> | <i>Location</i>                                       | <i>Change</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------------|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 140         | K328.2.1                                              | Subparagraphs (b) and (f) revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 140         | K328.3.1                                              | Revised in its entirety                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 141         | K330.1                                                | Revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 141         | K331                                                  | Revised in its entirety                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 143         | K332.4.1                                              | Revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 143         | K332.4.2                                              | Subparagraph (a) revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 143         | K333                                                  | Revised in its entirety                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 144         | K341.3.3                                              | Subparagraphs (a) and (b) revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 144         | K341.4.1                                              | (1) Subparagraph (b) revised<br>(2) Subparagraph (c) added                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 148         | K345.1                                                | Subparagraphs (a), (b), and (d) revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 148         | K345.2.1                                              | Former footnote 10 deleted                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 149         | K346.1                                                | Revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 149         | K346.2                                                | (1) Subparagraph (b) added, and subsequent subparagraphs redesignated<br>(2) Subparagraphs (d) and (f) revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 152         | U328                                                  | Revised                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 152         | U328.2                                                | Revised in its entirety                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 152         | U328.4.2                                              | Added                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 154         | U341.4.1                                              | (1) First paragraph and subparas. (a) and (b) revised<br>(2) Subparagraph (c) added                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 159         | Specification Index for Appendix A                    | (1) A381, B166, B462, B649, B688, and B690 revised<br>(2) B547 deleted                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 163         | Notes for Tables A-1, A-1M, A-1A, A-1B, A-2, and A-2M | (1) General Note (f) and in-text table in Note (42) revised<br>(2) Note (44) deleted                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 167         | Table A-1                                             | (1) Under Iron — Castings, for Gray A278 40, Note (9) reference deleted<br>(2) Under Carbon Steel — Pipes and Tubes, for A285 Gr. A A134, A285 Gr. B A134, and A285 Gr. C A134, Type/Grade and UNS No. added<br>(3) For A516 Gr. 60, stress values for 700°F and 800°F revised<br>(4) For A516 Gr. 65, stress values for 850°F and 900°F revised<br>(5) Under Carbon Steel — Pipes (Structural Grade), A283 Gr. A and B deleted<br>(6) A1011 Gr. 30, 33, 36, and 40; A36; A283; and A1011 Gr. 45 and 50 revised<br>(7) Under Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural), A283 A and B deleted<br>(8) A1011 30, 33, 36, 40, 45, and 50; A283 C and D; and A36 revised<br>(9) Under Stainless Steel — Pipes and Tubes, A376 16-8-2H deleted<br>(10) A312 TP310S revised<br>(11) A358 310S deleted<br>(12) For A813, A814, A249, and A312 S31254, Notes and stress values revised |

| <i>Page</i> | <i>Location</i> | <i>Change</i>                                                                                                               |
|-------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------|
|             |                 | (13) For A358 S31254, stress values revised                                                                                 |
|             |                 | (14) A789 S32900 deleted                                                                                                    |
|             |                 | (15) Under Stainless Steel — Plates and Sheets, A240 439 deleted                                                            |
|             |                 | (16) A240 310H revised                                                                                                      |
|             |                 | (17) A240 S31254 Notes and stress values revised                                                                            |
|             |                 | (18) Under Stainless Steel — Forgings and Fittings, A182 F10 deleted                                                        |
|             |                 | (19) A182 F310, A403 WP310S, and A403 WP310H revised                                                                        |
|             |                 | (20) For A182 and A403 S31254, Notes and stress values revised                                                              |
|             |                 | (21) A403 S31254, A815 S31803, A403 N08367, and A815 S32750 deleted                                                         |
|             |                 | (22) A815 S32101, A815 S32205, and A815 S32760 revised                                                                      |
|             |                 | (23) A182 S41000 and A182 S41026 deleted                                                                                    |
|             |                 | (24) A182 S32750 revised                                                                                                    |
|             |                 | (25) Under Stainless Steel — Bar, A479 S31254 Note and stress values revised                                                |
|             |                 | (26) A479 S32205 and A479 S20910 revised                                                                                    |
|             |                 | (27) Under Stainless Steel — Castings, for A351 CH10, A351 CH20, and A351 CF8C, stress values revised                       |
|             |                 | (28) Under Nickel and Nickel Alloy — Castings, A494 CX2MW reordered and revised                                             |
|             |                 | (29) A494 CW12MW and A494 CW6M revised                                                                                      |
|             |                 | (30) Under Zirconium and Zirconium Alloy — Pipes and Tubes, B523 R60702, B658 R60702, and B658 R60705 revised               |
|             |                 | (31) B523 R60705 deleted                                                                                                    |
|             |                 | (32) Under Zirconium and Zirconium Alloy — Plates and Sheets, B551 R60702 and B551 R60705 revised                           |
|             |                 | (33) Under Zirconium and Zirconium Alloy — Forgings and Bar, B493 R60702, B550 R60702, B493 R60705, and B550 R60705 revised |
|             |                 | (34) Aluminum Alloy — Welded Pipes and Tubes category deleted                                                               |
| 242         | Table A-1M      | (1) Listings for Nominal Composition Fe revised in their entirety                                                           |
|             |                 | (2) A134 revised                                                                                                            |
|             |                 | (3) For A524, A333, A334, A671, A672, A139, API 5L, and A381, stress values revised                                         |
|             |                 | (4) A516, A515, A1011, A283, A36, and A992 revised                                                                          |
|             |                 | (5) A376 deleted                                                                                                            |
|             |                 | (6) For A312, Type/Grade, UNS No., and Notes revised                                                                        |
|             |                 | (7) A358 deleted                                                                                                            |
|             |                 | (8) For A813, A814, A249, and A312, Notes deleted                                                                           |
|             |                 | (9) A789 and A240 deleted                                                                                                   |
|             |                 | (10) For A240 and A403, Type/Grade, UNS No., and Notes revised                                                              |
|             |                 | (11) A182, A403, A815, and A479 revised                                                                                     |
|             |                 | (12) For A351, stress values revised                                                                                        |
|             |                 | (13) Wld. tube B626 added                                                                                                   |
|             |                 | (14) A494, B523, B658, B551, B493, and B550 revised                                                                         |

| <i>Page</i> | <i>Location</i>                    | <i>Change</i>                                                                                                                      |
|-------------|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
|             |                                    | (15) B547 deleted                                                                                                                  |
| 349         | Table A-1B                         | B547 deleted                                                                                                                       |
| 354         | Table A-2                          | (1) A194 4 and A194 4L deleted<br>(2) A193 B8 added                                                                                |
| 364         | Table A-2M                         | (1) A194 4 and A194 4L deleted<br>(2) A193 B8 added                                                                                |
| 385         | Specification Index for Appendix B | D2447 and D3309 deleted                                                                                                            |
| 386         | Table B-1                          | D3309, D2239, D2447, D3035, and F714 deleted                                                                                       |
| 388         | Table B-1M                         | D3309, D2239, D2447, D3035, and F714 deleted                                                                                       |
| 412         | Appendix D                         | Deleted                                                                                                                            |
| 413         | Appendix E                         | Revised in its entirety                                                                                                            |
| 419         | F300.1.5                           | Former para. F300.1.4 editorially redesignated                                                                                     |
| 419         | F301.10.2                          | Revised                                                                                                                            |
| 420         | F302                               | Added                                                                                                                              |
| 421         | F323                               | Subparagraph (b) revised                                                                                                           |
| 423         | F331.1                             | Revised                                                                                                                            |
| 424         | FA328                              | Added                                                                                                                              |
| 428         | H301                               | Revised                                                                                                                            |
| 428         | H302                               | Revised                                                                                                                            |
| 429         | H303                               | Revised                                                                                                                            |
| 431         | H304                               | Revised                                                                                                                            |
| 437         | Appendix J                         | Cross-references updated                                                                                                           |
| 453         | Appendix K                         | (1) ASTM A928 added to Specification Index<br>(2) Page column deleted in Specification Index                                       |
| 455         | Notes for Table K-1                | (1) General Notes (b) and (d) and Notes (3), (4), and (20) revised<br>(2) General Note (h) added<br>(3) Notes (6) and (12) deleted |
| 456         | Table K-1                          | Revised in its entirety                                                                                                            |
| 474         | Figure M300                        | In Col. 1, cross-references to para. K300.1.5 revised to K300.1.6                                                                  |
| 477         | R301                               | (1) Subparagraph (b) revised<br>(2) Subparagraph (c) deleted                                                                       |
| 480         | Appendix S                         | Revised in its entirety                                                                                                            |
| 495         | V304                               | Revised in its entirety                                                                                                            |
| 500         | Table W302.1-4                     | Editorially redesignated                                                                                                           |
| 507         | Index                              | Added                                                                                                                              |

# Chapter I

## Scope and Definitions

### 300 GENERAL STATEMENTS

(a) *Identification.* This Process Piping Code is a Section of The American Society of Mechanical Engineers Code for Pressure Piping, ASME B31, an American National Standard. It is published as a separate document for convenience of Code users.

(b) *Responsibilities*

(1) *Owner.* The owner of a piping installation shall have overall responsibility for compliance with this Code, and for establishing the requirements for design, construction, examination, inspection, and testing that will govern the entire fluid handling or process installation of which the piping is a part. The owner is also responsible for designating piping in Category D, Category M, High Pressure, and High Purity Fluid Services, and for determining if a specific Quality System is to be employed. [See (d)(4) through (d)(7) and Appendix Q.] Where applicable, the owner shall consider requirements imposed by the authority having jurisdiction regarding the piping installation. The owner may designate a representative to carry out selected responsibilities required by this Code, but the owner retains ultimate responsibility for the actions of the representative.

(2) *Designer.* The designer is responsible to the owner for assurance that the engineering design of piping complies with the requirements of this Code and with any additional requirements established by the owner.

(3) *Manufacturer, Fabricator, and Erector.* The manufacturer, fabricator, and erector of piping are responsible for providing materials, components, and workmanship in compliance with the requirements of this Code and of the engineering design.

(4) *Owner's Inspector.* The owner's Inspector (see para. 340) is responsible to the owner for ensuring that the requirements of this Code for inspection, examination, and testing are met. If a Quality System is specified by the owner to be employed, the owner's Inspector is responsible for verifying that it is implemented.

(c) *Intent of the Code*

(1) It is the intent of this Code to set forth engineering requirements deemed necessary for safe design and construction of piping installations.

(2) This Code is not intended to apply to the operation, examination, inspection, testing, maintenance, or repair of piping that has been placed in service. See

para. F300.1 for examples of standards that may apply in these situations. The provisions of this Code may optionally be applied for those purposes, although other considerations may also be necessary.

(3) The Code generally specifies a simplified approach for many of its requirements. A designer may choose to use a more rigorous analysis to develop design and construction requirements. When the designer decides to take this approach, the designer shall provide to the owner details and calculations demonstrating that design, construction, examination, and testing are consistent with the design criteria of this Code. These details shall be adequate for the owner to verify the validity and shall be approved by the owner. The details shall be documented in the engineering design.

(4) Piping elements shall conform to the specifications and standards listed in this Code or, if not prohibited by this Code, shall be qualified for use as set forth in applicable Chapters of this Code.

(5) The engineering design shall specify any unusual requirements for a particular service. Where service requirements necessitate measures beyond those required by this Code, such measures shall be specified by the engineering design. Where so specified, the Code requires that they be accomplished.

(6) Compatibility of materials with the service and hazards from instability of contained fluids are not within the scope of this Code. See para. F323.

(d) *Determining Code Requirements*

(1) Code requirements for design and construction include fluid service requirements, which affect selection and application of materials, components, and joints. Fluid service requirements include prohibitions, limitations, and conditions, such as temperature limits or a requirement for safeguarding (see Appendix G). Code requirements for a piping system are the most restrictive of those that apply to any of its elements.

(2) For metallic piping not designated by the owner as Category M, High Pressure, or High Purity Fluid Service (see para. 300.2 and Appendix M), Code requirements are found in Chapters I through VI (the base Code) and fluid service requirements are found in

- (-a) Chapter III for materials
- (-b) Chapter II, Part 3, for components
- (-c) Chapter II, Part 4, for joints

(3) For nonmetallic piping and piping lined with nonmetals, all requirements are found in [Chapter VII](#). Paragraph designations begin with “A.”

(4) For piping in a fluid service designated as Category M, all requirements are found in [Chapter VIII](#). Paragraph designations begin with “M.”

(5) For piping in a fluid service designated as Category D, piping elements restricted to Category D Fluid Service in [Chapters I](#) through [VII](#), as well as elements suitable for other fluid services, may be used.

(6) For piping designated as High Pressure Fluid Service, all requirements are found in [Chapter IX](#). These rules apply only when specified by the owner. Paragraph designations begin with “K.”

(7) For piping designated as High Purity Fluid Service, all requirements are found in [Chapter X](#). Paragraph designations begin with “U.”

(8) Requirements for Normal Fluid Service in [Chapters I](#) through [VI](#) are applicable under severe cyclic conditions unless alternative requirements for severe cyclic conditions are stated.

(9) Requirements for Normal Fluid Service in [Chapters I](#) through [VI](#) are applicable for Elevated Temperature Fluid Service unless alternative requirements for Elevated Temperature Fluid Service are invoked.

(e) *Appendices*. Appendices of this Code contain Code requirements, supplementary guidance, or other information. See [para. 300.4](#) for a description of the status of each Appendix.

(f) *Code Cases*. ASME issues Code Cases that are applicable to this Code. The Code Cases

(1) modify the requirements of this Code

(2) are applicable from the issue date until the Cases are annulled

(3) may be used only when approved by the owner. When so approved, the Code Cases shall be specified in the engineering design and become requirements of this Code.

### 300.1 Scope

Rules for the Process Piping Code Section B31.3<sup>1</sup> have been developed considering piping typically found in petroleum refineries; onshore and offshore petroleum and natural gas production facilities; chemical, pharmaceutical, textile, paper, ore processing, semiconductor, and cryogenic plants; food and beverage processing facilities; and related processing plants and terminals.

#### 300.1.1 Content and Coverage

(a) This Code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping.

(b) This Code applies to piping for all fluids, including

(1) raw, intermediate, and finished chemicals

(2) petroleum products

(3) gas, steam, air, and water

(4) fluidized solids

(5) refrigerants

(6) cryogenic fluids

(c) See [Figure 300.1.1](#) for a diagram illustrating the application of B31.3 piping at equipment. The joint connecting piping to equipment is within the scope of B31.3.

**300.1.2 Packaged Equipment Piping.** Also included within the scope of this Code is piping that interconnects pieces or stages within a packaged equipment assembly.

**300.1.3 Exclusions.** This Code excludes the following:

(a) piping systems designed for internal gage pressures at or above zero but less than 105 kPa (15 psi), provided the fluid handled is nonflammable, nontoxic, and not damaging to human tissues as defined in [300.2](#), and its design temperature is from  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) through  $186^{\circ}\text{C}$  ( $366^{\circ}\text{F}$ )

(b) power boilers in accordance with ASME BPVC,<sup>2</sup> Section I and boiler external piping that is required to conform to ASME B31.1

(c) tubes, tube headers, crossovers, and manifolds of fired heaters that are internal to the heater enclosure

(d) pressure vessels, heat exchangers, pumps, compressors, and other fluid handling or processing equipment, including internal piping and connections for external piping

**300.1.4 Units of Measure.** This Code states values in both SI and U.S. Customary units. Within the text, the U.S. Customary units are shown in parentheses or in separate tables. The values stated in each system are not exact equivalents; therefore, each system of units should be used independently of the other.

When separate equations are provided for SI and U.S. Customary units, those equations shall be executed using variables in the units associated with the specific equation. The results obtained from execution of these equations may be converted to other units.

When necessary to convert from one system of units to another, conversion should be made by rounding the values to the number of significant digits of implied precision in the starting value but not less than four significant digits for use in calculations.

<sup>2</sup> ASME BPVC references here and elsewhere in this Code are to the ASME Boiler and Pressure Vessel Code and its various Sections as follows:

Section I, Rules for Construction of Power Boilers

Section II, Materials, Parts C and D

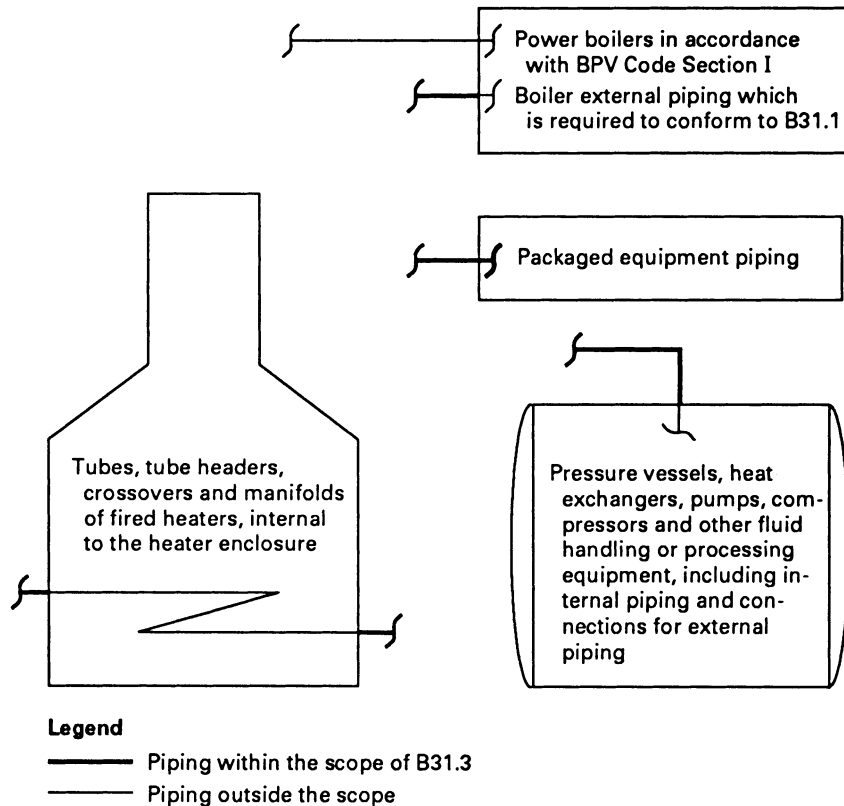
Section III, Rules for Construction of Nuclear Facility Components, Division 1, Subsection NH

Section V, Nondestructive Examination

Section VIII, Rules for Construction of Pressure Vessels, Divisions 1, 2, and 3

Section IX, Welding, Brazing, and Fusing Qualifications

<sup>1</sup> B31 references here and elsewhere in this Code are to the ASME B31 Code for Pressure Piping and its various Sections, which are identified and briefly described in the [Introduction](#).

**Figure 300.1.1 Diagram Illustrating Application of B31.3 Piping at Equipment**

GENERAL NOTE: The means by which piping is attached to equipment is within the scope of the applicable piping code.

**300.1.5 Rounding.** The rules described in this paragraph apply unless otherwise specified in the Code or the engineering design. For purposes of determining conformance with specified limits in this Code, an observed value or a calculated value shall be rounded “to the nearest unit” in the last right-hand significant digit used in expressing the requirement, in accordance with the rounding method of ASTM E29, Using Significant Digits in Test Data to Determine Conformance with Specifications. ASTM E29 requires that when rounding a number to one having a specified number of significant digits, choose that which is nearest. If two choices are possible, as when the digits dropped are exactly a 5 or a 5 followed only by zeros, choose that ending in an even digit. See [Appendix F, para. F300.1.5](#).

## 300.2 Definitions

Some of the terms relating to piping are defined below. For welding, brazing, and soldering terms not shown here, definitions in accordance with AWS Standard A3.0<sup>3</sup> apply.

<sup>3</sup> AWS A3.0M/A3.0, Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting and Thermal Spraying

*air-hardened steel:* a steel that hardens during cooling in air from a temperature above its transformation range.

*anneal heat treatment:* see *heat treatment*.

*arc cutting:* a group of cutting processes wherein the severing or removing of metals is effected by melting with the heat of an arc between an electrode and the base metal. (Includes carbon-arc cutting, metal-arc cutting, gas metal-arc cutting, gas tungsten-arc cutting, plasma-arc cutting, and air carbon-arc cutting.) See also *oxygen-arc cutting*.

*arc welding (AW):* a group of welding processes that produces coalescence of metals by heating them with an arc or arcs, with or without the application of pressure and with or without the use of filler metal.

*assembly:* the joining together of two or more piping components by bolting, welding, bonding, screwing, brazing, soldering, cementing, or use of packing devices as specified by the engineering design.

*autogenous weld:* a weld made by fusion of the base metal without the addition of filler metal [see also *gas tungsten-arc welding (GTAW)*].



*automatic welding*: welding with equipment that performs the welding operation without adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

*backing filler metal*: see *consumable insert*.

*backing ring*: material in the form of a ring used to support molten weld metal.

*balanced piping system*: see [para. 319.2.2\(a\)](#).

*base material*: the material to be brazed, soldered, welded, or otherwise fused.

*basic allowable stress*: see *stress terms frequently used*.

*bolt design stress*: see *stress terms frequently used*.

*bonded joint*: a permanent joint in nonmetallic piping made by one of the following methods:

(a) *adhesive joint*: a joint made by applying an adhesive to the surfaces to be joined and pressing them together

(b) *butt-and-wrapped joint*: a joint made by butting together the joining surfaces and wrapping the joint with plies of reinforcing fabric saturated with resin

(c) *heat fusion joint*: a joint made by heating the surfaces to be joined and pressing them together to achieve fusion

(d) *hot gas welded joint*: a joint made by simultaneously heating the surfaces to be joined and a filler material with a stream of hot air or hot inert gas, then pressing the surfaces together and applying the filler material to achieve fusion

(e) *solvent cemented joint*: a joint made by using a solvent cement to soften the surfaces to be joined and pressing them together

(f) *electrofusion joint*: a joint made by heating the surfaces to be joined using an electrical resistance wire coil that remains embedded in the joint.

*bonder*: one who performs a manual or semiautomatic bonding operation.

*bonding operator*: one who operates machine or automatic bonding equipment.

*bonding procedure*: the detailed methods and practices involved in the production of a bonded joint.

*bonding procedure specification (BPS)*: the document that lists the parameters to be used in the construction of bonded joints in accordance with the requirements of this Code.

*borescopic examination*: a visual examination aided by a mechanical or electromechanical device to examine the inside diameter of inaccessible welds.

*branch connection fitting*: an integrally reinforced fitting welded to a run pipe and connected to a branch pipe by a butt welding, socket welding, threaded, or flanged joint; includes a branch outlet fitting conforming to MSS SP-97.

*brazing*: a metal joining process wherein coalescence is produced by use of a nonferrous filler metal having a melting point above 427°C (800°F), but lower than that of the base metals being joined. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

*butt joint*: a joint between two members aligned approximately in the same plane.

*Category D*: see *fluid service*.

*Category M*: see *fluid service*.

*caulked joint*: a joint in which suitable material (or materials) is either poured or compressed by the use of tools into the annular space between a bell (or hub) and spigot (or plain end), thus comprising the joint seal.

*chemical plant*: an industrial plant for the manufacture or processing of chemicals, or of raw materials or intermediates for such chemicals. A chemical plant may include supporting and service facilities, such as storage, utility, and waste treatment units.

*cold spring*: see [para. 319.2.4](#).

*compression type tube fittings*: tube fittings consisting of a flareless, mechanical grip connection, including a body, nut, and single or dual ferrules. See also [para. U306.6](#).

*connections for external piping*: those integral parts of individual pieces of equipment that are designed for attachment of external piping.

*consumable insert*: preplaced filler metal that is completely fused into the root of the joint and becomes part of the weld.

*damaging to human tissues*: for the purposes of this Code, this phrase describes a fluid service in which exposure to the fluid, caused by leakage under expected operating conditions, can harm skin, eyes, or exposed mucous membranes so that irreversible damage may result unless prompt restorative measures are taken. (Restorative measures may include flushing with water, administration of antidotes, or medication.)

*design minimum temperature*: see [para. 301.3.1](#).

*design pressure*: see [para. 301.2](#).

*design temperature*: see [para. 301.3](#).

*designer*: the person or organization in responsible charge of the engineering design.

*displacement stress range*: see [para. 319.2.3](#).

*elements*: see *piping elements*.

*engineering design*: the detailed design governing a piping system, developed from process and mechanical requirements, conforming to Code requirements, and including all necessary specifications, drawings, and supporting documents.

*equipment connection*: see *connections for external piping*.

*erection*: the complete installation of a piping system in the locations and on the supports designated by the engineering design including any field assembly, fabrication, examination, inspection, and testing of the system as required by this Code.

*examination, examiner*: see [paras. 341.1](#) and [341.2](#).

*examination, types of*: see [para. 344.1.3](#) for the following:

- (a) 100% examination
- (b) random examination
- (c) spot examination
- (d) random spot examination

*extruded outlet header*: see [para. 304.3.4](#).

*fabrication*: the preparation of piping for assembly, including cutting, threading, grooving, forming, bending, and joining of components into subassemblies. Fabrication may be performed in the shop or in the field.

*face of weld*: the exposed surface of a weld on the side from which the welding was done.

*face seal fitting*: a High Purity Fluid Service fitting that incorporates two machined faces and a metallic gasket within an external/internal nut configuration to attain a high leak integrity seal. See also [para. U315.3\(b\)](#).

*filler material*: the material to be added in making metallic or nonmetallic joints.

*fillet weld*: a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint. (See also *size of weld* and *throat of a fillet weld*.)

*flammable*: for the purposes of this Code, describes a fluid that under ambient or expected operating conditions is a vapor or produces vapors that can be ignited and continue to burn in air. The term thus may apply, depending on service conditions, to fluids defined for other purposes as flammable or combustible.

*fluid service*: a general term concerning the application of a piping system, considering the combination of fluid properties, operating conditions, and other factors that establish the basis for design of the piping system. See [Appendix M](#).

(a) *Category D Fluid Service*: a fluid service in which all of the following apply:

- (1) the fluid handled is nonflammable, nontoxic, and not damaging to human tissues as defined in [para. 300.2](#)
- (2) the design gage pressure does not exceed 1 035 kPa (150 psi)
- (3) the design temperature is not greater than 186°C (366°F)
- (4) the fluid temperature caused by anything other than atmospheric conditions is not less than -29°C (-20°F)

(b) *Category M Fluid Service*: a fluid service in which both of the following apply:

(1) the fluid is so highly toxic that a single exposure to a very small quantity of the fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken

(2) after consideration of piping design, experience, service conditions, and location, the owner determines that the requirements for Normal Fluid Service do not sufficiently provide the leak tightness required to protect personnel from exposure

(c) *Elevated Temperature Fluid Service*: a fluid service in which the piping metal temperature is sustained equal to or greater than  $T_{cr}$  as defined in [Table 302.3.5](#), General Note (b).

(d) *High Pressure Fluid Service*: a fluid service for which the owner specifies the use of [Chapter IX](#) for piping design and construction; see also [para. K300](#).

(e) *High Purity Fluid Service*: a fluid service that requires alternative methods of fabrication, inspection, examination, and testing not covered elsewhere in the Code, with the intent to produce a controlled level of cleanliness. The term thus applies to piping systems defined for other purposes as high purity, ultra high purity, hygienic, or aseptic.

(f) *Normal Fluid Service*: a fluid service pertaining to most piping covered by this Code, i.e., not subject to the rules for Category D, Category M, Elevated Temperature, High Pressure, or High Purity Fluid Service.

*full fillet weld*: a fillet weld whose size is equal to the thickness of the thinner member joined.

*fusion*: the melting together of filler material and base material, or of base material only, that results in coalescence.

*gas metal-arc welding (GMAW)*: an arc-welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas, or gas mixture. Some variations of this process are called MIG or CO<sub>2</sub> welding (nonpreferred terms).

*gas tungsten-arc welding (GTAW)*: an arc-welding process that produces coalescence of metals by heating them with an arc between a single tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not be used and filler metal may or may not be used. (This process has sometimes been called TIG welding.)

*gas welding*: a group of welding processes wherein coalescence is produced by heating with a gas flame or flames, with or without the application of pressure, and with or without the use of filler material.

*groove weld*: a weld made in the groove between two members to be joined.



*heat-affected zone*: that portion of the base material which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, forming, or cutting.

*heat treatment*: the following terms describe various types and processes of heat treatment:

(a) *annealing*: heating to and holding at a suitable temperature above the transformation temperature range, followed by slow cooling to well below the transformation temperature range.

(b) *normalizing*: heating a ferrous metal to a temperature above the transformation temperature range, followed by cooling in room-temperature still air to well below the transformation temperature range.

(c) *quenching*: when used as a part of a heat-treating operation, a rapid cooling process that results in microstructural stabilization or changes in material properties that would not have occurred without rapid cooling.

(d) *recommended or required heat treatment*: the application of heat to a metal section subsequent to a cutting, forming, or welding operation, as provided in [para. 331](#).

(e) *solution heat treatment*: heating an alloy to a suitable temperature, holding at that temperature long enough to allow one or more constituents to enter into solid solution, and then cooling rapidly enough to hold the constituents in solution.

(f) *stress-relief*: uniform heating of a structure or portion thereof to a sufficient temperature below the transformation temperature range to relieve the major portion of the residual stresses, followed by uniform cooling slowly enough to minimize development of new residual stresses.

(g) *tempering*: reheating a hardened metal to a temperature below the transformation range to improve toughness.

(h) *transformation range*: the temperature range over which a phase change occurs.

(i) *transformation temperature*: the temperature at which a phase change begins or ends. In metals, phase changes can be solid-state changes.

*High Pressure Fluid Service*: see *fluid service*.

*High Purity Fluid Service*: see *fluid service*.

*hygienic clamp joint*: a tube outside-diameter union consisting of two neutered ferrules having flat faces with a concentric groove and mating gasket that is secured with a clamp, providing a nonprotruding, recessless product contact surface. See also [para. U315.3\(b\)](#).

*indication, linear*: in nondestructive examination, an indication having a length greater than 3 times its width.

*indication, rounded*: in nondestructive examination, an indication with a length equal to or less than 3 times its width. These indications may be circular, elliptical, conical, or irregular in shape and may have tails.

*inline portions of instruments*: pressure-containing portions of instruments that are in direct contact with the fluid when installed in a piping system. Permanently

sealed fluid-filled tubing systems furnished with instruments as temperature- or pressure-responsive devices, e.g., pressure gages, pressure transmitters, and transducers, are excluded.

*in-process examination*: see [para. 344.7](#).

*inspection, Inspector*: see [para. 340](#).

*integrally reinforced branch connection fitting*: see *branch connection fitting*.

*joint design*: the joint geometry together with the required dimensions of the welded joint.

*listed*: for the purposes of this Code, describes a material or component that conforms to a specification in [Appendix A](#), [Appendix B](#), or [Appendix K](#) or to a standard in [Table 326.1](#), [A326.1](#), or [K326.1](#).

*manual welding*: a welding operation performed and controlled completely by hand.

*may*: a term that indicates a provision is neither required nor prohibited.

*mechanical joint*: a joint for the purpose of mechanical strength or leak resistance, or both, in which the mechanical strength is developed by threaded, grooved, rolled, flared, or flanged pipe ends; or by bolts, pins, toggles, or rings; and the leak resistance is developed by threads and compounds, gaskets, rolled ends, caulking, or machined and mated surfaces.

*miter or miter bend*: for the purposes of this Code, two or more straight sections of pipe matched and joined in a plane bisecting the angle of junction so as to produce a change in direction greater than 3 deg.

*nominal*: a numerical identification of dimension, capacity, rating, or other characteristic used as a designation, not as an exact measurement.

*Normal Fluid Service*: see *fluid service*.

*normalizing*: see *heat treatment*.

*notch-sensitive*: describes a metal subject to reduction in strength in the presence of stress concentration. The degree of notch sensitivity is usually expressed as the strength determined in a notched specimen divided by the strength determined in an unnotched specimen, and can be obtained from either static or dynamic tests.

*NPS*: nominal pipe size (followed, when appropriate, by the specific size designation number without an inch symbol).

*orbital welding*: automatic or machine welding in which the electrode rotates (orbits) around the circumference of a stationary pipe or tube.

*owner*: the person, partnership, organization, or business ultimately responsible for design, construction, operation, and maintenance of a facility.

*oxygen-arc cutting (OAC)*: an oxygen-cutting process that uses an arc between the workpiece and a consumable electrode, through which oxygen is directed to the workpiece. For oxidation-resistant metals, a chemical flux or metal powder is used to facilitate the reaction.

*oxygen cutting (OC)*: a group of thermal cutting processes that severs or removes metal by means of the chemical reaction between oxygen and the base metal at elevated temperature. The necessary temperature is maintained by the heat from an arc, an oxyfuel gas flame, or other source.

*oxygen gouging*: thermal gouging that uses an oxygen cutting process variation to form a bevel or groove.

*packaged equipment*: an assembly of individual pieces or stages of equipment, complete with interconnecting piping and connections for external piping. The assembly may be mounted on a skid or other structure prior to delivery.

*petroleum refinery*: an industrial plant for processing or handling of petroleum and products derived directly from petroleum. Such a plant may be an individual gasoline recovery plant, a treating plant, a gas processing plant (including liquefaction), or an integrated refinery having various process units and attendant facilities.

*pipe*: a pressure-tight cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated “pipe” in applicable material specifications. Materials designated “tube” or “tubing” in the specifications are treated as pipe when intended for pressure service. Types of pipe, according to the method of manufacture, are defined as follows:

(a) *electric resistance-welded pipe*: pipe produced in individual lengths or in continuous lengths from coiled skelp and subsequently cut into individual lengths, having a longitudinal butt joint wherein coalescence is produced by the heat obtained from resistance of the pipe to the flow of electric current in a circuit of which the pipe is a part, and by the application of pressure.

(b) *furnace butt welded pipe, continuous welded*: pipe produced in continuous lengths from coiled skelp and subsequently cut into individual lengths, having its longitudinal butt joint forge welded by the mechanical pressure developed in passing the hot-formed and edge-heated skelp through a set of round pass welding rolls.

(c) *electric-fusion welded pipe*: pipe having a longitudinal butt joint wherein coalescence is produced in the preformed tube by manual or automatic electric-arc welding. The weld may be single (welded from one side) or double (welded from inside and outside) and may be made with or without the addition of filler metal.

(d) *double submerged-arc welded pipe*: pipe having a longitudinal butt joint produced by at least two passes, one of which is on the inside of the pipe. Coalescence is produced by heating with an electric arc or arcs between the bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular fusible material on the work. Pressure is not used and filler metal for the inside and outside welds is obtained from the electrode or electrodes.

(e) *seamless pipe*: pipe produced by piercing a billet followed by rolling or drawing, or both.

(f) *spiral (helical seam) welded pipe*: pipe having a helical seam with a butt, lap, or lock-seam joint that is welded using an electrical resistance, electric fusion, or double-submerged arc welding process.

*pipe-supporting elements*: pipe-supporting elements consist of fixtures and structural attachments as follows:

(a) *fixtures*: fixtures include elements that transfer the load from the pipe or structural attachment to the supporting structure or equipment. They include hanging type fixtures, such as hanger rods, spring hangers, sway braces, counterweights, turnbuckles, struts, chains, guides, and anchors; and bearing type fixtures, such as saddles, bases, rollers, brackets, and sliding supports.

(b) *structural attachments*: structural attachments include elements that are welded, bolted, or clamped to the pipe, such as clips, lugs, rings, clamps, clevises, straps, and skirts.

*piping*: assemblies of piping components used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows. Piping also includes pipe-supporting elements, but does not include support structures, such as building frames, bents, foundations, or any equipment excluded from this Code (see [para. 300.1.3](#)).

*piping components*: mechanical elements suitable for joining or assembly into pressure-tight fluid-containing piping systems. Components include pipe, tubing, fittings, flanges, gaskets, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, inline portions of instruments, and separators.

*piping elements*: any material or work required to plan and install a piping system. Elements of piping include design specifications, materials, components, supports, fabrication, examination, inspection, and testing.

*piping installation*: designed piping systems to which a selected Code edition and addenda apply.

*piping subassembly*: a portion of a piping system that consists of one or more piping components.

*piping system*: interconnected piping subject to the same set or sets of design conditions.

*plasma arc cutting (PAC)*: an arc cutting process that uses a constricted arc and removes molten metal with a high velocity jet of ionized gas issuing from the constricting orifice.

*postweld heat treatment*: see *heat treatment*.

*preheating*: the application of heat to the base material immediately before or during a forming, welding, or cutting process. See [para. 330](#).

*procedure qualification record (PQR)*: a document listing all pertinent data, including the essential variables employed and the test results, used in qualifying the procedure specification.

*process unit*: an area whose boundaries are designated by the engineering design within which reactions, separations, and other processes are carried out. Examples of installations that are *not* classified as process units are

loading areas or terminals, bulk plants, compounding plants, and tank farms and storage yards.

*quench annealing*: see *solution heat treatment* under *heat treatment*.

*quenching*: see *heat treatment*.

*readily accessible (for visual examination)*: those surfaces that can be examined from a distance of not more than 600 mm (24 in.) and at an angle of not less than 30 deg to the surface to be examined.

*reinforcement*: see [paras. 304.3](#) and [A304.3](#). See also *weld reinforcement*.

*representative*: a person, partnership, organization, or business designated by the owner to carry out selected responsibilities on the owner's behalf.

*room temperature*: temperature between 10°C and 38°C (50°F and 100°F).

*root opening*: the separation between the members to be joined, at the root of the joint.

*safeguarding*: provision of protective measures of the types outlined in [Appendix G](#), where deemed necessary. See [Appendix G](#) for detailed discussion.

*seal bond*: a bond intended primarily to provide joint tightness against leakage in nonmetallic piping.

*seal weld*: a weld intended primarily to provide joint tightness against leakage in metallic piping.

*semiautomatic arc welding*: arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

*severe cyclic conditions*: conditions applying to specific piping components or joints for which the owner or the designer determines that construction to better resist fatigue loading is warranted. See [Appendix F](#), [para. F301.10.3](#) for guidance on designating piping as being under severe cyclic conditions.

*shall*: a term that indicates a provision is a Code requirement.

*shielded metal-arc welding (SMAW)*: an arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

*should*: a term that indicates a provision is recommended as good practice but is not a Code requirement.

*size of weld*:

(a) *fillet weld*: the leg lengths (the leg length for equal-leg welds) of the sides, adjoining the members welded, of the largest triangle that can be inscribed within the weld cross section. For welds between perpendicular members, the definitions in [Figure 328.5.2A](#) apply.

NOTE: When the angle between members exceeds 105 deg, size is of less significance than effective throat (see also *throat of a fillet weld*).

(b) *groove weld*: the joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are the same.

*slag inclusion*: nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

*soldering*: a metal joining process wherein coalescence is produced by heating to suitable temperatures and by using a nonferrous alloy fusible at temperatures below 427°C (800°F) and having a melting point below that of the base metals being joined. The filler metal is distributed between closely fitted surfaces of the joint by capillary attraction. In general, solders are lead-tin alloys and may contain antimony, bismuth, and other elements.

*solution heat treatment*: see *heat treatment*.

*stress ratio*: see [para. 323.2.2\(b\)](#).

*stress relief*: see *heat treatment*.

*stress terms frequently used*:

(a) *basic allowable stress*: this term, symbol *S*, represents the stress value for any material determined by the appropriate stress basis in [para. 302.3.2](#)

(b) *bolt design stress*: this term represents the design stress used to determine the required cross-sectional area of bolts in a bolted joint

(c) *hydrostatic design basis*: selected properties of plastic piping materials to be used in accordance with ASTM D2837 or D2992 to determine the HDS [see (d) below] for the material

(d) *hydrostatic design stress (HDS)*: the maximum continuous stress due to internal pressure to be used in the design of plastic piping, determined from the hydrostatic design basis by use of a service (design) factor

*submerged arc welding (SAW)*: an arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

*tack weld*: a weld made to hold parts of a weldment in proper alignment until the final welds are made.

*tempering*: see *heat treatment*.

*thermoplastic*: a plastic that is capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature.

*thermosetting resin*: a resin capable of being changed into a substantially infusible or insoluble product when cured at room temperature, or by application of heat, or by chemical means.

*throat of a fillet weld*:

(a) *theoretical throat*: the perpendicular distance from the hypotenuse of the largest right triangle that can be inscribed in the weld cross section to the root of the joint

(b) *actual throat*: the shortest distance from the root of a fillet weld to its face

(c) *effective throat*: the minimum distance, minus any reinforcement (convexity), between the weld root and the face of a fillet weld

*toe of weld*: the junction between the face of a weld and the base material.

*tube*: see *pipe*.

*tungsten electrode*: a nonfiller-metal electrode used in arc welding or cutting, made principally of tungsten.

*unbalanced piping system*: see [para. 319.2.2\(b\)](#).

*undercut*: a groove melted into the base material adjacent to the toe or root of a weld and left unfilled by weld material.

*visual examination*: see [para. 344.2.1](#).

*weld*: a localized coalescence of material wherein coalescence is produced either by heating to suitable temperatures, with or without the application of pressure, or by application of pressure alone, and with or without the use of filler material.

*weld coupon*: a sample weld used to determine weld acceptance. Types of weld coupons are defined as follows:

(a) *primary weld coupon*: made prior to the start of production welding to establish a benchmark of weld acceptance

(b) *production weld coupon*: made when any of the conditions in [para. U341.4.5](#) exist and used to compare against a corresponding primary weld coupon to demonstrate continued acceptability of welds during production welding

*weld coupon examination*: see [para. U344.8.1](#).

*weld reinforcement*: weld material in excess of the specified weld size.

*welder*: one who performs a manual or semi-automatic welding operation. (This term is sometimes erroneously used to denote a welding machine.)

*welding operator*: one who operates machine or automatic welding equipment.

*welding procedure*: the detailed methods and practices involved in the production of a weldment.

*welding procedure specification (WPS)*: the document that lists the parameters to be used in construction of weldments in accordance with requirements of this Code.

*weldment*: an assembly whose component parts are joined by welding.

### 300.3 Nomenclature

Dimensional and mathematical symbols used in this Code are listed in [Appendix J](#), with definitions and location references to each. Uppercase and lowercase English letters are listed alphabetically, followed by Greek letters.

### 300.4 Status of Appendices

[Table 300.4](#) indicates for each Appendix of this Code whether it contains Code requirements, guidance, or supplemental information. See the first page of each Appendix for details.

(20)

**Table 300.4 Status of Appendices in B31.3**

| Appendix          | Title                                                                            | Status                            |
|-------------------|----------------------------------------------------------------------------------|-----------------------------------|
| <a href="#">A</a> | Allowable Stresses and Quality Factors for Metallic Piping and Bolting Materials | Requirements                      |
| <a href="#">B</a> | Stress Tables and Allowable Pressure Tables for Nonmetals                        | Requirements                      |
| <a href="#">C</a> | Physical Properties of Piping Materials                                          | Requirements <a href="#">(1)</a>  |
| <a href="#">E</a> | Reference Standards                                                              | Requirements                      |
| <a href="#">F</a> | Guidance and Precautionary Considerations                                        | Guidance <a href="#">(2)</a>      |
| <a href="#">G</a> | Safeguarding                                                                     | Guidance <a href="#">(2)</a>      |
| <a href="#">H</a> | Sample Calculations for Branch Reinforcement                                     | Guidance                          |
| <a href="#">J</a> | Nomenclature                                                                     | Information                       |
| <a href="#">K</a> | Allowable Stresses for High Pressure Piping                                      | Requirements <a href="#">(3)</a>  |
| <a href="#">L</a> | Aluminum Alloy Pipe Flanges                                                      | Specification <a href="#">(4)</a> |
| <a href="#">M</a> | Guide to Classifying Fluid Services                                              | Guidance <a href="#">(2)</a>      |
| <a href="#">N</a> | Application of ASME B31.3 Internationally                                        | Guidance <a href="#">(2)</a>      |
| <a href="#">Q</a> | Quality System Program                                                           | Guidance <a href="#">(2)</a>      |
| <a href="#">R</a> | Use of Alternative Ultrasonic Acceptance Criteria                                | Requirements <a href="#">(5)</a>  |
| <a href="#">S</a> | Piping System Stress Analysis Examples                                           | Guidance <a href="#">(2)</a>      |
| <a href="#">V</a> | Allowable Variations in Elevated Temperature Service                             | Guidance <a href="#">(2)</a>      |
| <a href="#">W</a> | High-Cycle Fatigue Assessment of Piping Systems                                  | Requirements                      |
| <a href="#">X</a> | Metallic Bellows Expansion Joints                                                | Requirements                      |
| <a href="#">Z</a> | Preparation of Technical Inquiries                                               | Requirements <a href="#">(5)</a>  |

## NOTES:

- (1) Contains default requirements, to be used unless more directly applicable data are available.  
(2) Contains no requirements but Code user is responsible for considering applicable items.  
(3) Contains requirements applicable only when use of [Chapter IX](#) is specified.  
(4) Contains pressure-temperature ratings, materials, dimensions, and markings of forged aluminum alloy flanges.  
(5) Contains administrative requirements.



## Chapter II Design

### PART 1 CONDITIONS AND CRITERIA

#### 301 DESIGN CONDITIONS

Paragraph 301 states the qualifications of the Designer, defines the temperatures, pressures, and forces applicable to the design of piping, and states the consideration that shall be given to various effects and their consequent loadings. See also Appendix F, para. F301.

##### 301.1 Qualifications of the Designer

The Designer is the person(s) in charge of the engineering design of a piping system and shall be experienced in the use of this Code. The qualifications and experience required of the Designer will depend on the complexity and criticality of the system and the nature of the individual's experience. The owner's approval is required if the individual does not meet at least one of the following criteria:

(a) Completion of a degree, accredited by an independent agency [such as ABET (U.S. and international), NBA (India), CTI (France), and CNAP (Chile)], in engineering, science, or technology, requiring the equivalent of at least 4 yr of full-time study that provides exposure to fundamental subject matter relevant to the design of piping systems, plus a minimum of 5 yr of experience in the design of related pressure piping.

(b) Professional Engineering registration, recognized by the local jurisdiction, and experience in the design of related pressure piping.

(c) Completion of an accredited engineering technician or associates degree, requiring the equivalent of at least 2 yr of study, plus a minimum of 10 yr of experience in the design of related pressure piping.

(d) Fifteen yr of experience in the design of related pressure piping.

Experience in the design of related pressure piping is satisfied by piping design experience that includes design calculations for pressure, sustained and occasional loads, and piping flexibility.

#### 301.2 Design Pressure

##### 301.2.1 General

(a) The design pressure of each component in a piping system shall be not less than the pressure at the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service, except as provided in para. 302.2.4.

(b) The most severe condition is that which results in the greatest required component thickness and the highest component rating.

(c) When more than one set of pressure-temperature conditions exist for a piping system, the conditions governing the rating of components conforming to listed standards may differ from the conditions governing the rating of components designed in accordance with para. 304.

(d) When a pipe is separated into individualized pressure-containing chambers (including jacketed piping, blanks, etc.), the partition wall shall be designed on the basis of the most severe coincident temperature (minimum or maximum) and differential pressure between the adjoining chambers expected during service, except as provided in para. 302.2.4.

##### 301.2.2 Required Pressure Containment or Relief

(a) Provision shall be made to safely contain or relieve (see para. 322.6.3) any expected pressure to which the piping may be subjected. Piping not protected by a pressure-relieving device, or that can be isolated from a pressure-relieving device, shall be designed for at least the highest expected pressure.

(b) Sources of pressure to be considered include ambient influences, pressure oscillations and surges, improper operation, decomposition of unstable fluids, static head, and failure of control devices.

(c) The allowances of para. 302.2.4(f) are permitted, provided that the other requirements of para. 302.2.4 are also met.

#### 301.3 Design Temperature

The design temperature of each component in a piping system is the temperature at which, under the coincident pressure, the greatest thickness or highest component rating is required in accordance with para. 301.2. (To satisfy the requirements of para. 301.2, different

components in the same piping system may have different design temperatures.)

In establishing design temperatures, consider at least the fluid temperatures, ambient temperatures, solar radiation, heating or cooling medium temperatures, and the applicable provisions of [paras. 301.3.2, 301.3.3, and 301.3.4](#).

**301.3.1 Design Minimum Temperature.** The design minimum temperature is the lowest component temperature expected in service. This temperature may establish special design requirements and material qualification requirements. See also [paras. 301.4.4 and 323.2.2](#).

(20) **301.3.2 Uninsulated Piping Components**

(a) For fluid temperatures below 65°C (150°F), the component temperature shall be taken as the fluid temperature unless solar radiation or other effects result in a higher temperature.

(b) For fluid temperatures 65°C (150°F) and above, unless a lower average wall temperature is determined by test or heat transfer calculation, the temperature for uninsulated components shall be no less than the following values:

- (1) valves, pipe, lapped ends, welding fittings, and other components having wall thickness comparable to that of the pipe — 95% of the fluid temperature
- (2) flanges (except lap joint) including those on fittings and valves — 90% of the fluid temperature
- (3) lap joint flanges — 85% of the fluid temperature
- (4) bolting — 80% of the fluid temperature

(20) **301.3.3 Externally Insulated Piping Components.** The component design temperature shall be the fluid temperature unless calculations, tests, or service experience based on measurements support the use of another temperature. Where piping is heated or cooled by tracing or jacketing, this effect shall be considered in establishing component design temperatures.

(20) **301.3.4 Internally Insulated Piping Components.** The component design temperature shall be based on heat transfer calculations or tests.

## 301.4 Ambient Effects

See [Appendix F, para. F301.4](#).

**301.4.1 Cooling — Effects on Pressure.** The cooling of a gas or vapor in a piping system may reduce the pressure sufficiently to create an internal vacuum. In such a case, the piping shall be capable of withstanding the external pressure at the lower temperature, or provision shall be made to break the vacuum.

**301.4.2 Fluid Expansion Effects.** Provision shall be made in the design either to withstand or to relieve increased pressure caused by the heating of static fluid in a piping component. See also [para. 322.6.3\(b\)\(2\)](#).

**301.4.3 Atmospheric Icing.** Where the design minimum temperature of a piping system is below 0°C (32°F), the possibility of moisture condensation and buildup of ice shall be considered and provisions made in the design to avoid resultant malfunctions. This applies to surfaces of moving parts of shutoff valves, control valves, pressure-relief devices including discharge piping, and other components.

**301.4.4 Low Ambient Temperature.** Consideration shall be given to low ambient temperature conditions for displacement stress analysis.

## 301.5 Dynamic Effects

**301.5.1 Impact.** Impact forces caused by external or internal conditions (including changes in flow rate, hydraulic shock, liquid or solid slugging, flashing, and geysering) shall be taken into account in the design of piping. See [Appendix F, para. F301.5.1](#).

**301.5.2 Wind.** The effect of wind loading shall be taken into account in the design of exposed piping. The analysis considerations and loads may be as described in ASCE 7. Authoritative local meteorological data may also be used to define or refine the design wind loads.

**301.5.3 Earthquake.** The effect of earthquake loading shall be taken into account in the design of piping. The analysis considerations and loads may be as described in ASCE 7. Authoritative local seismological data may also be used to define or refine the design earthquake loads.

**301.5.4 Vibration.** Piping shall be designed, arranged, and supported to eliminate excessive and harmful effects of vibration that may arise from such sources as impact, pressure pulsation, turbulent flow vortices, resonance in compressors, external vortex shedding (e.g., wind), and acoustically induced vibration.

**301.5.5 Discharge Reactions.** Piping shall be designed, arranged, and supported so as to withstand reaction forces due to let-down or discharge of fluids.

## 301.6 Weight Effects

The following weight effects, combined with loads and forces from other causes, shall be taken into account in the design of piping.

**301.6.1 Live Loads.** These loads include the weight of the medium transported or the medium used for test. Snow and ice loads due to both environmental and operating conditions shall be considered.

**301.6.2 Dead Loads.** These loads consist of the weight of piping components, insulation, and other superimposed permanent loads supported by the piping.

### 301.7 Thermal Expansion and Contraction Effects

The following thermal effects, combined with loads and forces from other causes, shall be taken into account in the design of piping. See also [Appendix F, para. F301.7](#).

**301.7.1 Thermal Loads Due to Restraints.** These loads consist of thrusts and moments that arise when free thermal expansion and contraction of the piping are prevented by restraints or anchors.

**301.7.2 Loads Due to Temperature Gradients.** These loads arise from stresses in pipe walls resulting from large rapid temperature changes or from unequal temperature distribution as may result from a high heat flux through a comparatively thick pipe or stratified two-phase flow causing bowing of the line.

**301.7.3 Loads Due to Differences in Expansion Characteristics.** These loads result from differences in thermal expansion where materials with different thermal expansion coefficients are combined, as in bimetallic, lined, jacketed, or metallic-nonmetallic piping.

### 301.8 Effects of Support, Anchor, and Terminal Movements

The effects of movements of piping supports, anchors, and connected equipment shall be taken into account in the design of piping. These movements may result from the flexibility and/or thermal expansion of equipment, supports, or anchors; and from settlement, tidal movements, or wind sway.

### 301.9 Reduced Ductility Effects

The harmful effects of reduced ductility shall be taken into account in the design of piping. The effects may, for example, result from welding, heat treatment, forming, bending, or low operating temperatures, including the chilling effect of sudden loss of pressure on highly volatile fluids. Low ambient temperatures expected during operation shall be considered.

### 301.10 Cyclic Effects

Fatigue due to pressure cycling, thermal cycling, and other cyclic loadings shall be considered in the design of piping. See [Appendix F, para. F301.10](#).

### 301.11 Air Condensation Effects

At operating temperatures below  $-191^{\circ}\text{C}$  ( $-312^{\circ}\text{F}$ ) in ambient air, condensation and oxygen enrichment occur. These shall be considered in selecting materials, including insulation, and adequate shielding and/or disposal shall be provided.

## 302 DESIGN CRITERIA

### 302.1 General

[Paragraph 302](#) states pressure-temperature ratings, stress criteria, design allowances, and minimum design values together with permissible variations of these factors as applied to the design of piping.

### 302.2 Pressure-Temperature Design Criteria

**302.2.1 Listed Components Having Established Ratings.** Except as limited elsewhere in the Code, pressure-temperature ratings contained in standards for piping components listed in [Table 326.1](#) are acceptable for design pressures and temperatures in accordance with this Code. When the owner approves, provisions of this Code may be used to extend the pressure-temperature ratings of a component beyond the ratings contained in the listed standard.

#### 302.2.2 Listed Components Not Having Specific Ratings

(a) Some of the standards for fittings in [Table 326.1](#) (e.g., ASME B16.9 and B16.11) state that pressure-temperature ratings are based on straight seamless pipe. Such fittings shall be rated as calculated for straight seamless pipe with the same allowable stresses as the fitting and the nominal thickness corresponding to the wall thickness or class designation of the fitting, less all applicable allowances (e.g., thread depth and corrosion allowance), and considering the manufacturing under-tolerances of the fittings and the pipe.

(b) For components with straight or spiral (helical seam) longitudinal welded joints, the pressure rating as determined for seamless pipe shall be multiplied by the weld joint strength reduction factor,  $W$ , as defined in [para. 302.3.5\(e\)](#).

(c) Other listed components not addressed in [para. 302.2.1](#) or [302.2.2\(a\)](#) shall have their pressure-temperature ratings established in accordance with the rules in [para. 304](#).

**302.2.3 Unlisted Components.** Piping components not listed in [Table 326.1](#) may be used subject to all of the following requirements:

(a) The material shall comply with [para. 323](#).

(b) The designer shall be satisfied that the design is suitable for the intended service.

(c) Pressure-temperature ratings shall be established in accordance with the rules in [para. 304](#).

**302.2.4 Allowances for Pressure and Temperature Variations.** Occasional variations of pressure, temperature, or both may occur in a piping system. Such variations shall be considered in selecting design pressure ([para. 301.2](#)) and design temperature ([para. 301.3](#)). The most severe coincident pressure and temperature



shall determine the design conditions unless all of the following criteria are met (see [Appendix F, para. F302.2.4](#)):

(a) The piping system shall have no pressure-containing components of gray iron or other nonductile metal.

(b) Circumferential pressure stresses (based on minimum pipe wall thickness, less allowances) shall not exceed the yield strength at temperature (see [para. 302.3](#) of this Code and  $S_y$  data in ASME BPVC, Section II, Part D, Table Y-1).

(c) Combined stresses shall not exceed the limits established in [para. 302.3.6](#).

(d) The total number of pressure-temperature variations above the design conditions shall not exceed 1000 during the life of the piping system.

(e) In no case shall the increased pressure exceed the test pressure used under [para. 345](#) for the piping system.

(f) Occasional variations above design conditions shall remain within one of the following limits for pressure design.

(1) Subject to the owner's approval, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than

(-a) 33% for no more than 10 h at any one time and no more than 100 h/y, or

(-b) 20% for no more than 50 h at any one time and no more than 500 h/y

The effects of such variations shall be determined by the designer to be safe over the service life of the piping system by methods acceptable to the owner. (See [Appendix V](#).)

(2) When the variation is self-limiting (e.g., due to a pressure-relieving event), and lasts no more than 50 h at any one time and not more than 500 h/y, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than 20%.

(g) The combined effects of the sustained and cyclic variations on the serviceability of all components in the system shall have been evaluated.

(h) Temperature variations below the minimum temperature shown in [Appendix A](#) are not permitted unless the requirements of [para. 323.2.2](#) are met for the lowest temperature during the variation.

(i) The application of pressures exceeding pressure-temperature ratings of valves may under certain conditions cause loss of seat tightness or difficulty of operation. The differential pressure on the valve closure element should not exceed the maximum differential pressure rating established by the valve manufacturer. Such applications are the owner's responsibility.

gating the two services shall be rated for the more severe service condition. Where multiple valves are used (e.g., in a double block and bleed arrangement), all of the valves shall be rated for the more severe service condition. If the valve(s) will operate at a different temperature due to remoteness from a header or piece of equipment, the valve(s) (and any mating flanges) may be selected on the basis of the different temperature.

### 302.3 Allowable Stresses and Other Stress Limits

**302.3.1 General.** The allowable stresses defined in (a), (b), and (c) shall be used in design calculations unless modified by other provisions of this Code.

(a) *Tension.* Basic allowable stresses,  $S$ , in tension for metals listed in [Tables A-1](#) and [A-1M](#), and design stresses,  $S$ , for bolting materials listed in [Tables A-2](#) and [A-2M](#) were determined in accordance with [para. 302.3.2](#).

In equations elsewhere in the Code where the product  $SE$  appears, the value  $S$  is multiplied by one of the following quality factors:<sup>1</sup>

(1) casting quality factor  $E_c$  as defined in [para. 302.3.3](#) and tabulated for various material specifications in [Table A-1A](#), and for various levels of supplementary examination in [Table 302.3.3C](#), or

(2) longitudinal weld joint factor  $E_j$  as defined in [302.3.4](#) and tabulated for various material specifications and classes in [Table A-1B](#), and for various types of joints and supplementary examinations in [Table 302.3.4](#)

The stress values in [Tables A-1](#), [A-1M](#), [A-2](#), and [A-2M](#) are grouped by materials and product forms, and are for stated temperatures up to the limit provided in [para. 323.2.1\(a\)](#). Straight-line interpolation between temperatures is permissible. The temperature intended is the design temperature (see [para. 301.3](#)).

(b) *Shear and Bearing.* Allowable stresses in shear shall be 0.80 times the basic allowable stress in tension tabulated in [Appendix A](#). Allowable stress in bearing shall be 1.60 times that value.

(c) *Compression.* Allowable stresses in compression shall be no greater than the basic allowable stresses in tension as tabulated in [Appendix A](#). Consideration shall be given to structural stability.

<sup>1</sup> If a component is made of castings joined by longitudinal welds, both a casting and a weld joint quality factor shall be applied. The equivalent quality factor  $E$  is the product of  $E_c$ , [Table A-1A](#), and  $E_j$ , [Table A-1B](#).

#### (20) 302.2.5 Ratings at Junction of Different Services.

When two services that operate at different pressure-temperature conditions are connected, the valve segre-

**302.3.2 Bases for Design Stresses.**<sup>2</sup> The bases for establishing design stress values for bolting materials and basic allowable stress values for other metallic materials in this Code are specified in (a) through (d). In the application of these criteria, the yield strength at temperature is considered to be  $S_Y R_Y$  and the tensile strength at temperature is considered to be  $1.1 S_T R_T$ , where

$R_T$  = ratio of the average temperature-dependent trend curve value of tensile strength to the room temperature tensile strength

$R_Y$  = ratio of the average temperature-dependent trend curve value of yield strength to the room temperature yield strength

$S_T$  = specified minimum tensile strength at room temperature

$S_Y$  = specified minimum yield strength at room temperature

(a) *Bolting Materials.* Design stress values at temperature for bolting materials shall not exceed the lowest of the following:

(1) at temperatures below the creep range, for bolting materials whose strength has not been enhanced by heat treatment or strain hardening, the lowest of one-fourth of  $S_T$ , one-fourth of tensile strength at temperature, two-thirds of  $S_Y$ , and two-thirds of yield strength at temperature

(2) at temperatures below the creep range, for bolting materials whose strength has been enhanced by heat treatment or strain hardening, the lowest of one-fifth of  $S_T$ , one-fourth of the tensile strength at temperature, one-fourth of  $S_Y$ , and two-thirds of the yield strength at temperature (unless these values are lower than corresponding values for annealed material, in which case the annealed values shall be used)

(3) 100% of the average stress for a creep rate of 0.01% per 1000 h

(4) 67% of the average stress for rupture at the end of 100 000 h

(5) 80% of minimum stress for rupture at the end of 100 000 h

(b) *Gray Iron.* Basic allowable stress values at temperature for gray iron shall not exceed the lower of the following:

(1) one-tenth of  $S_T$

(2) one-tenth of the tensile strength at temperature

(c) *Malleable Iron.* Basic allowable stress values at temperature for malleable iron shall not exceed the lower of the following:

(1) one-fifth of  $S_T$

(2) one-fifth of the tensile strength at temperature

(d) *Other Materials.* Basic allowable stress values at temperature for materials other than bolting materials, gray iron, and malleable iron shall not exceed the lowest of the following:

(1) the lower of one-third of  $S_T$  and one-third of tensile strength at temperature.

(2) except as provided in (3) below, the lower of two-thirds of  $S_Y$  and two-thirds of yield strength at temperature.

(3) for austenitic stainless steels and nickel alloys having similar stress-strain behavior, the lower of two-thirds of  $S_Y$  and 90% of yield strength at temperature [see (e)].

(4) 100% of the average stress for a creep rate of 0.01% per 1000 h.

(5) for temperatures up to and including 815°C (1,500°F), 67% of the average stress for rupture at the end of 100 000 h.

(6) for temperatures higher than 815°C (1,500°F),  $(100 \times F_{\text{avg}})\%$  times the average stress for rupture at the end of 100 000 h.  $F_{\text{avg}}$  is determined from the slope,  $n$ , of the log time-to-rupture versus log stress plot at 100 000 h such that  $\log F_{\text{avg}} = 1/n$ .  $F_{\text{avg}}$  shall not exceed 0.67.

(7) 80% of the minimum stress for rupture at the end of 100 000 h.

For structural grade materials, the basic allowable stress shall be 0.92 times the lowest value determined in (1) through (7).

(e) *Application Limits.* Application of stress values determined in accordance with (d)(3) is not recommended for flanged joints and other components in which slight deformation can cause leakage or malfunction.

(1) These values are shown in italics or boldface in Table A-1, as explained in Note (4a) to Appendix A Tables. Instead, either 75% of the stress value in Table A-1 or two-thirds of the yield strength at temperature listed in ASME BPVC, Section II, Part D, Table Y-1 should be used.

(2) Stress values determined in accordance with (d)(3) are not identified in Table A-1M. See Note (4b) to Appendix A. When using Table A-1M, two-thirds of the yield strength at temperature listed in ASME BPVC, Section II, Part D, Table Y-1 should be used.

### 302.3.3 Casting Quality Factor, $E_c$

(a) *General.* The casting quality factors,  $E_c$ , defined herein shall be used for cast components not having pressure-temperature ratings established by standards in Table 326.1.

<sup>2</sup> These bases are the same as those for ASME BPVC, Section III, Class 1 materials, given in ASME BPVC, Section II, Part D. Stress values in B31.3, Appendix A, at temperatures below the creep range generally are the same as those listed in ASME BPVC, Section II, Part D, Tables 2A and 2B, and in Table 3 for bolting, corresponding to those bases. They have been adjusted as necessary to exclude casting quality factors and longitudinal weld joint quality factors. Stress values at temperatures in the creep range generally are the same as those in ASME BPVC, Section II, Part D, Tables 1A and 1B, corresponding to the bases for ASME BPVC, Section VIII, Division 1.

(20) **Table 302.3.3C Increased Casting Quality Factors,  $E_c$** 

| Supplementary Examination<br>in Accordance With Note(s) | Factor, $E_c$ |
|---------------------------------------------------------|---------------|
| (1)                                                     | 0.85          |
| (2)(a) or (2)(b)                                        | 0.85          |
| (3)(a) or (3)(b)                                        | 0.95          |
| (1) and (2)(a) or (2)(b)                                | 0.90          |
| (1) and (3)(a) or (3)(b)                                | 1.00          |
| (2)(a) or (2)(b) and (3)(a) or (3)(b)                   | 1.00          |

GENERAL NOTE: Titles of standards referenced in this Table's Notes are as follows:

|            |                                                                                                                                                    |
|------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| ASME B46.1 | Surface Texture (Surface Roughness, Waviness and Lay)                                                                                              |
| ASTM E94   | Guide for Radiographic Examination Using Industrial Radiographic Film                                                                              |
| ASTM E114  | Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing                                                                                   |
| ASTM E165  | Practice for Liquid Penetrant Testing for General Industry                                                                                         |
| ASTM E709  | Guide for Magnetic Particle Testing                                                                                                                |
| MSS SP-53  | Quality Standard for Steel Castings and Forgings for Valves, Flanges, Fittings, and Other Piping Components — Magnetic Particle Examination Method |
| MSS SP-93  | Quality Standard for Steel Castings and Forgings for Valves, Flanges, Fittings, and Other Piping Components — Liquid Penetrant Examination Method  |

## NOTES:

- (1) Machine all surfaces to a finish of  $6.3 \mu\text{m } R_a$  ( $250 \mu\text{in. } R_a$  in accordance with ASME B46.1), thus increasing the effectiveness of surface examination.
- (2)
  - (a) Examine all surfaces of each casting (ferromagnetic material only) by the magnetic particle method in accordance with ASTM E709. Judge acceptability in accordance with MSS SP-53, Table 1.
  - (b) Examine all surfaces of each casting by the liquid penetrant method, in accordance with ASTM E165. Judge acceptability in accordance with SP-93, Table 1.
- (3)
  - (a) Fully examine each casting ultrasonically in accordance with ASTM E114, accepting a casting only if there is no evidence of depth of defects in excess of 5% of wall thickness.
  - (b) Fully radiograph each casting in accordance with ASTM E94. Judge in accordance with the stated acceptance levels in Table 302.3.3D.

(b) *Basic Quality Factors.* Castings of gray and malleable iron, conforming to listed specifications, are assigned a basic casting quality factor,  $E_c$ , of 1.00 (due to their conservative allowable stress basis). For most other metals, static castings that conform to the material specification and have been visually examined as required by MSS SP-55, Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components — Visual Method, are assigned a basic casting quality factor,  $E_c$ , of 0.80. Centrifugal castings that meet specification requirements only for chemical analysis, tensile, hydrostatic, and flattening tests, and visual examination are assigned a basic casting quality factor of 0.80. Basic casting quality factors are tabulated for listed specifications in Table A-1A.

(c) *Increased Quality Factors.* Casting quality factors may be increased when supplementary examinations are performed on each casting. Table 302.3.3C states the increased casting quality factors,  $E_c$ , that may be used for various combinations of supplementary examination. Table 302.3.3D states the acceptance criteria for the examination methods specified in the Notes to Table 302.3.3C. Quality factors higher than those shown in Table 302.3.3C do not result from combining tests (2)(a) and (2)(b), or (3)(a) and (3)(b). In no case shall the quality factor exceed 1.00.

Several of the specifications in Appendix A require machining of all surfaces and/or one or more of these supplementary examinations. In such cases, the appropriate increased quality factor is shown in Table A-1A.

### 302.3.4 Weld Joint Quality Factor, $E_j$

(a) *Basic Quality Factors.* The weld joint quality factors,  $E_j$ , tabulated in Table A-1B are basic factors for straight or spiral (helical seam) welded joints for pressure-containing components as shown in Table 302.3.4.

(b) *Increased Quality Factors.* Table 302.3.4 also indicates higher joint quality factors that may be substituted for those in Table A-1B for certain kinds of welds if additional examination is performed beyond that required by the product specification.

### 302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains

(a) *Internal Pressure Stresses.* Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, including any reinforcement, meets the requirements of para. 304.

(b) *External Pressure Stresses.* Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. 304.

(c) *Stresses Due to Sustained Loads,  $S_L$ .* The stresses due to sustained loads,  $S_L$ , in any component in a piping system (see para. 320), shall not exceed  $S_h$ , where  $S_h$  is the basic allowable stress provided in Table A-1 or Table A-1M at

**Table 302.3.3D Acceptance Levels for Castings**

| Material Examined Thickness, <i>T</i>               | Applicable Standard | Acceptance Level (or Class) | Acceptable Discontinuities     |
|-----------------------------------------------------|---------------------|-----------------------------|--------------------------------|
| Steel<br><i>T</i> ≤ 25 mm<br>(1 in.)                | ASTM E446           | 1                           | Types A, B, C                  |
| Steel<br><i>T</i> > 25 mm,<br>≤ 51 mm<br>(2 in.)    | ASTM E446           | 2                           | Types A, B, C                  |
| Steel<br><i>T</i> > 51 mm,<br>≤ 114 mm<br>(4½ in.)  | ASTM E186           | 2                           | Categories A, B, C             |
| Steel<br><i>T</i> > 114 mm,<br>≤ 305 mm<br>(12 in.) | ASTM E280           | 2                           | Categories A, B, C             |
| Aluminum and magnesium                              | ASTM E155           | ...                         | Shown in reference radiographs |
| Copper, Ni-Cu                                       | ASTM E272           | 2                           | Codes A, Ba, Bb                |
| Bronze                                              | ASTM E310           | 2                           | Codes A and B                  |

GENERAL NOTE: Titles of ASTM standards referenced in this Table are as follows:

|      |                                                                                      |
|------|--------------------------------------------------------------------------------------|
| E155 | Reference Radiographs for Inspection of Aluminum and Magnesium Castings              |
| E186 | Reference Radiographs for Heavy-Walled (2 to 4½-in. (50.8 to 114 mm)) Steel Castings |
| E272 | Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings |
| E280 | Reference Radiographs for Heavy-Walled (4½ to 12 in. (114 to 305 mm)) Steel Castings |
| E310 | Reference Radiographs for Tin Bronze Castings                                        |
| E446 | Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness          |

the metal temperature for the operating condition being considered.

(d) *Allowable Displacement Stress Range,  $S_A$* . The computed displacement stress range,  $S_E$ , in a piping system (see para. 319.4.4) shall not exceed the allowable displacement stress range,  $S_A$  (see paras. 319.2.3 and 319.3.4), calculated by eq. (1a)

$$S_A = f(1.25S_c + 0.25S_h) \quad (1a)$$

When  $S_h$  is greater than  $S_L$ , the difference between them may be added to the term  $0.25S_h$  in eq. (1a). In that case, the allowable stress range is calculated by eq. (1b)

$$S_A = f[1.25(S_c + S_h) - S_L] \quad (1b)$$

For eqs. (1a) and (1b)

$f$  = stress range factor,<sup>3</sup> calculated by eq. (1c)<sup>4</sup>

$$f \text{ (see Figure 302.3.5)} = 6.0(N)^{-0.2} \leq f_m \quad (1c)$$

$f_m$  = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at metal temperatures ≤ 371°C (700°F); otherwise  $f_m = 1.0$

$N$  = equivalent number of full displacement cycles during the expected service life of the piping system<sup>5</sup>

$S_c$  = basic allowable stress<sup>6</sup> at minimum metal temperature expected during the displacement cycle under analysis

= 138 MPa (20 ksi) maximum

$S_h$  = basic allowable stress<sup>6</sup> at maximum metal temperature expected during the displacement cycle under analysis

= 138 MPa (20 ksi) maximum

$S_L$  = stress due to sustained loads; in systems where supports may be active in some conditions and inactive in others, the maximum value of sustained stress, considering all support conditions, shall be used

When the computed stress range varies, whether from thermal expansion or other conditions,  $S_E$  is defined as the greatest computed displacement stress range. The value of  $N$  in such cases can be calculated by eq. (1d)

$$N = N_E + \sum (r_i^5 N_i) \text{ for } i = 1, 2, \dots, n \quad (1d)$$

where

$N_E$  = number of cycles of maximum computed displacement stress range,  $S_E$

$N_i$  = number of cycles associated with displacement stress range,  $S_i$

$r_i = S_i / S_E$

$S_i$  = any computed displacement stress range smaller than  $S_E$

When the total number of significant stress cycles due to all causes exceeds 100 000, and with the owner's approval, the designer may elect to apply the alternative fatigue

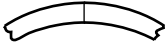
<sup>3</sup> Applies to essentially noncorroded piping. Corrosion can sharply decrease cyclic life; therefore, corrosion resistant materials should be considered where a large number of major stress cycles is anticipated.

<sup>4</sup> The minimum value for  $f$  is 0.15, which results in an allowable displacement stress range,  $S_A$ , for an indefinitely large number of cycles.

<sup>5</sup> The designer is cautioned that the fatigue life of materials operated at elevated temperature may be reduced.

<sup>6</sup> For castings, the basic allowable stress shall be multiplied by the applicable casting quality factor,  $E_c$ . For longitudinal welds, the basic allowable stress need not be multiplied by the weld quality factor,  $E_j$ .

**Table 302.3.4 Longitudinal Weld Joint Quality Factor,  $E_j$** 

| No. | Type of Joint                                                                                                                               | Type of Seam                                                         | Examination                                                                                                                                                                                              | Factor, $E_j$        |
|-----|---------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| 1   | Furnace butt weld, continuous weld<br>                     | Straight                                                             | As required by listed specification                                                                                                                                                                      | 0.60<br>[Note (1)]   |
| 2   | Electric resistance weld<br>                               | Straight or spiral (helical seam)                                    | As required by listed specification                                                                                                                                                                      | 0.85<br>[Note (1)]   |
| 3   | Electric fusion weld                                                                                                                        |                                                                      |                                                                                                                                                                                                          |                      |
|     | (a) Single butt weld<br>(with or without filler metal)<br> | Straight or spiral (helical seam)                                    | As required by listed specification or this Code<br>Additionally spot radiographed in accordance with para. 341.5.1<br>Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2 | 0.80<br>0.90<br>1.00 |
|     | (b) Double butt weld<br>(with or without filler metal)<br> | Straight or spiral (helical seam)<br>(except as provided in 4 below) | As required by listed specification or this Code<br>Additionally spot radiographed in accordance with para. 341.5.1<br>Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2 | 0.85<br>0.90<br>1.00 |
| 4   | Specific specification                                                                                                                      |                                                                      |                                                                                                                                                                                                          |                      |
|     | API 5L, electric fusion weld, double butt seam<br>        | Straight (with one or two seams) or spiral (helical seam)            | As required by specification<br>Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2                                                                                        | 0.95<br>1.00         |

NOTE: (1) It is not permitted to increase the joint quality factor by additional examination for joint 1 or 2.

assessment rules in [Appendix W](#) to satisfy the displacement stress range requirements of this paragraph and of [para. 319](#). A significant stress cycle is defined in [para. W300](#). When the alternative rules of [Appendix W](#) are applied, the calculations shall be documented in the engineering design.

(e) *Weld Joint Strength Reduction Factor,  $W$* . At elevated temperatures, the long-term strength of weld joints may be lower than the long-term strength of the base material.

The weld joint strength reduction factor,  $W$ , is the ratio of the nominal stress to cause failure of a weld joint to that of the corresponding base material for an elevated temperature condition of the same duration. It only applies at weld locations in longitudinal or spiral (helical seam) welded piping components. The designer is responsible for the application of weld joint strength reduction factors to other welds (e.g., circumferential).

When determining the required wall thickness for internal pressure in accordance with [para. 304](#), for each coincident operating pressure-temperature condition under consideration, the product of the *basic* allowable stress and the applicable weld quality factor,  $SE$ , shall be multiplied by  $W$ .

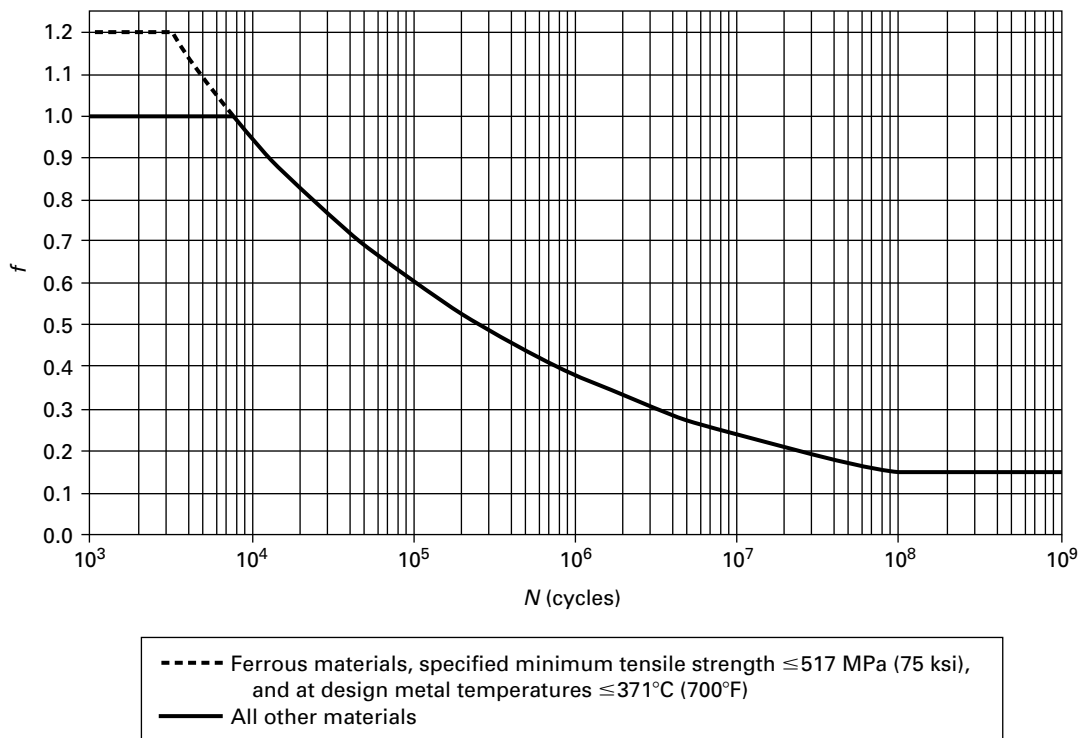
$W$  is equal to 1.0 when evaluating occasional loads, e.g., wind and earthquake, or when evaluating permissible variations in accordance with [para. 302.2.4](#). Application of  $W$  is not required when determining the pressure rating for the occasional load or *permissible* variation condition. It is also not required when calculating the allowable stress range for displacement stresses,  $S_A$ , in (d).

For other than occasional loads or permissible variations,  $W$  shall be in accordance with [Table 302.3.5](#) except as provided in (f).

(f) *Alternative Weld Strength Reduction Factors*. A weld strength reduction factor other than that listed in [Table 302.3.5](#) may be used in accordance with one of the following criteria:

(1) Creep test data may be used to determine the weld joint strength reduction factor,  $W$ . However, the use of creep test data to increase the factor  $W$  above that shown in [Table 302.3.5](#) is not permitted for the CrMo and Creep Strength Enhanced Ferritic (CSEF) steels materials, as defined in [Table 302.3.5](#). Creep testing of weld joints to determine weld joint strength reduction factors, when permitted, should be full thickness cross-weld specimens with test durations of at least 1 000 h. Full thickness tests shall be used unless



Figure 302.3.5 Stress Range Factor,  $f$ 

the designer otherwise considers effects such as stress redistribution across the weld.

(2) With the owner's approval, extensive successful experience may be used to justify the factor  $W$  above that shown in Table 302.3.5. Successful experience must include same or like material, weld metal composition, and welding process under equivalent, or more severe, sustained operating conditions.

### (20) 302.3.6 Limits of Calculated Stresses Due to Occasional Loads

(a) *Operation.* Stresses due to occasional loads may be calculated using the equations for stress due to sustained loads in para. 320.2.

(1) Subject to the limits of para. 302.2.4, the sum of the stresses due to sustained loads, such as pressure and weight,  $S_L$ , and of the stresses produced by occasional loads, such as wind and earthquake, shall not exceed 1.33 times the basic allowable stress provided in Table A-1 or Table A-1M at the metal temperature for the occasional condition being considered. Wind and earthquake forces need not be considered as acting concurrently.

(2) For Elevated Temperature Fluid Service (see definition in para. 300.2) of materials having ductile behavior, as an alternative to the use of 1.33 times the basic allowable stress provided in Table A-1 or Table A-1M, the allowable stress for occasional loads of short duration, e.g.,

surge, extreme wind, or earthquake, may be taken as the lowest of the following:

(-a) the weld strength reduction factor times 90% of the yield strength at the metal temperature for the occasional condition being considered

(-b) four times the basic allowable stress provided in Appendix A

(-c) for occasional loads that exceed 10 h over the life of the piping system, the stress resulting in a 20% creep usage factor in accordance with Appendix V

For (-a), the yield strength shall be as listed in ASME BPVC, Section II, Part D, Table Y-1 or determined in accordance with para. 302.3.2. The strength reduction factor represents the reduction in yield strength with long-term exposure of the material to elevated temperatures and, in the absence of more-applicable data, shall be taken as 1.0 for austenitic stainless steel and 0.8 for other materials.

For (-b), the basic allowable stress for castings shall also be multiplied by the casting quality factor,  $E_c$ . Where the allowable stress value exceeds two-thirds of yield strength at temperature, the allowable stress value must be reduced as specified in para. 302.3.2(e).

(b) *Test.* Stresses due to test conditions are not subject to the limitations in para. 302.3. It is not necessary to consider other occasional loads, e.g., wind and earthquake, as occurring concurrently with test loads.

### 302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread depth or groove depth. See definition for  $c$  in [para. 304.1.1\(b\)](#).

### 302.5 Mechanical Strength

(a) Designs shall be checked for adequacy of mechanical strength under applicable loadings. When necessary, the wall thickness shall be increased to prevent overstress, damage, collapse, or buckling due to superimposed loads from supports, ice formation, backfill, transportation, handling, or other loads enumerated in [para. 301](#).

(b) Where increasing the thickness would excessively increase local stresses or the risk of brittle fracture, or is otherwise impracticable, the impact of applied loads may be mitigated through additional supports, braces, or other means without requiring an increased wall thickness. Particular consideration should be given to the mechanical strength of small pipe connections to piping or equipment.

## PART 2

### PRESSURE DESIGN OF PIPING COMPONENTS

#### 303 GENERAL

Components manufactured in accordance with standards listed in [Table 326.1](#) shall be considered suitable for use at pressure-temperature ratings in accordance with [para. 302.2.1](#) or [302.2.2](#), as applicable. The rules in [para. 304](#) are intended for pressure design of components not covered in [Table 326.1](#), but may be used for a special or more-rigorous design of such components, or to satisfy requirements of [para. 302.2.2](#). Designs shall be checked for adequacy of mechanical strength as described in [para. 302.5](#).

#### 304 PRESSURE DESIGN OF COMPONENTS

##### 304.1 Straight Pipe

###### 304.1.1 General

(a) The required thickness of straight sections of pipe shall be determined in accordance with [eq. \(2\)](#)

$$t_m = t + c \quad (2)$$

The minimum thickness,  $T$ , for the pipe selected, considering manufacturer's minus tolerance, shall be not less than  $t_m$ .

(b) The following nomenclature is used in the equations for pressure design of straight pipe:

$c$  = sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances. For threaded components, the nominal thread depth (dimension  $h$  of ASME B1.20.1, or

equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

$D$  = outside diameter of pipe as listed in tables of standards or specifications or as measured

$d$  = inside diameter of pipe. For pressure design calculation, the inside diameter of the pipe is the maximum value allowable under the purchase specification.

$E$  = quality factor from [Table A-1A](#) or [Table A-1B](#)

$P$  = internal design gage pressure

$S$  = stress value for material from [Table A-1](#) or [Table A-1M](#)

$T$  = pipe wall thickness (measured or minimum in accordance with the purchase specification)

$t$  = pressure design thickness, as calculated in accordance with [para. 304.1.2](#) for internal pressure or as determined in accordance with [para. 304.1.3](#) for external pressure

$t_m$  = minimum required thickness, including mechanical, corrosion, and erosion allowances

$W$  = weld joint strength reduction factor in accordance with [para. 302.3.5\(e\)](#)

$Y$  = coefficient from [Table 304.1.1](#), valid for  $t < D/6$  and for materials shown. The value of  $Y$  may be interpolated for intermediate temperatures. For  $t \geq D/6$ ,

$$Y = \frac{d + 2c}{D + d + 2c}$$

##### 304.1.2 Straight Pipe Under Internal Pressure

(a) For  $t < D/6$ , the internal pressure design thickness for straight pipe shall be not less than that calculated in accordance with either [eq. \(3a\)](#) or [eq. \(3b\)](#)

$$t = \frac{PD}{2(SEW + PY)} \quad (3a)$$

$$t = \frac{P(d + 2c)}{2[SEW - P(1 - Y)]} \quad (3b)$$

(b) For  $t \geq D/6$  or for  $P/SE > 0.385$ , calculation of pressure design thickness for straight pipe requires special consideration of factors such as theory of failure, effects of fatigue, and thermal stress.

**304.1.3 Straight Pipe Under External Pressure.** To determine wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in ASME BPVC, Section VIII, Division 1, UG-28 through UG-30 shall be followed, using as the design length,  $L$ , the running centerline length between any

**Table 302.3.5 Weld Joint Strength Reduction Factor,  $W$** 

| Steel Group                                                                                                 | Component Temperature, $T_i$ , °C (°F) |              |              |              |                |                |                |                |                |                |                |                |                |                |                |
|-------------------------------------------------------------------------------------------------------------|----------------------------------------|--------------|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                                                                                                             | ≤427<br>(≤800)                         | 454<br>(850) | 482<br>(900) | 510<br>(950) | 538<br>(1,000) | 566<br>(1,050) | 593<br>(1,100) | 621<br>(1,150) | 649<br>(1,200) | 677<br>(1,250) | 704<br>(1,300) | 732<br>(1,350) | 760<br>(1,400) | 788<br>(1,450) | 816<br>(1,500) |
| Carbon Steel                                                                                                | 1                                      | 1            | 1            | 1            | 1              | 1              | 1              | ...            | ...            | ...            | ...            | ...            | ...            | ...            | ...            |
| CrMo<br>[Notes (1)–(3)]                                                                                     | 1                                      | 0.95         | 0.91         | 0.86         | 0.82           | 0.77           | 0.73           | 0.68           | 0.64           | ...            | ...            | ...            | ...            | ...            | ...            |
| CSEF (N + T)<br>[Notes (3)–(5)]                                                                             | ...                                    | ...          | ...          | 1            | 0.95           | 0.91           | 0.86           | 0.82           | 0.77           | ...            | ...            | ...            | ...            | ...            | ...            |
| CSEF<br>[Notes (3) and (4)]<br>(Subcritical PWHT)                                                           | ...                                    | ...          | 1            | 0.5          | 0.5            | 0.5            | 0.5            | 0.5            | 0.5            | ...            | ...            | ...            | ...            | ...            | ...            |
| Autogenous welds in austenitic<br>stainless grade 3xx, and N088xx<br>and N066xx nickel alloys<br>[Note (6)] | ...                                    | ...          | ...          | 1            | 1              | 1              | 1              | 1              | 1              | 1              | 1              | 1              | 1              | 1              | 1              |
| Austenitic stainless grade 3xx and<br>N088xx nickel alloys<br>[Notes (7) and (8)]                           | ...                                    | ...          | ...          | 1            | 0.95           | 0.91           | 0.86           | 0.82           | 0.77           | 0.73           | 0.68           | 0.64           | 0.59           | 0.55           | 0.5            |
| Other materials [Note (9)]                                                                                  | ...                                    | ...          | ...          | ...          | ...            | ...            | ...            | ...            | ...            | ...            | ...            | ...            | ...            | ...            | ...            |

## GENERAL NOTES:

- Weld joint strength reduction factors at temperatures above the upper temperature limit listed in [Appendix A](#) for the base metal or outside of the applicable range in [Table 302.3.5](#) are the responsibility of the designer. At temperatures below those where weld joint strength reduction factors are tabulated, a value of 1.0 shall be used for the factor  $W$  where required; however, the additional rules of this Table and Notes do not apply.
- $T_{cr}$  = temperature 25°C (50°F) below the temperature identifying the start of time-dependent properties listed under "NOTES - TIME-DEPENDENT PROPERTIES" ( $T_{xx}$ ) in the Notes to ASME BPVC, Section II, Part D, Tables 1A and 1B for the base metals joined by welding. For materials not listed in Section II, Part D,  $T_{cr}$  shall be the temperature where the creep rate or stress rupture criteria in [paras. 302.3.2\(d\)\(4\), \(5\), \(6\), and \(7\)](#) governs the basic allowable stress value of the metals joined by welding. When the base metals differ, the lower value of  $T_{cr}$  shall be used for the weld joint.
- $T_i$  = temperature, °C (°F), of the component for the coincident operating pressure–temperature condition,  $i$ , under consideration.
- CAUTIONARY NOTE: There are many factors that may affect the life of a welded joint at elevated temperature and all of those factors cannot be addressed in a table of weld strength reduction factors. For example, fabrication issues such as the deviation from a true circular form in pipe (e.g., "peaking" at longitudinal weld seams) or offset at the weld joint can cause an increase in stress that may result in reduced service life and control of these deviations is recommended.
- The weld joint strength reduction factor,  $W$ , may be determined using linear interpolation for intermediate temperature values.

## NOTES:

- The Cr–Mo Steels include:  $\frac{1}{2}$ Cr– $\frac{1}{2}$ Mo, 1Cr– $\frac{1}{2}$ Mo,  $1\frac{1}{4}$ Cr– $\frac{1}{2}$ Mo–Si,  $2\frac{1}{4}$ Cr–1Mo, 3Cr–1Mo, 5Cr– $\frac{1}{2}$ Mo, 9Cr–1Mo. Longitudinal and spiral (helical seam) welds shall be normalized, normalized and tempered, or subjected to proper subcritical postweld heat treatment (PWHT) for the alloy. Required examination is in accordance with [para. 341.4.4](#) or [305.2.4](#).
- Longitudinal and spiral (helical seam) seam fusion welded construction is not permitted for C– $\frac{1}{2}$ Mo steel above 454°C (850°F).
- The required carbon content of the weld filler metal shall be  $\geq 0.05$  C wt. %. See [para. 341.4.4\(b\)](#) for examination requirements. The basicity index of SAW flux shall be  $\geq 1.0$ .
- The CSEF (Creep Strength Enhanced Ferritic) steels include grades 91, 92, 911, 122, and 23.
- N + T = Normalizing + Tempering PWHT.
- Autogenous welds without filler metal in austenitic stainless steel (grade 3xx) and austenitic nickel alloys UNS Nos. N066xx and N088xx. A solution anneal after welding is required for use of the factors in the Table. See [para. 341.4.3\(b\)](#) for examination requirements.
- Alternatively, the 100,000 hr Stress Rupture Factors listed in ASME BPVC, Section III, Division 1, Subsection NH, Tables I-14.10 A-xx, B-xx, and C-xx may be used as the weld joint strength reduction factor for the materials and welding consumables specified.



Table 302.3.5 Weld Joint Strength Reduction Factor, *W* (Cont'd)

- NOTES: (Cont'd)
- (8) Certain heats of the austenitic stainless steels, particularly for those grades whose creep strength is enhanced by the precipitation of temper-resistant carbides and carbonitrides, can suffer from an embrittlement condition in the weld heat-affected zone that can lead to premature failure of welded components operating at elevated temperatures. A solution annealing heat treatment of the weld area mitigates this susceptibility.
  - (9) For materials other than carbon steel, CrMo, CSEF, and the austenitic alloys listed in Table 302.3.5, *W* shall be as follows: For  $T_i \leq T_{cr}$ ,  $W = 1.0$ . For SI units, for  $T_{cr} < T_i \leq 816^\circ\text{C}$ ,  $W = 1 - 0.00164(T_i - T_{cr})$ . For U.S. Customary units, for  $T_{cr} < T_i \leq 1,500^\circ\text{F}$ ,  $W = 1 - 0.000909(T_i - T_{cr})$ . If  $T_i$  exceeds the upper temperature for which an allowable stress value is listed in Appendix A for the base metal, the value for *W* is the responsibility of the designer.

**Table 304.1.1 Values of Coefficient Y for  $t < D/6$** 

| Material                                                           | Temperature, °C (°F)   |              |                |                |                |                |                |                          |
|--------------------------------------------------------------------|------------------------|--------------|----------------|----------------|----------------|----------------|----------------|--------------------------|
|                                                                    | 482 (900)<br>and Below | 510<br>(950) | 538<br>(1,000) | 566<br>(1,050) | 593<br>(1,100) | 621<br>(1,150) | 649<br>(1,200) | 677 (1,250)<br>and Above |
| Ferritic steels                                                    | 0.4                    | 0.5          | 0.7            | 0.7            | 0.7            | 0.7            | 0.7            | 0.7                      |
| Austenitic steels                                                  | 0.4                    | 0.4          | 0.4            | 0.4            | 0.5            | 0.7            | 0.7            | 0.7                      |
| Nickel alloys<br>UNS Nos. N06617,<br>N08800, N08810,<br>and N08825 | 0.4                    | 0.4          | 0.4            | 0.4            | 0.4            | 0.4            | 0.5            | 0.7                      |
| Gray iron                                                          | 0.0                    | ...          | ...            | ...            | ...            | ...            | ...            | ...                      |
| Other ductile metals                                               | 0.4                    | 0.4          | 0.4            | 0.4            | 0.4            | 0.4            | 0.4            | 0.4                      |

two sections stiffened in accordance with UG-29. As an exception, for pipe with  $D_o/t < 10$ , the value of  $S$  to be used in determining  $P_{a2}$  shall be the lesser of the following values for pipe material at design temperature:

(a) 1.5 times the stress value from Table A-1 or Table A-1M of this Code, or

(b) 0.9 times the yield strength tabulated in ASME BPVC, Section II, Part D, Table Y-1 for materials listed therein

(The symbol  $D_o$  in ASME BPVC, Section VIII is equivalent to  $D$  in this Code.)

### 304.2 Curved and Mitered Segments of Pipe

**304.2.1 Pipe Bends.** The minimum required thickness,  $t_m$ , of a bend, after bending, in its finished form, shall be determined in accordance with eqs. (2) and (3c)

$$t = \frac{PD}{2[(SEW/I) + PY]} \quad (3c)$$

where at the intrados (inside bend radius)

$$I = \frac{4(R_1/D) - 1}{4(R_1/D) - 2} \quad (3d)$$

and at the extrados (outside bend radius)

$$I = \frac{4(R_1/D) + 1}{4(R_1/D) + 2} \quad (3e)$$

and at the sidewall on the bend centerline radius,  $I = 1.0$ , and where

$R_1$  = bend radius of welding elbow or pipe bend

Thickness variations from the intrados to the extrados and along the length of the bend shall be gradual. The thickness requirements apply at the mid-span of the bend,  $\gamma/2$ , at the intrados, extrados, and bend centerline radius. The minimum thickness at the end tangents shall not be less than the requirements of para. 304.1 for straight pipe (see Figure 304.2.1).

**304.2.2 Elbows.** Manufactured elbows not in accordance with para. 303 shall be qualified as required by para. 304.7.2 or designed in accordance with para. 304.2.1, except as provided in para. 328.4.2(b)(6).

**304.2.3 Miter Bends.** An angular offset of 3 deg or less (angle  $\alpha$  in Figure 304.2.3) does not require design consideration as a miter bend. Acceptable methods for pressure design of multiple and single miter bends are given in (a) and (b) below.

(a) *Multiple Miter Bends.* The maximum allowable internal pressure shall be the lesser value calculated from eqs. (4a) and (4b). These equations are not applicable when  $\theta$  exceeds 22.5 deg.

$$P_m = \frac{SEW(T - c)}{r_2} \left( \frac{T - c}{(T - c) + 0.643 \tan \theta \sqrt{r_2(T - c)}} \right) \quad (4a)$$

$$P_m = \frac{SEW(T - c)}{r_2} \left( \frac{R_1 - r_2}{R_1 - 0.5r_2} \right) \quad (4b)$$

(b) *Single Miter Bends*

(1) The maximum allowable internal pressure for a single miter bend with angle  $\theta$  not greater than 22.5 deg shall be calculated by eq. (4a).

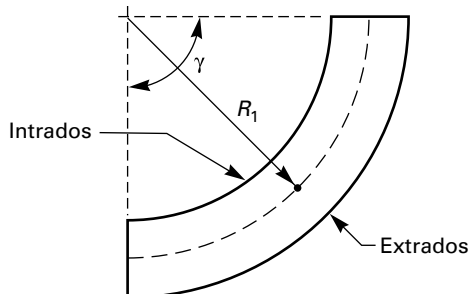
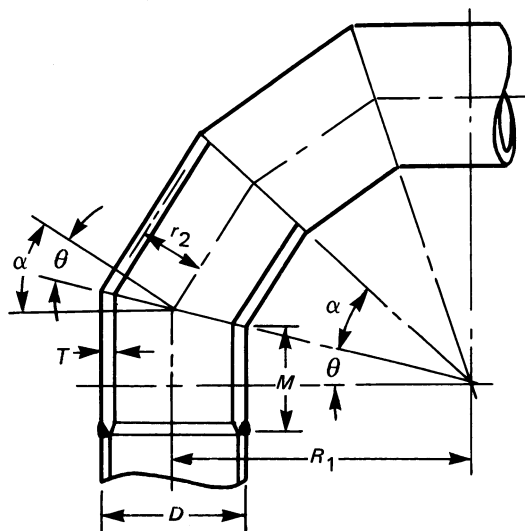
**Figure 304.2.1 Nomenclature for Pipe Bends**

**Figure 304.2.3 Nomenclature for Miter Bends**

(2) The maximum allowable internal pressure for a single miter bend with angle  $\theta$  greater than 22.5 deg shall be calculated by eq. (4c)

$$P_m = \frac{SEW(T - c)}{r_2} \left( \frac{T - c}{(T - c) + 1.25 \tan \theta \sqrt{r_2(T - c)}} \right) \quad (4c)$$

(c) The miter pipe wall thickness,  $T$ , used in eqs. (4a), (4b), and (4c) shall extend a distance not less than  $M$  from the inside crotch of the end miter welds where

$$M = \text{the larger of } 2.5(r_2 T)^{0.5} \text{ or } \tan \theta (R_1 - r_2)$$

The length of taper at the end of the miter pipe may be included in the distance,  $M$ .

(d) The following nomenclature is used in eqs. (4a), (4b), and (4c) for the pressure design of miter bends:

$c$  = same as defined in para. 304.1.1

$E$  = same as defined in para. 304.1.1

$P_m$  = maximum allowable internal pressure for miter bends

$R_1$  = effective radius of miter bend, defined as the shortest distance from the pipe centerline to the intersection of the planes of adjacent miter joints

$r_2$  = mean radius of pipe using nominal wall  $\bar{T}$

$S$  = same as defined in para. 304.1.1

$T$  = miter pipe wall thickness (measured or minimum in accordance with the purchase specification)

$W$  = same as defined in para. 304.1.1

$\alpha$  = angle of change in direction at miter joint  
=  $2\theta$

$\theta$  = angle of miter cut

For compliance with this Code, the value of  $R_1$  shall be not less than that given by eq. (5)

$$R_1 = \frac{A}{\tan \theta} + \frac{D}{2} \quad (5)$$

where  $A$  has the following empirical values:

(1) For SI units

| $(T - c)$ , mm      | $A$                 |
|---------------------|---------------------|
| $\leq 13$           | 25                  |
| $13 < (T - c) < 22$ | $2(T - c)$          |
| $\geq 22$           | $[2(T - c)/3] + 30$ |

(2) For U.S. Customary units

| $(T - c)$ , in.        | $A$                   |
|------------------------|-----------------------|
| $\leq 0.5$             | 1.0                   |
| $0.5 < (T - c) < 0.88$ | $2(T - c)$            |
| $\geq 0.88$            | $[2(T - c)/3] + 1.17$ |

**304.2.4 Curved and Mitered Segments of Pipe Under External Pressure.** The wall thickness of curved and mitered segments of pipe subjected to external pressure may be determined as specified for straight pipe in para. 304.1.3.

### 304.3 Branch Connections

#### 304.3.1 General

(20)

(a) Except as provided in (b) below, the requirements in paras. 304.3.2 through 304.3.4 are applicable to the following branch connections:

(1) fittings (tees, extruded outlets, branch outlet fittings in accordance with MSS SP-97, laterals, crosses)

(2) couplings not larger than DN 80 (NPS 3) and unlisted cast or forged branch connection fittings (see para. 300.2) attached to the run pipe by welding

(3) welding the branch pipe directly to the run pipe, with or without added reinforcement, as covered in para. 328.5.4

(b) The rules in paras. 304.3.2 through 304.3.4 are minimum requirements, valid only for branch connections in which (using the nomenclature of Figure 304.3.3)

(1) the run pipe diameter-to-thickness ratio ( $D_h/T_h$ ) is less than 100 and the branch-to-run diameter ratio ( $D_b/D_h$ ) is not greater than 1.0

(2) for run pipe with  $D_h/T_h \geq 100$ , the branch diameter,  $D_b$ , is less than one-half the run diameter,  $D_h$

(3) angle  $\beta$  is at least 45 deg

(4) the axis of the branch intersects the axis of the run  
(c) Where the provisions of (a) and (b) above are not met, pressure design shall be qualified as required by para. 304.7.2.

(d) Other design considerations relating to branch connections are stated in para. 304.3.5.

**304.3.2 Strength of Branch Connections.** A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement required to sustain the pressure shall be determined in accordance with [para. 304.3.3](#) or [304.3.4](#). There are, however, certain branch connections that have adequate pressure strength or reinforcement as constructed. It may be assumed without calculation that a branch connection has adequate strength to sustain the internal and external pressure that will be applied to it if

(a) the branch connection is made with a listed branch type fitting such as an ASME B16.9 or ASME B16.11 tee, or MSS SP-97 branch connection fitting. See [para. 303](#).

(b) the branch connection is made by welding a listed threaded or socket welding coupling or listed half coupling directly to the run in accordance with [para. 328.5.4](#), provided the size of the branch does not exceed DN 50 (NPS 2) nor one-fourth the nominal size of the run. The minimum wall thickness of the coupling anywhere in the reinforcement zone (if threads are in the zone, wall thickness is measured from root of thread to minimum outside diameter) shall be not less than that of the unthreaded branch pipe. In no case shall a coupling or half coupling have a rating less than Class 3000 in accordance with ASME B16.11.

(c) the branch connection utilizes an unlisted branch connection fitting (see [para. 300.2](#)), provided the fitting is made from materials listed in [Table A-1](#) or [Table A-1M](#) and provided that the branch connection is qualified as required by [para. 304.7.2](#).

**304.3.3 Reinforcement of Welded Branch Connections.** Added reinforcement is required to meet the criteria in (b) and (c) when it is not inherent in the components of the branch connection. Sample problems illustrating the calculations for branch reinforcement are shown in [Appendix H](#).

(a) *Nomenclature.* The nomenclature below is used in the pressure design of branch connections. It is illustrated in [Figure 304.3.3](#), which does not indicate details for construction or welding. Some of the terms defined in [Appendix J](#) are subject to further definitions or variations, as follows:

- $b$  = subscript referring to branch
- $d_1$  = effective length removed from pipe at branch. For branch intersections where the branch opening is a projection of the branch pipe inside diameter (e.g., pipe-to-pipe fabricated branch),  $d_1 = [D_b - 2(T_b - c)]/\sin \beta$
- $d_2$  = "half width" of reinforcement zone  
=  $d_1$  or  $(T_b - c) + (T_h - c) + d_1/2$ , whichever is greater, but in any case not more than  $D_h$
- $h$  = subscript referring to run or header
- $L_4$  = height of reinforcement zone outside of run pipe

=  $2.5(T_h - c)$  or  $2.5(T_b - c) + T_r$ , whichever is less  
 $T_b$  = branch pipe thickness (measured or minimum in accordance with the purchase specification) except for branch connection fittings (see [para. 300.2](#)). For such connections the value of  $T_b$  for use in calculating  $L_4$ ,  $d_2$ , and  $A_3$  is the thickness of the reinforcing barrel (minimum per purchase specification), provided that the barrel thickness is uniform (see [Figure K328.5.4](#)) and extends at least to the  $L_4$  limit (see [Figure 304.3.3](#)).

$T_r$  = minimum thickness of reinforcing ring or saddle made from pipe (use nominal thickness if made from plate)

= 0 if there is no reinforcing ring or saddle

$t$  = pressure design thickness of pipe, according to the appropriate wall thickness equation or procedure in [para. 304.1](#). For welded pipe, when the branch does not intersect the longitudinal weld of the run, the basic allowable stress,  $S$ , for the pipe may be used in determining  $t_h$  for the purpose of reinforcement calculation only. When the branch does intersect the longitudinal weld of the run, the product  $SEW$  (of the stress value,  $S$ ; the appropriate weld joint quality factor,  $E_j$ , from [Table A-1B](#); and the weld joint strength reduction factor,  $W$ ; see [para. 302.3.5](#)) for the run pipe shall be used in the calculation. The product  $SEW$  of the branch shall be used in calculating  $t_b$ .

$\beta$  = smaller angle between axes of branch and run

(b) *Required Reinforcement Area.* The reinforcement area,  $A_1$ , required for a branch connection under internal pressure is

$$A_1 = t_h d_1 (2 - \sin \beta) \quad (6)$$

For a branch connection under external pressure, area  $A_1$  is one-half the area calculated by [eq. \(6\)](#), using as  $t_h$  the thickness required for external pressure.

(c) *Available Area.* The area available for reinforcement is defined as

$$A_2 + A_3 + A_4 \geq A_1 \quad (6a)$$

These areas are all within the reinforcement zone and are further defined below.

(1) Area  $A_2$  is the area resulting from excess thickness in the run pipe wall

$$A_2 = (2d_2 - d_1)(T_h - t_h - c) \quad (7)$$

(2) Area  $A_3$  is the area resulting from excess thickness in the branch pipe wall

$$A_3 = 2L_4(T_b - t_b - c)/\sin \beta \quad (8)$$

If the allowable stress for the branch pipe wall is less than that for the run pipe, its calculated area must be reduced in the ratio of allowable stress values of the branch to the run in determining its contributions to area  $A_3$ .

(3) Area  $A_4$  is the area of other metal provided by welds and properly attached reinforcement. [See (f).] Weld areas shall be based on the minimum dimensions specified in para. 328.5.4, except that larger dimensions may be used if the welder has been specifically instructed to make the welds to those dimensions.

(d) *Reinforcement Zone*. The reinforcement zone is a parallelogram whose length extends a distance,  $d_2$ , on each side of the centerline of the branch pipe and whose width starts at the inside surface of the run pipe (in its corroded condition) and extends beyond the outside surface of the run pipe a perpendicular distance,  $L_4$ .

(e) *Multiple Branches*. When two or more branch connections are so closely spaced that their reinforcement zones overlap, the distance between centers of the openings should be at least  $1\frac{1}{2}$  times their average diameter, and the area of reinforcement between any two openings shall be not less than 50% of the total that both require. Each opening shall have adequate reinforcement in accordance with (b) and (c). No part of the metal cross section may apply to more than one opening or be evaluated more than once in any combined area. (Consult PFI Standard ES-7, Minimum Length and Spacing for Branch Connections, for detailed recommendations on spacing of welded nozzles.)

(f) *Added Reinforcement*

(1) Reinforcement added in the form of a ring or saddle as part of area  $A_4$  shall be of reasonably constant width.

(2) Material used for reinforcement may differ from that of the run pipe provided it is compatible with run and branch pipes with respect to weldability, heat treatment requirements, galvanic corrosion, thermal expansion, etc.

(3) If the allowable stress for the reinforcement material is less than that for the run pipe, its calculated area must be reduced in the ratio of allowable stress values in determining its contribution to area  $A_4$ .

(4) No additional credit may be taken for a material having higher allowable stress value than the run pipe.

### 304.3.4 Reinforcement of Extruded Outlet Headers

(a) The principles of reinforcement stated in para. 304.3.3 are essentially applicable to extruded outlet headers. An extruded outlet header is a length of pipe in which one or more outlets for branch connection have been formed by extrusion, using a die or dies to control the radii of the extrusion. The extruded outlet projects above the surface of the header a distance  $h_x$  at least equal to the external radius of the outlet  $r_x$  (i.e.,  $h_x \geq r_x$ ).

(b) The rules in this paragraph are minimum requirements, valid only within the limits of geometry shown in Figure 304.3.4, and only where the axis of the outlet intersects and is perpendicular to the axis of the header. Where these requirements are not met, or where nonintegral material such as a ring, pad, or saddle has been added to the outlet, pressure design shall be qualified as required by para. 304.7.2.

(c) *Nomenclature*. The nomenclature used herein is illustrated in Figure 304.3.4. Note the use of subscript  $x$  signifying extruded. Refer to para. 304.3.3(a) for nomenclature not listed here.

$d_x$  = the design inside diameter of the extruded outlet, measured at the level of the outside surface of the header. This dimension is taken after removal of all mechanical and corrosion allowances, and all thickness tolerances.

$d_2$  = half width of reinforcement zone (equal to  $d_x$ )

$h_x$  = height of the extruded outlet. This must be equal to or greater than  $r_x$  [except as shown in illustration (b) in Figure 304.3.4].

$L_5$  = height of reinforcement zone

$$= 0.7\sqrt{D_b T_x}$$

$r_x$  = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch

$T_x$  = corroded finished thickness of extruded outlet, measured at a height equal to  $r_x$  above the outside surface of the header

(d) *Limitations on Radius  $r_x$* . The external contour radius,  $r_x$ , is subject to the following limitations:

(1) minimum  $r_x$  — the lesser of  $0.05D_b$  or 38 mm (1.50 in.)

(2) maximum  $r_x$  shall not exceed

(-a) for  $D_b < \text{DN } 200$  (NPS 8), 32 mm (1.25 in.)

(-b) for  $D_b \geq \text{DN } 200$ ,  $0.1D_b + 13$  mm (0.50 in.)

(3) for an external contour with multiple radii, the requirements of (1) and (2) above apply, considering the best-fit radius over a 45-deg arc as the maximum radius

(4) machining shall not be employed in order to meet the above requirements

(e) *Required Reinforcement Area*. The required area of reinforcement is defined by

$$A_1 = K t_h d_x \quad (9)$$

where  $K$  is determined as follows:

(1) For  $D_b/D_h > 0.60$ ,  $K = 1.00$ .

(2) For  $0.60 \geq D_b/D_h > 0.15$ ,  $K = 0.6 + \frac{2}{3}(D_b/D_h)$ .

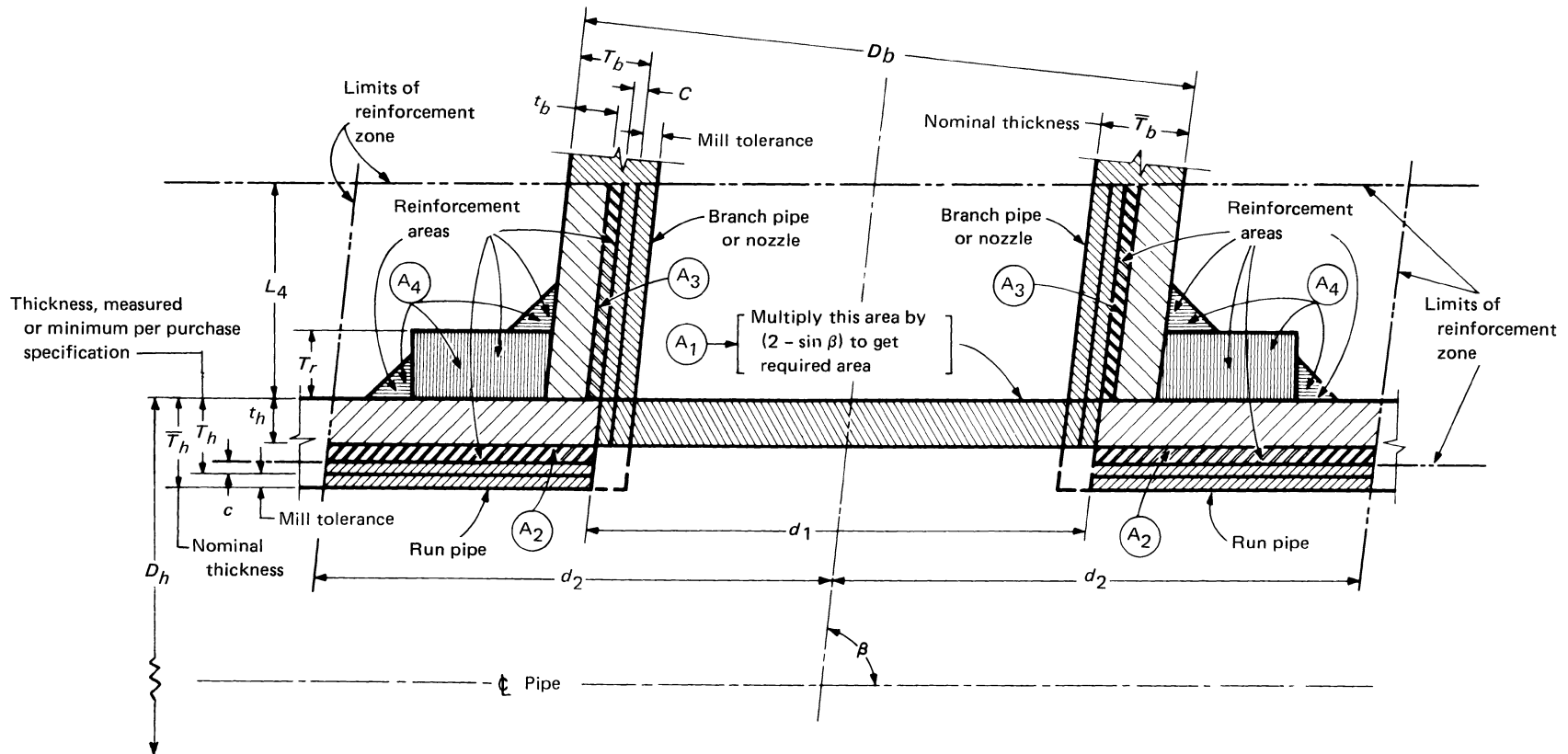
(3) For  $D_b/D_h \leq 0.15$ ,  $K = 0.70$ .

(f) *Available Area*. The area available for reinforcement is defined as

$$A_2 + A_3 + A_4 \geq A_1 \quad (9a)$$

These areas are all within the reinforcement zone and are further defined below.

Figure 304.3.3 Branch Connection Nomenclature



GENERAL NOTE: This Figure illustrates the nomenclature of [para. 304.3.3](#). It does not indicate complete welding details or a preferred method of construction. For typical weld details, see [Figure 328.5.4D](#) and [Figure 328.5.4F](#).



(1) Area  $A_2$  is the area resulting from excess thickness in the header wall

$$A_2 = (2d_2 - d_x)(T_h - t_h - c) \quad (10)$$

(2) Area  $A_3$  is the area resulting from excess thickness in the branch pipe wall

$$A_3 = 2L_5(T_b - t_b - c) \quad (11)$$

(3) Area  $A_4$  is the area resulting from excess thickness in the extruded outlet lip

$$A_4 = 2r_x[T_x - (T_b - c)] \quad (12)$$

(g) *Reinforcement of Multiple Openings.* The rules of para. 304.3.3(e) shall be followed, except that the required area and reinforcement area shall be as given in this paragraph.

(h) *Identification.* The manufacturer shall establish the design pressure and temperature for each extruded outlet header and shall mark the header with this information, together with the symbol "B31.3" (indicating the applicable Code Section) and the manufacturer's name or trademark.

**304.3.5 Additional Design Considerations.** The requirements of paras. 304.3.1 through 304.3.4 are intended to ensure satisfactory performance of a branch connection subject only to pressure. The designer shall also consider the following:

(a) In addition to pressure loadings, external forces and movements are applied to a branch connection by thermal expansion and contraction, dead and live loads, and movement of piping terminals and supports. Special consideration shall be given to the design of a branch connection to withstand these forces and movements.

(b) Branch connections made by welding the branch pipe directly to the run pipe should be avoided under the following circumstances:

(1) when branch size approaches run size, particularly if pipe formed by more than 1.5% cold expansion, or expanded pipe of a material subject to work hardening, is used as the run pipe

(2) where repetitive stresses may be imposed on the connection by vibration, pulsating pressure, temperature cycling, etc.

In such cases, it is recommended that the design be conservative and that consideration be given to the use of tee fittings or complete encirclement types of reinforcement.

(c) Adequate flexibility shall be provided in a small line that branches from a large run, to accommodate thermal expansion and other movements of the larger line (see para. 319.6).

(d) If ribs, gussets, or clamps are used to stiffen the branch connection, their areas cannot be counted as contributing to the reinforcement area determined in para. 304.3.3(c) or 304.3.4(f). However, ribs or gussets

may be used for pressure-strengthening a branch connection in lieu of reinforcement covered in paras. 304.3.3 and 304.3.4 if the design is qualified as required by para. 304.7.2.

(e) For branch connections that do not meet the requirements of para. 304.3.1(b), integral reinforcement, complete encirclement reinforcement, or other means of reinforcement should be considered.

**304.3.6 Branch Connections Under External Pressure.** Pressure design for a branch connection subjected to external pressure may be determined in accordance with para. 304.3.1, using the reinforcement area requirement stated in para. 304.3.3(b).

## 304.4 Closures

### 304.4.1 General

(a) Closures not in accordance with para. 303 or (b) shall be qualified as required by para. 304.7.2.

(b) For materials and design conditions covered therein, closures may be designed in accordance with rules in ASME BPVC, Section VIII, Division 1, calculated from eq. (13)

$$t_m = t + c \quad (13)$$

where

$c$  = sum of allowances defined in para. 304.1.1

$t$  = pressure design thickness, calculated for the type of closure and direction of loading, shown in Table 304.4.1, except that the symbols used to determine  $t$  shall be as follows:

$E$  = same as defined in para. 304.1.1

$P$  = design gage pressure

$S$  =  $S$  times  $W$ , with  $S$  and  $W$  as defined in para. 304.1.1

$t_m$  = minimum required thickness, including mechanical, corrosion, and erosion allowance

### 304.4.2 Openings in Closures

(a) The rules in (b) through (g) apply to openings not larger than one-half the inside diameter of the closure as defined in the ASME BPVC, Section VIII, Division 1, UG-36. A closure with a larger opening should be designed as a reducer in accordance with para. 304.6 or, if the closure is flat, as a flange in accordance with para. 304.5.

(b) A closure is weakened by an opening and, unless the thickness of the closure is sufficiently in excess of that required to sustain pressure, it is necessary to provide added reinforcement. The need for and amount of reinforcement required shall be determined in accordance with the subparagraphs below except that it shall be considered that the opening has adequate reinforcement if the outlet connection meets the requirements in para. 304.3.2(b) or 304.3.2(c).



**Figure 304.3.4 Extruded Outlet Header Nomenclature**

This Figure illustrates the nomenclature of [para. 304.3.4](#). It does not indicate complete details or a preferred method of construction.

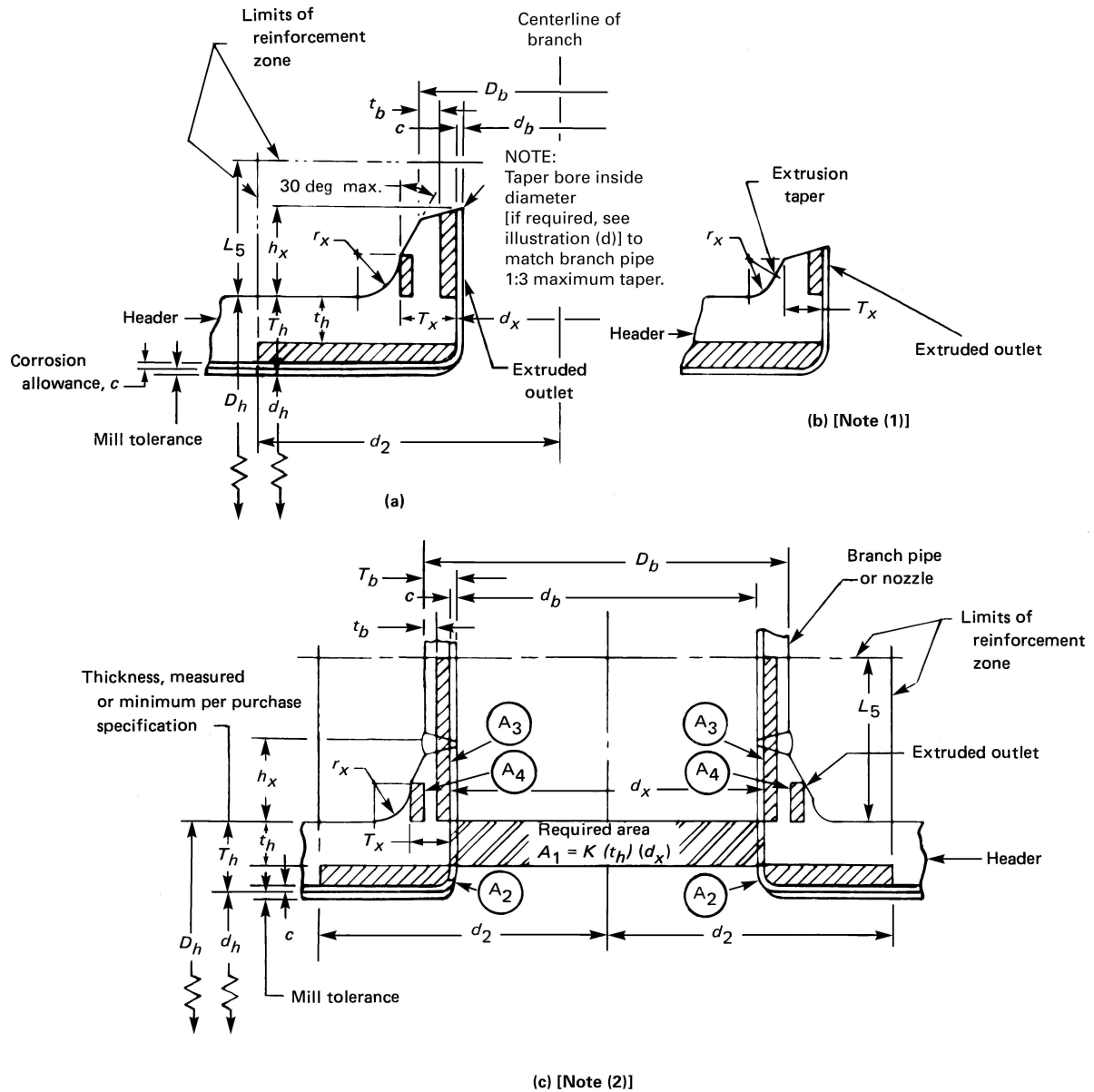
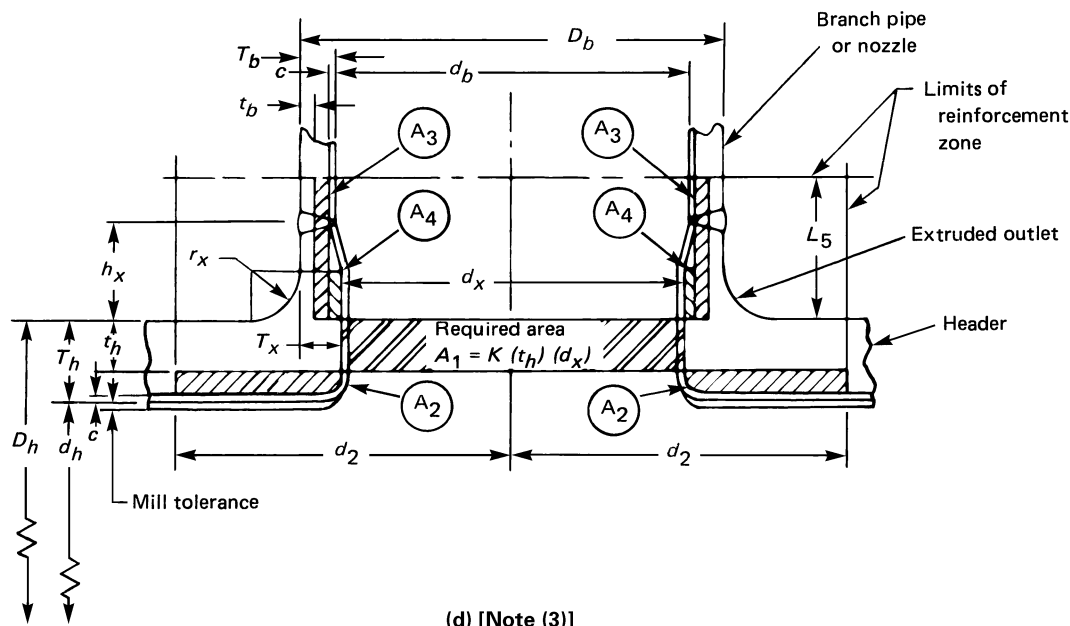


Figure 304.3.4 Extruded Outlet Header Nomenclature (Cont'd)



## NOTES:

- (1) Illustration to show method of establishing  $T_x$  when the taper encroaches on the crotch radius.  
 (2) Illustration is drawn for condition where  $K = 1.00$ .  
 (3) Illustration is drawn for condition where  $K = 1.00$  and  $d_x < d_b$ .

Table 304.4.1 ASME BPVC References for Closures

| Type of Closure                    | Concave to Pressure | Convex to Pressure |
|------------------------------------|---------------------|--------------------|
| Ellipsoidal                        | UG-32(d)            | UG-33(d)           |
| Torispherical                      | UG-32(e)            | UG-33(e)           |
| Hemispherical                      | UG-32(f)            | UG-33(c)           |
| Conical (no transition to knuckle) | UG-32(g)            | UG-33(f)           |
| Toriconical                        | UG-32(h)            | UG-33(f)           |
| Flat (pressure on either side)     | UG-34               |                    |

GENERAL NOTE: Paragraph numbers are from ASME BPVC, Section VIII, Division 1.

(c) Reinforcement for an opening in a closure shall be so distributed that reinforcement area on each side of an opening (considering any plane through the center of the opening normal to the surface of the closure) will equal at least one-half the required area in that plane.

(d) The total cross-sectional area required for reinforcement in any given plane passing through the center of the opening shall not be less than that defined in ASME BPVC, Section VIII, Division 1, UG-37 (b), UG-38, and UG-39.

(e) The reinforcement area and reinforcement zone shall be calculated in accordance with para. 304.3.3 or 304.3.4, considering the subscript  $h$  and other references to the run or header pipe as applying to the closure. Where the closure is curved, the boundaries of the reinforcement zone shall follow the contour of the closure, and dimensions of the reinforcement zone shall be measured parallel to and perpendicular to the closure surface.

(f) If two or more openings are to be located in a closure, the rules in paras. 304.3.3 and 304.3.4 for the reinforcement of multiple openings apply.

(g) The additional design considerations for branch connections discussed in para. 304.3.5 apply equally to openings in closures.

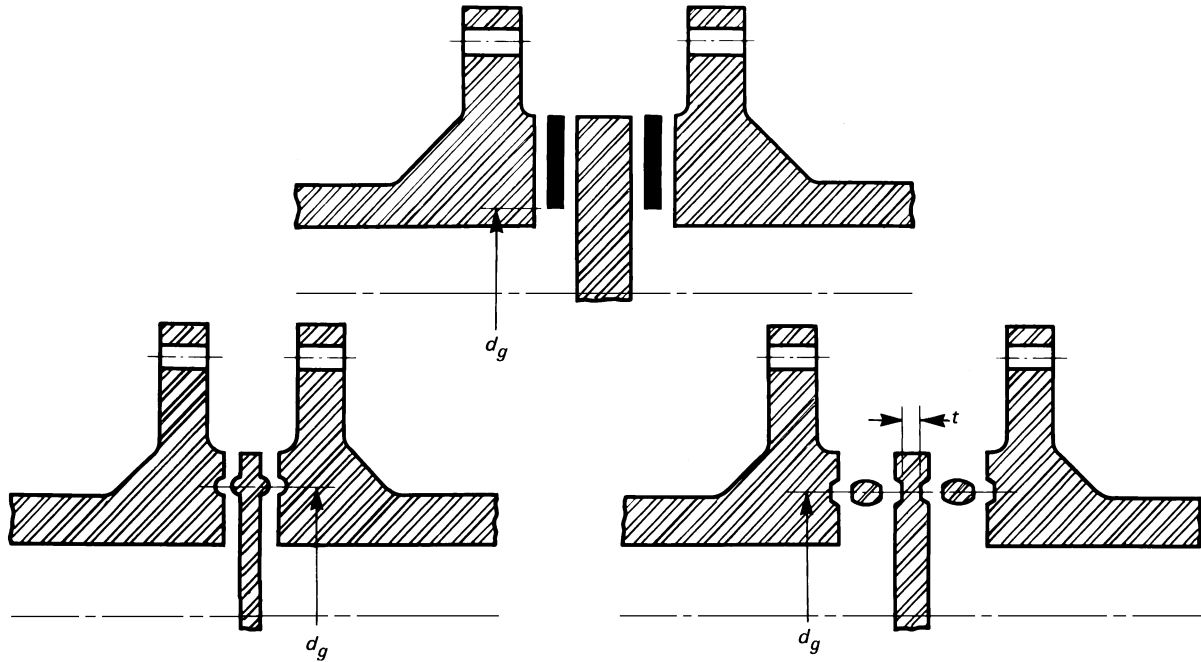
## 304.5 Pressure Design of Flanges and Blanks

### 304.5.1 Flanges — General

(a) Flanges not in accordance with para. 303 or (b) or (d) shall be qualified as required by para. 304.7.2.

(b) A flange may be designed in accordance with ASME BPVC, Section VIII, Division 1, Mandatory Appendix 2 (Rules for Bolted Flange Connections with Ring Type Gaskets) or ASME BPVC, Section VIII, Division 2, 4.16 (Design Rules for Flanged Joints), using the allowable stresses and temperature limits of this Code. Nomenclature shall be as defined in Appendix 2, except as follows:

Figure 304.5.3 Blanks



$P$  = design gage pressure

$S_a$  = bolt design stress at atmospheric temperature

$S_b$  = bolt design stress at design temperature

$S_f$  = product  $SEW$  [of the stress value,  $S$ ; the appropriate quality factor,  $E$ , from Table A-1A or Table A-1B; and weld joint strength reduction factor in accordance with para. 302.3.5(e)] for flange or pipe material. See para. 302.3.2(e).

(c) The rules in (b) above are not applicable to a flanged joint having a gasket that extends outside the bolts (usually to the outside diameter of the flange).

(d) For flanges that make solid contact outside the bolts, ASME BPVC, Section VIII, Division 1, Appendix Y should be used.

(e) See Section VIII, Division 1, Appendix S, for considerations applicable to bolted joint assembly.

### (20) 304.5.2 Blind Flanges

(a) Blind flanges not in accordance with para. 303 or 304.5.2(b) shall be qualified as required by para. 304.7.2.

(b) A blind flange may be designed in accordance with eq. (14). The minimum thickness, considering the manufacturer's minus tolerance, shall be not less than  $t_m$ :

$$t_m = t + c \quad (14)$$

where  $c$  is the sum of allowances defined in para. 304.1.1. To calculate  $t$ , the rules of ASME BPVC, Section VIII, Division 1, UG-34 may be used with the following changes to the UG-34 nomenclature:

$P$  = internal or external design gage pressure

$SE$  =  $SEW$  [product of the basic allowable stress value,  $S$ ; the appropriate quality factor,  $E$ , from Table A-1A or Table A-1B; and the weld joint strength reduction factor,  $W$ , in accordance with para. 302.3.5(e)] for flange material [see para. 302.3.2(e)]

$t$  = pressure design thickness, as calculated for the given styles of blind flange, using the appropriate equations for bolted flat cover plates in UG-34

### 304.5.3 Blanks

(a) Blanks not in accordance with para. 303 or (b) shall be qualified as required by para. 304.7.2.

(b) The minimum required thickness of a permanent blank (representative configurations shown in Figure 304.5.3) shall be calculated in accordance with eq. (15)

$$t_m = d_g \sqrt{\frac{3P}{16SEW}} + c \quad (15)$$

where

$c$  = sum of allowances defined in para. 304.1.1

$d_g$  = inside diameter of gasket for raised or flat face flanges, or the gasket pitch diameter for ring joint and fully retained gasketed flanges

$E$  = same as defined in [para. 304.1.1](#)

$P$  = design gage pressure

$S$  = same as defined in [para. 304.1.1](#)

$W$  = same as defined in [para. 304.1.1](#)

## 304.6 Reducers

### 304.6.1 Concentric Reducers

(a) Concentric reducers not in accordance with [para. 303](#) or (b) shall be qualified as required by [para. 304.7.2](#).

(b) Concentric reducers made in a conical or reversed curve section, or a combination of such sections, may be designed in accordance with the rules for conical and tori-conical closures stated in [para. 304.4.1](#).

**304.6.2 Eccentric Reducers.** Eccentric reducers not in accordance with [para. 303](#) shall be qualified as required by [para. 304.7.2](#).

## 304.7 Pressure Design of Other Components

**304.7.1 Listed Components.** Other pressure-containing components manufactured in accordance with standards in [Table 326.1](#) may be utilized in accordance with [para. 303](#).

(20) **304.7.2 Unlisted Components.** Pressure design of unlisted components to which the rules elsewhere in [para. 304](#) do not apply shall be based on the pressure design criteria of this Code. The designer shall ensure that the pressure design has been substantiated through one or more of the means stated in (a) through (d). Note that designs are also required to be checked for adequacy of mechanical strength as described in [para. 302.5](#). Documentation showing compliance with this paragraph shall be available for the owner's approval.

(a) extensive, successful service experience under comparable conditions with similarly proportioned components of the same or like material.

(b) experimental stress analysis, such as described in ASME BPVC, Section VIII, Division 2, Annex 5-F. The basic allowable stress from [Table A-1](#) or [Table A-1M](#) shall be used in place of the allowable stress,  $S$ , in Division 2 where applicable.

(c) proof test in accordance with ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101. The basic allowable stress from [Table A-1](#) or [Table A-1M](#) shall be used in place of the allowable stresses,  $S$  and  $S_2$ , in Division 1 where applicable.

(d) detailed stress analysis (e.g., finite element method) with results evaluated as described in ASME BPVC, Section VIII, Division 2, Part 5. The basic allowable stress from [Table A-1](#) or [Table A-1M](#) shall be used in place of the allowable stress,  $S$ , in Division 2 where applicable. Load design

factors used in a Division 2 evaluation shall be consistent with the design bases in [para. 302.3.2](#). At design temperatures in the creep range, additional considerations beyond the scope of Division 2 may be necessary.

(e) For any of the above, the designer may interpolate between sizes, wall thicknesses, and pressure classes, and may determine analogies among related materials.

**304.7.3 Metallic Components With Nonmetallic Pressure Parts.** Components not covered by standards listed in [Table 326.1](#), in which both metallic and nonmetallic parts contain the pressure, shall be evaluated by applicable requirements of [para. A304.7.2](#) as well as those of [para. 304.7.2](#).

### 304.7.4 Expansion Joints

(a) *Metallic Bellows Expansion Joints.* The design of bellows type expansion joints shall be in accordance with [Appendix X](#). See also [Appendix F](#), [para. F304.7.4](#) for further design considerations.

(b) *Slip Type Expansion Joints*

(1) Pressure-containing elements shall be in accordance with [para. 318](#) and other applicable requirements of this Code.

(2) External piping loads shall not impose excessive bending on the joint.

(3) The effective pressure thrust area shall be computed using the outside diameter of the pipe.

(c) *Other Types of Expansion Joint.* The design of other types of expansion joint shall be qualified as required by [para. 304.7.2](#).

## PART 3

## FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

### 305 PIPE

Pipe includes components designated as tube or tubing in the material specification, when intended for pressure service.

#### 305.1 General

Listed pipe may be used in Normal Fluid Service except as stated in [paras. 305.2.1](#) and [305.2.2](#). Unlisted pipe may be used only as provided in [para. 302.2.3](#).

#### 305.2 Specific Requirements

**305.2.1 Pipe for Category D Fluid Service.** The following carbon steel pipe may be used only for Category D Fluid Service:

API 5L continuous welded (furnace butt-welded)

ASTM A53, Type F

ASTM A134 made from other than ASTM A285 plate

**305.2.2 Pipe Requiring Safeguarding.** When used for other than Category D Fluid Service, the following carbon steel pipe shall be safeguarded:

ASTM A134 made from ASTM A285 plate  
ASTM A139

### 305.2.3 Pipe for Severe Cyclic Conditions

(a) Except as limited in (b) through (d), only the following pipe may be used under severe cyclic conditions:

- (1) pipe listed in Table A-1A, where  $E_c \geq 0.90$ ,<sup>7</sup> or
- (2) pipe listed in Table A-1B, where  $E_j \geq 0.90$ <sup>7</sup>

(b) For API 5L pipe, only the following materials may be used:

Grade A or B, seamless  
Grade A or B, SAW, str. seam,  $E_j \geq 0.95$   
Grade X42, seamless  
Grade X46, seamless  
Grade X52, seamless  
Grade X56, seamless  
Grade X60, seamless

(c) For copper pipe, only ASTM B42 may be used.

(d) For copper alloy pipe, only ASTM B466 may be used.

(e) For aluminum alloy pipe, only ASTM B210 and B241, both in tempers O and H112, may be used.

**305.2.4 Elevated Temperature Fluid Service.** In Elevated Temperature Fluid Service, all longitudinal or spiral (helical seam) welds in P-No. 4 or P-No. 5 materials shall be examined by 100% radiography or 100% ultrasonic examination. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Normal Fluid Service, unless otherwise specified.

## 306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. 306.1 through 306.5. Pipe and other materials used in such components shall be suitable for the manufacturing or fabrication process and the fluid service.

### 306.1 Pipe Fittings

**306.1.1 Listed Fittings.** Listed fittings may be used in Normal Fluid Service in accordance with para. 303.

**306.1.2 Unlisted Fittings.** Unlisted fittings may be used only in accordance with para. 302.2.3.

#### 306.1.3 Specific Fittings

(a) Proprietary welding branch outlet fittings that have been design proof tested successfully as prescribed in ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101 may be used within their established ratings.

(b) The lap thickness of a proprietary “Type C” lap-joint stub-end butt welding fitting shall conform to the requirements of para. 306.4.2 for flared laps.

### 306.1.4 Fittings for Severe Cyclic Conditions

(a) Only the following fittings may be used under severe cyclic conditions:

- (1) forged.
- (2) wrought, seamless or welded. If welded, requires 100% radiograph of welds in accordance with para. 344.5.1 and Table 341.3.2.
- (3) cast, with factor  $E_c \geq 0.90$ .<sup>7</sup>

(b) Fittings conforming to MSS SP-43, MSS SP-119, and proprietary “Type C” lap-joint stub-end welding fittings shall not be used under severe cyclic conditions.

## 306.2 Pipe Bends

### 306.2.1 General

(a) A pipe bend made in accordance with paras. 332.2.1 and 332.2.2, and verified for pressure design in accordance with para. 304.2.1, is suitable for the same service as the pipe from which it is made.

(b) A pipe bend made in accordance with para. 332.2.2, but not meeting the flattening limits of para. 332.2.1, may be qualified for pressure design by para. 304.7.2 and shall not exceed the rating of the straight pipe from which it is made.

**306.2.2 Corrugated and Other Bends.** Bends of other designs (such as creased or corrugated) shall be qualified for pressure design as required by para. 304.7.2.

**306.2.3 Bends for Severe Cyclic Conditions.** A pipe bend designed as creased or corrugated shall not be used under severe cyclic conditions.

### 306.3 Miter Bends

**306.3.1 General.** Except as stated in para. 306.3.2, a miter bend made in accordance with para. 304.2.3 and welded in accordance with para. 311.1 is suitable for use in Normal Fluid Service.

**306.3.2 Miter Bends for Category D Fluid Service.** A miter bend that makes a change in direction at a single joint (angle  $\alpha$  in Figure 304.2.3) greater than 45 deg, or is welded in accordance with para. 311.1, may be used only for Category D Fluid Service.

**306.3.3 Miter Bends for Severe Cyclic Conditions.** A miter bend to be used under severe cyclic conditions shall be made in accordance with para. 304.2.3 and welded in accordance with para. 311.1, and shall have an angle  $\alpha$  (see Figure 304.2.3)  $\leq 22.5$  deg.

<sup>7</sup> See para. 302.3.3.

### 306.4 Laps

The following requirements do not apply to fittings conforming to [para. 306.1](#), specifically lap-joint stub ends conforming to ASME B16.9, nor to laps integrally hot-forged on pipe ends, except as noted in [paras. 306.4.3](#) and [306.4.4\(a\)](#).

**306.4.1 Fabricated Laps.** A fabricated lap is suitable for use in Normal Fluid Service, provided that all of the following requirements are met:

(a) The outside diameter of the lap shall be within the dimensional tolerances of the corresponding ASME B16.9 lap-joint stub end.

(b) The lap thickness shall be at least equal to the nominal wall thickness of the pipe to which it is attached.

(c) The lap material shall have an allowable stress at least as great as that of the pipe.

(d) Welding shall be in accordance with [para. 311.1](#) and fabrication shall be in accordance with [para. 328.5.5](#).

**306.4.2 Flared Laps.** See [para. 308.2.5](#) for requirements of lapped flanges for use with flared laps. A flared lap is suitable for use in Normal Fluid Service, provided that all of the following requirements are met:

(a) The pipe used shall be of a specification and grade suitable for forming without cracks, surface buckling, or other defects.

(b) The outside diameter of the lap shall be within the dimensional tolerances of the corresponding ASME B16.9 lap-joint stub end.

(c) The radius of fillet shall not exceed 3 mm ( $\frac{1}{8}$  in.).

(d) The lap thickness at any point shall be at least 95% of the minimum pipe wall thickness,  $T$ , multiplied by the ratio of the pipe outside diameter to the diameter at which the lap thickness is measured.

(e) Pressure design shall be qualified as required by [para. 304.7.2](#).

**306.4.3 Forged Laps.** A lap integrally hot-forged on a pipe end is suitable for Normal Fluid Service only when the requirements of [para. 332](#) are met. Its dimensions shall conform to those for lap-joint stub ends given in ASME B16.9.

#### 306.4.4 Laps for Severe Cyclic Conditions

(a) A forged lap-joint stub end in accordance with [para. 306.1](#) or a lap integrally hot-forged on a pipe end in accordance with [para. 306.4.3](#) may be used under severe cyclic conditions.

(b) A fabricated lap to be used under severe cyclic conditions shall conform to the requirements of [para. 306.4.1](#), except that welding shall be in accordance with [para. 311.1](#). A fabricated lap shall conform to a detail shown in [Figure 328.5.5](#), illustration (d) or (e).

(c) A flared lap is not permitted under severe cyclic conditions.

### 306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to [para. 306.1](#).

**306.5.1 General.** A fabricated branch connection made and verified for pressure design in accordance with [para. 304.3](#), and welded in accordance with [para. 311.1](#), is suitable for use in Normal Fluid Service.

**306.5.2 Fabricated Branch Connections for Severe Cyclic Conditions.** A fabricated branch connection to be used under severe cyclic conditions shall conform to the requirements of [para. 306.5.1](#), except that weldings shall be in accordance with [para. 311.1](#), with fabrication limited to a detail equivalent to [Figure 328.5.4D](#), illustration (b) or (d), or to [Figure 328.5.4E](#). (20)

### 306.6 Thermowells

Thermowells shall comply with ASME PTC 19.3 TW where applicable.

## 307 VALVES AND SPECIALTY COMPONENTS

The following requirements for valves shall also be met as applicable by other pressure-containing piping components, such as traps, strainers, and separators. See also [Appendix F](#), [paras. F301.4](#) and [F307](#).

### 307.1 General

**307.1.1 Listed Valves.** A listed valve is suitable for use in Normal Fluid Service, except as stated in [para. 307.2](#).

**307.1.2 Unlisted Valves.** Unlisted valves may be used only in accordance with [para. 302.2.3](#). (20)

### 307.2 Specific Requirements

**307.2.1 Bonnet Bolting.** A bolted bonnet valve whose bonnet is secured to the body by less than four bolts, or by a U-bolt, may be used only for Category D Fluid Service.

**307.2.2 Stem Retention.** Valves shall be designed so that the stem seal retaining fasteners (e.g., packing, gland fasteners) alone do not retain the stem. Specifically, the design shall be such that the stem shall not be capable of removal from the valve, while the valve is under pressure, by the removal of the stem seal retainer (e.g., gland) alone.

## 308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

### 308.1 General

**308.1.1 Listed Components.** A listed flange, blank, or gasket is suitable for use in Normal Fluid Service, except as stated elsewhere in [para. 308](#).



**Table 308.2.1 Permissible Sizes/Rating Classes for Slip-On Flanges Used as Lapped Flanges**

| Rating Class | Maximum Flange Size |     |
|--------------|---------------------|-----|
|              | DN                  | NPS |
| 150          | 300                 | 12  |
| 300          | 200                 | 8   |

GENERAL NOTE: Actual thickness of the slip-on flange at the bolt circle shall be at least equal to the minimum required flange thickness for lapped flanges in ASME B16.5.

**308.1.2 Unlisted Components.** Unlisted flanges, blanks, and gaskets may be used only in accordance with [para. 302.2.3](#).

### 308.2 Specific Requirements for Flanges

See [Appendix F, paras. F308.2 and F312](#).

#### 308.2.1 Slip-On Flanges

(a) A slip-on flange shall be double-welded as shown in [Figure 328.5.2B](#) when the service is

(1) subject to severe erosion, crevice corrosion, or cyclic loading

(2) flammable, toxic, or damaging to human tissue

(3) under severe cyclic conditions

(4) at temperatures below  $-101^{\circ}\text{C}$  ( $-150^{\circ}\text{F}$ )

(b) The use of slip-on flanges should be avoided where many large temperature cycles are expected, particularly if the flanges are not insulated.

(c) *Slip-on Flanges as Lapped Flanges.* A slip-on flange may be used as a lapped flange only as shown in [Table 308.2.1](#) unless pressure design is qualified in accordance with [para. 304.5.1](#). A corner radius or bevel shall conform to one of the following as applicable:

(1) For an ASME B16.9 lap joint stub end or a forged lap (see [para. 306.4.3](#)), the corner radius shall be as specified in ASME B16.5, Tables 9 and 12, dimension  $r$ .

(2) For a fabricated lap, the corner bevel shall be at least half the nominal thickness of the pipe to which the lap is attached (see [Figure 328.5.5](#)).

(3) For a flared lap see [para. 308.2.5](#).

**308.2.2 Expanded-Joint Flanges.** A flange having an expanded-joint insert is subject to the requirements for expanded joints in [para. 313](#).

**308.2.3 Socket Welding and Threaded Flanges.** A socket welding flange is subject to the requirements for socket welds in [para. 311.2.2](#). A threaded flange is subject to the requirements for threaded joints in [para. 314](#).

**308.2.4 Flanges for Severe Cyclic Conditions.** Unless it is safeguarded, a flange to be used under severe cyclic conditions shall be welding neck conforming to ASME

B16.5 or ASME B16.47, or a similarly proportioned flange designed in accordance with [para. 304.5.1](#).

**308.2.5 Flanges for Flared Metallic Laps.** For a flange used with a flared metallic lap ([para. 306.4.2](#)), the intersection of face and bore shall be beveled or rounded approximately 3 mm ( $\frac{1}{8}$  in.). See also [para. 308.2.1\(c\)](#).

### 308.3 Flange Facings

The flange facing shall be compatible with the gasket and bolting employed.

### 308.4 Gaskets

Gaskets shall be selected so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting. See [Appendix F, para. F308.4](#).

## 309 BOLTING

Bolting includes bolts, bolt studs, studs, cap screws, nuts, and washers. See also [Appendix F, para. F309](#).

### 309.1 General

**309.1.1 Listed Bolting.** Listed bolting is suitable for use in Normal Fluid Service, except as stated elsewhere in [para. 309](#).

**309.1.2 Unlisted Bolting.** Unlisted bolting may be used only in accordance with [para. 302.2.3](#).

**309.1.3 Bolting for Components.** Bolting for components conforming to a listed standard shall be in accordance with that standard if specified therein.

**309.1.4 Selection Criteria.** Bolting selected shall be adequate to seat the gasket and maintain joint tightness under all design conditions.

### 309.2 Specific Bolting

**309.2.1 Low Yield Strength Bolting.** Bolting having not more than 207 MPa (30 ksi) specified minimum yield strength shall not be used for flanged joints rated ASME B16.5 Class 400 and higher, nor for flanged joints using metallic gaskets, unless calculations have been made showing adequate strength to maintain joint tightness.

**309.2.2 Carbon Steel Bolting.** Except where limited by other provisions of this Code, carbon steel bolting may be used with nonmetallic gaskets in flanged joints rated ASME B16.5 Class 300 and lower for bolt metal temperatures at  $-29^{\circ}\text{C}$  to  $204^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$  to  $400^{\circ}\text{F}$ ), inclusive. If these bolts are galvanized, heavy hexagon nuts, threaded to suit, shall be used.



**309.2.3 Bolting for Metallic Flange Combinations.**

Any bolting that meets the requirements of [para. 309](#) may be used with any combination of flange material and facing. If either flange is to the ASME B16.1, ASME B16.24 manufactured from an ASTM B61 or an ASTM B62 casting, MSS SP-42, or MSS SP-51 specification, the bolting material shall be no stronger than low yield strength bolting unless

(a) both flanges have flat faces and a full-face gasket is used, or

(b) sequence and torque limits for bolt-up are specified, with consideration of sustained loads, displacement strains, occasional loads (see [paras. 302.3.5](#) and [302.3.6](#)), and strength of the flanges

**309.2.4 Bolting for Severe Cyclic Conditions.** Low yield strength bolting (see [para. 309.2.1](#)) shall not be used for flanged joints under severe cyclic conditions.

**309.3 Tapped Holes**

Tapped holes for pressure-retaining bolting in metallic piping components shall be of sufficient depth that the thread engagement will be at least seven-eighths times the nominal thread diameter.

**PART 4****FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS****310 GENERAL**

Piping joints shall be selected considering joint tightness and mechanical strength under expected service and test conditions of pressure, temperature, and external loading. See [para. 302.5](#).

**311 WELDED JOINTS**

Joints may be made by welding in any material for which it is possible to qualify welding procedures, welders, and welding operators in conformance with the rules in [Chapter V](#).

**311.1 General**

Welds shall conform to the following:

- (a) Welding shall be in accordance with [para. 328](#).
- (b) Preheating and heat treatment shall be in accordance with [paras. 330](#) and [331](#), respectively.
- (c) Examination shall be in accordance with [para. 341.4](#).
- (d) Acceptance criteria shall be in accordance with [para. 341.3.2](#).

**311.2 Specific Requirements****311.2.1 Backing Rings and Consumable Inserts**

(a) If a backing ring is used where the resulting crevice is detrimental (e.g., subject to corrosion, vibration, or severe cyclic conditions), it should be removed and the internal joint face ground smooth. When it is impractical to remove the backing ring in such a case, consideration shall be given to welding without backing rings or to the use of consumable inserts or removable nonmetallic backing rings.

(b) Split backing rings shall not be used under severe cyclic conditions.

**311.2.2 Socket Welds**

(20)

(a) Socket welded joints ([para. 328.5.2](#)) should be avoided in any service where crevice corrosion or severe erosion may occur.

(b) Socket welded joints shall conform to the following:

(1) Socket dimensions shall conform to ASME B16.5 for flanges and ASME B16.11 or MSS SP-119 for other socket-welding components.

(2) Weld dimensions shall not be less than those shown in [Figures 328.5.2B](#) and [328.5.2C](#).

(c) Socket welds larger than DN 50 (NPS 2) shall not be used under severe cyclic conditions.

(d) A drain or bypass in a component may be attached by socket welding, provided the socket dimensions conform to ASME B16.5, [para. 6.12.3](#).

**311.2.3 Fillet Welds**

(a) Fillet welds in accordance with [para. 328.5.2](#) may be used as primary welds to attach socket welding components and slip-on flanges.

(b) Fillet welds may also be used to attach reinforcement and structural attachments, to supplement the strength or reduce stress concentration of primary welds, and to prevent disassembly of joints.

**311.2.4 Seal Welds.** Seal welds ([para. 328.5.3](#)) may be used only to prevent leakage of threaded joints and shall not be considered as contributing any strength to the joints.

**312 FLANGED JOINTS**

See [Appendix F](#), [para. F312.1](#).

**312.1 Joints Using Flanges of Different Ratings**

Where flanges of different ratings are bolted together, the rating of the joint shall not exceed that of the lower rated flange. Bolting torque shall be limited so that excessive loads will not be imposed on the lower rated flange in obtaining a tight joint.

**Table 314.2.1 Minimum Schedule of Components With External Threads**

| Fluid Service | Notch-Sensitive Material<br>[Note (1)] | Size Range<br>[Note (2)] |     | Minimum Schedule<br>[Note (3)] |
|---------------|----------------------------------------|--------------------------|-----|--------------------------------|
|               |                                        | DN                       | NPS |                                |
| Normal        | Yes                                    | ≤40                      | ≤1½ | 80                             |
|               |                                        | 50–150                   | 2–6 | 40                             |
|               |                                        | >150                     | >6  | None                           |
|               | No                                     | ≤150                     | ≤6  | 40                             |
|               |                                        | >150                     | >6  | None                           |
| Category D    | Either                                 | All                      | All | None                           |

**NOTES:**

- (1) Carbon steel is generally considered to be notch sensitive, whereas stainless steel is generally considered to be not notch sensitive.
- (2) For sizes over DN 50 (NPS 2), the joint shall be safeguarded (see [Appendix G](#)) for a fluid service that is flammable, toxic, or damaging to human tissue.
- (3) Minimum schedules 40 and 80 are listed in ASME B36.10M, which are identical to schedules 40S and 80S listed in ASME B36.19M for DN 150 (NPS 6) and smaller.

**312.2 Metal to Nonmetal Flanged Joints**

Where a metallic flange is bolted to a nonmetallic flange, both should be flat-faced. A full-faced gasket is preferred. If a gasket extending only to the inner edge of the bolts is used, bolting torque shall be limited so that the nonmetallic flange is not overloaded.

**312.3 Flanged Joint Assembly**

See [para. 335.2.5](#).

**313 EXPANDED JOINTS**

(a) Expanded joints shall not be used under severe cyclic conditions. For other services, adequate means shall be provided to prevent separation of the joint. If the fluid is toxic or damaging to human tissue, safeguarding is required.

(b) Consideration shall be given to the tightness of expanded joints when subjected to vibration, differential expansion or contraction due to temperature cycling, or external mechanical loads.

**314 THREADED JOINTS****314.1 General**

Threaded joints are suitable for Normal Fluid Service except as stated elsewhere in [para. 314](#). They may be used under severe cyclic conditions only as provided in [paras. 314.2.1\(c\)](#) and [314.2.2](#).

(a) Threaded joints should be avoided in any service where crevice corrosion, severe erosion, or cyclic loading may occur.

(b) When threaded joints are intended to be seal welded, thread sealing compound shall not be used.

(c) Layout of piping employing threaded joints should, insofar as possible, minimize stress on joints, giving special consideration to stresses due to thermal expansion and operation of valves (particularly a valve at a free end). Provision should be made to counteract forces that would tend to unscrew the joints.

(d) Except for specially designed joints employing lens rings or similar gaskets, threaded flanges in which the pipe ends project through to serve as the gasket surface may be used only for Category D Fluid Service.

**314.2 Specific Requirements**

**314.2.1 Taper-Threaded Joints.** For joints in which the threads of both mating components conform to ASME B1.20.1 (20)

(a) the minimum thickness of components with external threads shall be the greater of  $t_m$  in accordance with [para. 304.1.1](#) and the schedule shown in [Table 314.2.1](#)

(b) threaded components shall be checked for adequacy of mechanical strength as described in [para. 302.5](#)

(c) threaded components of a specialty nature that are not subject to external moment loading, such as thermowells, may be used under severe cyclic conditions

A coupling having straight threads may be used only for Category D Fluid Service, and only with taper-threaded mating components.

**314.2.2 Straight-Threaded Joints.** Threaded joints in which the tightness of the joint is provided by a seating surface other than the threads (e.g., a union comprising male and female ends joined with a threaded union nut, or other constructions shown typically in [Figure 335.3.3](#)) may be used. If such joints are used under severe cyclic conditions and are subject to external moment loadings, safeguarding is required.

**315 TUBING JOINTS****315.1 General**

In selecting and applying flared, flareless, and compression type tubing fittings, the designer shall consider the possible adverse effects on the joints of such factors as assembly and disassembly, cyclic loading, vibration, shock, and thermal expansion and contraction.

**315.2 Joints Conforming to Listed Standards**

Joints using flared, flareless, or compression type tubing fittings covered by listed standards may be used in Normal Fluid Service provided that

(a) the fittings and joints are compatible with the tubing with which they are to be used (considering maximum and minimum wall thickness) and are used within the pressure-temperature limitations of the fitting and the joint

(b) the joints are safeguarded when used under severe cyclic conditions

### 315.3 Joints Not Conforming to Listed Standards

Joints using flared, flareless, or compression type tubing fittings not listed in Table 326.1 may be used in accordance with para. 315.2 provided that the design is qualified in accordance with para. 304.7.2.

## 316 CAULKED JOINTS

Caulked joints such as bell type joints shall be limited to Category D Fluid Service and to a temperature not over 93°C (200°F). They shall be used within the pressure-temperature limitations of the joint and pipe. Provisions shall be made to prevent disengagement of joints, to prevent buckling of the piping, and to sustain lateral reactions produced by branch connections or other causes.

## 317 SOLDERED AND BRAZED JOINTS

### 317.1 Soldered Joints

Soldered joints shall be made in accordance with the provisions of para. 333 and may be used only in Category D fluid service. Fillet joints made with solder metal are not permitted. The low melting point of solder shall be considered where possible exposure to fire or elevated temperature is involved.

### 317.2 Brazed and Braze Welded Joints

(a) Brazed and braze welded joints made in accordance with the provisions in para. 333 are suitable for Normal Fluid Service. They shall be safeguarded in fluid services that are flammable, toxic, or damaging to human tissue. They shall not be used under severe cyclic conditions. The melting point of brazing alloys shall be considered where possible exposure to fire is involved.

(b) Fillet joints made with brazing filler metal are not permitted.

## 318 SPECIAL JOINTS

Special joints are those not covered elsewhere in Chapter II, Part 4, such as bell type and packed gland type joints.

### 318.1 General

**318.1.1 Listed Joints.** Joints using listed components are suitable for Normal Fluid Service.

**318.1.2 Unlisted Joints.** For joints that utilize unlisted components, pressure design shall be qualified as required by para. 304.7.2.

### 318.2 Specific Requirements

**318.2.1 Joint Integrity.** Separation of the joint shall be prevented by a means that has sufficient strength to withstand anticipated conditions of service.

**318.2.2 Joint Interlocks.** Either mechanical or welded interlocks shall be provided to prevent separation of any joint used for a fluid service that is flammable, toxic, or damaging to human tissues, of any joint to be used under severe cyclic conditions, and of any joint exposed to temperatures in the creep range.

**318.2.3 Bell and Gland Type Joints.** Bell-type and gland-type joints used under severe cyclic conditions shall be safeguarded.

## PART 5 FLEXIBILITY AND SUPPORT

### 319 PIPING FLEXIBILITY

#### 319.1 Requirements

**319.1.1 Basic Requirements.** Piping systems shall have sufficient flexibility to prevent thermal expansion or contraction or movements of piping supports and terminals from causing

(a) failure of piping or supports from overstress or fatigue

(b) leakage at joints

(c) detrimental stresses or distortion in piping and valves or in connected equipment (e.g., pumps and turbines), resulting from excessive thrusts and moments in the piping

**319.1.2 Specific Requirements.** In para. 319, concepts, data, and methods are given for determining the requirements for flexibility in a piping system and for assuring that the system meets all of these requirements. In brief, these requirements are that

(a) the computed stress range at any point due to displacements in the system shall not exceed the allowable stress range established in para. 302.3.5

(b) reaction forces computed in para. 319.5 shall not be detrimental to supports or connected equipment

(c) computed movement of the piping shall be within any prescribed limits, and properly accounted for in the flexibility calculations

If it is determined that a piping system does not have adequate inherent flexibility, means for increasing flexibility shall be provided in accordance with para. 319.7.

## 319.2 Concepts

Concepts characteristic of piping flexibility analysis are covered in the following paragraphs. Special consideration is given to displacements (strains) in the piping system, and to resultant axial, bending, and torsional displacement stress ranges.

### 319.2.1 Displacement Strains

(a) *Thermal Displacements.* A piping system will undergo dimensional changes with any change in temperature. If it is constrained from free expansion or contraction by connected equipment and restraints such as guides and anchors, it will be displaced from its unrestrained position.

(b) *Restraint Flexibility.* If restraints are not considered rigid, their flexibility may be considered in determining displacement stress range and reactions.

(c) *Externally Imposed Displacements.* Externally caused movement of restraints will impose displacements on the piping in addition to those related to thermal effects. Movements may result from tidal changes (dock piping), wind sway (e.g., piping supported from a tall slender tower), or temperature changes in connected equipment.

Movement due to earth settlement, since it is a single cycle effect, will not significantly influence fatigue life. A displacement stress range greater than that permitted by [para. 302.3.5\(d\)](#) may be allowable if due consideration is given to avoidance of excessive localized strain and end reactions.

(d) *Total Displacement Strains.* Thermal displacements, reaction displacements, and externally imposed displacements all have equivalent effects on the piping system, and shall be considered together in determining the total displacement strains (proportional deformation) in various parts of the piping system.

### 319.2.2 Displacement Stresses

(a) *Elastic Behavior.* Stresses may be considered proportional to the total displacement strains in a piping system in which the strains are well-distributed and not excessive at any point (a balanced system). Layout of systems should aim for such a condition, which is assumed in flexibility analysis methods provided in this Code.

(b) *Overstrained Behavior.* Stresses cannot be considered proportional to displacement strains throughout a piping system in which an excessive amount of strain may occur in localized portions of the system (an unbalanced system). Operation of an unbalanced system in the creep range may aggravate the deleterious effects due to creep strain accumulation in the most susceptible regions of the system. Unbalance may result from one or more of the following:

(1) highly stressed small size pipe runs in series with large or relatively stiff pipe runs.

(2) a local reduction in size or wall thickness, or local use of material having reduced yield strength (for example, girth welds of substantially lower strength than the base metal).

(3) a line configuration in a system of uniform size in which the expansion or contraction must be absorbed largely in a short offset from the major portion of the run.

(4) variation of piping material or temperature in a line. When differences in the elastic modulus within a piping system will significantly affect the stress distribution, the resulting displacement stresses shall be computed based on the actual elastic moduli at the respective operating temperatures for each segment in the system and then multiplied by the ratio of the elastic modulus at ambient temperature to the modulus used in the analysis for each segment.

Unbalance should be avoided or minimized by design and layout of piping systems, particularly those using materials of low ductility. Many of the effects of unbalance can be mitigated by selective use of cold spring. If unbalance cannot be avoided, the designer shall use appropriate analytical methods in accordance with [para. 319.4](#) to assure adequate flexibility as defined in [para. 319.1](#).

### 319.2.3 Displacement Stress Range

(a) In contrast with stresses from sustained loads, such as internal pressure or weight, displacement stresses may be permitted to attain sufficient magnitude to cause local yielding in various portions of a piping system. When the system is initially operated at the condition of greatest displacement (highest or lowest temperature, or greatest imposed movement) from its installed condition, any yielding or creep brings about a reduction or relaxation of stress. When the system is later returned to its original condition (or a condition of opposite displacement), a reversal and redistribution of stresses occurs that is referred to as self-springing. It is similar to cold springing in its effects.

(b) While stresses resulting from displacement strains diminish with time due to yielding or creep, the algebraic difference between strains in the extreme displacement condition and the original (as-installed) condition (or any anticipated condition with a greater differential effect) remains substantially constant during any one cycle of operation. This difference in strains produces a corresponding stress differential, the displacement stress range, that is used as the criterion in the design of piping for flexibility. In evaluating systems where supports may be active in some conditions and not others (e.g., pipes lifting off supports), this difference in strains may be influenced by the changing distribution of sustained load. In such cases, the displacement strain range is based on the algebraic difference between the calculated positions of the pipe that define the range. In addition to the displacement strain, each calculated



position shall include the sustained loads present in the condition under evaluation. See [para. 302.3.5\(d\)](#) for the allowable stress range,  $S_A$ , and [para. 319.4.4\(a\)](#) for the computed displacement stress range,  $S_E$ .

**319.2.4 Cold Spring.** Cold spring is the intentional deformation of piping during assembly to produce a desired initial displacement and reaction. Cold spring is beneficial in that it serves to balance the magnitude of the reaction under initial and extreme displacement conditions. When cold spring is properly applied there is less likelihood of overstrain during initial operation; hence, it is recommended especially for piping materials of limited ductility. There is also less deviation from as-installed dimensions during initial operation, so that hangers will not be displaced as far from their original settings.

Inasmuch as the service life of a piping system is affected more by the range of stress variation than by the magnitude of stress at a given time, no credit for cold spring is permitted in stress range calculations. However, in calculating the thrusts and moments where actual reactions as well as their range of variations are significant, credit is given for cold spring.

### 319.3 Properties for Flexibility Analysis

The following paragraphs deal with properties of piping materials and their application in piping flexibility stress analysis.

#### 319.3.1 Thermal Expansion Data

(a) *Values for Stress Range.* Values of thermal displacements to be used in determining total displacement strains for computing the stress range shall be determined from [Appendix C](#) as the algebraic difference between the value at maximum metal temperature and that at the minimum metal temperature for the thermal cycle under analysis.

(b) *Values for Reactions.* Values of thermal displacements to be used in determining total displacement strains for computation of reactions on supports and connected equipment shall be determined as the algebraic difference between the value at maximum (or minimum) temperature for the thermal cycle under analysis and the value at the temperature expected during installation.

**319.3.2 Modulus of Elasticity.** The reference modulus of elasticity at 21°C (70°F),  $E_a$ , and the modulus of elasticity at maximum or minimum temperature,  $E_m$ , shall be taken as the values shown in [Appendix C](#) for the temperatures determined in [para. 319.3.1\(a\)](#) or [319.3.1\(b\)](#). For materials not included in [Appendix C](#), reference shall be made to authoritative source data, such as publications of the National Institute of Standards and Technology.

**319.3.3 Poisson's Ratio.** Poisson's ratio may be taken as 0.3 at all temperatures for all metals. More accurate and authoritative data may be used if available.

#### 319.3.4 Allowable Stresses

(20)

(a) The allowable displacement stress range,  $S_A$ , and permissible additive stresses shall be as specified in [para. 302.3.5\(d\)](#) for systems primarily stressed in bending and/or torsion.

(b) The stress intensification factors in ASME B31J have been developed from fatigue tests of representative piping components and assemblies manufactured from ductile ferrous materials using the test procedures in ASME B31J and numerical methods. The allowable displacement stress range is based on tests of carbon and austenitic stainless steels. Caution should be exercised when using [eqs. \(1a\) and \(1b\)](#) ([para. 302.3.5](#)) for allowable displacement stress range for some nonferrous materials (e.g., certain copper and aluminum alloys) for other than low cycle applications.

**319.3.5 Dimensions.** Nominal thicknesses and outside diameters of pipe and fittings shall be used in flexibility calculations.

#### 319.3.6 Flexibility and Stress Intensification Factors. (20)

The flexibility factors,  $k$ , and stress intensification factors,  $i$ , shall not be less than unity. In the absence of more directly applicable data, the flexibility factor,  $k$ , and stress intensification factor,  $i$ , shown in ASME B31J shall be used for flexibility calculations described in [para. 319.4](#). Flexibility factors and stress intensification factors for branch connections are defined for in-plane, out-plane, and torsion moments on both the run and branch legs. Branch leg calculations shall use the appropriate branch factor (i.e.,  $k_{ib}$ ,  $k_{ob}$ ,  $k_{tb}$ ,  $i_{ib}$ ,  $i_{ob}$ , and  $i_{tb}$ ), and run leg calculations shall use the appropriate run factor (i.e.,  $k_{ir}$ ,  $k_{or}$ ,  $k_{tr}$ ,  $i_{ir}$ ,  $i_{or}$ , and  $i_{tr}$ ).

Flexibility factors and stress intensification factors may be developed in accordance with ASME B31J, Nonmandatory Appendices B and A, respectively.

For piping components or attachments (such as valves, strainers, anchor rings, or bands) not covered in ASME B31J, suitable stress intensification factors may be assumed by comparison of their significant geometry with that of the components shown. The validity of any assumptions is the responsibility of the designer. If two or more of the geometries shown in ASME B31J are combined, their combined  $k$  and  $i$  might be significantly different from the values shown. Examples include trunnions on elbows and branch connection fittings welded to anything other than straight pipe.

### 319.4 Flexibility Analysis

**319.4.1 Formal Analysis Not Required.** No formal analysis of adequate flexibility is required for a piping system that

(a) duplicates, or replaces without significant change, a system operating with a successful service record

(b) can readily be judged adequate by comparison with previously analyzed systems

(c) is of uniform size, has no more than two points of fixation, no intermediate restraints, and falls within the limitations of empirical eq. (16)<sup>8</sup>

$$\frac{Dy}{(L - U)^2} \leq K_1 \quad (16)$$

where

$D$  = outside diameter of pipe, mm (in.)

$E_a$  = reference modulus of elasticity at 21°C (70°F), MPa (ksi)

$K_1 = 208\,000\, S_A/E_a$ , (mm/m)<sup>2</sup>  
 $= 30\, S_A/E_a$ , (in./ft)<sup>2</sup>

$L$  = developed length of piping between anchors, m (ft)

$S_A$  = allowable displacement stress range in accordance with eq. (1a), MPa (ksi)

$U$  = anchor distance, straight line between anchors, m (ft)

$y$  = resultant of total displacement strains, mm (in.), to be absorbed by the piping system

### 319.4.2 Formal Analysis Requirements

(a) Any piping system that does not meet the criteria in para. 319.4.1 shall be analyzed by a simplified, approximate, or comprehensive method of analysis, as appropriate.

(b) A simplified or approximate method may be applied only if used within the range of configurations for which its adequacy has been demonstrated.

(c) Acceptable comprehensive methods of analysis include analytical and chart methods that provide an evaluation of the forces, moments, and stresses caused by displacement strains (see para. 319.2.1).

(d) Comprehensive analysis shall take into account stress intensification factors for any component other than straight pipe. Credit may be taken for the extra flexibility of such a component.

**319.4.3 Basic Assumptions and Requirements.** Standard assumptions specified in para. 319.3 shall be followed in all cases. In calculating the flexibility of a piping system between anchor points, the system shall be treated as a whole. The significance of all parts of the line and of all restraints introduced for the

purpose of reducing moments and forces on equipment or small branch lines, and also the restraint introduced by support friction, shall be recognized. Consider all displacements, as outlined in para. 319.2.1, over the temperature range defined by para. 319.3.1.

### 319.4.4 Flexibility Stresses

(20)

(a) The axial, bending, and torsional displacement stress ranges shall be computed using the reference modulus of elasticity at 21°C (70°F),  $E_a$ , except as provided in para. 319.2.2(b)(4), and then combined in accordance with eq. (17) to determine the computed displacement stress range,  $S_E$ , which shall not exceed the allowable displacement stress range,  $S_A$ , in para. 302.3.5(d). See also eq. (1d) and Appendix S, Example 3 for the greatest computed displacement stress range.

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \quad (17)$$

where

$A_p$  = cross-sectional area of pipe; see para. 319.3.5

$F_a$  = axial force range between any two conditions being evaluated

$i_a$  = axial stress intensification factor. In the absence of more-applicable data,  $i_a = 1.0$  for elbows, pipe bends, and miter bends (single, closely spaced, and widely spaced), and  $i_a = i_o$  for other components; see also para. 319.3.6.

$i_t$  = torsional stress intensification factor; see para. 319.3.6.

$M_t$  = torsional moment range between any two conditions being evaluated

$S_a$  = axial stress range due to displacement strains  
 $= i_a F_a / A_p$

$S_b$  = bending stress range due to displacement strains

$S_t$  = torsional stress range due to displacement strains  
 $= i_t M_t / 2Z$

$Z$  = section modulus of pipe; see para. 319.3.5

(b) The bending stress range,  $S_b$ , to be used in eq. (17) for elbows, miter bends, and branch connections (Legs 1, 2, and 3) shall be calculated in accordance with eq. (18), with moments as shown in Figures 319.4.4A and 319.4.4B

$$S_b = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \quad (18)$$

where

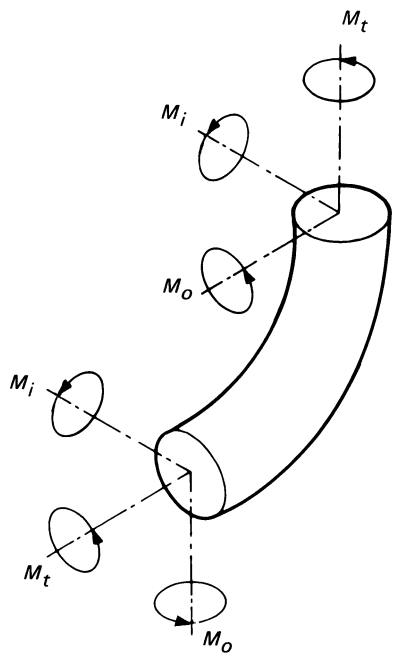
$i_i$  = in-plane stress intensification factor; see para. 319.3.6

$i_o$  = out-plane stress intensification factor; see para. 319.3.6

$M_i$  = in-plane bending moment range between any two conditions being evaluated

$M_o$  = out-plane bending moment range between any two conditions being evaluated

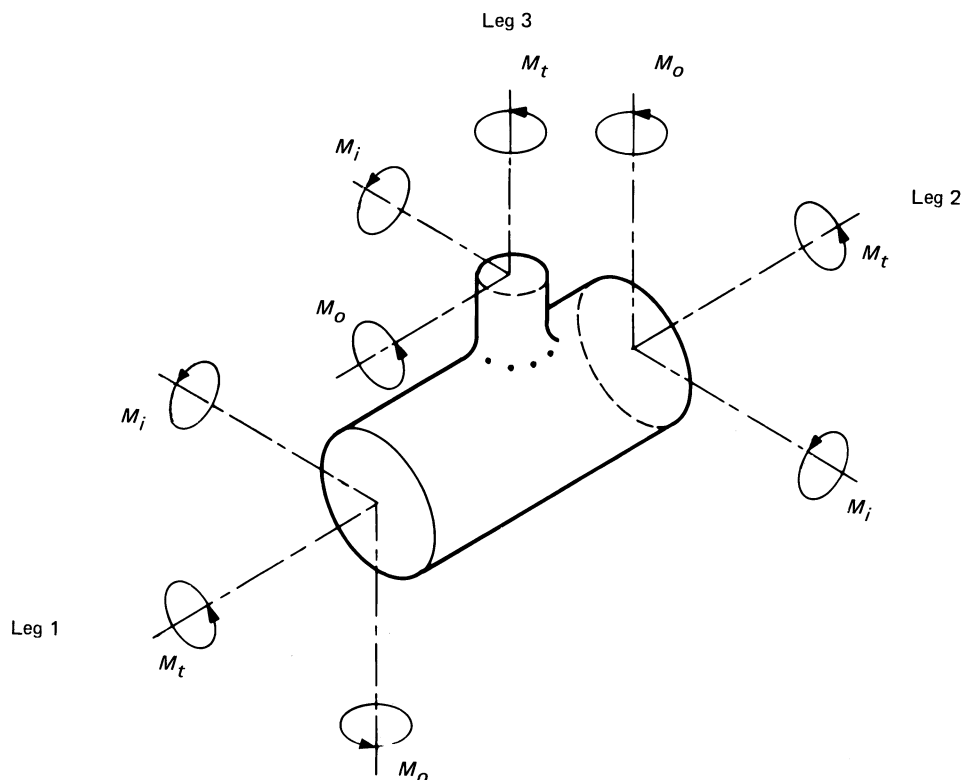
<sup>8</sup> **WARNING:** No general proof can be offered that this equation will yield accurate or consistently conservative results. It is not applicable to systems used under severe cyclic conditions. It should be used with caution in configurations such as unequal leg U-bends or near-straight "sawtooth" runs, or for large thin-wall pipe ( $i \geq 5$ ), or where extraneous displacements (not in the direction connecting anchor points) constitute a large part of the total displacement. There is no assurance that terminal reactions will be acceptably low, even if a piping system falls within the limitations of eq. (16).

**Figure 319.4.4A Moments in Bends****319.5 Reactions**

Reaction forces and moments used to design restraints and supports for a piping system, and to evaluate the effects of piping displacement on connected equipment, shall be based on the maximum load from operating conditions, including weight, pressure, and other sustained loads; thermal displacement; and, where applicable, occasional loads. The reactions shall be calculated using the modulus of elasticity at the temperature of the condition,  $E_m$  ( $E_a$  may be used instead of  $E_m$  when it provides a more conservative result). The temperature of the condition may differ in different locations within the piping system.

Where cold spring is used in the piping system, experience has shown that it cannot be fully assured. Therefore, the reactions shall be computed both with the assumption that only two-thirds of the design cold spring is present, and with four-thirds of the design cold spring present.

If it is necessary to determine the reactions at ambient temperature, the designer shall consider loads at that condition, including the design cold spring and self springing of piping. Self springing may occur if the operating stress in the piping system exceeds the yield strength of the material or if the piping operates at temperatures in the creep range of the material.

**Figure 319.4.4B Moments in Branch Connections**



**319.5.1 Maximum Reactions for Simple Systems.** For a two-anchor piping system without intermediate restraints, the maximum instantaneous values of reaction forces and moments may be estimated from eqs. (21) and (22).

(a) *For Extreme Displacement Conditions,  $R_m$ .* The temperature for this computation is the maximum or minimum metal temperature defined in para. 319.3.1(b), whichever produces the larger reaction.

$$R_m = R \left( 1 - \frac{2C}{3} \right) \frac{E_m}{E_a} \quad (21)$$

where

$C$  = cold-spring factor varying from zero for no cold spring to 1.0 for 100% cold spring. (The factor two-thirds is based on experience showing that specified cold spring cannot be fully assured, even with elaborate precautions.)

$E_a$  = reference modulus of elasticity at 21°C (70°F)

$E_m$  = modulus of elasticity at maximum or minimum metal temperature

$R$  = range of reaction forces or moments (derived from flexibility analysis) corresponding to the full displacement stress range and based on  $E_a$

$R_m$  = estimated instantaneous maximum reaction force or moment at maximum or minimum metal temperature

(b) *For Original Condition,  $R_a$ .* The temperature for this computation is the expected temperature at which the piping is to be assembled.

$R_a = CR$  or  $C_1R$ , whichever is greater, where nomenclature is as in para. 319.5.1(a) and

$$C_1 = 1 - \frac{S_h E_a}{S_E E_m} \quad (22)$$

= estimated self-spring or relaxation factor; use zero if value of  $C_1$  is negative

$R_a$  = estimated instantaneous reaction force or moment at installation temperature

$S_E$  = computed displacement stress range (see para. 319.4.4)

$S_h$  = see definition in para. 302.3.5(d)

**319.5.2 Maximum Reactions for Complex Systems.** For multianchor piping systems and for two-anchor systems with intermediate restraints, eqs. (21) and (22) are not applicable. Each case must be studied to estimate location, nature, and extent of local overstrain, and its effect on stress distribution and reactions.

### 319.6 Calculation of Movements

Calculations of displacements and rotations at specific locations may be required where clearance problems are involved. In cases where small-size branch pipes attached

to stiffer run pipes are to be calculated separately, the linear and angular movements of the junction point must be calculated or estimated for proper analysis of the branch.

### 319.7 Means of Increasing Flexibility

The layout of piping often provides inherent flexibility through changes in direction, so that displacements produce chiefly bending and torsional strains within prescribed limits. The amount of axial tension or compression strain (which produces large reactions) usually is small.

Where the piping lacks built-in changes of direction, or where it is unbalanced [see para. 319.2.2(b)], large reactions or detrimental overstrain may be encountered. The designer should consider adding flexibility by one or more of the following means: bends, loops, or offsets; swivel joints; corrugated pipe; expansion joints of the bellows or slip-joint type; or other devices permitting angular, rotational, or axial movement. Suitable anchors, ties, or other devices shall be provided as necessary to resist end forces produced by fluid pressure, frictional resistance to movement, and other causes. When expansion joints or other similar devices are provided, the stiffness of the joint or device should be considered in any flexibility analysis of the piping.

## 320 ANALYSIS OF SUSTAINED LOADS

### 320.1 Basic Assumptions and Requirements (20)

Sustained conditions may be evaluated by detailed analysis, approximate methods, or simplified means such as span tables. When detailed analysis is performed, the stress due to sustained loads,  $S_L$ , shall be computed and combined as described in this paragraph and shall not exceed the allowable described in para. 302.3.5(c). See Appendix S, Example 2 for guidance on loading conditions and support scenarios that result in the greatest  $S_L$  for each operating condition being considered. The loads due to weight should be based on the nominal thickness of all system components unless otherwise justified in a more rigorous analysis. Section moduli used to compute the stresses in this paragraph shall be based on nominal pipe dimensions less allowances, i.e., the sum of mechanical (thread or groove depth), internal and external corrosion, and erosion allowances. Areas used to compute the stresses in this paragraph assume nominal pipe dimensions less allowances affecting the inside diameter of the pipe, i.e., the sum of mechanical and internal corrosion and erosion allowances. It is the responsibility of the designer to determine sustained stress indices,  $I_a$ ,  $I_i$ ,  $I_o$ , and  $I_b$  when a piping component is not explicitly addressed in ASME B31J, e.g., base-ells, reducing elbows, crosses, close proximity fittings, etc., as well as elbows, pipe bends, or miters other than 90

deg or supported by a trunnion. Sustained stress indices shall not be lower than 1.00.

## (20) 320.2 Stress Due to Sustained Loads

The equation for the stress due to sustained loads, such as pressure and weight,  $S_L$ , is provided in eq. (23a). Equations for the stress due to sustained bending moments,  $S_b$ , are presented in eq. (23b).

$$S_L = \sqrt{(|S_d| + S_b)^2 + (2S_t)^2} \quad (23a)$$

$$S_b = \frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z} \quad (23b)$$

where

$I_i$  = sustained in-plane moment index. In the absence of more-applicable data,<sup>9</sup>  $I_i$  is taken as the greater of 0.75 $i_i$  or 1.00.

$I_o$  = sustained out-plane moment index. In the absence of more-applicable data,<sup>9</sup>  $I_o$  is taken as the greater of 0.75 $i_o$  or 1.00.

$M_i$  = in-plane moment due to sustained loads, e.g., pressure and weight

$M_o$  = out-plane moment due to sustained loads, e.g., pressure and weight

$Z$  = sustained section modulus.  $Z$  in eqs. (23b) and (23c), is described in para. 319.4.4 but is computed in this paragraph using nominal pipe dimensions less allowances; see para. 320.1.

The equation for the stress due to sustained torsional moment,  $S_t$ , is

$$S_t = \frac{I_t M_t}{2Z} \quad (23c)$$

where

$I_t$  = sustained torsional moment index. In the absence of more-applicable data,<sup>9</sup>  $I_t$  is taken as 1.00.

$M_t$  = torsional moment due to sustained loads, e.g., pressure and weight

The equation for the stress due to sustained longitudinal force,  $S_a$ , is

$$S_a = \frac{I_a F_a}{A_p} \quad (23d)$$

where

$A_p$  = cross-sectional area of the pipe, considering nominal pipe dimensions less allowances; see para. 320.1

$F_a$  = longitudinal force due to sustained loads, e.g., pressure and weight

$I_a$  = sustained longitudinal force index. In the absence of more-applicable data,<sup>9</sup>  $I_a$  is taken as 1.00.

The sustained longitudinal force,  $F_a$ , includes the sustained force due to pressure, which is  $P_j A_f$  unless the piping system includes an expansion joint that is not designed to carry this force itself, where  $P_j$  is the internal operating pressure for the condition being considered,  $A_f = \pi d^2/4$ , and  $d$  is the pipe inside diameter considering pipe wall thickness less applicable allowances; see para. 320.1. For piping systems that contain expansion joints, it is the responsibility of the designer to determine the sustained longitudinal force due to pressure in the piping system.

## 321 PIPING SUPPORT

### 321.1 General

The design of support structures (not covered by this Code) and of supporting elements (see definitions of piping and pipe supporting elements in para. 300.2) shall be based on all concurrently acting loads transmitted into such supports. These loads, defined in para. 301, include weight effects, loads introduced by service pressures and temperatures, vibration, wind, earthquake, shock, and displacement strain (see para. 319.2.2).

For piping containing gas or vapor, weight calculations need not include the weight of liquid if the designer has taken specific precautions against entrance of liquid into the piping, and if the piping is not to be subjected to hydrostatic testing at initial construction or subsequent inspections.

**321.1.1 Objectives.** The layout and design of piping and its supporting elements shall be directed toward preventing the following:

- (a) piping stresses in excess of those permitted in this Code
- (b) leakage at joints
- (c) excessive thrusts and moments on connected equipment (such as pumps and turbines)
- (d) excessive stresses in the supporting (or restraining) elements
- (e) resonance with imposed or fluid-induced vibrations
- (f) excessive interference with thermal expansion and contraction in piping which is otherwise adequately flexible
- (g) unintentional disengagement of piping from its supports

<sup>9</sup>The sustained stress or moment factor determined from ASME B31J, Table 1-1, General Note (d) may be considered as more applicable data.

(h) excessive piping sag in piping requiring drainage slope

(i) excessive distortion or sag of piping (e.g., thermoplastics) subject to creep under conditions of repeated thermal cycling

(j) excessive heat flow, exposing supporting elements to temperature extremes outside their design limits

**321.1.2 Analysis.** In general, the location and design of pipe supporting elements may be based on simple calculations and engineering judgment. However, when a more refined analysis is required and a piping analysis, which may include support stiffness, is made, the stresses, moments, and reactions determined thereby shall be used in the design of supporting elements.

**321.1.3 Stresses for Pipe Supporting Elements.** Allowable stresses for materials used for pipe supporting elements, except springs, shall be in accordance with [para. 302.3.1](#). Longitudinal weld joint factors,  $E_j$ , however, need not be applied to the allowable stresses for welded piping components that are to be used for pipe supporting elements.

#### 321.1.4 Materials

(a) Permanent supports and restraints shall be of material suitable for the service conditions. If steel is cold-formed to a centerline radius less than twice its thickness, it shall be annealed or normalized after forming.

(b) Gray, ductile, and malleable iron may be used for rollers, roller bases, anchor bases, and other supporting elements subject chiefly to compressive loading. Gray iron is not recommended if the piping may be subject to impact-type loading resulting from pulsation or vibration. Ductile and malleable iron may be used for pipe and beam clamps, hanger flanges, clips, brackets, and swivel rings.

(c) Steel of an unknown specification may be used for pipe supporting elements that are not welded directly to pressure-containing piping components. (Compatible intermediate materials of known specification may be welded directly to such components.) Basic allowable stress in tension or compression shall not exceed 82 MPa (12 ksi) and the support temperature shall be within the range of  $-29^{\circ}\text{C}$  to  $343^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$  to  $650^{\circ}\text{F}$ ). For stress values in shear and bearing, see [para. 302.3.1\(b\)](#).

(d) Wood or other materials may be used for pipe supporting elements, provided the supporting element is properly designed, considering temperature, strength, and durability.

(e) Attachments welded or bonded to the piping shall be of a material compatible with the piping and service. For other requirements, see [para. 321.3.2](#).

**321.1.5 Threads.** Screw threads shall conform to ASME B1.1 unless other threads are required for adjustment under heavy loads. Turnbuckles and adjusting nuts shall have the full length of internal threads engaged.

Any threaded adjustment shall be provided with a locknut, unless locked by other means.

## 321.2 Fixtures

### 321.2.1 Anchors and Guides

(a) A supporting element used as an anchor shall be designed to maintain an essentially fixed position.

(b) To protect terminal equipment or other (weaker) portions of the system, restraints (such as anchors and guides) shall be provided where necessary to control movement or to direct expansion into those portions of the system that are designed to absorb them. The design, arrangement, and location of restraints shall ensure that expansion joint movements occur in the directions for which the joint is designed. In addition to the other thermal forces and moments, the effects of friction in other supports of the system shall be considered in the design of such anchors and guides.

(c) Piping layout, anchors, restraints, guides, and supports for all types of expansion joints shall be designed in accordance with [para. X301.2](#) of [Appendix X](#).

### 321.2.2 Inextensible Supports Other Than Anchors and Guides<sup>10</sup>

(a) Supporting elements shall be designed to permit the free movement of piping caused by thermal expansion and contraction.

(b) Hangers include pipe and beam clamps, clips, brackets, rods, straps, chains, and other devices. They shall be proportioned for all required loads. Safe loads for threaded parts shall be based on the root area of the threads.

(c) *Sliding Supports.* Sliding supports (or shoes) and brackets shall be designed to resist the forces due to friction in addition to the loads imposed by bearing. The dimensions of the support shall provide for the expected movement of the supported piping.

### 321.2.3 Resilient Supports<sup>10</sup>

(a) Spring supports shall be designed to exert a supporting force, at the point of attachment to the pipe, equal to the load as determined by weight balance calculations. They shall be provided with means to prevent misalignment, buckling, or eccentric loading of the springs, and to prevent unintentional disengagement of the load.

(b) Constant-support spring hangers provide a substantially uniform supporting force throughout the range of travel. The use of this type of spring hanger is advantageous at locations subject to appreciable movement with thermal changes. Hangers of this type should be selected so that their travel range exceeds expected movements.

<sup>10</sup> Various types of inextensible (solid) and resilient supports are illustrated in MSS SP-58.

(c) Means shall be provided to prevent overstressing spring hangers due to excessive deflections. It is recommended that all spring hangers be provided with position indicators.

**321.2.4 Counterweight Supports.** Counterweights shall be provided with stops to limit travel. Weights shall be positively secured. Chains, cables, hangers, rocker arms, or other devices used to attach the counterweight load to the piping shall be subject to the requirements of [para. 321.2.2](#).

**321.2.5 Hydraulic Supports.** An arrangement utilizing a hydraulic cylinder may be used to give a constant supporting force. Safety devices and stops shall be provided to support the load in case of hydraulic failure.

### 321.3 Structural Attachments

External and internal attachments to piping shall be designed so that they will not cause undue flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that attachments be designed to minimize stress concentration, particularly in cyclic services.

**321.3.1 Nonintegral Attachments.** Nonintegral attachments, in which the reaction between the piping and the attachment is by contact, include clamps, slings, cradles, U-bolts, saddles, straps, and clevises. If the weight of a vertical pipe is supported by a clamp, it is recommended to prevent slippage that the clamp be located below a flange, fitting, or support lugs welded to the pipe.

**321.3.2 Integral Attachments.** Integral attachments include plugs, ears, shoes, plates, trunnions, stanchions, structural shapes, and angle clips, cast on or welded to the piping. The material for integral attachments attached by welding shall be of good weldable quality. [See [para. 321.1.4\(e\)](#) for material requirements.] Preheating, welding, and heat treatment requirements shall be in accordance with [Chapter V](#). Consideration shall be given to the localized stresses induced in the piping component by welding the integral attachment, as well as differential thermal displacement strains between the attachment and the component to which it is attached. Welds shall be proportioned so that the shear stresses meet the requirements of [para. 302.3.1\(b\)](#). If the allowed stress values differ between the piping component and the attachment material, the lower of the two values shall be used. Where postweld heat treatment of the piping is required by [para. 331](#), welds for structural attachments made directly to pressure-containing materials shall be postweld heat treated. Welds for structural attachments not made directly to pressure-containing materials do not require postweld heat treatment.

(a) Integral reinforcement, complete encirclement reinforcement, or intermediate pads of suitable alloy and design may be used to reduce contamination or undesirable heat effects in alloy piping.

(b) Intermediate pads, integral reinforcement, complete encirclement reinforcement, or other means of reinforcement may be used to distribute stresses.

The design of pipe-supporting elements and the local effects on the piping component are the responsibility of the designer. Nonmandatory guidance on the design of supports and attachments may be found as referenced in ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix G, G-9. The designer is cautioned that not all the listed standards and bulletins in G-9 are well suited for use on branch-diameter-to-run-diameter and run-diameter-to-run-thickness ratios typical for pipe support component analyses (e.g., Appendix A of WRC Bulletin 537<sup>11</sup> lists the limitations to WRC Bulletin 537).

### 321.4 Structural Connections

The load from piping and pipe supporting elements (including restraints and braces) shall be suitably transmitted to a pressure vessel, building, platform, support structure, foundation, or to other piping capable of bearing the load without deleterious effects. See [Appendix F](#), [para. F321.4](#).

## PART 6 SYSTEMS

### 322 SPECIFIC PIPING SYSTEMS

#### 322.3 Instrument Piping

**322.3.1 Definition.** Instrument piping within the scope of this Code includes all piping and piping components used to connect instruments to other piping or equipment, and control piping used to connect air or hydraulically operated control apparatus. It does not include instruments, or permanently sealed fluid-filled tubing systems furnished with instruments as temperature or pressure responsive devices.

**322.3.2 Requirements.** Instrument piping shall meet the applicable requirements of the Code and the following:

(a) The design pressure and temperature for instrument piping shall be determined in accordance with [para. 301](#). If more severe conditions are experienced during blowdown of the piping, they may be treated as occasional variations in accordance with [para. 302.2.4](#).

<sup>11</sup> WRC (Welding Research Council) 537-2010, "Precision Equations and Enhanced Diagrams for Local Stresses in Spherical and Cylindrical Shells Due to External Loadings for Implementation of WRC Bulletin 107."

(b) Consideration shall be given to the mechanical strength (including fatigue) of small instrument connections to piping or apparatus (see para. 304.3.5).

(c) Instrument piping containing fluids that are normally static and subject to freezing shall be protected by heat tracing or other heating methods, and insulation.

(d) If it will be necessary to blow down (or bleed) instrument piping containing toxic or flammable fluids, consideration shall be given to safe disposal.

## 322.6 Pressure-Relieving Systems

Pressure-relieving systems within the scope of this Code shall conform to the following requirements. See also Appendix F, para. F322.6.

**322.6.1 Stop Valves in Pressure Relief Piping.** If one or more stop valves are installed between the piping being protected and its protective device or devices, or between the protective device or devices and the point of discharge, they shall meet the requirements of (a) and either (b) or (c), below.

(a) A full-area stop valve may be installed on the inlet side of a pressure-relieving device. A full area stop valve may be placed on the discharge side of a pressure-relieving device when its discharge is connected to a common header with other discharge lines from other pressure-relieving devices. Stop valves of less than full area may be used on both the inlet side and discharge side of pressure-relieving devices as outlined herein if the stop valves are of such type and size that the increase in pressure drop will not reduce the relieving capacity below that required, nor adversely affect the proper operation of the pressure-relieving device.

(b) Stop valves to be used in pressure relief piping shall be so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure-relieving capacity provided by the unaffected relieving devices below the required relieving capacity.

(c) As an alternative to (b) above, stop valves shall be so constructed and arranged that they can be locked or sealed in either the open or closed position. See Appendix F, para. F322.6.

**322.6.2 Pressure Relief Discharge Piping.** Discharge lines from pressure-relieving safety devices shall be designed to facilitate drainage. When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel. Reactions on the piping system due to actuation of safety relief devices shall be considered, and adequate strength shall be provided to withstand these reactions.

## 322.6.3 Pressure-Relieving Devices

(a) Pressure-relieving devices required by para. 301.2.2(a) shall be in accordance with ASME BPVC, Section VIII, Division 1, UG-125(c), UG-126, UG-127, and UG-132 through UG-136, excluding UG-135(e) and UG-136(c). The terms *design pressure*<sup>12</sup> and *piping system* shall be substituted for *maximum allowable working pressure* and *vessel*, respectively, in these paragraphs. The required relieving capacity of any pressure-relieving device shall include consideration of all piping systems that it protects.

(b) Relief set pressure<sup>13</sup> shall be in accordance with Section VIII, Division 1, with the exceptions stated in alternatives (1) and (2), below.

(1) With the owner's approval, the set pressure may exceed the limits in Section VIII, Division 1, provided that the limit on maximum relieving pressure stated in (c) below will not be exceeded.

(2) For a liquid thermal expansion relief device that protects only a blocked-in portion of a piping system, the set pressure shall not exceed the lesser of the system test pressure or 120% of design pressure.

(c) The maximum relieving pressure<sup>14</sup> shall be in accordance with Section VIII, Division 1, with the exception that the allowances in para. 302.2.4(f) are permitted, provided that all other requirements of para. 302.2.4 are also met.

<sup>12</sup> The *design pressure* for pressure relief is the maximum design pressure permitted, considering all components in the piping system.

<sup>13</sup> *Set pressure* is the pressure at which the device begins to relieve, e.g., lift pressure of a spring-actuated relief valve, bursting pressure of a rupture disk, or breaking pressure of a breaking pin device.

<sup>14</sup> *Maximum relieving pressure* is the maximum system pressure during a pressure-relieving event.



## Chapter III Materials

### 323 GENERAL REQUIREMENTS

Chapter III states limitations and required qualifications for materials based on their inherent properties. Their use in piping is also subject to requirements and limitations in other parts of this Code [see para. 300(d)]. See also para. 321.1.4 for support materials, and Appendix F, para. F323, for precautionary considerations.

#### 323.1 Materials and Specifications

**323.1.1 Listed Materials.** Any material used in pressure-containing piping components shall conform to a listed specification except as provided in para. 323.1.2.

**323.1.2 Unlisted Materials.** Unlisted materials may be used provided they conform to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meet the requirements of this Code. See also ASME BPVC, Section II, Part D, Appendix 5. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Code or a more conservative basis.

**323.1.3 Unknown Materials.** Materials of unknown specification shall not be used for pressure-containing piping components.

**323.1.4 Reclaimed Materials.** Reclaimed pipe and other piping components may be used, provided they are properly identified as conforming to a listed or published specification (para. 323.1.1 or 323.1.2) and otherwise meet the requirements of this Code. Sufficient cleaning and inspection shall be made to determine minimum wall thickness and freedom from imperfections that would be unacceptable in the intended service.

#### 323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of the Code are suitable for service throughout the operating temperature range.

**323.2.1 Upper Temperature Limits, Listed Materials.** A listed material may be used at a temperature above the maximum for which a stress value or rating is shown, only if

- (a) there is no prohibition in Appendix A or elsewhere in the Code
- (b) the designer verifies the serviceability of the material in accordance with para. 323.2.4

#### 323.2.2 Lower Temperature Limits, Listed Materials.

Listed materials shall be tested as described in Table 323.2.2 except as exempted by (d) through (j). See Appendix F, para. F323.2.2.

(a) The allowable stress or component rating at any temperature colder than the minimum shown in Table A-1, Table A-1M, or Figure 323.2.2A shall not exceed the stress value or rating at the minimum temperature in Table A-1, Table A-1M, or the component standard.

(b) The stress ratio is used in Figure 323.2.2B to determine the allowable reduction in the impact test exemption temperature. The stress ratio is defined as the maximum of the following:

(1) circumferential pressure stress for the condition under consideration (based on minimum pipe wall thickness less allowances) divided by the basic allowable stress at the condition under consideration.

(2) for piping components with pressure ratings, the pressure for the condition under consideration divided by the pressure rating at the condition under consideration.

(3) combined stress due to pressure, dead loads, live loads, and displacement strain for the condition under consideration divided by the basic allowable stress at the condition under consideration. In calculating this combined stress, the forces and moments in the piping system for these combined sustained loads and displacement strains shall be calculated using nominal dimensions, and the stresses shall be calculated using eqs. (23a) through (23d) with all of the stress indices taken as 1.0 ( $I_a = I_i I_o = I_t = 1.0$ ) and using section properties based on the nominal dimensions less corrosion, erosion, and mechanical allowances. Also see Appendix F, para. F323.2.2.

(c) Minimum impact test exemption temperature reduction may be used only when all of the following apply:

(1) The piping is not in Elevated Temperature Fluid Service.

(2) Local stresses caused by shock loading, thermal bowing, and differential expansion between dissimilar metals (e.g., austenitic welded to ferritic) are less than 10% of the basic allowable stresses at the condition under consideration.

(3) The piping is safeguarded from maintenance loads, e.g., using a valve wheel wrench on a small bore valve.

(d) Impact testing of the base metal is not required if the design minimum temperature is warmer than or equal to the temperature listed in the Min. Temp. column of

**Table 323.2.2 Requirements for Low Temperature Toughness Tests for Metals**

(20)

These Toughness Test Requirements Are in Addition to Tests Required by the Material Specification

|                           | Type of Material                                                                                                                                                                                                                                                                                                                            | <b>Column A</b><br><b>Design Minimum Temperature at or Warmer Than Minimum Temperature in Table A-1, Table A-1M, or Figure 323.2.2A or as Described in Para. 323.2.2(h)</b>                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>Column B</b><br><b>Design Minimum Temperature Colder Than Minimum Temperature in Table A-1, Table A-1M, or Figure 323.2.2A or as Described in Para. 323.2.2(h)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Listed Materials</b>   | <b>1</b> Gray iron                                                                                                                                                                                                                                                                                                                          | <b>A-1</b> No additional requirements                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>B-1</b> No additional requirements                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                           | <b>2</b> Malleable and ductile iron; carbon steel in accordance with <a href="#">Note (1)</a>                                                                                                                                                                                                                                               | <b>A-2</b> No additional requirements                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>B-2</b> Materials designated in Box 2 shall not be used.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                           |                                                                                                                                                                                                                                                                                                                                             | <b>(a) Base Metal</b>                                                                                                                                                                                                                                                                                                                        | <b>(b) Weld Metal [<a href="#">Note (2)</a>]</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                           | <b>3</b> Other carbon steels; low and intermediate alloy steels; and ferritic, martensitic, and duplex stainless steels                                                                                                                                                                                                                     | <b>A-3</b> (a) No additional requirements                                                                                                                                                                                                                                                                                                    | <b>A-3</b> (b) The weld metal of the welding procedure qualification test coupon shall be impact tested at or below the design minimum temperature when that temperature is less than $-18^{\circ}\text{C}$ ( $0^{\circ}\text{F}$ ), except when <a href="#">Note (3)</a> or <a href="#">Note (4)</a> is satisfied; impact testing of the weld metal is not required when the classification of the welding consumables according to the filler metal specification requires impact testing at or below the design minimum temperature. | <b>B-3</b> Each heat, test unit, or lot of base material as identified in the applicable base metal specification shall be impact tested except when <a href="#">Note (3)</a> or <a href="#">Note (4)</a> is satisfied. When materials are subjected to heat treatment during fabrication, including hot bending or forming and postweld heat treatment such as that required by <a href="#">Table 331.1.1</a> , impact testing shall be performed on material that has been subjected to heat treatment simulating the anticipated heat treatment, including, for postweld heat treatment, at least 80% of the time at temperature. Each welding procedure specification shall be qualified in accordance with <a href="#">Table 323.3.1</a> . |
|                           | <b>4</b> Austenitic stainless steels                                                                                                                                                                                                                                                                                                        | <b>A-4</b> (a) If (1) carbon content by analysis $>0.1\%$ or (2) material is not in solution heat treated condition, then impact test in accordance with <a href="#">para. 323.3</a> for design minimum temperature $<-29^{\circ}\text{C}$ ( $-20^{\circ}\text{F}$ ) except as provided in <a href="#">Notes (5)</a> and <a href="#">(6)</a> | <b>A-4</b> (b) Weld metal deposits shall be impact tested in accordance with <a href="#">para. 323.3</a> if design minimum temperature $<-29^{\circ}\text{C}$ ( $-20^{\circ}\text{F}$ ) except as provided in <a href="#">para. 323.2.2</a> and in <a href="#">Notes (5)</a> and <a href="#">(6)</a>                                                                                                                                                                                                                                    | <b>B-4</b> Base metal and weld metal deposits shall be impact tested in accordance with <a href="#">para. 323.3</a> . See <a href="#">Notes (2)</a> , <a href="#">(5)</a> , and <a href="#">(6)</a> .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                           | <b>5</b> Austenitic ductile iron, ASTM A571                                                                                                                                                                                                                                                                                                 | <b>A-5</b> (a) No additional requirements                                                                                                                                                                                                                                                                                                    | <b>A-5</b> (b) Welding is not permitted.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>B-5</b> Base metal shall be impact tested in accordance with <a href="#">para. 323.3</a> . Do not use $<-196^{\circ}\text{C}$ ( $-320^{\circ}\text{F}$ ). Welding is not permitted.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Unlisted Materials</b> | <b>6</b> Aluminum, copper, nickel, and their alloys; unalloyed titanium                                                                                                                                                                                                                                                                     | <b>A-6</b> (a) No additional requirements                                                                                                                                                                                                                                                                                                    | <b>A-6</b> (b) No additional requirements unless filler metal composition is outside the range for base metal composition; then test in accordance with item B-6                                                                                                                                                                                                                                                                                                                                                                        | <b>B-6</b> Designer shall be assured by suitable tests [see <a href="#">Note (7)</a> ] that base metal, weld deposits, and HAZ are suitable at the design minimum temperature                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                           | <b>7</b> An unlisted material shall conform to a published specification. Where composition, heat treatment, and product form are comparable to those of a listed material, requirements for the corresponding listed material shall be met. Other unlisted materials shall be qualified as required in the applicable section of column B. |                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

## NOTES:

- Carbon steels conforming to the following are subject to the limitations in Box B-2: plates in accordance with ASTM A36, A283, and A570; pipe in accordance with ASTM A134 when made from these plates; structural shapes in accordance with ASTM A992; and pipe in accordance with ASTM A53 Type F and API 5L Gr. A25 butt weld.
- Impact tests that meet the requirements of [Table 323.3.1](#), which are performed as part of the weld procedure qualification, will satisfy all requirements of [para. 323.2.2](#), and need not be repeated for production welds.
- See [paras. 323.2.2\(g\)](#) through [\(i\)](#).



**Table 323.2.2 Requirements for Low Temperature Toughness Tests for Metals (Cont'd)**

NOTES: (Cont'd)

- (4) Impact tests are not required when the maximum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in.). Under these conditions, and where the stress ratio defined in [para. 323.2.2\(b\)](#) is greater than 0.3, the design minimum temperature shall not be colder than the lower of  $-48^{\circ}\text{C}$  ( $-55^{\circ}\text{F}$ ) or the minimum temperature for the material in [Table A-1](#) or [Table A-1M](#). See also [para. 323.2.2\(g\)](#).
- (5) Impact tests are not required when the maximum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in.).
- (6) For austenitic stainless steels, impact testing is not required if the design minimum temperature is warmer than or equal to  $-104^{\circ}\text{C}$  ( $-155^{\circ}\text{F}$ ), and the stress ratio as defined in [para. 323.2.2\(b\)](#) is 0.3 or less. See also [para. 323.2.2\(g\)](#).
- (7) Tests may include tensile elongation, sharp-notch tensile strength (to be compared with unnotched tensile strength), or other tests, conducted at or colder than design minimum temperature. See also [para. 323.3.4](#).

[Table A-1](#), or [Table A-1M](#), except as provided in [Table 323.2.2](#), Box A-4(a) for austenitic stainless steel base material. In some cases, welds will require either impact testing or testing as described in [Table 323.2.2](#), Box B-6 even when the base metal is not required to be tested. See [\(f\)](#) for steels or [Table 323.2.2](#), Box A-6 (b) for other materials.

*(e)* For carbon steels with a letter designation in the Min. Temp. column of [Table A-1](#) or [Table A-1M](#), the minimum temperature is defined by the applicable curve and Notes in [Figure 323.2.2A](#). If a design minimum temperature-thickness combination is on or above the curve, impact testing exemption requirements described in [\(d\)](#) apply.

*(f)* For steel materials, impact testing of welds, including those made in manufacturing (e.g., for seam welded pipe and welded tees), is required if either base material is required to be impact tested or if the design minimum temperature is colder than  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ), except for manufacturing welds in austenitic stainless steel base materials having a carbon content not exceeding 0.10% and supplied in the solution heat treated condition or as provided in [Table 323.2.2](#), Boxes A-3(b) and A-4(b). For impact testing of production welds, see [Table 323.2.2](#), Note (2).

*(g)* For steels, impact testing is not required for material (including welds) if the stress ratio as defined in [\(b\)](#) is 0.3 or less, the design minimum temperature is warmer than or equal to  $-104^{\circ}\text{C}$  ( $-155^{\circ}\text{F}$ ), and when [\(c\)](#) applies.

*(h)* For carbon, low alloy, and intermediate alloy steel materials (including welds) that have not been qualified by impact testing, the minimum temperature from [Table A-1](#), [Table A-1M](#), or [Figure 323.2.2A](#) may be reduced to a temperature no colder than  $-48^{\circ}\text{C}$  ( $-55^{\circ}\text{F}$ ) by the temperature reduction provided in [Figure 323.2.2B](#) when [\(c\)](#) applies. For carbon, low alloy, and intermediate alloy steel welds that require impact testing in accordance with [Table 323.2.2](#), Box A-3(b), the temperature reduction from [Figure 323.2.2B](#) shall be applied to  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ).

*(i)* For carbon, low alloy, and intermediate alloy steel materials (including welds) that have been qualified by impact testing, the permitted design minimum temperature may be reduced to a temperature no colder than

$-104^{\circ}\text{C}$  ( $-155^{\circ}\text{F}$ ) by the temperature reduction from [Figure 323.2.2B](#) when [\(c\)](#) applies.

*(j)* Impact testing is not required for the following combinations of weld metals and design minimum temperatures:

*(1)* for austenitic stainless steel base materials having a carbon content not exceeding 0.10%, welded without filler metal, at design minimum temperatures of  $-104^{\circ}\text{C}$  ( $-155^{\circ}\text{F}$ ) and warmer

*(2)* for austenitic weld metal

*(-a)* having a carbon content not exceeding 0.10%, and produced with filler metals conforming to AWS A5.4, A5.9, A5.11, A5.14, or A5.22<sup>1</sup> at design minimum temperatures of  $-104^{\circ}\text{C}$  ( $-155^{\circ}\text{F}$ ) and warmer, or

*(-b)* having a carbon content exceeding 0.10%, and produced with filler metals conforming to AWS A5.4, A5.9, A5.11, A5.14, or A5.22<sup>1</sup> at design minimum temperatures of  $-48^{\circ}\text{C}$  ( $-55^{\circ}\text{F}$ ) and warmer

**323.2.3 Temperature Limits, Unlisted Materials.** An unlisted material, acceptable under [para. 323.1.2](#), shall be qualified for service at all temperatures within a stated range, from design minimum temperature to design maximum temperature, in accordance with [para. 323.2.4](#).

### 323.2.4 Verification of Serviceability

*(a)* When an unlisted material is to be used, or when a listed material is to be used above the highest temperature for which stress values appear in [Appendix A](#), the designer is responsible for demonstrating the validity of the allowable stresses and other limits used in design and of the approach taken in using the material, including the

<sup>1</sup> Titles of referenced AWS standards are as follows:

AWS A5.4/A5.4M, Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding

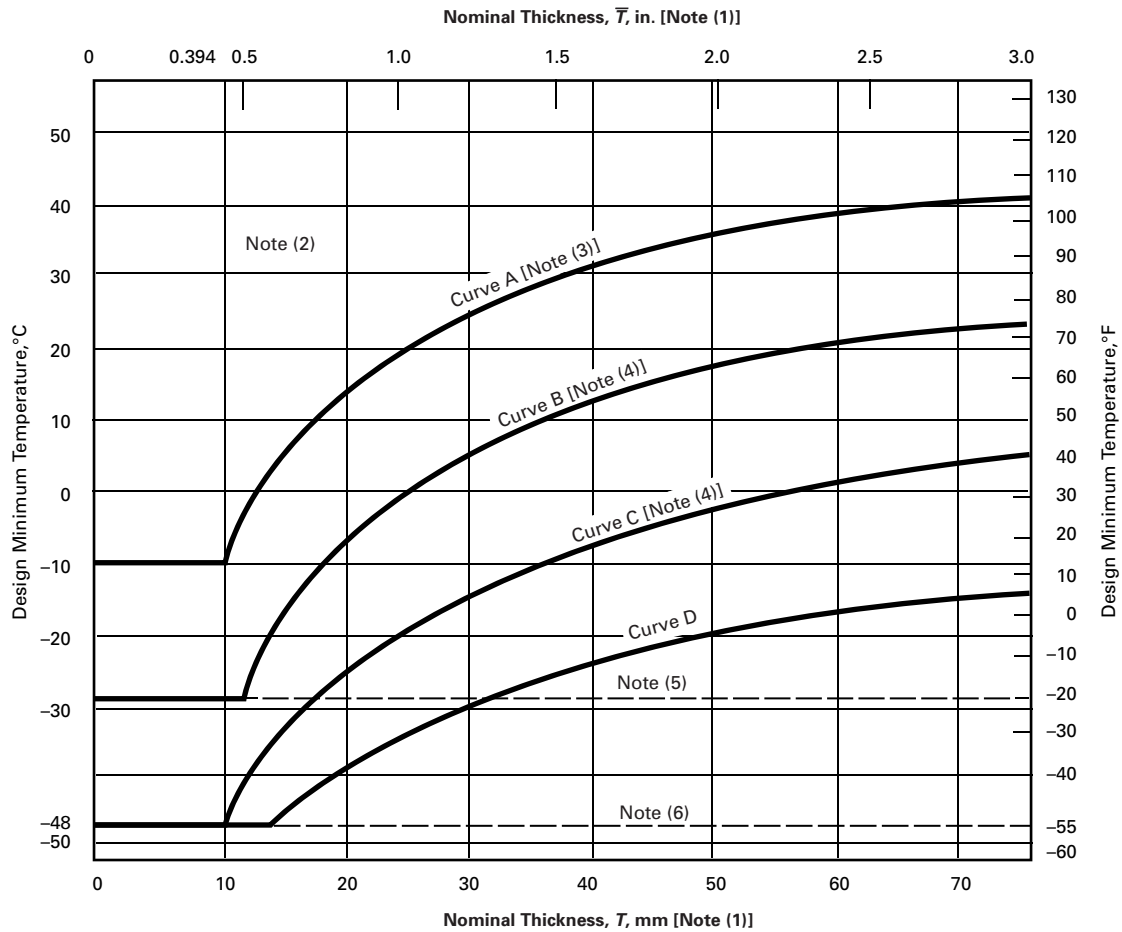
AWS A5.9/A5.9M, Welding Consumables—Wire Electrodes, Strip Electrodes, Wires, and Rods for Arc Welding of Stainless and Heat Resisting Steels—Classification

A5.11/A5.11M, Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding

A5.14/A5.14M, Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods

A5.22/A5.22M, Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods

**Figure 323.2.2A Minimum Temperatures Without Impact Testing for Carbon Steel Materials**  
 (See [Table A-1](#) or [Table A-1M](#) for Designated Curve for a Listed Material; see [Table 323.2.2A](#) for Tabular Values)



## NOTES:

- (1) For blind flanges and blanks made from materials with a letter designation in the Min. Temp. column of [Table A-1](#) or [Table A-1M](#),  $\bar{T}$  shall be  $\frac{1}{4}$  of the total thickness, where the total thickness is the thickness of the blind flange or blank including the thickness of the facing(s), if applicable.
- (2) Any carbon steel material may be used to a minimum temperature of  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) for Category D Fluid Service.
- (3) X Grades of API 5L, and ASTM A381 materials, may be used in accordance with Curve B if normalized or quenched and tempered.
- (4) The following materials may be used in accordance with Curve D if normalized:
  - (a) ASTM A516 plate, all grades
  - (b) ASTM A671 pipe made from A516 plate, all grades
  - (c) ASTM A672 pipe made from A516 plate, all grades
- (5) A welding procedure for the manufacture of pipe or components shall include impact testing of welds and HAZ for any design minimum temperature below  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ), except as provided in [Table 323.2.2, A-3\(b\)](#).
- (6) Impact testing in accordance with [para. 323.3](#) is required for any design minimum temperature below  $-48^{\circ}\text{C}$  ( $-55^{\circ}\text{F}$ ), except as permitted by [Note \(3\)](#) in [Table 323.2.2](#).

**Table 323.2.2A Tabular Values for Minimum Temperatures Without Impact Testing for Carbon Steel Materials**  
**(See Figure 323.2.2A for Curves)**

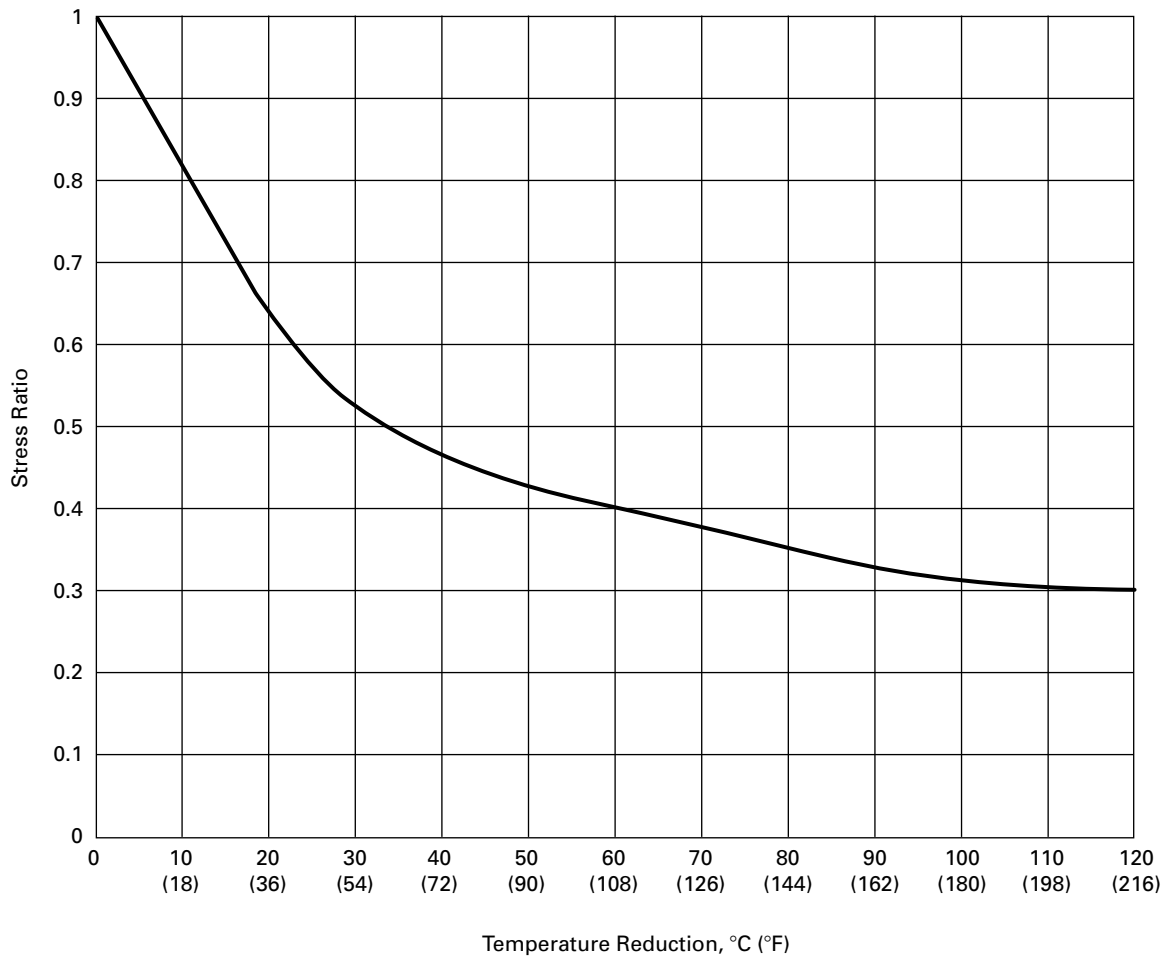
| Nominal Thickness,<br>$\bar{T}$ |        | Lowest Exemption Temperature |     |                       |     |                       |     |         |     |
|---------------------------------|--------|------------------------------|-----|-----------------------|-----|-----------------------|-----|---------|-----|
|                                 |        | Curve A<br>[Note (1)]        |     | Curve B<br>[Note (2)] |     | Curve C<br>[Note (3)] |     | Curve D |     |
| mm                              | in.    | °C                           | °F  | °C                    | °F  | °C                    | °F  | °C      | °F  |
| 6.4                             | 0.25   | -9.4                         | 15  | -28.9                 | -20 | -48.3                 | -55 | -48.3   | -55 |
| 7.9                             | 0.3125 | -9.4                         | 15  | -28.9                 | -20 | -48.3                 | -55 | -48.3   | -55 |
| 9.5                             | 0.375  | -9.4                         | 15  | -28.9                 | -20 | -48.3                 | -55 | -48.3   | -55 |
| 10.0                            | 0.394  | -9.4                         | 15  | -28.9                 | -20 | -48.3                 | -55 | -48.3   | -55 |
| 11.1                            | 0.4375 | -6.7                         | 20  | -28.9                 | -20 | -41.7                 | -43 | -48.3   | -55 |
| 12.7                            | 0.5    | -1.1                         | 30  | -28.9                 | -20 | -37.8                 | -36 | -48.3   | -55 |
| 14.3                            | 0.5625 | 2.8                          | 37  | -21.7                 | -7  | -35.0                 | -31 | -45.6   | -50 |
| 15.9                            | 0.625  | 6.1                          | 43  | -16.7                 | 2   | -32.2                 | -26 | -43.9   | -47 |
| 17.5                            | 0.6875 | 8.9                          | 48  | -12.8                 | 9   | -29.4                 | -21 | -41.7   | -43 |
| 19.1                            | 0.75   | 11.7                         | 53  | -9.4                  | 15  | -27.2                 | -17 | -40.0   | -40 |
| 20.6                            | 0.8125 | 14.4                         | 58  | -6.7                  | 20  | -25.0                 | -13 | -38.3   | -37 |
| 22.2                            | 0.875  | 16.7                         | 62  | -3.9                  | 25  | -23.3                 | -10 | -36.7   | -34 |
| 23.8                            | 0.9375 | 18.3                         | 65  | -1.7                  | 29  | -21.7                 | -7  | -35.6   | -32 |
| 25.4                            | 1.0    | 20.0                         | 68  | 0.6                   | 33  | -19.4                 | -3  | -34.4   | -30 |
| 27.0                            | 1.0625 | 22.2                         | 72  | 2.2                   | 36  | -18.3                 | -1  | -33.3   | -28 |
| 28.6                            | 1.125  | 23.9                         | 75  | 3.9                   | 39  | -16.7                 | 2   | -32.2   | -26 |
| 30.2                            | 1.1875 | 25.0                         | 77  | 5.6                   | 42  | -15.6                 | 4   | -30.6   | -23 |
| 31.8                            | 1.25   | 26.7                         | 80  | 6.7                   | 44  | -14.4                 | 6   | -29.4   | -21 |
| 33.3                            | 1.3125 | 27.8                         | 82  | 7.8                   | 46  | -13.3                 | 8   | -28.3   | -19 |
| 34.9                            | 1.375  | 28.9                         | 84  | 8.9                   | 48  | -12.2                 | 10  | -27.8   | -18 |
| 36.5                            | 1.4375 | 30.0                         | 86  | 9.4                   | 49  | -11.1                 | 12  | -26.7   | -16 |
| 38.1                            | 1.5    | 31.1                         | 88  | 10.6                  | 51  | -10.0                 | 14  | -25.6   | -14 |
| 39.7                            | 1.5625 | 32.2                         | 90  | 11.7                  | 53  | -8.9                  | 16  | -25.0   | -13 |
| 41.3                            | 1.625  | 33.3                         | 92  | 12.8                  | 55  | -8.3                  | 17  | -23.9   | -11 |
| 42.9                            | 1.6875 | 33.9                         | 93  | 13.9                  | 57  | -7.2                  | 19  | -23.3   | -10 |
| 44.5                            | 1.75   | 34.4                         | 94  | 14.4                  | 58  | -6.7                  | 20  | -22.2   | -8  |
| 46.0                            | 1.8125 | 35.6                         | 96  | 15.0                  | 59  | -5.6                  | 22  | -21.7   | -7  |
| 47.6                            | 1.875  | 36.1                         | 97  | 16.1                  | 61  | -5.0                  | 23  | -21.1   | -6  |
| 49.2                            | 1.9375 | 36.7                         | 98  | 16.7                  | 62  | -4.4                  | 24  | -20.6   | -5  |
| 50.8                            | 2.0    | 37.2                         | 99  | 17.2                  | 63  | -3.3                  | 26  | -20.0   | -4  |
| 52.4                            | 2.0625 | 37.8                         | 100 | 17.8                  | 64  | -2.8                  | 27  | -19.4   | -3  |
| 54.0                            | 2.125  | 38.3                         | 101 | 18.3                  | 65  | -2.2                  | 28  | -18.9   | -2  |
| 55.6                            | 2.1875 | 38.9                         | 102 | 18.9                  | 66  | -1.7                  | 29  | -18.3   | -1  |
| 57.2                            | 2.25   | 38.9                         | 102 | 19.4                  | 67  | -1.1                  | 30  | -17.8   | 0   |
| 58.7                            | 2.3125 | 39.4                         | 103 | 20.0                  | 68  | -0.6                  | 31  | -17.2   | 1   |
| 60.3                            | 2.375  | 40.0                         | 104 | 20.6                  | 69  | 0.0                   | 32  | -16.7   | 2   |
| 61.9                            | 2.4375 | 40.6                         | 105 | 21.1                  | 70  | 0.6                   | 33  | -16.1   | 3   |
| 63.5                            | 2.5    | 40.6                         | 105 | 21.7                  | 71  | 1.1                   | 34  | -15.6   | 4   |
| 65.1                            | 2.5625 | 41.1                         | 106 | 21.7                  | 71  | 1.7                   | 35  | -15.0   | 5   |
| 66.7                            | 2.625  | 41.7                         | 107 | 22.8                  | 73  | 2.2                   | 36  | -14.4   | 6   |
| 68.3                            | 2.6875 | 41.7                         | 107 | 22.8                  | 73  | 2.8                   | 37  | -13.9   | 7   |
| 69.9                            | 2.75   | 42.2                         | 108 | 23.3                  | 74  | 3.3                   | 38  | -13.3   | 8   |
| 71.4                            | 2.8125 | 42.2                         | 108 | 23.9                  | 75  | 3.9                   | 39  | -13.3   | 8   |
| 73.0                            | 2.875  | 42.8                         | 109 | 24.4                  | 76  | 4.4                   | 40  | -12.8   | 9   |
| 74.6                            | 2.9375 | 42.8                         | 109 | 25.0                  | 77  | 4.4                   | 40  | -12.2   | 10  |
| 76.2                            | 3.0    | 43.3                         | 110 | 25.0                  | 77  | 5.0                   | 41  | -11.7   | 11  |

**Table 323.2.2A Tabular Values for Minimum Temperatures Without Impact Testing for Carbon Steel Materials**  
**(See Figure 323.2.2A for Curves) (Cont'd)**

## NOTES:

- (1) For blind flanges and blanks made from materials with a letter designation in the Min. Temp. column of [Table A-1](#) or [Table A-1M](#),  $\bar{T}$  shall be  $\frac{1}{4}$  of the total thickness, where the total thickness is the thickness of the blind flange or blank including the thickness of the facing(s), if applicable.
- (2) X Grades of API 5L, and ASTM A381 materials, may be used in accordance with Curve B if normalized or quenched and tempered.
- (3) The following materials may be used in accordance with Curve D if normalized:
  - (a) ASTM A516 plate, all grades
  - (b) ASTM A671 pipe made from A516 plate, all grades
  - (c) ASTM A672 pipe made from A516 plate, all grades

**Figure 323.2.2B Reduction in Lowest Exemption Temperature for Steels Without Impact Testing**  
**(See Table 323.2.2B for Tabular Values)**



GENERAL NOTE: See [para. 323.2.2\(b\)](#) to determine stress ratio.

**Table 323.2.2B Tabular Values for Reduction in Lowest Exemption Temperature for Steels Without Impact Testing**  
 (See [Figure 323.2.2B](#) for Curve and Applicable Notes)

| Stress Ratio | Reduction in Exemption Temperature |    | Stress Ratio | Reduction in Exemption Temperature |     |
|--------------|------------------------------------|----|--------------|------------------------------------|-----|
|              | °C                                 | °F |              | °C                                 | °F  |
| 1.00         | 0                                  | 0  | 0.64         | 20                                 | 36  |
| 0.99         | 1                                  | 1  | 0.63         | 21                                 | 37  |
| 0.98         | 1                                  | 2  | 0.62         | 21                                 | 38  |
| 0.97         | 2                                  | 3  | 0.61         | 22                                 | 40  |
| 0.96         | 2                                  | 4  | 0.60         | 23                                 | 41  |
| 0.95         | 3                                  | 5  | 0.59         | 23                                 | 42  |
| 0.94         | 3                                  | 6  | 0.58         | 24                                 | 44  |
| 0.93         | 4                                  | 7  | 0.57         | 26                                 | 46  |
| 0.92         | 4                                  | 8  | 0.56         | 26                                 | 47  |
| 0.91         | 5                                  | 9  | 0.55         | 27                                 | 49  |
| 0.90         | 6                                  | 10 | 0.54         | 28                                 | 51  |
| 0.89         | 6                                  | 11 | 0.53         | 29                                 | 53  |
| 0.88         | 7                                  | 12 | 0.52         | 31                                 | 56  |
| 0.87         | 7                                  | 13 | 0.51         | 33                                 | 59  |
| 0.86         | 8                                  | 14 | 0.50         | 34                                 | 61  |
| 0.85         | 8                                  | 15 | 0.49         | 36                                 | 65  |
| 0.84         | 9                                  | 16 | 0.48         | 38                                 | 68  |
| 0.83         | 9                                  | 17 | 0.47         | 40                                 | 72  |
| 0.82         | 10                                 | 18 | 0.46         | 42                                 | 76  |
| 0.81         | 11                                 | 19 | 0.45         | 44                                 | 80  |
| 0.80         | 11                                 | 20 | 0.44         | 47                                 | 85  |
| 0.79         | 12                                 | 21 | 0.43         | 50                                 | 90  |
| 0.78         | 12                                 | 22 | 0.42         | 53                                 | 96  |
| 0.77         | 13                                 | 23 | 0.41         | 56                                 | 101 |
| 0.76         | 13                                 | 24 | 0.40         | 60                                 | 108 |
| 0.75         | 14                                 | 25 | 0.39         | 64                                 | 115 |
| 0.74         | 14                                 | 26 | 0.38         | 68                                 | 122 |
| 0.73         | 15                                 | 27 | 0.37         | 72                                 | 130 |
| 0.72         | 16                                 | 28 | 0.36         | 77                                 | 138 |
| 0.71         | 16                                 | 29 | 0.35         | 82                                 | 147 |
| 0.70         | 17                                 | 30 | 0.34         | 87                                 | 156 |
| 0.69         | 17                                 | 31 | 0.33         | 92                                 | 166 |
| 0.68         | 18                                 | 32 | 0.32         | 98                                 | 177 |
| 0.67         | 18                                 | 33 | 0.31         | 104                                | 188 |
| 0.66         | 18                                 | 33 | 0.30         | 111                                | 200 |
| 0.65         | 19                                 | 34 | 0.30         | 120                                | 217 |

derivation of stress data and the establishment of temperature limits.

(b) Data for the development of design limits shall be obtained from a sound scientific program carried out in accordance with recognized technology for both the material and the intended service conditions. Factors to be considered include

(1) applicability and reliability of the data, especially for extremes of the temperature range

(2) resistance of the material to deleterious effects of the fluid service and of the environment throughout the temperature range

(3) determination of allowable stresses in accordance with [para. 302.3](#)

### 323.3 Impact Testing Methods and Acceptance Criteria

**323.3.1 General.** When impact testing is required by [Table 323.2.2](#), provisions elsewhere in this Code, or the engineering design, it shall be done in accordance with [Table 323.3.1](#) using the testing methods and acceptance criteria described in [paras. 323.3.2](#) through [323.3.5](#).

**323.3.2 Procedure.** Impact testing of each product form of material for any specification (including welds in the components) shall be done using procedures and apparatus in accordance with ASTM A370. For material forms that are represented by the ASTM specifications listed below, impact tests shall be conducted in conformance with those requirements as well. When conflicts exist between the specific requirements of this Code and the requirements of those specifications, the requirements of this Code shall take precedence.

| Product Form | ASTM Spec. No. |
|--------------|----------------|
| Pipe         | A333           |
| Tube         | A334           |
| Fittings     | A420           |
| Forgings     | A350           |
| Castings     | A352           |
| Bolting      | A320           |
| Plate        | A20            |

GENERAL NOTE: Titles of referenced standards not listed in the Specifications Index for [Appendix A](#) are A20 General Requirements for Steel Plates for Pressure Vessels and A370 Test Methods and Definitions for Mechanical Testing of Steel Products.

**323.3.3 Test Specimens.** Each set of impact test specimens shall consist of three specimen bars. All impact tests shall be made using standard 10 mm (0.394 in.) square cross section Charpy V-notch specimen bars, except when the material shape or thickness does not permit. Charpy impact tests may be performed on specimens of full material thickness, which may be machined to remove surface

irregularities. Alternatively, such material may be reduced in thickness to produce the largest possible Charpy subsize specimen. See [Table 323.3.4](#).

**323.3.4 Test Temperatures.** For all Charpy impact tests, the test temperature criteria in (a) or (b) shall be observed. The test specimens, as well as the handling tongs, shall be cooled for a sufficient length of time to reach the test temperature.

(a) *For Materials of Thickness Equal to or Greater Than 10 mm (0.394 in.).* Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 8 mm (0.315 in.), the Charpy test using such a specimen shall be conducted at a temperature not higher than the design minimum temperature. Where the largest possible test specimen has a width along the notch less than 8 mm, the test shall be conducted at a temperature lower than the design minimum temperature by the amount shown in [Table 323.3.4](#) for that specimen width.

(b) *For Materials With Thickness Less Than 10 mm (0.394 in.).* Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 80% of the material thickness, the Charpy test of such a specimen shall be conducted at a temperature not higher than the design minimum temperature. Where the largest possible test specimen has a width along the notch of less than 80% of the material thickness, the test shall be conducted at a temperature lower than the design minimum temperature by an amount equal to the difference (referring to [Table 323.3.4](#)) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested.

### 323.3.5 Acceptance Criteria

(a) *Minimum Energy Requirements.* Except for bolting materials, the applicable minimum energy requirement for carbon and low alloy steels with specified minimum tensile strengths less than 656 MPa (95 ksi) shall be those shown in [Table 323.3.5](#).

(b) *Lateral Expansion Requirements.* Other carbon and low alloy steels having specified minimum tensile strengths equal to or greater than 656 MPa (95 ksi), all bolting materials, and all high alloy steels (P-Nos. 6, 7, 8, 10H, and 10I) shall have a lateral expansion opposite the notch of not less than 0.38 mm (0.015 in.) for all specimen sizes. The lateral expansion is the increase in width of the broken impact specimen over that of the unbroken specimen measured on the compression side, parallel to the line constituting the bottom of the V-notch (see ASTM A370).

(c) *Weld Impact Test Requirements.* Where two base metals having different required impact test acceptance criteria are joined by welding, the impact test acceptance criteria shall conform to the requirements of the base material having a specified minimum tensile strength



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**Table 323.3.1 Impact Testing Requirements for Metals**

| Test Characteristics                      |                                       | Column A<br>Materials Tested by the Manufacturer [Note (1)]<br>or Those in Table 323.2.2 Requiring Impact Tests<br>Only on Welds                                                                                                                                                                                                                                                                                                  | Column B<br>Materials Not Tested by the Manufacturer<br>or Those Tested But Heat Treated During<br>or After Fabrication                                                                                                                                                                                 |
|-------------------------------------------|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tests on Materials                        | Number of tests                       | A-1 The greater of the number required by<br>(a) the material specification or<br>(b) the applicable specification listed in<br>para. 323.3.2 [Note (2)]                                                                                                                                                                                                                                                                          | B-1 The number required by the applicable<br>specification listed in para. 323.3.2<br>[Note (2)]                                                                                                                                                                                                        |
|                                           | Location and orientation of specimens | 2 As required by the applicable specification listed in para. 323.3.2.                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                         |
|                                           | Tests by                              | A-3 The manufacturer                                                                                                                                                                                                                                                                                                                                                                                                              | B-3 The fabricator or erector                                                                                                                                                                                                                                                                           |
| Tests on Welds in Fabrication or Assembly | Qualification requirements            | 4 The supplementary essential variables of ASME BPVC, Section IX, shall apply to the welding procedure qualification.                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                         |
|                                           | Extent of testing [Note (3)]          | A-5 Impact tests shall be performed on the weld metal and the heat-affected zone (HAZ) of the procedure qualification test coupon at or below the design minimum temperature and shall meet the acceptance criteria applicable to the base metal in accordance with para. 323.3.                                                                                                                                                  | B-5 If simulated heat treatment is required by Table 323.2.2, item B-3, and materials were supplied without impact test data based on test pieces that were subjected to such heat treatment, the fabricator or erector shall conduct impact tests on material that has been given such heat treatment. |
|                                           | Location and orientation of specimens | 6<br>(a) Weld metal: across the weld, with notch in the weld metal; notch axis shall be normal to material surface, with one face of specimen $\leq 1.5$ mm ( $\frac{1}{16}$ in.) from the material surface.<br>(b) HAZ: across the weld and long enough to locate notch in the HAZ after etching; notch axis shall be approximately normal to material surface and shall include as much as possible of the HAZ in the fracture. |                                                                                                                                                                                                                                                                                                         |
|                                           | Tests by                              | 7 The fabricator or erector                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                         |

## NOTES:

- (1) A certified report of impact tests performed (after being appropriately heat treated as required by Table 323.2.2, item B-3) by the manufacturer shall be obtained as evidence that the material (including any welds used in its manufacture) meets the requirements of this Code and that
- (a) the tests were conducted on specimens representative of the material delivered to and used by the fabricator or erector, or
  - (b) the tests were conducted on specimens removed from test pieces of the material which received heat treatment separately in the same manner as the material (including heat treatment by the manufacturer) so as to be representative of the finished piping
- (2) If welding is used in manufacture, fabrication, or erection, tests of the HAZ will suffice for the tests of the base material.
- (3) The test piece shall be large enough to permit preparing three specimens from the weld metal and three from the HAZ (if required) in accordance with para. 323.3. If this is not possible, preparation of additional test pieces is required.

most closely matching the specified minimum tensile strength of the weld metal.

*(d) Retests*

(1) *For Absorbed Energy Criteria.* When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

(2) *For Lateral Expansion Criterion.* If the value of lateral expansion for one specimen in a group of three is below 0.38 mm (0.015 in.) but not below 0.25 mm (0.01 in.), and if the average value for three specimens equals or exceeds 0.38 mm (0.015 in.), a retest of three additional specimens may be made, each of

which must equal or exceed the specified minimum value of 0.38 mm (0.015 in.). In the case of heat treated materials, if the required values are not obtained in the retest or if the values in the initial test are below the minimum allowed for retest, the material may be reheated and retested. After reheat treatment, a set of three specimens shall be made. For acceptance, the lateral expansion of each of the specimens must equal or exceed the specified minimum value of 0.38 mm (0.015 in.).

(3) *For Erratic Test Results.* When an erratic result is caused by a defective specimen or there is uncertainty in the test procedure, a retest will be allowed.

**Table 323.3.4 Charpy Impact Test Temperature Reduction**

| Actual<br>Material Thickness<br>[See Para. 323.3.4(b)]<br>or Charpy Impact<br>Specimen Width<br>Along the Notch<br>[Note (1)] | Temperature<br>Reduction<br>Below Design<br>Minimum<br>Temperature |       |         |
|-------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|-------|---------|
|                                                                                                                               | mm                                                                 | in.   | °C °F   |
| 10 (full size standard bar)                                                                                                   |                                                                    | 0.394 | 0 0     |
| 9                                                                                                                             |                                                                    | 0.354 | 0 0     |
| 8                                                                                                                             |                                                                    | 0.315 | 0 0     |
| 7.5 ( $\frac{3}{4}$ size bar)                                                                                                 |                                                                    | 0.295 | 2.8 5   |
| 7                                                                                                                             |                                                                    | 0.276 | 4.4 8   |
| 6.67 ( $\frac{2}{3}$ size bar)                                                                                                |                                                                    | 0.262 | 5.6 10  |
| 6                                                                                                                             |                                                                    | 0.236 | 8.3 15  |
| 5 ( $\frac{1}{2}$ size bar)                                                                                                   |                                                                    | 0.197 | 11.1 20 |
| 4                                                                                                                             |                                                                    | 0.157 | 16.7 30 |
| 3.33 ( $\frac{1}{3}$ size bar)                                                                                                |                                                                    | 0.131 | 19.4 35 |
| 3                                                                                                                             |                                                                    | 0.118 | 22.2 40 |
| 2.5 ( $\frac{1}{4}$ size bar)                                                                                                 |                                                                    | 0.098 | 27.8 50 |

GENERAL NOTE: These temperature reduction criteria do not apply when Table 323.3.5 specifies lateral expansion for minimum required values.

NOTE: (1) Straight-line interpolation for intermediate values is permitted.

### 323.4 Fluid Service Requirements for Materials

**323.4.1 General.** Requirements in para. 323.4 apply to pressure-containing parts. They do not apply to materials used for supports, gaskets, packing, or bolting. See also Appendix F, para. F323.4.

#### 323.4.2 Specific Requirements

(a) *Ductile Iron.* Ductile iron shall not be used for pressure containing parts at temperatures below  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) (except austenitic ductile iron) or above  $343^{\circ}\text{C}$  ( $650^{\circ}\text{F}$ ). Austenitic ductile iron conforming to ASTM A571 may be used at temperatures below  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) down to the temperature of the impact test conducted in accordance with that specification but not below  $-196^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ).

Valves having bodies and bonnets or covers made of materials conforming to ASTM A395 and meeting the requirements of ASME B16.42 and additional requirements of ASME B16.34 Standard Class, API 594, API 599, or API

609 may be used within the pressure–temperature ratings given in ASME B16.42.

Welding shall not be performed in the fabrication or repair of ductile iron components nor in assembly of such components in a piping system.

(b) *Other Cast Irons.* The following shall not be used under severe cyclic conditions. If safeguarding is provided against excessive heat and thermal shock and mechanical shock and abuse, they may be used in other services subject to the following requirements:

(1) Gray iron shall not be used above ground within process unit limits in hydrocarbon or other flammable fluid service at temperatures above  $149^{\circ}\text{C}$  ( $300^{\circ}\text{F}$ ) nor at gage pressures above 1 035 kPa (150 psi). In other locations the pressure limit shall be 2 760 kPa (400 psi).

(2) Malleable iron shall not be used in any fluid service at temperatures below  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) or above  $343^{\circ}\text{C}$  ( $650^{\circ}\text{F}$ ) and shall not be used in flammable fluid service at temperatures above  $149^{\circ}\text{C}$  ( $300^{\circ}\text{F}$ ) nor at gage pressures above 2 760 kPa (400 psi).

(3) High silicon iron (14.5% Si) shall not be used in flammable fluid service. The manufacturer should be consulted for pressure–temperature ratings and for precautionary measures when using this material.

#### (c) Other Materials

(1) If welding or thermal cutting is performed on aluminum castings, the stress values in Appendix A and component ratings listed in Table 326.1 are not applicable. It is the designer's responsibility to establish such stresses and ratings consistent with the requirements of this Code.

(2) Lead and tin and their alloys shall not be used in flammable fluid services.

**323.4.3 Cladding and Lining Materials.** Materials with metallic cladding or metallic lining may be used in accordance with the following provisions:

(a) If piping components are made from integrally clad plate conforming to

(1) ASTM A263, Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip

(2) ASTM A264, Stainless Chromium-Nickel Steel Clad Plate, Sheet, and Strip

(3) ASTM A265, Nickel and Nickel-Base Alloy Clad Plate, Sheet, and Strip

Then pressure design in accordance with rules in para. 304 may be based upon the total thickness of base metal and cladding after any allowance for corrosion has been deducted, provided that both the base metal and the cladding metal are acceptable for Code use under para. 323.1, and provided that the clad plate has been shear tested and meets all shear test requirements of the applicable ASTM specification. The allowable stress for each material (base and cladding) shall be taken from Appendix A, or determined in accordance with the rules in para. 302.3, provided, however, that the allowable

**Table 323.3.5 Minimum Required Charpy V-Notch Impact Values**

| Specified Minimum<br>Tensile Strength      | Number of Specimens<br>[Note (1)] | Energy [Note (2)]          |        |                                       |        |
|--------------------------------------------|-----------------------------------|----------------------------|--------|---------------------------------------|--------|
|                                            |                                   | Fully Deoxidized<br>Steels |        | Other Than Fully<br>Deoxidized Steels |        |
|                                            |                                   | Joules                     | ft-lbf | Joules                                | ft-lbf |
| (a) Carbon and Low Alloy Steels            |                                   |                            |        |                                       |        |
| 448 MPa (65 ksi) and less                  | Average for 3 specimens           | 18                         | 13     | 14                                    | 10     |
|                                            | Minimum for 1 specimen            | 14                         | 10     | 10                                    | 7      |
| Over 448 to 517 MPa (75 ksi)               | Average for 3 specimens           | 20                         | 15     | 18                                    | 13     |
|                                            | Minimum for 1 specimen            | 16                         | 12     | 14                                    | 10     |
| Over 517 but not incl. 656 MPa (95 ksi)    | Average for 3 specimens           | 27                         | 20     | ...                                   | ...    |
|                                            | Minimum for 1 specimen            | 20                         | 15     | ...                                   | ...    |
| Lateral Expansion                          |                                   |                            |        |                                       |        |
| 656 MPa and over [Note (3)]                | Minimum for 3 specimens           | 0.38 mm (0.015 in.)        |        |                                       |        |
| (b) Steels in P-Nos. 6, 7, 8, 10H, and 10I | Minimum for 3 specimens           | 0.38 mm (0.015 in.)        |        |                                       |        |

## NOTES:

- (1) See [para. 323.3.5\(d\)](#) for permissible retests.
- (2) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).
- (3) For bolting of this strength level in nominal sizes M 52 (2 in.) and under, the impact requirements of ASTM A320 may be applied. For bolting over M 52, requirements of this Table shall apply.

stress used for the cladding portion of the design thickness shall never be greater than the allowable stress used for the base portion.

(b) For all other metallic clad or lined piping components, the base metal shall be an acceptable Code material as defined in [para. 323.1](#) and the thickness used in pressure design in accordance with [para. 304](#) shall not include the thickness of the cladding or lining. The allowable stress used shall be that for the base metal at the design temperature. For such components, the cladding or lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping component.

(c) Except for components designed in accordance with provisions of (a), fluid service requirements for materials stated in this Code shall not restrict their use as cladding or lining in pipe or other components. Fluid service requirements for the outer material (including those for components and joints) shall govern, except that temperature limitations of both inner and outer materials, and of any bond between them, shall be considered.

(d) Fabrication by welding of clad or lined piping components and the inspection and testing of such components shall be done in accordance with applicable provisions of ASME BPVC, Section VIII, Division 1, UCL-30 through UCL-52, or the provisions of [Chapters V](#) and [VI](#) of this Code, whichever are more stringent.

### 323.5 Deterioration of Materials in Service

Selection of material to resist deterioration in service is not within the scope of this Code. See [para. 300\(c\)\(6\)](#). Recommendations based on experience are presented for guidance in [Appendix F](#), [para. F323](#).

## 325 MATERIALS — MISCELLANEOUS

### 325.1 Joining and Auxiliary Materials

When selecting materials such as adhesives, cements, solvents, solders, brazing materials, packing, and O-rings for making or sealing joints, the designer shall consider their suitability for the fluid service. (Consideration should also be given to the possible effects of the joining or auxiliary materials on the fluid handled.)

## Chapter IV

# Standards for Piping Components

### 326 DIMENSIONS AND RATINGS OF COMPONENTS

#### 326.1 Dimensional Requirements

**326.1.1 Listed Piping Components.** Dimensional standards<sup>1</sup> for piping components are listed in [Table 326.1](#). Dimensional requirements contained in specifications listed in [Appendix A](#) shall also be considered requirements of this Code.

**326.1.2 Unlisted Piping Components.** Piping components not listed in [Table 326.1](#) or [Appendix A](#) shall meet the pressure design requirements described in [para. 302.2.3](#) and the mechanical strength requirements described in [para. 302.5](#).

**326.1.3 Threads.** The dimensions of piping connection threads not otherwise covered by a governing component standard or specification shall conform to the requirements of applicable standards listed in [Table 326.1](#) or [Appendix A](#).

#### 326.2 Ratings of Components

**326.2.1 Listed Components.** The pressure-temperature ratings of components listed in [Table 326.1](#) are accepted for pressure design in accordance with [para. 303](#).

**326.2.2 Unlisted Components.** The pressure-temperature ratings of unlisted piping components shall conform to the applicable provisions of [para. 304](#).

#### 326.3 Reference Documents

The documents listed in [Table 326.1](#) contain references to codes, standards, and specifications not listed in [Table 326.1](#). Such unlisted codes, standards, and specifications shall be used only in the context of the listed documents in which they appear.

The design, materials, fabrication, assembly, examination, inspection, and testing requirements of this Code are not applicable to components manufactured in accordance with the documents listed in [Table 326.1](#), unless specifically stated in this Code or the listed document.

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<sup>1</sup>It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of sponsoring organizations, are shown in [Appendix E](#).

(20)

**Table 326.1 Component Standards**

| Standard or Specification                                                                                                       | Designation   |
|---------------------------------------------------------------------------------------------------------------------------------|---------------|
| <b>Bolting</b>                                                                                                                  |               |
| Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series) . . . . . | ASME B18.2.1  |
| Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series) . . . .             | ASME B18.2.2  |
| Continuous Thread Stud, Double-End Stud, and Flange Bolting Stud (Stud Bolt) (Inch Series) . . . . .                            | ASME B18.31.2 |
| <b>Metallic Fittings, Valves, and Flanges</b>                                                                                   |               |
| Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250 . . . . .                                                 | ASME B16.1    |
| Malleable Iron Threaded Fittings: Classes 150 and 300 . . . . .                                                                 | ASME B16.3    |
| Gray Iron Threaded Fittings: Classes 125 and 250 . . . . .                                                                      | ASME B16.4    |
| Pipe Flanges and Flanged Fittings: NPS 1/2 Through NPS 24 Metric/Inch Standard . . . . .                                        | ASME B16.5    |
| Factory-Made Wrought Butt welding Fittings . . . . .                                                                            | ASME B16.9    |
| Face-to-Face and End-To-End Dimensions of Valves . . . . .                                                                      | ASME B16.10   |
| Forged Fittings, Socket-Welding and Threaded . . . . .                                                                          | ASME B16.11   |
| Ferrous Pipe Plugs, Bushings, and Locknuts With Pipe Threads . . . . .                                                          | ASME B16.14   |
| Cast Copper Alloy Threaded Fittings: Classes 125 and 250 [Note (1)] . . . . .                                                   | ASME B16.15   |
| Cast Copper Alloy Solder Joint Pressure Fittings . . . . .                                                                      | ASME B16.18   |
| Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings . . . . .                                                        | ASME B16.22   |
| Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves: Classes 150, 300, 600, 900, 1500, and 2500 . . . . .              | ASME B16.24   |
| Cast Copper Alloy Fittings for Flared Copper Tubes . . . . .                                                                    | ASME B16.26   |
| Valves — Flanged, Threaded, and Welding End . . . . .                                                                           | ASME B16.34   |
| Orifice Flanges . . . . .                                                                                                       | ASME B16.36   |
| Malleable Iron Threaded Pipe Unions: Classes 150, 250, and 300 . . . . .                                                        | ASME B16.39   |
| Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150 and 300 . . . . .                                                   | ASME B16.42   |
| Large Diameter Steel Flanges: NPS 26 Through NPS 60 Metric/Inch Standard . . . . .                                              | ASME B16.47   |
| Line Blanks . . . . .                                                                                                           | ASME B16.48   |
| Wrought Copper and Copper Alloy Braze-Joint Pressure Fittings . . . . .                                                         | ASME B16.50   |
| Bioprocessing Equipment [Note (2)] . . . . .                                                                                    | ASME BPE      |
| Specification for Pipeline and Piping Valves [Note (3)] . . . . .                                                               | API 6D        |
| Flanged Steel Pressure-relief Valves . . . . .                                                                                  | API 526       |
| Check Valves: Flanged, Lug, Wafer, and Butt-welding . . . . .                                                                   | API 594       |
| Metal Plug Valves — Flanged, Threaded, and Welding Ends . . . . .                                                               | API 599       |
| Steel Gate Valves — Flanged and Butt-welding Ends, Bolted Bonnets . . . . .                                                     | API 600       |
| Gate, Globe, and Check Valves for Sizes DN 100 (NPS 4) and Smaller for the Petroleum and Natural Gas Industries . . . . .       | API 602       |
| Corrosion-resistant, Bolted Bonnet Gate Valves — Flanged and Butt-welding Ends . . . . .                                        | API 603       |
| Metal Ball Valves — Flanged, Threaded, and Welding Ends . . . . .                                                               | API 608       |
| Butterfly Valves: Double-flanged, Lug- and Wafer-type . . . . .                                                                 | API 609       |
| Performance of Gasketed Mechanical Couplings for Use in Piping Applications . . . . .                                           | ASTM F1476    |
| Performance of Fittings for Use with Gasketed Mechanical Couplings Used in Piping Applications . . . . .                        | ASTM F1548    |
| Ductile-Iron and Gray-Iron Fittings . . . . .                                                                                   | AWWA C110     |
| Flanged Ductile-Iron Pipe With Ductile-Iron or Gray-Iron Threaded Flanges . . . . .                                             | AWWA C115     |
| Steel Pipe Flanges for Waterworks Service, Sizes 4 in. Through 144 in. (100 mm Through 3,600 mm) . . . . .                      | AWWA C207     |
| Dimensions for Fabricated Steel Water Pipe Fittings . . . . .                                                                   | AWWA C208     |
| Metal-Seated Gate Valves for Water Supply Service . . . . .                                                                     | AWWA C500     |
| Standard Finishes for Contact Faces of Pipe Flanges and Connecting-End Flanges of Valves and Fittings . . . . .                 | MSS SP-6      |
| Spot Facing for Bronze, Iron, and Steel Flanges . . . . .                                                                       | MSS SP-9      |
| Standard Marking System for Valves, Fittings, Flanges, and Unions . . . . .                                                     | MSS SP-25     |

**Table 326.1 Component Standards (Cont'd)**

| Standard or Specification                                                                                                               | Designation      |
|-----------------------------------------------------------------------------------------------------------------------------------------|------------------|
| <b>Metallic Fittings, Valves, and Flanges (Cont'd)</b>                                                                                  |                  |
| Corrosion-Resistant Gate, Globe, Angle, and Check Valves with Flanged and Butt Weld Ends (Classes 150, 300, & 600)                      | MSS SP-42        |
| Wrought and Fabricated Butt-Welding Fittings for Low Pressure, Corrosion Resistant Applications [Note (4)] . . . . .                    | MSS SP-43        |
| Steel Pipeline Flanges . . . . .                                                                                                        | MSS SP-44        |
| Bypass and Drain Connections . . . . .                                                                                                  | MSS SP-45        |
| Class 150LW Corrosion Resistant Flanges and Cast Flanged Fittings . . . . .                                                             | MSS SP-51        |
| High Pressure Chemical Industry Flanges and Threaded Stubs for Use with Lens Gaskets . . . . .                                          | MSS SP-65        |
| Gray Iron Gate Valves, Flanged and Threaded Ends . . . . .                                                                              | MSS SP-70        |
| Gray Iron Swing Check Valves, Flanged and Threaded Ends . . . . .                                                                       | MSS SP-71        |
| Ball Valves with Flanged or Butt-Welding Ends for General Service . . . . .                                                             | MSS SP-72        |
| High-Strength, Wrought, Butt-Welding Fittings . . . . .                                                                                 | MSS SP-75        |
| Gray Iron Plug Valves, Flanged and Threaded Ends . . . . .                                                                              | MSS SP-78        |
| Socket Welding Reducer Inserts . . . . .                                                                                                | MSS SP-79        |
| Bronze Gate, Globe, Angle, and Check Valves . . . . .                                                                                   | MSS SP-80        |
| Stainless-Steel or Stainless-Steel-Lined, Bonnetless, Knife Gate Valves with Flanged Ends . . . . .                                     | MSS SP-81        |
| Class 3000 and 6000 Pipe Unions, Socket Welding and Threaded (Carbon Steel, Alloy Steel, Stainless Steels, and Nickel Alloys) . . . . . | MSS SP-83        |
| Gray Iron Globe and Angle Valves, Flanged and Threaded Ends . . . . .                                                                   | MSS SP-85        |
| Diaphragm Valves . . . . .                                                                                                              | MSS SP-88        |
| Swage(d) Nipples and Bull Plugs . . . . .                                                                                               | MSS SP-95        |
| Integrally Reinforced Forged Branch Outlet Fittings — Socket Welding, Threaded, and Buttwelding Ends . . . . .                          | MSS SP-97        |
| Instrument Valves for Code Applications . . . . .                                                                                       | MSS SP-105       |
| Cast Copper Alloy Flanges and Flanged Fittings: Class 125, 150, and 300 . . . . .                                                       | MSS SP-106       |
| Factory-Made Wrought Belled End Pipe Fittings for Socket-Welding [Note (5)] . . . . .                                                   | MSS SP-119       |
| Refrigeration Tube Fittings — General Specifications . . . . .                                                                          | SAE J513         |
| Hydraulic Tube Fittings . . . . .                                                                                                       | SAE J514         |
| Hydraulic Flanged Tube, Pipe, and Hose Connections, 4-Screw Flange Connection Part 1: 3.5 MPa to 35 MPa (Code 61)                       | SAE J518-1       |
| Hydraulic Flanged Tube, Pipe, and Hose Connections, 4-Screw Flange Connection Part 2: 42 MPa (Code 62) . . . . .                        | SAE J518-2       |
| <b>Metallic Pipe and Tubes [Note (6)]</b>                                                                                               |                  |
| Welded and Seamless Wrought Steel Pipe . . . . .                                                                                        | ASME B36.10M     |
| Stainless Steel Pipe . . . . .                                                                                                          | ASME B36.19M     |
| Flanged Ductile-Iron Pipe With Ductile-Iron or Gray-Iron Threaded Flanges . . . . .                                                     | AWWA C115        |
| Thickness Design of Ductile-Iron Pipe . . . . .                                                                                         | AWWA C150        |
| Ductile-Iron Pipe, Centrifugally Cast . . . . .                                                                                         | AWWA C151        |
| Steel Water Pipe, 6 in. (150 mm) and Larger . . . . .                                                                                   | AWWA C200        |
| <b>Miscellaneous</b>                                                                                                                    |                  |
| Unified Inch Screw Threads (UN and UNR Thread Form) . . . . .                                                                           | ASME B1.1        |
| Pipe Threads, General Purpose (Inch) . . . . .                                                                                          | ASME B1.20.1     |
| Dryseal Pipe Threads (Inch) . . . . .                                                                                                   | ASME B1.20.3     |
| Hose Coupling Screw Threads (Inch) . . . . .                                                                                            | ASME B1.20.7     |
| Metallic Gaskets for Pipe Flanges . . . . .                                                                                             | ASME B16.20      |
| Nonmetallic Flat Gaskets for Pipe Flanges . . . . .                                                                                     | ASME B16.21      |
| Buttwelding Ends . . . . .                                                                                                              | ASME B16.25      |
| Surface Texture (Surface Roughness, Waviness, and Lay) . . . . .                                                                        | ASME B46.1       |
| Thermowells [Note (7)] . . . . .                                                                                                        | ASME PTC 19.3 TW |
| Specification for Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads . . . . .                          | API 5B           |
| Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings . . . . .                                                              | AWWA C111        |

**Table 326.1 Component Standards (Cont'd)**

| Standard or Specification                                                                            | Designation     |
|------------------------------------------------------------------------------------------------------|-----------------|
| <b>Miscellaneous (Cont'd)</b>                                                                        |                 |
| Grooved and Shouldered Joints [Note (8)]                                                             | AWWA C606       |
| Flexible Metal Hose [Notes (9) and (10)]                                                             | BS 6501, Part 1 |
| Pipe Hangers and Supports — Materials, Design, Manufacture, Selection, Application, and Installation | MSS SP-58       |
| Standard for Fire Hose Connections                                                                   | NFPA 1963       |

## GENERAL NOTES:

- (a) It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in [Appendix E](#).
- (b) Many of the listed standards allow the use of unlisted materials; see [para. 323.1.2](#).

## NOTES:

- (1) This standard allows straight pipe threads in sizes  $\leq$  DN 15 (NPS  $\frac{1}{2}$ ); see last paragraph of [para. 314.2.1](#).
- (2) Part DT of ASME BPE covers dimensions and tolerances for stainless steel automatic welding and hygienic clamp tube fittings and process components.
- (3) API 6D allows design and calculations for pressure-containing elements to be in accordance with various internationally recognized design codes or standards. Only API 6D valves with design and calculations for pressure-containing elements in accordance with ASME B16.34 are considered a “listed component” for the purpose of this Code.
- (4) *Cautionary Note:* See MSS SP-43 for special provisions concerning ratings. (In accordance with MSS SP-43, the pressure ratings for Class CR fittings are 30% of those calculated for straight seamless pipe of *minimum* wall thickness.)
- (5) MSS SP-119 includes three classes of fittings: MP, MARINE, and CR. Only the MP class fittings are considered a “Listed Component” for the purpose of this Code. *Cautionary Note:* See MSS SP-119 (Section 5) for special provisions concerning ratings. (In accordance with MSS SP-119, the pressure ratings for MP class fittings are 87.5% of those calculated for straight seamless pipe of *minimum* wall thickness.)
- (6) See also [Appendix A](#).
- (7) ASME PTC 19.3 TW allows mechanical design of thermowells to be in accordance with various design codes. Only PTC 19.3 TW thermowells with design and calculations for pressure-containing elements in accordance with ASME B31.3 are considered a “listed component” for the purpose of this Code.
- (8) For use with this Code, the rated pressure of components covered by this standard shall be based on no greater than one-third the hydrostatic test failure pressure (the pressure at fracture or leakage), rather than one-half the hydrostatic test failure pressure specified in AWWA C606.
- (9) Welding and brazing to be in accordance with [paras. 328](#) and [333](#), respectively, in lieu of the referenced specifications in this standard.
- (10) This standard contains recommended materials of construction for certain chemical services; the responsibility for the ultimate selection of material is the responsibility of the Owner and is, therefore, not within the scope of this Code.



## Chapter V

# Fabrication, Assembly, and Erection

### 327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in [paras. 328, 330, 331, 332, and 333](#). When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

### 328 WELDING AND BRAZING

Welding and brazing shall conform to the requirements of this Chapter and the applicable requirements of [para. 311.2](#).

#### 328.1 Responsibility

Each employer is responsible for

(a) the welding and brazing performed by personnel of its organization

(b) conducting the qualification tests required to qualify the welding or brazing procedure specifications used by personnel in its organization, except as provided in [paras. 328.2.1 and 328.2.2](#)

(c) conducting the qualification tests required to qualify the welders, brazers, and operators, except as provided in [para. 328.2.3](#)

#### 328.2 Welding and Brazing Qualification

Welding and brazing procedure specifications (WPSs and BPSs) to be followed in production welding shall be prepared and qualified, and welders, brazers, and operators shall be qualified as required by ASME BPVC, Section IX except as modified by [para. 333](#) for brazing of Category D Fluid Service piping and by the following subparagraphs.

**328.2.1 Standard Welding Procedure Specifications.** Standard welding procedure specifications published by the American Welding Society and listed in ASME BPVC, Section IX, Appendix E are permitted for Code construction within the limitations established by ASME BPVC, Section IX, Article V.

**328.2.2 Procedure Qualification by Others.** In order to avoid duplication of effort and subject to the approval of the owner, WPSs and BPSs qualified by a technically competent group or agency may be used provided the following are met:

(a) The procedures meet the requirements of ASME BPVC, Section IX and any additional qualification requirements of this Code.

(b) The employer has qualified at least one welder, brazer, or operator following each WPS or BPS.

(c) The employer's business name shall be shown on each WPS and BPS, and on each qualification record. In addition, qualification records shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

**328.2.3 Performance Qualification by Others.** In order to avoid duplication of effort and subject to the approval of the owner, an employer may accept the performance qualification of a welder, brazer, or operator made by a previous employer. This acceptance is limited to performance qualifications that were made on pipe or tube test coupons. The new employer shall have the WPS or BPS that was followed during qualification or an equivalent WPS or BPS that is within the limits of the essential variables set forth in ASME BPVC, Section IX. An employer accepting such qualification tests shall obtain a copy of the performance qualification test record from the previous employer. The record shall show the name of the employer by whom the welder, brazer, or operator was qualified and the date of that qualification. Evidence shall also be provided that the welder, brazer, or operator has maintained qualification in accordance with QW-322 and QB-322 of ASME BPVC, Section IX, except that this evidence may be provided by an employer responsible for the individual's welding or brazing performance even if not the original qualifying employer. The new employer's business name shall be shown on the qualification record, and it shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

**328.2.4 Qualification Records.** The employer shall maintain copies of the procedure and performance qualification records specified by ASME BPVC, Section IX that shall be available to the Inspector at the location where welding is being done.

#### 328.3 Welding Materials

**328.3.1 Electrodes and Filler Metal.** Welding electrodes and filler metal, including consumable inserts, shall conform to the requirements of ASME BPVC,

Section II, Part C. An electrode or filler metal not conforming to the above may be used provided the WPS and the welders who will follow the WPS have been qualified as required by ASME BPVC, Section IX. Unless otherwise specified by the Designer, welding electrodes and filler metals used shall produce weld metal that complies with the following:

(a) The nominal tensile strength of the weld metal shall equal or exceed the minimum specified tensile strength of the base metals being joined, or the weaker of the two if base metals of two different strengths are being joined.

(b) The nominal chemical analysis of the weld metal shall be similar to the nominal chemical analysis of the major alloying elements of the base metal (e.g., 2¼% Cr, 1% Mo steels should be joined using 2¼% Cr, 1% Mo filler metals).

(c) If base metals of different chemical analysis are being joined, the nominal chemical analysis of the weld metal shall be similar to either base metal or an intermediate composition, except as specified below for austenitic steels joined to ferritic steels.

(d) When austenitic steels are joined to ferritic steels, the weld metal shall have a predominantly austenitic microstructure.

(e) For nonferrous metals, the weld metal shall be that recommended by the manufacturer of the nonferrous base metal or by industry associations for that metal.

**328.3.2 Weld Backing Material.** When backing rings are used, they shall conform to the following:

(a) *Ferrous Metal Backing Rings.* These shall be of weldable quality. Sulfur content shall not exceed 0.05%.

(b) If two abutting surfaces are to be welded to a third member used as a backing ring and one or two of the three members are ferritic and the other member or members are austenitic, the satisfactory use of such materials shall be demonstrated by welding procedure qualified as required by para. 328.2.

Backing rings may be of the continuous machined or split-band type. Some commonly used types are shown in Figure 328.3.2.

(c) *Nonferrous and Nonmetallic Backing Rings.* Backing rings of nonferrous or nonmetallic material may be used, provided the designer approves their use and the welding procedure using them is qualified as required by para. 328.2.

**328.3.3 Consumable Inserts.** Consumable inserts may be used, provided they are of the same nominal composition as the filler metal, will not cause detrimental alloying of the weld metal, and the welding procedure using them is qualified as required by para. 328.2. Some commonly used types are shown in Figure 328.3.2.

## 328.4 Preparation for Welding

**328.4.1 Cleaning.** Internal and external surfaces to be thermally cut or welded shall be clean and free from paint, oil, rust, scale, and other material that would be detrimental to either the weld or the base metal when heat is applied.

### 328.4.2 End Preparation

#### (a) General

(1) End preparation is acceptable only if the surface is reasonably smooth and true, and slag from oxygen or arc cutting is cleaned from thermally cut surfaces. Discoloration remaining on a thermally cut surface is not considered detrimental oxidation.

(2) End preparation for groove welds specified in ASME B16.25, or any other that meets the WPS, is acceptable. [For convenience, the basic bevel angles of ASME B16.25 and some additional J-bevel angles are shown in Figure 328.4.2, illustrations (a) and (b).]

#### (b) Circumferential Welds

(1) If component ends are trimmed as shown in Figure 328.3.2, illustration (a) or (b) to fit backing rings or consumable inserts, or as shown in Figure 328.4.3, illustration (a) or (b) to correct internal misalignment, such trimming shall not reduce the finished wall thickness below the required minimum wall thickness,  $t_m$ .

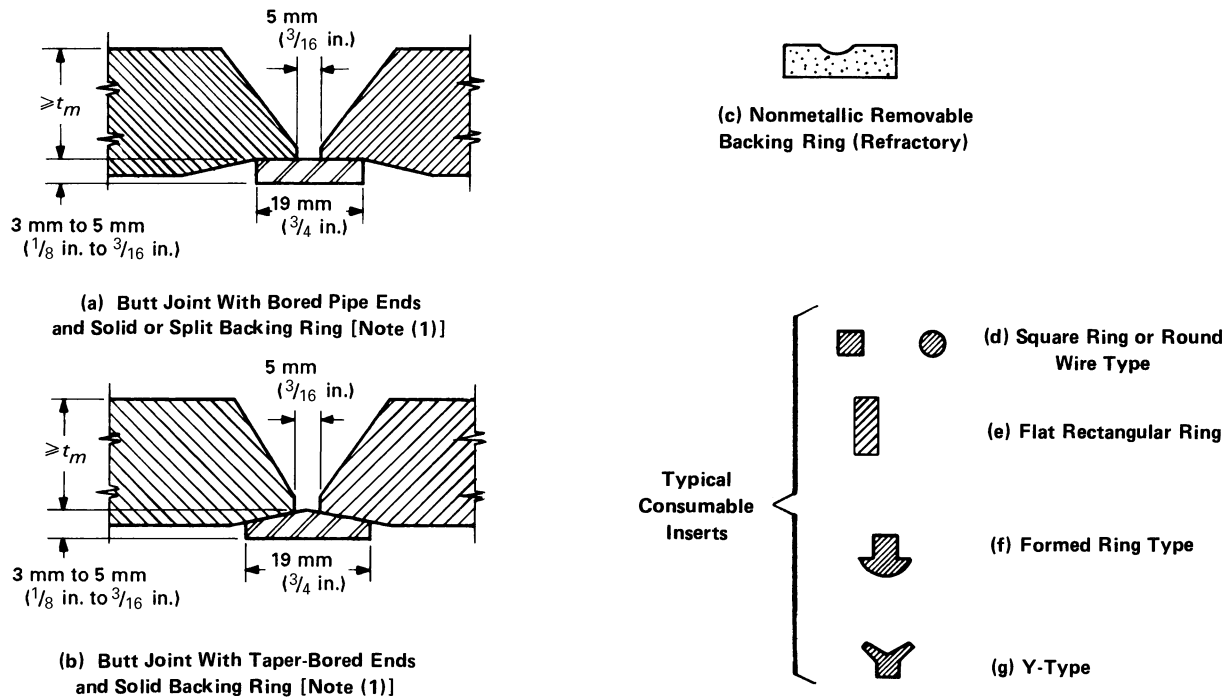
(2) Component ends may be bored to allow for a completely recessed backing ring, provided the remaining net thickness of the finished ends is not less than  $t_m$ .

(3) It is permissible to size pipe ends of the same nominal size to improve alignment if wall thickness requirements are maintained.

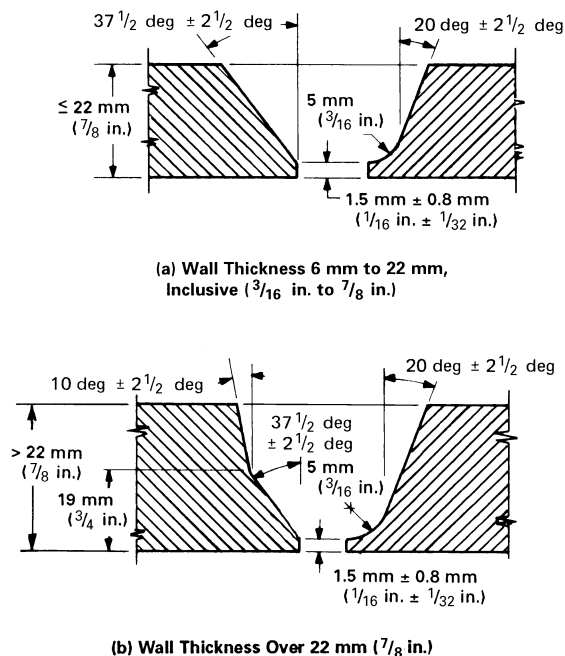
(4) Where necessary, weld metal may be deposited inside or outside of the component to permit alignment or provide for machining to ensure satisfactory seating of rings or inserts.

(5) When a girth or miter groove weld joins components of unequal wall thickness and one is more than 1½ times the thickness of the other, end preparation and geometry shall be in accordance with acceptable designs for unequal wall thickness in ASME B16.25.

(6) Butt-weld fittings manufactured in accordance with ASME B16.9 may be trimmed to produce an angular joint offset in their connections to pipe or to other butt-weld fittings without being subject to design qualifications in accordance with para. 304.7.2, provided the total angular offset produced between the two jointed parts does not exceed 3 deg.

**Figure 328.3.2 Typical Backing Rings and Consumable Inserts**

NOTE: (1) Refer to ASME B16.25 for detailed dimensional information on welding ends.

**Figure 328.4.2 Typical Butt Weld End Preparation**

### 328.4.3 Alignment

#### (a) Circumferential Welds

(1) Inside surfaces of components at ends to be joined in girth or miter groove welds shall be aligned within the dimensional limits in the WPS and the engineering design.

(2) If the external surfaces of the components are not aligned, the weld shall be tapered between them.

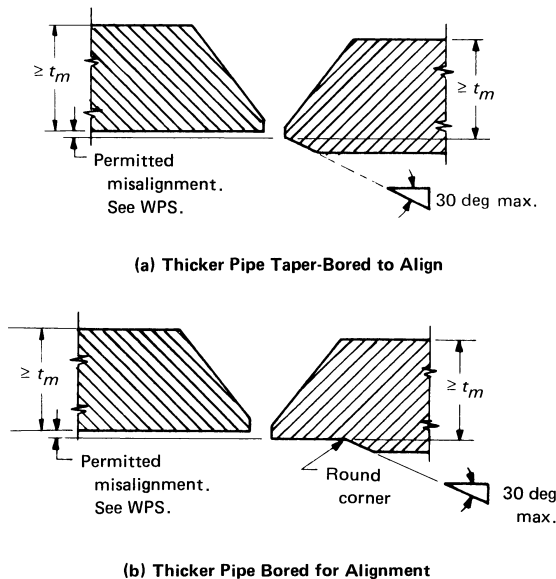
(b) *Longitudinal Welds.* Alignment of longitudinal groove welds (not made in accordance with a standard listed in [Table A-1](#), [Table A-1M](#), or [Table 326.1](#)) shall conform to the requirements of [para. 328.4.3\(a\)](#).

#### (c) Branch Connection Welds

(1) Branch connections that abut the outside surface of the run pipe shall be contoured for groove welds that meet the WPS requirements [see [Figure 328.4.4](#), illustrations (a) and (b)].

(2) Branch connections that are inserted through a run opening shall be inserted at least as far as the inside surface of the run pipe at all points [see [Figure 328.4.4](#), illustration (c)] and shall otherwise conform to [para. 328.4.3\(c\)\(1\)](#).

(3) Run openings for branch connections shall not deviate from the required contour more than the dimension  $m$  in [Figure 328.4.4](#). In no case shall deviations of the shape of the opening cause the root spacing tolerance

**Figure 328.4.3 Trimming and Permitted Misalignment**

limits in the WPS to be exceeded. Weld metal may be added and refinished if necessary for compliance.

(d) *Spacing.* The root opening of the joint shall be within the tolerance limits in the WPS.

## 328.5 Welding Requirements

### 328.5.1 General

(a) Welds, including addition of weld metal for alignment [paras. 328.4.2(b)(4) and 328.4.3(c)(3)], shall be made in accordance with a qualified procedure and by qualified welders or welding operators.

(b) Each qualified welder and welding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing weld or adjacent area shall be marked with the identification symbol of the welder or welding operator. In lieu of marking the weld, appropriate records shall be filed.

(c) Tack welds at the root of the joint shall be made with filler metal equivalent to that used in the root pass. Tack welds shall be made by a qualified welder or welding operator. Tack welds shall be fused with the root pass weld, except that those that have cracked shall be removed. Bridge tacks (above the weld) shall be removed.

(d) Peening is prohibited on the root pass and final pass of a weld.

(e) No welding shall be done if there is impingement on the weld area of rain, snow, sleet, or excessive wind, or if the weld area is frosted or wet.

(f) *Welding End Valves.* The welding sequence and procedure and any heat treatment for a welding end valve shall be such as to preserve the seat tightness of the valve.

### 328.5.2 Fillet and Socket Welds.

(20)

(a) Fillet and socket welds may vary from convex to concave. The size of these welds shall be determined as shown in Figure 328.5.2A.

(b) Minimum attachment weld dimensions for double-welded slip-on flanges, socket welding flanges, and other socket welding components shall be as shown in Figures 328.5.2B and 328.5.2C.

(c) If slip-on flanges are single welded, the weld shall be at the hub, i.e., the  $X_{\min}$  by  $X_{\min}$  weld illustrated in Figure 328.5.2B.

**328.5.3 Seal Welds.** Seal welding shall be done by a qualified welder. Seal welds shall cover all exposed threads.

### 328.5.4 Welded Branch Connections

(20)

(a) Figures 328.5.4A through 328.5.4F show acceptable details of branch connections with and without added reinforcement, in which the branch pipe is connected directly to the run pipe. The illustrations are typical and are not intended to exclude acceptable types of construction not shown.

(b) Figure 328.5.4D shows basic types of weld attachments used in the fabrication of branch connections. The location and minimum size of attachment welds shall conform to the requirements herein. Welds shall be calculated in accordance with para. 304.3.3 but shall be not less than the sizes shown in Figure 328.5.4D. Figure 328.5.4F shows the basic types of attachment welds used with integrally reinforced branch connection fittings. The location and the minimum size of the attachment welds shall conform to the requirements of (i) below.

(c) The nomenclature and symbols used herein, in Figure 328.5.4D, and in Figure 328.5.4F are

$\bar{T}_b$  = nominal thickness of branch

$\bar{T}_h$  = nominal thickness of header

$\bar{T}_m$  = nominal thickness of the branch weld for integrally reinforced branch connection fittings

(1) as specified by the manufacturer of the branch connection fitting

(2) the full depth of the resultant weld groove, after fit-up, if no manufacturer's weld thickness is specified

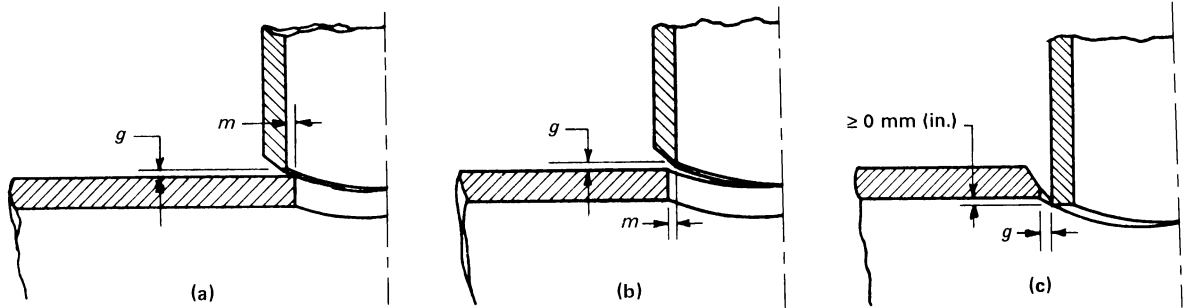
(3) as documented and specified in the engineering design in accordance with para. 300(c)(3), or

(4) calculated and documented in accordance with the requirements of para. 304.7.2

$\bar{T}_r$  = nominal thickness of reinforcing pad or saddle

$t_c$  = lesser of  $0.7 \bar{T}_b$  or 6 mm ( $1/4$  in.)

$t_{\min}$  = lesser of  $\bar{T}_b$  or  $\bar{T}_r$

**Figure 328.4.4 Preparation for Branch Connections**


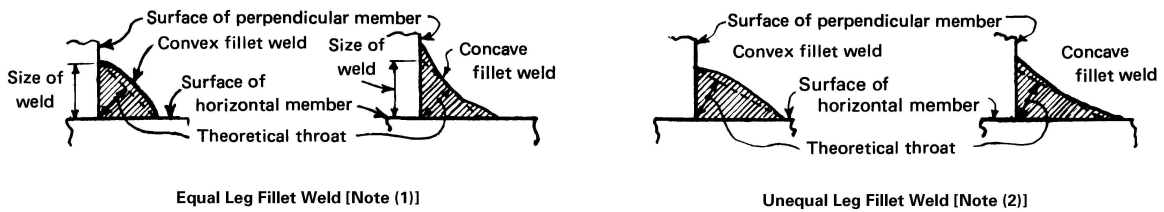
Legend:

$g$  = root gap per welding specification

$m$  = the lesser of 3.2 mm ( $1/8$  in.) or  $0.5 \bar{T}_b$

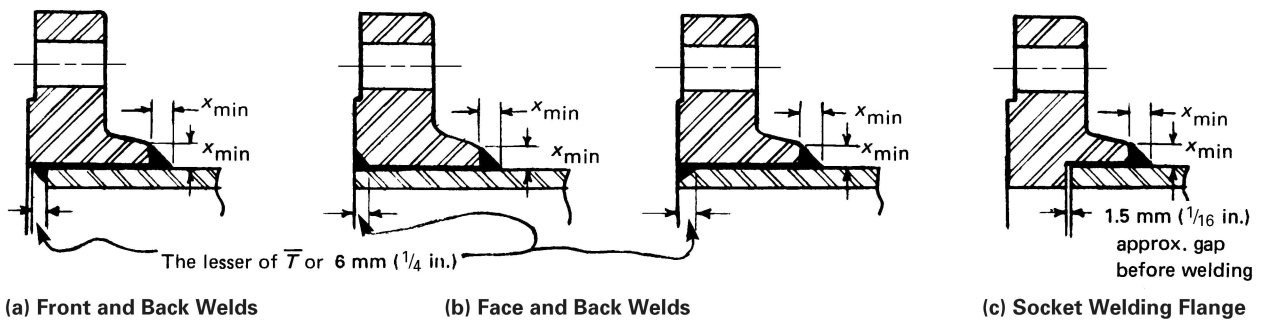
**Figure 328.5.2A Fillet and Socket Weld Sizes**

(20)



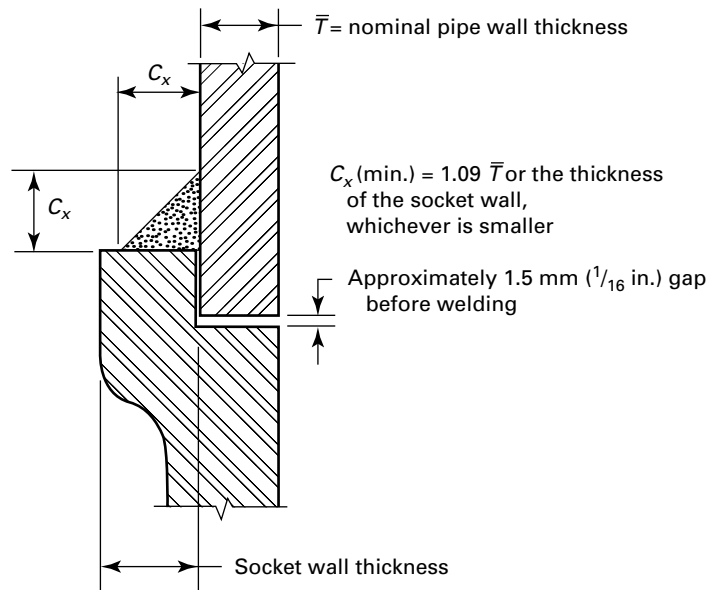
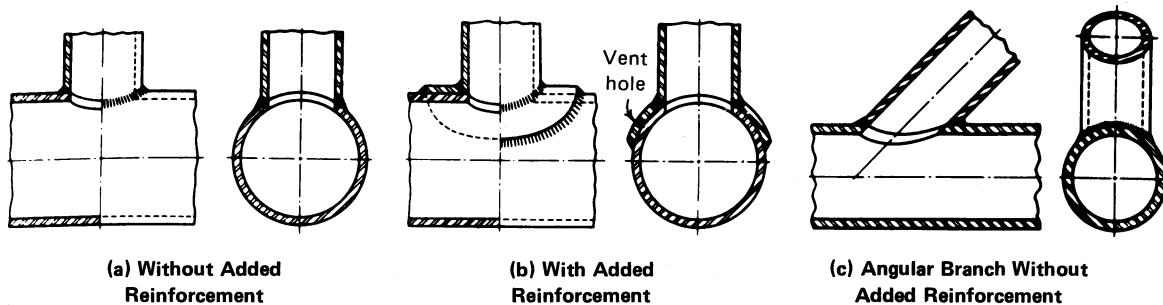
NOTES:

- (1) The size of an equal leg fillet weld is the leg length of the largest inscribed isosceles right triangle (theoretical throat =  $0.707 \times \text{size}$ ).
- (2) The size of unequal leg fillet weld is the leg lengths of the largest right triangle that can be inscribed within the weld cross section [e.g., 13 mm  $\times$  19 mm ( $1/2$  in.  $\times$   $3/4$  in.)].

**Figure 328.5.2B Minimum Attachment Weld Dimensions for Double-Welded Slip-On and Socket Welding Flanges** (20)


Legend:

$x_{\min}$  = the lesser of  $1.4 \bar{T}$  or the thickness of the hub

(20) **Figure 328.5.2C Minimum Attachment Weld Dimensions for Socket Welding Components Other Than Flanges****Figures 328.5.4A, B, C Typical Welded Branch Connections**

(d) Branch connections, including branch connection fittings (see [paras. 300.2](#) and [304.3.2](#)), that abut the outside of the run or that are inserted in an opening in the run shall be attached by fully penetrated groove welds. The welds shall be finished with cover fillet welds having a throat dimension not less than  $t_c$ . See [Figure 328.5.4D](#), illustrations (a) and (b).

(e) A reinforcing pad or saddle shall be attached to the branch pipe by either

(1) a fully penetrated groove weld finished with a cover fillet weld having a throat dimension not less than  $t_c$ , or

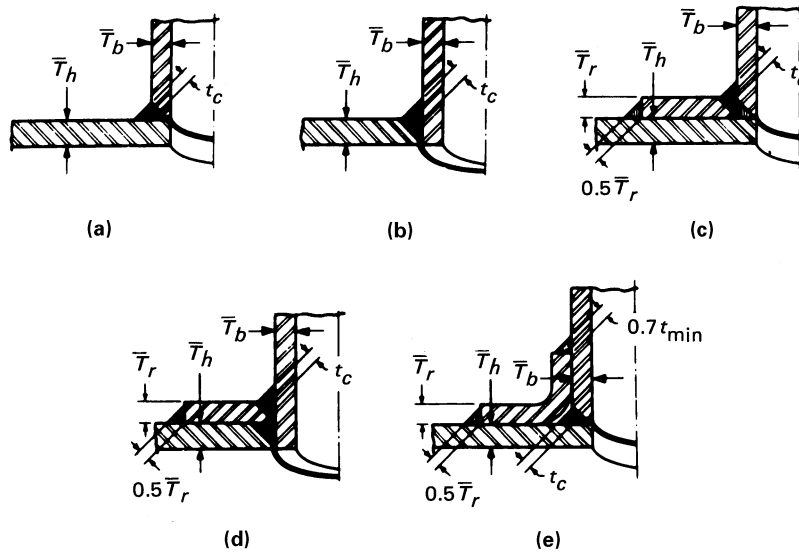
(2) a fillet weld having a throat dimension not less than  $0.7t_{min}$ . See [Figure 328.5.4D](#), illustration (e).

(f) The outer edge of a reinforcing pad or saddle shall be attached to the run pipe by a fillet weld having a throat dimension not less than  $0.5 \bar{T}_r$ . See [Figure 328.5.4D](#), illustrations (c), (d), and (e).

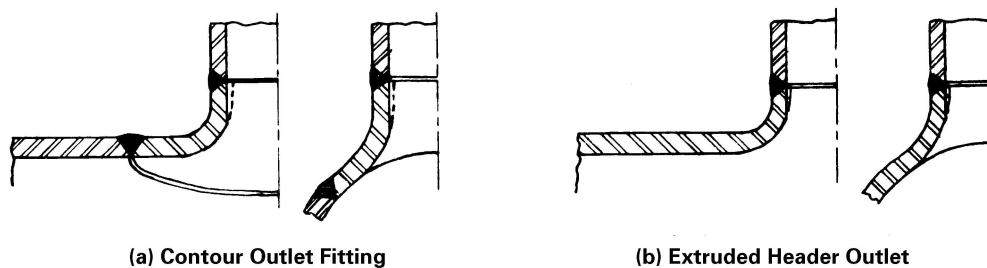
(g) Reinforcing pads and saddles shall have a good fit with the parts to which they are attached. A vent hole shall be provided at the side (not at the crotch) of any pad or saddle to reveal leakage in the weld between branch and run and to allow venting during welding and heat treatment. A pad or saddle may be made in more than one piece if joints between pieces have strength equivalent to pad or saddle parent metal, and if each piece has a vent hole.

(h) Examination and any necessary repairs of the completed weld between branch and run shall be made before adding a pad or saddle.



**Figure 328.5.4D Acceptable Details for Branch Attachment Welds**

GENERAL NOTE: These illustrations show minimum acceptable welds. Welds may be larger than those shown here.

**Figure 328.5.4E Acceptable Details for Branch Attachments Suitable for 100% Radiography**

(i) Figure 328.5.4F shows additional integrally reinforced branch connections typical of MSS SP-97 fittings that abut the outside of the run attached by a full penetration groove weld. The welds shall be finished with cover fillets having a throat dimension not less than  $t_c$ . The cover fillet weld shall fill and smoothly transition to the attachment weld and run pipe or fitting.

**328.5.5 Fabricated Laps.** Figure 328.5.5 shows typical fabricated laps. Fabrication shall be in accordance with the applicable requirements of para. 328.5.4.

**328.5.6 Welding for Severe Cyclic Conditions.** A welding procedure shall be employed that provides a smooth, regular, fully penetrated inner surface.

## 328.6 Weld Repair

(20)

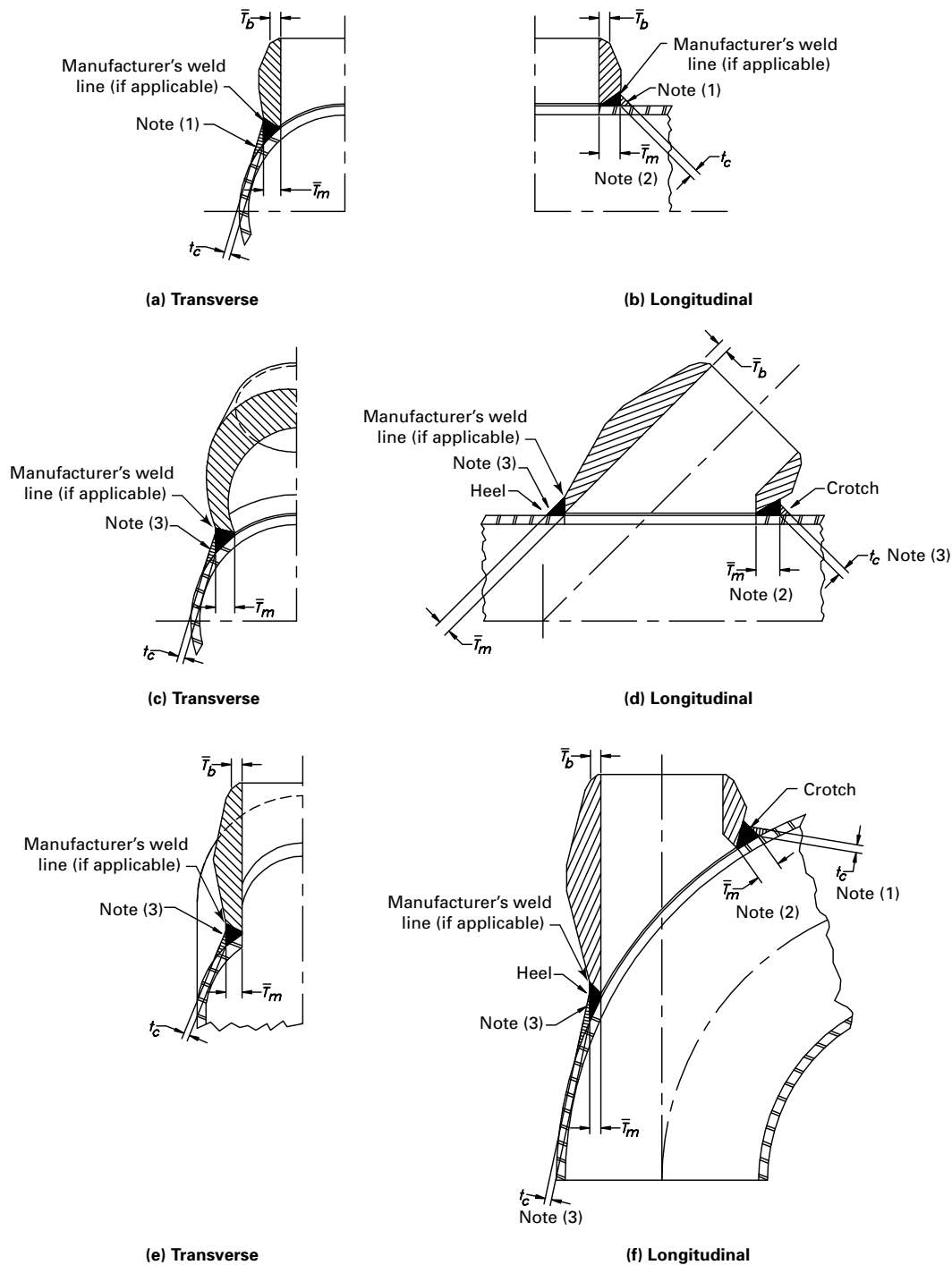
A weld defect to be repaired shall be removed to sound metal. Repair welds shall be made using a welding procedure qualified in accordance with para. 328.2, recognizing that the cavity to be repaired may differ in contour and dimensions from the original joint. Repair welds shall be made by welders or welding operators qualified in accordance with para. 328.2. Preheating and heat treatment shall be as required for the original welding. See also para. 341.3.3.

## 328.7 Attachment Welds

Structural attachments may be made by complete penetration, partial penetration, or fillet welds.

Low energy capacitor discharge welding may be used for welding temporary attachments (e.g., thermocouples) and permanent nonstructural attachments without



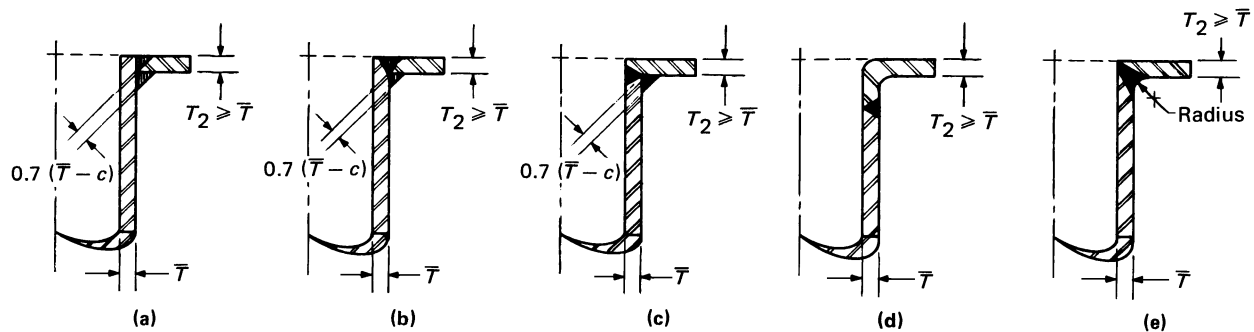
**Figure 328.5.4F Acceptable Details for Integrally Reinforced Branch Connections**

GENERAL NOTE: Welds shall be in accordance with [para. 328.5.4\(i\)](#).

NOTES:

- (1) Cover fillet weld shall provide a smooth transition to the run pipe with an equal leg fillet at the longitudinal section to an equal leg fillet, unequal (oblique) leg fillet, or groove butt joint at the transverse section (depending on branch connection size).
- (2) Heat treatment requirements shall be in accordance with [para. 331.1.3\(a\)](#).
- (3) Cover fillet weld shall provide a smooth transition to the run pipe with an equal leg fillet at the crotch in the longitudinal section to an equal leg fillet, unequal (oblique) leg fillet, or groove butt joint at the transverse section (depending on branch connection size) to nothing at the heel of the branch connection fitting in the longitudinal section.

Figure 328.5.5 Typical Fabricated Laps



GENERAL NOTE: Laps shall be machined (front and back) or trued after welding. Plate flanges in accordance with para. 304.5 or lap joint flanges in accordance with ASME B16.5 may be used. Welds may be machined to radius, as in illustration (e), if necessary to match ASME B16.5 lap joint flanges.

preheat above 10°C (50°F) or subsequent postweld heat treatment on P-No. 1 through P-No. 5B and P-No. 15E materials, provided

(a) a Welding Procedure Specification is prepared, describing the low energy capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required

(b) the energy output of the welding process is limited to 125 W-sec

(c) for P-No. 5A, P-No. 5B, and P-No. 15E materials, the maximum carbon content of the material is 0.15%

(d) after thermocouples are removed, the areas shall be visually examined for evidence of defects to be repaired

### 330 PREHEATING

#### (20) 330.1 General

The preheat requirements herein apply to all types of welding, including tack welds, repair welds, and seal welds on threaded joints.

The preheating rules in ASME B31P may be used as an alternate.

**330.1.1 Requirements.** Unless specified otherwise in the engineering design, the minimum preheat temperatures for materials of various P-Numbers are given in Table 330.1.1. The thickness intended in Table 330.1.1 is that of the nominal thickness of the thicker component [as defined in para. 331.1.3(c)]. Higher minimum preheat temperatures may be required by the WPS or by the engineering design.

**330.1.2 Unlisted Materials.** Preheat requirements for an unlisted material shall be specified in the WPS.

#### 330.1.3 Preheat Temperature Verification

(a) Preheat temperature shall be checked by use of temperature indicating crayons, thermocouple pyrometers, or other suitable means to ensure that the temperature specified in the WPS is obtained prior to and maintained during welding.

(b) Thermocouples may be temporarily attached directly to pressure-containing parts using the low energy capacitor discharge method of welding in accordance with para. 328.7.

**330.1.4 Preheat Zone.** The preheat zone shall be at or above the specified minimum temperature in all directions from the point of welding for a distance of the larger of 75 mm (3 in.) or 1.5 times the greater nominal thickness.

The base metal temperature for tack welds shall be at or above the specified minimum temperature for a distance not less than 25 mm (1 in.) in all directions from the point of welding.

#### 330.2 Specific Requirements

**330.2.1 Different P-No. Materials.** When welding two different P-No. materials, the preheat temperature shall be the higher temperature for the material being welded as shown in Table 330.1.1.

**330.2.2 Interruption of Welding.** After welding commences, the minimum preheat temperature shall be maintained until any required PWHT is performed on P-Nos. 3, 4, 5A, 5B, 6, and 15E, except when all of the following conditions are satisfied:

(a) A minimum of at least 10 mm ( $\frac{3}{8}$  in.) thickness of weld is deposited or 25% of the welding groove is filled, whichever is less (the weld shall be sufficiently supported to prevent overstressing the weld if the weldment is to be moved or otherwise loaded). Caution is advised that the

**Table 330.1.1 Preheat Temperatures**

| Base Metal P-No.<br>[Note (1)] | Base Metal Group            | Greater Material Thickness |      | Additional Limits<br>[Note (2)] | Required Minimum Temperature |                |
|--------------------------------|-----------------------------|----------------------------|------|---------------------------------|------------------------------|----------------|
|                                |                             | mm                         | in.  |                                 | °C                           | °F             |
| 1                              | Carbon steel                | ≤25                        | ≤1   | None                            | 10                           | 50             |
|                                |                             | >25                        | >1   | %C ≤ 0.30 [Note (3)]            | 10                           | 50             |
|                                |                             | >25                        | >1   | %C > 0.30 [Note (3)]            | 95                           | 200            |
| 3                              | Alloy steel, Cr ≤ 1/2%      | ≤13                        | ≤1/2 | SMTS ≤ 450 MPa (65 ksi)         | 10                           | 50             |
|                                |                             | >13                        | >1/2 | SMTS ≤ 450 MPa (65 ksi)         | 95                           | 200            |
|                                |                             | All                        | All  | SMTS > 450 MPa (65 ksi)         | 95                           | 200            |
| 4                              | Alloy steel, 1/2% < Cr ≤ 2% | All                        | All  | None                            | 120                          | 250            |
| 5A                             | Alloy steel                 | All                        | All  | SMTS ≤ 414 MPa (60 ksi)         | 150                          | 300            |
|                                |                             | All                        | All  | SMTS > 414 MPa (60 ksi)         | 200                          | 400            |
| 5B                             | Alloy steel                 | All                        | All  | SMTS ≤ 414 MPa (60 ksi)         | 150                          | 300            |
|                                |                             | All                        | All  | SMTS > 414 MPa (60 ksi)         | 200                          | 400            |
|                                |                             | >13                        | >1/2 | %Cr > 6.0 [Note (3)]            | 200                          | 400            |
| 6                              | Martensitic stainless steel | All                        | All  | None                            | 200 [Note (4)]               | 400 [Note (4)] |
| 9A                             | Nickel alloy steel          | All                        | All  | None                            | 120                          | 250            |
| 9B                             | Nickel alloy steel          | All                        | All  | None                            | 150                          | 300            |
| 10I                            | 27Cr steel                  | All                        | All  | None                            | 150 [Note (5)]               | 300 [Note (5)] |
| 15E                            | 9Cr–1Mo–V CSEF steel        | All                        | All  | None                            | 200                          | 400            |
| ...                            | All other materials         | ...                        | ...  | None                            | 10                           | 50             |

## NOTES:

(1) P-Nos. and Group Nos. from ASME BPVC, Section IX, QW/QB-422.

(2) SMTS = Specified Minimum Tensile Strength.

(3) Composition may be based on ladle or product analysis or in accordance with specification limits.

(4) Maximum interpass temperature 315°C (600°F).

(5) Maintain interpass temperature between 150°C and 230°C (300°F and 450°F).

surface condition prior to cooling should be smooth and free of sharp discontinuities.

(b) For P-Nos. 3, 4, and 5A materials, the weld is allowed to cool slowly to room temperature.

(c) For P-Nos. 5B, 6, and 15E materials, the weld is subjected to an adequate intermediate heat treatment with a controlled rate of cooling. The preheat temperature may be reduced to 95°C (200°F) (minimum) for the purpose of root examination without performing an intermediate heat treatment. Intermediate heat treatment for P-No. 5B or P-No. 15E materials may be omitted when using low-hydrogen electrodes and filler metals classified by the filler metal specification with an optional supple-

mental diffusible-hydrogen designator of H4 or lower and suitably controlled by maintenance procedures to avoid contamination by hydrogen-producing sources. The surface of the base metal prepared for welding shall be free of contaminants.

(d) After cooling and before welding is resumed, visual examination of the weld shall be performed to assure that no cracks have formed.

(e) Required preheat shall be applied before welding is resumed.

### 331 HEAT TREATMENT

#### 331.1 General

##### (20) 331.1.1 Postweld Heat Treatment Requirements

(a) PWHT shall be in accordance with the material groupings (P-Nos. and Group Nos.) and ranges in Table 331.1.1 except as provided in Table 331.1.2 and Table 331.1.3. The PWHT rules in ASME B31P may be used as an alternate. See Appendix F, para. F331.1. The P-Numbers and Group Numbers are defined in ASME BPVC, Section IX, Table QW/QB-422. (Note that the P-Nos. are also listed in Appendix A.)

(b) The PWHT to be used after production welding shall be specified in the WPS and shall be used in qualifying the welding procedure.

(c) The engineering design shall specify the examination and/or other production quality control (not less than the requirements of this Code) to ensure that the final welds are of adequate quality.

##### 331.1.2 Other Heat Treatments

(a) Heat treatment for bending and forming shall be in accordance with para. 332.4.

(b) See Table 302.3.5 for special heat treatment requirements for longitudinal or spiral (helical seam) welds in Elevated Temperature Fluid Service.

##### (20) 331.1.3 Definition of Thicknesses Governing PWHT

(a) The term *control thickness* as used in Table 331.1.1 and Table 331.1.3 is the lesser of

(1) the thickness of the weld

(2) the thickness of the materials being joined at the weld or the thickness of the pressure-containing material if the weld is attaching a nonpressure-containing material to a pressure-containing material.

(b) Thickness of the weld, which is a factor in determining the control thickness, is defined as follows:

(1) groove welds (girth and longitudinal) — the thicker of the two abutting ends after weld preparation, including I.D. machining

(2) fillet welds — the throat thickness of the weld

(3) partial penetration welds — the depth of the weld groove

(4) material repair welds — the depth of the cavity to be repaired

(5) branch welds — the dimension existing in the plane intersecting the longitudinal axes, calculated as indicated for each detail using the thickness through the weld for the details shown in Figure 328.5.4D and Figure 328.5.4F. This thickness shall be computed using the following formulas:

(-a) for Figure 328.5.4D use

$$\text{illustration (a)} = \bar{T}_b + t_c$$

$$\text{illustration (b)} = \bar{T}_h + t_c$$

$$\text{illustration (c)} = \text{greater of } \bar{T}_b + t_c \text{ or } \bar{T}_r + t_c$$

$$\text{illustration (d)} = \bar{T}_h + \bar{T}_r + t_c$$

$$\text{illustration (e)} = \bar{T}_b + t_c$$

(-b) for Figure 328.5.4F use  $\bar{T}_m + t_c$  for all illustrations

(c) The term *nominal material thickness* as used in Table 331.1.3 is the thicker of the materials being joined at the weld.

**331.1.4 Heating and Cooling.** The heating method shall provide the required metal temperature, metal temperature uniformity, and temperature control, and may include an enclosed furnace, local flame heating, electric resistance, electric induction, or exothermic chemical reaction. Above 315°C (600°F), the rate of heating and cooling shall not exceed 335°C/h (600°F/hr) divided by one-half the maximum material thickness in inches at the weld, but in no case shall the rate exceed 335°C/h (600°F/hr). See Table 331.1.1 for cooling rate requirements for P-Nos. 7, 10I, 11A, and 62 materials.

**331.1.6 Temperature Verification.** Heat treatment temperature shall be checked by thermocouple pyrometers or other suitable methods to ensure that the WPS requirements are met. See para. 328.7 for attachment of thermocouples by the low energy capacitor discharge method of welding.

(a) If used, the heat treatment furnace shall be calibrated such that the PWHT can be controlled within the required temperature range.

(b) Any required PWHT shall be as required by the qualified WPS.

(c) For welds that require PWHT in accordance with Table 331.1.1, the temperature of the material during PWHT shall be within the range specified. However, if specified by the designer, the range may be extended as permitted by Table 331.1.2, provided the lower transformation temperature of the material is not exceeded.

#### 331.2 Specific Requirements

Where warranted by experience or knowledge of service conditions, alternative methods of heat treatment or exceptions to the basic heat treatment provisions of para. 331.1 may be adopted as provided in paras. 331.2.1 and 331.2.2.

(20)

**Table 331.1.1 Postweld Heat Treatment**

| P-No. and Group No.<br>(ASME BPVC, Section IX, QW/QB-420) | Holding Temperature Range,<br>°C (°F) [Note (1)]                    | Minimum Holding Time at Temperature for<br>Control Thickness [Note (2)] |                                                                                                                       |
|-----------------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
|                                                           |                                                                     | Up to 50 mm (2 in.)                                                     | Over 50 mm (2 in.)                                                                                                    |
| P-No. 1, Group Nos. 1–3                                   | 595 to 650 (1,100 to 1,200)                                         | 1 h/25 mm (1 hr/in.);                                                   | 2 hr plus 15 min for each                                                                                             |
| P-No. 3, Group Nos. 1 and 2                               | 595 to 650 (1,100 to 1,200)                                         | 15 min min.                                                             | additional 25 mm (in.)                                                                                                |
| P-No. 4, Group Nos. 1 and 2                               | 650 to 705 (1,200 to 1,300)                                         |                                                                         | over 50 mm (2 in.)                                                                                                    |
| P-No. 5A, Group No. 1                                     | 675 to 760 (1,250 to 1,400)                                         |                                                                         |                                                                                                                       |
| P-No. 5B, Group No. 1                                     | 675 to 760 (1,250 to 1,400)                                         |                                                                         |                                                                                                                       |
| P-No. 6, Group Nos. 1–3                                   | 760 to 800 (1,400 to 1,475)                                         |                                                                         |                                                                                                                       |
| P-No. 7, Group Nos. 1 and 2 [Note (3)]                    | 730 to 775 (1,350 to 1,425)                                         |                                                                         |                                                                                                                       |
| P-No. 8, Group Nos. 1–4                                   | PWHT not required unless required by WPS                            |                                                                         |                                                                                                                       |
| P-No. 9A, Group No. 1                                     | 595 to 650 (1,100 to 1,200)                                         |                                                                         |                                                                                                                       |
| P-No. 9B, Group No. 1                                     | 595 to 650 (1,100 to 1,200)                                         |                                                                         |                                                                                                                       |
| P-No. 10H, Group No. 1                                    | PWHT not required unless required by<br>WPS. If done, see Note (4). |                                                                         |                                                                                                                       |
| P-No. 10I, Group No. 1 [Note (3)]                         | 730 to 815 (1,350 to 1,500)                                         |                                                                         |                                                                                                                       |
| P-No. 11A                                                 | 550 to 585 (1,025 to 1,085) [Note (5)]                              |                                                                         |                                                                                                                       |
| P-No. 15E, Group No. 1                                    | 705 to 775 (1,300 to 1,425)<br>[Notes (6) and (7)]                  | 1 h/25 mm (1 hr/in.);<br>30 min min.                                    | 1 h/25 mm (1 hr/in.) up<br>to 125 mm (5 in.) plus<br>15 min for each<br>additional 25 mm (in.)<br>over 125 mm (5 in.) |
| P-No. 62                                                  | 540 to 595 (1,000 to 1,100)                                         | ...                                                                     | See Note (8)                                                                                                          |
| All other materials                                       | PWHT as required by WPS                                             | In accordance with WPS                                                  | In accordance with WPS                                                                                                |

GENERAL NOTE: The exemptions for mandatory PWHT are defined in Table 331.1.3.

NOTES:

- (1) The holding temperature range is further defined in para. 331.1.6(c) and Table 331.1.2.
- (2) The control thickness is defined in para. 331.1.3.
- (3) Cooling rate shall not be greater than 55°C (100°F) per hour in the range above 650°C (1,200°F), after which the cooling rate shall be sufficiently rapid to prevent embrittlement.
- (4) If PWHT is performed after welding, it shall be within the following temperature ranges for the specific alloy, followed by rapid cooling:
  - Alloys S31803 and S32205 — 1020°C to 1100°C (1,870°F to 2,010°F)
  - Alloy S32550 — 1040°C to 1120°C (1,900°F to 2,050°F)
  - Alloy S32750 — 1025°C to 1125°C (1,880°F to 2,060°F)
  - All others — 980°C to 1040°C (1,800°F to 1,900°F)
- (5) Cooling rate shall be >165°C (300°F)/h to 315°C (600°F)/h.
- (6) The minimum PWHT holding temperature may be 675°C (1,250°F) for nominal material thicknesses [see para. 331.1.3(c)] ≤13 mm (½ in.).
- (7) The Ni + Mn content of the filler metal shall not exceed 1.2% unless specified by the designer, in which case the maximum temperature to be reached during PWHT shall be the lower transformation temperature of the filler metal, as determined by analysis and calculation or by test, but not exceeding 800°C (1,470°F). If the 800°C (1,470°F) limit was not exceeded but the lower transformation temperature of the filler metal was exceeded or if the composition of the filler metal is unknown, the weld must be removed and replaced. It shall then be rewelded with compliant filler metal and subjected to a compliant PWHT. If the 800°C (1,470°F) limit was exceeded, the weld and the entire area affected by the PWHT will be removed and, if reused, shall be renormalized and tempered prior to reinstallation. The lower transformation temperature is the steady-state temperature at which the austenite phase transformation occurs.
- (8) Heat treat within 14 days after welding. Hold time shall be increased by 1.2 h for each 25 mm (1 in.) over 25 mm (1 in.) thickness. Cool to 425°C (800°F) at a rate ≤280°C (500°F)/h.

**Table 331.1.2 Alternate Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels, P-Nos. 1 and 3**

| Decrease in Specified Minimum Temperature, °C (°F) | Minimum Holding Time at Decreased Temperature, h [Note (1)] |
|----------------------------------------------------|-------------------------------------------------------------|
| 30 (50)                                            | 2                                                           |
| 55 (100)                                           | 4                                                           |
| 85 (150) [Note (2)]                                | 10                                                          |
| 110 (200) [Note (2)]                               | 20                                                          |

NOTES:

- (1) Times shown apply to thicknesses ≤25 mm (1 in.). Add 15 min/25 mm (15 min/in.) of thickness for control thicknesses >25 mm (1 in.) (see para. 331.1.3).
- (2) A decrease >55°C (100°F) below the minimum specified temperature is allowable only for P-No. 1, Group Nos. 1 and 2 materials.

**331.2.1 Alternative Heat Treatment.** Normalizing, or normalizing and tempering, or annealing may be applied in lieu of the required heat treatment after welding, bending, or forming, provided that the mechanical properties of any affected weld and base metal meet specification requirements after such treatment and that the substitution is approved by the designer.

**331.2.2 Exceptions to Basic Requirements.** As indicated in para. 331, the basic practices therein may require modification to suit service conditions in some cases. In such cases, the designer may specify more-stringent requirements in the engineering design, including heat treatment and hardness limitations for lesser thickness, or may specify less stringent heat treatment and hardness requirements, including none.

When provisions less stringent than those in para. 331 are specified, the designer must demonstrate to the owner's satisfaction the adequacy of those provisions by comparable service experience, considering service temperature and its effects, frequency and intensity of thermal cycling, flexibility stress levels, probability of brittle failure, and other pertinent factors. In addition, appropriate tests shall be conducted, including WPS qualification tests.

### 331.2.3 Dissimilar Materials

(a) Heat treatment of welded joints between dissimilar ferritic metals or between ferritic metals using dissimilar ferritic filler metal shall be at the higher of the temperature ranges in Table 331.1.1 for the materials in the joint. This may require the use of material transition joint designs.

(b) Heat treatment of welded joints including both ferritic and austenitic components and filler metals shall be as required for the ferritic material or materials unless otherwise specified in the engineering design.

**331.2.4 Delayed Heat Treatment.** If a weldment is allowed to cool prior to heat treatment, the rate of cooling shall be controlled or other means shall be used to prevent detrimental effects in the piping.

**331.2.5 Partial Heat Treatment.** When an entire piping assembly to be heat treated cannot be fitted into the furnace, it is permissible to heat treat in more than one heat, provided there is at least 300 mm (1 ft) overlap between successive heats, and that parts of the assembly outside the furnace are protected from harmful temperature gradients. This method may not be used for austenitizing heat treatments for ferritic materials.

**331.2.6 Local Heat Treatment.** Welds may be locally postweld heat treated by heating a circumferential band around the entire component with the weld located in the center of the band. The width of the band heated to the specified temperature range shall be at least three times the wall thickness at the weld of the thickest part being joined. For nozzle and attachment welds, the width of the band heated to the specified temperature range shall extend beyond the nozzle weld or attachment weld on each side at least two times the run pipe thickness, and shall extend completely around the run pipe. Guidance for the placement of thermocouples on circumferential butt welds is provided in AWS D10.10, Sections 5, 6, and 8. Special consideration shall be given to the placement of thermocouples when heating welds adjacent to large heat sinks such as valves or fittings, or when joining parts of different thicknesses. No part of the materials subjected to the heat source shall exceed the lower transformation temperature of the material except as permitted by para. 331.2.1. Particular care must be exercised when the applicable PWHT temperature is close to the material's lower transformation temperature, such as for P-No. 15E materials or when materials of different P-Nos. are being joined. This method may not be used for austenitizing heat treatments.

## 332 BENDING AND FORMING

### 332.1 General

Pipe may be bent and components may be formed by any hot or cold method that is suitable for the material, the fluid service, and the severity of the bending or forming process.<sup>1</sup> The finished surface shall be free of cracks and substantially free from buckling. Thickness after bending or forming shall be not less than that required by the design.

<sup>1</sup>For pipe bending, PFI Standard ES-24, Pipe Bending Methods, Tolerances, Process and Material Requirements, may be used as a guide.

**Table 331.1.3 Exemptions to Mandatory Postweld Heat Treatment**

| P-No. and Group No.<br>(ASME BPVC, Section IX,<br>QW/QB-420) [Note (1)] | Control Thickness,<br>mm (in.) [Note (2)]                                                                  | Type of Weld                                            | Additional Limitations Required for<br>Exemption From PWHT [Notes (3)–(5)]                                                                                                                                                                                                                                                                                         |
|-------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| P-No. 1, all Group Nos.                                                 | All                                                                                                        | All                                                     | A preheat of 95°C (200°F) is applied prior to welding on any nominal material thickness >25 mm (1 in.)<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)]                                                                                                                                                 |
| P-No. 3, Group Nos. 1 and 2                                             | ≤16 mm ( $\frac{5}{8}$ in.)                                                                                | All                                                     | A preheat of 95°C (200°F) is applied prior to welding on any nominal material thickness >13 mm ( $\frac{1}{2}$ in.)<br>A specified carbon content of the base materials ≤0.25%<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)]                                                                         |
| P-No. 4, Group No. 1                                                    | ≤16 mm ( $\frac{5}{8}$ in.)                                                                                | Groove                                                  | Mandatory preheat has been applied<br>Specified carbon content of the base materials ≤0.15%<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)]                                                                                                                                                            |
|                                                                         | ≤16 mm ( $\frac{5}{8}$ in.) except the thickness of a socket weld fitting or flange need not be considered | Socket and fillet welds                                 | Mandatory preheat has been applied<br>Throat thickness of the fillet weld or the socket weld ≤13 mm ( $\frac{1}{2}$ in.)<br>Specified carbon content of the pipe material ≤0.15%<br>Nominal material thickness of the pipe ≤16 mm ( $\frac{5}{8}$ in.)<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)] |
|                                                                         | ≤16 mm ( $\frac{5}{8}$ in.)                                                                                | Seal welds and non-load-carrying attachments [Note (7)] | Mandatory preheat has been applied<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)]                                                                                                                                                                                                                     |
| P-No. 5A, Group No. 1                                                   | ≤16 mm ( $\frac{5}{8}$ in.)                                                                                | Groove                                                  | Mandatory preheat has been applied<br>Specified carbon content of the base materials ≤0.15%<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)]                                                                                                                                                            |
|                                                                         | ≤16 mm ( $\frac{5}{8}$ in.) except the thickness of a socket weld fitting or flange need not be considered | Socket and fillet welds                                 | Mandatory preheat has been applied<br>Throat thickness of the fillet weld or the socket weld ≤13 mm ( $\frac{1}{2}$ in.)<br>Specified carbon content of the pipe material ≤0.15%<br>Nominal thickness of the pipe ≤5 mm ( $\frac{3}{16}$ in.)<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)]          |
|                                                                         | ≤16 mm ( $\frac{5}{8}$ in.)                                                                                | Seal welds and non-load-carrying attachments [Note (7)] | Mandatory preheat has been applied<br>Multiple layer welds are used when the nominal material thickness >5 mm ( $\frac{3}{16}$ in.) [Note (6)]                                                                                                                                                                                                                     |
| P-No. 5B, Group No. 1                                                   | ...                                                                                                        | ...                                                     | No exemptions from PWHT                                                                                                                                                                                                                                                                                                                                            |
| P-No. 6, Group Nos. 1–3                                                 | All                                                                                                        | All                                                     | Specified carbon content of the base materials ≤0.08%<br>Nominal material thickness ≤10 mm ( $\frac{3}{8}$ in.)<br>Weld filler metal is A-No. 8, A-No. 9, or F-No. 43 composition [Note (8)]                                                                                                                                                                       |



**Table 331.1.3 Exemptions to Mandatory Postweld Heat Treatment (Cont'd)**

| P-No. and Group No.<br>(ASME BPVC, Section IX,<br>QW/QB-420) [Note (1)] | Control Thickness,<br>mm (in.) [Note (2)] | Type of Weld | Additional Limitations Required for<br>Exemption From PWHT [Notes (3)–(5)]                                                                                                                         |
|-------------------------------------------------------------------------|-------------------------------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| P-No. 7, Group No. 1                                                    | All                                       | All          | Specified carbon content of the base materials<br>≤0.08%<br>Nominal material thickness ≤10 mm ( $\frac{3}{8}$ in.)<br>Weld filler metal is A-No. 8, A-No. 9, or<br>F-No. 43 composition [Note (8)] |
| P-No. 7, Group No. 2                                                    | ...                                       | ...          | No exemptions from PWHT                                                                                                                                                                            |
| P-No. 8, all Group Nos.                                                 | All                                       | All          | PWHT neither required nor prohibited                                                                                                                                                               |
| P-No. 9A, Group No. 1                                                   | All                                       | All          | Specified carbon content of the pipe material<br>≤0.15%<br>Nominal material thickness ≤13 mm ( $\frac{1}{2}$ in.)<br>Mandatory preheat has been applied                                            |
| P-No. 9B, Group No. 1                                                   | All                                       | All          | Nominal material thickness ≤16 mm ( $\frac{5}{8}$ in.) and<br>the WPS has been qualified using a material<br>of equal or greater thickness than used in the<br>production weld                     |
| P-No. 10H, Group No. 1                                                  | All                                       | All          | PWHT neither required nor prohibited                                                                                                                                                               |
| P-No. 10I, Group No. 1                                                  | All                                       | All          | PWHT neither required nor prohibited for<br>nominal material thickness ≤13 mm ( $\frac{1}{2}$ in.)                                                                                                 |
| P-No. 11A                                                               | ≤50 mm (2 in.)                            | All          | ...                                                                                                                                                                                                |
| P-No. 15E                                                               | ...                                       | ...          | No exemptions from PWHT                                                                                                                                                                            |
| P-No. 62                                                                | ...                                       | ...          | No exemptions from PWHT                                                                                                                                                                            |

## NOTES:

- (1) If differences with the P-No. listed in [Appendix A](#) are found, the P-No. listed in ASME BPVC, Section IX, Table QW/QB-422 applies.
- (2) The control thickness is defined in [para. 331.1.3](#).
- (3) The nominal material thickness is defined in [para. 331.1.3\(c\)](#).
- (4) No exemptions are permitted for PWHTs required by the designer or the WPS.
- (5) Additional exemptions for welds made in accordance with [para. 328.7](#) may be taken for the materials addressed.
- (6) Single-layer or single-pass welds may be exempted from PWHT, provided the WPS has been qualified using single-pass welds with ±10% heat input and that all other conditions for exemption are met.
- (7) Non-load-carrying attachments are defined as items where no pressure loads or significant mechanical loads are transmitted through the attachment to the pipe or pressure-containing material.
- (8) The A-Nos. and the F-Nos. are found in ASME BPVC, Section IX, Tables QW-442 and QW-432, respectively.

### 332.2 Bending

**332.2.1 Bend Flattening.** Flattening of a bend, the difference between maximum and minimum diameters at any cross section, shall not exceed 8% of nominal outside diameter for internal pressure and 3% for external pressure. Removal of metal shall not be used to achieve these requirements.

#### 332.2.2 Bending Temperature

(a) Cold bending of ferritic materials shall be done at a temperature below the transformation range.

(b) Hot bending shall be done at a temperature above the transformation range and in any case within a temperature range consistent with the material and the intended service.

**332.2.3 Corrugated and Other Bends.** Dimensions and configuration shall conform to the design qualified in accordance with [para. 306.2.2](#).

### 332.3 Forming

The temperature range for forming shall be consistent with material, intended service, and specified heat treatment.

### (20) 332.4 Required Heat Treatment

Heat treatment shall be performed in accordance with [para. 331.1.1](#) when required by [para. 332.4.1](#) or [332.4.2](#). The process and temperature control methods described in ASME B31P are recommended.

**332.4.1 Hot Bending and Forming.** After hot bending and forming, heat treatment is required for P-Nos. 3, 4, 5, 6, and 10A materials in all thicknesses. Durations and temperatures shall be in accordance with [para. 331](#).

**332.4.2 Cold Bending and Forming.** After cold bending and forming, heat treatment is required (for all thicknesses, and with temperature and duration as given in [Table 331.1.1](#)) when any of the following conditions exist:

(a) for P-Nos. 1 through 6 materials, where the maximum calculated fiber elongation after bending or forming exceeds 50% of specified basic minimum elongation (in the direction of severest forming) for the applicable specification, grade, and thickness. This requirement may be waived if it can be demonstrated that the selection of pipe and the choice of bending or forming process provide assurance that, in the finished condition, the most severely strained material retains at least 10% elongation.

(b) for any material requiring impact testing, where the maximum calculated fiber elongation after bending or forming will exceed 5%.

(c) when specified in the engineering design.

## 333 BRAZING AND SOLDERING

### 333.1 Qualification

**333.1.1 Brazing Qualification.** The qualification of brazing procedures, brazers, and brazing operators shall be in accordance with [para. 328.2](#). For Category D Fluid Service at design temperature not over 93°C (200°F), such qualification is not required unless specified in the engineering design.

**333.1.2 Soldering Qualification.** The qualification of solderers shall be in accordance with the requirements of ASTM B828, Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings.

### 333.2 Brazing and Soldering Materials

**333.2.1 Brazing Filler Metal and Flux.** Brazing filler metal and flux shall comply with AWS A5.8, Specification for Filler Metals for Brazing and Braze Welding, and AWS A5.31, Specification for Fluxes for Brazing and Braze Welding, respectively, or other filler metals and fluxes that have been qualified in accordance with ASME BPVC, Section IX.

**333.2.2 Soldering Filler Metal and Flux.** Soldering filler metal and flux shall comply with ASTM B32, Standard Specification for Solder Metal, and ASTM B813, Standard Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube, respectively.

### 333.3 Preparation and Cleaning

**333.3.1 Surface Preparation.** The surfaces to be brazed or soldered shall be clean and free from grease, oxides, paint, scale, and dirt of any kind. A suitable chemical or mechanical cleaning method shall be used if necessary to provide a clean wettable surface.

**333.3.2 Joint Clearance.** The clearance between surfaces to be joined by soldering or brazing shall be no larger than necessary to allow complete capillary distribution of the filler metal.

**333.3.3 Flux Removal.** Residual flux shall be removed.

## 335 ASSEMBLY AND ERECTION

### 335.1 Alignment

(a) *Piping Distortions.* Any distortion of piping to bring it into alignment for joint assembly that introduces a detrimental strain in equipment or piping components is prohibited.

(b) *Cold Spring.* Before assembling any joints to be cold sprung, guides, supports, and anchors shall be examined for errors that might interfere with desired movement or lead to undesired movement. The gap or overlap of piping

prior to assembly shall be checked against the drawing and corrected if necessary. Heating shall not be used to help in closing the gap because it defeats the purpose of cold springing.

(c) *Flanged Joints.* Unless otherwise specified in the engineering design, flanged joints shall be aligned as described in (1) or (2), and (3).

(1) Before bolting, mating gasket contact surfaces shall be aligned to each other within 1 mm in 200 mm ( $\frac{1}{16}$  in./ft), measured across any diameter.

(2) The flanged joint shall be capable of being bolted such that the gasket contact surfaces bear uniformly on the gasket.

(3) Flange bolt holes shall be aligned within 3 mm ( $\frac{1}{8}$  in.) maximum offset.

### 335.2 Flanged Joints

**335.2.1 Preparation for Assembly.** Any damage to the gasket seating surface that would prevent gasket seating shall be repaired, or the flange shall be replaced.

#### 335.2.2 Bolting Torque

(a) In assembling flanged joints, the gasket shall be uniformly compressed to the proper design loading.

(b) Special care shall be used in assembling flanged joints in which the flanges have widely differing mechanical properties. Tightening to a predetermined torque is recommended.

**335.2.3 Bolt Length.** Bolts shall extend through their nuts such that there is complete thread engagement for the full depth of the nut.

**335.2.4 Gaskets.** No more than one gasket shall be used between contact faces in assembling a flanged joint.

**335.2.5 Flanged Joint Assembly.** Assembly requirements for bolted flanged joints and flanged joint assembler qualifications shall be considered in the engineering design. For guidance, see ASME PCC-1, Guidelines for Pressure Boundary Bolted Flange Joint Assembly, and ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix S.

### 335.3 Threaded Joints

**335.3.1 Thread Compound or Lubricant.** Any compound or lubricant used on threads shall be suitable for the service temperatures and shall not react unfavorably with either the service fluid or the piping material.

**335.3.2 Joints for Seal Welding.** A threaded joint to be seal welded shall be made up without thread compound. A joint containing thread compound that leaks during leak

testing may be seal welded in accordance with [para. 328.5.3](#), provided all compound is removed from exposed threads.

**335.3.3 Straight Threaded Joints.** Typical joints using straight threads, with sealing at a surface other than the threads, are shown in [Figure 335.3.3](#), illustrations (a), (b), and (c). Care shall be taken to avoid distorting the seat when incorporating such joints into piping assemblies by welding, brazing, or bonding.

### 335.4 Tubing Joints

**335.4.1 Flared Tubing Joints.** The sealing surface of the flare shall be examined for imperfections before assembly and any flare having imperfections shall be rejected.

**335.4.2 Flareless and Compression Tubing Joints.** Where the manufacturer's instructions call for a specified number of turns of the nut, these shall be counted from the point at which the nut becomes finger tight.

### 335.5 Caulked Joints

Caulked joints shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure adequate engagement of joint members.

### 335.6 Expanded Joints and Special Joints

**335.6.1 General.** Expanded joints and special joints (as defined in [para. 318](#)) shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure adequate engagement of joint members.

**335.6.2 Packed Joints.** Where a packed joint is used to absorb thermal expansion, proper clearance shall be provided at the bottom of the socket to permit this movement.

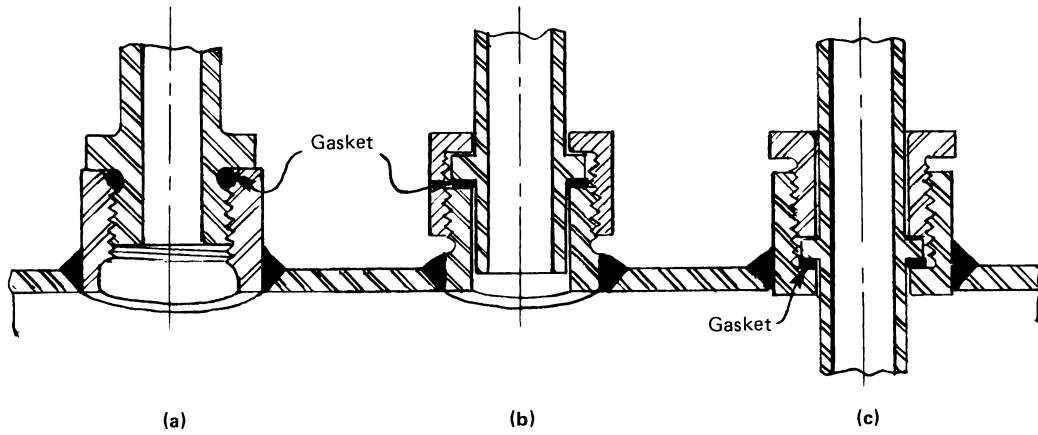
### 335.9 Cleaning of Piping

This Code does not prescribe mandatory procedures for flushing and cleaning. However, for potential hazards that may result from performing such procedures refer to [Appendix F](#), [para. F335.9](#) for precautionary considerations.

### 335.10 Identification of Piping

See [Appendix F](#), [para. F335.10](#).

**Figure 335.3.3 Typical Threaded Joints Using Straight Threads**



GENERAL NOTE: Threads are ASME B1.1 straight threads.

## Chapter VI

# Inspection, Examination, and Testing

### 340 INSPECTION

#### 340.1 General

This Code distinguishes between examination (see [para. 341](#)) and inspection. Inspection applies to functions performed for the owner by the owner's Inspector or the Inspector's delegates. References in this Code to the "Inspector" are to the owner's Inspector or the Inspector's delegates.

#### 340.2 Responsibility for Inspection

It is the owner's responsibility, exercised through the owner's Inspector, to verify that all required examinations and testing have been completed and to inspect the piping to the extent necessary to be satisfied that it conforms to all applicable examination requirements of the Code and of the engineering design.

#### 340.3 Rights of the Owner's Inspector

The owner's Inspector and the Inspector's delegates shall have access to any place where work concerned with the piping installation is being performed. This includes manufacture, fabrication, heat treatment, assembly, erection, examination, and testing of the piping. They shall have the right to audit any examination, to inspect the piping using any examination method specified by the engineering design, and to review all certifications and records necessary to satisfy the owner's responsibility stated in [para. 340.2](#).

#### 340.4 Qualifications of the Owner's Inspector

(a) The owner's Inspector shall be designated by the owner and shall be the owner, an employee of the owner, an employee of an engineering or scientific organization, or the employee of a recognized insurance or inspection company acting as the owner's agent. The owner's Inspector shall not represent nor be an employee of the piping manufacturer, fabricator, or erector unless the owner is also the manufacturer, fabricator, or erector.

(b) The owner's Inspector shall meet one of the following requirements:

(1) have at least 10 yr of experience in the design, fabrication, or examination of industrial pressure piping. Each 20% of satisfactorily completed work toward an ac-

credited engineering degree shall be considered equivalent to 1 yr of experience, up to 5 yr total.

(2) have a professional engineering registration or nationally recognized equivalent with at least 5 yr of experience in the design, fabrication, or examination of industrial pressure piping.

(3) be a certified welding inspector or a senior certified welding inspector as defined in AWS QC1, Specification for AWS Certification of Welding Inspectors, or nationally recognized equivalent with at least 5 yr of experience in the design, fabrication, or examination of industrial pressure piping.

(4) be an authorized piping inspector as defined in API 570, Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems, with at least 5 yr of experience in the design, fabrication, or examination of industrial pressure piping.

(c) In delegating performance of inspection, the owner's Inspector is responsible for determining that a person to whom an inspection function is delegated is qualified to perform that function.

### 341 EXAMINATION

#### 341.1 General

Examination applies to quality control functions performed by the manufacturer (for components only), fabricator, or erector. Reference in this Code to an examiner is to a person who performs quality control examinations.

#### 341.2 Responsibility for Examination

Inspection does not relieve the manufacturer, the fabricator, or the erector of the responsibility for

(a) providing materials, components, and workmanship in accordance with the requirements of this Code and of the engineering design [see [para. 300\(b\)\(3\)](#)]

(b) performing all required examinations

(c) preparing suitable records of examinations and tests for the Inspector's use

#### 341.3 Examination Requirements

**341.3.1 General.** Prior to initial operation, each piping installation, including components and workmanship, shall be examined in accordance with the applicable

requirements of [para. 341](#). The type and extent of any additional examination required by the engineering design, and the acceptance criteria to be applied, shall be specified. Joints not included in examinations required by [para. 341.4](#) or by the engineering design are accepted if they pass the leak test required by [para. 345](#).

(a) For P-Nos. 3, 4, 5A, 5B, 5C, and 15E materials, examinations shall be performed after completion of heat treatment. However, examinations need not be repeated on welds or portions of welds that are subjected to additional heat treatments and have not been repaired by welding.

(b) For a welded branch connection, the examination of, and any necessary repairs to, the pressure-containing weld shall be completed before any reinforcing pad or saddle is added.

**341.3.2 Acceptance Criteria.** Acceptance criteria shall be as stated in the engineering design and shall at least meet the applicable requirements stated below.

(a) *Welds.* See [Figure 341.3.2](#) for typical weld imperfections.

(1) For radiography and visual, see [Table 341.3.2](#).

(2) For magnetic particle, see [para. 344.3.2](#).

(3) For liquid penetrant, see [para. 344.4.2](#).

(4) For ultrasonic, see [para. 344.6.2](#).

(b) *Castings.* Acceptance criteria for castings are specified in [para. 302.3.3](#).

**341.3.3 Defective Components and Workmanship.** Defects (imperfections of a type or magnitude not acceptable by the criteria specified in [para. 341.3.2](#)) shall be repaired, or the defective item or work shall be replaced. Discontinuities detected outside the area required to be examined during weld joint examinations should be evaluated and resolved in a manner acceptable to the owner and designer.

Examination shall be as follows:

(a) When the defective item or work is repaired, the repaired portion of the item or work shall be examined. The examination shall use the same methods and acceptance criteria employed for the original examination. See also [para. 341.3.1\(a\)](#).

(b) When the defective item or work is replaced, the new item or work used to replace the defective item or work shall be examined. The examination shall use any method and applicable acceptance criteria that meet the requirements for the original examination. See also [para. 341.3.1\(a\)](#).

**341.3.4 Progressive Sampling for Examination.** When required spot or random examination reveals a defect, then

(a) two additional samples of the same kind (if welded or bonded joints, by the same welder, bonder, or operator) from the original designated lot shall be given the same type of examination

(b) if the items examined as required by (a) above are acceptable, the defective item shall be repaired or replaced and reexamined as specified in [para. 341.3.3](#), and all items represented by these two additional samples shall be accepted, but

(c) if any of the items examined as required by (a) above reveals a defect, two further samples of the same kind shall be examined for each defective item found by that sampling

(d) if all the items examined as required by (c) above are acceptable, the defective item(s) shall be repaired or replaced and reexamined as specified in [para. 341.3.3](#), and all items represented by the additional sampling shall be accepted, but

(e) if any of the items examined as required by (c) above reveals a defect, all items represented by the progressive sampling shall be either

(1) repaired or replaced and reexamined as required, or

(2) fully examined and repaired or replaced as necessary, and reexamined as necessary to meet the requirements of this Code

(f) If any of the defective items are repaired or replaced, reexamined, and a defect is again detected in the repaired or replaced item, continued progressive sampling in accordance with (a), (c), and (e) is not required based on the new defects found. The defective item(s) shall be repaired or replaced and reexamined until acceptance as specified in [para. 341.3.3](#). Spot or random examination (whichever is applicable) is then performed on the remaining unexamined joints.

## 341.4 Extent of Required Examination

**341.4.1 Examination — Normal Fluid Service.** Piping in Normal Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in [para. 341.3.2](#) and in [Table 341.3.2](#), for Normal Fluid Service unless otherwise specified.

(a) *Visual Examination.* At least the following shall be examined in accordance with [para. 344.2](#):

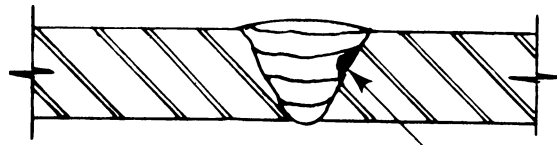
(1) sufficient materials and components, selected at random, to satisfy the examiner that they conform to specifications and are free from defects.

(2) at least 5% of fabrication, as defined in [para. 300.2](#).

(3) 100% of all completed welds, except those in components made in accordance with a listed standard. See [para. 341.5.1\(a\)](#) for examination of longitudinal welds required to have a joint factor,  $E_j$ , of 0.90.

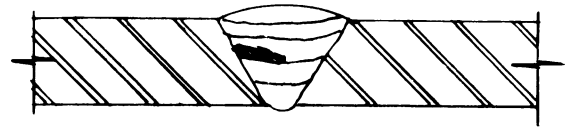
(4) random examination of the assembly of threaded, bolted, and other joints to satisfy the examiner that they conform to the applicable requirements of [para. 335](#). When pneumatic testing is to be performed, all threaded, bolted, and other mechanical joints shall be examined.

**Figure 341.3.2 Typical Weld Imperfections**

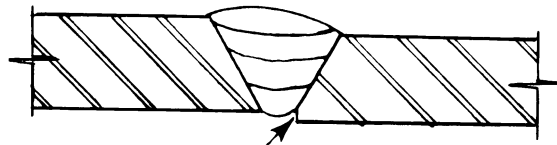


Lack of fusion between weld bead and base metal

**(a) Side Wall Lack of Fusion**

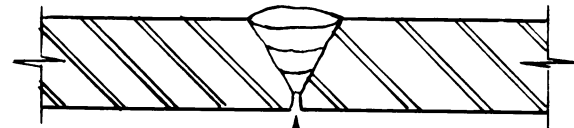


**(b) Lack of Fusion Between Adjacent Passes**



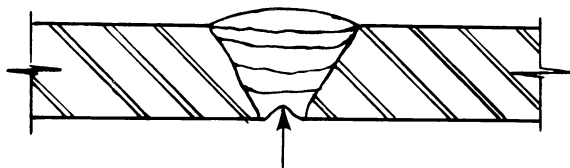
Incomplete filling at root on one side only

**(c) Incomplete Penetration due to Internal Misalignment**



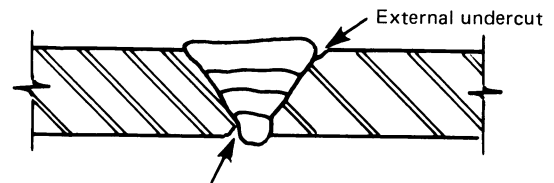
Incomplete filling at root

**(d) Incomplete Penetration of Weld Groove**



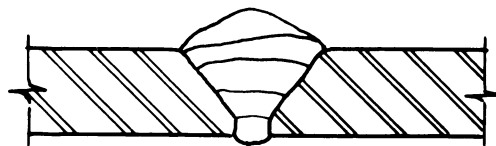
Root bead fused to both inside surfaces but center of root slightly below inside surface of pipe (not incomplete penetration)

**(e) Concave Root Surface (Suck-Up)**



Internal undercut

**(f) Undercut**



**(g) Excess External Reinforcement**



**Table 341.3.2 Acceptance Criteria for Welds — Visual and Radiographic Examination**

| Criteria (A to M) for Types of Welds and for Service Conditions [Note (1)] |                                     |                        |                                                             |                                     |                        |                              |                                     |                        |                                   | Weld Imperfection                                     | Examination Methods |             |
|----------------------------------------------------------------------------|-------------------------------------|------------------------|-------------------------------------------------------------|-------------------------------------|------------------------|------------------------------|-------------------------------------|------------------------|-----------------------------------|-------------------------------------------------------|---------------------|-------------|
| Normal and Category M Fluid Service                                        |                                     |                        | Severe Cyclic Conditions                                    |                                     |                        | Category D Fluid Service     |                                     |                        |                                   |                                                       | Visual              | Radiography |
| Girth, Miter Groove, and Branch Connection Welds [Note (2)]                | Longitudinal Groove Weld [Note (3)] | Fillet Weld [Note (4)] | Girth, Miter Groove, and Branch Connection Welds [Note (2)] | Longitudinal Groove Weld [Note (3)] | Fillet Weld [Note (4)] | Girth and Miter Groove Welds | Longitudinal Groove Weld [Note (3)] | Fillet Weld [Note (4)] | Branch Connection Weld [Note (2)] |                                                       |                     |             |
| A                                                                          | A                                   | A                      | A                                                           | A                                   | A                      | A                            | A                                   | A                      | A                                 | Crack                                                 | ✓                   | ✓           |
| A                                                                          | A                                   | A                      | A                                                           | A                                   | A                      | C                            | A                                   | N/A                    | A                                 | Lack of fusion                                        | ✓                   | ✓           |
| B                                                                          | A                                   | N/A                    | A                                                           | A                                   | N/A                    | C                            | A                                   | N/A                    | B                                 | Incomplete penetration                                | ✓                   | ✓           |
| E                                                                          | E                                   | N/A                    | D                                                           | D                                   | N/A                    | N/A                          | N/A                                 | N/A                    | N/A                               | Rounded Indications                                   | ...                 | ✓           |
| G                                                                          | G                                   | N/A                    | F                                                           | F                                   | N/A                    | N/A                          | N/A                                 | N/A                    | N/A                               | Linear indications                                    | ...                 | ✓           |
| H                                                                          | A                                   | H                      | A                                                           | A                                   | A                      | I                            | A                                   | H                      | H                                 | Undercutting                                          | ✓                   | ✓           |
| A                                                                          | A                                   | A                      | A                                                           | A                                   | A                      | A                            | A                                   | A                      | A                                 | Surface porosity or exposed slag inclusion [Note (5)] | ✓                   | ...         |
| N/A                                                                        | N/A                                 | N/A                    | J                                                           | J                                   | J                      | N/A                          | N/A                                 | N/A                    | N/A                               | Surface finish                                        | ✓                   | ...         |
| K                                                                          | K                                   | N/A                    | K                                                           | K                                   | N/A                    | K                            | K                                   | N/A                    | K                                 | Concave surface, concave root, or burn-through        | ✓                   | ✓           |
| L                                                                          | L                                   | L                      | L                                                           | L                                   | L                      | M                            | M                                   | M                      | M                                 | Weld reinforcement or internal protrusion             | ✓                   | ...         |

**GENERAL NOTES:**

- (a) Weld imperfections are evaluated by one or more of the types of examination methods given, as specified in paras. 341.4.1, 341.4.2, 341.4.3, and M341.4, or by the engineering design.
- (b) "N/A" indicates the Code does not establish acceptance criteria or does not require evaluation of this kind of imperfection for this type of weld.
- (c) Check (✓) indicates examination method generally used for evaluating this kind of weld imperfection.
- (d) Ellipsis (...) indicates examination method not generally used for evaluating this kind of weld imperfection.

**NOTES:**

- (1) Criteria given are for required examination. More-stringent criteria may be specified in the engineering design. See also paras. 341.5 and 341.5.3.
- (2) Branch connection weld includes pressure containing welds in branches and fabricated laps.
- (3) Longitudinal groove weld includes straight and spiral (helical) seam. Criteria are not intended to apply to welds made in accordance with a standard listed in Table A-1, Table A-1M, or Table 326.1. Alternative Leak Test requires examination of these welds; see para. 345.9.
- (4) Fillet weld includes socket and seal welds, and attachment welds for slip-on flanges, branch reinforcement, and supports.
- (5) These imperfections are evaluated only for welds  $\leq 5$  mm ( $\frac{3}{16}$  in.) in nominal thickness.

**Criterion Value Notes for Table 341.3.2**

| Criterion |                                                                                                                                                                                                                                                                        | Acceptable Value Limits [Note (1)]                                                                                                                               |                               |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| Symbol    | Measure                                                                                                                                                                                                                                                                |                                                                                                                                                                  |                               |
| A         | Extent of imperfection                                                                                                                                                                                                                                                 | Zero (no evident imperfection)                                                                                                                                   |                               |
| B         | Cumulative length of incomplete penetration                                                                                                                                                                                                                            | $\leq 38$ mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less                                                          |                               |
| C         | Cumulative length of lack of fusion and incomplete penetration                                                                                                                                                                                                         | $\leq 38$ mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less                                                          |                               |
| D         | Size and distribution of rounded indications                                                                                                                                                                                                                           | See ASME BPVC, Section VIII, Division 1, Appendix 4 [Note (2)]                                                                                                   |                               |
| E         | Size and distribution of rounded indications                                                                                                                                                                                                                           | For $\bar{T}_w \leq 6$ mm ( $\frac{1}{4}$ in.), limit is same as D [Note (2)]<br>For $\bar{T}_w > 6$ mm ( $\frac{1}{4}$ in.), limit is $1.5 \times D$ [Note (2)] |                               |
| F         | Linear indications                                                                                                                                                                                                                                                     |                                                                                                                                                                  |                               |
|           | Individual length                                                                                                                                                                                                                                                      | $\leq \bar{T}_w/3$                                                                                                                                               |                               |
|           | Individual width                                                                                                                                                                                                                                                       | $\leq 2.5$ mm ( $\frac{3}{32}$ in.) and $\leq \bar{T}_w/3$                                                                                                       |                               |
|           | Cumulative length                                                                                                                                                                                                                                                      | $\leq \bar{T}_w$ in any 12 $\bar{T}_w$ weld length [Note (2)]                                                                                                    |                               |
| G         | Linear indications                                                                                                                                                                                                                                                     |                                                                                                                                                                  |                               |
|           | Individual length                                                                                                                                                                                                                                                      | $\leq 2\bar{T}_w$                                                                                                                                                |                               |
|           | Individual width                                                                                                                                                                                                                                                       | $\leq 3$ mm ( $\frac{1}{8}$ in.) and $\leq \bar{T}_w/2$                                                                                                          |                               |
|           | Cumulative length                                                                                                                                                                                                                                                      | $\leq 4\bar{T}_w$ in any 150 mm (6 in.) weld length [Note (2)]                                                                                                   |                               |
| H         | Depth of undercut                                                                                                                                                                                                                                                      | $\leq 1$ mm ( $\frac{1}{32}$ in.) and $\leq \bar{T}_w/4$                                                                                                         |                               |
|           | Cumulative length of internal and external undercut                                                                                                                                                                                                                    | $\leq 38$ mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less                                                          |                               |
| I         | Depth of undercut                                                                                                                                                                                                                                                      | $\leq 1.5$ mm ( $\frac{1}{16}$ in.) and $\leq [\bar{T}_w/4 \text{ or } 1 \text{ mm } (\frac{1}{32} \text{ in.})]$                                                |                               |
|           | Cumulative length of internal and external undercut                                                                                                                                                                                                                    | $\leq 38$ mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less                                                          |                               |
| J         | Surface roughness                                                                                                                                                                                                                                                      | $\leq 12.5 \mu\text{m}$ (500 $\mu\text{in.}$ ) $R_a$ in accordance with ASME B46.1                                                                               |                               |
| K         | Depth of surface concavity, root concavity, or burn-through                                                                                                                                                                                                            | Total joint thickness, including weld reinforcement, $\geq \bar{T}_w$ [Notes (3) and (4)]                                                                        |                               |
| L         | Height of reinforcement or internal protrusion [Note (5)] in any plane through the weld shall be within limits of the applicable height value in the tabulation at right, except as provided in Note (6). Weld metal shall merge smoothly into the component surfaces. | For $\bar{T}_w$ , mm (in.)                                                                                                                                       | Height, mm (in.)              |
|           |                                                                                                                                                                                                                                                                        | $\leq 6$ ( $\frac{1}{4}$ )                                                                                                                                       | $\leq 1.5$ ( $\frac{1}{16}$ ) |
|           |                                                                                                                                                                                                                                                                        | $> 6$ ( $\frac{1}{4}$ ), $\leq 13$ ( $\frac{1}{2}$ )                                                                                                             | $\leq 3$ ( $\frac{1}{8}$ )    |
|           |                                                                                                                                                                                                                                                                        | $> 13$ ( $\frac{1}{2}$ ), $\leq 25$ (1)                                                                                                                          | $\leq 4$ ( $\frac{5}{32}$ )   |
|           |                                                                                                                                                                                                                                                                        | $> 25$ (1)                                                                                                                                                       | $\leq 5$ ( $\frac{3}{16}$ )   |
| M         | Height of reinforcement or internal protrusion [Note (5)] as described in L. Note (6) does not apply.                                                                                                                                                                  | Limit is twice the value applicable for L above                                                                                                                  |                               |

NOTES:

- (1) Where two limiting values are separated by "and," the lesser of the values determines acceptance. Where two sets of values are separated by "or," the larger value is acceptable.  $\bar{T}_w$  is the nominal wall thickness of the thinner of two components joined by a butt weld.

### Criterion Value Notes for Table 341.3.2 (Cont'd)

NOTES: (Cont'd)

- (2) Porosity and inclusions such as slag or tungsten are defined as rounded indications where the maximum length is three times the width or less. These indications may be circular, elliptical, or irregular in shape; may have tails; and may vary in density. Indications where the length is greater than three times the width are defined as linear indications and may also be slag, porosity, or tungsten.
- (3) For circumferential groove welded joints in pipe, tube, and headers made entirely without the addition of filler metal, external concavity shall not exceed the lesser of 1 mm ( $\frac{1}{32}$  in.) or 10% of the joint nominal thickness. The contour of the concavity shall blend smoothly with the base metal. The total joint thickness, including any reinforcement, shall not be less than the minimum wall thickness,  $t_m$ .
- (4) For radiography, acceptability may be determined by comparing the density of the image through the affected area to the density through the adjacent base metal ( $\bar{T}_w$ ). If digital radiography is used, brightness comparison may be utilized. A density or brightness darker than the adjacent base metal is cause for rejection.
- (5) For groove welds, height is the lesser of the measurements made from the surfaces of the adjacent components; both reinforcement and internal protrusion are permitted in a weld. For fillet welds, height is measured from the theoretical throat, [Figure 328.5.2A](#); internal protrusion does not apply.
- (6) For welds in aluminum alloy only, internal protrusion shall not exceed the following values:
  - (a) 1.5 mm ( $\frac{1}{16}$  in.) for thickness  $\leq 2$  mm ( $\frac{5}{64}$  in.)
  - (b) 2.5 mm ( $\frac{3}{32}$  in.) for thickness  $> 2$  mm and  $\leq 6$  mm ( $\frac{1}{4}$  in.)For external reinforcement and for greater thicknesses, see the tabulation for symbol L.

(5) random examination during erection of piping, including checking of alignment, supports, and cold spring.

(6) examination of erected piping for evidence of defects that would require repair or replacement, and for other evident deviations from the intent of the design.

*(b) Other Examination*

(1) Not less than 5% of circumferential butt and miter groove welds shall be examined fully by random radiography in accordance with [para. 344.5](#) or by random ultrasonic examination in accordance with [para. 344.6](#). The welds to be examined in each designated lot shall include the work product of each welder or welding operator whose welds are part of the lot. The work of welders depositing only tack welds need not be represented as part of the lot. Welds shall also be selected to maximize coverage of intersections with longitudinal joints. When a circumferential weld with an intersecting longitudinal weld(s) is examined, at least the adjacent 38 mm (1½ in.) of each intersecting weld shall be examined. In-process examination in accordance with [para. 344.7](#) may be substituted for all or part of the radiographic or ultrasonic examination on a weld-for-weld basis if specified in the engineering design or specifically authorized by the Inspector.

(2) Not less than 5% of all brazed joints shall be examined by in-process examination in accordance with [para. 344.7](#), the joints to be examined being selected to ensure that the work of each brazer making the production joints is included.

*(c) Certifications and Records.* The examiner shall be assured, by examination of certifications, records, and other evidence, that the materials and components are of the specified grades and that they have received required heat treatment, examination, and testing. The examiner shall provide the Inspector with a certification that all the quality control requirements of the Code and of the engineering design have been carried out.

**341.4.2 Examination — Category D Fluid Service.**

Piping and piping elements for Category D Fluid Service as designated in the engineering design shall be visually examined in accordance with [para. 344.2](#) to the extent necessary to satisfy the examiner that components, materials, and workmanship conform to the requirements of this Code and the engineering design. Acceptance criteria are as stated in [para. 341.3.2](#) and in [Table 341.3.2](#), for Category D fluid service, unless otherwise specified.

**341.4.3 Examination — Severe Cyclic Conditions.**

Piping to be used under severe cyclic conditions shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in [para. 341.3.2](#) and in [Table 341.3.2](#), for severe cyclic conditions, unless otherwise specified.

*(a) Visual Examination.* The requirements of [para. 341.4.1\(a\)](#) apply with the following exceptions:

(1) All fabrication shall be examined.

(2) All threaded, bolted, and other joints shall be examined.

(3) All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

*(b) Other Examination.* All circumferential butt and miter groove welds and all fabricated branch connection welds comparable to those shown in [Figure 328.5.4E](#) shall be examined by 100% radiography in accordance with [para. 344.5](#), or (if specified in the engineering design) by 100% ultrasonic examination in accordance with [para. 344.6](#). Socket welds and branch connection welds that are not radiographed shall be examined by magnetic particle or liquid penetrant methods in accordance with [para. 344.3](#) or [344.4](#).

*(c) In-process examination* in accordance with [para. 344.7](#), supplemented by appropriate nondestructive examination, may be substituted for the examination required in [\(b\)](#) above on a weld-for-weld basis if specified in the engineering design or specifically authorized by the Inspector.

*(d) Certification and Records.* The requirements of [para. 341.4.1\(c\)](#) apply.

**341.4.4 Examination — Elevated Temperature Fluid Service.** Piping in Elevated Temperature Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in [para. 341.3.2](#) and in [Table 341.3.2](#), for Normal Fluid Service, unless the requirements for severe cyclic conditions apply or otherwise specified.

*(a) Visual Examination.* The requirements of [para. 341.4.1\(a\)](#) apply with the following exceptions:

(1) All fabrication shall be examined.

(2) All threaded, bolted, and other joints shall be examined.

(3) All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

*(b) Additional Examination.* The examination requirements of [para. 341.4.1\(b\)](#) apply with the following exceptions:

(1) Fabrication for longitudinal and spiral (helical seam) welds in P-No. 4 and P-No. 5 materials, except those in components made in accordance with a listed specification, shall be examined by 100% radiography

in accordance with [para. 344.5](#), or by 100% ultrasonic examination in accordance with [para. 344.6](#).

(2) Socket welds and branch connection welds in P-No. 4 and P-No. 5 materials that are not radiographed or ultrasonically examined shall be examined by magnetic particle or liquid penetrant methods in accordance with [para. 344.3](#) or [344.4](#).

(c) *Additional Examination Required for Autogenous Welds, Without Filler Metal, in Austenitic Stainless Steel and Austenitic High Nickel Alloys.* Autogenously welded pipe shall receive nondestructive examination in accordance with the material specification. Autogenously welded expansion joint bellows shall be examined in accordance with [para. X302.2.2\(c\)](#).

(d) *Certification and Records.* The requirements of [para. 341.4.1\(c\)](#) apply.

### 341.5 Supplementary Examination

Any of the methods of examination described in [para. 344](#) may be specified by the engineering design to supplement the examination required by [para. 341.4](#). The extent of supplementary examination to be performed and any acceptance criteria that differ from those in [para. 341.3.2](#) shall be specified in the engineering design.

#### 341.5.1 Spot Radiography

(a) *Longitudinal Welds.* Spot radiography for longitudinal groove welds required to have a weld joint factor  $E_j$  of 0.90 requires examination by radiography in accordance with [para. 344.5](#) of at least 300 mm (1 ft) in each 30 m (100 ft) of weld for each welder or welding operator. Acceptance criteria are those stated in [Table 341.3.2](#) for radiography under Normal Fluid Service.

(b) *Circumferential Butt Welds and Other Welds.* It is recommended that the extent of examination be not less than one shot on one in each 20 welds for each welder or welding operator. Unless otherwise specified, acceptance criteria are as stated in [Table 341.3.2](#) for radiography under Normal Fluid Service for the type of joint examined.

(c) *Progressive Sampling for Examination.* The provisions of [para. 341.3.4](#) are applicable.

(d) *Welds to Be Examined.* The locations of welds and the points at which they are to be examined by spot radiography shall be selected or approved by the Inspector.

**341.5.2 Hardness Tests.** Hardness tests are not required to verify proper heat treatment except as otherwise specified in the engineering design.

**341.5.3 Examinations to Resolve Uncertainty.** Any method may be used to resolve doubtful indications. Acceptance criteria shall be those for the required examination.

## 342 EXAMINATION PERSONNEL

### 342.1 Personnel Qualification and Certification

Personnel performing nondestructive examination to the requirements of this Code shall be qualified and certified for the method to be utilized following a procedure as described in ASME BPVC, Section V, Article 1, T-120(e) or (f).

### 342.2 Specific Requirement

For in-process examination, the examinations shall be performed by personnel other than those performing the production work.

## 343 EXAMINATION PROCEDURES

Any examination shall be performed in accordance with a written procedure that conforms to one of the methods specified in [para. 344](#), including special methods (see [para. 344.1.2](#)). Procedures shall be written as required in ASME BPVC, Section V, Article 1, T-150. The employer shall make the examination procedures employed available to the Inspector.

## 344 TYPES OF EXAMINATION

### 344.1 General

**344.1.1 Methods.** Except as provided in [para. 344.1.2](#), any examination required by this Code, by the engineering design, or by the Inspector shall be performed in accordance with one of the methods specified herein.

**344.1.2 Special Methods.** If a method not specified herein is to be used, it and its acceptance criteria shall be specified in the engineering design in enough detail to permit qualification of the necessary procedures and examiners.

**344.1.3 Definitions.** The following terms apply to any type of examination:

*100% examination*<sup>1</sup>: complete examination of all of a specified kind of item in a designated lot of piping<sup>1</sup>

*random examination*<sup>2</sup>: complete examination of a percentage of a specified kind of item in a designated lot of piping<sup>1</sup>

<sup>1</sup> A designated lot is that quantity of piping to be considered in applying the requirements for examination in this Code. The quantity or extent of a designated lot should be established by agreement between the contracting parties before the start of work. More than one kind of designated lot may be established for different kinds of piping work. See Pipe Fabrication Institute Standard ES-48, Random Examination, for examples of lot selection.

<sup>2</sup> Random or spot examination will not ensure a fabrication product of a prescribed quality level throughout. Items not examined in a lot of piping represented by such examination may contain defects that further examination could disclose. Specifically, if all radiographically disclosable weld defects must be eliminated from a lot of piping, 100% radiographic examination must be specified.

*spot examination*<sup>2</sup>: a specified partial examination of each of a specified kind of item in a designated lot of piping,<sup>1</sup> e.g., of part of the length of all shop-fabricated welds in a lot of jacketed piping

*random spot examination*<sup>2</sup>: a specified partial examination of a percentage of a specified kind of item in a designated lot of piping<sup>1</sup>

### 344.2 Visual Examination

**344.2.1 Definition.** Visual examination is the direct observation of the external and internal portions of components, joints, and other piping elements that are readily accessible or can be exposed to view before, during, or after manufacture, fabrication, assembly, erection, examination, or testing. This examination includes verification of Code and engineering design requirements for materials, components, dimensions, joint preparation, alignment, welding, bonding, brazing, bolting, threading, or other joining method, supports, assembly, and erection.

**344.2.2 Method.** Visual examination shall be performed in accordance with ASME BPVC, Section V, Article 9. Examination shall be by the direct visual technique. The use of a remote visual technique and the acceptance criteria beyond the requirements of this Code shall be a matter of agreement between contracting parties prior to the start of fabrication.

Records of individual visual examinations are not required except for those of in-process examinations as specified in [para. 344.7](#).

### 344.3 Magnetic Particle Examination

**344.3.1 Method.** Examination of castings is covered in [para. 302.3.3](#). Magnetic particle examination of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 7.

**344.3.2 Acceptance Criteria.** Magnetic particle indications are caused by the attraction of the test media to surface or near-surface discontinuities in the area under test. However, all such indications are not necessarily imperfections, since excessive roughness, magnetic permeability variations, etc., may produce nonrelevant indications. Inadvertent accumulation of particles not related to magnetic attraction is classified as a false indication. Indications shall be verified as being relevant, nonrelevant, or false. Additional surface preparation and/or other test methods may be used as needed to verify the relevance of an indication.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications that have any dimension greater than 1.5 mm ( $\frac{1}{16}$  in.) shall be considered relevant.

(a) *Indications*

(1) A linear indication is one having a length greater than three times its width.

(2) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

(b) *Examination.* All surfaces to be examined shall be free of

(1) relevant linear indications

(2) relevant rounded indications >5.0 mm ( $\frac{3}{16}$  in.)

(3) four or more relevant rounded indications in a line separated by 1.5 mm ( $\frac{1}{16}$  in.) or less, edge to edge

### 344.4 Liquid Penetrant Examination

**344.4.1 Method.** Examination of castings is covered in [para. 302.3.3](#). Liquid penetrant examination of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 6.

**344.4.2 Acceptance Criteria.** Liquid penetrant indications are caused by the bleed-out of a visible or fluorescent dye from a surface discontinuity in the area under test. However, all such indications are not necessarily imperfections, since excessive roughness, poor surface preparation, etc., may produce nonrelevant indications. Inadvertent evidence of penetrant not related to actual bleed-out is classified as a false indication. Indications shall be verified as being relevant, nonrelevant, or false. Additional surface preparation and/or other test methods may be used as needed to verify the relevance of an indication.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications that have any dimension greater than 1.5 mm ( $\frac{1}{16}$  in.) shall be considered relevant.

(a) *Indications*

(1) A linear indication is one having a length greater than three times its width.

(2) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

(b) *Examination.* All surfaces to be examined shall be free of

(1) relevant linear indications

(2) relevant rounded indications >5.0 mm ( $\frac{3}{16}$  in.)

(3) four or more relevant rounded indications in a line separated by 1.5 mm ( $\frac{1}{16}$  in.) or less, edge to edge

### 344.5 Radiographic Examination

**344.5.1 Method.** Radiography of castings is covered in [para. 302.3.3](#). Radiography of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 2. For the purpose of image quality indicator (IQI) selection, for welds with reinforcement, the thickness used shall be the nominal wall



thickness,  $\bar{T}_w$ , plus the allowable external reinforcement and internal reinforcement (protrusion) combined.

### 344.5.2 Extent of Radiography

(a) *100% Radiography.* This applies only to girth and miter groove welds and to fabricated branch connection welds comparable to Figure 328.5.4E, unless otherwise specified in the engineering design.

(b) *Random Radiography.* This applies only to girth and miter groove welds.

(c) *Spot Radiography.* This requires a single exposure radiograph in accordance with para. 344.5.1 at a point within a specified extent of welding. For girth, miter, and branch groove welds, the minimum requirement is

(1) for sizes  $\leq$  DN 65 (NPS  $2\frac{1}{2}$ ), a single elliptical exposure encompassing the entire weld circumference

(2) for sizes  $>$  DN 65, the lesser of 25% of the inside circumference or 152 mm (6 in.)

For longitudinal welds, the minimum requirement is 152 mm (6 in.) of weld length.

## 344.6 Ultrasonic Examination

**344.6.1 Method.** Examination of castings is covered in para. 302.3.3; other product forms are not covered. Ultrasonic examination of welds shall be performed in accordance with ASME BPVC, Section V, Article 4, except that the alternative specified in (a) and (b) below is permitted for basic calibration blocks specified in T-434.2.1 and T-434.3.

(a) When the basic calibration blocks have not received heat treatment in accordance with T-434.1.5, transfer methods shall be used to correlate the responses from the basic calibration block and the component. Transfer is accomplished by noting the difference between responses received from the same reference reflector in the basic calibration block and in the component and correcting for the difference.

(b) The reference reflector may be a V-notch (which must subsequently be removed), an angle beam search unit acting as a reflector, or any other reflector that will aid in accomplishing the transfer.

(c) When the transfer method is chosen as an alternative, it shall be used, at the minimum

(1) for sizes  $\leq$  DN 50 (NPS 2), once in each ten welded joints examined

(2) for sizes  $>$  DN 50 and  $\leq$  DN 450 (NPS 18), once in each 1.5 m (5 ft) of welding examined

(3) for sizes  $>$  DN 450, once for each welded joint examined

(d) Each type of material and each size and wall thickness shall be considered separately in applying the transfer method. In addition, the transfer method shall be used at least twice on each type of weld joint.

(e) The reference level for monitoring discontinuities shall be modified to reflect the transfer correction when the transfer method is used.

**344.6.2 Acceptance Criteria.** Acceptance criteria shall be as described in (a) or (b). (20)

(a) A discontinuity is unacceptable if the amplitude of the indication exceeds the reference level and its length exceeds

(1) 6 mm ( $\frac{1}{4}$  in.) for  $\bar{T}_w \leq 19$  mm ( $\frac{3}{4}$  in.)

(2)  $\bar{T}_w/3$  for  $19$  mm ( $\frac{3}{4}$  in.)  $< \bar{T}_w \leq 57$  mm ( $2\frac{1}{4}$  in.)

(3) 19 mm ( $\frac{3}{4}$  in.) for  $\bar{T}_w > 57$  mm ( $2\frac{1}{4}$  in.)

(b) The fracture-mechanics-based ultrasonic examination acceptance criteria in Appendix R may be used if all requirements of Appendix R are met.

## 344.7 In-Process Examination

**344.7.1 Definition.** In-process examination comprises examination of the following, as applicable:

(a) joint preparation and cleanliness

(b) preheating

(c) fit-up, joint clearance, and internal alignment prior to joining

(d) variables specified by the joining procedure, including filler material

(1) (for welding) position and electrode

(2) (for brazing) position, flux, brazing temperature, proper wetting, and capillary action

(e) (for welding) condition of the root pass after cleaning — external and, where accessible, internal — aided by liquid penetrant or magnetic particle examination when specified in the engineering design

(f) (for welding) slag removal and weld condition between passes

(g) appearance of the finished joint

**344.7.2 Method.** The examination is visual, in accordance with para. 344.2, unless additional methods are specified in the engineering design.

## 345 TESTING

### 345.1 Required Leak Test

Prior to initial operation, and after completion of the applicable examinations required by para. 341, each piping system shall be tested to ensure tightness. The test shall be a hydrostatic leak test in accordance with para. 345.4 except as provided herein.

(a) At the owner's option, a piping system in Category D fluid service may be subjected to an initial service leak test in accordance with para. 345.7, in lieu of the hydrostatic leak test.

(b) Where the owner considers a hydrostatic leak test impracticable, either a pneumatic test in accordance with para. 345.5 or a combined hydrostatic-pneumatic test in



accordance with [para. 345.6](#) may be substituted, recognizing the hazard of energy stored in compressed gas.

(c) Where the owner considers both hydrostatic and pneumatic leak testing impracticable, the alternative specified in [para. 345.9](#) may be used if both of the following conditions apply:

- (1) a hydrostatic test would
  - (-a) damage linings or internal insulation
  - (-b) contaminate a process that would be hazardous, corrosive, or inoperative in the presence of moisture
  - (-c) require significant support modifications for the hydrostatic test load or
  - (-d) present the danger of brittle fracture due to low metal temperature during the test
- (2) a pneumatic test would
  - (-a) present an undue hazard of possible release of energy stored in the system or
  - (-b) present the danger of brittle fracture due to low metal temperature during the test
- (d) Unless specified in the engineering design, lines open to the atmosphere, such as vents or drains downstream of the last shutoff valve, need not be leak tested.

### 345.2 General Requirements for Leak Tests

Requirements in [para. 345.2](#) apply to more than one type of leak test.

#### 345.2.1 Limitations on Pressure

(a) *Reduced Test Pressure.* If the test pressure would produce a circumferential or longitudinal stress (based on minimum pipe wall thickness) in excess of yield strength at test temperature or is greater than 1.5 times the component rating at test temperature, the test pressure may be reduced to the maximum pressure that will not exceed the lesser of the yield strength or 1.5 times a component rating at test temperature. [See [para. 302.3.2.](#)] For metallic bellows expansion joints, see [Appendix X, para. X302.2.3\(a\)](#).

(b) *Test Fluid Expansion.* If a pressure test is to be maintained for a period of time and the test fluid in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

(c) *Preliminary Pneumatic Test.* A preliminary test using air at no more than 170 kPa (25 psi) gage pressure may be made prior to hydrostatic testing to locate major leaks.

#### 345.2.2 Other Test Requirements

(a) *Examination for Leaks.* The leak test pressure shall be maintained for at least 10 min and then all joints and connections shall be examined for leaks. The test pressure may be reduced to not less than the design pressure while performing this examination.

(b) *Heat Treatment.* Leak tests shall be conducted after any heat treatment has been completed.

(c) *Low Test Temperature.* The possibility of brittle fracture shall be considered when conducting leak tests at metal temperatures near the ductile–brittle transition temperature.

#### 345.2.3 Special Provisions for Testing

(a) *Piping Components and Subassemblies.* Piping components and subassemblies may be tested either separately or as assembled piping.

(b) *Flanged Joints.* Flanged joints used to connect piping components and subassemblies that have previously been tested, and flanged joints at which a blank or blind is used to isolate equipment or other piping during a test, need not be leak tested in accordance with [para. 345.1](#).

(c) *Closure Welds.* The final weld connecting piping systems or components that have been successfully tested in accordance with [para. 345](#) need not be leak tested provided the weld is examined in-process in accordance with [para. 344.7](#) and passes with 100% radiographic examination in accordance with [para. 344.5](#) or 100% ultrasonic examination in accordance with [para. 344.6](#).

(d) *Instrument Connections.* Threaded joints, tubing joints, or a combination of these joints used to connect instruments to previously leak tested piping need not be leak tested in accordance with [para. 345.1](#).

(e) See also [Appendix F, para. F345.2.3](#).

#### 345.2.4 Externally Pressured Piping

(a) Except as provided in (b) below, piping systems subject to external pressure shall be tested at an internal gage pressure 1.5 times the external differential pressure, but not less than 105 kPa (15 psi).

(b) As an alternative to leak testing under internal pressure, piping systems designed for vacuum service only may be subjected to a vacuum leak test method, technique, and acceptance criteria specified by the owner. The vacuum leak test shall be performed following a written procedure complying with the applicable technical requirements of ASME BPVC, Section V, Article 10. Leak-testing personnel shall be qualified and certified as required by ASME BPVC, Section V, Article 1, T-120(e) or (f).

#### 345.2.5 Jacketed Piping

(a) The internal line shall be leak tested on the basis of the internal or external design pressure, whichever results in a higher test pressure. This test must be performed before the jacket is completed if it is necessary to provide visual access to joints of the internal line as required by [para. 345.3.1](#).

(b) The jacket shall be leak tested in accordance with [para. 345.1](#) based on the jacket design conditions. The test pressure is permitted to be lower when so specified in the engineering design.

**345.2.6 Repairs or Additions After Leak Testing.** If repairs or additions are made following the leak test, the affected piping shall be retested, except that for minor repairs or additions the owner may waive retest requirements when precautionary measures are taken to assure sound construction.

**345.2.7 Test Records.** Records shall be made of each piping system during the testing, including

- (a) date of test
- (b) identification of piping system tested
- (c) test fluid
- (d) test pressure
- (e) certification of results by examiner

These records need not be retained after completion of the test if a certification by the Inspector that the piping has satisfactorily passed pressure testing as required by this Code is retained.

### 345.3 Preparation for Leak Test

#### 345.3.1 Joints Exposed

(a) Except as provided in (b) and (c) below, all joints, welds (including structural attachment welds to pressure-containing components), and bonds shall be left uninsulated and exposed for examination during leak testing.

(b) Joints previously tested in accordance with this Code may be insulated or covered.

(c) At the owner's option, joints in Category D Fluid Service that are subject to a hydrostatic leak test (para. 345.4) or an initial service leak test (para. 345.7) may be insulated and have protective weather sheathing installed prior to leak testing. Consideration shall be given to increasing the test period to allow time for possible leakage to pass through the insulation and weather sheathing.

(d) All joints may be primed and painted prior to leak testing unless a sensitive leak test (para. 345.8) is required.

**345.3.2 Temporary Supports.** Piping designed for vapor or gas shall be provided with additional temporary supports, if necessary, to support the weight of test liquid.

#### 345.3.3 Piping With Expansion Joints

(a) Unrestrained expansion joints depend on external main anchors to resist pressure thrust forces. Except as limited in (c), a piping system containing unrestrained expansion joints shall be leak tested without any temporary restraints in accordance with para. 345 up to 150% of the expansion joint design pressure. If the required test pressure exceeds 150% of the expansion joint design pressure and the main anchors are not designed to resist the pressure thrust forces at the required test pressure, for that portion of the test when the pressure exceeds 150% of the expansion joint design pressure, the expansion joint shall either

be temporarily removed or temporary restraints shall be added to resist the pressure thrust forces.

(b) Self-restrained metallic bellows expansion joints (i.e., tied, hinged, pressure balanced, etc.) have restraint hardware designed to resist the pressure thrust forces. Except as limited in (c), a piping system containing self-restrained expansion joints shall be leak tested in accordance with para. 345. A self-restrained expansion joint previously shop tested by the manufacturer in accordance with Appendix X may be excluded from the system to be leak tested, except when a sensitive leak test in accordance with para. 345.8 is required. Restraint hardware for all types of expansion joints shall be designed for the pressure thrust forces at the test pressure.

(c) When a metallic bellows expansion joint is installed in the piping system subject to a leak test and the leak test pressure determined in accordance with para. 345 exceeds the pressure of the test performed by the manufacturer in accordance with Appendix X, the required leak test pressure shall be reduced to the manufacturer's test pressure.

**345.3.4 Limits of Tested Piping.** Equipment that is not to be tested shall be either disconnected from the piping or isolated by blinds or other means during the test. A valve may be used provided the valve (including its closure mechanism) is suitable for the test pressure.

### 345.4 Hydrostatic Leak Test

**345.4.1 Test Fluid.** The fluid shall be water unless there is the possibility of damage due to freezing or to adverse effects of water on the piping or the process (see para. F345.4.1). In that case another suitable nontoxic liquid may be used. If the liquid is flammable, its flash point shall be at least 49°C (120°F), and consideration shall be given to the test environment.

**345.4.2 Test Pressure.** Except as provided in para. 345.4.3, the hydrostatic test pressure at every point in a metallic piping system shall be as follows:

(a) not less than 1.5 times the design pressure.

(b) when the design temperature is greater than the test temperature, the minimum test pressure, at the point under consideration, shall be calculated using eq. (24).

$$P_T = 1.5 P S_T / S \quad (24)$$

where

$P$  = internal design gage pressure

$P_T$  = minimum test gage pressure

$S$  = allowable stress at component design temperature for the prevalent pipe material; see Table A-1 or Table A-1M

$S_T$  = allowable stress at test temperature for the prevalent pipe material; see Table A-1 or Table A-1M

(c) in those cases where the piping system may not include pipe itself, any other component in the piping system, other than pipe-supporting elements and bolting, may be used to determine the  $S_T/S$  ratio based on the applicable allowable stresses obtained from Table A-1 or Table A-1M. In those cases where the piping system may be made up of equivalent lengths of more than one material, the  $S_T/S$  ratio shall be based on the minimum calculated ratio of the included materials.

### 345.4.3 Hydrostatic Test of Piping With Vessels as a System<sup>3</sup>

(a) Where the test pressure of piping attached to a vessel is the same as or less than the test pressure for the vessel, the piping may be tested with the vessel at the piping test pressure.

(b) Where the test pressure of the piping exceeds the vessel test pressure, and it is not considered practicable to isolate the piping from the vessel, the piping and the vessel may be tested together at the vessel test pressure, provided the owner approves and the vessel test pressure is not less than 77% of the piping test pressure calculated in accordance with para. 345.4.2(b).

## 345.5 Pneumatic Leak Test

**345.5.1 Precautions.** Pneumatic testing involves the hazard of released energy stored in compressed gas. Particular care must therefore be taken to minimize the chance of brittle failure during a pneumatic leak test. Test temperature is important in this regard and must be considered when the designer chooses the material of construction. See para. 345.2.2(c) and Appendix F, paras. F323.4 and F345.5.1.

**345.5.2 Pressure Relief Device.** A pressure relief device shall be provided, having a set pressure not higher than the test pressure plus the lesser of 345 kPa (50 psi) or 10% of the test pressure.

**345.5.3 Test Fluid.** The gas used as test fluid, if not air, shall be nonflammable and nontoxic.

**345.5.4 Test Pressure.** The test pressure shall be not less than 1.1 times the design pressure and shall not exceed the lesser of

(a) 1.33 times the design pressure

(b) the pressure that would exceed 90% of the pressure described in para. 345.2.1(a)

**345.5.5 Procedure.** The pressure shall be gradually increased until a gage pressure that is the lesser of one-half the test pressure or 170 kPa (25 psi) is attained, at which time a preliminary check shall be made, including examination of joints in accordance with para. 341.4.1(a).

Thereafter, the pressure shall be gradually increased in steps until the test pressure is reached, holding the pressure at each step long enough to equalize piping strains. The pressure shall then be reduced to the design pressure before examining for leakage in accordance with para. 345.2.2(a).

## 345.6 Hydrostatic-Pneumatic Leak Test

If a combination hydrostatic-pneumatic leak test is used, the requirements of para. 345.5 shall be met, and the pressure in the liquid filled part of the piping shall not exceed the limits stated in para. 345.4.2.

## 345.7 Initial Service Leak Test

This test is applicable only to piping in Category D Fluid Service, at the owner's option. See para. 345.1(a).

**345.7.1 Test Fluid.** The test fluid is the service fluid.

**345.7.2 Procedure.** During or prior to initial operation, the pressure shall be gradually increased in steps until the operating pressure is reached, holding the pressure at each step long enough to equalize piping strains. A preliminary check shall be made as described in para. 345.5.5 if the service fluid is a gas or vapor.

**345.7.3 Examination for Leaks.** The examination for leaks required by para. 345.2.2(a) shall be conducted while the system is at operating pressure. It is permissible to omit examination for leaks of joints and connections previously tested in accordance with this Code.

## 345.8 Sensitive Leak Test

**345.8.1 Precautions.** The precautions described in para. 345.5.1 shall be considered when applicable.

**345.8.2 Method.** The test shall be the Bubble Test — Direct Pressure Technique in accordance with ASME BPVC, Section V, Article 10, Mandatory Appendix I or another leak test method that has a demonstrated sensitivity not less than  $10^{-3}$  std mL/s under test conditions.

When the Bubble Test — Direct Pressure Technique is used

(a) the test pressure shall be at least the lesser of 105 kPa (15 psi) or 25% of the design pressure.

(b) the pressure shall be gradually increased until a gage pressure equal to the lesser of one-half the test pressure or 170 kPa (25 psi) is attained, at which time a preliminary check shall be made. Then the pressure shall be gradually increased in steps until the test pressure is reached, the pressure being held long enough at each step to equalize piping strains.

## 345.9 Alternative Leak Test

The following procedures and leak test method may be used only under the conditions stated in para. 345.1(c).

<sup>3</sup> The provisions of para. 345.4.3 do not affect the pressure test requirements of any applicable vessel code.

**345.9.1 Examination of Welds.** Welds, including those used in the manufacture of welded pipe and fittings, that have not been subjected to hydrostatic or pneumatic leak tests in accordance with this Code, shall be examined as follows:

(a) Circumferential, longitudinal, and spiral (helical seam) groove welds shall be 100% radiographed in accordance with [para. 344.5](#) or 100% ultrasonically examined in accordance with [para. 344.6](#).

(b) All welds, including structural attachment welds, not covered in (a) above, shall be examined using the liquid penetrant method ([para. 344.4](#)) or, for magnetic materials, the magnetic particle method ([para. 344.3](#)).

**345.9.2 Flexibility Analysis.** A flexibility analysis of the piping system shall have been made in accordance with the requirements of [para. 319.4.2\(b\)](#), if applicable, or [paras. 319.4.2\(c\)](#) and [319.4.2\(d\)](#).

**345.9.3 Test Method.** The system shall be subjected to a sensitive leak test in accordance with [para. 345.8](#).

## 346 RECORDS

### 346.2 Responsibility

It is the responsibility of the piping designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Code and by the engineering design.

### 346.3 Retention of Records

Unless otherwise specified by the engineering design, the following records shall be retained for at least 5 yr after the record is generated for the project:

- (a) examination procedures
- (b) examination personnel qualifications
- (c) examination reports

# Chapter VII

## Nonmetallic Piping and Piping Lined With Nonmetals

### A300 GENERAL STATEMENTS

(a) [Chapter VII](#) pertains to nonmetallic piping and to piping lined with nonmetals.

(b) The organization, content, and paragraph designations of this Chapter correspond to those of the first six Chapters (the base Code). The prefix A is used.

(c) Provisions and requirements of the base Code apply only as stated in this Chapter.

(d) Metallic piping that provides the pressure containment for a nonmetallic lining shall conform to the requirements of [Chapters I](#) through [VI](#), and to those in [Chapter VII](#) not limited to nonmetals.

(e) This Chapter makes no provision for piping to be used under severe cyclic conditions.

(f) With the exceptions stated above, [Chapter I](#) applies in its entirety.

### PART 1 CONDITIONS AND CRITERIA

#### A301 DESIGN CONDITIONS

[Paragraph 301](#) applies in its entirety, with the exception of [paras. 301.2](#) and [301.3](#). See below.

##### A301.2 Design Pressure

[Paragraph 301.2](#) applies in its entirety, except that references to [paras. A302.2.4](#) and [A304](#) replace references to [paras. 302.2.4](#) and [304](#), respectively.

##### A301.3 Design Temperature

[Paragraph 301.3](#) applies with the following exceptions.

**A301.3.1 Design Minimum Temperature.** [Paragraph 301.3.1](#) applies; but see [para. A323.2.2](#), rather than [para. 323.2.2](#).

**A301.3.2 Uninsulated Components.** The component design temperature shall be the fluid temperature, unless a higher temperature will result from solar radiation or other external heat sources.

### A302 DESIGN CRITERIA

[Paragraph A302](#) states pressure–temperature ratings, stress criteria, design allowances, and minimum design values, together with permissible variations of these factors as applied to the design of piping.

#### A302.1 General

The designer shall be satisfied as to the adequacy of the nonmetallic material and its manufacture, considering at least the following:

- (a) tensile, compressive, flexural, and shear strength, and modulus of elasticity, at design temperature (long term and short term)
- (b) creep rate at design conditions
- (c) design stress and its basis
- (d) ductility and plasticity
- (e) impact and thermal shock properties
- (f) temperature limits
- (g) transition temperature — melting and vaporization
- (h) porosity and permeability
- (i) testing methods
- (j) methods of making joints and their efficiency
- (k) possibility of deterioration in service

#### A302.2 Pressure–Temperature Design Criteria

**A302.2.1 Listed Components Having Established Ratings.** [Paragraph 302.2.1](#) applies, except that reference to [Table A326.1](#) replaces reference to [Table 326.1](#).

**A302.2.2 Listed Components Not Having Specific Ratings.** Nonmetallic piping components for which design stresses have been developed in accordance with [para. A302.3](#), but which do not have specific pressure–temperature ratings, shall be rated by rules for pressure design in [para. A304](#), within the range of temperatures for which stresses are shown in [Appendix B](#), modified as applicable by other rules of this Code.

Piping components that do not have allowable stresses or pressure–temperature ratings shall be qualified for pressure design as required by [para. A304.7.2](#).

**A302.2.3 Unlisted Components.** [Paragraph 302.2.3](#) applies, except that references to [Table A326.1](#) and [paras. A304](#) and [A323](#) replace references to [Table 326.1](#) and [paras. 304](#) and [323](#), respectively.



#### A302.2.4 Allowances for Pressure and Temperature Variations

(a) *Nonmetallic Piping.* Allowances for variations of pressure or temperature, or both, above design conditions are not permitted. The most severe conditions of coincident pressure and temperature shall be used to determine the design conditions for a piping system. See [paras. 301.2](#) and [301.3](#).

(b) *Metallic Piping With Nonmetallic Lining.* Allowances for pressure and temperature variations provided in [para. 302.2.4](#) are permitted only if the suitability of the lining material for the increased conditions is established through prior successful service experience or tests under comparable conditions.

**A302.2.5 Rating at Junction of Different Services.** When two services that operate at different pressure-temperature conditions are connected, the valve segregating the two services shall be rated for the more severe service condition.

### A302.3 Allowable Stresses and Other Design Limits

#### A302.3.1 General

(a) [Table B-1](#) contains hydrostatic design stresses (HDS). [Tables B-2](#) and [B-3](#) provide listings of specifications that meet the criteria of [paras. A302.3.2\(b\)](#) and [A302.3.2\(c\)](#), respectively. [Tables B-4](#) and [B-5](#) contain allowable pressures. These HDS values, allowable stress criteria, and pressures shall be used in accordance with the Notes to [Appendix B](#), and may be used in design calculations (where the allowable stress  $S$  means the appropriate design stress) except as modified by other provisions of this Code. Use of hydrostatic design stresses for calculations other than pressure design has not been verified. The bases for determining allowable stresses and pressures are outlined in [para. A302.3.2](#).

(b) The stresses and allowable pressures are grouped by materials and listed for stated temperatures. Straight-line interpolation between temperatures is permissible.

#### A302.3.2 Bases for Allowable Stresses and Pressures<sup>1</sup>

(a) *Thermoplastics.* The method of determining HDS is described in ASTM D2837. HDS values are given in [Table B-1](#) for those materials and temperatures for which sufficient data have been compiled to substantiate the determination of stress.

(b) *Reinforced Thermosetting Resin (Laminated).* The design stress (DS) values for materials listed in [Table B-2](#) shall be one-tenth of the minimum tensile strengths specified in ASTM C582 and are valid only in the temperature range from  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) through  $82^{\circ}\text{C}$  ( $180^{\circ}\text{F}$ ).

(c) *Reinforced Thermosetting Resin and Reinforced Plastic Mortar (Filament Wound and Centrifugally Cast).* The hydrostatic design basis stress (HDBS) values for materials listed in [Table B-3](#) shall be obtained by the procedures in ASTM D2992 and are valid only at  $23^{\circ}\text{C}$  ( $73^{\circ}\text{F}$ ). HDS shall be obtained by multiplying the HDBS by a service (design) factor<sup>2</sup> selected for the application, in accordance with procedures described in ASTM D2992, within the following limits:

(1) When using the cyclic HDBS, the service (design) factor  $F$  shall not exceed 1.0.

(2) When using the static HDBS, the service (design) factor  $F$  shall not exceed 0.5.

(d) *Other Materials.* Allowable pressures in [Tables B-4](#) and [B-5](#) have been determined conservatively from physical properties of materials conforming to the listed specifications, and have been confirmed by extensive experience. Use of other materials shall be qualified as required by [para. A304.7.2](#).

<sup>1</sup> Titles of ASTM Specifications and AWWA Standards referenced herein are as follows:

ASTM C14, Concrete Sewer, Storm Drain, and Culvert Pipe  
 ASTM C301, Method of Testing Vitrified Clay Pipe  
 ASTM C582, Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment  
 ASTM D2321, Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications  
 ASTM D2837, Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products  
 ASTM D2992, Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-RTR) Pipe and Fittings  
 ASTM D3839, Underground Installation of Fiberglass Pipe  
 AWWA C900, Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm)  
 AWWA C950, Glass-Fiber-Reinforced Thermosetting Resin Pressure Pipe

<sup>2</sup> The service (design) factor,  $F$ , should be selected by the designer after evaluating fully the service conditions and the engineering properties of the specific material under consideration. Aside from the limits in [paras. A302.3.2\(c\)\(1\)](#) and [A302.3.2\(c\)\(2\)](#), it is not the intent of this Code to specify service (design) factors.

### A302.3.3 Limits of Calculated Stresses Due to Sustained Loads<sup>1</sup>

(a) *Internal Pressure Stresses.* Limits of stress due to internal pressure are covered in [para. A304](#).

(b) *External Pressure Stresses.* Stresses due to uniform external pressure shall be considered safe when the wall thickness of the component and its means of stiffening have been qualified as required by [para. A304.7.2](#).

(c) *External Loading Stresses.* Design of piping under external loading shall be based on the following:

(1) *Thermoplastic Piping.* ASTM D2321 or AWWA C900.

(2) *Reinforced Thermosetting Resin (RTR) and Reinforced Plastic Mortar (RPM) Piping.* ASTM D3839 or Appendix A of AWWA C950.

(3) Strain and possible buckling shall be considered when determining the maximum allowable deflection in (1) or (2) above, but in no case shall the allowable diametral deflection exceed 5% of the pipe inside diameter.

(4) Nonmetallic piping not covered in (1) or (2) above shall be subjected to a crushing or three-edge bearing test in accordance with ASTM C14 or C301; the allowable load shall be 25% of the minimum value obtained.

### A302.3.4 Limits of Calculated Stresses Due to Occasional Loads

(a) *Operation*

(1) For other than RTR and RPM piping, the sum of stresses in any component in a piping system due to sustained loads, such as pressure and weight, and of the stresses produced by occasional loads, such as wind or earthquake, shall not exceed the limits in the applicable part of [para. A302.3.3](#).

(2) For RTR and RPM piping, the sum of stresses due to operating loads plus stresses due to occasional loads may be as much as 1.33 times the limits in the applicable part of [para. A302.3.3](#).

(3) Wind and earthquake forces need not be considered as acting concurrently.

(b) *Test.* Stresses due to test conditions are not subject to the limitations in [para. A302.3.3](#). It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

### A302.4 Allowances

[Paragraph 302.4](#) applies in its entirety.

## PART 2 PRESSURE DESIGN OF PIPING COMPONENTS

### A303 GENERAL

[Paragraph 303](#) applies, except that references to [Table A326.1](#) and [para. A302.2.1](#) replace references to [Table 326.1](#) and [para. 302.2.1](#). For nonmetallic components, reference to [para. A304](#) replaces reference to [para. 304](#).

### A304 PRESSURE DESIGN OF PIPING COMPONENTS

#### A304.1 Straight Pipe

##### A304.1.1 General

(a) The required thickness of straight sections of pipe shall be determined by [eq. \(25\)](#).

$$t_m = t + c \quad (25)$$

The minimum thickness  $T$  for the pipe selected, considering manufacturer's minus tolerance, shall be not less than  $t_m$ .

(b) The following nomenclature is used in the equations for pressure design of straight pipe:

$c$  = the sum of mechanical allowances (thread or groove depth) plus corrosion and erosion allowance. For threaded components, the nominal thread depth (dimension  $h$  of ASME B1.20.1 or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

$D$  = outside diameter of pipe

$F$  = service (design) factor. See [para. A302.3.2\(c\)](#).

$P$  = internal design gage pressure

$S$  = design stress from applicable Table in [Appendix B](#)

$T$  = pipe wall thickness (measured or minimum in accordance with the purchase specification)

$t$  = pressure design thickness, as calculated in accordance with [para. A304.1.2](#) for internal pressure or as determined in accordance with [para. A304.1.3](#) for external pressure

$t_m$  = minimum required thickness, including mechanical, corrosion, and erosion allowances

**A304.1.2 Straight Nonmetallic Pipe Under Internal Pressure.** The internal pressure design thickness,  $t$ , shall be not less than that calculated by one of the following equations, using stress values listed in or derived from the appropriate table in [Appendix B](#):



(a) *Thermoplastic Pipe* [see para. A302.3.2(a)]

$$t = \frac{PD}{2S + P} \text{ (Table B-1)} \quad (26a)$$

(b) *RTR (Laminated) Pipe* [see para. A302.3.2(b)]<sup>3</sup>

$$t = \frac{PD}{2S + P} \text{ (Table B-2)} \quad (26b)$$

(c) *RTR (Filament Wound) and RPM (Centrifugally Cast) Pipe* [see para. A302.3.2(c)]<sup>3</sup>

$$t = \frac{PD}{2SF + P} \text{ (Table B-3)} \quad (26c)$$

### A304.1.3 Straight Pipe Under External Pressure

(a) *Nonmetallic Pipe.* The external pressure design thickness,  $t$ , shall be qualified as required by para. A304.7.2.

(b) *Metallic Pipe Lined With Nonmetals*

(1) The external pressure design thickness,  $t$ , for the base (outer) material shall be determined in accordance with para. 304.1.3.

(2) The external pressure design thickness,  $t$ , for the lining material shall be qualified as required by para. A304.7.2.

## A304.2 Curved and Mitered Segments of Pipe

**A304.2.1 Pipe Bends.** The minimum required thickness,  $t_m$ , of a bend, after bending, shall be determined as for straight pipe in accordance with para. A304.1.

**A304.2.2 Elbows.** Manufactured elbows not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

**A304.2.3 Miter Bends.** Miter bends shall be qualified as required by para. A304.7.2.

## A304.3 Branch Connections

**A304.3.1 General.** A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement shall be qualified as required by para. A304.7.2 except as provided in para. A304.3.2.

**A304.3.2 Branch Connections Using Fittings.** It may be assumed without calculation that a branch connection has adequate strength to sustain the internal and external pressure that will be applied to it if it utilizes a fitting (a tee, lateral, or cross) in accordance with para. A303.

**A304.3.3 Additional Design Considerations.** The requirements of paras. A304.3.1 and A304.3.2 are intended to assure satisfactory performance of a branch connection subjected only to internal or external pressure. The designer shall also consider paras. 304.3.5(a), (c), and (d).

## A304.4 Closures

Closures not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

## A304.5 Pressure Design of Nonmetallic Flanges

### A304.5.1 General

(a) Flanges not in accordance with para. A303 or (b) or (d) shall be qualified as required by para. A304.7.2.

(b) Flanges for use with flat ring gaskets may be designed in accordance with ASME BPVC, Section VIII, Division 1, Appendix 2, except that the allowable stresses and temperature limits of this Code shall govern. Nomenclature shall be as defined in ASME BPVC, except for the following:

$P$  = design gage pressure

$S_a$  = bolt design stress at atmospheric temperature<sup>4</sup>

$S_b$  = bolt design stress at design temperature<sup>4</sup>

$S_f$  = allowable stress for flange material from Table B-1, B-2, or B-3

(c) The rules in (b) above are not applicable to a flanged joint having a gasket that extends outside the bolts (usually to the outside diameter of the flange).

(d) For flanges that make solid contact outside the bolts, ASME BPVC, Section VIII, Division 1, Appendix Y should be used.

**A304.5.2 Blind Flanges.** Blind flanges not in accordance with para. A303 may be designed in accordance with para. 304.5.2, except that allowable stress,  $S$ , shall be taken from Tables in Appendix B. Otherwise, they shall be qualified as required by para. A304.7.2.

## A304.6 Reducers

Reducers not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

## A304.7 Pressure Design of Other Components

**A304.7.1 Listed Components.** Other pressure containing components, manufactured in accordance with standards in Table A326.1 but not covered elsewhere in para. A304, may be utilized in accordance with para. A303.

**A304.7.2 Unlisted Components.** Pressure design of unlisted components and joints, to which the rules elsewhere in para. A304 do not apply, shall be based on calculations consistent with the design criteria of this Code.

<sup>3</sup> The internal design pressure thickness,  $t$ , shall not include any thickness of the pipe wall reinforced with less than 20% by weight of reinforcing fibers.

<sup>4</sup> Bolt design stresses shall not exceed those in Table A-2 or Table A-2M.

Calculations shall be substantiated by one or both of the means stated in (a) and (b) below, considering applicable ambient and dynamic effects in paras. 301.4 through 301.11.

(a) extensive, successful service experience under comparable design conditions with similarly proportioned components made of the same or like material

(b) performance test under design conditions including applicable dynamic and creep effects, continued for a time period sufficient to determine the acceptability of the component or joint for its design life

For (a) or (b) above, the designer may interpolate between sizes, wall thicknesses, and pressure classes, and may determine analogies among related materials.

**A304.7.3 Nonmetallic Components With Metallic Pressure Parts.** Components not covered by standards in Table A326.1, in which both nonmetallic and metallic parts contain the pressure, shall be evaluated by applicable requirements of para. 304.7.2 as well as those of para. A304.7.2.

### PART 3 FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

#### A305 PIPE

Listed pipe may be used in Normal Fluid Service, subject to the limitations of the pressure-containing material and para. A323.4. Unlisted pipe may be used only in accordance with para. A302.2.3.

#### A306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

*General.* Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. A306.1 through A306.5. Pipe and other materials used in such components shall be suitable for the manufacturing process and the fluid service.

##### A306.1 Pipe Fittings

**A306.1.1 Listed Fittings.** Listed fittings may be used in Normal Fluid Service subject to limitations on materials.

**A306.1.2 Unlisted Fittings.** Unlisted fittings may be used only in accordance with para. A302.2.3.

##### A306.2 Pipe Bends

**A306.2.1 General.** A bend made in accordance with para. A332 and verified for pressure design in accordance with para. A304.2.1 shall be suitable for the same service as the pipe from which it is made.

**A306.2.2 Corrugated and Other Bends.** Bends of other designs (such as creased or corrugated) shall be qualified for pressure design as required by para. A304.7.2.

##### A306.3 Miter Bends

Except as specified in para. 306.3.2, a miter bend that conforms to para. A304.2.3 may be used in Normal Fluid Service.

##### A306.4 Fabricated or Flared Laps

The following requirements do not apply to fittings conforming to para. A306.1.

###### A306.4.1 Fabricated Laps

(a) The requirements in paras. 306.4.1(a) and (b) shall be met.

(b) Lap material shall be suitable for the service conditions. Pressure design shall be qualified as required by para. A304.7.2.

**A306.4.2 Flared Laps.** Flared laps shall not be used in nonmetallic piping.

##### A306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to para. A306.1.

**A306.5.1 General.** A fabricated branch connection made by bonding the branch pipe directly to the header pipe, with or without added reinforcement as stated in para. 328.5.4, and shown in Figure 328.5.4, may be used in Normal Fluid Service, provided that pressure design is qualified as required by para. A304.7.2.

**A306.5.2 Specific Requirements.** Fabricated branch connections shall be made as specified in para. A328.5.

#### A307 VALVES AND SPECIALTY COMPONENTS

Paragraph 307 applies in its entirety, except that in para. 307.1.2 references to paras. A302.2.3 and A304.7.2 replace references to paras. 302.2.3 and 304.7.2, respectively.

#### A308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

##### A308.1 General

Paragraph 308.1 applies, except that in para. 308.1.2 reference to para. A302.2.3 replaces reference to para. 302.2.3.

## A308.2 Nonmetallic Flanges

### A308.2.1 General

(a) Flanges shall be adequate, with suitable facing, gasketing, and bolting, to develop the full rating of the joint and to withstand expected external loadings.

(b) The designer should consult the manufacturer for ratings of flanges.

**A308.2.2 Threaded Flanges.** Threaded flanges are subject to the requirements for threaded joints in [para. A314](#).

## A308.3 Flange Facings

[Paragraph 308.3](#) applies in its entirety.

## A308.4 Limitations on Gaskets

See also [Appendix F, para. F308.4](#).

**A308.4.1 Lining Used as Facing or Gasket.** Lining material extended over the flange face and used as a gasket shall conform to [para. 308.4](#).

## A309 BOLTING

Bolting includes bolts, bolt studs, studs, cap screws, nuts, and washers. See [Appendix F, para. F309](#).

### A309.1 General

[Paragraph 309.1](#) applies in its entirety.

### A309.2 Specific Bolting

Any bolting that meets the requirements of [para. 309.1](#) may be used with any combination of flange materials and flange facings. Joint assembly shall conform to the requirements of [para. A335.2](#).

### A309.3 Tapped Holes in Nonmetallic Components

Tapped holes for pressure-retaining bolting in piping components may be used provided pressure design is qualified as required by [para. A304.7.2](#).

## PART 4 FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

### A310 GENERAL

[Paragraph 310](#) applies in its entirety.

## A311 BONDED JOINTS IN PLASTICS

### A311.1 General

Bonding shall be in accordance with [para. A328](#) and examination shall be in accordance with [para. A341.4.1](#) for use in Normal Fluid Service, subject to the limitations of the material.

### A311.2 Specific Requirements

**A311.2.1 Fillet Bonds.** A fillet bond may be used only in conjunction with a qualified hot gas welding procedure for bonding (see [para. A328.5.2](#)).

**A311.2.2 Seal Bonds.** A seal bond may be used only to prevent leakage of a threaded joint and only if it has been demonstrated that there will be no deleterious effect on the materials bonded.

**A311.2.3 Joints Limited to Category D Fluid Service.** Joints that have been examined in accordance with [para. 341.4.2](#) may be used only for Category D Fluid Service.

## A312 FLANGED JOINTS

The designer should consult the manufacturer for ratings of flanged joints in nonmetallic piping and in piping lined with nonmetals.

## A313 EXPANDED JOINTS

[Paragraph 313](#) applies in its entirety.

## A314 THREADED JOINTS

### A314.1 General

A threaded joint is suitable for use in Normal Fluid Service, subject to the limitations of the material and requirements elsewhere in [para. A314](#). A joint conforming to [para. 314.1\(d\)](#) shall not be used.

### A314.2 Specific Requirements

#### A314.2.1 Thermoplastic Piping

(a) Polyethylene (PE) pipe and tubing shall not be joined by threaded joints.

(b) Threaded joints in other thermoplastic piping shall conform to all of the following:

(1) The pipe wall shall be at least as thick as Schedule 80 as defined in ASTM D1785.

(2) Threads shall be NPT, and shall conform to ASME B1.20.1 or ASTM F1498.

(3) Threads shall conform to applicable standards in [Table A326.1](#).

(4) A suitable thread sealant shall be used.

**A314.2.2 Reinforced Thermosetting Resin Piping.**

Threaded joints in reinforced thermosetting resin (RTR) piping shall conform to the following:

(a) External threads shall be factory cut or molded on special thick-walled pipe ends.

(b) Matching internal threads shall be factory cut or molded in the fittings.

(c) Threading of plain ends of RTR pipe is not permitted, except where such threads are limited to the function of a mechanical lock to matching internal threads factory cut or molded in the bottom portions of fittings with deep sockets.

(d) Factory cut or molded threaded nipples, couplings, or adapters, bonded to plain-end RTR pipe and fittings, may be used where it is necessary to provide connections to threaded metallic piping.

**A314.2.3 Reinforced Plastic Mortar Piping.** Threaded joints are not permitted in reinforced plastic mortar (RPM) piping.

**A315 TUBING JOINTS**

Paragraph 315 applies in its entirety, subject to material limitations, exclusion of 315.2(b) regarding severe cyclic conditions, and replacement of references to Table 326.1 and para. 304.7.2 with references to Table A326.1 and para. A304.7.2, respectively.

**A316 CAULKED JOINTS**

Paragraph 316 applies in its entirety.

**A318 SPECIAL JOINTS**

Special joints are those not covered elsewhere in Chapter VII, Part 4, such as bell type and packed gland type joints.

**A318.1 General**

Paragraph 318.1 applies in its entirety, except that, in para. 318.1.2, reference to para. A304.7.2 replaces reference to para. 304.7.2.

**A318.2 Specific Requirements**

Paragraph 318.2 applies with the exception of para. 318.2.3.

**A318.3 Piping Lined With Nonmetals****A318.3.1 Welding of Metallic Piping**

(a) *General.* Joints made in accordance with the rules in para. A329.1 may be used in Normal Fluid Service, subject to material limitations.

(b) *Specific Requirements.* Welds shall be limited to those that do not affect the serviceability of the lining.

**A318.3.2 Flared Linings**

(a) *General.* Flared ends of linings made in accordance with the rules in para. A329.2 may be used in Normal Fluid Service, subject to material limitations.

(b) *Specific Requirements.* Flaring shall be limited to applications that do not affect the serviceability of the lining.

**A318.4 Flexible Elastomeric Sealed Joints**

Flexible elastomeric seals conforming to the following may be used in Normal Fluid Service, subject to material limitations:

(a) Seals for joints in thermoplastic piping shall conform to ASTM D3139.

(b) Seals for joints in RTR and RPM piping shall conform to ASTM D4161.

## PART 5 FLEXIBILITY AND SUPPORT

**A319 FLEXIBILITY OF NONMETALLIC PIPING****A319.1 Requirements**

**A319.1.1 Basic Requirements.** Piping systems shall be designed to prevent thermal expansion or contraction, pressure expansion, or movement of piping supports and terminals from causing

(a) failure of piping or supports from overstrain or fatigue

(b) leakage at joints

(c) detrimental stresses or distortion in piping or in connected equipment (e.g., pumps), resulting from excessive thrusts and moments in the piping

**A319.1.2 Specific Requirements**

(a) In para. A319, guidance, concepts, and data are given to assist the designer in assuring adequate flexibility in piping systems. No specific stress-limiting criteria or methods of stress analysis are presented, since stress-strain behavior of most nonmetals differs considerably from that of metals covered by para. 319 and is less well defined for mathematical analysis.

(b) Piping systems should be designed and laid out so that flexural stresses resulting from displacement due to expansion, contraction, and other movement are minimized. This concept requires special attention to supports, terminals, and other restraints, as well as to the techniques outlined in para. A319.7. See also para. A319.2.2(b).

(c) Further information on design of thermoplastic piping can be found in PPI Technical Report TR-21.

## A319.2 Concepts

**A319.2.1 Displacement Strains.** The concepts of strain imposed by restraint of thermal expansion or contraction, and by external movement, described in [para. 319.2.1](#), apply in principle to nonmetals. Nevertheless, the assumption that stresses throughout the piping systems can be predicted from these strains because of fully elastic behavior of the piping materials is not always valid.

(a) In thermoplastics piping, displacement strains are not likely to produce immediate failure but may result in detrimental distortion. Progressive deformation may occur upon repeated thermal cycling or on prolonged exposure to elevated temperature.

(b) In brittle piping (e.g., porcelain and glass) and some RTR and RPM piping, the materials show rigid behavior and develop high displacement stresses up to the point of sudden breakage due to overstrain.

(c) RTR and RPM piping are assumed to display linear elastic behavior, having displacement stresses proportional to displacement strains.

### A319.2.2 Displacement Stresses

(a) *Elastic Behavior.* The assumption that displacement strains will produce proportional stress over a sufficiently wide range to justify an elastic stress analysis is not always valid for nonmetals. RTR and RPM piping shall be designed for linear elastic behavior, having displacement stresses proportional to displacement strains. In brittle piping, strains initially will produce relatively large elastic stresses. The total displacement strain must be kept small, however, since overstrain results in failure rather than plastic deformation. In thermoplastic piping, strains generally will produce stresses of the overstrained (plastic) type, even at relatively low values of total displacement strain. If a method of flexibility analysis that assumes elastic behavior is selected for thermoplastic piping, the designer shall demonstrate its validity for the piping system under consideration and shall establish safe limits for computed stresses.

(b) *Overstrained Behavior.* Stresses cannot be considered proportional to displacement strains throughout a piping system in which an excessive amount of strain may occur in localized portions of the piping [an unbalanced system; see [para. 319.2.2\(b\)](#)] or in which elastic behavior of the piping material cannot be assumed. Overstrain shall be minimized by system layout and excessive displacements shall be minimized by special joints or expansion devices (see [para. A319.7](#)).

**A319.2.3 Cold Spring.** Cold spring is the intentional deformation of piping during assembly to produce a desired initial displacement or reaction. Cold spring may be beneficial in serving to balance the magnitude of the reaction under initial and extreme displacement conditions. When cold spring is properly applied, there is less likelihood of overstrain during initial operation.

There is also less deviation from as-installed dimensions during initial operation, so that hangers will not be displaced as far from their original settings. No credit for cold spring is permitted in stress range calculations, or in calculating thrusts and moments.

## A319.3 Properties for Flexibility Analysis

**A319.3.1 Thermal Expansion Data.** [Appendix C](#) lists coefficients of thermal expansion for several nonmetals. More precise values in some instances may be obtainable from manufacturers of components. If these values are to be used in stress analysis, the thermal displacements shall be determined as stated in [para. 319.3.1](#).

**A319.3.2 Modulus of Elasticity.** [Appendix C](#) lists representative data on the tensile modulus of elasticity,  $E$ , for several nonmetals as obtained under typical laboratory rate of strain (loading) conditions. More precise values of the short-term and working estimates of effective moduli of elasticity for given conditions of loading and temperature may be obtainable from the manufacturer. For materials and temperatures not listed, refer to ASTM or PPI documents, or to manufacturer's data.

(a) Because of their viscoelasticity, the effective moduli of thermoplastics under actual conditions of use will depend on both the specific course of the strain (or load) with time and the specific characteristics of the thermoplastic.

(b) The modulus may also vary with the orientation of the specimen. Because the reinforcement plays a significant role in developing the physical properties for RTR and RPM piping, the modulus may vary with the type and orientation of the reinforcement.

**A319.3.3 Poisson's Ratio.** Poisson's ratio varies widely depending upon material and temperature. For that reason, simplified formulas used in stress analysis for metals may not be valid for nonmetals. For RTR and RPM piping, Poisson's ratio varies with the orientation of the reinforcement.

**A319.3.4 Dimensions.** Nominal thicknesses and outside diameters of pipe and fittings shall be used in flexibility calculations.

## A319.4 Analysis

**A319.4.1 Formal Analysis Not Required.** No formal analysis is required for a piping system that

(a) duplicates, or replaces without significant change, a system operating with a successful service record

(b) can readily be judged adequate by comparison with previously analyzed systems, or

(c) is laid out with a conservative margin of inherent flexibility, or employs joining methods or expansion joint devices, or a combination of these methods, in accordance with manufacturers' instructions



**A319.4.2 Formal Analysis Requirements.** For a piping system that does not meet the above criteria, the designer shall demonstrate adequate flexibility by simplified, approximate, or comprehensive stress analysis, using a method that can be shown to be valid for the specific case. If substantially elastic behavior can be demonstrated for the piping system [see [para. A319.2.2\(a\)](#)], methods outlined in [para. 319.4](#) may be applicable.

### A319.5 Reactions

[Paragraph 319.5](#) may be applicable if a formal stress analysis can be shown to be valid for the specific case.

### A319.6 Movements

Special attention shall be given to movement (displacement or rotation) of piping with respect to supports and points of close clearance. Movements of the run pipe at the junction of a small branch connection shall be considered in determining the need for flexibility in the branch pipe.

### A319.7 Means of Increasing Flexibility

Piping layout often provides adequate inherent flexibility through changes in direction, wherein displacements produce chiefly bending and torsional strains of low magnitude. The amount of tension or compression strain (which can produce larger reactions) usually is small.

Where piping lacks inherent flexibility or is unbalanced, additional flexibility shall be provided by one or more of the following means: bends, loops, or offsets; swivel or flexible joints; corrugated, bellows, or slip-joint expansion joints; or other devices permitting angular, rotational, or axial movement. Suitable anchors, ties, or other devices shall be provided as necessary to resist end forces produced by fluid pressure, frictional resistance to movement, and other causes.

## A321 PIPING SUPPORT

[Paragraph 321](#) applies in its entirety.

### A321.5 Supports for Nonmetallic Piping

- (20) **A321.5.1 General.** In addition to other applicable requirements of [para. 321](#), supports, guides, and anchors shall be selected and applied to comply with the principles and requirements of [para. A319](#) and the following:

(a) Piping shall be supported, guided, and anchored in such a manner as to prevent damage to the piping. Point loads and narrow areas of contact between piping and supports shall be avoided. Suitable padding, compatible with the piping material, shall be placed between piping and supports where damage to piping may occur. Local stresses at points of support, including clamping forces, shall be considered.

(b) Valves and equipment that would transmit excessive loads to the piping shall be independently supported to prevent such loads.

(c) Consideration shall be given to mechanical guarding in traffic areas.

(d) Manufacturers' recommendations for support shall be considered.

### A321.5.2 Supports for Thermoplastic, RTR, and RPM Piping. (20)

(a) Supports shall be spaced to avoid excessive sag or deformation at the design temperature and within the design life of the piping system.

(b) Decreases in the modulus of elasticity with increasing temperature and creep of material with time shall be considered when applicable.

(c) The thermal expansion of the piping system shall be considered in the design and location of supports.

(d) Where axial restraint is required, positive stops, such as shear collars, shall be provided as axial restraint. Frictional forces from clamping pressure shall not be considered as an anchor mechanism unless the support/anchor is specifically recommended for this purpose by the manufacturer.

**A321.5.3 Supports for Brittle Piping.** Brittle piping, such as glass, shall be well supported but free of hindrance to expansion or other movement. Not more than one anchor shall be provided in any straight run without an expansion joint.

## PART 6 SYSTEMS

## A322 SPECIFIC PIPING SYSTEMS

### A322.3 Instrument Piping

[Paragraph 322.3](#) applies in its entirety, except that references to [paras. A301](#) and [A302.2.4](#) replace references to [paras. 301](#) and [302.2.4](#), respectively.

### A322.6 Pressure-Relieving Systems

[Paragraph 322.6](#) applies in its entirety, except for [para. 322.6.3](#). See [para. A322.6.3](#).

**A322.6.3 Overpressure Protection.** [Paragraph 322.6.3](#) applies, except that maximum relieving pressure shall be in accordance with [para. A302.2.4](#).



## PART 7 MATERIALS

### A323 GENERAL REQUIREMENTS

#### A323.1 Materials and Specifications

Paragraph 323.1 applies except for para. 323.1.4. See para. A323.1.4.

**A323.1.4 Reclaimed Materials.** Reclaimed piping components may be used, provided they are properly identified as conforming to a listed or published specification (see para. 323.1.1) and otherwise meet the requirements of this Code. The user shall verify that components are suitable for the intended service. Sufficient cleaning, examination, and testing shall be performed to determine the minimum available wall thickness and freedom from any of the following to an extent that would be unacceptable in the intended service:

- (a) imperfections
- (b) reduction of mechanical properties, or
- (c) absorption of deleterious substances

#### A323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of the Code are suitable for service throughout the operating temperature range. Also see the Notes for Tables B-1 through B-5 in Appendix B.

##### A323.2.1 Upper Temperature Limits, Listed Materials

(a) Except as provided in (b) below, a listed material shall not be used at a design temperature higher than the maximum for which a stress value or rating is shown, or higher than the maximum recommended temperature in Table A323.4.2C for RTR materials and in Table A323.4.3 for thermoplastics used as linings.

(b) A listed material may be used at a temperature higher than the maximum stated in (a) above if there is no prohibition in Appendix B or elsewhere in the Code, and if the designer verifies the serviceability of the material in accordance with para. 323.2.4.

##### A323.2.2 Lower Temperature Limits, Listed Materials

(a) Materials for use at design minimum temperatures below certain limits must usually be tested to determine that they have suitable toughness for use in Code piping. Table A323.2.2 sets forth those requirements.

(b) When materials are qualified for use at temperatures below the minimum temperature listed in Appendix B, the allowable stresses or pressures shall not exceed the values for the lowest temperatures shown.

(c) See also the recommended limits in Table A323.4.2C for reinforced thermosetting resin pipe and in Table A323.4.3 for thermoplastics used as linings.

**A323.2.3 Temperature Limits, Unlisted Materials.** Paragraph 323.2.3 applies.

**A323.2.4 Verification of Serviceability.** When an unlisted material is to be used, or when a listed material is to be used above or below the limits in Appendix B, Table A323.4.2C, or Table A323.4.3, the designer shall comply with the requirements of para. 323.2.4.

#### A323.4 Fluid Service Requirements for Nonmetallic Materials

##### A323.4.1 General

(a) Nonmetallic materials shall be safeguarded against excessive temperature, shock, vibration, pulsation, and mechanical abuse in all fluid services.

(b) Requirements in para. A323.4 apply to pressure-containing parts. They do not apply to materials used for supports, gaskets, or packing. See also Appendix F, para. FA323.4.

##### A323.4.2 Specific Requirements

###### (a) Thermoplastics

(1) They shall not be used in flammable fluid service above ground, unless all of the following are met:

- (-a) The size of the piping does not exceed DN 25 (NPS 1).
- (-b) Owner's approval is obtained.
- (-c) Safeguarding in accordance with Appendix G is provided.

(-d) The precautions of Appendix F, paras. F323.1(a) through F323.1(c) are considered.

(2) They shall be safeguarded when used in other than Category D Fluid Service.

(3) PVC and CPVC shall not be used in compressed air or other compressed gas service.

(b) *Reinforced Plastic Mortars (RPM) Piping.* This piping shall be safeguarded when used in other than Category D Fluid Service.

(c) *Reinforced Thermosetting Resins (RTR) Piping.* This piping shall be safeguarded when used in toxic or flammable fluid services. Table A323.4.2C gives the recommended temperature limits for reinforced thermosetting resins.

###### (d) Borosilicate Glass and Porcelain

(1) They shall be safeguarded when used in toxic or flammable fluid services.

(2) They shall be safeguarded against large, rapid temperature changes in fluid services.

##### A323.4.3 Piping Lined With Nonmetals

(a) *Metallic Piping Lined With Nonmetals.* Fluid service requirements for the base (outer) material in para. 323.4 govern except as stated in (d) below.

**Table A323.2.2 Requirements for Low Temperature Toughness Tests for Nonmetals**

| Type of Material             | Column A<br>At or Above Listed<br>Minimum<br>Temperature                                                                                                                                                                                                                                             | Column B<br>Below Listed Minimum<br>Temperature                                                                                                                                                                     |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Listed nonmetallic materials | No added requirement                                                                                                                                                                                                                                                                                 | The designer shall have test results at or below the lowest expected service temperature which assure that the materials and bonds will have adequate toughness and are suitable at the design minimum temperature. |
| Unlisted materials           | An unlisted material shall conform to a published specification. Where composition, properties, and product form are comparable to those of a listed material, requirements for the corresponding listed material shall be met. Other unlisted materials shall be qualified as required in Column B. |                                                                                                                                                                                                                     |

GENERAL NOTE: These requirements are in addition to the requirements of the material specification.

**Table A323.4.2C Recommended Temperature Limits for Reinforced Thermosetting Resin Pipe**

| Materials   |             | Recommended Temperature Limits |     |         |     |
|-------------|-------------|--------------------------------|-----|---------|-----|
|             |             | Minimum                        |     | Maximum |     |
| Resin       | Reinforcing | °C                             | °F  | °C      | °F  |
| Epoxy       | Glass fiber | -29                            | -20 | 149     | 300 |
| Phenolic    | Glass fiber | -29                            | -20 | 149     | 300 |
| Furan       | Carbon      | -29                            | -20 | 93      | 200 |
| Furan       | Glass fiber | -29                            | -20 | 93      | 200 |
| Polyester   | Glass fiber | -29                            | -20 | 93      | 200 |
| Vinyl ester | Glass fiber | -29                            | -20 | 93      | 200 |

GENERAL NOTE: These temperature limits apply only to materials listed and do not reflect evidence of successful use in specific fluid services at these temperatures. The designer should consult the manufacturer for specific applications, particularly as the temperature limits are approached.

(b) *Nonmetallic Piping Lined With Nonmetals.* Fluid service requirements for the base (outer) material in para. A323.4.2 govern, except as stated in (d) below.

(c) *Nonmetallic Lining Materials.* The lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping. Fluid service requirements in para. A323.4.2 do not apply to materials used as linings.

(d) Properties of both the base and lining materials, and of any bond between them, shall be considered in establishing temperature limitations. Table A323.4.3 gives recommended temperature limits for thermoplastic materials used as linings.

### A323.5 Deterioration of Materials in Service

Paragraph 323.5 applies in its entirety.

### A325 MATERIALS — MISCELLANEOUS

Paragraph 325 applies in its entirety.

## PART 8 STANDARDS FOR PIPING COMPONENTS

### A326 DIMENSIONS AND RATINGS OF COMPONENTS

#### A326.1 Requirements

Paragraph 326 applies in its entirety except that references to Table A326.1 and Appendix B replace references to Table 326.1 and Appendix A, respectively.

#### A326.4 Abbreviations in Table A326.1 and Appendix B

The abbreviations tabulated below are used in this Chapter to replace lengthy phrases in the text, in the titles of standards in Table A326.1, and in the Specification Index for Appendix B. Those marked with an asterisk (\*)

**Table A323.4.3 Recommended Temperature Limits for Thermoplastics Used as Linings**

| Materials<br>[Note (1)] | Minimum |      | Maximum |     |
|-------------------------|---------|------|---------|-----|
|                         | °C      | °F   | °C      | °F  |
| PFA                     | -198    | -325 | 260     | 500 |
| PTFE                    | -198    | -325 | 260     | 500 |
| FEP                     | -198    | -325 | 204     | 400 |
| ECTFE                   | -198    | -325 | 171     | 340 |
| ETFE                    | -198    | -325 | 149     | 300 |
| PVDF                    | -18     | 0    | 135     | 275 |
| PP                      | -18     | 0    | 107     | 225 |
| PVDC                    | -18     | 0    | 79      | 175 |

GENERAL NOTE: These temperature limits are based on material tests and do not necessarily reflect evidence of successful use as piping component linings in specific fluid services at these temperatures. The designer should consult the manufacturer for specific applications, particularly as temperature limits are approached.

NOTE: (1) See para. A326.4 for definitions of materials.

are in accordance with ASTM D1600, Standard Terminology for Abbreviated Terms Relating to Plastics. Those items marked with a dagger (†) are in accordance with ASTM F412, Standard Terminology Relating to Plastic Piping Systems.

| Abbreviation | Term                                      |
|--------------|-------------------------------------------|
| ABS*†        | Acrylonitrile-butadiene-styrene plastics  |
| BPS          | Bonding Procedure Specification           |
| CPVC*†       | Chlorinated poly(vinyl chloride) plastics |
| DR†          | Dimension ratio                           |
| DS           | Design stress                             |
| E-CTFE*      | Ethylene-chlorotrifluoroethylene          |
| ETFE*        | Ethylene-tetrafluoroethylene copolymer    |
| FEP*         | Perfluoro (ethylene-propylene) copolymer  |
| HDBS         | Hydrostatic Design Basis Stress           |
| HDS†         | Hydrostatic Design Stress                 |
| PB*†         | Polybutylene-1                            |
| PE*†         | Polyethylene                              |
| PEX          | Cross-linked polyethylene                 |
| PFA*         | Perfluoro (alkoxyalkane)                  |
| PP*†         | Polypropylene                             |
| PQR          | Procedure Qualification Record            |
| PR†          | Pressure rating                           |
| PTFE*        | Polytetrafluoroethylene                   |
| PVC*†        | Poly(vinyl chloride)                      |
| PVDC*        | Poly(vinylidene chloride)                 |
| PVDF*        | Poly(vinylidene fluoride)                 |
| RPM          | Reinforced plastic mortar                 |
| RTP          | Reinforced thermosetting plastic          |
| RTR          | Reinforced thermosetting resin            |
| SDR†         | Standard dimension ratios                 |
| SIDR†        | Standard inside diameter dimension ratio  |
| WPS          | Welding Procedure Specification           |

## PART 9

### FABRICATION, ASSEMBLY, AND ERECTION

#### A327 GENERAL

Piping materials and components are prepared for assembly and erection by one or more of the fabrication processes in [paras. A328, A329, A332, and A334](#). When any of these processes is used in assembly and erection, requirements are the same as for fabrication.

#### A328 BONDING OF PLASTICS

[Paragraph A328](#) applies only to joints in thermoplastic, RTR, and RPM piping. Bonding shall conform to [paras. A328.1 through A328.7](#) and the applicable requirements of [para. A311](#).

#### A328.1 Bonding Responsibility

Each employer is responsible for the bonding done by personnel of his/her organization and, except as provided in [paras. A328.2.2 and A328.2.3](#), shall conduct the required performance qualification tests to qualify bonding procedure specifications (BPS) and bonders or bonding operators.

#### A328.2 Bonding Qualifications

##### A328.2.1 Qualification Requirements

(20)

(a) Qualification of the BPS to be used, and of the performance of bonders and bonding operators, is required. To qualify a BPS, all tests and examinations specified therein and in [para. A328.2.5](#) shall be completed successfully.

(b) In addition to the procedure for making the bonds, the BPS shall specify at least the following:

- (1) all materials and supplies (including storage requirements)
- (2) tools and fixtures (including proper care and handling)
- (3) environmental requirements (e.g., temperature, humidity, and methods of measurement)
- (4) joint preparation
- (5) dimensional requirements and tolerances
- (6) cure time (see [para. FA328.2.1](#))
- (7) protection of work
- (8) tests and examinations other than those required by [para. A328.2.5](#)

(9) acceptance criteria for the completed test assembly

**A328.2.2 Procedure Qualification by Others.** Subject to the specific approval of the Inspector, a BPS qualified by others may be used provided that

(a) the Inspector satisfies him/herself that the proposed qualified BPS has been prepared and executed by a responsible recognized organization with expertise in the field of bonding

(b) by signature, the employer accepts both the BPS and procedure qualification record (PQR) as his/her own

(c) the employer has at least one currently employed bonder who, while in his/her employ, has satisfactorily passed a performance qualification test using the proposed qualified BPS

##### A328.2.3 Performance Qualification by Others.

Without the Inspector's specific approval, an employer shall not accept a performance qualification test made by a bonder or bonding operator for another employer. If approval is given, it is limited to work on piping using the same or equivalent BPS. An employer accepting such performance qualification tests shall obtain a copy of the performance qualification test record from the previous employer, showing the name of the employer by whom the bonder or bonding operator was qualified,

**Table A326.1 Component Standards**

(20)

| Standard or Specification                                                         | Designation       |
|-----------------------------------------------------------------------------------|-------------------|
| <b>Nonmetallic Fittings, Valves, and Flanges</b>                                  |                   |
| Process Glass Pipe and Fittings                                                   | ASTM C599         |
| Threaded PVC Plastic Pipe Fittings, Sch 80                                        | ASTM D2464        |
| PVC Plastic Pipe Fittings, Sch 40                                                 | ASTM D2466        |
| PVC Plastic Pipe Fittings, Sch 80                                                 | ASTM D2467        |
| Socket-Type ABS Plastic Pipe Fittings, Sch 40                                     | ASTM D2468        |
| Thermoplastic Gas Pressure Pipe, Tubing, and Fittings                             | ASTM D2513        |
| Reinforced Epoxy Resin Gas Pressure Pipe and Fittings                             | ASTM D2517        |
| Plastic Insert Fittings for PE Plastic Pipe                                       | ASTM D2609        |
| Socket-Type PE Fittings for Outside Diameter-Controlled PE Pipe and Tubing        | ASTM D2683        |
| CPVC Plastic Hot- and Cold-Water Distribution Systems                             | ASTM D2846/D2846M |
| Butt Heat Fusion PE Plastic Fittings for PE Plastic Pipe and Tubing               | ASTM D3261        |
| Fiberglass RTR Pipe Fittings for Nonpressure Applications [Note (1)]              | ASTM D3840        |
| Machine Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges    | ASTM D4024        |
| Contact Molded Fiberglass RTR Flanges [Note (1)]                                  | ASTM D5421        |
| Fiberglass Pressure Pipe Fittings                                                 | ASTM D5685        |
| Threaded CPVC Plastic Pipe Fittings, Sch 80                                       | ASTM F437         |
| Socket-Type CPVC Plastic Pipe Fittings, Sch 40                                    | ASTM F438         |
| CPVC Plastic Pipe Fittings, Schedule 80                                           | ASTM F439         |
| Electrofusion Type PE Fittings for Outside Diameter Controlled PE Pipe and Tubing | ASTM F1055        |
| Plastic-Lined Ferrous Metal Pipe, Fittings, and Flanges [Notes (2), (3), and (4)] | ASTM F1545        |
| Pressure-Rated Polypropylene (PP) Piping Systems                                  | ASTM F2389        |
| Plastic Industrial Ball Valves [Notes (2) and (3)]                                | MSS SP-122        |
| <b>Nonmetallic Pipes and Tubes</b>                                                |                   |
| PE Line Pipe                                                                      | API 15LE          |
| Low Pressure Fiberglass Line Pipe                                                 | API 15LR          |
| Reinforced Concrete Low-Head Pressure Pipe                                        | ASTM C361         |
| Process Glass Pipe and Fittings                                                   | ASTM C599         |
| ABS Plastic Pipe, Sch 40 and 80                                                   | ASTM D1527        |
| PVC Plastic Pipe, Sch 40, 80 and 120                                              | ASTM D1785        |
| PE Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter                     | ASTM D2239        |
| PVC Plastic Pressure-Rated Pipe (SDR Series)                                      | ASTM D2241        |
| ABS Plastic Pipe (SDR-PR)                                                         | ASTM D2282        |
| Thermoplastic Gas Pressure Pipe, Tubing, and Fittings                             | ASTM D2513        |
| Reinforced Epoxy Resin Gas Pressure Pipe and Fittings                             | ASTM D2517        |
| PB Plastic Pipe (SDR-PR)                                                          | ASTM D2662        |
| PB Plastic Tubing                                                                 | ASTM D2666        |
| Joints for IPS PVC Pipe Using Solvent Cement                                      | ASTM D2672        |
| PE Plastic Tubing                                                                 | ASTM D2737        |
| CPVC Plastic Hot- and Cold-Water Distribution System                              | ASTM D2846/D2846M |
| Filament-Wound Fiberglass RTR Pipe [Note (1)]                                     | ASTM D2996        |

**Table A326.1 Component Standards (Cont'd)**

| Standard or Specification                                                                                      | Designation       |
|----------------------------------------------------------------------------------------------------------------|-------------------|
| <b>Nonmetallic Pipes and Tubes (Cont'd)</b>                                                                    |                   |
| Centrifugally Cast Fiberglass RTR Pipe .....                                                                   | ASTM D2997        |
| PB Plastic Pipe (SDR-PR) Based on Outside Diameter .....                                                       | ASTM D3000        |
| PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter .....                                             | ASTM D3035        |
| Fiberglass RTR Pressure Pipe [Note (1)] .....                                                                  | ASTM D3517        |
| Fiberglass RTR Sewer and Industrial Pressure Pipe [Note (1)] .....                                             | ASTM D3754        |
| CPVC Plastic Pipe, Sch 40 and 80 .....                                                                         | ASTM F441/F441M   |
| CPVC Plastic Pipe (SDR-PR) .....                                                                               | ASTM F442/F442M   |
| Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene (PEX-AL-PEX) Pressure Pipe .....                    | ASTM F1281        |
| Polyethylene/Aluminum/Polyethylene (PE-AL-PE) Composite Pressure Pipe .....                                    | ASTM F1282        |
| Polyolefin Pipe and Fittings for Corrosive Waste Drainage Systems [Notes (2) and (3)] .....                    | ASTM F1412        |
| Plastic-Lined Ferrous Metal Pipe, Fittings, and Flanges [Notes (2), (3), and (4)] .....                        | ASTM F1545        |
| PVDF Corrosive Waste Drainage Systems .....                                                                    | ASTM F1673        |
| Pressure-Rated Polypropylene (PP) Piping Systems .....                                                         | ASTM F2389        |
| Metric and Inch-sized Crosslinked Polyethylene (PEX) Pipe .....                                                | ASTM F2788/F2788M |
| Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids .....                      | AWWA C300         |
| Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids .....                     | AWWA C301         |
| Reinforced Concrete Pressure Pipe, Noncylinder Type .....                                                      | AWWA C302         |
| Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm) | AWWA C900         |
| Fiberglass Pressure Pipe .....                                                                                 | AWWA C950         |
| <b>Miscellaneous</b>                                                                                           |                   |
| Contact-Molded RTP Laminates for Corrosion Resistant Equipment .....                                           | ASTM C582         |
| Threads for Fiberglass RTR Pipe (60 deg stub) [Note (1)] .....                                                 | ASTM D1694        |
| Solvent Cements for ABS Plastic Pipe and Fittings .....                                                        | ASTM D2235        |
| Solvent Cements for PVC Plastic Piping Systems .....                                                           | ASTM D2564        |
| Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals .....                                       | ASTM D3139        |
| Fiberglass RTR Pipe Joints Using Flexible Elastomeric Seals [Note (1)] .....                                   | ASTM D4161        |
| Design and Construction of Nonmetallic Enveloped Gaskets for Corrosive Service .....                           | ASTM F336         |
| Solvent Cements for CPVC Plastic Pipe and Fittings .....                                                       | ASTM F493         |
| Taper Pipe Threads 60° for Thermoplastic Pipe and Fittings .....                                               | ASTM F1498        |

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in [Appendix E](#).

NOTES:

- (1) The term “fiberglass RTR” takes the place of the ASTM designation “fiberglass (glass-fiber-reinforced thermosetting resin).”
- (2) This Standard allows the use of unlisted materials; see [para. 323.1.2](#).
- (3) This Standard contains no pressure-temperature ratings.
- (4) Cautionary Note: A metallic piping component lined with nonmetal requires proper interaction between liner and host metallic piping component. This is demonstrated by qualification testing required in ASTM F1545. The designer should review this documentation for compliance.



the date of such qualification, and the date the bonder or bonding operator last bonded pressure piping under such performance qualification.

**A328.2.4 Qualification Records.** The employer shall maintain a self-certified record, available to the owner or owner's agent and to the Inspector, of the BPS used and the bonders or bonding operators employed by him/her, and showing the dates and results of BPS qualifications and bonding performance qualifications.

- (20) **A328.2.5 Qualification Tests.** Tests, as specified in para. A328.2.1(a), shall be performed to qualify each BPS and the performance of each bonder and bonding operator. Test assemblies shall conform to (a) below and the test method shall be in accordance with either (b) or (c).

(a) *Test Assembly.* The assembly shall be fabricated in one pipe size in accordance with the BPS and shall contain at least one of each different type of joint identified in the BPS. More than one test assembly may be prepared if necessary to accommodate all of the joint types or to assure that at least one of each joint type is loaded in both circumferential and longitudinal directions. The size of pipe and fittings in the assembly shall be as follows:

(1) When the largest size to be qualified is DN 100 (NPS 4) or smaller, the test assembly shall be the largest size qualified.

(2) When the largest size to be qualified is greater than DN 100 (NPS 4), the size of the test assembly shall be between 25% and 100% of the largest piping size qualified, but shall be a minimum of DN 100 (NPS 4).

(b) *Burst Test Method.* The test assembly shall be subjected to a burst test in accordance with the applicable sections of ASTM D1599.<sup>5</sup> The time to burst in this standard may be extended. The test is successful if failure initiates outside of any bonded joint.

(c) *Hydrostatic Test Method.* The test assembly shall be subjected to hydrostatic pressure of at least  $P_T$  for not less than 1 hr with no leakage or separation of joints.

(1) For thermoplastics,  $P_T$  shall be determined in accordance with eq. (27)

$$P_T = 0.80\bar{T} \left( \frac{S_S + S_H}{D - \bar{T}} \right) \quad (27)$$

where

$D$  = outside diameter of pipe

$S_H$  = mean long-term hydrostatic strength (LTHS) at the test temperature, in accordance with ASTM D2837 or from the applicable component standard or manufacturer's data

$S_S$  = mean short-term burst stress at the test temperature, in accordance with ASTM D1599<sup>5</sup> or from the applicable component standard or manufacturer's data

$\bar{T}$  = nominal thickness of pipe

(2) For RTR (laminated and filament-wound) and RPM,  $P_T$  shall be 3 times the manufacturer's allowable pressure for the components being joined.

(3) The test shall be conducted so that the joint is loaded in both the circumferential and longitudinal directions.

**A328.2.6 Performance Requalification.** Renewal of a bonding performance qualification is required when

(a) a bonder or bonding operator has not used the specific bonding process for a period of 6 months or more, or

(b) there is specific reason to question the individual's ability to make bonds that meet the BPS

### A328.3 Bonding Materials and Equipment

**A328.3.1 Materials.** Bonding materials that have deteriorated by exposure to air or prolonged storage, or will not spread smoothly, shall not be used in making joints.

**A328.3.2 Equipment.** Fixtures and tools used in making joints shall be in such condition as to perform their functions satisfactorily.

### A328.4 Preparation for Bonding

Preparation shall be defined in the BPS and shall specify such requirements as

- (a) cutting
- (b) cleaning
- (c) preheat
- (d) end preparation
- (e) fit-up

### A328.5 Bonding Requirements

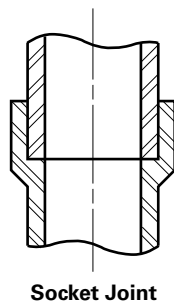
#### A328.5.1 General

(a) Production joints shall be made only in accordance with a written bonding procedure specification (BPS) that has been qualified in accordance with para. A328.2. Manufacturers of piping materials, bonding materials, and bonding equipment should be consulted in the preparation of the BPS.

(b) Production joints shall be made only by qualified bonders or bonding operators who have appropriate training or experience in the use of the applicable BPS and have satisfactorily passed a performance qualification test that was performed in accordance with a qualified BPS.

<sup>5</sup> Titles of referenced standards and specifications are listed in Table A326.1, except ASTM D1599, Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings; ASTM D2657, Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings; ASTM D2855, Practice for Making Solvent-Cemented Joints with PVC Pipe and Fittings; and ASTM F1290, Practice for Electrofusion Joining Polyolefin Pipe and Fittings.



**Figure A328.5.3 Thermoplastic Solvent Cemented Joint**

(c) Each qualified bonder and bonding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing bond or adjacent area shall be stenciled or otherwise suitably marked with the identification symbol of the bonder or bonding operator. Identification stamping shall not be used and any marking paint or ink shall not be detrimental to the piping material. In lieu of marking the bond, appropriate records may be filed.

(d) Qualification in one BPS does not qualify a bonder or bonding operator for any other bonding procedure.

(e) Longitudinal joints are not covered in [para. A328](#).

#### **A328.5.2 Hot Gas Welded Joints in Thermoplastic Piping<sup>5</sup>**

(a) *Preparation.* Surfaces to be hot gas welded together shall be cleaned of any foreign material. For butt welds, the joining edges should be beveled at 20 deg to 40 deg with 1 mm ( $\frac{1}{32}$  in.) root face and root gap.

(b) *Procedure.* Joints shall be made in accordance with the qualified BPS.

(c) *Branch Connections.* A fabricated branch connection shall be made by inserting the branch pipe in the hole in the run pipe. Dimensions of the joint shall conform to [Figure 328.4.4](#), illustration (c). The hole in the run pipe shall be beveled at 45 deg. Alternatively, a fabricated branch connection shall be made using a manufactured full reinforcement saddle with integral socket.

#### **A328.5.3 Solvent Cemented Joints in Thermoplastic Piping<sup>5</sup>**

(a) *Preparation.* Thermoplastic pipe and fitting surfaces shall be prepared in accordance with ASTM D2855 for PVC, ASTM F493 for CPVC, and ASTM D2235 for ABS. A dry fit test of each joint is required before solvent cementing. The pipe shall enter the fitting socket between one-third and two-thirds of the full socket depth when assembled by hand.

(b) *Procedure.* Joints shall be made in accordance with the qualified BPS. ASTM D2855 provides a suitable basis for development of such a procedure. Solvent cements for PVC, CPVC, and ABS shall conform to ASTM D2564, D2846, and D2235, respectively. Application of cement to both surfaces to be joined and assembly of these surfaces shall produce a continuous bond between them with visual evidence of cement at least flush with the outer end of the fitting bore around the entire joint perimeter. See [Figure A328.5.3](#).

(c) *Branch Connections.* A fabricated branch connection shall be made using a manufactured full reinforcement saddle with integral branch socket. The reinforcement saddle shall be solvent cemented to the run pipe over its entire contact surface.

#### **A328.5.4 Heat Fusion Joints in Thermoplastic Piping<sup>5</sup>**

(a) *Preparation.* Surfaces to be heat fused together shall be cleaned of all foreign material.

(b) *Procedure.* Joints shall be made in accordance with the qualified BPS. The general procedures in ASTM D2657, Techniques I — Socket Fusion, II — Butt Fusion, and III — Saddle Fusion, provide a suitable basis for development of such a procedure. Uniform heating of both surfaces to be joined and assembly of these surfaces shall produce a continuous homogeneous bond between them and shall produce a small fillet of fused material at the outer limits of the joint. See [Figure A328.5.4](#) for typical heat fusion joints. Fixtures shall be used to align components when joints are made.

(c) *Branch Connections.* A fabricated branch connection is permitted only where molded fittings are unavailable.

#### **A328.5.5 Electrofusion Joints in Thermoplastic Piping<sup>5</sup>**

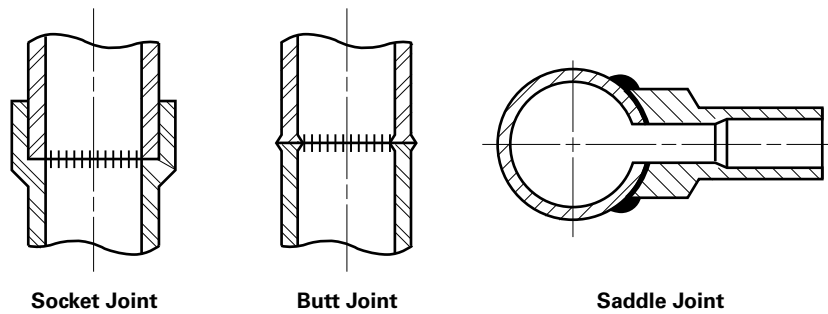
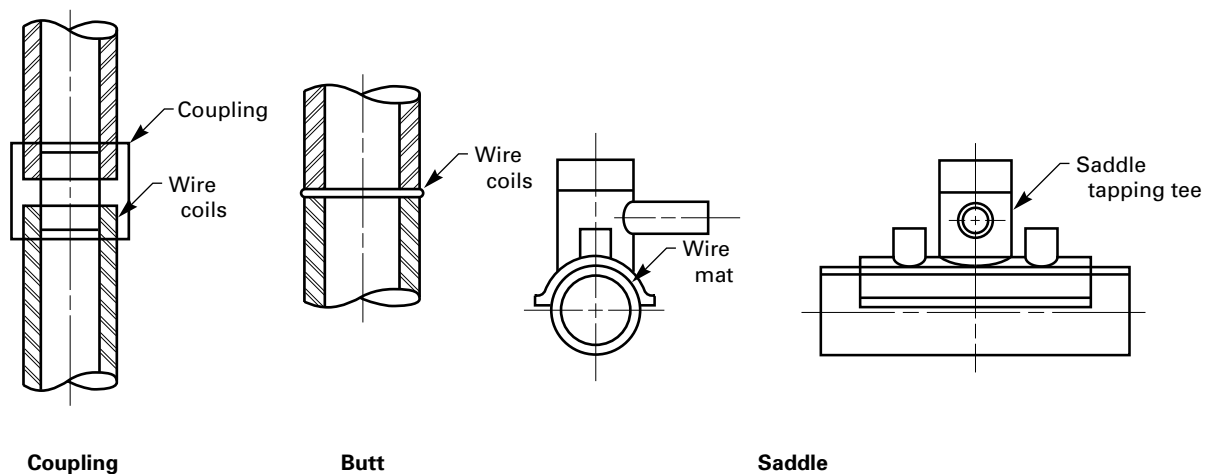
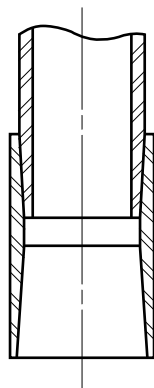
(a) *Preparation.* Surfaces to be heat fused together shall be cleaned of all foreign material.

(b) *Procedure.* Joints shall be made in accordance with the qualified BPS. The general procedures in ASTM F1290, Technique I — Coupling Procedure and Technique II — Saddle Procedure, provide a suitable basis for the development of such a procedure. See [Figure A328.5.5](#).

#### **A328.5.6 Adhesive Joints in RTR and RPM Piping**

(a) *Procedure.* Joints shall be made in accordance with the qualified BPS. Application of adhesive to the surfaces to be joined and assembly of these surfaces shall produce a continuous bond between them and shall seal over all cuts to protect the reinforcement from the service fluid. See [Figure A328.5.6](#).

(b) *Branch Connections.* A fabricated branch connection shall be made using a manufactured full reinforcement saddle having a socket or integral length of branch pipe suitable for a nozzle or coupling. The hole in the run pipe shall be made with a hole saw; the cut

**Figure A328.5.4 Thermoplastic Heat Fusion Joints****Figure A328.5.5 Thermoplastic Electrofusion Joints****Figure A328.5.6 Fully Tapered Thermosetting Adhesive Joint**

edges of the hole shall be sealed with adhesive at the time the saddle is bonded to the run pipe.

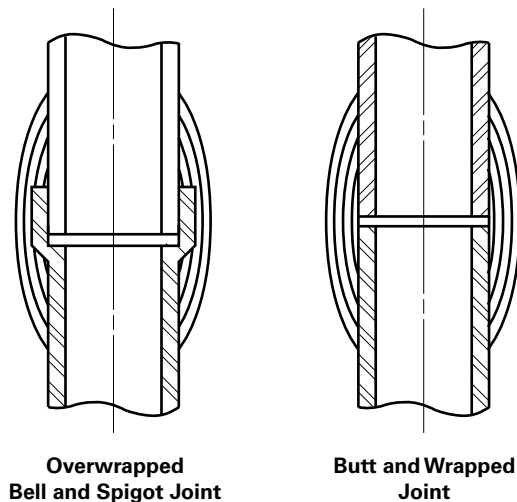
### **A328.5.7 Butt-and-Wrapped Joints in RTR and RPM Piping<sup>5</sup>**

(a) *Procedure.* Joints shall be made in accordance with the qualified BPS. Application of plies of reinforcement saturated with catalyzed resin to the surfaces to be joined shall produce a continuous structure with them. Cuts shall be sealed to protect the reinforcement from the service fluid. See [Figure A328.5.7](#).

(b) *Branch Connections.* For a fabricated branch connection made by inserting the branch pipe into a hole in the run pipe, the hole shall be made with a hole saw.

### **A328.6 Bonding Repair**

Defective material, joints, and other workmanship that fails to meet the requirements of this Code and of the engineering design shall be repaired or replaced. See also [para. 341.3.3](#).

**Figure A328.5.7 Thermosetting Wrapped Joints****A328.7 Seal Bonds**

If threaded joints are to be seal bonded in accordance with [para. A311.2.2](#), the work shall be done by qualified bonders and all exposed threads shall be covered by the seal bond.

**A329 FABRICATION OF PIPING LINED WITH NONMETALS****A329.1 Welding of Metallic Piping****A329.1.1 General**

(a) [Paragraph A329.1](#) applies only to welding subassemblies of metallic piping that have previously been lined with nonmetals.

(b) Welding that conforms to [para. A329.1](#) may be used in accordance with [para. A318.3.1](#).

**A329.1.2 Specific Welding Requirements.** Welding shall conform to the requirements of [para. 328](#) and the following additional requirements:

(a) Modifications made in preparation for welding to suit manufacturer's recommendations shall be specified in the engineering design.

(b) Welding shall be performed so as to maintain the continuity of the lining and its serviceability.

(c) If a lining has been damaged, it shall be repaired or replaced.

(d) Qualification to one WPS for a specific lining material does not qualify a welder or welding operator for any other welding procedure involving different lining materials.

**A329.2 Flaring of Nonmetallic Linings****A329.2.1 General**

(a) [Paragraph A329.2](#) applies only to the flaring of linings in pipe that has previously been lined with nonmetals.

(b) Flaring that conforms to [para. A329.2](#) may be used in accordance with [para. A318.3.2](#).

(c) Flaring shall be performed only in accordance with a written flaring procedure specification, and only by qualified operators who have appropriate training or experience in the use of the applicable flaring procedure specification.

**A332 BENDING AND FORMING****A332.1 General**

[Paragraph 332.1](#) applies in its entirety.

**A332.2 Bending**

[Paragraph 332.2](#) applies, except [para. 332.2.2](#).

**A332.3 Forming**

[Paragraph 332.3](#) applies, except for heat treatment.

**A334 JOINING NONPLASTIC PIPING****A334.1 Borosilicate Glass Piping**

Short unflanged pieces used to correct for differences between fabrication drawings and field dimensions may be cut to length and finished in the field.

**A334.2 Repair of Defects**

Defective material, joints, and other workmanship in nonplastic piping that fail to meet the requirements of [para. A334](#) or of the engineering design shall be repaired or replaced.

Completed repairs and replacements shall be examined, subject to the same limitations on imperfections as the original work.

**A335 ASSEMBLY AND ERECTION****A335.1 Alignment**

[Paragraph 335.1](#) applies in its entirety.

**A335.2 Flanged and Mechanical Joints**

[Paragraph 335.2](#) applies in its entirety.

**A335.2.5 Nonmetallic Bolted Joints**

(a) Bolted joints in nonmetallic piping may be assembled with any combination of flange material and flange facings, except that the following apply when other than flat face flanges and full face gaskets are used:

(1) consideration shall be given to the strength of the flanges, and to sustained loads, displacement strains, and occasional loads described in [paras. A302.3.3](#) and [A302.3.4](#)

(2) an appropriate bolt-up sequence shall be specified

(b) Appropriate limits shall be specified for bolt-up torque, and those limits shall not be exceeded.

(c) Flat washers shall be used under bolt heads and nuts.

**A335.2.6 Metallic Piping Lined With Nonmetals.** In assembling mechanical joints in metallic piping lined with nonmetals, consideration shall be given to means for maintaining electrical continuity between pipe sections, where static sparking could cause ignition of flammable vapors. See [Appendix F, para. FA323.4\(a\)](#).

### A335.3 Threaded Joints

[Paragraph 335.3](#) applies except for [para. 335.3.2](#). See [para. A335.3.2](#).

**A335.3.2 Joints for Seal Bonding.** A threaded joint to be seal bonded shall be made up without thread compound. A joint containing thread compound that leaks during leak testing may be seal bonded in accordance with [para. A328.6](#), provided all compound is removed from exposed threads.

**A335.3.4 Tools, Nonmetallic Piping.** Either strap wrenches or other full circumference wrenches shall be used to tighten threaded pipe joints. Tools and other devices used to hold or apply forces to the pipe shall be such that the pipe surface is not scored or deeply scratched.

**A335.3.5 RTR and RPM Piping.** In assembling threaded joints in RTR and RPM piping, where threads may be exposed to fluids that can attack the reinforcing material, threads shall be coated with sufficient resin to cover the threads and completely fill the clearance between the pipe and the fitting.

### A335.4 Tubing Joints

**A335.4.1 Flared Joints in Thermoplastic Tubing.** In addition to preparation in accordance with [para. 335.4.1](#), the end of the tubing shall be cut perpendicular to the tube centerline, preferably with a tubing cutter specially made for thermoplastic tubing. No cuts, scratches, dirt, or surface damage to either inside or outside diameter are permitted on the pipe end to be flared.

**A335.4.2 Flareless and Compression Tubing Joints.** [Paragraph 335.4.2](#) applies.

### A335.5 Caulked Joints

[Paragraph 335.5](#) applies.

### A335.6 Special Joints

[Paragraph 335.6](#) applies, except that expanded joints are not permitted.

#### A335.6.3 Flexible Elastomeric Sealed Joints.

Assembly of flexible elastomeric sealed joints shall be in accordance with the manufacturer's recommendations and the following:

(a) Seal and bearing surfaces shall be free from injurious imperfections.

(b) Any lubricant used to facilitate joint assembly shall be compatible with the joint components and the intended service.

(c) Proper joint clearances and piping restraints (if not integral in the joint design) shall be provided to prevent joint separation when expansion can occur due to thermal and/or pressure effects.

### A335.8 Assembly of Brittle Piping

**A335.8.1 General.** Care shall be used to avoid scratching of brittle nonmetallic piping in handling and supporting. Any scratched or chipped components shall be replaced. Care shall be used in handling glass-lined and cement-lined metal pipe because the lining can be injured or broken by blows that do not dent or break the pipe.

**A335.8.2 Borosilicate Glass Piping.** In addition to the precaution in [para. A335.8.1](#), borosilicate glass piping components shall be protected from weld spatter. Any component so damaged shall be replaced. Flanges and cushion inserts shall be carefully fitted and aligned to pipe, fittings, and valve ends. Gaskets shall be of the construction recommended for the joint. Installation and torquing of bolts shall be in accordance with the manufacturer's recommendations.

### A335.9 Cleaning of Piping

See [Appendix F, para. F335.9](#).

## PART 10

## INSPECTION, EXAMINATION, AND TESTING

### A340 INSPECTION

[Paragraph 340](#) applies in its entirety.

### A341 EXAMINATION

#### A341.1 General

[Paragraph 341.1](#) applies.

#### A341.2 Responsibility for Examination

[Paragraph 341.2](#) applies in its entirety.

**Table A341.3.2 Acceptance Criteria for Bonds**

| Type of Imperfection                                               | Thermoplastic Material |                        |                     | RTR and RPM Materials<br>[Note (1)] — Adhesive<br>Cemented Joint |
|--------------------------------------------------------------------|------------------------|------------------------|---------------------|------------------------------------------------------------------|
|                                                                    | Hot Gas Welded Joint   | Solvent Cemented Joint | Heat Fusion Joint   |                                                                  |
| Cracks                                                             | None permitted         | Not applicable         | None permitted      | None permitted                                                   |
| Unfilled areas in joint                                            | None permitted         | None permitted         | None permitted      | None permitted                                                   |
| Unbonded areas in joint                                            | None permitted         | None permitted         | None permitted      | None permitted                                                   |
| Inclusions of charred material                                     | None permitted         | Not applicable         | None permitted      | None permitted                                                   |
| Unfused filler material inclusions                                 | None permitted         | Not applicable         | Not applicable      | None permitted                                                   |
| Protrusion of material into pipe<br>bore, % of pipe wall thickness | Not applicable         | Cement, 50%            | Fused material, 25% | Adhesive, 25%                                                    |

NOTE: (1) RTR = reinforced thermosetting resin; RPM = reinforced plastic mortar.

### A341.3 Examination Requirements

**A341.3.1 Responsibility for Examination.** Paragraph 341.3.1 applies, except for paras. 341.3.1(a) and 341.3.1(b), which apply only for metals.

**A341.3.2 Acceptance Criteria.** Acceptance criteria shall be as stated in the engineering design, and shall at least meet the applicable requirements for bonds in Table A341.3.2 and requirements elsewhere in the Code.

**A341.3.3 Defective Components and Workmanship.** Paragraph 341.3.3 applies in its entirety.

**A341.3.4 Progressive Sampling for Examination.** Paragraph 341.3.4 applies in its entirety.

### A341.4 Extent of Required Examination

**A341.4.1 Examination Normally Required.** Piping in Normal Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. A341.3.2 unless otherwise specified.

(a) *Visual Examination.* At least the following shall be examined in accordance with para. 344.2:

(1) materials and components in accordance with para. 341.4.1(a)(1).

(2) at least 5% of fabrication. For bonds, each type of bond made by each bonder and bonding operator shall be represented.

(3) 100% of fabrication for bonds other than circumferential, except those in components made in accordance with a listed specification.

(4) assembly and erection of piping in accordance with paras. 341.4.1(a)(4), 341.4.1(a)(5), and 341.4.1(a)(6).

(b) *Other Examination.* Not less than 5% of all bonded joints shall be examined by in-process examination in accordance with para. 344.7, the joints to be examined being selected to ensure that the work of each bonder and bonding operator making the production joints is examined.

(c) *Certifications and Records.* Paragraph 341.4.1(c) applies.

**A341.4.2 Examination — Category D Fluid Service.** Piping and piping elements for Category D Fluid Service as designated in the engineering design shall be visually examined to the extent necessary to satisfy the examiner that components, materials, and workmanship conform to the requirements of this Code and the engineering design.

### A341.5 Supplementary Examination

**A341.5.1 General.** Any applicable method of examination described in para. 344 may be specified by the engineering design to supplement the examination required by para. A341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those in para. A341.3.2 shall be specified in the engineering design.

**A341.5.2 Examinations to Resolve Uncertainty.** Paragraph 341.5.3 applies.

### A342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

### A343 EXAMINATION PROCEDURES

Paragraph 343 applies in its entirety.

### A344 TYPES OF EXAMINATION

#### A344.1 General

Paragraph 344.1 applies in its entirety.

#### A344.2 Visual Examination

Paragraph 344.2 applies in its entirety.

#### A344.5 Radiographic Examination

Radiographic examination may be used in accordance with para. 344.1.2.

**A344.6 Ultrasonic Examination**

Ultrasonic examination may be used in accordance with [para. 344.1.2](#).

**A344.7 In-Process Examination**

[Paragraph 344.7](#) applies in its entirety.

**A345 TESTING****A345.1 Required Leak Test**

(a) Prior to initial operation, each piping system shall be tested to ensure tightness. The test shall be a hydrostatic leak test in accordance with [para. A345.4](#), except as provided herein.

(b) [Paragraphs 345.1\(a\)](#) and [345.1\(b\)](#) apply.

**A345.2 General Requirements for Leak Test**

Requirements in [para. A345.2](#) apply to more than one type of leak test.

**A345.2.1 Limitations on Pressure.** [Paragraphs 345.2.1\(b\)](#) and [345.2.1\(c\)](#) apply.

**A345.2.2 Other Test Requirements**

(a) [Paragraph 345.2.2\(a\)](#) applies.

(b) The possibility of brittle fracture shall be considered when conducting leak tests on brittle materials or at low temperature.

(c) [Paragraphs 345.2.3](#) through [345.2.7](#) apply.

**A345.3 Preparation for Leak Test**

[Paragraph 345.3](#) applies in its entirety, considering bonds in place of welds, and excluding expansion joints.

**A345.4 Hydrostatic Leak Test**

**A345.4.1 Test Fluid.** [Paragraph 345.4.1](#) applies.

**A345.4.2 Test Pressure**

(a) *Nonmetallic Piping.* Except as provided in [para. A345.4.3](#), the hydrostatic test pressure at any point in a nonmetallic piping system shall be not less

than 1.5 times the design pressure, but shall not exceed 1.5 times the maximum rated pressure of the lowest-rated component in the system.

(b) *Thermoplastic Piping.* For piping systems in which the design temperature is above the test temperature, [para. 345.4.2\(b\)](#) applies, except that  $S$  and  $S_T$  shall be from [Table B-1](#) instead of [Table A-1](#) or [Table A-1M](#).

(c) *Metallic Piping With Nonmetallic Lining.* [Paragraph 345.4.2](#) applies.

**A345.4.3 Hydrostatic Test of Piping With Vessels as a System.** [Paragraph 345.4.3](#) applies.

**A345.5 Pneumatic Leak Test**

**A345.5.1 Precautions.** In addition to the requirements of [para. 345.5.1](#), a pneumatic test of nonmetallic piping is permitted only with the owner's approval, and precautions in [Appendix F](#), [para. FA323.4](#) should be considered.

**A345.5.2 Other Requirements**

(a) [Paragraphs 345.5.2](#) through [345.5.5](#) apply.

(b) PVC and CPVC piping shall not be pneumatically tested.

**A345.6 Hydrostatic-Pneumatic Leak Test**

If a combined hydrostatic-pneumatic leak test is used, the requirements of [para. A345.5](#) shall be met, and the pressure in the liquid-filled part of the piping shall not exceed the values calculated in accordance with [para. A345.4.2](#) or [345.4.2](#), as applicable.

**A345.7 Initial Service Leak Test**

[Paragraph 345.7](#) applies in its entirety for Category D Fluid Service only.

**A345.8 Sensitive Leak Test**

[Paragraph 345.8](#) applies.

**A346 RECORDS**

[Paragraph 346](#) applies in its entirety.



## Chapter VIII

# Piping for Category M Fluid Service

### M300 GENERAL STATEMENTS

(a) Chapter VIII pertains to piping designated by the owner as being in Category M Fluid Service. See para. 300(b)(1) and Appendix M.

(b) The organization, content, and paragraph designations of this Chapter correspond to those of the base Code (Chapters I through VI) and Chapter VII. The prefix M is used.

(c) Provisions and requirements of the base Code and Chapter VII apply only as stated in this Chapter.

(d) Consideration shall be given to the possible need for engineered safeguards as described in Appendix G, para. G300.3, in addition to the inherent safeguards described in paras. G300.1 and G300.2.

(e) This Chapter makes no provision for piping to be used under severe cyclic conditions. If it is not feasible to eliminate the severe cyclic conditions, the engineering design shall specify any necessary provisions in accordance with para. 300(c)(5).

(f) Chapter I applies in its entirety.

### PART 1 CONDITIONS AND CRITERIA

#### M301 DESIGN CONDITIONS

Paragraph 301 applies in its entirety, with the exceptions of paras. 301.3 and 301.5. See paras. M301.3 and M301.5.

#### M301.3 Design Temperature, Metallic Piping

Use of any temperature other than the fluid temperature as the design temperature shall be substantiated by heat transfer calculations confirmed by tests or by experimental measurements.

#### M301.5 Dynamic Effects

Paragraph 301.5 applies with the exception of paras. 301.5.1 and 301.5.4. See paras. M301.5.1 and M301.5.4.

**M301.5.1 Impact.** Design, layout, and operation of piping shall be conducted so as to minimize impact and shock loads. In the event that such loadings are unavoidable, para. 301.5.1 applies.

**M301.5.4 Vibration.** Suitable dynamic analysis, such as computer simulation, shall be made where necessary to avoid or minimize conditions that lead to detrimental vibration, pulsation, or resonance effects in the piping.

### M302 DESIGN CRITERIA

#### M302.1 General

Paragraph M302 pertains to pressure-temperature ratings, stress criteria, design allowances, and minimum design values, together with permissible variations of these factors as applied to piping design. Paragraph 302 applies in its entirety, with the exception of para. 302.2.4. See para. M302.2.4.

**M302.2.4 Allowance for Pressure and Temperature Variations, Metallic Piping.** Use of allowances in para. 302.2.4 is not permitted.

### PART 2 PRESSURE DESIGN OF METALLIC PIPING COMPONENTS

#### M303 GENERAL

Paragraph 303 applies in its entirety.

#### M304 PRESSURE DESIGN OF METALLIC COMPONENTS

Paragraph 304 applies in its entirety.

### PART 3 FLUID SERVICE REQUIREMENTS FOR METALLIC PIPING COMPONENTS

#### M305 PIPE

##### M305.1 General

Listed pipe may be used in accordance with para. M305.2. Unlisted pipe may be used only as provided in para. 302.2.3.

## M305.2 Specific Requirements for Metallic Pipe

Pipe listed in [para. 305.2.2](#) shall not be used. The provision for severe cyclic conditions in [para. 305.2.3](#) does not apply [see [para. M300\(e\)](#)].

## M306 METALLIC FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

*General.* Fittings, bends, miters, laps, and branch connections may be used in accordance with [paras. M306.1](#) through [M306.6](#). Pipe and other materials used in such components shall be suitable for the manufacturing process and the fluid service.

### M306.1 Pipe Fittings

[Paragraph 306.1](#) applies in its entirety, with the exception of [paras. 306.1.3](#) and [306.1.4](#). See [para. M306.1.3](#).

#### M306.1.3 Specific Fittings

(a) Proprietary welding branch outlet fittings that have been design proof tested successfully as prescribed in ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101 may be used within their established ratings.

(b) Fittings conforming to MSS SP-43 and MSS SP-119 shall not be used.

(c) Proprietary “Type C” lap-joint stub-end butt-welding fittings shall not be used.

### M306.2 Pipe Bends

[Paragraph 306.2](#) applies, except that bends designed as creased or corrugated shall not be used.

### M306.3 Miter Bends

A miter bend shall conform to [para. 306.3.1](#) and shall not make a change in direction at a single joint (angle  $\alpha$  in [Figure 304.2.3](#)) greater than 22.5 deg. [Paragraph 306.3.3](#) does not apply [see [para. M300\(e\)](#)].

### M306.4 Fabricated or Flared Laps

**M306.4.1 General.** The following requirements do not apply to fittings conforming to [para. M306.1](#), nor to laps integrally forged on pipe ends. [Paragraph 306.4.1](#) applies.

**M306.4.2 Flared Laps.** Flared laps shall not be used.

### M306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to [para. M306.1](#). [Paragraph 306.5.1](#) applies, with the following exceptions:

(a) Of the methods listed in [para. 304.3.1\(a\)](#), the one in [para. 304.3.1\(a\)\(3\)](#) may be used only if those in [paras. 304.3.1\(a\)\(1\)](#) and [304.3.1\(a\)\(2\)](#) are unavailable.

(b) Of the branch connections described in [paras. 304.3.2\(b\)](#) and [304.3.2\(c\)](#), those having threaded outlets are permitted only in accordance with [para. M314](#) and those having socket welding outlets are permitted only in accordance with [para. M311.2](#).

### M306.6 Closures

The following requirements do not apply to blind flanges or to fittings conforming to [para. M306.1](#). Of the closures described in [para. 304.4](#), flat closures in accordance with ASME BPVC, Section VIII, Division 1, UG-34 and UW-13, and conical closures without transition knuckles [UG-32(g) and UG-33(f)], may be used only if others are not available. The requirements in [M306.5](#) apply to openings in closures [see also [para. 304.4.2\(b\)](#)].

## M307 METALLIC VALVES AND SPECIALTY COMPONENTS

The following requirements for valves shall also be met as applicable by other pressure-containing piping components, e.g., traps, strainers, and separators. See also [Appendix F](#), [paras. F301.4](#) and [F307](#).

### M307.1 General

[Paragraph 307.1](#) applies, subject to the requirements in [para. M307.2](#).

### M307.2 Specific Requirements

(a) [Paragraph 307.2.2](#) applies.

(b) Valves having threaded bonnet joints (other than union joints) shall not be used.

(c) Only metallic valves conforming to the following requirements may be used:

(1) Special consideration shall be given to valve design to prevent stem leakage to the environment.

(2) Bonnet or cover plate closures and body joints shall be flanged, secured by at least four bolts with gasketing conforming to [para. 308.4](#); or proprietary, attached by bolts, lugs, or other substantial means, and having a gasket design that increases gasket compression as fluid pressure increases; or secured with a full penetration weld made in accordance with [para. M311](#); or secured by a straight thread sufficient for mechanical strength, a metal-to-metal seat, and a seal weld made in accordance with [para. M311](#), all acting in series.

## M308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

[Paragraph 308.1](#) applies in its entirety.

### M308.2 Specific Requirements for Metallic Flanges

[Paragraph 308.2.4](#) does not apply [see [para. M300\(e\)](#)]. The following shall not be used:

- (a) single-welded slip-on flanges
- (b) expanded-joint flanges
- (c) slip-on flanges used as lapped flanges unless the requirements in [para. 308.2.1\(c\)](#) are met
- (d) threaded metallic flanges, except those employing lens rings or similar gaskets and those used in lined pipe where the liner extends over the gasket face

### M308.3 Flange Facings

[Paragraph 308.3](#) applies in its entirety.

### M308.4 Gaskets

[Paragraph 308.4](#) applies in its entirety.

### M308.5 Blanks

All blanks shall be marked with material, rating, and size.

## M309 BOLTING

[Paragraph 309](#) applies, except for [para. 309.2.4](#) [see [para. M300\(e\)](#)].

## PART 4

### FLUID SERVICE REQUIREMENTS FOR METALLIC PIPING JOINTS

#### M310 METALLIC PIPING, GENERAL

[Paragraph 310](#) applies in its entirety.

#### M311 WELDED JOINTS IN METALLIC PIPING

Welded joints may be made in any metal for which it is possible to qualify welding procedures, welders, and welding operators in accordance with [para. M328](#).

##### M311.1 General

[Paragraph 311.1](#) applies with the following exceptions:

- (a) Split backing rings shall not be used.
- (b) Socket welded joints greater than DN 50 (NPS 2) are not permitted.
- (c) Examination shall be in accordance with [para. M341.4](#).

##### M311.2 Specific Requirements

[Paragraphs 311.2.1\(a\); 311.2.2\(a\), 311.2.2\(b\), and 311.2.2\(d\); 311.2.3; and 311.2.4](#) apply.

#### M312 FLANGED JOINTS IN METALLIC PIPING

[Paragraph 312](#) applies in its entirety.

#### M313 EXPANDED JOINTS IN METALLIC PIPING

Expanded joints shall not be used.

#### M314 THREADED JOINTS IN METALLIC PIPING

##### M314.1 General

[Paragraphs 314.1\(a\), 314.1\(b\), and 314.1\(c\)](#) apply.

##### M314.2 Specific Requirements

**M314.2.1 Taper-Threaded Joints.** [Paragraph 314.2.1](#) applies except that only components suitable for Normal Fluid Service in sizes  $8 \leq DN \leq 25$  ( $\frac{1}{4} \leq NPS \leq 1$ ) are permitted (see [Table 314.2.1](#)). Sizes smaller than DN 20 (NPS  $\frac{3}{4}$ ) shall be safeguarded (see [Appendix G](#)).

**M314.2.2 Straight-Threaded Joints.** [Paragraph 314.2.2](#) applies. In addition, components shall have adequate mechanical strength and the joint shall have a confined seating surface not subject to relative rotation as or after the joint is tightened. [See [Figure 335.3.3](#), illustrations (b) and (c) for acceptable construction.]

#### M315 TUBING JOINTS IN METALLIC PIPING

[Paragraph 315](#) applies, except for [para. 315.2\(b\)](#).

#### M316 CAULKED JOINTS

Caulked joints shall not be used.

#### M317 SOLDERED AND BRAZED JOINTS

Soldered, brazed, and braze welded joints shall not be used.

#### M318 SPECIAL JOINTS IN METALLIC PIPING

[Paragraph 318](#) applies, with the exception that adhesive joints and bell type joints shall not be used.

## PART 5

### FLEXIBILITY AND SUPPORT OF METALLIC PIPING

#### M319 FLEXIBILITY OF METALLIC PIPING

[Paragraph 319](#) applies, with the exception that the simplified rules in [para. 319.4.1\(c\)](#) do not apply.

#### M320 ANALYSIS OF SUSTAINED LOADS

[Paragraph 320](#) applies.

#### M321 PIPING SUPPORT

[Paragraph 321](#) applies, except that supporting elements welded to the piping shall be of listed material.

## PART 6 SYSTEMS

### M322 SPECIFIC PIPING SYSTEMS

#### M322.3 Instrument Piping

Paragraph 322.3 applies, with the exception that for signal tubing in contact with process fluids and process temperature-pressure conditions

(a) tubing shall be not larger than 16 mm ( $\frac{5}{8}$  in.) O.D. and shall be suitable for the service

(b) an accessible block valve shall be provided to isolate the tubing from the pipeline

(c) joining methods shall conform to the requirements of para. M315

#### M322.6 Pressure-Relieving Systems

Paragraph 322.6 applies, except for para. 322.6.3. See para. M322.6.3.

##### M322.6.3 Overpressure Protection

(a) Paragraph 322.6.3(a) applies.

(b) Relief set pressure shall be in accordance with ASME BPVC, Section VIII, Division 1.

(c) The maximum relieving pressure shall be in accordance with Section VIII, Division 1.

## PART 7 METALLIC MATERIALS

### M323 GENERAL REQUIREMENTS

#### M323.1 Materials and Specifications

Paragraph 323.1.1 applies. See paras. M323.1.2, M323.1.3, and M323.1.4.

**M323.1.2 Unlisted Materials.** Paragraph 323.1.2 applies, with the additional requirement that the designer shall fully document the determination of allowable stresses as part of the engineering design.

**M323.1.3 Unknown Materials.** Materials of unknown specification shall not be used.

**M323.1.4 Reclaimed Metallic Materials.** Reclaimed materials may be used when the material certification records are available for the specific materials employed, and the designer is assured that the material is sound and free from harmful defects.

#### M323.2 Temperature Limitations

Paragraph 323.2 applies with the exception that, in regard to lower temperature limits, the relaxation of minimum temperature limits stated in Notes (3) and (6) of Table 323.2.2 and in paras. 323.2.2(h) and 323.2.2(i) is not permitted.

#### M323.3 Impact Testing Methods and Acceptance Criteria

Paragraph 323.3 applies in its entirety.

#### M323.4 Fluid Service Requirements for Metallic Materials

Paragraph 323.4.1 applies.

**M323.4.2 Specific Requirements.** Paragraph 323.4.2 applies, except that cast irons other than ductile iron shall not be used for pressure-containing parts, and lead and tin shall be used only as linings.

**M323.4.3 Metallic Cladding and Lining Materials.** In addition to the requirements of para. 323.4.3, where materials covered in paras. 323.4.2(c)(2) and 323.4.3 are used as cladding or lining in which the cladding or lining also serves as a gasket or as part of the flange facing, consideration shall be given to the design of the flanged joint to prevent leakage to the environment.

#### M323.5 Deterioration of Materials in Service

Paragraph 323.5 applies in its entirety.

### M325 MATERIALS — MISCELLANEOUS

#### M325.1 Joining and Auxiliary Materials

In applying para. 325, materials such as solvents, brazes, and solders shall not be used. Nonmetallic materials used as gaskets and packing materials shall be suitable for the fluid service.

## PART 8 STANDARDS FOR PIPING COMPONENTS

### M326 DIMENSIONS AND RATINGS OF COMPONENTS

Paragraph 326.1.3 applies.

#### M326.1 Dimensional Requirements

**M326.1.1 Listed Piping Components.** Except for prohibitions and restrictions stated elsewhere in Chapter VIII, components made in accordance with standards and specifications listed in Table 326.1 may be used in Category M service.

**M326.1.2 Unlisted Piping Components.** Paragraph 326.1.2 applies, except that dimensions of unlisted components shall be governed by requirements in paras. 303 and 304.

#### M326.2 Ratings of Components

Paragraph 326.2 applies in its entirety.

**M326.3 Reference Documents**

Paragraph 326.3 applies in its entirety.

**PART 9  
FABRICATION, ASSEMBLY, AND ERECTION OF  
METALLIC PIPING**

**M327 GENERAL**

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes in paras. M328, M330, M331, and M332. When any of these processes is used in assembly and erection, requirements are the same as for fabrication.

**M328 WELDING OF METALS**

Welding shall be in accordance with paras. M311.1 and 328, except see para. M328.3.

**M328.3 Welding Materials**

Paragraph 328.3 applies in its entirety, except that split backing rings shall not be used, and removable backing rings and consumable inserts may be used only where their suitability has been demonstrated by procedure qualification.

**M330 PREHEATING OF METALS**

Paragraph 330 applies in its entirety.

**(20) M331 HEAT TREATMENT OF METALS**

Paragraph 331 applies in its entirety, with the exception that no requirements less stringent than those of Table 331.1.2 or Table 331.1.3 for PWHT shall be specified.

**M332 BENDING AND FORMING OF METALS**

Paragraph 332 applies in its entirety, except that bending that conforms to para. 332.2.3 is not permitted.

**M335 ASSEMBLY AND ERECTION OF METALLIC PIPING****M335.1 General**

**M335.1.1 Alignment.** In addition to the requirements of para. 335.1, any bending or forming required for alignment and fit-up shall be heat treated if required by para. 332.4.

**M335.2 Flanged Joints**

Paragraph 335.2 applies in its entirety.

**M335.3 Threaded Joints**

Paragraphs 335.3.1 and 335.3.2 apply. See paras. M335.3.3 and M335.3.4.

**M335.3.3 Straight-Threaded Joints.** The requirements of para. 335.3.3 are subject to the limitations in para. M322.

**M335.3.4 Condition of Threads.** Taper-threaded components and threaded ends permitted under para. M314.2.1 shall be examined before assembly for cleanliness and continuity of threads and shall be rejected if not in conformance with ASME B1.20.1 or other applicable standards.

**M335.4 Tubing Joints**

**M335.4.1 Flared Tubing Joints.** The requirements of para. 335.4.1 apply; however, see para. M322 for limitations associated with specific piping systems.

**M335.4.2 Flareless and Compression Tubing Joints.** The requirements of para. 335.4.2 apply; however, see para. M322 for limitations associated with specific piping systems.

**M335.6 Special Joints**

Special joints shall be in accordance with paras. M318 and 335.6.1.

**M335.9 Cleaning of Piping**

See Appendix F, para. F335.9.

**M335.10 Identification of Piping**

See Appendix F, para. F335.10.

**PART 10  
INSPECTION, EXAMINATION, TESTING, AND  
RECORDS OF METALLIC PIPING**

**M340 INSPECTION**

Paragraph 340 applies in its entirety.

**M341 EXAMINATION**

Paragraphs 341.1, 341.2, 341.3, and 341.5 apply in their entirety. See para. M341.4.

**M341.4 Extent of Required Examination**

Paragraph 341.4.1 applies with the following exceptions:

(a) *Visual Examination*

(1) All fabrication shall be examined.

(2) All threaded, bolted, and other mechanical joints shall be examined.

(b) *Other Examination.* The radiography/ultrasonic examination requirements of [para. 341.4.1\(b\)\(1\)](#) apply, except that 100% of circumferential butt and miter welds and of fabricated lap and branch connection welds comparable to those shown in [Figure 328.5.4E](#); [Figure 328.5.4F](#); and [Figure 328.5.5](#), illustrations (d) and (e), shall be examined.

#### **M342 EXAMINATION PERSONNEL**

[Paragraph 342](#) applies.

#### **M343 EXAMINATION PROCEDURES**

[Paragraph 343](#) applies.

#### **M344 TYPES OF EXAMINATION**

[Paragraph 344](#) applies in its entirety.

#### **M345 TESTING**

[Paragraph 345](#) applies, except that

(a) a sensitive leak test in accordance with [para. 345.8](#) shall be included in the required leak test ([para. 345.1](#))

(b) the initial service leak test ([para. 345.7](#)) does not apply

#### **M346 RECORDS**

[Paragraph 346](#) applies in its entirety.

### **PARTS 11 THROUGH 20, CORRESPONDING TO CHAPTER VII**

See [para. M300\(b\)](#).

#### **MA300 GENERAL STATEMENTS**

[Paragraphs MA300](#) through [MA346](#) apply to nonmetallic piping and piping lined with nonmetals, based on [Chapter VII](#). [Paragraph A300\(d\)](#) applies.

### **PART 11 CONDITIONS AND CRITERIA**

#### **MA301 DESIGN CONDITIONS**

[Paragraph A301](#) applies in its entirety.

#### **MA302 DESIGN CRITERIA**

[Paragraphs A302.1](#) and [A302.4](#) apply. See [paras. MA302.2](#) and [MA302.3](#).

#### **MA302.2 Pressure-Temperature Design Criteria**

[Paragraph A302.2](#) applies, with the exception of [para. A302.2.4](#). See [para. MA302.2.4](#).

**MA302.2.4 Allowances for Pressure and Temperature Variation.** [Paragraph A302.2.4\(a\)](#) applies to both nonmetallic piping and to metallic piping with nonmetallic lining.

#### **MA302.3 Allowable Stresses and Other Design Limits**

[Paragraph A302.3](#) applies.

#### **MA302.4 Allowances**

[Paragraph 302.4](#) applies in its entirety.

### **PART 12 PRESSURE DESIGN OF NONMETALLIC PIPING COMPONENTS**

#### **MA303 GENERAL**

[Paragraph A303](#) applies in its entirety.

#### **MA304 PRESSURE DESIGN OF NONMETALLIC COMPONENTS**

[Paragraph A304](#) applies in its entirety.

### **PART 13 FLUID SERVICE REQUIREMENTS FOR NONMETALLIC PIPING COMPONENTS**

#### **MA305 PIPE**

[Paragraph A305](#) applies in its entirety.

#### **MA306 NONMETALLIC FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS**

[Paragraphs A306.1](#) and [A306.2](#) apply. See [para. MA306.3](#).

#### **MA306.3 Miter Bends**

Miter bends not designated as fittings conforming to [para. A306.1](#) shall not be used.

#### **MA306.4 Fabricated Laps**

Fabricated laps shall not be used.

#### **MA306.5 Fabricated Branch Connections**

Nonmetallic fabricated branch connections shall not be used.



**MA307 VALVES AND SPECIALTY COMPONENTS**

[Paragraph A307](#) applies, except that nonmetallic valves and specialty components shall not be used.

**MA308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS**

[Paragraphs A308.1, 308.3, and A308.4](#) apply in their entirety. See [para. MA308.2](#).

**MA308.2 Nonmetallic Flanges**

Threaded nonmetallic flanges shall not be used.

**MA309 BOLTING**

[Paragraph A309](#) applies in its entirety.

**PART 14  
FLUID SERVICE REQUIREMENTS FOR  
NONMETALLIC PIPING JOINTS**

**MA310 GENERAL**

[Paragraph 310](#) applies in its entirety.

**MA311 BONDED JOINTS****MA311.1 General**

[Paragraph A311.1](#) applies in its entirety.

**MA311.2 Specific Requirements**

Hot gas welded, heat fusion, solvent cemented, and adhesive bonded joints are not permitted except in linings.

**MA312 FLANGED JOINTS**

[Paragraph 312](#) applies in its entirety.

**MA313 EXPANDED JOINTS**

Expanded joints shall not be used.

**MA314 THREADED JOINTS****MA314.1 General**

Threaded joints shall not be used.

**MA315 TUBING JOINTS IN NONMETALLIC PIPING**

[Paragraph A315](#) applies in its entirety.

**MA316 CAULKED JOINTS**

Caulked joints shall not be used.

**MA318 SPECIAL JOINTS**

[Paragraph A318](#) applies in its entirety.

**PART 15  
FLEXIBILITY AND SUPPORT OF NONMETALLIC  
PIPING**

**MA319 PIPING FLEXIBILITY**

[Paragraph A319](#) applies in its entirety.

**MA321 PIPING SUPPORT**

[Paragraph A321](#) applies in its entirety.

**PART 16  
NONMETALLIC AND NONMETALLIC-LINED  
SYSTEMS**

**MA322 SPECIFIC PIPING SYSTEMS**

[Paragraph A322](#) applies in its entirety.

**PART 17  
NONMETALLIC MATERIALS**

**MA323 GENERAL REQUIREMENTS**

[Paragraph A323.1](#) applies with the additional requirement described in [para. MA323.1.2](#). [Paragraph A323.2](#) applies in its entirety. See [para. MA323.4](#).

**MA323.1.2 Unlisted Materials.** [Paragraph 323.1.2](#) applies with the additional requirement that the designer shall fully document the determination of allowable stresses as part of the engineering design.

**MA323.4 Fluid Service Requirements for Nonmetallic Materials**

[Paragraph A323.4.1](#) applies. See [paras. MA323.4.2 and MA323.4.3](#).

**MA323.4.2 Specific Requirements.** [Paragraph A323.4.2](#) applies, except that materials listed under [paras. A323.4.2\(a\), A323.4.2\(b\), and A323.4.2\(d\)](#) may be used only as linings. Thermoplastics may be used as gaskets in accordance with [paras. M325.1 and MA323.4.3](#).

**MA323.4.3 Nonmetallic Lining Materials.** [Paragraph A323.4.3](#) applies with the additional requirement that where a material in [para. A323.4.2](#) is used as a lining that also serves as a gasket or as part of the flange facing, consideration shall be given to design of the flanged joint to prevent leakage to the environment.

**PART 18**  
**STANDARDS FOR NONMETALLIC AND**  
**NONMETALLIC-LINED PIPING COMPONENTS**

**MA326 DIMENSIONS AND RATINGS OF COMPONENTS**

Paragraph A326 applies in its entirety. Table A326.1 applies, except for components and systems prohibited or restricted elsewhere in this Chapter.

**PART 19**  
**FABRICATION, ASSEMBLY, AND ERECTION OF**  
**NONMETALLIC AND NONMETALLIC-LINED PIPING**

**MA327 GENERAL**

Paragraph A327 applies in its entirety.

**MA328 BONDING OF PLASTICS**

Paragraph A328 applies in its entirety.

**MA329 FABRICATION OF PIPING LINED WITH NONMETALS**

Paragraph A329 applies in its entirety.

**MA332 BENDING AND FORMING**

Paragraph A332 applies in its entirety.

**MA334 JOINING NONPLASTIC PIPING**

Paragraph A334 applies in its entirety.

**MA335 ASSEMBLY AND ERECTION**

Paragraph A335 applies in its entirety.

**PART 20**  
**INSPECTION, EXAMINATION, TESTING, AND**  
**RECORDS OF NONMETALLIC AND**  
**NONMETALLIC-LINED PIPING**

**MA340 INSPECTION**

Paragraph 340 applies in its entirety.

**MA341 EXAMINATION**

Paragraph A341 applies in its entirety.

**MA341.1 General**

Paragraphs 341.1, 341.2, A341.3, and A341.5 apply in their entirety. See para. MA341.4.

**MA341.4 Extent of Required Examination**

Paragraph A341.4.1 applies, except as follows:

(a) *Visual Examination*

(1) All fabrication shall be visually examined.

(2) All bolted and other mechanical joints shall be examined.

**MA342 EXAMINATION PERSONNEL**

Paragraph 342 applies in its entirety.

**MA343 EXAMINATION PROCEDURES**

Paragraph 343 applies in its entirety.

**MA344 TYPES OF EXAMINATION**

Paragraph A344 applies in its entirety.

**MA345 TESTING**

Paragraph A345 applies except that

(a) a sensitive leak test in accordance with para. 345.8 shall be included in the required leak test (para. A345.1)

(b) the initial service leak test (para. A345.7) does not apply

**MA346 RECORDS**

Paragraph 346 applies in its entirety.

# Chapter IX

## High Pressure Piping

### (20) K300 GENERAL STATEMENTS

(a) **Chapter IX** provides alternative rules for design and construction of piping designated by the owner as being in High Pressure Fluid Service. See [para. 300\(b\)\(1\)](#) and [Appendix M](#).

(1) Use of this Chapter is permitted only when the owner designates the piping as being in High Pressure Fluid Service. When piping is so designated, the requirements of this Chapter apply in their entirety.

(2) There are no pressure limitations for the application of these rules. See [Appendix F, para. FK300](#).

(b) **Responsibilities.** In addition to the responsibilities stated in [para. 300\(b\)](#)

(1) for piping designated as being in High Pressure Fluid Service, the owner shall provide all system operations information necessary for the designer to perform the analyses and testing required by this Chapter

(2) the designer shall make a written report to the owner summarizing the design calculations and certifying that the design has been performed in accordance with this Chapter

(c) The organization, content, and, wherever possible, paragraph designations of this Chapter correspond to those of the base Code ([Chapters I](#) through [VI](#)). The prefix K is used.

(d) Provisions and requirements of the base Code apply only as stated in this Chapter.

(e) [Paragraphs 300\(a\)](#) and [300\(c\)](#) through [300\(f\)](#) apply.

### (20) K300.1 Scope

**K300.1.1 Content and Coverage.** [Paragraph 300.1.1](#) applies with the exceptions stated in [paras. K300.1.3](#) and [K300.1.6](#).

**K300.1.2 Packaged Equipment Piping.** Interconnecting piping as described in [para. 300.1.2](#) shall conform to the requirements of this Chapter.

**K300.1.3 Exclusions.** In addition to the exclusions stated in [para. 300.1.3](#), this Chapter excludes nonmetallic piping and piping lined with nonmetals.

**K300.1.4 Units of Measure.** [Paragraph 300.1.4](#) applies.

**K300.1.5 Rounding.** [Paragraph 300.1.5](#) applies.

**K300.1.6 Category M Fluid Service.** This Chapter makes no provision for piping in Category M Fluid Service. If such piping is required by the owner, the engineering design shall be developed as provided in [para. 300\(c\)\(5\)](#).

### K300.2 Definitions

[Paragraph 300.2](#) applies except for terms relating only to nonmetals and severe cyclic conditions.

The term “allowable stress” is used in lieu of basic allowable stress.

The term “safeguarding” and other terms characterizing hazardous fluid services are not used in this Chapter but should be taken into account in design.

### K300.3 Nomenclature

[Paragraph 300.3](#) applies.

### K300.4 Status of Appendices

[Paragraph 300.4](#) and [Table 300.4](#) apply, except for [Appendices A, B, H, L, R, S, V, and X](#).

## PART 1

### CONDITIONS AND CRITERIA

### K301 DESIGN CONDITIONS

[Paragraph 301](#) applies with the exceptions of [paras. 301.2, 301.3, 301.4.2, 301.5, and 301.7.3](#).

### K301.2 Design Pressure

**K301.2.1 General.** [Paragraph 301.2.1](#) applies, except that references to [para. 302.2.4](#) are not applicable and refer to [para. K304](#) instead of [para. 304](#).

**K301.2.2 Required Pressure Containment or Relief.** [Paragraphs 301.2.2\(a\) and 301.2.2\(b\)](#) apply, but refer to [para. K322.6.3](#) instead of [para. 322.6.3](#). [Paragraph 301.2.2\(c\)](#) is not applicable.

### K301.3 Design Temperature

[Paragraph 301.3](#) applies with the exceptions of [paras. 301.3.1 and 301.3.2](#) and the following exceptions in the text:

(a) Refer to [para. K301.2](#) instead of [para. 301.2](#).

(b) Refer to [para. K301.3.2](#) instead of [para. 301.3.2](#).

**K301.3.1 Design Minimum Temperature.** [Paragraph 301.3.1](#) applies, but refer to [para. K323.2.2](#) instead of [para. 323.2.2](#).

**K301.3.2 Uninsulated Components.** The fluid temperature shall be used as the component temperature.

## K301.4 Ambient Effects

**K301.4.2 Fluid Expansion Effects.** [Paragraph 301.4.2](#) applies, except that reference to [para. 322.6.3\(b\)\(2\)](#) is not applicable.

## K301.5 Dynamic Effects

[Paragraph 301.5](#) applies with the exception of [para. 301.5.4](#).

**K301.5.4 Vibration.** Suitable dynamic analysis shall be made where necessary, to avoid or minimize conditions that lead to detrimental vibration, pulsation, or resonance effects in the piping.

## K301.7 Thermal Expansion and Contraction Effects

**K301.7.3 Loads Due to Differences in Expansion Characteristics.** [Paragraph 301.7.3](#) applies, except that reference to metallic-nonmetallic piping is not applicable.

# K302 DESIGN CRITERIA

## K302.1 General

In [para. K302](#), pressure-temperature ratings, stress criteria, design allowances, and minimum design values are stated, and permissible variations of these factors as applied to design of high pressure piping systems are formulated.

The designer shall be satisfied as to the adequacy of the design, and of materials and their manufacture, considering at least the following:

- (a) tensile, compressive, flexural, and shear strength at design temperature
- (b) fatigue strength
- (c) design stress and its basis
- (d) ductility and toughness
- (e) possible deterioration of mechanical properties in service
- (f) thermal properties
- (g) temperature limits
- (h) resistance to corrosion and erosion
- (i) fabrication methods
- (j) examination and testing methods
- (k) hydrostatic test conditions
- (l) bore imperfections

## K302.2 Pressure-Temperature Design Criteria

**K302.2.1 Listed Components Having Established Ratings.** Pressure-temperature ratings for certain piping components have been established and are contained in some of the standards in [Table K326.1](#). Unless limited elsewhere in this Chapter, those ratings are acceptable for design pressures and temperatures under this Chapter. With the owner's approval, the rules and limits of this Chapter may be used to extend the pressure-temperature ratings of a component beyond the ratings of the listed standard, but not beyond the limits stated in [para. K323.2](#).

### K302.2.2 Listed Components Not Having Specific Ratings

(a) Piping components for which design stresses have been developed in accordance with [para. K302.3](#), but that do not have specific pressure-temperature ratings, shall be rated by rules for pressure design in [para. K304](#), within the range of temperatures for which stresses are shown in [Table K-1](#), modified as applicable by other rules of this Chapter.

(b) Piping components that do not have allowable stresses or pressure-temperature ratings shall be qualified for pressure design as required by [para. K304.7.2](#).

**K302.2.3 Unlisted Components.** Piping components not listed in [Table K326.1](#) may be used subject to all of the following requirements:

- (a) The material shall comply with [para. K323](#).
- (b) The designer shall be satisfied that the design is suitable for the intended service.
- (c) Pressure-temperature ratings shall be established in accordance with the rules in [para. K304](#).
- (d) Fatigue analysis shall be performed as required by [para. K304.8](#).

**K302.2.4 Allowance for Pressure and Temperature Variations.** Variations in pressure, temperature, or both above the design conditions, except during pressure-relieving events (see [para. K322.6.3](#)), are not permitted for any piping system. The design pressure and design temperature resulting in the most severe coincident pressure and temperature shall determine the design conditions. See [paras. K301.2](#) and [K301.3](#).

**K302.2.5 Ratings at Junction of Different Services.** [Paragraph 302.2.5](#) applies.

## K302.3 Allowable Stresses and Other Design Limits

**K302.3.1 General.** The allowable stresses defined (20) below shall be used in design calculations unless modified by other provisions of this Chapter.

(a) *Tension.* Allowable stresses in tension for use in design in accordance with this Chapter are listed in [Table K-1](#), except that maximum allowable stress values and design stress intensity values for bolting, respectively, are listed in ASME BPVC, Section II, Part D, Tables 3 and 4.

The tabulated stress values in [Table K-1](#) are grouped by materials and product form and are for stated temperatures up to the limit provided for the materials in [para. K323.2.1](#). Straight line interpolation between temperatures to determine the allowable stress for a specific design temperature is permissible. Extrapolation is not permitted.

(b) *Shear and Bearing.* Allowable stress in shear shall be 0.57 times  $S_{yt}$ . Allowable stress in bearing shall be 1.0 times  $S_{yt}$ . See [para. K302.3.2\(b\)](#) for definition of  $S_{yt}$ .

(c) *Compression.* Allowable stress in compression shall be no greater than the allowable stress in tension tabulated in [Table K-1](#). Consideration shall be given to structural stability.

(d) *Fatigue.* Allowable values of stress amplitude, which are provided as a function of design life in ASME BPVC, Section VIII, Division 3, Article KD-3, may be used in fatigue analysis in accordance with [para. K304.8](#).

(20) **K302.3.2 Bases for Allowable Stresses.** The bases for establishing allowable stress values for materials in this Chapter are as follows:

(a) *Bolting Materials.* The criteria of ASME BPVC, Section II, Part D, Appendix 2, 2-120 or 2-130, or Section VIII, Division 3, Article KD-6, KD-620, as applicable, apply.

(b) *Other Materials.* Allowable stress values at temperature for materials other than bolting materials shall not exceed the lower of the values calculated from [eqs. \(31a\)](#) and [\(31b\)](#).  $S_{ut}$  and  $S_{yt}$  shall be determined in accordance with [eqs. \(31d\)](#) and [\(31c\)](#), except that  $S_{ut}$  and  $S_{yt}$  shall not exceed  $S_T$  and  $S_Y$ , respectively.

$$S = \frac{1}{1.25} S_{yt} \quad (31a)$$

$$S = \frac{1}{3} (S_{ut} + S_{yt}) \quad (31b)$$

$$S_{yt} = S_Y R_Y \quad (31c)$$

$$S_{ut} = 1.1 S_T R_T \quad (31d)$$

where

$R_T$  = ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength

$R_Y$  = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength

$S$  = allowable stress

$S_T$  = specified minimum tensile strength at room temperature

$S_{ut}$  = tensile strength at temperature

$S_Y$  = specified minimum yield strength at room temperature

$S_{yt}$  = yield strength at temperature

(c) *Unlisted Materials.* For a material that conforms to [para. K323.1.2](#), allowable stress values at temperature shall be calculated in accordance with [\(b\)](#).

(1) Except as provided in [\(2\)](#),  $S_{ut}$  and  $S_{yt}$  shall be determined in accordance with [eqs. \(31d\)](#) and [\(31c\)](#), respectively.

(2) If the tensile and yield strengths at temperature for an unlisted material are contained in ASME BPVC, Section II, Part D, Tables U-1 and Y-1, respectively, those tensile and yield strengths at temperature values may be used directly in the determination of allowable stress.

(d) *Cyclic Stresses.* Allowable values of alternating stress shall be in accordance with ASME BPVC, Section VIII, Division 3, Article KD-3.

**K302.3.3 Castings.<sup>1</sup>** Cast piping components shall conform to all of the following requirements:

(a) All surfaces shall have a roughness average,  $R_a$ , not greater than 6.3  $\mu\text{m}$   $R_a$  (250  $\mu\text{in.}$   $R_a$ ); see ASME B46.1 for a definition of  $R_a$ .

(b) All nonferromagnetic surfaces shall be examined using the liquid penetrant method in accordance with ASTM E165, with acceptability judged in accordance with MSS SP-93, Table 1. All ferromagnetic surfaces shall be examined using either the liquid penetrant method or the magnetic particle method, in accordance with ASTM E165 or ASTM E709, respectively. Acceptability of imperfections, including those in weld repairs, shall be judged in accordance with MSS SP-93, Table 1 or MSS SP-53, Table 1, respectively.

(c) Each casting shall be fully examined either ultrasonically in accordance with ASTM E114 or radiographically in accordance with ASTM E94. Cracks and hot tears (Category D and E discontinuities in accordance with the standards listed in [Table K302.3.3D](#)) and imperfections whose depths exceed 3% of nominal wall thickness are not permitted. Acceptable severity levels for radiographic examination of castings shall be in accordance with [Table K302.3.3D](#).

<sup>1</sup> See Notes to [Tables 302.3.3C](#) and [302.3.3D](#) for titles of standards referenced herein.

**Table K302.3.3D Acceptable Severity Levels for Steel Castings**

| Thickness Examined, mm (in.)  | Applicable Standards | Acceptable Severity Level | Acceptable Discontinuity Categories |
|-------------------------------|----------------------|---------------------------|-------------------------------------|
| $\bar{T} \leq 51$ (2)         | ASTM E446            | 1                         | A, B, C                             |
| $51 < \bar{T} \leq 114$ (4.5) | ASTM E186            | 1                         | A, B, C                             |
| $114 < \bar{T} \leq 305$ (12) | ASTM E280            | 1                         | A, B, C                             |

**K302.3.4 Weld Joint Quality Factor.** Piping components containing welds shall have a weld joint quality factor  $E_j = 1.00$  (see Table 302.3.4), except that the acceptance criteria for these welds shall be in accordance with para. K341.3.2. Spiral (helical seam) welds are not permitted.

### K302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains

(a) *Internal Pressure Stresses.* Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. K304.

(b) *External Pressure Stresses.* Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. K304.

(c) *Stresses Due to Sustained Loads,  $S_L$ .* The stresses due to sustained loads,  $S_L$ , in any component in a piping system (see para. K320) shall not exceed  $S_h$ , where  $S_h$  is the allowable stress provided in Table K-1 at the metal temperature for the operating condition being considered. The thickness of pipe used in calculating  $S_L$  shall be the nominal thickness minus the mechanical, corrosion, and erosion allowance,  $c$ .

(d) *Allowable Displacement Stress Range,  $S_A$ .* The computed displacement stress range,  $S_E$ , in a piping system (see para. 319.4.4) shall not exceed the allowable displacement stress range,  $S_A$  (see para. 319.2.3), calculated by

$$S_A = 1.25S_c + 0.25S_h \quad (32)$$

where

$S_c$  = allowable stress from Table K-1 at minimum metal temperature expected during the displacement cycle under analysis

$S_h$  = allowable stress from Table K-1 at maximum metal temperature expected during the displacement cycle under analysis

### K302.3.6 Limits of Calculated Stresses Due to Occasional Loads (20)

(a) *Operation.* Stresses due to occasional loads may be calculated using the equations for stress due to sustained loads in para. K320.2. The sum of the stresses due to sustained loads, such as pressure and weight,  $S_L$ , and of the stresses produced by occasional loads, such as wind and earthquake, shall not exceed 1.2 times the allowable stress provided in Table K-1. Wind and earthquake forces need not be considered as acting concurrently.

(b) *Test.* Stresses due to test conditions are not subject to the limitations in para. K302.3. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

### K302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread or groove depth. See the definition of  $c$  in para. K304.1.1(b).

### K302.5 Mechanical Strength

Paragraph 302.5 applies.

## PART 2

## PRESSURE DESIGN OF PIPING COMPONENTS

### K303 GENERAL

Components manufactured in accordance with standards listed in Table K326.1 shall be considered suitable for use at pressure-temperature ratings in accordance with para. K302.2.

### K304 PRESSURE DESIGN OF HIGH PRESSURE COMPONENTS

#### K304.1 Straight Pipe

##### K304.1.1 General

(a) The required wall thickness of straight sections of pipe shall be determined in accordance with eq. (33).

$$t_m = t + c \quad (33)$$

The minimum wall thickness,  $T$ , for the pipe selected, considering manufacturer's minus tolerance, shall be not less than  $t_m$ .

(b) The following nomenclature is used in the equation for pressure design of straight pipe:



$$c = c_i + c_o$$

= the sum of mechanical allowances<sup>2</sup> (thread or groove depth) plus corrosion and erosion allowances (where  $c_i$  = the sum of *internal* allowances and  $c_o$  = the sum of *external* allowances). For threaded components, the nominal thread depth (dimension  $h$  of ASME B1.20.1 or equivalent) shall apply, except that for straight threaded connections, the external thread groove depth need not be considered provided

(1) it does not exceed 20% of the wall thickness

(2) the ratio of outside to inside diameter,  $D/d$ , is greater than 1.1

(3) the internally threaded attachment provides adequate reinforcement

(4) the thread plus the undercut area, if any, does not extend beyond the reinforcement for a distance more than the nominal wall thickness of the pipe

$t$  = pressure design wall thickness, as calculated in [para. K304.1.2](#) for internal pressure, or in accordance with the procedure listed in [para. K304.1.3](#) for external pressure

$t_m$  = minimum required wall thickness, including mechanical, corrosion, and erosion allowances

Adequate reinforcement by the attachment is defined as that necessary to ensure that the static burst pressure of the connection will equal or exceed that of the unthreaded portion of the pipe. The adequacy of the reinforcement shall be substantiated as required by [para. K304.7.2](#).

- (20) **K304.1.2 Straight Pipe Under Internal Pressure.** The internal pressure design wall thickness,  $t$ , shall be not less than that calculated in accordance with [eq. \(34a\)](#) for pipe with a specified outside diameter and minimum wall thickness, or [eq. \(34b\)](#) for pipe with a specified inside diameter and minimum wall thickness<sup>3</sup>

$$t = \frac{D - 2c_o}{2} \left[ 1 - e^{(-P/S)} \right] \quad (34a)$$

or

$$t = \frac{d + 2c_i}{2} \left[ e^{(-P/S)} - 1 \right] \quad (34b)$$

Alternatively, the internal design gage pressure,  $P$ , may be calculated by [eq. \(35a\)](#) or [\(35b\)](#)<sup>3</sup>

$$P = S \times \ln \left[ \frac{D - 2c_o}{D - 2(T - c_i)} \right] \quad (35a)$$

<sup>2</sup> For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

or

$$P = S \times \ln \left[ \frac{d + 2(T - c_o)}{d + 2c_i} \right] \quad (35b)$$

where

$D$  = outside diameter of pipe. For design calculations in accordance with this Chapter, the outside diameter of the pipe is the maximum value allowable under the specifications.

$d$  = inside diameter of pipe. For design calculations in accordance with this Chapter, the inside diameter of the pipe is the maximum value allowable under the specifications.

$P$  = internal design gage pressure

$S$  = allowable stress from [Table K-1](#)

$T$  = pipe wall thickness (measured or minimum in accordance with the purchase specification)

**K304.1.3 Straight Pipe Under External Pressure.** The (20) pressure design thickness for straight pipe under external pressure shall be determined in accordance with [para. K304.1.2](#). Straight pipe under external pressure shall also meet the criteria against buckling given in ASME BPVC, Section VIII, Division 3, Article KD-2, KD-222.

## K304.2 Curved and Mitered Segments of Pipe

**K304.2.1 Pipe Bends.** The minimum required wall thickness,  $t_m$ , of a bend, after bending, may be determined as for straight pipe in accordance with [para. K304.1](#), provided that the bend radius of the pipe centerline is equal to or greater than ten times the nominal pipe outside diameter and the tolerances and strain limits of [para. K332](#) are met. Otherwise the design shall be qualified as required by [para. K304.7.2](#).

**K304.2.2 Elbows.** Manufactured elbows not in accordance with [para. K303](#) and pipe bends not in accordance with [para. K304.2.1](#) shall be qualified as required by [para. K304.7.2](#).

**K304.2.3 Miter Bends.** Miter bends are not permitted.

**K304.2.4 Curved Segments of Pipe Under External Pressure.** The wall thickness of curved segments of pipe subjected to external pressure may be determined as specified for straight pipe in [para. K304.1.3](#).

## K304.3 Branch Connections

**K304.3.1 General.** Acceptable branch connections include a fitting in accordance with [para. K303](#), an extruded outlet in accordance with [para. 304.3.4](#), or a

<sup>3</sup> Any mechanical, corrosion, or erosion allowance,  $c$ , not specified as internal,  $c_i$ , or external,  $c_o$ , shall be assumed to be internal, i.e.,  $c = c_i$  and  $c_o = 0$ .

branch connection fitting (see [para. 300.2](#)) similar to that shown in [Figure K328.5.4](#).

### K304.3.2 Strength of Branch Connections

(a) The opening made for a branch connection reduces both static and fatigue strength of the run pipe. There shall be sufficient material in the branch connection to contain pressure and meet reinforcement requirements.

(b) Static pressure design of a branch connection not in accordance with [para. K303](#) shall conform to [para. 304.3.4](#) for an extruded outlet or shall be qualified as required by [para. K304.7.2](#).

**K304.3.3 Reinforcement of Welded Branch Connections.** Branch connections made as provided in [para. 304.3.3](#) are not permitted.

### K304.4 Closures

(a) Closures not in accordance with [para. K303](#) or (b) below shall be qualified as required by [para. K304.7.2](#).

(b) Closures may be designed in accordance with the methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2 or Division 3, and ASME BPVC, Section II, Part D.

### K304.5 Pressure Design of Flanges and Blanks

#### K304.5.1 Flanges — General

(a) Flanges not in accordance with [para. K303](#) or (b) below shall be qualified as required by [para. K304.7.2](#).

(b) A flange may be designed in accordance with the methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.16, or Part 5, or Division 3, Article KD-6, and ASME BPVC, Section II, Part D.

#### K304.5.2 Blind Flanges

(a) Blind flanges not in accordance with [para. K303](#) or (b) or (c) below shall be qualified as required by [para. K304.7.2](#).

(b) A blind flange may be designed in accordance with [eq. \(36\)](#). The thickness of the flange selected shall be not less than  $t_m$  (see [para. K304.1.1](#) for nomenclature), considering manufacturing tolerance

$$t_m = t + c \quad (36)$$

The methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.6 may be used, with the following changes in nomenclature, to calculate  $t_m$ :

$c$  = sum of mechanical allowances, defined in [para. K304.1.1](#)

$t$  = pressure design thickness as calculated for the given style of blind flange using the appropriate equation of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.6

(c) A blind flange may be designed in accordance with the rules, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 3, Article KD-6 and ASME BPVC, Section II, Part D.

**K304.5.3 Blanks.** Design of blanks shall be in accordance with [para. 304.5.3\(b\)](#), except that  $E$  shall be 1.00 and the definitions of  $S$  and  $c$  shall be in accordance with [para. K304.1.1](#).

### K304.6 Reducers

Reducers not in accordance with [para. K303](#) shall be qualified as required by [para. K304.7.2](#).

### K304.7 Pressure Design of Other Components

**K304.7.1 Listed Components.** Other pressure-containing components manufactured in accordance with standards in [Table K326.1](#) may be utilized in accordance with [para. K303](#).

**K304.7.2 Unlisted Components.** Pressure design of (20) unlisted components to which the rules elsewhere in [para. K304](#) do not apply shall be based on the pressure design criteria of this Chapter. The designer shall ensure that the pressure design has been substantiated through one or more of the means stated in (a), (b), and (c) below. Note that designs are also required to be checked for adequacy of mechanical strength as described in [para. K302.5](#).

(a) extensive, successful service experience under comparable design conditions with similarly proportioned components made of the same or like material.

(b) performance testing sufficient to substantiate both the static pressure design and fatigue life at the intended operating conditions. Static pressure design may be substantiated by demonstrating that failure or excessive plastic deformation does not occur at a pressure equivalent to two times the internal design pressure,  $P$ . The test pressure shall be two times the design pressure multiplied by the ratio of allowable stress at test temperature to the allowable stress at design temperature, and by the ratio of actual yield strength to the specified minimum yield strength at room temperature from [Table K-1](#).

(c) detailed stress analysis (e.g., finite element method) with results evaluated as described in ASME BPVC, Section VIII, Division 3, Article KD-2, except that for linear elastic analysis, the Division 3 stress intensity limits due to combined sustained and occasional loads may be increased by the same factor applied in [para. K302.3.6\(a\)](#).

(d) for (a), (b), and (c) above, interpolations supported by analysis are permitted between sizes, wall thicknesses, and pressure classes, as well as analogies among related materials with supporting material property data. Extrapolation is not permitted.

- (20) **K304.7.3 Components With Nonmetallic Parts.** Gaskets, packing, seals, and valve seats that meet the applicable requirements of [para. A302.1](#) may be used. Other nonmetallic parts are not permitted.

**K304.7.4 Expansion Joints.** Expansion joints are not permitted.

## K304.8 Fatigue Analysis

- (20) **K304.8.1 General.** A fatigue analysis shall be performed on each piping system, including all components<sup>4</sup> and joints therein, and considering the stresses resulting from attachments, to determine its suitability for the cyclic operating conditions<sup>5</sup> specified in the engineering design. Except as permitted in (a) and (b) below, or in [paras. K304.8.4](#) and [K304.8.5](#), this analysis shall be in accordance with ASME BPVC, Section VIII, Division 3.<sup>6</sup> The cyclic conditions shall include pressure variations as well as thermal variations or displacement stresses. The requirements for a flexibility analysis stated in [para. K319](#). No formal fatigue analysis is required in systems that

(a) are duplicates of successfully operating installations or replacements without significant change of systems with a satisfactory service record or

(b) can readily be judged adequate by comparison with previously analyzed systems

- (20) **K304.8.2 Amplitude of Alternating Stress**

(a) The values of the alternating stress intensity, the associated mean stress, and the equivalent alternating stress intensity shall be determined in accordance with ASME BPVC, Section VIII, Division 3, Articles KD-2 and KD-3. The allowable amplitude of the equivalent alternating stress shall be determined from the applicable design fatigue curve in Article KD-3.

(b) If it can be shown that the piping component will fail in a leak-before-burst mode, the number of design cycles (design fatigue life) may be calculated in accordance with either ASME BPVC, Section VIII, Division 3, Article KD-3 or Article KD-4. If a leak-before-burst mode of failure cannot be shown, the fracture mechanics evaluation outlined in Article KD-4 shall be used to determine the number of design cycles of the component.

(c) *Additional Considerations.* The designer is cautioned that the considerations listed in [para. K302.1](#) may reduce the fatigue life of the component below the value predicted by [para. \(a\)](#) or [\(b\)](#) above.

<sup>4</sup> Bore imperfections may reduce fatigue life.

<sup>5</sup> If the range of temperature change varies, equivalent full temperature cycles  $N$  may be computed using [eq. \(1d\)](#) in [para. 302.3.5](#).

<sup>6</sup> Fatigue analysis in accordance with ASME BPVC, Section VIII, Division 3 requires that stress concentration factors be used in computing the cyclic stresses.

## K304.8.3 Pressure Stress Evaluation for Fatigue Analysis (20)

(a) For fatigue analysis of straight pipe, [eq. \(37\)](#) may be used to calculate the stress intensity<sup>7</sup> at the inside surface due only to internal pressure

$$S = \frac{PD^2}{2(T - c)[D - (T - c)]} \quad (37)$$

(b) For fatigue analysis of curved pipe, [eq. \(37\)](#) may be used, with the dimensions of the straight pipe from which it was formed, to calculate the maximum stress intensity at the inside surface due only to internal pressure, provided that the centerline bend radius is not less than ten times the nominal outside diameter of the pipe, and that the tolerance and strain limits of [para. K332](#) are met. Bends of smaller radius shall be qualified as required by [para. K304.7.2](#).

(c) If the value of  $S$  calculated by [eq. \(37\)](#) exceeds two times  $S_{yt}$  at the average temperature during the loading cycle, an inelastic analysis shall be performed. See [para. K302.3.2\(b\)](#) for the definition of  $S_{yt}$ .

**K304.8.4 Fatigue Evaluation by Test.** With the owner's approval, the design fatigue life of a component may be established by destructive testing in accordance with [para. K304.7.2](#) in lieu of the above analysis requirements.

**K304.8.5 Extended Fatigue Life.** The design fatigue life (20) of piping components may be extended beyond that determined by ASME BPVC, Section VIII, Division 3, Article KD-3 by the use of one of the following methods, provided that the component is qualified in accordance with [para. K304.7.2](#):

(a) surface treatments, such as improved surface finish

(b) prestressing methods, such as autofrettage, shot peening, or shrink fit

The designer is cautioned that the benefits of prestress may be reduced due to thermal, strain softening, or other effects.

## PART 3 FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

### K305 PIPE

Pipe includes components designated as tube or tubing in the material specification, when intended for pressure service.

<sup>7</sup> The term "stress intensity" is defined in ASME BPVC, Section VIII, Division 3.

**Table K305.1.2 Required Ultrasonic or Eddy Current Examination of Pipe and Tubing for Longitudinal Defects**

| Diameter, mm (in.)                                                                                                                         | Examination Required                            | Paragraph Reference |
|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|---------------------|
| $d < 3.2 \left(\frac{1}{8}\right)$ or $D < 6.4 \left(\frac{1}{4}\right)$                                                                   | None                                            | ...                 |
| $3.2 \left(\frac{1}{8}\right) \leq d \leq 17.5 \left(\frac{11}{16}\right)$ and $6.4 \left(\frac{1}{4}\right) \leq D \leq 25.4 \text{ (1)}$ | Eddy current (ET) [Note (1)] or ultrasonic (UT) | K344.8 or K344.6    |
| $d > 17.5 \left(\frac{11}{16}\right)$ or $D > 25.4 \text{ (1)}$                                                                            | Ultrasonic (UT)                                 | K344.6              |

NOTE: (1) This examination is limited to cold drawn austenitic stainless steel pipe and tubing.

### K305.1 Requirements

**K305.1.1 General.** Pipe and tubing shall be either seamless or longitudinally welded with straight seam and a joint quality factor  $E_j = 1.00$ , examined in accordance with Note (2) of Table K341.3.2. Spiral (helical seam) welds are not permitted.

**K305.1.2 Additional Examination.** Pipe and tubing shall have passed a 100% examination for longitudinal defects in accordance with Table K305.1.2. This examination is in addition to acceptance tests required by the material specification.

**K305.1.3 Heat Treatment.** Heat treatment, if required, shall be in accordance with para. K331.

**K305.1.4 Unlisted Pipe and Tubing.** Unlisted pipe and tubing may be used only in accordance with para. K302.2.3.

### K306 FITTINGS, BENDS, AND BRANCH CONNECTIONS

Pipe and other materials used in fittings, bends, and branch connections shall be suitable for the manufacturing or fabrication process and otherwise suitable for the service.

#### K306.1 Pipe Fittings

**K306.1.1 General.** All castings shall have examination and acceptance criteria in accordance with para. K302.3.3. All welds shall have a weld quality factor  $E_j = 1.00$ , with examination and acceptance criteria in accordance with paras. K341 through K344. Spiral (helical seam) welds are not permitted. Listed fittings may be used in accordance with para. K303. Unlisted fittings may be used only in accordance with para. K302.2.3.

#### K306.1.2 Specific Fittings

(a) Socket welding fittings are not permitted.

(b) Threaded fittings are permitted only in accordance with para. K314.

(c) Branch connection fittings (see para. 300.2) whose design has been performance tested successfully as required by para. K304.7.2(b) may be used within their established ratings.

### K306.2 Pipe Bends

**K306.2.1 General.** A bend made in accordance with para. K332.2 and verified for pressure design in accordance with para. K304.2.1 shall be suitable for the same service as the pipe from which it is made.

**K306.2.2 Corrugated and Other Bends.** Bends of other design (such as creased or corrugated) are not permitted.

### K306.3 Miter Bends

Miter bends are not permitted.

### K306.4 Fabricated or Flared Laps

Only forged laps are permitted.

### K306.5 Fabricated Branch Connections

Fabricated branch connections constructed by welding shall be fabricated in accordance with para. K328.5.4 and examined in accordance with para. K341.4.

## K307 VALVES AND SPECIALTY COMPONENTS (20)

The following requirements for valves shall also be met, as applicable, by other pressure-containing piping components, e.g., traps, strainers, and separators. See also Appendix F, paras. F301.4 and F307.

### K307.1 General

**K307.1.1 Listed Valves.** A listed valve is suitable for use in High Pressure Fluid Service, except as stated in para. K307.2.

**K307.1.2 Unlisted Valves.** Unlisted valves may be used only in accordance with para. K302.2.3.

### K307.2 Specific Requirements

**K307.2.1 Bonnet Bolting.** The bonnets of bolted bonnet valves shall be secured to their bodies by at least four bolts.

**K307.2.2 Stem Retention.** Paragraph 307.2.2 applies.

## K308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

### K308.1 General

Pressure design of unlisted flanges shall be verified in accordance with para. K304.5.1 or qualified as required by para. K304.7.2.

## K308.2 Specific Flanges

**K308.2.1 Threaded Flanges.** Threaded flanges may be used only within the limitations on threaded joints in [para. K314](#).

**K308.2.2 Other Flange Types.** Slip-on, socket welding, and expanded joint flanges, and flanges for flared laps, are not permitted.

## K308.3 Flange Facings

The flange facing shall be suitable for the service and for the gasket and bolting employed.

## K308.4 Gaskets

Gaskets shall be selected so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting. Materials shall be suitable for the service conditions. Mode of gasket failure shall be considered in gasket selection and joint design.

## K308.5 Blanks

Blanks shall have a marking, identifying material, pressure-temperature rating, and size, that is visible after installation.

## K309 BOLTING

Bolting, including bolts, bolt studs, studs, cap screws, nuts, and washers, shall meet the requirements of ASME BPVC, Section VIII, Division 2, Part 3, [para. 3.7](#); Part 4, [para. 4.16](#); and Part 5, [para. 5.7](#). See also [Appendix F, para. F309](#), of this Code.

## PART 4

### FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

## K310 GENERAL

Joints shall be suitable for the fluid handled, and for the pressure-temperature and other mechanical loadings expected in service.

Factors such as assembly and disassembly (if applicable), cyclic loading, vibration, shock, bending, and thermal expansion and contraction of joints shall be considered in the engineering design.

## K311 WELDED JOINTS

### K311.1 General

Welds shall conform to the following:

- (a) Welding shall be in accordance with [para. K328](#).
- (b) Preheating and heat treatment shall be in accordance with [paras. K330](#) and [K331](#), respectively.

(c) Examination shall be in accordance with [para. K341.4](#), with acceptance criteria as shown in [Table K341.3.2](#).

## K311.2 Specific Requirements

**K311.2.1 Backing Rings and Consumable Inserts.** Backing rings shall not be used. Consumable inserts shall not be used in butt welded joints except when specified by the engineering design.

**K311.2.2 Fillet Welds.** Fillet welds may be used only for structural attachments in accordance with the requirements of [paras. K321](#) and [K328.5.2](#).

**K311.2.3 Other Weld Types.** Socket welds and seal welds are not permitted.

## K312 FLANGED JOINTS

Flanged joints shall be selected for leak tightness, considering the requirements of [para. K308](#), flange facing finish, and method of attachment. See also [para. F312](#).

### K312.1 Joints Using Flanges of Different Ratings

[Paragraph 312.1](#) applies.

## K313 EXPANDED JOINTS

Expanded joints are not permitted.

## K314 THREADED PIPE JOINTS

For the purposes of this paragraph, "pipe" does not include tube or tubing.

### K314.1 General

Except as provided in [paras. K314.2](#) and [K314.3](#), threaded pipe joints are not permitted.

(a) Layout of piping shall be such as to minimize strain on threaded joints that could adversely affect sealing.

(b) Supports shall be designed to control or minimize strain and vibration on threaded joints and seals.

### K314.2 Taper-Threaded Pipe Joints

(20)

(a) Taper-threaded pipe joints shall be used only for instrumentation, vents, drains, and similar purposes, and shall be not larger than DN 15 (NPS  $\frac{1}{2}$ ).

(b) The nominal wall thickness of piping components with external taper threads shall be at least as thick as that specified for Schedule 160 in ASME B36.10M.

### K314.3 Straight-Threaded Pipe Joints

**K314.3.1 Joints With Seal Formed by Projecting Pipe.** Threaded joints where the threads are used to attach flanges or fittings, and in which the pipe end projects through the flange or fitting and is machined to form



the sealing surface with a lens ring, cone ring, the mating pipe end, or other similar sealing device, may be used. Such joints shall be qualified in accordance with [para. K304.7.2](#).

### **K314.3.2 Other Straight-Threaded Joints**

(a) *Other Joints Using Components Conforming to Listed Standards.* Pipe joints may incorporate straight-threaded fittings conforming to listed standards in [Table K326.1](#), provided the fittings

(1) are compatible with the pipe with which they are used, considering tolerances and other characteristics

(2) comply with [para. K302.2.1](#) or [K302.2.2](#)

(b) *Other Joints Using Components Not Conforming to Listed Standards.* Other straight-threaded pipe joints (e.g., a union comprising external and internal ends joined with a threaded union nut, or other constructions shown typically in [Figure 335.3.3](#)) may be used. Such joints shall be qualified by performance testing in accordance with [para. K304.7.2\(b\)](#). Testing shall be conducted for each material type/grade and heat treatment condition, component configuration (e.g., elbow), size (e.g., NPS), and pressure rating. Performance testing of joints in which the process of making up the joint involves significant uncontrolled loads (e.g., hammer unions) shall include testing designed to simulate actual loads.

## **K315 TUBING JOINTS**

### **K315.1 Flared End Tubing Joints**

Flared end tubing joints, whether the flare provides the seal, carries the load, or both, may be used, provided the type of fitting selected is adequate for the design pressure, other loadings, and the design temperature. The design shall also be qualified in accordance with [para. K304.7.2](#).

### **K315.2 Flareless Tubing Joints Using Components Conforming to Listed Standards**

Tubing joints may incorporate flareless type fittings conforming to listed standards in [Table K326.1](#), provided the fittings

(a) are compatible with the tubing with which they are used, considering tolerances and other characteristics

(b) comply with [para. K302.2.1](#) or [K302.2.2](#)

### **K315.3 Flareless Tubing Joints Using Components Not Conforming to Listed Standards**

Tubing joints may incorporate flareless type fittings not conforming to listed standards in [Table K326.1](#), provided the type of fitting selected is adequate for the design pressure, other loadings, and the design temperature, and meets the requirements of [para. K302.2.3](#).

## **K316 CAULKED JOINTS**

Caulked joints are not permitted.

## **K317 SOLDERED AND BRAZED JOINTS**

### **K317.1 Soldered Joints**

Soldered joints are not permitted.

### **K317.2 Brazed and Braze Welded Joints**

(20)

(a) Braze welded joints and fillet joints made with brazing filler metal are not permitted.

(b) Brazed joints shall be made in accordance with [para. K333](#) and shall be qualified as required by [para. K304.7.2](#). Such application is the owner's responsibility. The melting point of brazing alloys shall be considered when exposure to fire is possible.

## **K318 SPECIAL JOINTS**

Special joints are those not covered elsewhere in this Part.

### **K318.1 General**

Joints may be used in accordance with [para. 318.2](#) and the requirements for materials and components in this Chapter.

### **K318.2 Specific Requirements**

**K318.2.1 Prototype Tests.** A prototype joint shall have been subjected to performance tests in accordance with [para. K304.7.2\(b\)](#) to determine the safety of the joint under test conditions simulating all expected service conditions. Testing shall include cyclic simulation.

**K318.2.2 Prohibited Joints.** Bell type and adhesive joints are not permitted.

## **PART 5 FLEXIBILITY AND SUPPORT**

### **K319 FLEXIBILITY**

Flexibility analysis shall be performed for each piping system. [Paragraphs 319.1](#) through [319.6](#) apply, except for [para. 319.4.1\(c\)](#). The computed displacement stress range shall be within the allowable displacement stress range in [para. K302.3.5](#) and shall also be included in the fatigue analysis in accordance with [para. K304.8](#).

### **K320 ANALYSIS OF SUSTAINED LOADS**

#### **K320.1 Basic Assumptions and Requirements**

[Paragraph 320.1](#) applies, but refer to [para. K302.3.5\(c\)](#) instead of [para. 302.3.5\(c\)](#).

#### **K320.2 Stress Due to Sustained Loads**

[Paragraph 320.2](#) applies, except that references to expansion joints are not applicable.



## K321 PIPING SUPPORT

Piping supports and methods of attachment shall be in accordance with [para. 321](#) except as modified below, and shall be detailed in the engineering design.

### K321.1 General

**K321.1.1 Objectives.** [Paragraph 321.1.1](#) applies, but substitute “Chapter” for “Code” in [321.1.1\(a\)](#).

**K321.1.4 Materials.** [Paragraph 321.1.4](#) applies, but replace [321.1.4\(e\)](#) with the following:

(e) Attachments welded to the piping shall be of a material compatible with the piping and the service. Other requirements are specified in [paras. K321.3.2](#) and [K323.4.2\(b\)](#).

### K321.3 Structural Attachments

**K321.3.2 Integral Attachments.** [Paragraph 321.3.2](#) applies, but substitute “K321.1.4(e)” for “321.1.4(e)” and “Chapter IX” for “Chapter V.”

## PART 6 SYSTEMS

## K322 SPECIFIC PIPING SYSTEMS

### K322.3 Instrument Piping

**K322.3.1 Definition.** Instrument piping within the scope of this Chapter includes all piping and piping components used to connect instruments to high pressure piping or equipment. Instruments, permanently sealed fluid-filled tubing systems furnished with instruments as temperature- or pressure-responsive devices, and control piping for air or hydraulically operated control apparatus (not connected directly to the high pressure piping or equipment) are not within the scope of this Chapter.

**K322.3.2 Requirements.** Instrument piping within the scope of this Chapter shall be in accordance with [para. 322.3.2](#) except that the design pressure and temperature shall be determined in accordance with [para. K301](#), and the requirements of [para. K310](#) shall apply. Instruments, and control piping not within the scope of this Chapter, shall be designed in accordance with [para. 322.3](#).

### K322.6 Pressure-Relieving Systems

[Paragraph 322.6](#) applies, except for [para. 322.6.3](#).

- (20) **K322.6.3 Overpressure Protection.** Overpressure protection for high pressure piping systems shall conform to the following:

(a) The cumulative capacity of pressure relief devices shall be sufficient to prevent the pressure from rising more than 10% above the design pressure at the operating temperature during the relieving condition.

(b) System protection shall include one pressure relief device with a set pressure at or below the design pressure at the operating temperature for the relieving condition. The set pressure of additional pressure relief devices shall not exceed 105% of the design pressure.

## PART 7 MATERIALS

## K323 GENERAL REQUIREMENTS

(a) [Paragraph K323](#) states limitations and required qualifications for materials based on their inherent properties. Their use is also subject to requirements elsewhere in [Chapter IX](#) and in [Table K-1](#).

(b) Specific attention should be given to the manufacturing process to ensure uniformity of properties throughout each piping component.

(c) See [para. K321.1.4](#) for support materials.

### K323.1 Materials and Specifications

#### K323.1.1 Listed Materials

(a) Any material used in a pressure-containing piping component shall conform to a listed specification, except as provided in [\(b\)](#) below or in [para. K323.1.2](#).

(b) Materials manufactured to specification editions different from those listed in [Appendix E](#) may be used, provided

(1) the requirements for chemical composition and heat-treatment condition in the edition of the specification to which the material was manufactured meet the requirements of the listed edition

(2) the specified minimum tensile and yield strengths, and, if applicable, the specified maximum tensile and yield strengths, required by the two editions of the specification are the same, and

(3) the material has been tested and examined in accordance with the requirements of the listed edition of the specification

A material that does not meet the requirements of [\(b\)\(1\)](#), [\(b\)\(2\)](#), and [\(b\)\(3\)](#) may be evaluated as an unlisted material in accordance with [para. K323.1.2](#).

**K323.1.2 Unlisted Materials.** An unlisted material may be used, provided it conforms to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meets the requirements of this Chapter. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Chapter or a more conservative basis.

**K323.1.3 Unknown Materials.** Materials of unknown specification, type, or grade are not permitted.

**K323.1.4 Reclaimed Materials.** Reclaimed pipe and other piping components may be used provided they are properly identified as conforming to a listed specification, have documented service history for the material and fatigue life evaluation, and otherwise meet the requirements of this Chapter. Sufficient cleaning and inspection shall be made to determine minimum wall thickness and freedom from defects that would be unacceptable in the intended service.

**K323.1.5 Product Analysis.** Conformance of materials to the product analysis chemical requirements of the applicable specification shall be verified, and certification shall be supplied. Requirements for product analysis are defined in the applicable materials specification.

**K323.1.6 Repair of Materials by Welding.** A material defect may be repaired by welding, provided that all of the following criteria are met:

- (a) The material specification provides for weld repair.
- (b) The welding procedure and welders or welding operators are qualified as required by [para. K328.2](#).
- (c) The repair and its examination are performed in accordance with the material specification and with the owner's approval.

## K323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of this Chapter are suitable for service throughout the operating temperature range.

**K323.2.1 Upper Temperature Limits, Listed Materials.** A listed material shall not be used at a temperature above the maximum for which a stress value is shown in [Appendix K, Table K-1](#).

### (20) K323.2.2 Lower Temperature Limits, Listed Materials

- (a) The design minimum temperature for listed materials and their welds shall not be colder than the impact test temperature determined in accordance with [para. K323.3.4\(a\)](#), except as provided in (b) or (c) below.
- (b) For listed materials and their welds subjected to neither longitudinal nor circumferential stress greater than 41 MPa (6 ksi), the design minimum temperature shall not be colder than the lower of  $-46^{\circ}\text{C}$  ( $-50^{\circ}\text{F}$ ) and the impact test temperature determined in accordance with [para. K323.3.4\(a\)](#).
- (c) For listed materials and their welds exempted from Charpy impact testing by [Table K323.3.1, Note \(2\)](#), the design minimum temperature shall not be colder than  $-46^{\circ}\text{C}$  ( $-50^{\circ}\text{F}$ ).

**K323.2.3 Temperature Limits, Unlisted Materials.** An unlisted material acceptable under [para. K323.1.2](#) shall be qualified for service at all temperatures within a stated

range from design minimum temperature to design (maximum) temperature, in accordance with [para. K323.2.4](#). However, the upper temperature limit shall be less than the temperature for which an allowable stress, determined in accordance with [para. 302.3.2](#), is governed by the creep or stress rupture provisions of that paragraph.

### K323.2.4 Verification of Serviceability

(a) When an unlisted material is used, the designer is responsible for demonstrating the validity of the allowable stresses and other design limits, and of the approach taken in using the material, including the derivation of stress data and the establishment of temperature limits.

(b) [Paragraph 323.2.4\(b\)](#) applies except that allowable stress values shall be determined in accordance with [para. K302.3](#).

## K323.3 Impact Testing Methods and Acceptance Criteria

**K323.3.1 General.** Except as provided in (20) [Table K323.3.1, Note \(2\)](#), piping components and welds used in High Pressure Fluid Service shall be subjected to Charpy V-notch impact testing. The testing shall be performed in accordance with [Table K323.3.1](#) on representative samples using the testing methods described in [paras. K323.3.2, K323.3.3, and K323.3.4](#). Acceptance criteria are described in [para. K323.3.5](#).

**K323.3.2 Procedure.** [Paragraph 323.3.2](#) applies.

### K323.3.3 Test Specimens

(a) Each set of impact test specimens shall consist of three specimen bars. Impact tests shall be made using standard 10 mm (0.394 in.) square cross section Charpy V-notch specimen bars oriented in the transverse direction.

(b) Where component size and/or shape does not permit specimens as specified in (a) above, standard 10 mm square cross-section longitudinal Charpy specimens may be prepared.

(c) Where component size and/or shape does not permit specimens as specified in (a) or (b) above, subsize longitudinal Charpy specimens may be prepared. Test temperature shall be reduced in accordance with [Table 323.3.4](#). See also [Table K323.3.1, Note \(2\)](#).

(d) If necessary in (a), (b), or (c) above, corners of specimens parallel to and on the side opposite the notch may be as shown in [Figure K323.3.3](#).

**K323.3.4 Test Temperatures.** For all Charpy impact (20) tests, the test temperature criteria in (a) or (c) below shall be observed.

(a) Charpy impact tests shall be conducted at a temperature no warmer than the coldest of the following:

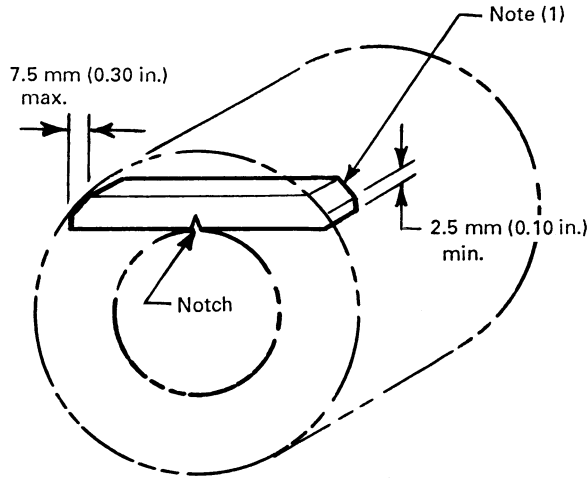
- (1)  $20^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ )

**Table K323.3.1 Impact Testing Requirements**

| Test Characteristics                               |                                                                       | Column A<br>Pipe, Tubes, and Components<br>Made From Pipe or Tubes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Column B<br>Other Components, Fittings, Etc.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Column C<br>Bolts                                                                                                                                                                                                                                                                                          |
|----------------------------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tests on<br>Materials                              | Number of tests                                                       | As required by the material specification, or one test set per lot [see <a href="#">Note (1)</a> ], whichever is greater, except as permitted by <a href="#">Note (2)</a> .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                            |
|                                                    | Location and orientation of specimens [see <a href="#">Note (3)</a> ] | (a) Transverse to the longitudinal axis, with notch parallel to axis. [See <a href="#">Note (4)</a> .]<br>(b) Where component size and/or shape does not permit specimens as specified in (a) above, <a href="#">paras. K323.3.3(b)</a> , <a href="#">(c)</a> , and <a href="#">(d)</a> apply as needed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | (a) Transverse to the direction of maximum elongation during rolling or to direction of major working during forging. Notch shall be oriented parallel to direction of maximum elongation or major working.<br>(b) If there is no single identifiable axis, e.g., for castings or triaxial forgings, specimens shall either meet the longitudinal values of <a href="#">Table K323.3.5</a> , or three sets of orthogonal specimens shall be prepared, and the lowest impact values obtained from any set shall meet the transverse values of <a href="#">Table K323.3.5</a> .<br>(c) Where component size and/or shape does not permit specimens as specified in (a) or (b) above, <a href="#">paras. K323.3.3(c)</a> and <a href="#">(d)</a> apply as needed. | (a) Bolts $\leq 52$ mm (2 in.) nominal size made in accordance with ASTM A320 shall meet the impact requirements of that specification.<br>(b) For all other bolts, longitudinal specimens shall be taken. The impact values obtained shall meet the transverse values of <a href="#">Table K323.3.5</a> . |
| Tests on<br>Welds in<br>Fabrication<br>or Assembly | Test pieces [see <a href="#">Note (5)</a> ]                           | Test pieces for preparation of impact specimens shall be made for each welding procedure, type of electrode, or filler metal (i.e., AWS E-XXXX classification) and each flux to be used. All test pieces shall be subject to heat treatment, including cooling rates and aggregate time at temperature or temperatures, essentially the same as the heat treatment which the finished component will have received.                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                            |
|                                                    | Number of test pieces [see <a href="#">Note (6)</a> ]                 | (1) One test piece with a thickness $T$ for each range of material thicknesses which can vary from $\frac{1}{2}T$ to $T + 6$ mm ( $\frac{1}{4}$ in.).<br>(2) Unless otherwise specified in this Chapter [see <a href="#">Note (4)</a> ] or the engineering design, test pieces need not be made from individual material lots, or from material for each job, provided welds in other certified material of the same thickness ranges and to the same specification (type and grade, not heat or lot) have been tested as required and the records of those tests are made available.                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                            |
|                                                    | Location and orientation of specimens                                 | (1) Weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch axis is normal to the surface of the material and one face of the specimen shall be within 1.5 mm ( $\frac{1}{16}$ in.) of the surface of the material.<br>(2) Heat-affected zone impact specimens shall be taken across the weld and have sufficient length to locate the notch in the heat-affected zone, after etching. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone material as possible in the resulting fracture.<br>(3) The impact values obtained from both the weld metal and heat-affected zone specimens shall be compared to the transverse values in <a href="#">Table K323.3.5</a> for the determination of acceptance criteria. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                            |

## NOTES:

- (1) A lot shall consist of pipe or components of the same nominal size, made from the same heat of material, and heat treated together. If a continuous type furnace is used, pipe or components may be considered to have been heat treated together if they are processed during a single continuous time period at the same furnace conditions.
- (2) Impact tests are not required when the maximum obtainable longitudinal Charpy specimen has a width along the notch less than 2.5 mm (0.098 in.). See [para. K323.2.2\(c\)](#).
- (3) Impact tests shall be performed on a representative sample of material after completion of all heat treatment and forming operations involving plastic deformation, except that cold bends made in accordance with [para. K304.2.1](#) need not be tested after bending.
- (4) For longitudinally welded pipe, specimens shall be taken from the base metal, weld metal, and the heat-affected zone.
- (5) For welds in the fabrication or assembly of piping or components, including repair welds.
- (6) The test piece shall be large enough to permit preparing the number of specimens required by [para. K323.3](#). If this is not possible, additional test pieces shall be prepared.

**Figure K323.3.3 Example of an Acceptable Impact Test Specimen**

GENERAL NOTE: This Figure illustrates how an acceptable transverse Charpy specimen can be obtained from a tubing or component shape too small for a full length standard specimen in accordance with ASTM A370. The corners of a longitudinal specimen parallel to and on the side opposite the notch may be as shown.

NOTE: (1) Corners of the Charpy specimen [see para. K323.3.3(d)] may follow the contour of the component within the dimension limits shown.

(2) when the design minimum temperature is warmer than or equal to  $-46^{\circ}\text{C}$  ( $-50^{\circ}\text{F}$ ), the lowest component temperature expected in service at which a material or weld will be subjected to a longitudinal or circumferential stress greater than 41 MPa (6 ksi)

(3) when the design minimum temperature is colder than  $-46^{\circ}\text{C}$  ( $-50^{\circ}\text{F}$ ), the design minimum temperature

(b) In specifying the temperatures in (a)(2) and (a)(3), the following shall be considered:

- (1) range of operating conditions
- (2) upset conditions
- (3) ambient temperature extremes
- (4) required leak test temperature

(c) Where the largest possible test specimen has a width along the notch less than the lesser of 80% of the material thickness or 8 mm (0.315 in.), the test shall be conducted at a reduced temperature in accordance with Table 323.3.4, considering the temperature as reduced below the test temperature required by (a).

### K323.3.5 Acceptance Criteria

(a) *Minimum Energy Requirements for Materials Other Than Bolting.* The applicable minimum impact energy requirements for materials shall be those shown in Table K323.3.5. Lateral expansion shall be measured in accordance with ASTM A370 (for title see para.

**Table K323.3.5 Minimum Required Charpy V-Notch Impact Values**

| Specimen Orientation | Pipe Wall or Component Thickness, mm (in.)  | Number of Specimens [Note (1)] | Energy, J (ft-lbf) [Note (2)] for Specified Minimum Yield Strength, MPa (ksi) |                     |
|----------------------|---------------------------------------------|--------------------------------|-------------------------------------------------------------------------------|---------------------|
|                      |                                             |                                | $\leq 932$ ( $\leq 135$ )                                                     | $> 932$ ( $> 135$ ) |
| Transverse           | $\leq 25$ ( $\leq 1$ )                      | Average for 3                  | 27 (20)                                                                       | 34 (25)             |
|                      |                                             | Minimum for 1                  | 20 (15)                                                                       | 27 (20)             |
|                      | $> 25$ and $\leq 51$ ( $> 1$ and $\leq 2$ ) | Average for 3                  | 34 (25)                                                                       | 41 (30)             |
|                      |                                             | Minimum for 1                  | 27 (20)                                                                       | 33 (24)             |
|                      | $> 51$ ( $> 2$ )                            | Average for 3                  | 41 (30)                                                                       | 47 (35)             |
|                      |                                             | Minimum for 1                  | 33 (24)                                                                       | 38 (28)             |
| Longitudinal         | $\leq 25$ ( $\leq 1$ )                      | Average for 3                  | 54 (40)                                                                       | 68 (50)             |
|                      |                                             | Minimum for 1                  | 41 (30)                                                                       | 54 (40)             |
|                      | $> 25$ and $\leq 51$ ( $> 1$ and $\leq 2$ ) | Average for 3                  | 68 (50)                                                                       | 81 (60)             |
|                      |                                             | Minimum for 1                  | 54 (40)                                                                       | 65 (48)             |
|                      | $> 51$ ( $> 2$ )                            | Average for 3                  | 81 (60)                                                                       | 95 (70)             |
|                      |                                             | Minimum for 1                  | 65 (48)                                                                       | 76 (56)             |

NOTES:

(1) See para. K323.3.5(c) for permissible retests.

(2) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).

323.3.2). The results shall be included in the impact test report.

(b) *Minimum Energy Requirements for Bolting Materials.* The applicable minimum energy requirements shall be those shown in Table K323.3.5 except as provided in Table K323.3.1.

(c) *Weld Impact Test Requirements.* Where two base metals having different required impact energy values are joined by welding, the impact test energy requirements shall equal or exceed the requirements of the base material having the lower required impact energy.

(d) *Retests*

(1) *Retest for Absorbed Energy Criteria.* When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen, and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

(2) *Retest for Erratic Test Results.* When an erratic result is caused by a defective specimen or uncertainty in the test, a retest will be allowed. The report giving test results shall specifically state why the original specimen was considered defective or which step of the test procedure was carried out incorrectly.

#### K323.4 Requirements for Materials

**K323.4.1 General.** Requirements in para. K323.4 apply to pressure-containing parts, not to materials used as supports, gaskets, packing, or bolting. See also Appendix F, para. F323.4.

##### K323.4.2 Specific Requirements

(a) Ductile iron and other cast irons are not permitted.

(b) Zinc-coated materials are not permitted for pressure-containing components and may not be attached to pressure-containing components by welding.

**K323.4.3 Metallic Clad and Lined Materials.** Materials with metallic cladding or lining may be used in accordance with the following provisions:

(a) For metallic clad or lined piping components, the base metal shall be an acceptable material as defined in para. K323, and the thickness used in pressure design in accordance with para. K304 shall not include the thickness of the cladding or lining. The allowable stress used shall be that for the base metal at the design temperature. For such components, the cladding or lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping component.

(b) Fabrication by welding of clad or lined piping components and the inspection and testing of such components shall be done in accordance with applicable provisions of ASME BPVC, Section VIII, Division 1, UCL-30 through UCL-52, and the provisions of this Chapter.

(c) If a metallic liner also serves as a gasket or as part of the flange facing, the requirements and limitations in para. K308.4 apply.

#### K323.5 Deterioration of Materials in Service

Paragraph 323.5 applies.

#### K325 MISCELLANEOUS MATERIALS

Paragraph 325 applies.

### PART 8 STANDARDS FOR PIPING COMPONENTS

#### K326 REQUIREMENTS FOR COMPONENTS

##### K326.1 Dimensional Requirements

**K326.1.1 Listed Piping Components.** Dimensional standards for piping components are listed in Table K326.1. Dimensional requirements contained in specifications listed in Appendix K shall also be considered requirements of this Code.

**K326.1.2 Unlisted Piping Components.** Piping components not listed in Table K326.1 or Appendix K shall meet the pressure design requirements described in para. K302.2.3 and the mechanical strength requirements described in para. K302.5.

**K326.1.3 Threads.** The dimensions of piping connection threads not otherwise covered by a governing component standard or specification shall conform to the requirements of applicable standards listed in Table K326.1 or Appendix K.

##### K326.2 Ratings of Components

**K326.2.1 Listed Components.** The pressure-temperature ratings of components listed in Table K326.1 are accepted for pressure design in accordance with para. K303.

**K326.2.2 Unlisted Components.** The pressure-temperature ratings of unlisted piping components shall conform to the applicable provisions of para. K304.

##### K326.3 Reference Documents

The documents listed in Table K326.1 contain references to codes, standards, and specifications not listed in Table K326.1. Such unlisted codes, standards, and specifications shall be used only in the context of the listed documents in which they appear.



**Table K326.1 Component Standards**

(20)

| Standard or Specification                                                                                                       | Designation  |
|---------------------------------------------------------------------------------------------------------------------------------|--------------|
| <b>Bolting</b>                                                                                                                  |              |
| Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series) . . . . . | ASME B18.2.1 |
| Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series) . . . . .           | ASME B18.2.2 |
| <b>Metallic Fittings, Valves, and Flanges</b>                                                                                   |              |
| Pipe Flanges and Flanged Fittings: NPS $\frac{1}{2}$ Through NPS 24 Metric/Inch Standard [Note (1)] . . . . .                   | ASME B16.5   |
| Factory-Made Wrought Buttwelding Fittings [Note (1)] . . . . .                                                                  | ASME B16.9   |
| Forged Fittings, Socket-Welding and Threaded [Note (1)] . . . . .                                                               | ASME B16.11  |
| Valves — Flanged, Threaded, and Welding End [Note (1)] . . . . .                                                                | ASME B16.34  |
| Line Blanks [Note (1)] . . . . .                                                                                                | ASME B16.48  |
| Standard Marking System for Valves, Fittings, Flanges, and Unions . . . . .                                                     | MSS SP-25    |
| High Pressure Chemical Industry Flanges and Threaded Stubs for Use with Lens Gaskets [Note (1)] . . . . .                       | MSS SP-65    |
| <b>Metallic Pipe and Tubes</b>                                                                                                  |              |
| Welded and Seamless Wrought Steel Pipe [Note (1)] . . . . .                                                                     | ASME B36.10M |
| Stainless Steel Pipe [Note (1)] . . . . .                                                                                       | ASME B36.19M |
| <b>Miscellaneous</b>                                                                                                            |              |
| Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads . . . . .                                    | API 5B       |
| Unified Inch Screw Threads (UN and UNR Thread Form) . . . . .                                                                   | ASME B1.1    |
| Pipe Threads, General Purpose (Inch) . . . . .                                                                                  | ASME B1.20.1 |
| Metallic Gaskets for Pipe Flanges . . . . .                                                                                     | ASME B16.20  |
| Buttwelding Ends . . . . .                                                                                                      | ASME B16.25  |
| Surface Texture (Surface Roughness, Waviness, and Lay) . . . . .                                                                | ASME B46.1   |

GENERAL NOTE: The approved edition dates of these standards and specifications, along with the names and addresses of the sponsoring organizations, are shown in [Appendix E](#).

NOTE: (1) The use of components made in accordance with these standards is permissible, provided they are

(a) examined and leak tested in accordance with the requirements of [paras. K341](#) and [K345](#), respectively.

(b) impact tested in accordance with the methods described in [paras. K323.3.1](#) through [K323.3.4](#), and meet the acceptance criteria specified in [para. K323.3.5](#). Note that such impact testing may require the destruction of one component from the same lot as the component to be used in service [see [Table K323.3.1](#), Note (1)].

(c) in accordance with the fluid service requirements in [Parts 3](#) and [4](#) of this Chapter.

The design, materials, fabrication, assembly, examination, inspection, and testing requirements of this Chapter are not applicable to components manufactured in accordance with the documents listed in [Table K326.1](#), unless specifically stated in this Chapter or in the listed document.

#### **K326.4 Repair of Piping Components by Welding**

A defect in a piping component may be repaired by welding subject to all of the following requirements:

(a) The piping component specification provides for weld repair or, if not covered by a specification, the manufacturer allows for weld repair.

(b) The welding procedure and welders or welding operators are qualified as required by [para. K328.2](#).

(c) The repair and its examination are performed in accordance with the piping component specification or, if not covered by a specification, the manufacturer's requirements.

(d) The owner approves the weld repair.

### **PART 9 FABRICATION, ASSEMBLY, AND ERECTION**

#### **K327 GENERAL**

Piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in [paras. K328](#), [K330](#), [K331](#), [K332](#), and [K333](#). When any of these processes is used in assembly or erection, requirements are the same as for fabrication.



**(20) K328 WELDING**

Welding shall conform to the requirements of this Part and the applicable requirements of [para. K311](#).

**(20) K328.1 Welding Responsibility**

Each employer is responsible for

- (a) the welding performed by personnel of its organization
- (b) conducting the qualification tests required to qualify the welding procedure specifications used by personnel in its organization
- (c) conducting the qualification tests required to qualify its welders and welding operators

**K328.2 Welding Qualifications**

- (20) K328.2.1 Qualification Requirements.** Qualification of the welding procedures to be used and of the performance of welders and welding operators shall comply with the requirements of ASME BPVC, Section IX, except as modified herein.

- (a) Impact tests shall be performed for all procedure qualifications in accordance with [para. K323.3](#).
- (b) Except as provided in (f), test weldments shall be made using the same specification and type or grade of base metal(s), and the same specification and classification of filler metal(s) as will be used in production welding.
- (c) Test weldments shall be subjected to essentially the same heat treatment, including cooling rate and cumulative time at temperature, as the production welds.
- (d) When tensile specimens are required by ASME BPVC, Section IX, the yield strength shall also be determined, using the method required for the base metal. The yield strength of each test specimen shall be not less than the specified minimum yield strength at room temperature ( $S_Y$ ) for the base metals joined. Where two base metals having different  $S_Y$  values are joined by welding, the yield strength of each test specimen shall be not less than the lower of the two  $S_Y$  values.
- (e) Mechanical testing is required for all performance qualification tests.
- (f) If the same specification and classification of filler metal(s) as will be used in production welding are employed, qualification on pipe or tubing shall also qualify for plate of the same type or grade, but qualification on plate does not qualify for pipe or tubing.
- (g) For thickness greater than 51 mm (2 in.), the procedure test coupon shall be at least 75% as thick as the thickest joint to be welded in production.

**K328.2.2 Procedure Qualification by Others.** Qualification of welding procedures by others is not permitted.

**K328.2.3 Performance Qualification by Others.** Welding performance qualification by others is not permitted.

**K328.2.4 Qualification Records.** [Paragraph 328.2.4](#) applies.

**K328.3 Materials**

**K328.3.1 Electrodes and Filler Metal.** [Paragraph 328.3.1](#) applies, together with the following additional requirements:

- (a) Welding electrodes and filler metals shall be specified in the engineering design.
- (b) With the owner's approval, a welding electrode or filler metal not conforming to a specification listed in ASME BPVC, Section II, Part C may be used if a procedure qualification test, including an all-weld-metal test in accordance with AWS B4.0M or AWS B4.0<sup>8</sup>, is first successfully made.

**K328.3.2 Weld Backing Material.** Backing rings shall not be used.

**K328.3.3 Consumable Inserts.** [Paragraph 328.3.3](#) applies, except that procedures shall be qualified as required by [para. K328.2](#).

**K328.4 Preparation for Welding**

**K328.4.1 Cleaning.** [Paragraph 328.4.1](#) applies.

**K328.4.2 End Preparation**

(a) *General*

- (1) Butt weld end preparation is acceptable only if the surface is machined or ground to bright metal.
- (2) Butt welding end preparation contained in ASME B16.25 or any other end preparation that meets the procedure qualification is acceptable. [For convenience, the basic bevel angles taken from ASME B16.25, with some additional J-bevel angles, are shown in [Figure 328.4.2](#), illustrations (a) and (b).]

(b) *Circumferential Welds*

- (1) If components' ends are trimmed as shown in [Figure 328.4.2](#), illustration (a) or (b) to accommodate consumable inserts, or as shown in [Figure K328.4.3](#) to correct internal misalignment, such trimming shall not result in a finished wall thickness before welding less than the required minimum wall thickness,  $t_m$ .
- (2) It is permissible to size pipe ends of the same nominal size to improve alignment, if wall thickness requirements are maintained.
- (3) Where necessary, weld metal may be deposited on the inside or outside of the component to permit alignment or provide for machining to ensure satisfactory seating of inserts.
- (4) When a butt weld joins sections of unequal wall thickness and the thicker wall is more than  $1\frac{1}{2}$  times the thickness of the other, end preparation and geometry shall

<sup>8</sup>Titles of referenced AWS standards are as follows: AWS B4.0M, Standard Methods for Mechanical Testing of Welds, and AWS B4.0, Standard Methods for Mechanical Testing of Welds.

be in accordance with acceptable designs for unequal wall thickness in ASME B16.5.

### K328.4.3 Alignment

#### (a) Girth Butt Welds

(1) Inside diameters of components at the ends to be joined shall be aligned within the dimensional limits in the welding procedure and the engineering design, except that no more than 1.5 mm ( $1/16$  in.) misalignment is permitted as shown in Figure K328.4.3.

(2) If the external surfaces of the two components are not aligned, the weld shall be tapered between the two surfaces with a slope not steeper than 1:4.

(b) *Longitudinal Butt Joints.* Preparation for longitudinal butt welds (not made in accordance with a standard listed in Table K-1 or Table K326.1) shall conform to the requirements of (a).

#### (c) Branch Connection Welds

(1) The dimension  $m$  in Figure K328.5.4 shall not exceed  $\pm 1.5$  mm ( $1/16$  in.).

(2) The dimension  $g$  in Figure K328.5.4 shall be specified in the engineering design and the welding procedure.

### K328.5 Welding Requirements

**K328.5.1 General.** The requirements of paras. 328.5.1(b), 328.5.1(d), 328.5.1(e), and 328.5.1(f) apply in addition to the requirements specified below.

(a) All welds, including tack welds, repair welds, and the addition of weld metal for alignment [paras. K328.4.2(b)(3) and K328.4.3(c)(1)], shall be made by qualified welders or welding operators, in accordance with a qualified procedure.

(b) Tack welds at the root of the joint shall be made with filler metal equivalent to that used for the root pass. Tack welds shall be fused with the root pass weld, except that those that have cracked shall be removed. Bridge tacks (above the root) shall be removed.

**K328.5.2 Fillet Welds.** Fillet welds, where permitted (see para. K311.2.2), shall be fused with and shall merge smoothly into the component surfaces.

**K328.5.3 Seal Welds.** Seal welds are not permitted.

**K328.5.4 Welded Branch Connections.** Branch connection fittings (see para. 300.2), attached by smoothly contoured full penetration groove welds of a design that permits 100% interpretable radiographic examination, are the only types acceptable.

Figure K328.5.4 shows acceptable details of welded branch connections. The illustrations are typical and are not intended to exclude acceptable types of construction not shown.

**K328.5.5 Fabricated Laps.** Fabricated laps are not permitted.

### K328.6 Weld Repair

Paragraph 328.6 applies, except that procedures and performance shall be qualified as required by para. K328.2.1. See also para. K341.3.3.

## K330 PREHEATING

### K330.1 General

(20)

The preheat requirements herein apply to all types of welding, including tack welds and repair welds.

**K330.1.1 Requirements.** Paragraph 330.1.1 applies.

**K330.1.2 Unlisted Materials.** Paragraph 330.1.2 applies.

**K330.1.3 Temperature Verification.** Paragraph 330.1.3(a) applies. Temperature-indicating materials and techniques shall not be detrimental to the base metals.

**K330.1.4 Preheat Zone.** Paragraph 330.1.4 applies.

### K330.2 Specific Requirements

Paragraph 330.2 applies in its entirety.

## K331 HEAT TREATMENT

(20)

### K331.1 General

**K331.1.1 Postweld Heat Treatment Requirements.** The provisions of para. 331.1.1 and Tables 331.1.1, 331.1.2, and 331.1.3 apply, except as specified below.

(a) The exemptions to mandatory postweld heat treatment in Table 331.1.3 for P-No. 1, all Group Nos., are not permitted when the control thickness exceeds 19 mm ( $3/4$  in.).

(b) The exemptions to mandatory postweld heat treatment in Table 331.1.3 for P-No. 4, Group No. 1 and P-No. 5A, Group No. 1 materials are not permitted.

(c) For quenched and tempered materials, any heat treatment of other than longitudinal welds shall be performed at a temperature no warmer than 28°C

**Figure K328.4.3 Pipe Bored for Alignment: Trimming and Permitted Misalignment**

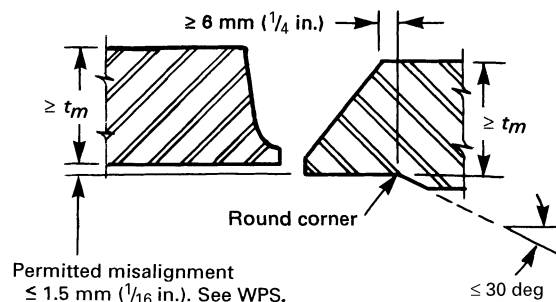
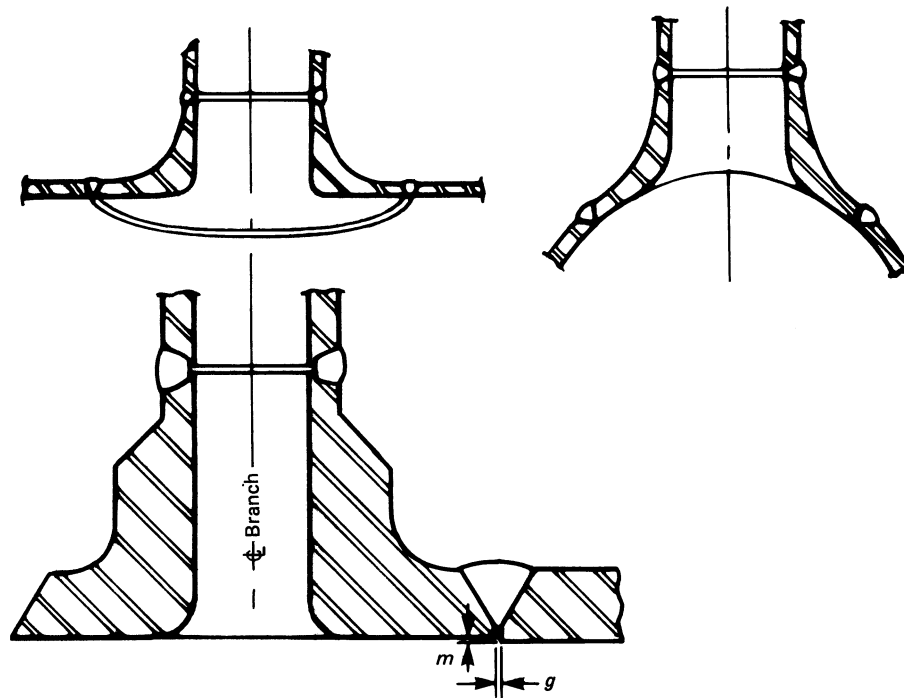


Figure K328.5.4 Some Acceptable Welded Branch Connections Suitable for 100% Radiography



(50°F) below the tempering temperature of the material. When this heat treatment temperature is lower than the range specified in [Table 331.1.1](#), the decrease in heat treatment temperature shall be accompanied by an increase in holding time in accordance with [Table 331.1.2](#).

(d) Longitudinal welds in quenched and tempered material shall be heat treated in accordance with the applicable material specification.

(e) Refer to [para. K331.1.3](#) instead of [para. 331.1.3](#).

(f) Refer to [Appendix K](#) instead of [Appendix A](#).

(g) ASME B31P and [para. 328.7](#) do not apply.

**K331.1.2 Other Heat Treatments.** Heat treatment for bending and forming shall be in accordance with [para. K332.4](#).

**K331.1.3 Definition of Thicknesses Governing Post-weld Heat Treatment.** The provisions of [para. 331.1.3](#) apply, except for [331.1.3\(b\)\(5\)](#).

**K331.1.4 Heating and Cooling.** [Paragraph 331.1.4](#) applies.

**K331.1.6 Temperature Verification.** Heat treatment temperature shall be checked by thermocouple pyrometers or other suitable methods to ensure that the WPS requirements are met. Temperature-indicating materials and techniques shall not be detrimental to the base metals.

## K331.2 Specific Requirements

[Paragraph 331.2](#) applies, but refer to [para. K331.1](#) instead of [para 331.1](#).

## K332 BENDING AND FORMING

### K332.1 General

Pipe shall be hot or cold bent in accordance with a written procedure to any radius that will result in surfaces free of cracks and free of buckles. The procedure shall address at least the following, as applicable:

- (a) material specification and range of size and thickness
- (b) range of bend radii and fiber elongation
- (c) minimum and maximum metal temperature during bending
- (d) method of heating and maximum hold time
- (e) description of bending apparatus and procedure to be used
- (f) mandrels or material and procedure used to fill the bore
- (g) method for protection of thread and machined surfaces
- (h) examination to be performed
- (i) required heat treatment
- (j) postheat treatment dimensional adjustment technique

## K332.2 Bending

**K332.2.1 Bend Flattening.** The difference between the maximum and the minimum diameters at any cross section of a bend shall not exceed 8% of nominal outside diameter for internal pressure and 3% for external pressure.

**K332.2.2 Bending Temperature.** Paragraph 332.2.2 applies, except that in cold bending of quenched and tempered ferritic materials, the temperature shall be at least 28°C (50°F) below the tempering temperature.

## K332.3 Forming

Piping components shall be formed in accordance with a written procedure. The temperature range shall be consistent with material characteristics, end use, and specified heat treatment. The thickness after forming shall be not less than required by design. The procedure shall address at least the following, as applicable:

- (a) material specification and range of size and thickness
- (b) maximum fiber elongation expected during forming
- (c) minimum and maximum metal temperature during bending
- (d) method of heating and maximum hold time
- (e) description of forming apparatus and procedure to be used
- (f) materials and procedures used to provide internal support during forming
- (g) examination to be performed
- (h) required heat treatment

## K332.4 Required Heat Treatment

- (20) **K332.4.1 Hot Bending and Forming.** After hot bending and forming, heat treatment is required for all thicknesses of P-Nos. 3, 4, 5A, 5B, 6, 10A, 10B, and 15E materials that are not quenched and tempered. Times and temperatures shall be in accordance with para. 331. Quenched and tempered materials shall be reheat treated to the original material specification.

- (20) **K332.4.2 Cold Bending and Forming**

(a) After cold bending and forming, heat treatment in accordance with (b) below is required, regardless of thickness, when specified in the engineering design or when the maximum calculated fiber elongation exceeds 5% strain or 50% of the basic minimum specified longitudinal elongation for the applicable specification, grade, and thickness for P-Nos. 1, 3, 4, 5A, 5B, 6, 10A, 10B, and 15E materials (unless it has been demonstrated that the selection of the pipe and the procedure for making the components provide assurance that the most severely formed portion of the material has retained an elongation of not less than 10%).

(b) Heat treatment is required regardless of thickness and shall conform to the temperatures and durations given in Table 331.1.1, except that for quenched and tempered materials, the stress relieving temperature shall not exceed a temperature 28°C (50°F) below the tempering temperature of the material.

## K333 BRAZING AND SOLDERING

(20)

Brazing shall conform to the requirements of this Part and the applicable requirements of para. K317.2. Braze welding and soldering are not permitted.

### K333.1 Brazing Responsibility

Each employer is responsible for

- (a) the brazing performed by personnel of its organization
- (b) conducting the qualification tests required to qualify the brazing procedure specifications used by personnel in its organization
- (c) conducting the qualification tests required to qualify its brazers and brazing operators

### K333.2 Brazing Qualifications

**K333.2.1 Qualification Requirements.** The qualification of brazing procedures, brazers, and brazing operators shall be in accordance with the requirements of ASME BPVC, Section IX.

**K333.2.2 Procedure Qualification by Others.** Brazing procedure specifications qualified by a technically competent group or agency may be used, provided the following requirements are met:

- (a) The owner shall approve the use of brazing procedure specifications qualified by others.
- (b) The brazing procedure specifications shall meet the requirements of para. K333.2.1.
- (c) The employer's business name shall be shown on each brazing procedure specification and on each brazing procedure qualification record.
- (d) The employer shall accept responsibility for each brazing procedure qualification performed by others by signing and dating each brazing procedure qualification record.
- (e) The employer shall conduct the qualification tests required to qualify its brazers and brazing operators.

**K333.2.3 Performance Qualification by Others.** An employer may accept the performance qualification of a brazer or brazing operator made by a technically competent group or agency, provided the following requirements are met:

- (a) The owner shall approve the use of brazing performance qualifications qualified by others.
- (b) The brazer or brazing operator performance qualifications were made on pipe test coupons.

(c) The employer shall have a brazing procedure specification such that the performance qualification is within the limits of the essential variables set forth in ASME BPVC, Section IX.

(d) The employer shall have a copy of the performance qualification test record. The record shall show the name of the technically competent group or agency by whom the brazer or brazing operator was qualified and the date of that qualification. Evidence shall also be provided that the brazer or brazing operator has maintained qualification in accordance with ASME BPVC, Section IX, QB-322.

(e) The employer's business name shall be shown on the brazing performance qualification record.

(f) The employer shall accept responsibility for the brazing performance qualifications performed by others by signing and dating the qualification.

**K333.2.4 Qualification Records.** The employer shall maintain copies of the brazing procedure specification and performance qualification records specified by ASME BPVC, Section IX. These records shall be made available to the Inspector upon request.

### K333.3 Materials

Brazing filler metals and flux shall be in accordance with [para. 333.2.1](#).

### K333.4 Preparation and Cleaning

[Paragraph 333.3](#) applies, except that soldering is not permitted.

## K335 ASSEMBLY AND ERECTION

### K335.1 General

[Paragraph 335.1](#) applies.

### K335.2 Flanged Joints

[Paragraph 335.2](#) applies, except that bolts shall extend completely through their nuts.

### K335.3 Threaded Joints

[Paragraph 335.3](#) applies, except that threaded joints shall not be seal welded.

### K335.4 Special Joints

Special joints (as defined in [para. K318](#)) shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure full engagement of joint members.

### K335.5 Cleaning of Piping

See [Appendix F, para. F335.9](#).

## PART 10 INSPECTION, EXAMINATION, AND TESTING

### K340 INSPECTION

[Paragraphs 340.1](#) through [340.4](#) apply.

### K341 EXAMINATION

[Paragraphs 341.1](#) and [341.2](#) apply.

#### K341.3 Examination Requirements

**K341.3.1 General.** Prior to initial operation, each piping installation, including components and workmanship, shall be examined in accordance with [para. K341.4](#) and the engineering design. If heat treatment is performed, examination shall be conducted after its completion.

**K341.3.2 Acceptance Criteria.** Acceptance criteria shall be as stated in the engineering design and shall at least meet the applicable requirements stated in (a) and (b) below, and elsewhere in this Chapter.

(a) [Table K341.3.2](#) states acceptance criteria (limits on imperfections) for welds. See [Figure 341.3.2](#) for typical weld imperfections.

(b) Acceptance criteria for castings are specified in [para. K302.3.3](#).

**K341.3.3 Defective Components and Workmanship.** (20) Defects (imperfections of a type or magnitude not acceptable by the criteria specified in [para. K341.3.2](#)) shall be repaired, or the defective item or work shall be replaced.

Examination shall be as follows:

(a) When the defective item or work is repaired, the repaired portion of the item or work shall be examined after the completion of any required heat treatment. The examination shall use the same methods and acceptance criteria employed for the original examination.

(b) When the defective item or work is replaced, the new item or work used to replace the defective item or work shall be examined after the completion of any required heat treatment. The examination shall use any method and applicable acceptance criteria that meet the requirements for the original examination.

#### K341.4 Extent of Required Examination

Piping shall be examined to the extent specified herein or to any greater extent specified in the engineering design.

##### K341.4.1 Visual Examination (20)

(a) The requirements of [para. 341.4.1\(a\)](#) apply with the following exceptions in regard to extent of examination:

- (1) *Materials and Components.* 100%.
- (2) *Fabrication.* 100%.
- (3) *Threaded, Bolted, and Other Joints.* 100%.



**Table K341.3.2 Acceptance Criteria for Welds**

| Type of Imperfection                       | Criteria (A–F) for Types of Welds, and for Required Examination Methods <a href="#">[Note (1)]</a> |                            |              |                                                |                                   |                                              |
|--------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------|--------------|------------------------------------------------|-----------------------------------|----------------------------------------------|
|                                            | Methods                                                                                            |                            | Type of Weld |                                                |                                   |                                              |
|                                            | Visual                                                                                             | Ultrasonics or Radiography | Girth Groove | Longitudinal Groove <a href="#">[Note (2)]</a> | Fillet <a href="#">[Note (3)]</a> | Branch Connection <a href="#">[Note (4)]</a> |
| Crack                                      | ✓                                                                                                  | ✓                          | A            | A                                              | A                                 | A                                            |
| Lack of fusion                             | ✓                                                                                                  | ✓                          | A            | A                                              | A                                 | A                                            |
| Incomplete penetration                     | ✓                                                                                                  | ✓                          | A            | A                                              | A                                 | A                                            |
| Internal porosity                          | ...                                                                                                | ✓                          | B            | B                                              | N/A                               | B                                            |
| Linear indication                          | ...                                                                                                | ✓                          | C            | C                                              | N/A                               | C                                            |
| Undercutting                               | ✓                                                                                                  | ✓                          | A            | A                                              | A                                 | A                                            |
| Surface porosity or exposed slag inclusion | ✓                                                                                                  | ...                        | A            | A                                              | A                                 | A                                            |
| Concave root surface (suck-up)             | ✓                                                                                                  | ✓                          | D            | D                                              | N/A                               | D                                            |
| Surface finish                             | ✓                                                                                                  | ...                        | E            | E                                              | E                                 | E                                            |
| Reinforcement or internal protrusion       | ✓                                                                                                  | ...                        | F            | F                                              | F                                 | F                                            |

## GENERAL NOTES:

- (a) Weld imperfections are evaluated by one or more of the types of examination methods given, as specified in [paras. K341.4.1](#) and [K341.4.2](#).
- (b) “N/A” indicates this Chapter does not establish acceptance criteria or does not require evaluation of this kind of imperfection for this type of weld.
- (c) Check (✓) indicates examination method generally used for evaluating this kind of weld imperfection.
- (d) Ellipsis (...) indicates examination method not generally used for evaluating this kind of weld imperfection.
- (e) Symbols A through F are explained in the table on the next page.

## NOTES:

- (1) Criteria given are for required examination. More-stringent criteria may be specified in the engineering design.
- (2) Longitudinal welds include only those permitted in [paras. K302.3.4](#) and [K305](#). The criteria shall be met by all welds, including those made in accordance with a standard listed in [Table K326.1](#) or in [Appendix K](#).
- (3) Fillet welds include only those permitted in [para. K311.2.2](#).
- (4) Branch connection welds include only those permitted in [para. K328.5.4](#).



## Criterion Value Notes for Table K341.3.2

| Criterion                                 |                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|----------------------------------------------------------------------|---------------|-------------------|------------------------------|----------------|------------|-----------------|
| Symbol                                    | Measure                                                                                                                                                                                                                                                          | Acceptable Value Limits [Note (1)]                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                           |                                                                      |               |                   |                              |                |            |                 |
| A                                         | Extent of imperfection                                                                                                                                                                                                                                           | Zero (no evident imperfection)                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                           |                                                                      |               |                   |                              |                |            |                 |
| B                                         | Size and distribution of internal porosity                                                                                                                                                                                                                       | See ASME BPVC, Section VIII, Division 1, Appendix 4                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                           |                                                                      |               |                   |                              |                |            |                 |
| C                                         | Internal slag inclusion, tungsten inclusion, or linear indication. Indications are unacceptable if the amplitude exceeds the reference level, or indications have lengths that exceed<br><br>Individual length [Note (2)]<br><br>Cumulative length               | Zero (no evident imperfection)<br>See ASME BPVC, Section VIII, Division 1, Appendix 4<br>6 mm (¼ in.) for $\bar{T}_w \leq 19$ mm (¾ in.)<br>$\bar{T}_w/3$ for 19 mm (¾ in.) < $\bar{T}_w \leq 57$ mm (2¼ in.)<br>19 mm (¾ in.) for $\bar{T}_w > 57$ mm (2¼ in.)<br>$\leq \bar{T}_w$ in any 12 $\bar{T}_w$ weld length                                                                                                                                                               |                                           |                                                                      |               |                   |                              |                |            |                 |
| D                                         | Depth of root surface concavity                                                                                                                                                                                                                                  | <table><tr><th>Wall Thickness,<br/><math>\bar{T}_w</math>, mm (in.)</th><th>Depth of Surface<br/>Concavity, mm (in.)</th></tr><tr><td><math>\leq 13</math> (½)</td><td><math>\leq 1.5</math> (1/16)</td></tr><tr><td><math>&gt; 13</math> (½) and <math>\leq 51</math> (2)</td><td><math>\leq 3</math> (1/8)</td></tr><tr><td><math>&gt; 51</math> (2)</td><td><math>\leq 4</math> (5/32)</td></tr></table> and total joint thickness including weld reinforcement $\geq \bar{T}_w$ | Wall Thickness,<br>$\bar{T}_w$ , mm (in.) | Depth of Surface<br>Concavity, mm (in.)                              | $\leq 13$ (½) | $\leq 1.5$ (1/16) | $> 13$ (½) and $\leq 51$ (2) | $\leq 3$ (1/8) | $> 51$ (2) | $\leq 4$ (5/32) |
| Wall Thickness,<br>$\bar{T}_w$ , mm (in.) | Depth of Surface<br>Concavity, mm (in.)                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
| $\leq 13$ (½)                             | $\leq 1.5$ (1/16)                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
| $> 13$ (½) and $\leq 51$ (2)              | $\leq 3$ (1/8)                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
| $> 51$ (2)                                | $\leq 4$ (5/32)                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
| E                                         | Surface roughness                                                                                                                                                                                                                                                | $\leq 12.5$ µm (500 µin.) $R_a$ (see ASME B46.1 for definition of roughness average, $R_a$ )                                                                                                                                                                                                                                                                                                                                                                                        |                                           |                                                                      |               |                   |                              |                |            |                 |
| F                                         | Height of reinforcement or internal protrusion [Note (3)] in any plane through the weld shall be within the limits of the applicable height value in the tabulation at the right. Weld metal shall be fused with and merge smoothly into the component surfaces. | <table><tr><th>Wall Thickness,<br/><math>\bar{T}_w</math>, mm (in.)</th><th>External Weld Reinforcement<br/>or Internal Weld Protrusion, mm (in.)</th></tr><tr><td><math>\leq 13</math> (½)</td><td><math>\leq 1.5</math> (1/16)</td></tr><tr><td><math>&gt; 13</math> (½) and <math>\leq 51</math> (2)</td><td><math>\leq 3</math> (1/8)</td></tr><tr><td><math>&gt; 51</math> (2)</td><td><math>\leq 4</math> (5/32)</td></tr></table>                                            | Wall Thickness,<br>$\bar{T}_w$ , mm (in.) | External Weld Reinforcement<br>or Internal Weld Protrusion, mm (in.) | $\leq 13$ (½) | $\leq 1.5$ (1/16) | $> 13$ (½) and $\leq 51$ (2) | $\leq 3$ (1/8) | $> 51$ (2) | $\leq 4$ (5/32) |
| Wall Thickness,<br>$\bar{T}_w$ , mm (in.) | External Weld Reinforcement<br>or Internal Weld Protrusion, mm (in.)                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
| $\leq 13$ (½)                             | $\leq 1.5$ (1/16)                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
| $> 13$ (½) and $\leq 51$ (2)              | $\leq 3$ (1/8)                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |
| $> 51$ (2)                                | $\leq 4$ (5/32)                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                           |                                                                      |               |                   |                              |                |            |                 |

## NOTES:

- (1) Where two limiting values are given, the lesser measured value governs acceptance.  $\bar{T}_w$  is the nominal wall thickness of the thinner of two components joined by a butt weld.
- (2) For ultrasonic examination, refer to para. K344.6.3 for acceptable value limits.
- (3) For groove welds, height is the lesser of the measurements made from the surfaces of the adjacent components. For fillet welds, height is measured from the theoretical throat; internal protrusion does not apply. Required thickness  $t_m$  shall not include reinforcement or internal protrusion.

(4) *Piping Erection.* All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

(b) *Pressure-Containing Threads.* 100% examination for finish and fit is required. Items with visible imperfections in thread finish or any of the following defects shall be rejected:

(1) *Tapered Threads.* Failure to meet gaging requirements in API Spec 5B or ASME B1.20.1, as applicable.

(2) *Straight Threads.* Excessively loose or tight fit when gaged for light interference fit.

(c) *Brazed Joints.* 100% of all brazed joints shall be examined by in-process examination in accordance with para. K344.7.

#### K341.4.2 Radiographic and Ultrasonic Examination

(a) All girth, longitudinal, and branch connection welds shall be 100% radiographically examined, except as permitted in (b) below.

(b) When specified in the engineering design and with the owner's approval, ultrasonic examination of welds may be substituted for radiographic examination where  $\bar{T}_w \geq 13 \text{ mm } (\frac{1}{2} \text{ in.})$ .

(c) In-process examination (see para. 344.7) shall not be substituted for radiographic or ultrasonic examination of welds.

**K341.4.3 Certifications and Records.** Paragraph 341.4.1(c) applies.

#### K341.5 Supplementary Examination

Any of the examination methods described in para. K344 may be specified by the engineering design to supplement the examination required by para. K341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those specified in para. K341.3.2 shall be specified in the engineering design.

**K341.5.1 Hardness Tests.** Paragraph 341.5.2 applies.

**K341.5.2 Examinations to Resolve Uncertainty.** Paragraph 341.5.3 applies.

#### K342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

#### K343 EXAMINATION PROCEDURES

Paragraph 343 applies, except that the examination methods shall comply with para. K344.

#### K344 TYPES OF EXAMINATION

##### K344.1 General

Paragraphs 344.1.1 and 344.1.2 apply. In para. 344.1.3, terms other than "100% examination" apply only to supplementary examinations.

##### K344.2 Visual Examination

Paragraph 344.2 applies in its entirety.

##### K344.3 Magnetic Particle Examination

The method for magnetic particle examination shall be as specified in

(a) paragraph K302.3.3(b) for castings

(b) ASME BPVC, Section V, Article 7 for welds and other components

##### K344.4 Liquid Penetrant Examination

The method for liquid penetrant examination shall be as specified in

(a) paragraph K302.3.3(b) for castings

(b) ASME BPVC, Section V, Article 6 for welds and other components

##### K344.5 Radiographic Examination

The method for radiographic examination shall be as specified in

(a) paragraph K302.3.3(c) for castings

(b) ASME BPVC, Section V, Article 2 for welds and other components

##### K344.6 Ultrasonic Examination

**K344.6.1 Castings.** The method for ultrasonic examination of castings shall be as specified in para. K302.3.3(c).

##### K344.6.2 Pipe and Tubing

(a) *Method.* Pipe and tubing, required or selected in accordance with Table K305.1.2 to undergo ultrasonic examination, shall pass a 100% examination for longitudinal defects in accordance with ASTM E213, Ultrasonic Testing of Metal Pipe and Tubing. Longitudinal (axial) reference notches shall be introduced on the outer and inner surfaces of the calibration (reference) standard in accordance with Figure 3(c) of ASTM E213 to a depth not greater than the larger of 0.1 mm (0.004 in.) or 4% of specimen thickness and a length not more than 10 times the notch depth.

(b) *Acceptance Criteria.* Any indication greater than that produced by the calibration notch represents a defect; defective pipe and tubing shall be rejected.

(c) *Records.* For pipe and tubing that passes this examination, a report shall be prepared that contains at least the information specified in 15.2.1 through 15.2.6 of ASTM E213.

### K344.6.3 Welds

(a) *Method.* The method for ultrasonic examination of welds shall be as specified in ASME BPVC, Section V, Article 4 for nominal thickness,  $\bar{T}_w$ , greater than or equal to 13 mm ( $\frac{1}{2}$  in.) but less than 25 mm (1 in.), and ASME BPVC, Section VIII, Division 3, KE-301 and KE-302 for nominal wall thickness,  $\bar{T}_w$ , greater than or equal to 25 mm (1 in.).

(b) *Acceptance Criteria.* Cracks, lack of fusion, incomplete penetration, or undercutting are unacceptable regardless of size or length (see Table K341.3.2). In addition, for an internal slag inclusion, tungsten inclusion, or linear indication

(1) for nominal wall thickness,  $\bar{T}_w$ , greater than or equal to 13 mm ( $\frac{1}{2}$  in.) but less than 25 mm (1 in.), the acceptance criterion for the thickness to be examined specified in para. 344.6.2 applies.

(2) for nominal wall thickness,  $\bar{T}_w$ , greater than or equal to 25 mm (1 in.), the acceptance criteria specified in ASME BPVC, Section VIII, Division 3, KE-333 for the thickness to be examined apply.

### K344.7 In-Process Examination

Paragraph 344.7 applies in its entirety.

### K344.8 Eddy Current Examination

**K344.8.1 Method.** The method for eddy current examination of pipe and tubing shall follow the general guidelines of ASME BPVC, Section V, Article 8, subject to the following specific requirements:

(a) Cold drawn austenitic stainless steel pipe and tubing, selected in accordance with Table K305.1.2 for eddy current examination, shall pass a 100% examination for longitudinal defects.

(b) A calibration (reference) standard shall be prepared from a representative sample. A longitudinal (axial) reference notch shall be introduced on the inner surface of the standard to a depth not greater than the larger of 0.1 mm (0.004 in.) or 5% of specimen thickness and a length not more than 6.4 mm (0.25 in.).

**K344.8.2 Acceptance Criteria.** Any indication greater than that produced by the calibration notch represents a defect; defective pipe or tubing shall be rejected.

**K344.8.3 Records.** For pipe and tubing that passes this examination, a report shall be prepared that includes at least the following information:

- (a) material identification by type, size, lot, heat, etc.
- (b) listing of examination equipment and accessories
- (c) details of examination technique (including examination speed and frequency) and end effects, if any
- (d) description of the calibration standard, including dimensions of the notch, as measured
- (e) examination results

## K345 LEAK TESTING

### K345.1 Required Leak Test

(20)

Prior to initial operation, each piping system shall be leak tested.

(a) Each weld and each piping component, except bolting and individual gaskets to be used during final system assembly and pressure relief devices to be used during operation, shall be hydrostatically or pneumatically leak tested in accordance with para. K345.4 or K345.5, respectively. The organization conducting the test shall ensure that during the required leak testing of components and welds, adequate protection is provided to prevent injury to people and damage to property from missile fragments, shock waves, or other consequences of any failure that might occur in the pressurized system.

(b) In addition to the requirements of (a) above, a leak test of the installed piping system, excluding pressure relief devices to be used during operation, shall be conducted at a pressure not less than 110% of the design pressure to ensure tightness, except as provided in (c) or (d) below.

(c) If the leak test required in (a) above is conducted on the installed piping system, the additional test in (b) above is not required.

(d) With the owner's approval, pressure relief devices to be used during operation may be included in the leak test required in (b) above. The leak test pressure may be reduced to prevent the operation of, or damage to, the pressure relief devices, but shall not be less than 90% of the lowest set pressure of the pressure relief devices in the system.

(e) For closure welds, examination in accordance with para. K345.2.3(c) may be substituted for the leak test required in (a) above.

(f) None of the following leak tests may be used in lieu of the leak tests required in para. K345.1:

- (1) initial service leak test (para. 345.7)
- (2) sensitive leak test (para. 345.8)
- (3) alternative leak test (para. 345.9)

### K345.2 General Requirements for Leak Tests

Paragraphs 345.2.4 through 345.2.7 apply. See below for paras. K345.2.1, K345.2.2, and K345.2.3.

#### K345.2.1 Limitations on Pressure

(20)

(a) *Through-Thickness Yielding.* If the test pressure would produce stress (exclusive of stress intensification) in excess of  $S_{yt}$  at the outside surface of a component at test temperature, as determined by calculation or by testing in accordance with para. K304.7.2(b), the test pressure may be reduced to the maximum pressure that will result in a stress (exclusive of stress intensification) at the outside surface that will not exceed  $S_{yt}$ .

(b) The provisions of paras. 345.2.1(b) and 345.2.1(c) apply.

**K345.2.2 Other Test Requirements.** Paragraph 345.2.2 applies. In addition, the minimum metal temperature during testing shall be not less than the impact test temperature (see para. K323.3.4).

**K345.2.3 Special Provisions for Leak Testing.** Paragraphs (a), (b), and (c) below apply only to the leak test specified in para. K345.1(a). They are not applicable to the installed piping system leak test specified in para. K345.1(b).

(a) *Piping Components and Subassemblies.* Piping components and subassemblies may be leak tested either separately or as assembled piping.

(b) *Flanged Joints.* Flanged joints used to connect piping components that have previously been leak tested, and flanged joints at which a blank or blind flange is used to isolate equipment or other piping during the leak test, need not be leak tested.

(c) *Closure Welds.* Leak testing of the final weld connecting piping systems or components that have been successfully leak tested is not required, provided the weld is examined in-process in accordance with para. 344.7 and passes the required 100% radiographic examination in accordance with para. K341.4.2.

### K345.3 Preparation for Leak Test

Paragraph 345.3 applies in its entirety.

### K345.4 Hydrostatic Leak Test

Paragraph 345.4.1 applies. See paras. K345.4.2 and K345.4.3 below.

**K345.4.2 Test Pressure for Components and Welds.** Except as provided in para. K345.4.3, the hydrostatic test pressure at every point in a metallic piping system shall be as follows:

- (a) not less than 1.25 times the design pressure.
- (b) when the design temperature is greater than the test temperature, the minimum test pressure, at the point under consideration, shall be calculated by eq. (38)

$$P_T = 1.25PS_T/S \quad (38)$$

where

- $P$  = internal design gage pressure
- $P_T$  = minimum test gage pressure
- $S$  = allowable stress at component design temperature for the prevalent pipe material; see Appendix K, Table K-1
- $S_T$  = allowable stress at test temperature for the prevalent pipe material; see Table K-1

(c) in those cases where the piping system may not include pipe itself, any other component in the piping system, other than pipe-supporting elements and bolting, may be used to determine the  $S_T/S$  ratio based on the applicable allowable stresses obtained from

Table K-1. In those cases where the piping system may be made up of equivalent lengths of more than one material, the  $S_T/S$  ratio shall be based on the minimum calculated ratio of the included materials.

**K345.4.3 Hydrostatic Test of Piping With Vessels as a System.** Paragraph 345.4.3(a) applies.

### K345.5 Pneumatic Leak Test

Paragraph 345.5 applies, except for para. 345.5.4. See para. K345.5.4 below.

**K345.5.4 Test Pressure.** The pneumatic test pressure for components and welds shall be identical to that required for the hydrostatic test in accordance with para. K345.4.2.

### K345.6 Hydrostatic-Pneumatic Leak Test for Components and Welds

If a combination hydrostatic-pneumatic leak test is used, the requirements of para. K345.5 shall be met, and the pressure in the liquid-filled part of the piping shall not exceed the limits stated in para. K345.4.2.

## K346 RECORDS

### K346.1 Responsibility

(20)

It is the responsibility of the designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Chapter and by the engineering design.

### K346.2 Required Records

(20)

At least the following records, as applicable, shall be provided to the owner or the Inspector by the person responsible for their preparation:

- (a) the engineering design
- (b) the written report required in para. K300(b)(2)
- (c) material certifications
- (d) procedures used for fabrication, welding, brazing, heat treatment, examination, and testing
- (e) repair records of materials and piping components, including the welding procedure used for each, and location of repairs
- (f) performance qualifications for welders, brazers, and welding and brazing operators
- (g) qualifications of examination personnel
- (h) records of examination of pipe and tubing for longitudinal defects as specified in paras. K344.6.2(c) and K344.8.3, as applicable

### K346.3 Retention of Records

The owner shall retain one set of the required records for at least 5 yr after they are received.

# Chapter X

## High Purity Piping

### U300 GENERAL STATEMENTS

(a) Chapter X pertains to piping designated by the owner as being in High Purity Fluid Service. See also Appendix M.

(b) The organization, content, and paragraph designations of this Chapter correspond to those of the base Code (Chapters I through VI), Chapter VII, and Chapter VIII. The prefix U is used to designate Chapter X requirements.

(c) Provisions and requirements of the base Code, Chapter VII, and Chapter VIII apply only as stated in this Chapter.

(d) For piping not in High Purity Fluid Service, Code requirements are found in Chapters I through IX.

(e) High Purity Piping. Chapter X provides alternative rules for design and construction of piping designated by the owner as being High Purity Fluid Service.

(1) These rules apply only when specified by the owner, and only as a whole, not in part.

(2) Chapter X rules do not provide for High Pressure Fluid Service.

(3) Chapter VII applies to nonmetallic piping and piping lined with nonmetals in High Purity Fluid Service.

(f) Chapter I applies.

### PART 1 CONDITIONS AND CRITERIA

Chapter II, Part 1 applies. See para. U301.3.2(b)(5).

### U301 DESIGN CONDITIONS

#### U301.3 Design Temperature

##### U301.3.2 Uninsulated Components

(b)

(5) compression, face seal, and hygienic clamped fittings and joints — 100% of the fluid temperature

### PART 2 PRESSURE DESIGN OF PIPING COMPONENTS

Chapter II, Part 2 applies. See Figure U304.5.3 for representative configuration for metal face seal blanks.

### PART 3 FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

Chapter II, Part 3 applies. See paras. U306.6, U307.3, and U308.

### U306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

#### U306.6 Tube Fittings

(a) Tube fittings not listed in Table 326.1 or Appendix A shall meet the pressure design requirements described in para. 302.2.3 and the mechanical strength requirements described in para. 303.

(b) Compression-type tube fittings may be used in accordance with para. U315.2 provided that the type of fitting selected complies with the following:

(1) The gripping action of the fitting shall provide vibration resistance as demonstrated by exhibiting a stress intensity factor equal to or less than 1.5.

(2) Intermixing of components from different manufacturers is permitted only when specified in the engineering design.

(c) Face seal or hygienic clamp-type fittings in which the tightness of the joint is provided by a seating surface other than the threads (e.g., a metal face-seal fitting comprising internal and external threaded components, glands, and gasket or other constructions shown typically in Figure U335.7.1) may be used.

### U307 VALVES AND SPECIALTY COMPONENTS

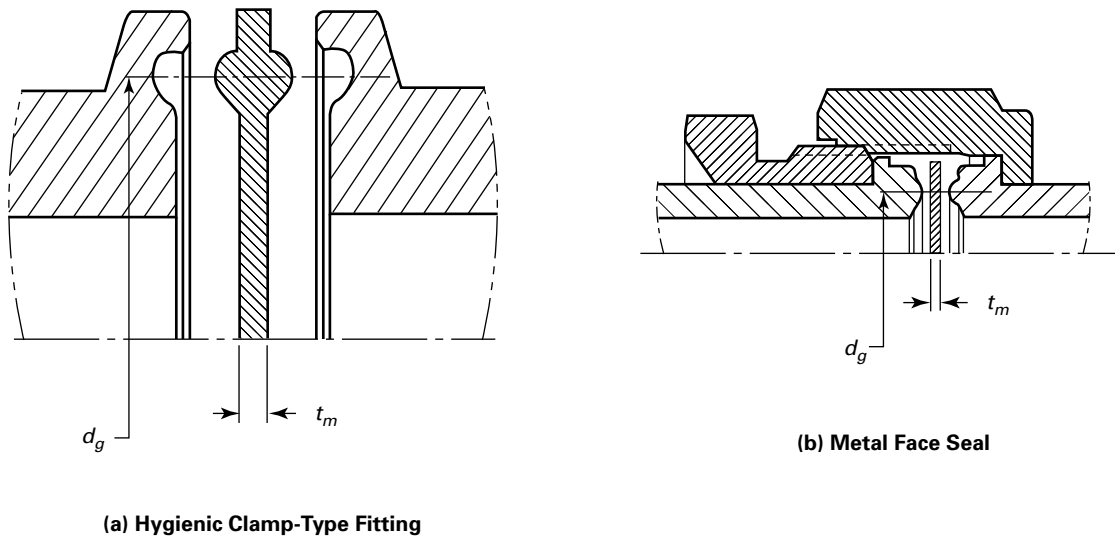
#### U307.3 High Purity Fluid Service Valves

Valves such as ball, bellows, and diaphragm valves designed for High Purity Fluid Service that are not listed in Table 326.1 shall meet the pressure design requirements described in para. 302.2.2 and the mechanical strength requirements described in para. 303.

### U308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

Flanges should be avoided whenever possible. When flanges are utilized, para. 308 applies, except expanded joint flanges described in para. 308.2.2 are not permitted.

Figure U304.5.3 Blanks



## PART 4 FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

Chapter II, Part 4 applies, except expanded joints, flared tube fittings, and caulked joints, described in paras. 313, 315, and 316, respectively, are not permitted. See paras. U311, U311.1(c), U314, and U315.

### U311 WELDED JOINTS

Paragraph 311 applies, except for para. 311.1(c). See para. U311.1(c).

#### U311.1 General

(c) Examination shall be in accordance with para. U341.4.1.

### U314 THREADED JOINTS

Threaded joints should be avoided whenever possible. When threaded joints are utilized, para. 314 applies.

### U315 TUBING JOINTS

Paragraph 315 applies. See paras. U315.1, U315.2(c), and U315.3.

#### U315.1 General

In selecting and applying compression, face seal, and hygienic clamp-type tube fittings, the designer shall consider the possible adverse effects on the joints of such factors as assembly and disassembly, cyclic loading, vibration, shock, and thermal expansion and contraction. See para. FU315.

### U315.2 Joints Conforming to Listed Standards

(c) Joints using compression, face seal, hygienic clamp, and automatic welding tube fittings covered by listed standards may be used.

### U315.3 Joints Not Conforming to Listed Standards

(a) Compression-type tube fitting joints shall be fully gageable on initial installation to ensure sufficient tightening.

(b) Safeguarding is required for face seal or hygienic clamp-type joints used under severe cyclic conditions.

## PART 5 FLEXIBILITY AND SUPPORT

Chapter II, Part 5 applies. See para. U319.3.6.

### U319 PIPING FLEXIBILITY

#### U319.3 Properties for Flexibility Analysis

**U319.3.6 Flexibility and Stress Intensification Factors.** Paragraph 319.3.6 applies; however, piping components used in high-purity applications, e.g., multi-port block valves, hygienic unions, crosses, and point-of-use and adaptor fittings, often do not have geometries similar to those in ASME B31J.

## PART 6 SYSTEMS

Chapter II, Part 6 applies.



## PART 7 METALLIC MATERIALS

The provisions and requirements in [Chapter III](#) for materials apply. Materials commonly used in high purity process piping systems include austenitic, ferritic, and duplex stainless steels, and nickel and nickel alloys.

## PART 8 STANDARDS FOR PIPING COMPONENTS

[Chapter IV](#) applies.

## PART 9 FABRICATION, ASSEMBLY, AND ERECTION

### U327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in [paras. U328, U330, U331, and U332](#). When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

### (20) U328 WELDING

[Paragraph 328](#) applies, except for [paras. 328.3.2, 328.5.4, and 328.5.5](#). See [paras. U328.2\(a\), U328.2\(b\), U328.2\(c\), U328.4, U328.4.2, U328.4.4, and U328.5.1\(g\)](#) for additional requirements.

### (20) U328.2 Welding and Brazing Qualification

The welding process shall be orbital GTAW, except for the following:

(a) Tack welds made prior to orbital welding may be manual GTAW.

(b) Manual GTAW may be used, with the owner's approval, on those welds where the orbital welding equipment cannot be used.

(c) A change in the type or nominal composition of the backing (purge) gas shall require requalification.

### U328.4 Preparation for Welding

[Paragraph 328.4.1](#) applies. Additionally, when weld coupon examination is specified in the engineering design or in the referencing code or standard (e.g., ASME BPE or SEMI), primary weld coupons shall be made in accordance with [para. U328.4.4\(b\)\(1\)](#) and examined in accordance with [para. U344.8](#) prior to the start of production welding. This will demonstrate that the orbital welding equipment is set up properly and the weld program is sufficient to make repeatable production welds in accordance with the qualified welding procedure specification (WPS).

### U328.4.2 End Preparations

(20)

(a) [Paragraph 328.4.2\(a\)\(1\)](#) applies, with the exception that discoloration requirements shall be based on the referencing code or standard (e.g., ASME BPE or SEMI).

(b) End preparations for GTAW are as follows:

(1) Components having nominal wall thickness of 3 mm ( $1/8$  in.) and less shall have ends prepared in accordance with the referencing code or standard (e.g., ASME BPE or SEMI).

(2) Pipe from 5 mm to 22 mm ( $3/16$  in. to  $7/8$  in.) nominal wall thickness shall be in accordance with ASME B16.25. "J" or bevel groove angles suitable for orbital welding are shown in [Figure U328.4.2](#).

(3) For pipe with nominal wall thickness 5 mm to 22 mm ( $3/16$  in. to  $7/8$  in.), a modified "J" end preparation with an extended land as shown in [Figure U328.4.2](#), illustration (a) may be used.

(4) A pipe with a modified "J" end preparation may be welded to a pipe fitting with a  $37^{1/2}$ -deg bevel end as shown in [Figure U328.4.2](#), illustration (b).

### U328.4.4 Preparation of Weld Coupons

(a) Weld coupons shall be made by qualified welding operators using the same qualified WPS and the same variables used for production welds.

(b) *Methods*

(1) Primary weld coupons shall be made from two short sections of tubing selected from the same diameter, wall thickness, and alloy as the material used for production. Sections shall be of sufficient length for fit up in the weld head allowing for attachment of inside diameter purge apparatus outside of the weld head. The sections shall be welded together in a square groove weld on a butt joint.

(2) Production weld coupons may be made in accordance with (1) or, at the owner's discretion, may be cut from actual production welds. The weld coupons shall be selected to ensure that the work product of each welding operator doing the production welding is represented.

### U328.5 Welding Requirements

#### U328.5.1 General

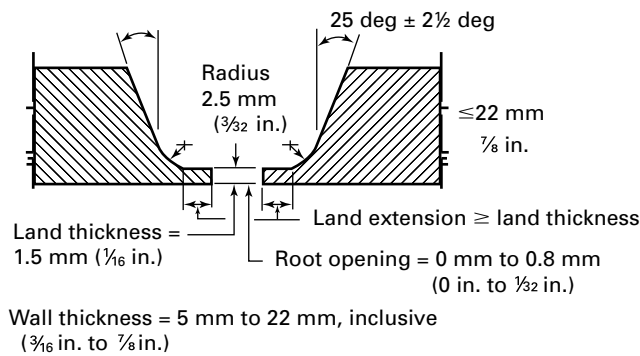
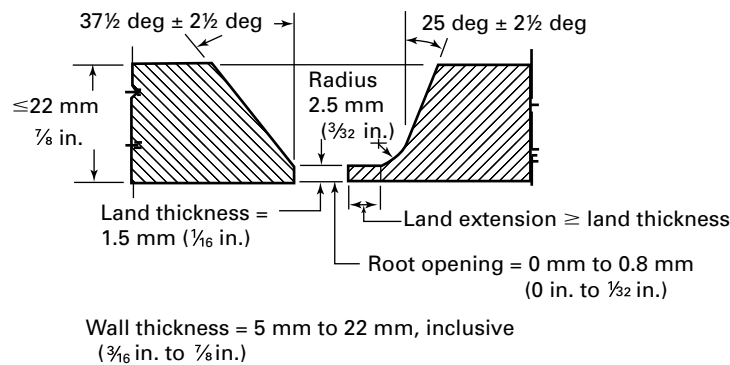
(g) Tack welds shall be fully consumed after completion of the weld. Tack welds shall be made by a qualified welder or welding operator.

### U330 PREHEATING

[Paragraph 330](#) applies.

### U331 HEAT TREATMENT

[Paragraph 331](#) applies.

**Figure U328.4.2 Modified Pipe End Preparations****(a) Modified "J" Preparation****(b) Modified Butt Weld Preparation****U332 BENDING AND FORMING**

Paragraph 332 applies in its entirety.

**U333 BRAZING AND SOLDERING**

Brazing and soldering are not permitted.

**U335 ASSEMBLY AND ERECTION**

Paragraph 335 applies, except for paras. 335.4.1, 335.5, and 335.6. See paras. U335.7 and U335.8.

**U335.7 Face Seal Joints**

**U335.7.1 Metal Face Seal.** Metal face seal joints shall be installed and assembled in accordance with manufacturer's instructions. See Figure U335.7.1, illustration (a).

**U335.7.2 Nonmetallic Face Seal.** Nonmetallic face seal joints shall be installed and assembled in accordance with manufacturer's instructions. Care shall be taken to avoid distorting the seal when incorporating such joints into piping assemblies by welding. See Figure U335.7.1, illustration (b).

**U335.8 Hygienic Clamp Joint Assembly**

Hygienic clamp joint assembly components, e.g., those shown in Figures U335.8A, U335.8B, and U335.8C, shall be installed and assembled in accordance with the manufacturer's instructions. Care shall be taken to avoid distorting the seal when incorporating such joints into piping assemblies by welding.

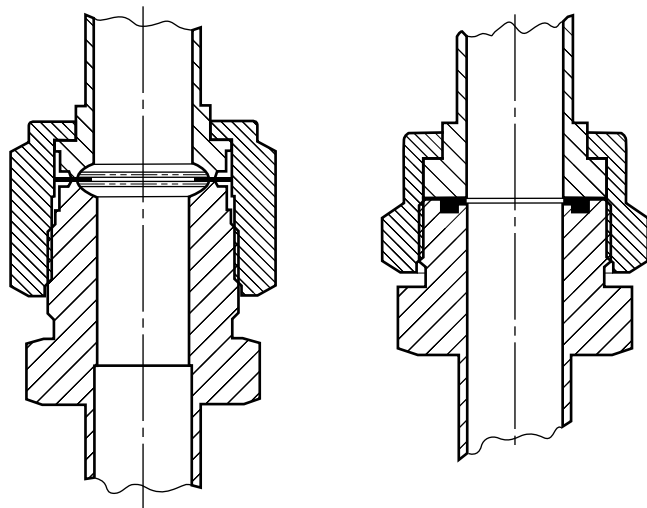
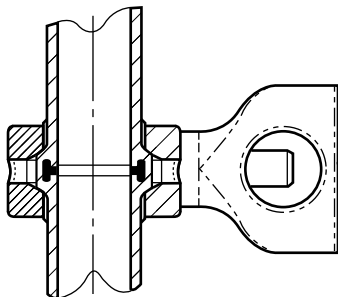
## PART 10 INSPECTION, EXAMINATION, AND TESTING

**U340 INSPECTION**

Paragraph 340 applies in its entirety.

**U341 EXAMINATION**

Paragraph 341 applies. See paras. U341.3.2 and U341.4.1.

**Figure U335.7.1 Face Seal Joints****(a) Metal Face Seal****(b) Nonmetallic Face Seal****Figure U335.8A Hygienic Clamp Joint Assembly****U341.3 Examination Requirements**

**U341.3.2 Acceptance Criteria.** Acceptance criteria for all coupon and production welds shall be as stated in the engineering design or in the referencing code or standard (e.g., ASME BPE or SEMI) and shall at least meet the applicable requirements in [para. 341.3.2](#).

**U341.4 Extent of Required Examination**

- (20) **U341.4.1 Examination.** Production weld coupon examination in accordance with [para. U344.8](#) may be used in lieu of the 5% random radiography/ultrasonic examination required in [para. 341.4.1\(b\)\(1\)](#) when any of the following are employed in fabrication:

- (a) autogenous automatic or machine orbital welding
- (b) automatic or machine orbital welding with the use of consumable inserts

(c) automatic or machine orbital welding with the use of filler wire

**U341.4.5 Weld Coupon Examination.** Weld coupons shall be made and examined in accordance with [para. U344.8](#) when any of the following conditions exist:

- (a) beginning of shift
- (b) change of purge source
- (c) change of power supply
- (d) change of equipment, e.g., weld head, weld-head extensions, tungsten
- (e) any time there is a weld defect

**U342 EXAMINATION PERSONNEL**

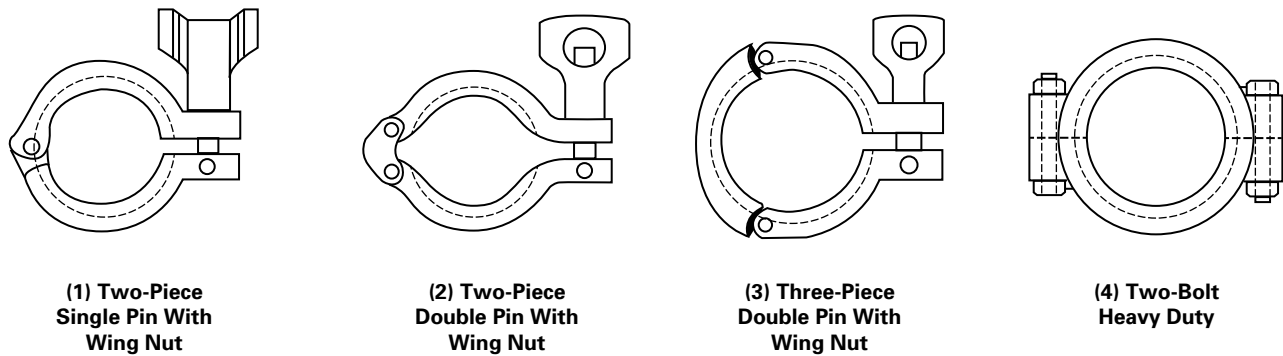
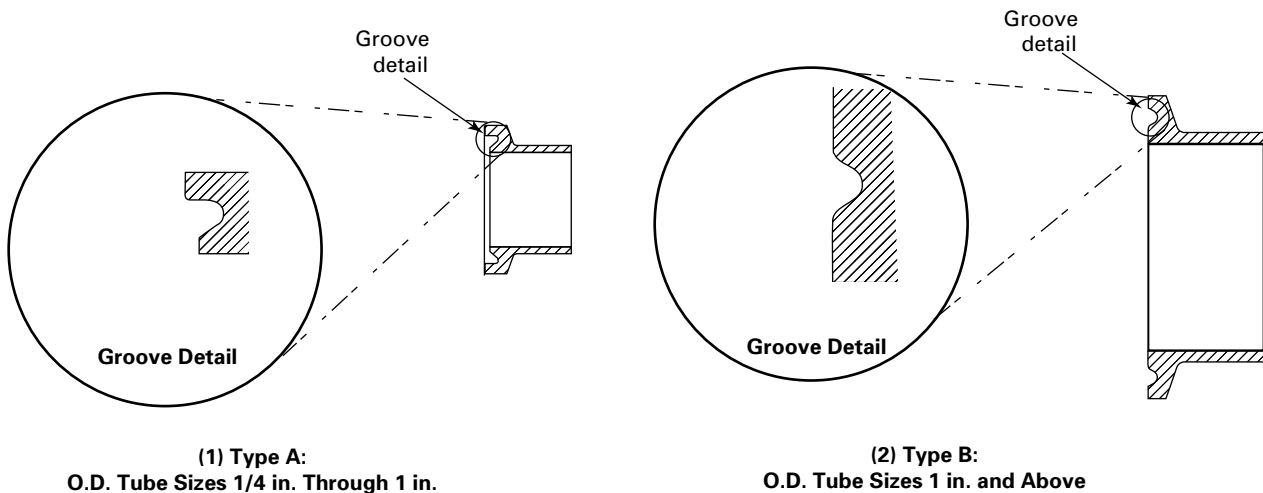
[Paragraph 342](#) applies in its entirety. See [para. U342.2\(a\)](#).

**U342.2 Specific Requirement**

- (a) For weld coupon examination
  - (1) the examinations shall be performed by personnel other than those performing the production work or
  - (2) with the owner's approval, the personnel performing the production work shall be permitted to perform the examination, provided the personnel meet the personnel qualification and certification requirements in [para. 342.1](#)

**U343 EXAMINATION PROCEDURES**

[Paragraph 343](#) applies.

**Figure U335.8B Hygienic Clamp Types****Figure U335.8C Hygienic Ferrules****U344 TYPES OF EXAMINATION**

Paragraph 344 applies. See paras. U344.2 and U344.8.

**U344.2 Visual Examination**

Paragraph 344.2 applies, except that in addition to the method described in para. 344.2.2, borescopic examination shall be acceptable.

**U344.8 Weld Coupon Examination**

**U344.8.1 Requirements.** Weld coupon examination comprises examination of weld coupons for the following, as applicable:

(a) prior to welding of coupons made in accordance with para. U328.4.4(b)(1)

- (1) joint preparation and cleanliness
- (2) fit-up, collet or clamp grip, and alignment in the weld head

(3) variables in the orbital welding machine specified in the WPS

(b) after welding of coupons made in accordance with para. U328.4.4(b)(1), and for weld coupons made in accordance with para. U328.4.4(b)(2), for compliance with para. U341.3.2

- (1) alignment
- (2) weld penetration
- (3) weld bead width variation
- (4) weld bead meander
- (5) discoloration
- (6) weld defects, e.g., cracks, porosity, or sulfur stringers

To allow direct visual examination of the inside surfaces, the weld coupon may be cut or a suitable indirect visual examination method (e.g., borescopic examination) may be used.

**U344.8.2 Method.** A weld coupon shall be made to allow visual examination in accordance with [para. U344.2](#), unless otherwise specified in the engineering design.

## U345 TESTING

Paragraph 345 applies except for [paras. 345.1, 345.8, and 345.9](#). See [paras. U345.1, U345.8, and U345.9](#).

### U345.1 Required Leak Test

Paragraph 345.1 applies, except that, at the owner's option, a helium mass spectrometer test in accordance with [para. U345.8.1](#) may be substituted for the hydrostatic leak test.

### U345.8 Sensitive Leak Test

Paragraph 345.8 applies, except that the helium mass spectrometer test described in [para. U345.8.1](#) is also an acceptable method.

**U345.8.1 Helium Mass Spectrometer Test.** The test shall be one of the following methods and performed in accordance with the following:

(a) For pressurized systems, the test shall be in accordance with ASME BPVC, Section V, Article 10, Appendix IV (Helium Mass Spectrometer — Detector Probe Technique).

(1) The test pressure shall be the lesser of 105 kPa (15 psig) gage or 25% of the design pressure.

(2) Prior to testing, the test pressure shall be held a minimum of 30 min.

(3) Unless otherwise specified in the engineering design, the system tested is acceptable when no leakage is detected that exceeds the allowable leakage rate of  $1 \times 10^{-4}$  std cc/s.

(b) For evacuated systems, the test shall be in accordance with ASME BPVC, Section V, Article 10, Appendix V (Helium Mass Spectrometer Test — Tracer Probe Technique).

(1) The piping system shall be evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system.

(2) Unless otherwise specified in the engineering design, the system tested is acceptable when no leakage is detected that exceeds the allowable leakage rate of  $1 \times 10^{-5}$  std cc/s.

### U345.9 Alternative Leak Test

Paragraph 345.9 applies, except that welds may be examined by weld coupon examination method in accordance with [para. U341.4.5](#) and the test method may be helium mass spectrometer test in accordance with [para. U345.8.1](#).

## U346 RECORDS

### U346.2 Responsibility

It is the responsibility of the piping designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Code, ASME BPE, SEMI, or other industry standard as specified in the engineering design.

### U346.3 Retention of Records

Paragraph 346.3 applies.

## PART 11

## HIGH PURITY PIPING IN CATEGORY M FLUID SERVICE

## UM300 GENERAL STATEMENTS

(a) Chapter X, Part 11 pertains to piping designated by the owner as being high purity piping in Category M Fluid Service. See also [Appendix M](#).

(b) The organization, content, and paragraph designations of these Parts correspond to those of Chapter VIII. The prefix UM is used.

(c) Paragraphs M300(d), M300(e), and M300(f) apply.

(d) Provisions and requirements of Chapter VIII apply with the additional requirements in [paras. UM307, UM307.2, UM322, UM322.3, UM328, UM335, UM335.3.3, UM341, UM341.4\(b\)\(1\) and UM341.4\(b\)\(2\), and UM345\(b\)](#).

## UM307 METALLIC VALVES AND SPECIALTY COMPONENTS

Paragraph M307 applies in its entirety. See also [para. UM307.2\(a\)](#).

### UM307.2 Specific Requirements

(a) For bellows or diaphragm sealed type valves, the bonnet or cover plate closure shall be secured by a straight thread sufficient for mechanical strength, have a metal-to-metal seat, and include a secondary stem seal.

## UM322 SPECIFIC PIPING SYSTEMS

Paragraph M322 applies, except for [para. M322.3\(c\)](#). See [para. UM322.3\(c\)](#).

### UM322.3 Instrument Piping

(c) joining methods shall conform to the requirements of [para. U315](#)

**UM328 WELDING OF MATERIALS**

Welding shall be in accordance with [paras. M311.1](#) and [U328](#), except examination shall be in accordance with [para. UM341](#).

**UM335 ASSEMBLY AND ERECTION OF METALLIC PIPING**

[Paragraph M335](#) applies, except for [para. M335.3.3](#). See [para. UM335.3.3](#).

**UM335.3.3 Straight-Threaded Joints.** The requirements of [para. M335.3.3](#) are subject to the limitations in [para. UM322](#).

**UM341 EXAMINATION**

[Paragraph M341](#) applies. See [UM341.4\(b\)\(1\)](#) and [UM341.4\(b\)\(2\)](#).

**UM341.4 Extent of Required Examination***(b) Other Examination*

*(1)* The 100% radiography/ultrasonic examination required in [para. M341.4\(b\)](#) applies.

*(2)* The in-process examination alternative permitted in [para. 341.4.1\(b\)\(1\)](#) applies, except a weld coupon examination in accordance with [para. U344.8](#) is also an acceptable substitute when specified in the engineering design or by the Inspector.

**UM345 TESTING**

[Paragraph M345\(a\)](#) applies. See [\(b\)](#).

*(b)* A sensitive leak test in accordance with [para. U345.8](#) shall be included in the required leak test ([para. U345.1](#)).



## **APPENDIX A**

# **ALLOWABLE STRESSES AND QUALITY FACTORS FOR METALLIC PIPING AND BOLTING MATERIALS**

Begins on the next page.

Specification Index for **Appendix A**

(20)

| Spec. No.   | Title                                                                                                                        | Spec. No.            | Title                                                                                                                        |
|-------------|------------------------------------------------------------------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------|
| <b>ASTM</b> |                                                                                                                              | <b>ASTM (Cont'd)</b> |                                                                                                                              |
| A36         | Carbon Structural Steel                                                                                                      | A285                 | Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength                                                 |
| A47         | Ferritic Malleable Iron Castings                                                                                             | A299                 | Pressure Vessel Plates, Carbon Steel, Manganese-Silicon                                                                      |
| A48         | Gray Iron Castings                                                                                                           |                      |                                                                                                                              |
| A53         | Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless                                                          | A302                 | Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum and Manganese-Molybdenum-Nickel                                    |
| A105        | Carbon Steel Forgings for Piping Applications                                                                                | A307                 | Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength                                                                    |
| A106        | Seamless Carbon Steel Pipe for High-Temperature Service                                                                      | A312                 | Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes                                                   |
| A126        | Gray Iron Castings for Valves, Flanges, and Pipe Fittings                                                                    | A320                 | Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service                                                          |
| A134        | Pipe, Steel, Electric-Fusion (Arc)-Welded (Sizes NPS 16 and Over)                                                            | A333                 | Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications with Required Notch Toughness              |
| A135        | Electric-Resistance-Welded Steel Pipe                                                                                        | A334                 | Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service                                                 |
| A139        | Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over)                                                                     | A335                 | Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service                                                              |
| A179        | Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes                                                      | A350                 | Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components                                 |
| A181        | Carbon Steel Forgings, for General-Purpose Piping                                                                            | A351                 | Castings, Austenitic, for Pressure-Containing Parts                                                                          |
| A182        | Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service  | A352                 | Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service                |
| A193        | Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications | A353                 | Pressure Vessel Plates, Alloy Steel, Double-Normalized and Tempered 9% Nickel                                                |
| A194        | Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both         | A354                 | Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners                                      |
| A197        | Cupola Malleable Iron                                                                                                        | A358                 | Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications |
| A203        | Pressure Vessel Plates, Alloy Steel, Nickel                                                                                  | A369                 | Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service                                           |
| A204        | Pressure Vessel Plates, Alloy Steel, Molybdenum                                                                              | A376                 | Seamless Austenitic Steel Pipe for High-Temperature Service                                                                  |
| A213        | Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes                                   | A381                 | Metal-Arc-Welded Carbon or High-Strength Low-Alloy Steel Pipe for Use With High-Pressure Transmission Systems                |
| A216        | Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service                                            | A387                 | Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum                                                                     |
| A217        | Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service        | A395                 | Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures                                           |
| A234        | Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service                            | A403                 | Wrought Austenitic Stainless Steel Piping Fittings                                                                           |
| A240        | Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications       | A409                 | Welded Large Diameter Austenitic Steel Pipe for Corrosive or High-Temperature Service                                        |
| A268        | Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service                                      | A420                 | Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service                                          |
| A269        | Seamless and Welded Austenitic Stainless Steel Tubing for General Service                                                    | A426                 | Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service                                                    |
| A270        | Seamless and Welded Austenitic and Ferritic/Austenitic Stainless Steel Sanitary Tubing                                       | A437                 | Stainless and Alloy-Steel Turbine-Type Bolting Material Specially Heat Treated for High-Temperature Service                  |
| A276        | Stainless Steel Bars and Shapes                                                                                              |                      |                                                                                                                              |
| A278        | Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (350°C)                                        |                      |                                                                                                                              |
| A283        | Low and Intermediate Tensile Strength Carbon Steel Plates                                                                    |                      |                                                                                                                              |

Specification Index for **Appendix A (Cont'd)**

| Spec. No.            | Title                                                                                                                | Spec. No.            | Title                                                                                                                                                                                                     |
|----------------------|----------------------------------------------------------------------------------------------------------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ASTM (Cont'd)</b> |                                                                                                                      | <b>ASTM (Cont'd)</b> |                                                                                                                                                                                                           |
| A451                 | Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service                                                | A815                 | Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings                                                                                                                    |
| A453                 | High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels                      | A860                 | Wrought High-Strength Ferritic Steel Butt-Welding Fittings                                                                                                                                                |
| A479                 | Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels                                        | A928                 | Ferritic/Austenitic (Duplex) Stainless Steel Pipe Electric Fusion Welded with Addition of Filler Metal                                                                                                    |
| A487                 | Steel Castings Suitable for Pressure Service                                                                         | A992                 | Structural Steel Shapes                                                                                                                                                                                   |
| A494                 | Castings, Nickel and Nickel Alloy                                                                                    | A995                 | Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts                                                                                                                     |
| A515                 | Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service                               | A1010                | Higher-Strength Martensitic Stainless Steel Plate, Sheet, and Strip                                                                                                                                       |
| A516                 | Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service                                    | A1011                | Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength                                               |
| A524                 | Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures                                                    | A1053                | Welded Ferritic-Martensitic Stainless Steel Pipe                                                                                                                                                          |
| A536                 | Ductile Iron Castings                                                                                                | B21                  | Naval Brass Rod, Bar, and Shapes                                                                                                                                                                          |
| A537                 | Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel                                                 | B26                  | Aluminum-Alloy Sand Castings                                                                                                                                                                              |
| A553                 | Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 7, 8, and 9 % Nickel                                      | B42                  | Seamless Copper Pipe, Standard Sizes                                                                                                                                                                      |
| A563                 | Carbon and Alloy Steel Nuts                                                                                          | B43                  | Seamless Red Brass Pipe, Standard Sizes                                                                                                                                                                   |
| A571                 | Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service                  | B61                  | Steam or Valve Bronze Castings                                                                                                                                                                            |
| A587                 | Electric-Resistance-Welded Low-Carbon Steel Pipe for the Chemical Industry                                           | B62                  | Composition Bronze or Ounce Metal Castings                                                                                                                                                                |
| A645                 | Pressure Vessel Plates, 5 % and 5 ½ % Nickel Alloy Steels, Specially Heat Treated                                    | B68                  | Seamless Copper Tube, Bright Annealed                                                                                                                                                                     |
| A671                 | Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures                                             | B75                  | Seamless Copper Tube                                                                                                                                                                                      |
| A672                 | Electric-Fusion-Welded Steel Pipe for High-Pressure Service at Moderate Temperatures                                 | B88                  | Seamless Copper Water Tube                                                                                                                                                                                |
| A675                 | Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties                                              | B96                  | Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels                                                                                                        |
| A691                 | Carbon and Alloy Steel Pipe, Electric-Fusion-Welded for High-Pressure Service at High Temperatures                   | B98                  | Copper-Silicon Alloy Rod, Bar and Shapes                                                                                                                                                                  |
| A694                 | Carbon and Alloy Steel Forgings for Pipe Flanges, Fittings, Valves, and Parts for High-Pressure Transmission Service | B127                 | Nickel-Copper Alloy (UNS N04400) Plate, Sheet, and Strip                                                                                                                                                  |
| A696                 | Steel Bars, Carbon, Hot-Wrought or Cold-Finished, Special Quality, for Pressure Piping Components                    | B148                 | Aluminum-Bronze Sand Castings                                                                                                                                                                             |
| A707                 | Forged Carbon and Alloy Steel Flanges for Low-Temperature Service                                                    | B150                 | Aluminum Bronze Rod, Bar and Shapes                                                                                                                                                                       |
| A789                 | Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service                                   | B152                 | Copper Sheet, Strip, Plate and Rolled Bar                                                                                                                                                                 |
| A790                 | Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe                                                         | B160                 | Nickel Rod and Bar                                                                                                                                                                                        |
| A813                 | Single- or Double-Welded Austenitic Stainless Steel Pipe                                                             | B161                 | Nickel Seamless Pipe and Tube                                                                                                                                                                             |
| A814                 | Cold-Worked Welded Austenitic Stainless Steel Pipe                                                                   | B162                 | Nickel Plate, Sheet and Strip                                                                                                                                                                             |
|                      |                                                                                                                      | B163                 | Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes                                                                                                                                       |
|                      |                                                                                                                      | B164                 | Nickel-Copper Alloy Rod, Bar, and Wire                                                                                                                                                                    |
|                      |                                                                                                                      | B165                 | Nickel-Copper Alloy (UNS N04400) Seamless Pipe and Tube                                                                                                                                                   |
|                      |                                                                                                                      | B166                 | Nickel-Chromium-Aluminum Alloy, Nickel-Chromium-Iron Alloys, Nickel-Chromium-Cobalt-Molybdenum Alloy, Nickel-Iron-Chromium-Tungsten Alloy, and Nickel-Chromium-Molybdenum-Copper Alloy Rod, Bar, and Wire |

Specification Index for **Appendix A (Cont'd)**

| Spec. No.            | Title                                                                                                                                                                                                                                   | Spec. No.            | Title                                                                                                                                                                                                                                    |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ASTM (Cont'd)</b> |                                                                                                                                                                                                                                         | <b>ASTM (Cont'd)</b> |                                                                                                                                                                                                                                          |
| B167                 | Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Seamless Pipe and Tube | B409                 | Nickel-Iron-Chromium Alloy Plate, Sheet, and Strip                                                                                                                                                                                       |
| B168                 | Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Plate, Sheet and Strip | B423                 | Nickel-Iron-Chromium-Molybdenum-Copper Alloy (UNS N08825, N08221, and N06845) Seamless Pipe and Tube                                                                                                                                     |
| B169                 | Aluminum Bronze Sheet, Strip, and Rolled Bar                                                                                                                                                                                            | B424                 | Ni-Fe-Cr-Mo-Cu Alloy (UNS N08825, UNS N08221, and UNS N06845) Plate, Sheet, and Strip                                                                                                                                                    |
| B171                 | Copper-Alloy Plate and Sheet for Pressure Vessels, Condensers, and Heat Exchangers                                                                                                                                                      | B425                 | Ni-Fe-Cr-Mo-Cu Alloy (UNS N08825, UNS N08221, and UNS N06845) Rod and Bar                                                                                                                                                                |
| B187                 | Copper, Bus Bar, Rod, and Shapes and General Purpose Rod, Bar, and Shapes                                                                                                                                                               | B435                 | UNS N06002, UNS N06230, UNS N12160, and UNS R30556 Plate, Sheet, and Strip                                                                                                                                                               |
| B209                 | Aluminum and Aluminum-Alloy Sheet and Plate                                                                                                                                                                                             | B443                 | Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Plate, Sheet, and Strip                                                                                                |
| B210                 | Aluminum and Aluminum-Alloy Drawn Seamless Tubes                                                                                                                                                                                        | B444                 | Nickel-Chromium-Molybdenum-Columbium Alloys (UNS N06625 and UNS N06852) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Pipe and Tube                                                                                          |
| B211                 | Aluminum and Aluminum-Alloy Rolled or Cold Finished Bar, Rod, and Wire                                                                                                                                                                  | B446                 | Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625), Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219), and Nickel-Chromium-Molybdenum-Tungsten Alloy (UNS N06650) Rod and Bar                                                   |
| B221                 | Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes                                                                                                                                                              | B462                 | Forged or Rolled Nickel Alloy Pipe Flanges, Forged Fittings, and Valves and Parts for Corrosive High-Temperature Service                                                                                                                 |
| B241                 | Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube                                                                                                                                                                    | B463                 | UNS N08020 Alloy Plate, Sheet, and Strip                                                                                                                                                                                                 |
| B247                 | Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings                                                                                                                                                       | B464                 | Welded UNS N08020 Alloy Pipe                                                                                                                                                                                                             |
| B265                 | Titanium and Titanium Alloy Strip, Sheet, and Plate                                                                                                                                                                                     | B466                 | Seamless Copper-Nickel Pipe and Tube                                                                                                                                                                                                     |
| B280                 | Seamless Copper Tube for Air Conditioning and Refrigeration Field Service                                                                                                                                                               | B467                 | Welded Copper-Nickel Pipe                                                                                                                                                                                                                |
| B283                 | Copper and Copper-Alloy Die Forgings (Hot-Pressed)                                                                                                                                                                                      | B474                 | Electric Fusion Welded Nickel and Nickel Alloy Pipe                                                                                                                                                                                      |
| B333                 | Nickel-Molybdenum Alloy Plate, Sheet, and Strip                                                                                                                                                                                         | B491                 | Aluminum and Aluminum-Alloy Extruded Round Tubes for General-Purpose Applications                                                                                                                                                        |
| B335                 | Nickel-Molybdenum Alloy Rod                                                                                                                                                                                                             | B493                 | Zirconium and Zirconium Alloy Forgings                                                                                                                                                                                                   |
| B345                 | Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube for Gas and Oil Transmission and Distribution Piping Systems                                                                                                       | B514                 | Welded Nickel-Iron-Chromium Alloy Pipe                                                                                                                                                                                                   |
| B348                 | Titanium and Titanium Alloy Bars and Billets                                                                                                                                                                                            | B515                 | Welded UNS N08120, UNS N08800, UNS N08810, and UNS N08811 Alloy Tubes                                                                                                                                                                    |
| B361                 | Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings                                                                                                                                                                       | B517                 | Welded Nickel-Chromium-Iron-Alloy (UNS N06600, UNS N06603, UNS N06025, and UNS N06045) Pipe                                                                                                                                              |
| B363                 | Seamless and Welded Unalloyed Titanium and Titanium Alloy Welding Fittings                                                                                                                                                              | B523                 | Seamless and Welded Zirconium and Zirconium Alloy Tubes                                                                                                                                                                                  |
| B366                 | Factory-Made Wrought Nickel and Nickel Alloy Fittings                                                                                                                                                                                   | B550                 | Zirconium and Zirconium Alloy Bar and Wire                                                                                                                                                                                               |
| B367                 | Titanium and Titanium Alloy Castings                                                                                                                                                                                                    | B551                 | Zirconium and Zirconium Alloy Strip, Sheet, and Plate                                                                                                                                                                                    |
| B371                 | Copper-Zinc-Silicon Alloy Rod                                                                                                                                                                                                           | B564                 | Nickel Alloy Forgings                                                                                                                                                                                                                    |
| B381                 | Titanium and Titanium Alloy Forgings                                                                                                                                                                                                    | B572                 | UNS N06002, UNS N06230, UNS N12160, and UNS R30556 Rod                                                                                                                                                                                   |
| B407                 | Nickel-Iron-Chromium Alloy Seamless Pipe and Tube                                                                                                                                                                                       | B574                 | Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Molybdenum-Chromium-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Rod |
| B408                 | Nickel-Iron-Chromium Alloy Rod and Bar                                                                                                                                                                                                  |                      |                                                                                                                                                                                                                                          |

Specification Index for **Appendix A (Cont'd)**

| Spec. No.            | Title                                                                                                                                                                                                                                                       | Spec. No.            | Title                                                                                                                                  |
|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| <b>ASTM (Cont'd)</b> |                                                                                                                                                                                                                                                             | <b>ASTM (Cont'd)</b> |                                                                                                                                        |
| B575                 | Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Tungsten, and Low-Carbon Nickel-Molybdenum-Chromium Alloy Plate, Sheet and Strip | B688                 | Chromium-Nickel-Molybdenum-Iron (UNS N08367) Plate, Sheet, and Strip                                                                   |
| B581                 | Nickel-Chromium-Iron-Molybdenum-Copper Alloy Rod                                                                                                                                                                                                            | B690                 | Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08367) Seamless Pipe and Tube                                                              |
| B582                 | Nickel-Chromium-Iron-Molybdenum-Copper Alloy Plate, Sheet, and Strip                                                                                                                                                                                        | B704                 | Welded UNS N06625, UNS N06219 and UNS N08825 Alloy Tubes                                                                               |
| B584                 | Copper Alloy Sand Castings for General Applications                                                                                                                                                                                                         | B705                 | Nickel-Alloy (UNS N06625, N06219 and N08825) Welded Pipe                                                                               |
| B619                 | Welded Nickel and Nickel-Cobalt Alloy Pipe                                                                                                                                                                                                                  | B709                 | Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08028) Plate, Sheet, and Strip                                                             |
| B620                 | Nickel-Iron-Chromium-Molybdenum Alloy (UNS N08320) Plate, Sheet, and Strip                                                                                                                                                                                  | B725                 | Welded Nickel (UNS N02200/UNS N02201) and Nickel Copper Alloy (UNS N04400) Pipe                                                        |
| B621                 | Nickel-Iron-Chromium-Molybdenum Alloy (UNS N08320) Rod                                                                                                                                                                                                      | B729                 | Seamless UNS N08020, UNS N08026, and UNS N08024 Nickel-Alloy Pipe and Tube                                                             |
| B622                 | Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube                                                                                                                                                                                                       | B804                 | UNS N08367 and UNS N08926 Welded Pipe                                                                                                  |
| B625                 | UNS N08925, UNS N08031, UNS N08932, UNS N08926, UNS N08354, UNS N08830, and UNS R20033 Plate, Sheet, and Strip                                                                                                                                              | B861                 | Titanium and Titanium Alloy Seamless Pipe                                                                                              |
| B626                 | Welded Nickel and Nickel-Cobalt Alloy Tube                                                                                                                                                                                                                  | B862                 | Titanium and Titanium Alloy Welded Pipe                                                                                                |
| B649                 | Ni-Fe-Cr-Mo-Cu-N Low-Carbon Alloys (UNS N08925, UNS N08031, UNS N08034, UNS N08354, and UNS N08926), and Cr-Ni-Fe-N Low-Carbon Alloy (UNS R20033) Bar and Wire, and Ni-Cr-Fe-Mo-N Alloy (UNS N08936) Wire                                                   | E112                 | Standard Test Methods for Determining Average Grain Size                                                                               |
| B658                 | Seamless and Welded Zirconium and Zirconium Alloy Pipe                                                                                                                                                                                                      | F3125                | High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength |
| B668                 | UNS N08028 Seamless Pipe and Tube                                                                                                                                                                                                                           | <b>API</b>           |                                                                                                                                        |
| B675                 | UNS N08367 Welded Pipe                                                                                                                                                                                                                                      | 5L                   | Line Pipe                                                                                                                              |
|                      |                                                                                                                                                                                                                                                             | <b>CSA</b>           |                                                                                                                                        |
|                      |                                                                                                                                                                                                                                                             | Z245.1               | Steel Pipe                                                                                                                             |

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in [Appendix E](#).

# NOTES FOR TABLES A-1, A-1M, A-1A, A-1B, A-2, AND A-2M (20)

## GENERAL NOTES:

- (a) The allowable stress values, P-Number assignments, weld joint and casting quality factors, and minimum temperatures in [Tables A-1, A-1A, A-1B, A-2, and A-2M](#), together with the referenced Notes in the stress tables, are requirements of this Code.
  - (b) [Notes \(1\) through \(7\)](#) are referenced in column headings and in body headings for material type and product form; [Notes \(8\)](#) and following are referenced in the Notes column for specific materials. Notes marked with an asterisk (\*) restate requirements found in the text of the Code.
  - (c) The stress values given in ksi as shown in [Tables A-1 and A-2](#), and given in MPa as shown in [Tables A-1M and A-2M](#), may be used. The values stated in ksi are not exact equivalents to the values stated in MPa. Therefore, for any given material, the user of the Code should use only the ksi or the MPa values.
  - (d) For copper and copper alloys, the following symbols are used in the Temper column: H = drawn; H01 = quarter hard; H02 = half hard; H06 = extra hard; H55 = light drawn; H58 = drawn, general purpose; H80 = hard drawn; HR50 = drawn, stress relieved; M20 = hot rolled; O25 = hot rolled, annealed; O50 = light annealed; O60 = soft annealed; O61 = annealed; W050 = welded, annealed; and W061 = welded, fully finished, annealed.
  - (e) For nickel and nickel alloys, the following abbreviations are used in the Class column: ann., annealed; C.D., cold worked; forg., forged; H.F., hot finished; H.R., hot rolled; H.W., hot worked; plt., plate; R., rolled; rel., relieved; sol., solution; str., stress; and tr., treated.
  - (f) In [Table A-1M](#), the following abbreviations are used in the Product Form column: forg., forgings; ftg., fittings; pl., plate; shps., shapes; sht., sheet; smls., seamless; struct., structural; and wld., welded.
- the material specification or by reference to [Note \(30\)](#) or [\(31\)](#).
- (4a) \*In [Table A-1](#), stress values printed in *italics* exceed two-thirds of the expected yield strength at temperature. Stress values in **boldface** are equal to 90% of expected yield strength at temperature. See [paras. 302.3.2\(d\)\(3\) and 302.3.2\(e\)](#).
  - (4b) \*In [Table A-1M](#), stress values printed in *italics* are tensile-controlled values. Yield-controlled stress values are in normal font and time-dependent stress values are in **boldface**.
  - (5) \*See ASME BPVC, Section IX, QW-200.3 for a description of P-Number groupings. P-Numbers are indicated by number or by a number followed by a letter (e.g., 8, 5B, or 11A).
  - (6) \*The minimum temperature shown is that design minimum temperature for which the material is normally suitable without impact testing other than that required by the material specification. However, the use of a material at a design minimum temperature colder than  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) is established by rules elsewhere in this Code, including [para. 323.2.2](#) and other impact test requirements. For carbon steels with a letter designation in the Min. Temp. column, see [para. 323.2.2\(e\)](#) and the applicable curve and Notes in [Figure 323.2.2A](#).
  - (7) The letter “a” indicates alloys that are not recommended for welding and that, if welded, must be individually qualified. The letter “b” indicates copper base alloys that must be individually qualified.
  - (8) \*There are restrictions on the use of this material in the text of the Code as follows:
    - (a) See [para. 305.2.1](#); temperature limits are  $-29^{\circ}\text{C}$  to  $186^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$  to  $366^{\circ}\text{F}$ ).
    - (b) See [para. 305.2.2](#); pipe shall be safeguarded when used outside the temperature limits in [Note \(8a\)](#).
    - (c) See [Table 323.2.2](#), box B-2.
    - (d) See [para. 323.4.2\(a\)](#).
    - (e) See [para. 323.4.2\(b\)](#).
    - (f) See [para. 309.2.1](#).
    - (g) See [para. 309.2.2](#).
  - (9) \*For pressure-temperature ratings of components made in accordance with standards listed in [Table 326.1](#), see [para. 326.2.1](#). Stress values in [Tables A-1 and A-1M](#) may be used to calculate ratings for unlisted components, and special ratings for listed components, as permitted by [para. 303](#).
  - (9a) Component standards listed in [Table 326.1](#) impose the following restrictions on this material when used as a forging: composition, properties, heat treatment, and grain size shall conform to this specification; manufacturing procedures, tolerances, tests, certification, and markings shall be in accordance with ASTM B564.

## NOTES:

- (1) \*The stress values in [Tables A-1 and A-1M](#), and the design stress values in [Tables A-2 and A-2M](#), are basic allowable stresses in tension in accordance with [para. 302.3.1\(a\)](#). For pressure design, the stress values from [Tables A-1 and A-1M](#) are multiplied by the appropriate quality factor  $E$  ( $E_c$  from [Table A-1A](#) or  $E_f$  from [Table A-1B](#)). Stress values in shear and bearing are stated in [para. 302.3.1\(b\)](#); those in compression in [para. 302.3.1\(c\)](#).
- (2) \*The quality factors for castings  $E_c$  in [Table A-1A](#) are basic factors in accordance with [para. 302.3.3\(b\)](#). The quality factors for longitudinal weld joints  $E_f$  in [Table A-1B](#) are basic factors in accordance with [para. 302.3.4\(a\)](#). See [paras. 302.3.3\(c\) and 302.3.4\(b\)](#) for enhancement of quality factors. See also [para. 302.3.1\(a\)](#), footnote 1.
- (3) The stress values for austenitic stainless steels in these Tables may not be applicable if the material has been given a final heat treatment other than that required by



- (10) \*This casting quality factor is applicable only when proper supplementary examination has been performed (see [para. 302.3.3](#)).
- (11) \*For use under this Code, radiography shall be performed after heat treatment.
- (12) \*Certain forms of this material, as stated in [Table 323.2.2](#), must be impact tested to qualify for service below  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ). Alternatively, if provisions for impact testing are included in the material specification as supplementary requirements and are invoked, the material may be used down to the temperature at which the test was conducted in accordance with the specification.
- (13) Properties of this material vary with thickness or size. Stress values are based on minimum properties for the thickness listed.
- (14) For use in Code piping at the stated stress values, the required minimum tensile and yield properties must be verified by tensile test. If such tests are not required by the material specification, they shall be specified in the purchase order.
- (15) These stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints where freedom from leakage over a long period of time without retightening is required, lower stress values may be necessary as determined from the flexibility of the flange and bolts and corresponding relaxation properties.
- (16) DELETED.
- (17) DELETED.
- (18) DELETED.
- (19) \*This specification includes requirements for random radiographic inspection for mill quality control. If the 0.90 joint factor is to be used, the welds shall meet the requirements of [Table 341.3.2](#) for longitudinal butt welds with spot radiography in accordance with [Table 302.3.4](#). This shall be a matter of special agreement between purchaser and manufacturer.
- (20) For pipe sizes  $\geq \text{DN } 200$  (NPS 8) with wall thicknesses  $\geq \text{Sch } 140$ , the specified minimum tensile strength is 483 MPa (70 ksi).
- (21) For material thickness  $>127 \text{ mm}$  (5 in.), the specified minimum tensile strength is 483 MPa (70 ksi).
- (21a) For material thickness  $>127 \text{ mm}$  (5 in.), the specified minimum tensile strength is 448 MPa (65 ksi).
- (22) The minimum tensile strength for weld (qualification) and stress values shown shall be multiplied by 0.90 for pipe having an outside diameter less than 51 mm (2 in.) and a  $D/t$  value less than 15. This requirement may be waived if it can be shown that the welding procedure to be used will consistently produce welds that meet the listed minimum tensile strength of 165 MPa (24 ksi).
- (23) DELETED.
- (24) Yield strength is not stated in the material specification. The value shown is based on yield strengths of materials with similar characteristics.
- (25) This steel may develop embrittlement after service at approximately  $316^{\circ}\text{C}$  ( $600^{\circ}\text{F}$ ) and higher temperature.
- (26) This unstabilized grade of stainless steel increasingly tends to precipitate intergranular carbides as the carbon content increases above 0.03%. See also [para. F323.4\(c\)\(2\)](#).
- (27) For temperatures above  $427^{\circ}\text{C}$  ( $800^{\circ}\text{F}$ ), these stress values apply only when the carbon content is 0.04% or higher.
- (28) For temperatures above  $538^{\circ}\text{C}$  ( $1,000^{\circ}\text{F}$ ), these stress values apply only when the carbon content is 0.04% or higher.
- (29) The stress values above  $538^{\circ}\text{C}$  ( $1,000^{\circ}\text{F}$ ) listed here shall be used only when the steel's austenitic micrograin size, as defined in ASTM E112, is No. 6 or less (coarser grain). Otherwise, the lower stress values listed for the same material, specification, and grade shall be used.
- (30) For temperatures above  $538^{\circ}\text{C}$  ( $1,000^{\circ}\text{F}$ ), these stress values may be used only if the material has been heat treated by heating to a minimum temperature of  $1093^{\circ}\text{C}$  ( $2,000^{\circ}\text{F}$ ) and quenching in water or rapidly cooling by other means.
- (31) For temperatures above  $538^{\circ}\text{C}$  ( $1,000^{\circ}\text{F}$ ), these stress values may be used only if the material has been heat treated by heating to a minimum temperature of  $1038^{\circ}\text{C}$  ( $1,900^{\circ}\text{F}$ ) and quenching in water or rapidly cooling by other means.
- (32) Stress values shown are for the lowest strength base material permitted by the specification to be used in the manufacture of this grade of fitting. If a higher strength base material is used, the higher stress values for that material may be used in design.
- (33) For welded construction with work hardened grades, use the stress values for annealed material; for welded construction with precipitation hardened grades, use the special stress values for welded construction given in the Tables.
- (34) If material is welded, brazed, or soldered, the allowable stress values for the annealed condition shall be used.
- (35) This steel is intended for use at high temperatures; it may have low ductility and/or low impact properties at room temperature after being used above the temperature indicated by [para. F323.4\(c\)\(4\)](#).
- (36) The specification permits this material to be furnished without solution heat treatment or with other than a solution heat treatment. When the material has not been solution heat treated, the minimum temperature shall be  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) unless the material is impact tested in accordance with [para. 323.3](#).
- (37) Impact requirements for seamless fittings shall be governed by those listed in this Table for the particular base material specification in the grades permitted (A312, A240, and A182). When A276 materials are used in the manufacture of these fittings, the Notes, minimum temperatures, and allowable stresses for comparable grades of A240 materials shall apply.
- (38) DELETED.
- (39) This material when used below  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) shall be impact tested if the carbon content is above 0.10%.
- (40) \*This casting quality factor can be enhanced by supplementary examination in accordance with [para. 302.3.3\(c\)](#) and [Table 302.3.3C](#). The higher factor from [Table 302.3.3C](#) may be substituted for this factor in pressure design equations.
- (41) Design stresses for the cold drawn temper are based on hot rolled properties until required data on cold drawn are submitted.

- (42) This is a product specification. No design stresses are necessary. Limitations on metal temperature for materials covered by this specification are as follows:

| Grade(s)            | Metal Temperature, °C (°F)  |
|---------------------|-----------------------------|
| 1                   | –29 to 482 (–20 to 900)     |
| 2, 2H, and 2HM      | –48 to 593 (–55 to 1,100)   |
| 3                   | –29 to 593 (–20 to 1,100)   |
| 6                   | –29 to 427 (–20 to 800)     |
| 7                   | –48 to 593 (–55 to 1,100)   |
| 7L                  | –101 to 593 (–150 to 1,100) |
| 7M                  | –48 to 593 (–55 to 1,100)   |
| 7ML                 | –73 to 593 (–100 to 1,100)  |
| 8FA [see Note (39)] | –29 to 427 (–20 to 800)     |
| 8MA and 8TA         | –198 to 816 (–325 to 1,500) |
| 8, 8A, and 8CA      | –254 to 816 (–425 to 1,500) |

(42a) DELETED.

(42b) This is a product specification. No design stresses are necessary. For limitations on usage, see [paras. 309.2.1](#) and [309.2.2](#).

(43) \*The stress values given for this material are not applicable when either welding or thermal cutting is employed [see [para. 323.4.2\(c\)](#)].

(44) DELETED.

(45) Stress values shown are applicable for “die” forgings only.

(46) Lines of allowable stresses in [Tables A-1](#) and [A-1M](#) for all materials in A312 include heavily cold worked (HCW) material as defined in A312, para. 6.1.4.

(47) If no welding is employed in fabrication of piping from these materials, the stress values may be increased to 230 MPa (33.3 ksi).

(48) The stress value to be used for this gray iron material at its upper temperature limit of 232°C (450°F) is the same as that shown in the 204°C (400°F) column.

(49) If the chemical composition of this Grade is such as to render it hardenable, qualification under P-No. 6 is required.

(50) This material is grouped in P-No. 7 because its hardenability is low.

(51) This material may require special consideration for welding qualification. See ASME BPVC, Section IX, QW/QB-422. For use in this Code, a qualified WPS is required for each strength level of material.

(52) Copper-silicon alloys are not always suitable when exposed to certain media and high temperature, particularly above 100°C (212°F). The user should satisfy himself/herself that the alloy selected is satisfactory for the service for which it is to be used.

(53) Stress relief heat treatment is required for service above 232°C (450°F).

(54) The maximum operating temperature is arbitrarily set at 260°C (500°F) because hard temper adversely affects design stress in the creep rupture temperature ranges.

(55) Pipe produced to this specification is not intended for high temperature service. The stress values apply to either nonexpanded or cold expanded material in the as-rolled, normalized, or normalized and tempered condition.

(56) Because of thermal instability, this material is not recommended for service above 427°C (800°F).

(57) Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 427°C (800°F). See [para. F323.4\(b\)\(2\)](#).

(58) Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 468°C (875°F). See [para. F323.4\(b\)\(3\)](#).

(59) For temperatures above 482°C (900°F), consider the advantages of killed steel. See [para. F323.4\(b\)\(4\)](#).

(60) For all design temperatures, the maximum hardness shall be Rockwell C35 immediately under the thread roots. The hardness shall be taken on a flat area at least 3 mm ( $\frac{1}{8}$  in.) across, prepared by removing threads. No more material than necessary shall be removed to prepare the area. Hardness determination shall be made at the same frequency as tensile tests.

(61) Annealed at approximately 982°C (1,800°F).

(62) Annealed at approximately 1 121°C (2,050°F).

(63) For stress relieved tempers (T351, T3510, T3511, T451, T4510, T4511, T651, T6510, T6511), stress values for material in the listed temper shall be used.

(64) The minimum tensile strength of the reduced section tensile specimen in accordance with ASME BPVC, Section IX, QW-462.1, shall not be less than 758 MPa (110.0 ksi).

(65) The minimum temperature shown in [Tables A-1](#) and [A-1M](#) is for the heaviest wall meeting the specified mechanical property requirements in the specification. The minimum temperature for lighter walls shall be as shown in the following tabulation:

**Impact Test Temperature (°C) for Plate Thicknesses Shown**

| Spec. No. and Grade | Max. 51 mm | Over 51 mm to 76 mm |
|---------------------|------------|---------------------|
| A203 A              | –68        | –59                 |
| A203 B              | –68        | –59                 |
| A203 D              | –101       | –87                 |
| A203 E              | –101       | –87                 |

**Impact Test Temperature (°F) for Plate Thicknesses Shown**

| Spec. No. and Grade | Max. 2 in. | Over 2 in. to 3 in. |
|---------------------|------------|---------------------|
| A203 A              | –90        | –75                 |
| A203 B              | –90        | –75                 |
| A203 D              | –150       | –125                |
| A203 E              | –150       | –125                |

(66) Stress values shown are 90% of those for the corresponding core material.

(67) For use under this Code, the heat treatment requirements for pipe manufactured to A671, A672, and A691 shall be as required by [para. 331](#) for the particular material being used.

(68) The tension test specimen from plate 12.7 mm ( $\frac{1}{2}$  in.) and thicker is machined from the core and does not include the cladding alloy; therefore, the stress values listed are those for materials less than 12.7 mm.

(69) This material may be used only in nonpressure applications.

- (70) Alloy 625 (UNS N06625) in the annealed condition is subject to severe loss of impact strength at room temperature after exposure in the range of 538°C to 760°C (1,000°F to 1,400°F).
- (71) These materials are normally microalloyed with Cb, V, and/or Ti. Supplemental specifications agreed to by manufacturer and purchaser commonly establish chemistry more restrictive than the base specification, as well as plate rolling specifications and requirements for weldability (i.e., C-equivalent) and toughness.
- (72) For service temperature >454°C (850°F), weld metal shall have a carbon content >0.05%.
- (73) Heat treatment is required after welding for all products of zirconium Grade R60705. See [Table 331.1.1](#).
- (74) Mechanical properties of fittings made from forging stock shall meet the minimum tensile requirements of one of the bar, forging, or rod specifications listed in Table 2 of B366 for which tensile testing is required.
- (75) Stress values shown are for materials in the normalized and tempered condition, or when the heat treatment is unknown. If material is annealed, use the following values above 510°C (950°F):

| Temp., °C | 538  | 566  | 593  | 621  | 649 |
|-----------|------|------|------|------|-----|
| S, MPa    | 55.1 | 39.3 | 26.2 | 16.5 | 9.6 |

| Temp., °F | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 |
|-----------|-------|-------|-------|-------|-------|
| S, ksi    | 8.0   | 5.7   | 3.8   | 2.4   | 1.4   |

(76) DELETED.

- (77) The pipe grades listed below, produced in accordance with CSA (Canadian Standards Association) Z245.1, shall be considered as equivalents to API 5L and treated as listed materials.

| Grade Equivalents |            |
|-------------------|------------|
| API 5L            | CSA Z245.1 |
| B                 | 241        |
| X42               | 290        |
| X46               | 317        |
| X52               | 359        |
| X56               | 386        |
| X60               | 414        |
| X65               | 448        |
| X70               | 483        |
| X80               | 550        |

- (78) Not permitted for the P4 and P5 materials in [Table 302.3.5](#) for Elevated Temperature Fluid Service.
- (79) For use under this Code, impact testing shall be performed in accordance with [para. 323.3](#) at the design minimum temperature but not warmer than -29°C (-20°F).

**Table A-1 Basic Allowable Stresses in Tension for Metals**

(20)

Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                    |           |            |         |                      |               |                    | Specified Min. Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |       |        |      |      |      |      |      |      |  |
|--------------------|-----------|------------|---------|----------------------|---------------|--------------------|-------------------------------------------------------------------------------------------|-------|--------|------|------|------|------|------|------|--|
| Material           | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Notes         | Min. Temp., °F (6) | Min. Temp.                                                                                |       |        |      |      |      |      |      |      |  |
|                    |           |            |         |                      |               |                    | Tensile                                                                                   | Yield | to 100 | 200  | 300  | 400  | 500  | 600  | 650  |  |
| Iron — Castings    |           |            |         |                      |               |                    |                                                                                           |       |        |      |      |      |      |      |      |  |
| Gray               | A48       | 20         | F11401  | ...                  | (8e) (48)     | −20                | 20                                                                                        | ...   | 2.0    | 2.0  | 2.0  | 2.0  | ...  | ...  | ...  |  |
| Gray               | A278      | 20         | F11401  | ...                  | (8e) (48)     | −20                | 20                                                                                        | ...   | 2.0    | 2.0  | 2.0  | 2.0  | ...  | ...  | ...  |  |
| Gray               | A126      | A          | F11501  | ...                  | (8e) (9) (48) | −20                | 21                                                                                        | ...   | 2.0    | 2.0  | 2.0  | 2.0  | ...  | ...  | ...  |  |
| Gray               | A48       | 25         | F11701  | ...                  | (8e) (48)     | −20                | 25                                                                                        | ...   | 2.5    | 2.5  | 2.5  | 2.5  | ...  | ...  | ...  |  |
| Gray               | A278      | 25         | F11701  | ...                  | (8e) (48)     | −20                | 25                                                                                        | ...   | 2.5    | 2.5  | 2.5  | 2.5  | ...  | ...  | ...  |  |
| Gray               | A48       | 30         | F12101  | ...                  | (8e) (48)     | −20                | 30                                                                                        | ...   | 3.0    | 3.0  | 3.0  | 3.0  | ...  | ...  | ...  |  |
| Gray               | A278      | 30         | F12101  | ...                  | (8e) (48)     | −20                | 30                                                                                        | ...   | 3.0    | 3.0  | 3.0  | 3.0  | ...  | ...  | ...  |  |
| Gray               | A126      | B          | F12102  | ...                  | (8e) (9) (48) | −20                | 31                                                                                        | ...   | 3.0    | 3.0  | 3.0  | 3.0  | ...  | ...  | ...  |  |
| Gray               | A48       | 35         | F12401  | ...                  | (8e) (48)     | −20                | 35                                                                                        | ...   | 3.5    | 3.5  | 3.5  | 3.5  | ...  | ...  | ...  |  |
| Gray               | A278      | 35         | F12401  | ...                  | (8e) (48)     | −20                | 35                                                                                        | ...   | 3.5    | 3.5  | 3.5  | 3.5  | ...  | ...  | ...  |  |
| Gray               | A48       | 40         | F12801  | ...                  | (8e) (9) (48) | −20                | 40                                                                                        | ...   | 4.0    | 4.0  | 4.0  | 4.0  | ...  | ...  | ...  |  |
| Gray               | A126      | C          | F12802  | ...                  | (8e) (9) (48) | −20                | 41                                                                                        | ...   | 4.0    | 4.0  | 4.0  | 4.0  | ...  | ...  | ...  |  |
| Gray               | A278      | 40         | F12803  | ...                  | (8e) (53)     | −20                | 40                                                                                        | ...   | 4.0    | 4.0  | 4.0  | 4.0  | 4.0  | 4.0  | 4.0  |  |
| Gray               | A48       | 45         | F13101  | ...                  | (8e) (48)     | −20                | 45                                                                                        | ...   | 4.5    | 4.5  | 4.5  | 4.5  | ...  | ...  | ...  |  |
| Gray               | A48       | 50         | F13501  | ...                  | (8e) (48)     | −20                | 50                                                                                        | ...   | 5.0    | 5.0  | 5.0  | 5.0  | ...  | ...  | ...  |  |
| Gray               | A278      | 50         | F13502  | ...                  | (8e) (53)     | −20                | 50                                                                                        | ...   | 5.0    | 5.0  | 5.0  | 5.0  | 5.0  | 5.0  | 5.0  |  |
| Gray               | A48       | 55         | F13801  | ...                  | (8e) (48)     | −20                | 55                                                                                        | ...   | 5.5    | 5.5  | 5.5  | 5.5  | ...  | ...  | ...  |  |
| Gray               | A48       | 60         | F14101  | ...                  | (8e) (48)     | −20                | 60                                                                                        | ...   | 6.0    | 6.0  | 6.0  | 6.0  | ...  | ...  | ...  |  |
| Gray               | A278      | 60         | F14102  | ...                  | (8e) (53)     | −20                | 60                                                                                        | ...   | 6.0    | 6.0  | 6.0  | 6.0  | 6.0  | 6.0  | 6.0  |  |
| Cupola malleable   | A197      | ...        | F22000  | ...                  | (8e) (9)      | −20                | 40                                                                                        | 30    | 8.0    | 8.0  | 8.0  | 8.0  | 8.0  | 8.0  | 8.0  |  |
| Malleable          | A47       | 32510      | F22200  | ...                  | (8e) (9)      | −20                | 50                                                                                        | 32.5  | 10.0   | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |  |
| Ferritic ductile   | A395      | 60-40-18   | F32800  | ...                  | (8d) (9)      | −20                | 60                                                                                        | 40    | 20.0   | 19.0 | 17.9 | 16.9 | 15.9 | 14.9 | 14.1 |  |
| Austenitic ductile | A571      | D-2M       | F43010  | 1                    | (8d)          | −20                | 65                                                                                        | 30    | 20.0   | ...  | ...  | ...  | ...  | ...  | ...  |  |
| Ductile            | A536      | 65-45-12   | F33100  | ...                  | (8d) (9)      | −20                | 65                                                                                        | 45    | 21.7   | 21.7 | 21.7 | 21.7 | 21.6 | ...  | ...  |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Material                       | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes          | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |  |
|--------------------------------|-----------|-------------|---------|--------------------------|-----------|-----------|----------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|--|
|                                |           |             |         |                          |           |           |                |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 200  |  |
|                                |           |             |         |                          |           |           |                |                    |                              |       |                                                                            |      |  |
| Carbon Steel — Pipes and Tubes |           |             |         |                          |           |           |                |                    |                              |       |                                                                            |      |  |
| A285 Gr. A                     | A134      | A285A       | K01700  | ...                      | ...       | 1         | (8b) (57)      | B                  | 45                           | 24    | 15.0                                                                       | 14.7 |  |
| A285 Gr. A                     | A672      | A45         | K01700  | ...                      | ...       | 1         | (57) (59) (67) | B                  | 45                           | 24    | 15.0                                                                       | 14.7 |  |
| Butt weld                      | API 5L    | A25         | ...     | ...                      | ...       | 1         | (8a) (77)      | −20                | 45                           | 25    | 15.0                                                                       | 15.0 |  |
| Smls & ERW                     | API 5L    | A25         | ...     | ...                      | ...       | 1         | (57) (59) (77) | B                  | 45                           | 25    | 15.0                                                                       | 15.0 |  |
| ...                            | A179      | ...         | K01200  | ...                      | ...       | 1         | (57) (59)      | −20                | 47                           | 26    | 15.7                                                                       | 15.7 |  |
| Type F                         | A53       | A           | K02504  | ...                      | ...       | 1         | (8a)           | 20                 | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| ...                            | A139      | A           | ...     | ...                      | ...       | 1         | (8b)           | A                  | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| ...                            | A587      | ...         | K11500  | ...                      | ...       | 1         | (57) (59)      | −20                | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| ...                            | A53       | A           | K02504  | ...                      | ...       | 1         | (57) (59)      | B                  | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| ...                            | A106      | A           | K02501  | ...                      | ...       | 1         | (57)           | B                  | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| ...                            | A135      | A           | ...     | ...                      | ...       | 1         | (57) (59)      | B                  | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| ...                            | A369      | FPA         | K02501  | ...                      | ...       | 1         | (57)           | B                  | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| ...                            | API 5L    | A           | ...     | ...                      | ...       | 1         | (57) (59)      | B                  | 48                           | 30    | 16.0                                                                       | 16.0 |  |
| A285 Gr. B                     | A134      | A285B       | K02200  | ...                      | ...       | 1         | (8b) (57)      | B                  | 50                           | 27    | 16.7                                                                       | 16.5 |  |
| A285 Gr. B                     | A672      | A50         | K02200  | ...                      | ...       | 1         | (57) (59) (67) | B                  | 50                           | 27    | 16.7                                                                       | 16.5 |  |
| A285 Gr. C                     | A134      | A285C       | K02801  | ...                      | ...       | 1         | (8b) (57)      | A                  | 55                           | 30    | 18.3                                                                       | 18.3 |  |
| ...                            | A524      | II          | K02104  | ...                      | ...       | 1         | (57)           | −20                | 55                           | 30    | 18.3                                                                       | 18.3 |  |
| ...                            | A333      | 1           | K03008  | ...                      | ...       | 1         | (57) (59)      | −50                | 55                           | 30    | 18.3                                                                       | 18.3 |  |
| ...                            | A334      | 1           | K03008  | ...                      | ...       | 1         | (57) (59)      | −50                | 55                           | 30    | 18.3                                                                       | 18.3 |  |
| A285 Gr. C                     | A671      | CA55        | K02801  | ...                      | ...       | 1         | (59) (67)      | A                  | 55                           | 30    | 18.3                                                                       | 18.3 |  |
| A285 Gr. C                     | A672      | A55         | K02801  | ...                      | ...       | 1         | (57) (59) (67) | A                  | 55                           | 30    | 18.3                                                                       | 18.3 |  |
| A516 Gr. 55                    | A672      | C55         | K01800  | ...                      | ...       | 1         | (57) (67)      | C                  | 55                           | 30    | 18.3                                                                       | 18.3 |  |
| A516 Gr. 60                    | A671      | CC60        | K02100  | ...                      | ...       | 1         | (57) (67)      | C                  | 60                           | 32    | 20.0                                                                       | 19.5 |  |
| A515 Gr. 60                    | A671      | CB60        | K02401  | ...                      | ...       | 1         | (57) (67)      | B                  | 60                           | 32    | 20.0                                                                       | 19.5 |  |
| A515 Gr. 60                    | A672      | B60         | K02401  | ...                      | ...       | 1         | (57) (67)      | B                  | 60                           | 32    | 20.0                                                                       | 19.5 |  |
| A516 Gr. 60                    | A672      | C60         | K02100  | ...                      | ...       | 1         | (57) (67)      | C                  | 60                           | 32    | 20.0                                                                       | 19.5 |  |
| ...                            | A139      | B           | K03003  | ...                      | ...       | 1         | (8b)           | A                  | 60                           | 35    | 20.0                                                                       | 20.0 |  |
| ...                            | A135      | B           | K03018  | ...                      | ...       | 1         | (57) (59)      | B                  | 60                           | 35    | 20.0                                                                       | 20.0 |  |
| ...                            | A524      | I           | K02104  | ...                      | ...       | 1         | (57)           | −20                | 60                           | 35    | 20.0                                                                       | 20.0 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |     |     |     |       |       |       | Type/<br>Grade                 | Spec. No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|-----|-----|-----|-------|-------|-------|--------------------------------|-----------|
| 300                                                                        | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Carbon Steel — Pipes and Tubes |           |
| 14.2                                                                       | 13.7 | 13.0 | 12.3 | 11.9 | 11.5 | 10.7 | 9.2  | 7.9 | 5.9 | ... | ...   | ...   | ...   | ...                            | A134      |
| 14.2                                                                       | 13.7 | 13.0 | 12.3 | 11.9 | 11.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A45                            | A672      |
| 14.7                                                                       | 14.2 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A25                            | API 5L    |
| 14.7                                                                       | 14.2 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A25                            | API 5L    |
| 15.3                                                                       | 14.8 | 14.1 | 13.3 | 12.8 | 12.4 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | ...                            | A179      |
| 16.0                                                                       | 16.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A                              | A53       |
| 16.0                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A                              | A139      |
| 16.0                                                                       | 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2  | 7.9 | ... | ... | ...   | ...   | ...   | ...                            | A587      |
| 16.0                                                                       | 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A                              | A53       |
| 16.0                                                                       | 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A                              | A106      |
| 16.0                                                                       | 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A                              | A135      |
| 16.0                                                                       | 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | FPA                            | A369      |
| 16.0                                                                       | 16.0 | 16.0 | 15.3 | 14.6 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A                              | API 5L    |
| 15.9                                                                       | 15.4 | 14.7 | 13.8 | 13.3 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | ... | ...   | ...   | ...   | ...                            | A134      |
| 15.9                                                                       | 15.4 | 14.7 | 13.8 | 13.3 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A50                            | A672      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | ... | ...   | ...   | ...   | ...                            | A134      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | II                             | A524      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | 1                              | A333      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | 1                              | A334      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | CA55                           | A671      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A55                            | A672      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | C55                            | A672      |
| 18.9                                                                       | 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | CC60                           | A671      |
| 18.9                                                                       | 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | CB60                           | A671      |
| 18.9                                                                       | 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | B60                            | A672      |
| 18.9                                                                       | 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | C60                            | A672      |
| 20.0                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | B                              | A139      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | B                              | A135      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | I                              | A524      |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                |              |                |         |                                |              |              |                        |                          |                                    |       | Basic Allowable<br>Stress, S, ksi,<br>at Metal<br>Temperature,<br>°F [Notes (1),<br>(4a)] |      |
|--------------------------------|--------------|----------------|---------|--------------------------------|--------------|--------------|------------------------|--------------------------|------------------------------------|-------|-------------------------------------------------------------------------------------------|------|
| Material                       | Spec.<br>No. | Type/<br>Grade | UNS No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes                  | Min.<br>Temp.,<br>°F (6) | Specified<br>Min.<br>Strength, ksi |       | Min.<br>Temp.<br>to 100                                                                   | 200  |
|                                |              |                |         |                                |              |              |                        |                          | Tensile                            | Yield |                                                                                           |      |
| Carbon Steel — Pipes and Tubes |              |                |         |                                |              |              |                        |                          |                                    |       |                                                                                           |      |
| ...                            | A53          | B              | K03005  | ...                            | ...          | 1            | (57) (59)              | B                        | 60                                 | 35    | 20.0                                                                                      | 20.0 |
| ...                            | A106         | B              | K03006  | ...                            | ...          | 1            | (57)                   | B                        | 60                                 | 35    | 20.0                                                                                      | 20.0 |
| ...                            | A333         | 6              | K03006  | ...                            | ...          | 1            | (57)                   | −50                      | 60                                 | 35    | 20.0                                                                                      | 20.0 |
| ...                            | A334         | 6              | K03006  | ...                            | ...          | 1            | (57)                   | −50                      | 60                                 | 35    | 20.0                                                                                      | 20.0 |
| ...                            | A369         | FPB            | K03006  | ...                            | ...          | 1            | (57)                   | −20                      | 60                                 | 35    | 20.0                                                                                      | 20.0 |
| ...                            | A381         | Y35            | ...     | ...                            | ...          | 1            | ...                    | A                        | 60                                 | 35    | 20.0                                                                                      | 20.0 |
| ...                            | API 5L       | B              | ...     | ...                            | ...          | 1            | (57) (59)<br>(77)      | B                        | 60                                 | 35    | 20.0                                                                                      | 20.0 |
| ...                            | A139         | C              | K03004  | ...                            | ...          | 1            | (8b)                   | A                        | 60                                 | 42    | 20.0                                                                                      | 20.0 |
| ...                            | A139         | D              | K03010  | ...                            | ...          | 1            | (8b)                   | A                        | 60                                 | 46    | 20.0                                                                                      | 20.0 |
| ...                            | API 5L       | X42            | ...     | ...                            | ...          | 1            | (55) (77)              | A                        | 60                                 | 42    | 20.0                                                                                      | 20.0 |
| ...                            | A381         | Y42            | ...     | ...                            | ...          | 1            | ...                    | A                        | 60                                 | 42    | 20.0                                                                                      | 20.0 |
| ...                            | A381         | Y48            | ...     | ...                            | ...          | 1            | ...                    | A                        | 62                                 | 48    | 20.7                                                                                      | 20.7 |
| ...                            | API 5L       | X46            | ...     | ...                            | ...          | 1            | (55) (77)              | A                        | 63                                 | 46    | 21.0                                                                                      | 21.0 |
| ...                            | A381         | Y46            | ...     | ...                            | ...          | 1            | ...                    | A                        | 63                                 | 46    | 21.0                                                                                      | 21.0 |
| ...                            | A381         | Y50            | ...     | ...                            | ...          | 1            | ...                    | A                        | 64                                 | 50    | 21.3                                                                                      | 21.3 |
| A516 Gr. 65                    | A671         | CC65           | K02403  | ...                            | ...          | 1            | (57) (67)              | B                        | 65                                 | 35    | 21.7                                                                                      | 21.4 |
| A515 Gr. 65                    | A671         | CB65           | K02800  | ...                            | ...          | 1            | (57) (67)              | A                        | 65                                 | 35    | 21.7                                                                                      | 21.4 |
| A515 Gr. 65                    | A672         | B65            | K02800  | ...                            | ...          | 1            | (57) (67)              | A                        | 65                                 | 35    | 21.7                                                                                      | 21.4 |
| A516 Gr. 65                    | A672         | C65            | K02403  | ...                            | ...          | 1            | (57) (67)              | B                        | 65                                 | 35    | 21.7                                                                                      | 21.4 |
| ...                            | A139         | E              | K03012  | ...                            | ...          | 1            | (8b)                   | A                        | 66                                 | 52    | 22.0                                                                                      | 22.0 |
| ...                            | API 5L       | X52            | ...     | ...                            | ...          | 1            | (55) (77)              | A                        | 66                                 | 52    | 22.0                                                                                      | 22.0 |
| ...                            | A381         | Y52            | ...     | ...                            | ...          | 1            | ...                    | A                        | 66                                 | 52    | 22.0                                                                                      | 22.0 |
| A516 Gr. 70                    | A671         | CC70           | K02700  | ...                            | ...          | 1            | (57) (67)              | B                        | 70                                 | 38    | 23.3                                                                                      | 23.2 |
| A515 Gr. 70                    | A671         | CB70           | K03101  | ...                            | ...          | 1            | (57) (67)              | A                        | 70                                 | 38    | 23.3                                                                                      | 23.2 |
| A515 Gr. 70                    | A672         | B70            | K03101  | ...                            | ...          | 1            | (57) (67)              | A                        | 70                                 | 38    | 23.3                                                                                      | 23.2 |
| A516 Gr. 70                    | A672         | C70            | K02700  | ...                            | ...          | 1            | (57) (67)              | B                        | 70                                 | 38    | 23.3                                                                                      | 23.2 |
| ...                            | A106         | C              | K03501  | ...                            | ...          | 1            | (57)                   | B                        | 70                                 | 40    | 23.3                                                                                      | 23.3 |
| A537 Cl. 1                     | A671         | CD70           | K12437  | ...                            | ≤2½ thk.     | 1            | (67)                   | D                        | 70                                 | 50    | 23.3                                                                                      | 23.3 |
| A537 Cl. 1                     | A672         | D70            | K12437  | ...                            | ≤2½ thk.     | 1            | (67)                   | D                        | 70                                 | 50    | 23.3                                                                                      | 23.3 |
| A537 Cl. 1                     | A691         | CMSH-70        | K12437  | ...                            | ≤2½ thk.     | 1            | (67)                   | D                        | 70                                 | 50    | 23.3                                                                                      | 23.3 |
| ...                            | API 5L       | X56            | ...     | ...                            | ...          | 1            | (51) (55)<br>(71) (77) | A                        | 71                                 | 56    | 23.7                                                                                      | 23.7 |
| ...                            | A381         | Y56            | ...     | ...                            | ...          | 1            | (51) (55)<br>(71)      | A                        | 71                                 | 56    | 23.7                                                                                      | 23.7 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |     |     |     |       |       |       | Type/<br>Grade                          | Spec. No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|-----|-----|-----|-------|-------|-------|-----------------------------------------|-----------|
| 300                                                                        | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Carbon Steel — Pipes and Tubes (Cont'd) |           |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | B                                       | A53       |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | B                                       | A106      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | 6                                       | A333      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | 6                                       | A334      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | FPB                                     | A369      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | Y35                                     | A381      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | B                                       | API 5L    |
| 20.0                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | C                                       | A139      |
| 20.0                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | D                                       | A139      |
| 20.0                                                                       | 20.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X42                                     | API 5L    |
| 20.0                                                                       | 20.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Y42                                     | A381      |
| 20.7                                                                       | 20.7 | 20.7 | 20.7 | 18.7 | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Y48                                     | A381      |
| 21.0                                                                       | 21.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X46                                     | API 5L    |
| 21.0                                                                       | 21.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Y46                                     | A381      |
| 21.3                                                                       | 21.3 | 21.3 | 21.3 | 18.7 | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Y50                                     | A381      |
| 20.6                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | CC65                                    | A671      |
| 20.6                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | CB65                                    | A671      |
| 20.6                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | B65                                     | A672      |
| 20.6                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | C65                                     | A672      |
| 22.0                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | E                                       | A139      |
| 22.0                                                                       | 22.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X52                                     | API 5L    |
| 22.0                                                                       | 22.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Y52                                     | A381      |
| 22.4                                                                       | 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | ...   | ...   | CC70                                    | A671      |
| 22.4                                                                       | 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | CB70                                    | A671      |
| 22.4                                                                       | 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | B70                                     | A672      |
| 22.4                                                                       | 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | C70                                     | A672      |
| 23.3                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 18.3 | 14.8 | 12.0 | ... | ... | ... | ...   | ...   | ...   | C                                       | A106      |
| 22.8                                                                       | 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | CD70                                    | A671      |
| 22.8                                                                       | 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | D70                                     | A672      |
| 22.8                                                                       | 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | CMSH-70                                 | A691      |
| 23.7                                                                       | 23.7 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X56                                     | API 5L    |
| 23.7                                                                       | 23.7 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Y56                                     | A381      |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                                 |              |                |         |                                |              |              |                        |                          |                                    |       | Basic Allowable<br>Stress, S, ksi,<br>at Metal<br>Temperature,<br>°F [Notes (1),<br>(4a)] |      |
|-------------------------------------------------|--------------|----------------|---------|--------------------------------|--------------|--------------|------------------------|--------------------------|------------------------------------|-------|-------------------------------------------------------------------------------------------|------|
| Material                                        | Spec.<br>No. | Type/<br>Grade | UNS No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes                  | Min.<br>Temp.,<br>°F (6) | Specified<br>Min.<br>Strength, ksi |       | Min.<br>Temp.<br>to 100<br>200                                                            |      |
|                                                 |              |                |         |                                |              |              |                        |                          | Tensile                            | Yield |                                                                                           |      |
| Carbon Steel — Pipes and Tubes                  |              |                |         |                                |              |              |                        |                          |                                    |       |                                                                                           |      |
| A299 Gr. A                                      | A671         | CK75           | K02803  | ...                            | >1 thk.      | 1            | (57) (67)              | A                        | 75                                 | 40    | 25.0                                                                                      | 24.4 |
| A299 Gr. A                                      | A672         | N75            | K02803  | ...                            | >1 thk.      | 1            | (57) (67)              | A                        | 75                                 | 40    | 25.0                                                                                      | 24.4 |
| A299 Gr. A                                      | A691         | CMS-75         | K02803  | ...                            | >1 thk.      | 1            | (57) (67)              | A                        | 75                                 | 40    | 25.0                                                                                      | 24.4 |
| A299 Gr. A                                      | A671         | CK75           | K02803  | ...                            | ≤1 thk.      | 1            | (57) (67)              | A                        | 75                                 | 42    | 25.0                                                                                      | 25.0 |
| A299 Gr. A                                      | A672         | N75            | K02803  | ...                            | ≤1 thk.      | 1            | (57) (67)              | A                        | 75                                 | 42    | 25.0                                                                                      | 25.0 |
| A299 Gr. A                                      | A691         | CMS-75         | K02803  | ...                            | ≤1 thk.      | 1            | (57) (67)              | A                        | 75                                 | 42    | 25.0                                                                                      | 25.0 |
| ...                                             | API 5L       | X60            | ...     | ...                            | ...          | 1            | (51) (55)<br>(71) (77) | A                        | 75                                 | 60    | 25.0                                                                                      | 25.0 |
| ...                                             | API 5L       | X65            | ...     | ...                            | ...          | 1            | (51) (55)<br>(71) (77) | A                        | 77                                 | 65    | 25.7                                                                                      | 25.7 |
| ...                                             | API 5L       | X70            | ...     | ...                            | ...          | 1            | (51) (55)<br>(71) (77) | A                        | 82                                 | 70    | 27.3                                                                                      | 27.3 |
| ...                                             | API 5L       | X80            | ...     | ...                            | ...          | 1            | (51) (55)<br>(71) (77) | A                        | 90                                 | 80    | 30.0                                                                                      | 30.0 |
| ...                                             | A381         | Y60            | ...     | ...                            | ...          | 1            | (51) (71)              | A                        | 75                                 | 60    | 25.0                                                                                      | 25.0 |
| Carbon Steel — Pipes (Structural Grade)         |              |                |         |                                |              |              |                        |                          |                                    |       |                                                                                           |      |
| A1011 Gr. 30                                    | A134         | A1011SS30      | K02502  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 49                                 | 30    | 15.0                                                                                      | 15.0 |
| A1011 Gr. 33                                    | A134         | A1011SS33      | K02502  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 52                                 | 33    | 15.9                                                                                      | 15.9 |
| A1011 Gr. 36                                    | A134         | A1011SS36-T1   | K02502  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 53                                 | 36    | 16.3                                                                                      | 16.3 |
| A1011 Gr. 40                                    | A134         | A1011SS40      | K02502  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 55                                 | 40    | 16.9                                                                                      | 16.9 |
| A36                                             | A134         | A36            | K02600  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 58                                 | 36    | 17.8                                                                                      | 17.8 |
| A283 Gr. D                                      | A134         | A283D          | K02702  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 60                                 | 33    | 18.4                                                                                      | 18.4 |
| A1011 Gr. 45                                    | A134         | A1011SS45      | K02507  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 60                                 | 45    | 18.4                                                                                      | 18.4 |
| A1011 Gr. 50                                    | A134         | A1011SS50      | K02507  | ...                            | ...          | 1            | (8a) (8c)              | −20                      | 65                                 | 50    | 19.9                                                                                      | 19.9 |
| Carbon Steel — Plates, Bars, Shapes, and Sheets |              |                |         |                                |              |              |                        |                          |                                    |       |                                                                                           |      |
| ...                                             | A285         | A              | K01700  | ...                            | ...          | 1            | (57) (59)              | B                        | 45                                 | 24    | 15.0                                                                                      | 14.7 |
| ...                                             | A285         | B              | K02200  | ...                            | ...          | 1            | (57) (59)              | B                        | 50                                 | 27    | 16.7                                                                                      | 16.5 |
| ...                                             | A516         | 55             | K01800  | ...                            | ...          | 1            | (57)                   | C                        | 55                                 | 30    | 18.3                                                                                      | 18.3 |
| ...                                             | A285         | C              | K02801  | ...                            | ...          | 1            | (57) (59)              | A                        | 55                                 | 30    | 18.3                                                                                      | 18.3 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |     |     |     |       |       |       | Type/<br>Grade                          | Spec. No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|-----|-----|-----|-------|-------|-------|-----------------------------------------|-----------|
| 300                                                                        | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Carbon Steel — Pipes and Tubes (Cont'd) |           |
| 23.6                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | CK75                                    | A671      |
| 23.6                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | N75                                     | A672      |
| 23.6                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | CMS-75                                  | A691      |
| 24.8                                                                       | 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | CK75                                    | A671      |
| 24.8                                                                       | 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | N75                                     | A672      |
| 24.8                                                                       | 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | CMS-75                                  | A691      |
| 25.0                                                                       | 25.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X60                                     | API 5L    |
| 25.7                                                                       | 25.7 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X65                                     | API 5L    |
| 27.3                                                                       | 27.3 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X70                                     | API 5L    |
| 30.0                                                                       | 30.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | X80                                     | API 5L    |
| 25.0                                                                       | 25.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Y60                                     | A381      |
| Carbon Steel — Pipes (Structural Grade)                                    |      |      |      |      |      |      |      |     |     |     |       |       |       |                                         |           |
| 15.0                                                                       | 15.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A1011SS30                               | A134      |
| 15.9                                                                       | 15.9 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A1011SS33                               | A134      |
| 16.3                                                                       | 16.3 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A1011SS36-T1                            | A134      |
| 16.9                                                                       | 16.9 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A1011SS40                               | A134      |
| 17.8                                                                       | 17.8 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A36                                     | A134      |
| 17.9                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A283D                                   | A134      |
| 18.4                                                                       | 18.4 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | A1011SS45                               | A134      |
| 19.9                                                                       | 19.9 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | 1011SS50                                | A134      |
| Carbon Steel — Plates, Bars, Shapes, and Sheets                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                                         |           |
| 14.2                                                                       | 13.7 | 13.0 | 12.3 | 11.9 | 11.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | A                                       | A285      |
| 15.9                                                                       | 15.4 | 14.7 | 13.8 | 13.3 | 12.5 | 10.7 | 9.2  | 7.9 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | B                                       | A285      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | 55                                      | A516      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | C                                       | A285      |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                                              |           |            |         |                         |           |           |               |                    |                              | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |                       |      |
|--------------------------------------------------------------|-----------|------------|---------|-------------------------|-----------|-----------|---------------|--------------------|------------------------------|----------------------------------------------------------------------------|-----------------------|------|
| Material                                                     | Spec. No. | Type/Grade | UNS No. | Class/Condition/ Temper | Size, in. | P-No. (5) | Notes         | Min. Temp., °F (6) | Specified Min. Strength, ksi |                                                                            | Min. Temp. to 100 200 |      |
|                                                              |           |            |         |                         |           |           |               |                    | Tensile                      | Yield                                                                      |                       |      |
| Carbon Steel — Plates, Bars, Shapes, and Sheets              |           |            |         |                         |           |           |               |                    |                              |                                                                            |                       |      |
| ...                                                          | A516      | 60         | K02100  | ...                     | ...       | 1         | (57)          | C                  | 60                           | 32                                                                         | 20.0                  | 19.5 |
| ...                                                          | A515      | 60         | K02401  | ...                     | ...       | 1         | (57)          | B                  | 60                           | 32                                                                         | 20.0                  | 19.5 |
| ...                                                          | A696      | B          | K03200  | ...                     | ...       | 1         | (57)          | A                  | 60                           | 35                                                                         | 20.0                  | 20.0 |
| ...                                                          | A516      | 65         | K02403  | ...                     | ...       | 1         | (57)          | B                  | 65                           | 35                                                                         | 21.7                  | 21.4 |
| ...                                                          | A515      | 65         | K02800  | ...                     | ...       | 1         | (57)          | A                  | 65                           | 35                                                                         | 21.7                  | 21.4 |
| ...                                                          | A516      | 70         | K02700  | ...                     | ...       | 1         | (57)          | B                  | 70                           | 38                                                                         | 23.3                  | 23.2 |
| ...                                                          | A515      | 70         | K03101  | ...                     | ...       | 1         | (57)          | A                  | 70                           | 38                                                                         | 23.3                  | 23.2 |
| ...                                                          | A696      | C          | K03200  | ...                     | ...       | 1         | (57)          | A                  | 70                           | 40                                                                         | 23.3                  | 23.3 |
| ...                                                          | A537      | ...        | K12437  | 1                       | ≤2½ thk.  | 1         | ...           | D                  | 70                           | 50                                                                         | 23.3                  | 23.3 |
| ...                                                          | A299      | A          | K02803  | ...                     | >1 thk.   | 1         | (57)          | A                  | 75                           | 40                                                                         | 25.0                  | 24.4 |
| ...                                                          | A299      | A          | K02803  | ...                     | ≤1 thk.   | 1         | (57)          | A                  | 75                           | 42                                                                         | 25.0                  | 25.0 |
| Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural) |           |            |         |                         |           |           |               |                    |                              |                                                                            |                       |      |
| ...                                                          | A1011     | SS30       | K02502  | ...                     | ...       | 1         | (8c) (57)     | A                  | 49                           | 30                                                                         | 15.0                  | 15.0 |
| ...                                                          | A1011     | SS33       | K02502  | ...                     | ...       | 1         | (8c) (57)     | A                  | 52                           | 33                                                                         | 15.9                  | 15.9 |
| ...                                                          | A1011     | SS36-T1    | K02502  | ...                     | ...       | 1         | (8c) (57)     | A                  | 53                           | 36                                                                         | 16.3                  | 16.3 |
| ...                                                          | A283      | C          | K02401  | ...                     | ...       | 1         | (8c) (57)     | A                  | 55                           | 30                                                                         | 16.8                  | 16.8 |
| ...                                                          | A1011     | SS40       | K02502  | ...                     | ...       | 1         | (8c) (57)     | A                  | 55                           | 40                                                                         | 16.8                  | 16.8 |
| ...                                                          | A36       | ...        | K02600  | ...                     | ...       | 1         | (8c)          | A                  | 58                           | 36                                                                         | 17.8                  | 17.8 |
| ...                                                          | A283      | D          | K02702  | ...                     | ...       | 1         | (8c) (57)     | A                  | 60                           | 33                                                                         | 18.4                  | 18.4 |
| ...                                                          | A1011     | SS45       | K02507  | ...                     | ...       | 1         | (8c) (57)     | A                  | 60                           | 45                                                                         | 18.4                  | 18.4 |
| ...                                                          | A1011     | SS50       | K02507  | ...                     | ...       | 1         | (8c) (57)     | A                  | 65                           | 50                                                                         | 19.9                  | 19.9 |
| ...                                                          | A992      | ...        | ...     | ...                     | ...       | 1         | (8c) (57)     | A                  | 65                           | 50                                                                         | 19.9                  | 19.9 |
| Carbon Steel — Forgings and Fittings                         |           |            |         |                         |           |           |               |                    |                              |                                                                            |                       |      |
| ...                                                          | A350      | LF1        | K03009  | ...                     | ...       | 1         | (9) (57) (59) | −20                | 60                           | 30                                                                         | 20.0                  | 18.3 |
| ...                                                          | A181      | ...        | K03502  | 60                      | ...       | 1         | (9) (57) (59) | A                  | 60                           | 30                                                                         | 20.0                  | 18.3 |
| ...                                                          | A420      | WPL6       | K03006  | ...                     | ...       | 1         | (57)          | −50                | 60                           | 35                                                                         | 20.0                  | 20.0 |
| ...                                                          | A234      | WPB        | K03006  | ...                     | ...       | 1         | (57) (59)     | B                  | 60                           | 35                                                                         | 20.0                  | 20.0 |
| ...                                                          | A694      | F42        | K03014  | ...                     | ...       | 1         | (9)           | −20                | 60                           | 42                                                                         | 20.0                  | 20.0 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |     |     |     |       |       |       | Type/<br>Grade | Spec. No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|-----|-----|-----|-------|-------|-------|----------------|-----------|
| 300                                                                        | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 |                |           |
| Carbon Steel — Plates, Bars, Shapes, and Sheets (Cont'd)                   |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 18.9                                                                       | 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | 60             | A516      |
| 18.9                                                                       | 18.2 | 17.4 | 16.4 | 15.8 | 15.3 | 13.0 | 10.8 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | 60             | A515      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 15.6 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | B              | A696      |
| 20.6                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | 65             | A516      |
| 20.6                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | 65             | A515      |
| 22.4                                                                       | 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | ...   | ...   | 70             | A516      |
| 22.4                                                                       | 21.6 | 20.6 | 19.4 | 18.8 | 18.1 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | ...   | ...   | 70             | A515      |
| 23.3                                                                       | 22.8 | 21.7 | 20.5 | 19.7 | 18.3 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | C              | A696      |
| 22.8                                                                       | 22.7 | 22.7 | 22.4 | 21.9 | 18.3 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | Cl. 1          | A537      |
| 23.6                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 19.1 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | A              | A299      |
| 24.8                                                                       | 23.9 | 22.8 | 21.5 | 20.8 | 19.6 | 15.7 | 12.6 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | A              | A299      |
| Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural)               |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 15.0                                                                       | 15.0 | 15.0 | 14.1 | 13.4 | 11.5 | 9.8  | ...  | ... | ... | ... | ...   | ...   | ...   | 30             | A1011     |
| 15.9                                                                       | 15.9 | 15.9 | 15.5 | 13.4 | 11.5 | 9.8  | ...  | ... | ... | ... | ...   | ...   | ...   | 33             | A1011     |
| 16.3                                                                       | 16.3 | 16.3 | 16.3 | 13.4 | 11.5 | 9.8  | ...  | ... | ... | ... | ...   | ...   | ...   | 36             | A1011     |
| 16.3                                                                       | 15.7 | 15.0 | 14.1 | 13.6 | 13.2 | 12.0 | ...  | ... | ... | ... | ...   | ...   | ...   | C              | A283      |
| 16.8                                                                       | 16.8 | 16.8 | 16.8 | 16.8 | 14.4 | 12.0 | ...  | ... | ... | ... | ...   | ...   | ...   | 40             | A1011     |
| 17.8                                                                       | 17.8 | 17.8 | 16.9 | 16.4 | 14.4 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | ...            | A36       |
| 17.9                                                                       | 17.3 | 16.5 | 15.5 | 15.0 | 14.5 | 12.8 | ...  | ... | ... | ... | ...   | ...   | ...   | D              | A283      |
| 18.4                                                                       | 18.4 | 18.4 | 18.4 | 18.4 | 15.5 | 12.8 | ...  | ... | ... | ... | ...   | ...   | ...   | 45             | A1011     |
| 19.9                                                                       | 19.9 | 19.9 | 19.9 | 18.9 | 15.5 | 12.8 | ...  | ... | ... | ... | ...   | ...   | ...   | 50             | A1011     |
| 19.9                                                                       | 19.9 | 19.9 | 19.9 | 18.9 | 15.5 | 12.8 | 10.5 | ... | ... | ... | ...   | ...   | ...   | ...            | A992      |
| Carbon Steel — Forgings and Fittings                                       |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.8 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | LF1            | A350      |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.8 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | Cl. 60         | A181      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | ...   | ...   | WPL6           | A420      |
| 20.0                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | WPB            | A234      |
| 20.0                                                                       | 20.0 | 19.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | F42            | A694      |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Material                             | Spec. No. | Type/ Grade | UNS No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes         | Min.<br>Temp.,<br>°F (6) | Specified<br>Min.<br>Strength, ksi |       | Basic Allowable<br>Stress, S, ksi,<br>at Metal<br>Temperature,<br>°F [Notes (1),<br>(4a)] |      |  |
|--------------------------------------|-----------|-------------|---------|--------------------------------|--------------|--------------|---------------|--------------------------|------------------------------------|-------|-------------------------------------------------------------------------------------------|------|--|
|                                      |           |             |         |                                |              |              |               |                          | Tensile                            | Yield | Min.<br>Temp.<br>to 100                                                                   | 200  |  |
|                                      |           |             |         |                                |              |              |               |                          |                                    |       |                                                                                           |      |  |
| Carbon Steel — Forgings and Fittings |           |             |         |                                |              |              |               |                          |                                    |       |                                                                                           |      |  |
| ...                                  | A707      | L1          | K02302  | 1                              | ...          | 1            | (9)           | −20                      | 60                                 | 42    | 20.0                                                                                      | 20.0 |  |
| ...                                  | A707      | L2          | K03301  | 1                              | ...          | 1            | (9)           | −50                      | 60                                 | 42    | 20.0                                                                                      | 20.0 |  |
| ...                                  | A707      | L3          | K12510  | 1                              | ...          | 1            | (9)           | −50                      | 60                                 | 42    | 20.0                                                                                      | 20.0 |  |
| ...                                  | A860      | WPHY 42     | ...     | ...                            | ...          | 1            | ...           | −50                      | 60                                 | 42    | 20.0                                                                                      | 20.0 |  |
| ...                                  | A694      | F46         | K03014  | ...                            | ...          | 1            | (9)           | −20                      | 63                                 | 46    | 21.0                                                                                      | 21.0 |  |
| ...                                  | A860      | WPHY 46     | ...     | ...                            | ...          | 1            | ...           | −50                      | 63                                 | 46    | 21.0                                                                                      | 21.0 |  |
| ...                                  | A694      | F52         | K03014  | ...                            | ...          | 1            | (9)           | −20                      | 66                                 | 52    | 22.0                                                                                      | 22.0 |  |
| ...                                  | A707      | L1          | K02302  | 2                              | ...          | 1            | (9)           | −20                      | 66                                 | 52    | 22.0                                                                                      | 22.0 |  |
| ...                                  | A707      | L2          | K03301  | 2                              | ...          | 1            | (9)           | −50                      | 66                                 | 52    | 22.0                                                                                      | 22.0 |  |
| ...                                  | A707      | L3          | K12510  | 2                              | ...          | 1            | (9)           | −50                      | 66                                 | 52    | 22.0                                                                                      | 22.0 |  |
| ...                                  | A860      | WPHY 52     | ...     | ...                            | ...          | 1            | ...           | −50                      | 66                                 | 52    | 22.0                                                                                      | 22.0 |  |
| ...                                  | A350      | LF2         | K03011  | 1                              | ...          | 1            | (9) (57)      | −50                      | 70                                 | 36    | 23.3                                                                                      | 22.0 |  |
| ...                                  | A350      | LF2         | K03011  | 2                              | ...          | 1            | (9) (57)      | 0                        | 70                                 | 36    | 23.3                                                                                      | 22.0 |  |
| ...                                  | A105      | ...         | K03504  | ...                            | ...          | 1            | (9) (57) (59) | −20                      | 70                                 | 36    | 23.3                                                                                      | 22.0 |  |
| ...                                  | A181      | ...         | K03502  | 70                             | ...          | 1            | (9) (57) (59) | A                        | 70                                 | 36    | 23.3                                                                                      | 22.0 |  |
| ...                                  | A234      | WPC         | K03501  | ...                            | ...          | 1            | (57) (59)     | B                        | 70                                 | 40    | 23.3                                                                                      | 23.3 |  |
| ...                                  | A694      | F56         | K03014  | ...                            | ...          | 1            | (9)           | −20                      | 71                                 | 56    | 23.7                                                                                      | 23.7 |  |
| ...                                  | A694      | F60         | K03014  | ...                            | ...          | 1            | (9)           | −20                      | 75                                 | 60    | 25.0                                                                                      | 25.0 |  |
| ...                                  | A707      | L2          | K03301  | 3                              | ...          | 1            | (9)           | −50                      | 75                                 | 60    | 25.0                                                                                      | 25.0 |  |
| ...                                  | A707      | L3          | K12510  | 3                              | ...          | 1            | (9)           | −50                      | 75                                 | 60    | 25.0                                                                                      | 25.0 |  |
| ...                                  | A860      | WPHY 60     | ...     | ...                            | ...          | 1            | ...           | −50                      | 75                                 | 60    | 25.0                                                                                      | 25.0 |  |
| ...                                  | A694      | F65         | K03014  | ...                            | ...          | 1            | (9)           | −20                      | 77                                 | 65    | 25.7                                                                                      | 25.7 |  |
| ...                                  | A860      | WPHY 65     | ...     | ...                            | ...          | 1            | ...           | −50                      | 77                                 | 65    | 25.7                                                                                      | 25.7 |  |
| ...                                  | A694      | F70         | K03014  | ...                            | ...          | 1            | (9) (79)      | ...                      | 82                                 | 70    | 27.3                                                                                      | 27.3 |  |
| ...                                  | A860      | WPHY 70     | ...     | ...                            | ...          | 1            | ...           | −50                      | 82                                 | 70    | 27.3                                                                                      | 27.3 |  |
| Carbon Steel — Castings              |           |             |         |                                |              |              |               |                          |                                    |       |                                                                                           |      |  |
| ...                                  | A216      | WCA         | J02502  | ...                            | ...          | 1            | (57)          | −20                      | 60                                 | 30    | 20.0                                                                                      | 18.3 |  |
| ...                                  | A352      | LCB         | J03003  | ...                            | ...          | 1            | (9) (57)      | −50                      | 65                                 | 35    | 21.7                                                                                      | 21.4 |  |
| ...                                  | A352      | LCC         | J02505  | ...                            | ...          | 1            | (9)           | −50                      | 70                                 | 40    | 23.3                                                                                      | 23.3 |  |
| ...                                  | A216      | WCB         | J03002  | ...                            | ...          | 1            | (9) (57)      | −20                      | 70                                 | 36    | 23.3                                                                                      | 22.0 |  |
| ...                                  | A216      | WCC         | J02503  | ...                            | ...          | 1            | (9) (57)      | −20                      | 70                                 | 40    | 23.3                                                                                      | 23.3 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|-----|-----|-----|-------|-------|-------|----------------|-----------|
| 300                                                                        | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | Type/<br>Grade | Spec. No. |
| Carbon Steel — Forgings and Fittings (Cont'd)                              |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 20.0                                                                       | 20.0 | 19.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L1             | A707      |
| 20.0                                                                       | 20.0 | 19.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L2             | A707      |
| 20.0                                                                       | 20.0 | 19.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L3             | A707      |
| 20.0                                                                       | 20.0 | 19.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | WPHY 42        | A860      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 21.0                                                                       | 21.0 | 21.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | F46            | A694      |
| 21.0                                                                       | 21.0 | 21.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | WPHY 46        | A860      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 22.0                                                                       | 22.0 | 22.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | F52            | A694      |
| 22.0                                                                       | 22.0 | 22.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L1             | A707      |
| 22.0                                                                       | 22.0 | 22.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L2             | A707      |
| 22.0                                                                       | 22.0 | 22.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L3             | A707      |
| 22.0                                                                       | 22.0 | 22.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | WPHY 52        | A860      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 21.2                                                                       | 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | ...   | ...   | LF2 Cl. 1      | A350      |
| 21.2                                                                       | 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | ...   | ...   | LF2 Cl. 2      | A350      |
| 21.2                                                                       | 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | ...            | A105      |
| 21.2                                                                       | 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | Cl. 70         | A181      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 23.3                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 18.3 | 14.8 | 12.0 | ... | ... | ... | ...   | ...   | ...   | WPC            | A234      |
| 23.7                                                                       | 23.7 | 23.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | F56            | A694      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 25.0                                                                       | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | F60            | A694      |
| 25.0                                                                       | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L2             | A707      |
| 25.0                                                                       | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | L3             | A707      |
| 25.0                                                                       | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | WPHY 60        | A860      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 25.7                                                                       | 25.7 | 25.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | F65            | A694      |
| 25.7                                                                       | 25.7 | 25.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | WPHY 65        | A860      |
| 27.3                                                                       | 27.3 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | F70            | A694      |
| 27.3                                                                       | 27.3 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | WPHY 70        | A860      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| Carbon Steel — Castings                                                    |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 17.7                                                                       | 17.1 | 16.3 | 15.3 | 14.8 | 14.3 | 13.8 | 11.4 | 8.7 | 5.9 | 4.0 | 2.5   | 1.6   | 1.0   | WCA            | A216      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 20.6                                                                       | 19.9 | 19.0 | 17.9 | 17.3 | 16.7 | 13.9 | 11.4 | 9.0 | 6.3 | 4.0 | 2.5   | 1.6   | 1.0   | LCB            | A352      |
| 23.3                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 19.2 | ...  | ...  | ... | ... | ... | ...   | ...   | ...   | LCC            | A352      |
|                                                                            |      |      |      |      |      |      |      |     |     |     |       |       |       |                |           |
| 21.2                                                                       | 20.5 | 19.6 | 18.4 | 17.8 | 17.2 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | 1.6   | 1.0   | WCB            | A216      |
| 23.3                                                                       | 22.8 | 21.7 | 20.4 | 19.8 | 18.3 | 14.8 | 12.0 | 9.3 | 6.7 | 4.0 | 2.5   | ...   | ...   | WCC            | A216      |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                   | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes     | Min.<br>Temp.,<br>°F (6) | Specified Min. |       | Basic<br>Allowable<br>Stress, S,<br>ksi, at Metal<br>Temperature,<br>°F [Notes (1),<br>(4a)] |      |  |
|------------------------------------------|--------------|----------------|------------|--------------------------------|--------------|--------------|-----------|--------------------------|----------------|-------|----------------------------------------------------------------------------------------------|------|--|
|                                          |              |                |            |                                |              |              |           |                          | Strength, ksi  |       | Min.<br>Temp.<br>to 100                                                                      | 200  |  |
|                                          |              |                |            |                                |              |              |           |                          | Tensile        | Yield |                                                                                              |      |  |
| Low and Intermediate Alloy Steel — Pipes |              |                |            |                                |              |              |           |                          |                |       |                                                                                              |      |  |
| ½Cr–½Mo                                  | A335         | P2             | K11547     | ...                            | ...          | 3            | ...       | –20                      | 55             | 30    | 18.3                                                                                         | 18.3 |  |
| ½Cr–½Mo<br>A387 Gr. 2 Cl. 1              | A691         | ½CR            | K12143     | ...                            | ...          | 3            | (11) (67) | –20                      | 55             | 33    | 18.3                                                                                         | 18.3 |  |
| C–½Mo                                    | A335         | P1             | K11522     | ...                            | ...          | 3            | (58)      | –20                      | 55             | 30    | 18.3                                                                                         | 18.3 |  |
| C–½Mo                                    | A369         | FP1            | K11522     | ...                            | ...          | 3            | (58)      | –20                      | 55             | 30    | 18.3                                                                                         | 18.3 |  |
| ½Cr–½Mo                                  | A369         | FP2            | K11547     | ...                            | ...          | 3            | ...       | –20                      | 55             | 30    | 18.3                                                                                         | 18.3 |  |
| 1Cr–½Mo<br>A387 Gr. 12 Cl. 1             | A691         | 1CR            | K11757     | ...                            | ...          | 4            | (11) (67) | –20                      | 55             | 33    | 18.3                                                                                         | 18.3 |  |
| ½Cr–½Mo                                  | A426         | CP2            | J11547     | ...                            | ...          | 3            | (10)      | –20                      | 60             | 30    | 20.0                                                                                         | 18.8 |  |
| 1½Si–½Mo                                 | A335         | P15            | K11578     | ...                            | ...          | 3            | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.8 |  |
| C–½Mo–Si                                 | A426         | CP15           | J11522     | ...                            | ...          | 3            | (10)      | –20                      | 60             | 30    | 20.0                                                                                         | 18.8 |  |
| 1Cr–½Mo                                  | A426         | CP12           | J11562     | ...                            | ...          | 4            | (10)      | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 5Cr–1½Si–½Mo                             | A426         | CP5b           | J51545     | ...                            | ...          | 5B           | (10)      | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 3Cr–Mo                                   | A426         | CP21           | J31545     | ...                            | ...          | 5A           | (10)      | –20                      | 60             | 30    | 20.0                                                                                         | 18.7 |  |
| ¾Cr–¾Ni–Cu–Al                            | A333         | 4              | K11267     | ...                            | ...          | 4            | ...       | –150                     | 60             | 35    | 20.0                                                                                         | 19.1 |  |
| 2Cr–½Mo                                  | A369         | FP3b           | K21509     | ...                            | ...          | 4            | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.7 |  |
| 1Cr–½Mo                                  | A335         | P12            | K11562     | ...                            | ...          | 4            | ...       | –20                      | 60             | 32    | 20.0                                                                                         | 19.3 |  |
| 1Cr–½Mo                                  | A369         | FP12           | K11562     | ...                            | ...          | 4            | ...       | –20                      | 60             | 32    | 20.0                                                                                         | 19.3 |  |
| 1¼Cr–½Mo–Si                              | A335         | P11            | K11597     | ...                            | ...          | 4            | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.5 |  |
| 1¼Cr–½Mo–Si                              | A369         | FP11           | K11597     | ...                            | ...          | 4            | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.5 |  |
| 1¼Cr–½Mo–Si<br>A387 Gr. 11 Cl. 1         | A691         | 1¼CR           | K11789     | ...                            | ...          | 4            | (11) (67) | –20                      | 60             | 35    | 20.0                                                                                         | 20.0 |  |
| 5Cr–½Mo<br>A387 Gr. 5 Cl. 1              | A691         | 5CR            | K41545     | ...                            | ...          | 5B           | (11) (67) | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 5Cr–½Mo                                  | A335         | P5             | K41545     | ...                            | ...          | 5B           | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 5Cr–½Mo–Si                               | A335         | P5b            | K51545     | ...                            | ...          | 5B           | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 5Cr–½Mo–Ti                               | A335         | P5c            | K41245     | ...                            | ...          | 5B           | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 5Cr–½Mo                                  | A369         | FP5            | K41545     | ...                            | ...          | 5B           | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 9Cr–1Mo                                  | A335         | P9             | K90941     | ...                            | ...          | 5B           | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 9Cr–1Mo                                  | A369         | FP9            | K90941     | ...                            | ...          | 5B           | ...       | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |
| 9Cr–1Mo<br>A387 Gr. 9 Cl. 1              | A691         | 9CR            | K90941     | ...                            | ...          | 5B           | (11) (67) | –20                      | 60             | 30    | 20.0                                                                                         | 18.1 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, <i>S</i> , ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |                                          | Type/ Spec. No. |
|------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|------------------------------------------|-----------------|
| 300                                                                                | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Low and Intermediate Alloy Steel — Pipes |                 |
| 18.0                                                                               | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.9 | 9.2  | 5.9   | ...   | ...   | ...   | ...   | P2                                       | A335            |
| 18.3                                                                               | 18.3 | 18.3 | 18.0 | 17.7 | 17.3 | 16.9 | 16.4 | 15.9 | 14.3 | 9.2  | 5.9   | ...   | ...   | ...   | ...   | ½CR                                      | A691            |
| 18.0                                                                               | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | P1                                       | A335            |
| 18.0                                                                               | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | FP1                                      | A369            |
| 18.0                                                                               | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.9 | 9.2  | 5.9   | 4.1   | 2.5   | ...   | ...   | FP2                                      | A369            |
| 17.6                                                                               | 17.6 | 17.2 | 16.8 | 16.5 | 16.3 | 16.0 | 15.7 | 15.4 | 15.0 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | 1CR                                      | A691            |
| 18.0                                                                               | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.9 | 9.2  | 5.9   | 4.0   | 2.4   | ...   | ...   | CP2                                      | A426            |
| 18.2                                                                               | 17.7 | 17.3 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 13.8 | 12.5 | 10.0 | 6.3   | 4.0   | 2.4   | ...   | ...   | P15                                      | A335            |
| 18.2                                                                               | 17.7 | 17.3 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 13.8 | 12.5 | 10.0 | 6.3   | 4.0   | 2.4   | ...   | ...   | CP15                                     | A426            |
| 17.0                                                                               | 16.2 | 15.7 | 15.2 | 15.0 | 14.8 | 14.6 | 14.3 | 14.0 | 13.6 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | CP12                                     | A426            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | CP5b                                     | A426            |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0  | 7.0   | 5.5   | 4.0   | 2.7   | 1.5   | CP21                                     | A426            |
| 18.2                                                                               | 17.3 | 16.4 | 15.5 | 15.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | 4                                        | A333            |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.5 | 12.5 | 10.0 | 6.2   | 4.2   | 2.6   | 1.4   | 1.0   | FP3b                                     | A369            |
| 18.1                                                                               | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | P12                                      | A335            |
| 18.1                                                                               | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | FP12                                     | A369            |
| 17.6                                                                               | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | P11                                      | A335            |
| 17.6                                                                               | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | FP11                                     | A369            |
| 20.0                                                                               | 19.6 | 18.9 | 18.3 | 18.0 | 17.6 | 17.2 | 16.8 | 16.4 | 13.7 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | 1¼CR                                     | A691            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | 5CR                                      | A691            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | P5                                       | A335            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | P5b                                      | A335            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | P5c                                      | A335            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | FP5                                      | A369            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | P9                                       | A335            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | FP9                                      | A369            |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | 9CR                                      | A691            |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition                      | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in.   | P-No. (5) | Notes               | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |  |
|------------------------------------------|-----------|-------------|---------|--------------------------|-------------|-----------|---------------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|--|
|                                          |           |             |         |                          |             |           |                     |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 200  |  |
|                                          |           |             |         |                          |             |           |                     |                    |                              |       |                                                                            |      |  |
| Low and Intermediate Alloy Steel — Pipes |           |             |         |                          |             |           |                     |                    |                              |       |                                                                            |      |  |
| 3Cr–1Mo                                  | A335      | P21         | K31545  | ...                      | ...         | 5A        | ...                 | –20                | 60                           | 30    | 20.0                                                                       | 18.7 |  |
| 3Cr–1Mo                                  | A369      | FP21        | K31545  | ...                      | ...         | 5A        | ...                 | –20                | 60                           | 30    | 20.0                                                                       | 18.7 |  |
| 3Cr–1Mo<br>A387 Gr. 21 Cl. 1             | A691      | 3CR         | K31545  | ...                      | ...         | 5A        | (11) (67)           | –20                | 60                           | 30    | 20.0                                                                       | 18.5 |  |
| 2¼Cr–1Mo<br>A387 Gr. 22 Cl. 1            | A691      | 2¼CR        | K21590  | ...                      | ...         | 5A        | (11) (67) (72) (75) | –20                | 60                           | 30    | 20.0                                                                       | 18.7 |  |
| 2¼Cr–1Mo                                 | A369      | FP22        | K21590  | ...                      | ...         | 5A        | (72) (75)           | –20                | 60                           | 30    | 20.0                                                                       | 18.7 |  |
| 2¼Cr–1Mo                                 | A335      | P22         | K21590  | ...                      | ...         | 5A        | (72) (75)           | –20                | 60                           | 30    | 20.0                                                                       | 18.7 |  |
| 2Ni–1Cu                                  | A333      | 9           | K22035  | ...                      | ...         | 9A        | ...                 | –100               | 63                           | 46    | 21.0                                                                       | ...  |  |
| 2Ni–1Cu                                  | A334      | 9           | K22035  | ...                      | ...         | 9A        | ...                 | –100               | 63                           | 46    | 21.0                                                                       | ...  |  |
| 2¼Ni                                     | A333      | 7           | K21903  | ...                      | ...         | 9A        | ...                 | –100               | 65                           | 35    | 21.7                                                                       | 21.4 |  |
| 2¼Ni                                     | A334      | 7           | K21903  | ...                      | ...         | 9A        | ...                 | –100               | 65                           | 35    | 21.7                                                                       | 21.4 |  |
| 3½Ni                                     | A333      | 3           | K31918  | ...                      | ...         | 9B        | ...                 | –150               | 65                           | 35    | 21.7                                                                       | 21.4 |  |
| 3½Ni                                     | A334      | 3           | K31918  | ...                      | ...         | 9B        | ...                 | –150               | 65                           | 35    | 21.7                                                                       | 21.4 |  |
| C–½Mo                                    | A426      | CP1         | J12521  | ...                      | ...         | 3         | (10) (58)           | –20                | 65                           | 35    | 21.7                                                                       | 21.7 |  |
| C–½Mo A204 Gr. A                         | A672      | L65         | K11820  | ...                      | ...         | 3         | (11) (58) (67)      | –20                | 65                           | 37    | 21.7                                                                       | 21.7 |  |
| C–½Mo A204 Gr. A                         | A691      | CM-65       | K11820  | ...                      | ...         | 3         | (11) (58) (67)      | –20                | 65                           | 37    | 21.7                                                                       | 21.7 |  |
| 2¼Ni A203 Gr. B                          | A671      | CFB70       | K22103  | ...                      | ...         | 9A        | (11) (65) (67)      | –20                | 70                           | 40    | 23.3                                                                       | ...  |  |
| 3½Ni A203 Gr. E                          | A671      | CFE70       | K32018  | ...                      | ...         | 9B        | (11) (65) (67)      | –20                | 70                           | 40    | 23.3                                                                       | ...  |  |
| C–½Mo A204 Gr. B                         | A672      | L70         | K12020  | ...                      | ...         | 3         | (11) (58) (67)      | –20                | 70                           | 40    | 23.3                                                                       | 23.3 |  |
| C–½Mo A204 Gr. B                         | A691      | CM-70       | K12020  | ...                      | ...         | 3         | (11) (58) (67)      | –20                | 70                           | 40    | 23.3                                                                       | 23.3 |  |
| 1¼Cr–½Mo                                 | A426      | CP11        | J12072  | ...                      | ...         | 4         | (10)                | –20                | 70                           | 40    | 23.3                                                                       | 23.3 |  |
| 2¼Cr–1Mo                                 | A426      | CP22        | J21890  | ...                      | ...         | 5A        | (10) (72)           | –20                | 70                           | 40    | 23.3                                                                       | 23.3 |  |
| C–½Mo A204 Gr. C                         | A672      | L75         | K12320  | ...                      | ...         | 3         | (11) (58) (67)      | –20                | 75                           | 43    | 25.0                                                                       | 25.0 |  |
| C–½Mo A204 Gr. C                         | A691      | CM-75       | K12320  | ...                      | ...         | 3         | (11) (58) (67)      | –20                | 75                           | 43    | 25.0                                                                       | 25.0 |  |
| 9Cr–1Mo–V                                | A335      | P91         | K90901  | ...                      | ≤3 thk. 15E | 15E       | ...                 | –20                | 85                           | 60    | 28.3                                                                       | 28.3 |  |
| 9Cr–1Mo–V                                | A691      | 91          | K90901  | ...                      | ≤3 thk. 15E | 15E       | (11) (67)           | –20                | 85                           | 60    | 28.3                                                                       | 28.3 |  |
| 5Cr–½Mo                                  | A426      | CP5         | J42045  | ...                      | ...         | 5B        | (10)                | –20                | 90                           | 60    | 30.0                                                                       | 29.9 |  |
| 9Cr–1Mo                                  | A426      | CP9         | J82090  | ...                      | ...         | 5B        | (10)                | –20                | 90                           | 60    | 30.0                                                                       | 29.9 |  |
| 9Ni                                      | A333      | 8           | K81340  | ...                      | ...         | 11A       | (47)                | –320               | 100                          | 75    | 33.3                                                                       | 33.3 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, <i>S</i> , ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |                                                   | Type/ Spec. No. |
|------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|---------------------------------------------------|-----------------|
| 300                                                                                | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Low and Intermediate Alloy Steel — Pipes (Cont'd) |                 |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0  | 7.0   | 5.5   | 4.0   | 2.7   | 1.5   | P21                                               | A335            |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0  | 7.0   | 5.5   | 4.0   | 2.7   | 1.5   | FP21                                              | A369            |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 16.0 | 12.0 | 9.0  | 7.0   | 5.5   | 4.0   | 2.7   | 1.5   | 3CR                                               | A691            |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0   | 5.7   | 3.8   | 2.4   | 1.4   | 2 <sup>1</sup> / <sub>4</sub> CR                  | A691            |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0   | 5.7   | 3.8   | 2.4   | 1.4   | FP22                                              | A369            |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0   | 5.7   | 3.8   | 2.4   | 1.4   | P22                                               | A335            |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | 9                                                 | A333            |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | 9                                                 | A334            |
| 20.6                                                                               | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0  | 6.5  | 4.5  | 2.5   | 1.6   | 1.0   | ...   | ...   | 7                                                 | A333            |
| 20.6                                                                               | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0  | 6.5  | 4.5  | 2.5   | 1.6   | 1.0   | ...   | ...   | 7                                                 | A334            |
| 20.6                                                                               | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0  | 6.5  | 4.5  | 2.5   | 1.6   | 1.0   | ...   | ...   | 3                                                 | A333            |
| 20.6                                                                               | 19.9 | 18.9 | 17.5 | 16.7 | 15.7 | 13.9 | 11.4 | 9.0  | 6.5  | 4.5  | 2.5   | 1.6   | 1.0   | ...   | ...   | 3                                                 | A334            |
| 21.0                                                                               | 20.3 | 19.7 | 19.1 | 18.7 | 18.4 | 17.9 | 17.4 | 16.9 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | CP1                                               | A426            |
| 21.7                                                                               | 21.5 | 20.8 | 20.2 | 19.8 | 19.4 | 19.0 | 18.4 | 17.9 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | L65                                               | A672            |
| 21.7                                                                               | 21.5 | 20.8 | 20.2 | 19.8 | 19.4 | 19.0 | 18.4 | 17.9 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | CM-65                                             | A691            |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | CFB70                                             | A671            |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | CFE70                                             | A671            |
| 23.3                                                                               | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | L70                                               | A672            |
| 23.3                                                                               | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | CM-70                                             | A691            |
| 23.3                                                                               | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | CP11                                              | A426            |
| 22.6                                                                               | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 21.9 | 15.8 | 11.4 | 7.8   | 5.1   | 3.2   | 2.0   | 1.2   | CP22                                              | A426            |
| 25.0                                                                               | 25.0 | 24.2 | 23.4 | 23.0 | 22.6 | 22.0 | 21.4 | 20.7 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | L75                                               | A672            |
| 25.0                                                                               | 25.0 | 24.2 | 23.4 | 23.0 | 22.6 | 22.0 | 21.4 | 20.7 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | CM-75                                             | A691            |
| 28.3                                                                               | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0  | 14.0  | 10.3  | 7.0   | 4.3   | P91                                               | A335            |
| 28.3                                                                               | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0  | 14.0  | 10.3  | 7.0   | 4.3   | 91                                                | A691            |
| 29.1                                                                               | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 24.2 | 16.4 | 11.0 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | CP5                                               | A426            |
| 29.1                                                                               | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 24.2 | 16.4 | 11.0 | 7.4   | 5.0   | 3.8   | 2.2   | 1.5   | CP9                                               | A426            |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | 8                                                 | A333            |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                    | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes     | Min.<br>Temp.,<br>°F (6) | Specified Min. |       | Basic<br>Allowable<br>Stress, S,<br>ksi, at Metal<br>Temperature,<br>°F [Notes (1),<br>(4a)] |      |
|-------------------------------------------|--------------|----------------|------------|--------------------------------|--------------|--------------|-----------|--------------------------|----------------|-------|----------------------------------------------------------------------------------------------|------|
|                                           |              |                |            |                                |              |              |           |                          | Strength, ksi  |       | Min.<br>Temp.<br>to 100                                                                      | 200  |
|                                           |              |                |            |                                |              |              |           |                          | Tensile        | Yield |                                                                                              |      |
| Low and Intermediate Alloy Steel — Pipes  |              |                |            |                                |              |              |           |                          |                |       |                                                                                              |      |
| 9Ni                                       | A334         | 8              | K81340     | ...                            | ...          | 11A          | ...       | −320                     | 100            | 75    | 33.3                                                                                         | 33.3 |
| Low and Intermediate Alloy Steel — Plates |              |                |            |                                |              |              |           |                          |                |       |                                                                                              |      |
| ½Cr−½Mo                                   | A387         | 2              | K12143     | 1                              | ...          | 3            | ...       | −20                      | 55             | 33    | 18.3                                                                                         | 18.3 |
| 1Cr−½Mo                                   | A387         | 12             | K11757     | 1                              | ...          | 4            | ...       | −20                      | 55             | 33    | 18.3                                                                                         | 18.0 |
| 9Cr−1Mo                                   | A387         | 9              | K90941     | 1                              | ...          | 5B           | ...       | −20                      | 60             | 30    | 20.0                                                                                         | 18.1 |
| 1¼Cr−½Mo−Si                               | A387         | 11             | K11789     | 1                              | ...          | 4            | ...       | −20                      | 60             | 35    | 20.0                                                                                         | 20.0 |
| 5Cr−½Mo                                   | A387         | 5              | K41545     | 1                              | ...          | 5B           | ...       | −20                      | 60             | 30    | 20.0                                                                                         | 18.1 |
| 3Cr−1Mo                                   | A387         | 21             | K31545     | 1                              | ...          | 5A           | ...       | −20                      | 60             | 30    | 20.0                                                                                         | 18.3 |
| 2¼Cr−1Mo                                  | A387         | 22             | K21590     | 1                              | ...          | 5A           | (72)      | −20                      | 60             | 30    | 20.0                                                                                         | 18.7 |
| 2¼Ni                                      | A203         | A              | K21703     | ...                            | ...          | 9A           | (12) (65) | −20                      | 65             | 37    | 21.7                                                                                         | 21.7 |
| 3½Ni                                      | A203         | D              | K31718     | ...                            | ...          | 9B           | (12) (65) | −20                      | 65             | 37    | 21.7                                                                                         | 21.7 |
| C−½Mo                                     | A204         | A              | K11820     | ...                            | ...          | 3            | (58)      | −20                      | 65             | 37    | 21.7                                                                                         | 21.7 |
| 1Cr−½Mo                                   | A387         | 12             | K11757     | 2                              | ...          | 4            | ...       | −20                      | 65             | 40    | 21.7                                                                                         | 21.3 |
| 2¼Ni                                      | A203         | B              | K22103     | ...                            | ...          | 9A           | (12) (65) | −20                      | 70             | 40    | 23.3                                                                                         | 23.3 |
| 3½Ni                                      | A203         | E              | K32018     | ...                            | ...          | 9B           | (12) (65) | −20                      | 70             | 40    | 23.3                                                                                         | 23.3 |
| ½Cr−½Mo                                   | A387         | 2              | K12143     | 2                              | ...          | 3            | ...       | −20                      | 70             | 45    | 23.3                                                                                         | 23.3 |
| C−½Mo                                     | A204         | B              | K12020     | ...                            | ...          | 3            | (58)      | −20                      | 70             | 40    | 23.3                                                                                         | 23.3 |
| Mn−½Mo                                    | A302         | A              | K12021     | ...                            | ...          | 3            | ...       | −20                      | 75             | 45    | 25.0                                                                                         | 25.0 |
| C−½Mo                                     | A204         | C              | K12320     | ...                            | ...          | 3            | (58)      | −20                      | 75             | 43    | 25.0                                                                                         | 25.0 |
| 1¼Cr−½Mo−Si                               | A387         | 11             | K11789     | 2                              | ...          | 4            | ...       | −20                      | 75             | 45    | 25.0                                                                                         | 25.0 |
| 5Cr−½Mo                                   | A387         | 5              | K41545     | 2                              | ...          | 5B           | ...       | −20                      | 75             | 45    | 25.0                                                                                         | 24.9 |
| 3Cr−1Mo                                   | A387         | 21             | K31545     | 2                              | ...          | 5A           | ...       | −20                      | 75             | 45    | 25.0                                                                                         | 25.0 |
| 2¼Cr−1Mo                                  | A387         | 22             | K21590     | 2                              | ...          | 5A           | (72)      | −20                      | 75             | 45    | 25.0                                                                                         | 25.0 |
| Mn−½Mo                                    | A302         | B              | K12022     | ...                            | ...          | 3            | ...       | −20                      | 80             | 50    | 26.7                                                                                         | 26.7 |
| Mn−½Mo−½Ni                                | A302         | C              | K12039     | ...                            | ...          | 3            | ...       | −20                      | 80             | 50    | 26.7                                                                                         | 26.7 |
| Mn−½Mo−¾Ni                                | A302         | D              | K12054     | ...                            | ...          | 3            | ...       | −20                      | 80             | 50    | 26.7                                                                                         | 26.7 |
| 9Cr−1Mo−V                                 | A387         | 91             | K90901     | 2                              | ≤3 thk.      | 15E          | ...       | −20                      | 85             | 60    | 28.3                                                                                         | 28.3 |
| 8Ni                                       | A553         | II             | K71340     | ...                            | ...          | 11A          | (47)      | −275                     | 100            | 85    | 33.3                                                                                         | ...  |
| 5Ni−¼Mo                                   | A645         | A              | K41583     | ...                            | ...          | 11A          | ...       | −275                     | 95             | 65    | 31.7                                                                                         | 31.7 |
| 9Ni                                       | A553         | I              | K81340     | ...                            | ...          | 11A          | (47)      | −320                     | 100            | 85    | 33.3                                                                                         | 33.3 |
| 9Ni                                       | A353         | ...            | K81340     | ...                            | ...          | 11A          | (47)      | −320                     | 100            | 75    | 33.3                                                                                         | 33.3 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, <i>S</i> , ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |          | Type/ Spec. |
|------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|----------|-------------|
| 300                                                                                | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Grade    | No.         |
| Low and Intermediate Alloy Steel — Pipes (Cont'd)                                  |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |          |             |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | 8        | A334        |
| Low and Intermediate Alloy Steel — Plates                                          |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |          |             |
| 18.3                                                                               | 18.3 | 18.3 | 18.0 | 17.7 | 17.3 | 16.9 | 16.4 | 15.9 | 14.3 | 9.2  | 5.9   | ...   | ...   | ...   | ...   | 2 Cl. 1  | A387        |
| 17.6                                                                               | 17.6 | 17.2 | 16.8 | 16.5 | 16.3 | 16.0 | 15.7 | 15.4 | 15.0 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | 12 Cl. 1 | A387        |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 10.6 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | 9 Cl. 1  | A387        |
| 20.0                                                                               | 19.6 | 18.9 | 18.3 | 18.0 | 17.6 | 17.2 | 16.8 | 16.4 | 13.7 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | 11 Cl. 1 | A387        |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | 5 Cl. 1  | A387        |
| 17.5                                                                               | 17.0 | 16.6 | 16.2 | 16.0 | 15.8 | 15.5 | 15.2 | 14.9 | 12.0 | 9.0  | 7.0   | 5.5   | 4.0   | 2.7   | 1.5   | 21 Cl. 1 | A387        |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0   | 5.7   | 3.8   | 2.4   | 1.4   | 22 Cl. 1 | A387        |
| 21.7                                                                               | 21.1 | 20.0 | 18.5 | 17.6 | 16.6 | 13.9 | 11.4 | 9.0  | 6.5  | 4.5  | 2.5   | ...   | ...   | ...   | ...   | A        | A203        |
| 21.7                                                                               | 21.1 | 20.0 | 18.5 | 17.6 | 16.6 | 13.9 | 11.4 | 9.0  | 6.5  | 4.5  | 2.5   | ...   | ...   | ...   | ...   | D        | A203        |
| 21.7                                                                               | 21.5 | 20.8 | 20.2 | 19.8 | 19.4 | 19.0 | 18.4 | 17.9 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | A        | A204        |
| 20.8                                                                               | 20.8 | 20.8 | 20.3 | 20.0 | 19.7 | 19.4 | 19.1 | 18.6 | 18.0 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | 12 Cl. 2 | A387        |
| 23.3                                                                               | 22.8 | 21.6 | 20.0 | 19.0 | 16.9 | 13.9 | 11.4 | 9.0  | 6.5  | 4.5  | 2.5   | ...   | ...   | ...   | ...   | B        | A203        |
| 23.3                                                                               | 22.8 | 21.6 | 20.0 | 19.0 | 18.0 | 14.8 | 12.0 | 9.3  | 6.5  | 4.5  | 2.5   | ...   | ...   | ...   | ...   | E        | A203        |
| 23.3                                                                               | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.1 | 22.4 | 21.7 | 20.9 | 9.2  | 5.9   | ...   | ...   | ...   | ...   | 2 Cl. 2  | A387        |
| 23.3                                                                               | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | B        | A204        |
| 25.0                                                                               | 25.0 | 25.0 | 25.0 | 24.9 | 24.4 | 23.9 | 23.2 | 20.0 | 13.7 | 8.2  | 4.8   | ...   | ...   | ...   | ...   | A        | A302        |
| 25.0                                                                               | 25.0 | 24.2 | 23.4 | 23.0 | 22.6 | 22.0 | 21.4 | 20.7 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | C        | A204        |
| 25.0                                                                               | 25.0 | 24.4 | 23.5 | 23.1 | 22.6 | 22.2 | 21.6 | 20.2 | 13.7 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | 11 Cl. 2 | A387        |
| 24.2                                                                               | 24.0 | 24.0 | 23.6 | 23.2 | 22.7 | 16.5 | 16.0 | 15.1 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | 5 Cl. 2  | A387        |
| 24.2                                                                               | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 18.1 | 13.1 | 9.5  | 6.8   | 4.9   | 3.2   | 2.4   | 1.3   | 21 Cl. 2 | A387        |
| 24.3                                                                               | 24.1 | 24.0 | 23.8 | 23.6 | 23.4 | 23.0 | 22.5 | 21.9 | 15.8 | 11.4 | 7.8   | 5.1   | 3.2   | 2.0   | 1.2   | 22 Cl. 2 | A387        |
| 26.7                                                                               | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.5 | 25.7 | 20.0 | 13.7 | 8.2  | 4.8   | ...   | ...   | ...   | ...   | B        | A302        |
| 26.7                                                                               | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.5 | 25.7 | 20.0 | 13.7 | 8.2  | 4.8   | ...   | ...   | ...   | ...   | C        | A302        |
| 26.7                                                                               | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.5 | 25.7 | 20.0 | 13.7 | 8.2  | 4.8   | ...   | ...   | ...   | ...   | D        | A302        |
| 28.3                                                                               | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0  | 14.0  | 10.3  | 7.0   | 4.3   | 91 Cl. 2 | A387        |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | II       | A553        |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | A        | A645        |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | I        | A553        |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...      | A353        |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                                   | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes         | Min.<br>Temp.,<br>°F (6) | Specified Min.<br>Strength, ksi |       | Basic<br>Allowable<br>Stress, S,<br>ksi, at Metal<br>Temperature,<br>°F [Notes (1),<br>(4a)] |      |  |
|----------------------------------------------------------|--------------|----------------|------------|--------------------------------|--------------|--------------|---------------|--------------------------|---------------------------------|-------|----------------------------------------------------------------------------------------------|------|--|
|                                                          |              |                |            |                                |              |              |               |                          | Tensile                         | Yield | Min.<br>Temp.<br>to 100                                                                      | 200  |  |
|                                                          |              |                |            |                                |              |              |               |                          |                                 |       |                                                                                              |      |  |
| Low and Intermediate Alloy Steel — Forgings and Fittings |              |                |            |                                |              |              |               |                          |                                 |       |                                                                                              |      |  |
| C-½Mo                                                    | A234         | WP1            | K12821     | ...                            | ...          | 3            | (58)          | -20                      | 55                              | 30    | 18.3                                                                                         | 18.3 |  |
| 1Cr-½Mo                                                  | A182         | F12            | K11562     | 1                              | ...          | 4            | (9)           | -20                      | 60                              | 32    | 20.0                                                                                         | 19.3 |  |
| 1Cr-½Mo                                                  | A234         | WP12           | K12062     | 1                              | ...          | 4            | ...           | -20                      | 60                              | 32    | 20.0                                                                                         | 19.3 |  |
| 1¼Cr-½Mo-Si                                              | A182         | F11            | K11597     | 1                              | ...          | 4            | (9)           | -20                      | 60                              | 30    | 20.0                                                                                         | 18.5 |  |
| 1¼Cr-½Mo-Si                                              | A234         | WP11           | K11597     | 1                              | ...          | 4            | ...           | -20                      | 60                              | 30    | 20.0                                                                                         | 18.5 |  |
| 2¼Cr-1Mo                                                 | A182         | F22            | K21590     | 1                              | ...          | 5A           | (9) (72) (75) | -20                      | 60                              | 30    | 20.0                                                                                         | 18.7 |  |
| 2¼Cr-1Mo                                                 | A234         | WP22           | K21590     | 1                              | ...          | 5A           | (72)          | -20                      | 60                              | 30    | 20.0                                                                                         | 18.7 |  |
| 5Cr-½Mo                                                  | A234         | WP5            | K41545     | ...                            | ...          | 5B           | ...           | -20                      | 60                              | 30    | 20.0                                                                                         | 18.1 |  |
| 9Cr-1Mo                                                  | A234         | WP9            | K90941     | ...                            | ...          | 5B           | ...           | -20                      | 60                              | 30    | 20.0                                                                                         | 18.1 |  |
| 3½Ni                                                     | A420         | WPL3           | K31918     | ...                            | ...          | 9B           | ...           | -150                     | 65                              | 35    | 21.7                                                                                         | 21.4 |  |
| 3½Ni                                                     | A350         | LF3            | K32025     | ...                            | ...          | 9B           | (9)           | -150                     | 70                              | 37.5  | 23.3                                                                                         | 22.9 |  |
| ½Cr-½Mo                                                  | A182         | F2             | K12122     | ...                            | ...          | 3            | (9)           | -20                      | 70                              | 40    | 23.3                                                                                         | 23.3 |  |
| C-½Mo                                                    | A182         | F1             | K12822     | ...                            | ...          | 3            | (9) (58)      | -20                      | 70                              | 40    | 23.3                                                                                         | 23.3 |  |
| 1Cr-½Mo                                                  | A182         | F12            | K11564     | 2                              | ...          | 4            | (9)           | -20                      | 70                              | 40    | 23.3                                                                                         | 22.9 |  |
| 1Cr-½Mo                                                  | A234         | WP12           | K12062     | 2                              | ...          | 4            | ...           | -20                      | 70                              | 40    | 23.3                                                                                         | 22.9 |  |
| 1¼Cr-½Mo-Si                                              | A182         | F11            | K11572     | 2                              | ...          | 4            | (9)           | -20                      | 70                              | 40    | 23.3                                                                                         | 23.3 |  |
| 1¼Cr-½Mo-Si                                              | A234         | WP11           | K11572     | 2                              | ...          | 4            | ...           | -20                      | 70                              | 40    | 23.3                                                                                         | 23.3 |  |
| 5Cr-½Mo                                                  | A182         | F5             | K41545     | ...                            | ...          | 5B           | (9)           | -20                      | 70                              | 40    | 23.3                                                                                         | 23.3 |  |
| 3Cr-1Mo                                                  | A182         | F21            | K31545     | ...                            | ...          | 5A           | (9)           | -20                      | 75                              | 45    | 25.0                                                                                         | 25.0 |  |
| 2¼Cr-1Mo                                                 | A182         | F22            | K21590     | 3                              | ...          | 5A           | (9) (72)      | -20                      | 75                              | 45    | 25.0                                                                                         | 25.0 |  |
| 2¼Cr-1Mo                                                 | A234         | WP22           | K21590     | 3                              | ...          | 5A           | (72)          | -20                      | 75                              | 45    | 25.0                                                                                         | 25.0 |  |
| 9Cr-1Mo                                                  | A182         | F9             | K90941     | ...                            | ...          | 5B           | (9)           | -20                      | 85                              | 55    | 28.3                                                                                         | 28.3 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, <i>S</i> , ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |            | Type/ Spec. |
|------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|------------|-------------|
| 300                                                                                | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Grade      | No.         |
| Low and Intermediate Alloy Steel — Forgings and Fittings                           |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |            |             |
| 18.0                                                                               | 17.4 | 16.9 | 16.4 | 16.1 | 15.7 | 15.4 | 14.9 | 14.5 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | WP1        | A234        |
| 18.1                                                                               | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | F12 Cl. 1  | A182        |
| 18.1                                                                               | 17.3 | 16.7 | 16.3 | 16.0 | 15.8 | 15.5 | 15.3 | 14.9 | 14.5 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | WP12 Cl. 1 | A234        |
| 17.6                                                                               | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | F11 Cl. 1  | A182        |
| 17.6                                                                               | 16.8 | 16.2 | 15.7 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | WP11 Cl. 1 | A234        |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0   | 5.7   | 3.8   | 2.4   | 1.4   | F22 Cl. 1  | A182        |
| 18.2                                                                               | 18.0 | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | 17.7 | 17.1 | 13.6 | 10.8 | 8.0   | 5.7   | 3.8   | 2.4   | 1.4   | WP22 Cl. 1 | A234        |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | WP5        | A234        |
| 17.4                                                                               | 17.2 | 17.1 | 16.8 | 16.6 | 16.3 | 15.9 | 15.4 | 14.8 | 14.1 | 11.0 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | WP9        | A234        |
| 20.6                                                                               | 19.9 | 18.9 | 17.5 | 16.7 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | WPL3       | A420        |
| 22.1                                                                               | 21.4 | 20.3 | 18.8 | 17.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | LF3        | A350        |
| 23.3                                                                               | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 18.6 | 9.2  | 5.9   | ...   | ...   | ...   | ...   | F2         | A182        |
| 23.3                                                                               | 23.2 | 22.5 | 21.8 | 21.4 | 21.0 | 20.5 | 19.9 | 19.3 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | F1         | A182        |
| 22.4                                                                               | 21.7 | 20.9 | 20.3 | 20.0 | 19.7 | 19.4 | 19.1 | 18.6 | 18.0 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | F12 Cl. 2  | A182        |
| 22.4                                                                               | 21.7 | 20.9 | 20.3 | 20.0 | 19.7 | 19.4 | 19.1 | 18.6 | 18.0 | 11.3 | 7.2   | 4.5   | 2.8   | 1.8   | 1.1   | WP12 Cl. 2 | A234        |
| 23.3                                                                               | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | F11 Cl. 2  | A182        |
| 23.3                                                                               | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | WP11 Cl. 2 | A234        |
| 22.6                                                                               | 22.4 | 22.4 | 22.0 | 21.7 | 21.2 | 20.6 | 19.8 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | F5         | A182        |
| 24.3                                                                               | 24.1 | 24.0 | 23.8 | 23.6 | 23.4 | 23.0 | 22.5 | 18.1 | 13.1 | 9.5  | 6.8   | 4.9   | 3.2   | 2.4   | 1.3   | F21        | A182        |
| 24.2                                                                               | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 21.9 | 15.8 | 11.4 | 7.8   | 5.1   | 3.2   | 2.0   | 1.2   | F22 Cl. 3  | A182        |
| 24.2                                                                               | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 21.9 | 15.8 | 11.4 | 7.8   | 5.1   | 3.2   | 2.0   | 1.2   | WP22 Cl. 3 | A234        |
| 27.4                                                                               | 27.2 | 27.1 | 26.8 | 26.3 | 25.8 | 25.0 | 24.0 | 22.9 | 15.2 | 10.6 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | F9         | A182        |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                                              | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes    | Min.<br>Temp.,<br>°F (6) | Specified Min. |       | Basic                                                                               |      |
|---------------------------------------------------------------------|--------------|----------------|------------|--------------------------------|--------------|--------------|----------|--------------------------|----------------|-------|-------------------------------------------------------------------------------------|------|
|                                                                     |              |                |            |                                |              |              |          |                          | Strength, ksi  |       | Allowable<br>Stress, S,<br>ksi, at Metal<br>Temperature,<br>°F [Notes (1),<br>(4a)] |      |
|                                                                     |              |                |            |                                |              |              |          |                          | Tensile        | Yield | Min.<br>Temp.<br>to 100                                                             | 200  |
| Low and Intermediate Alloy Steel — Forgings and Fittings            |              |                |            |                                |              |              |          |                          |                |       |                                                                                     |      |
| 9Cr-1Mo-V                                                           | A182         | F91            | K90901     | ...                            | ≤3 thk.      | 15E          | ...      | -20                      | 85             | 60    | 28.3                                                                                | 28.3 |
| 9Cr-1Mo-V                                                           | A234         | WP91           | K90901     | ...                            | ≤3 thk.      | 15E          | ...      | -20                      | 85             | 60    | 28.3                                                                                | 28.3 |
| 5Cr- <sup>1</sup> / <sub>2</sub> Mo                                 | A182         | F5a            | K42544     | ...                            | ...          | 5B           | (9)      | -20                      | 90             | 65    | 30.0                                                                                | 29.9 |
| 9Ni                                                                 | A420         | WPL8           | K81340     | ...                            | ...          | 11A          | (47)     | -320                     | 100            | 75    | 33.3                                                                                | 33.3 |
| Low and Intermediate Alloy Steel — Castings                         |              |                |            |                                |              |              |          |                          |                |       |                                                                                     |      |
| C- <sup>1</sup> / <sub>2</sub> Mo                                   | A352         | LC1            | J12522     | ...                            | ...          | 3            | (9) (58) | -75                      | 65             | 35    | 21.7                                                                                | 21.7 |
| C- <sup>1</sup> / <sub>2</sub> Mo                                   | A217         | WC1            | J12524     | ...                            | ...          | 3            | (9) (58) | -20                      | 65             | 35    | 21.7                                                                                | 21.7 |
| 2 <sup>1</sup> / <sub>2</sub> Ni                                    | A352         | LC2            | J22500     | ...                            | ...          | 9A           | (9)      | -100                     | 70             | 40    | 23.3                                                                                | 23.3 |
| 3 <sup>1</sup> / <sub>2</sub> Ni                                    | A352         | LC3            | J31550     | ...                            | ...          | 9B           | (9)      | -150                     | 70             | 40    | 23.3                                                                                | 23.3 |
| 1Ni- <sup>1</sup> / <sub>2</sub> Cr- <sup>1</sup> / <sub>2</sub> Mo | A217         | WC4            | J12082     | ...                            | ...          | 4            | (9)      | -20                      | 70             | 40    | 23.3                                                                                | 23.3 |
| <sup>3</sup> / <sub>4</sub> Ni-1Mo- <sup>3</sup> / <sub>4</sub> Cr  | A217         | WC5            | J22000     | ...                            | ...          | 4            | (9)      | -20                      | 70             | 40    | 23.3                                                                                | 23.3 |
| 1 <sup>1</sup> / <sub>4</sub> Cr- <sup>1</sup> / <sub>2</sub> Mo    | A217         | WC6            | J12072     | ...                            | ...          | 4            | (9)      | -20                      | 70             | 40    | 23.3                                                                                | 23.3 |
| 2 <sup>1</sup> / <sub>4</sub> Cr-1Mo                                | A217         | WC9            | J21890     | ...                            | ...          | 5A           | (9)      | -20                      | 70             | 40    | 23.3                                                                                | 23.3 |
| 5Cr- <sup>1</sup> / <sub>2</sub> Mo                                 | A217         | C5             | J42045     | ...                            | ...          | 5B           | (9)      | -20                      | 90             | 60    | 30.0                                                                                | 29.9 |
| 9Cr-1Mo                                                             | A217         | C12            | J82090     | ...                            | ...          | 5B           | (9)      | -20                      | 90             | 60    | 30.0                                                                                | 29.9 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, <i>S</i> , ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       | Type/ Spec. |
|------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------------|
| 300                                                                                | 400  | 500  | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | Grade | No.         |
| <b>Low and Intermediate Alloy Steel — Forgings and Fittings (Cont'd)</b>           |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |             |
| 28.3                                                                               | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0  | 14.0  | 10.3  | 7.0   | 4.3   | F91   | A182        |
| 28.3                                                                               | 28.2 | 28.1 | 27.7 | 27.3 | 26.7 | 25.9 | 24.9 | 23.7 | 22.3 | 20.7 | 18.0  | 14.0  | 10.3  | 7.0   | 4.3   | WP91  | A234        |
| 29.1                                                                               | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | F5a   | A182        |
| ...                                                                                | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | WPL8  | A420        |
| <b>Low and Intermediate Alloy Steel — Castings</b>                                 |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |             |
| 21.0                                                                               | 20.3 | 19.7 | 19.1 | 18.7 | 18.4 | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | LC1   | A352        |
| 21.0                                                                               | 20.3 | 19.7 | 19.1 | 18.7 | 18.4 | 17.9 | 17.4 | 16.9 | 13.7 | 8.2  | 4.8   | 4.0   | 2.4   | ...   | ...   | WC1   | A217        |
| 23.3                                                                               | 22.8 | 21.6 | 20.0 | 19.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | LC2   | A352        |
| 23.3                                                                               | 22.8 | 21.6 | 20.0 | 19.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | LC3   | A352        |
| 23.3                                                                               | 23.3 | 23.0 | 22.4 | 22.1 | 21.7 | 21.2 | 20.6 | 19.8 | 14.3 | 9.2  | 5.9   | ...   | ...   | ...   | ...   | WC4   | A217        |
| 23.3                                                                               | 23.3 | 23.0 | 22.4 | 22.1 | 21.7 | 21.2 | 20.6 | 19.8 | 14.3 | 9.2  | 5.9   | 4.0   | 2.4   | ...   | ...   | WC5   | A217        |
| 23.3                                                                               | 22.5 | 21.7 | 20.9 | 20.5 | 20.1 | 19.7 | 19.2 | 18.7 | 13.7 | 9.3  | 6.3   | 4.2   | 2.8   | 1.9   | 1.2   | WC6   | A217        |
| 22.6                                                                               | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 21.9 | 15.8 | 11.4 | 7.8   | 5.1   | 3.2   | 2.0   | 1.2   | WC9   | A217        |
| 29.1                                                                               | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | C5    | A217        |
| 29.1                                                                               | 28.8 | 28.7 | 28.3 | 27.9 | 27.3 | 26.5 | 25.5 | 24.2 | 15.2 | 10.6 | 7.4   | 5.0   | 3.3   | 2.2   | 1.5   | C12   | A217        |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                           |              |           |             |         |                          |                                    |           |                     |                    |                              |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |
|-------------------------------------------|--------------|-----------|-------------|---------|--------------------------|------------------------------------|-----------|---------------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|
|                                           |              |           |             |         |                          |                                    |           |                     |                    |                              |       |                                                                            |      |      |      |
| Nominal Composition                       | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in.                          | P-No. (5) | Notes               | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Min. Temp.                                                                 |      |      |      |
|                                           |              |           |             |         |                          |                                    |           |                     |                    | Tensile                      | Yield | to 100                                                                     | 200  | 300  | 400  |
| Stainless Steel — Pipes and Tubes (3)(4a) |              |           |             |         |                          |                                    |           |                     |                    |                              |       |                                                                            |      |      |      |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A312      | TP321       | S32100  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (28)                | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A376      | TP321       | S32100  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (28) (36)           | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 |
| 18Cr–8Ni                                  | Tube         | A213      | TP304L      | S30403  | ...                      | ...                                | 8         | (14) (36)           | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.8 |
| 18Cr–8Ni                                  | Tube         | A269      | TP304L      | S30403  | ...                      | ...                                | 8         | (14) (36)           | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.8 |
| 18Cr–8Ni                                  | Tube         | A270      | TP304L      | S30403  | ...                      | ...                                | 8         | (14)                | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.8 |
| 18Cr–8Ni                                  | Pipe         | A312      | TP304L      | S30403  | ...                      | ...                                | 8         | ...                 | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.8 |
| 18Cr–8Ni                                  | Pipe         | A358      | 304L        | S30403  | ...                      | ...                                | 8         | (36)                | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.8 |
| 16Cr–12Ni–2Mo                             | Tube         | A213      | TP316L      | S31603  | ...                      | ...                                | 8         | (14) (36)           | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.7 |
| 16Cr–12Ni–2Mo                             | Tube         | A269      | TP316L      | S31603  | ...                      | ...                                | 8         | (14) (36)           | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.7 |
| 16Cr–12Ni–2Mo                             | Tube         | A270      | TP316L      | S31603  | ...                      | ...                                | 8         | (14)                | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.7 |
| 16Cr–12Ni–2Mo                             | Pipe         | A312      | TP316L      | S31603  | ...                      | ...                                | 8         | ...                 | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.7 |
| 16Cr–12Ni–2Mo                             | Pipe         | A358      | 316L        | S31603  | ...                      | ...                                | 8         | (36)                | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.7 |
| 16Cr–12Ni–2Mo–Ti                          | Tube         | A213      | TP316Ti     | S31635  | ...                      | ...                                | 8         | (30)                | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A312      | TP321       | S32100  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (28) (30)           | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A376      | TP321       | S32100  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (28) (30) (36)      | –425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A312      | TP321H      | S32109  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (30)                | –325               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A376      | TP321H      | S32109  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (30) (36)           | –325               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 |
| 25Cr–12Ni                                 | ...          | A451      | CPH8        | J93400  | ...                      | ...                                | 8         | (26) (28) (35)      | –325               | 65                           | 28    | 18.7                                                                       | 18.7 | 18.5 | 18.0 |
| 25Cr–20Ni                                 | ...          | A451      | CPK20       | J94202  | ...                      | ...                                | 8         | (12) (28) (35) (39) | –325               | 65                           | 28    | 18.7                                                                       | 18.7 | 18.5 | 18.0 |
| 11Cr–Ti                                   | Tube         | A268      | TP409       | S40900  | ...                      | ...                                | 7         | (35)                | –20                | 60                           | 30    | 20.0                                                                       | ...  | ...  | ...  |
| 18Cr–Ti                                   | Tube         | A268      | TP430Ti     | S43036  | ...                      | ...                                | 7         | (35) (49)           | –20                | 60                           | 40    | 20.0                                                                       | ...  | ...  | ...  |
| 16Cr–14Ni–2Mo                             | ...          | A451      | CPF10MC     | J92971  | ...                      | ...                                | 8         | (28)                | –325               | 70                           | 30    | 20.0                                                                       | ...  | ...  | ...  |
| 12Cr–Al                                   | Tube         | A268      | TP405       | S40500  | ...                      | ...                                | 7         | (35)                | –20                | 60                           | 30    | 20.0                                                                       | 20.0 | 19.6 | 19.3 |
| 13Cr                                      | Tube         | A268      | TP410       | S41000  | ...                      | ...                                | 6         | (35)                | –20                | 60                           | 30    | 20.0                                                                       | 20.0 | 19.6 | 19.3 |
| 17Cr                                      | Tube         | A268      | TP430       | S43000  | ...                      | ...                                | 7         | (35) (49)           | –20                | 60                           | 35    | 20.0                                                                       | 20.0 | 19.6 | 19.3 |
| 18Cr–13Ni–3Mo                             | Pipe         | A312      | TP317L      | S31703  | ...                      | ...                                | 8         | ...                 | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.9 |
| 25Cr–20Ni                                 | Pipe         | A312      | TP310S      | S31008  | ...                      | ...                                | 8         | (28) (35)           | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 25Cr–20Ni                                 | ...          | A358      | 310S        | S31008  | ...                      | ...                                | 8         | (28) (35) (36)      | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 25Cr–20Ni                                 | Pipe         | A409      | TP310S      | S31008  | ...                      | ...                                | 8         | (28) (31) (35) (36) | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A312      | TP321       | S32100  | ...                      | ≤ <sup>3</sup> / <sub>8</sub> thk. | 8         | (28)                | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                              | Wld. pipe    | A312      | TP321       | S32100  | ...                      | ...                                | 8         | (28)                | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                              | Wld. pipe    | A358      | 321         | S32100  | ...                      | ...                                | 8         | (28) (36)           | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                              | Smls. pipe   | A376      | TP321       | S32100  | ...                      | ≤ <sup>3</sup> / <sub>8</sub> thk. | 8         | (28) (36)           | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                              | Wld. pipe    | A409      | TP321       | S32100  | ...                      | ...                                | 8         | (28) (36)           | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 23Cr–12Ni                                 | Pipe         | A312      | TP309       | ...     | ...                      | ...                                | 8         | (28) (35) (39)      | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|----------------|--------------|
| <b>Stainless Steel — Pipes and Tubes (3)(4a)</b>                           |      |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |                |              |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321          | A312         |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321          | A376         |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0 | 6.3  | 5.1  | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L         | A213         |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0 | 6.3  | 5.1  | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L         | A269         |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0 | 6.3  | 5.1  | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L         | A270         |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0 | 6.3  | 5.1  | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | TP304L         | A312         |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0 | 6.3  | 5.1  | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | 304L           | A358         |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | 11.4 | 8.8 | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L         | A213         |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | 11.4 | 8.8 | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L         | A269         |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | 11.4 | 8.8 | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L         | A270         |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | 11.4 | 8.8 | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | TP316L         | A312         |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8 | 11.6 | 11.4 | 8.8 | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | 316L           | A358         |
| 17.8                                                                       | 16.8 | 16.5 | 16.2 | 16.1 | 15.9 | 15.8 | 15.7 | 15.5 | 15.3 | 15.1 | 12.3 | 9.8 | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | TP316Ti        | A213         |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1  | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321          | A312         |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1  | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321          | A376         |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1  | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321H         | A312         |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5 | 12.3 | 9.1  | 6.9 | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | TP321H         | A376         |
| 17.7                                                                       | 17.1 | 16.7 | 16.3 | 15.9 | 15.4 | 14.9 | 14.4 | 13.9 | 11.1 | 8.5  | 6.5  | 5.0 | 3.8 | 2.9 | 2.3 | 1.8 | 1.3 | 0.9 | 0.8 | CPH8           | A451         |
| 17.7                                                                       | 17.1 | 16.7 | 16.3 | 15.9 | 15.4 | 14.9 | 14.4 | 13.9 | 11.3 | 9.8  | 8.5  | 7.3 | 6.0 | 4.8 | 3.5 | 2.4 | 1.6 | 1.1 | 0.8 | CPK20          | A451         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | TP409          | A268         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | TP430Ti        | A268         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | CPF10MC        | A451         |
| 19.0                                                                       | 18.5 | 18.1 | 17.7 | 17.1 | 16.4 | 15.6 | 14.3 | 8.4  | 4.0  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | TP405          | A268         |
| 19.0                                                                       | 18.5 | 18.1 | 17.7 | 17.1 | 16.4 | 15.6 | 12.3 | 8.8  | 6.4  | 4.4  | 2.9  | 1.8 | 1.0 | ... | ... | ... | ... | ... | ... | TP410          | A268         |
| 19.0                                                                       | 18.5 | 18.1 | 17.7 | 17.1 | 16.4 | 15.6 | 12.0 | 9.2  | 6.5  | 4.5  | 3.2  | 2.4 | 1.8 | ... | ... | ... | ... | ... | ... | TP430          | A268         |
| 17.7                                                                       | 16.9 | 16.5 | 16.2 | 15.8 | 15.5 | 15.2 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | TP317L         | A312         |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 15.9 | 9.9  | 7.1  | 5.0  | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | TP310S         | A312         |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 15.9 | 9.9  | 7.1  | 5.0  | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | 310S           | A358         |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 15.9 | 9.9  | 7.1  | 5.0  | 3.6 | 2.5 | 1.5 | 0.8 | 0.5 | 0.4 | 0.3 | 0.2 | TP310S         | A409         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321          | A312         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321          | A312         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | 321            | A358         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321          | A376         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | TP321          | A409         |
| 19.4                                                                       | 18.8 | 18.5 | 18.2 | 18.0 | 17.7 | 17.5 | 17.2 | 16.9 | 13.8 | 10.3 | 7.6  | 5.5 | 4.0 | 3.0 | 2.2 | 1.7 | 1.3 | 1.0 | 0.8 | TP309          | A312         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                           |              |           |            |         |                      |           |           |                          |                    |                              |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |
|-------------------------------------------|--------------|-----------|------------|---------|----------------------|-----------|-----------|--------------------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|
| Nominal Composition                       | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size, in. | P-No. (5) | Notes                    | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Min. Temp. to 100                                                          | 200  | 300  | 400  |
|                                           |              |           |            |         |                      |           |           |                          |                    | Tensile                      | Yield |                                                                            |      |      |      |
| Stainless Steel — Pipes and Tubes (3)(4a) |              |           |            |         |                      |           |           |                          |                    |                              |       |                                                                            |      |      |      |
| 23Cr-12Ni                                 | ...          | A358      | 309S       | S30908  | ...                  | ...       | 8         | (28) (31) (35) (36)      | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-8Ni                                  | ...          | A451      | CPF8       | J92600  | ...                  | ...       | 8         | (26) (28)                | -425               | 70                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr-10Ni-Cb                              | Pipe         | A312      | TP347      | S34700  | ...                  | ...       | 8         | ...                      | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | Pipe         | A358      | 347        | S34700  | ...                  | ...       | 8         | (30) (36)                | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | Pipe         | A376      | TP347      | S34700  | ...                  | ...       | 8         | (30) (36)                | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | Pipe         | A409      | TP347      | S34700  | ...                  | ...       | 8         | (30) (36)                | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | Pipe         | A312      | TP348      | S34800  | ...                  | ...       | 8         | ...                      | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | Pipe         | A358      | 348        | S34800  | ...                  | ...       | 8         | (30) (36)                | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | Pipe         | A376      | TP348      | S34800  | ...                  | ...       | 8         | (30) (36)                | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | Pipe         | A409      | TP348      | S34800  | ...                  | ...       | 8         | (30) (36)                | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 25Cr-12Ni                                 | ...          | A451      | CPH10      | J93402  | ...                  | ...       | 8         | (12) (14) (28) (35) (39) | -325               | 70                           | 30    | 20.0                                                                       | 20.0 | 19.9 | 19.4 |
| 25Cr-12Ni                                 | ...          | A451      | CPH20      | J93402  | ...                  | ...       | 8         | (12) (14) (28) (35) (39) | -325               | 70                           | 30    | 20.0                                                                       | 20.0 | 19.9 | 19.4 |
| 25Cr-20Ni                                 | Pipe         | A312      | TP310H     | S31009  | ...                  | ...       | 8         | (29) (35) (39)           | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Cb                              | ...          | A451      | CPF8C      | J92710  | ...                  | ...       | 8         | (28)                     | -325               | 70                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr-10Ni-Ti                              | Smls. pipe   | A312      | TP321      | S32100  | ...                  | ≤3⁄8 thk. | 8         | (28) (30)                | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Wld. pipe    | A312      | TP321      | S32100  | ...                  | ...       | 8         | (28) (30)                | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Wld. pipe    | A358      | 321        | S32100  | ...                  | ...       | 8         | (28) (30) (36)           | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Smls. pipe   | A376      | TP321      | S32100  | ...                  | ≤3⁄8 thk. | 8         | (28) (30) (36)           | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Wld. pipe    | A409      | TP321      | S32100  | ...                  | ...       | 8         | (28) (30) (36)           | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Smls. pipe   | A312      | TP321H     | S32109  | ...                  | ≤3⁄8 thk. | 8         | (30)                     | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Wld. pipe    | A312      | TP321H     | S32109  | ...                  | ...       | 8         | (30)                     | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Wld. pipe    | A358      | 321H       | S32109  | ...                  | ...       | 8         | (30) (36)                | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr-10Ni-Ti                              | Smls. pipe   | A376      | TP321H     | S32109  | ...                  | ≤3⁄8 thk. | 8         | (30) (36)                | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 16Cr-12Ni-2Mo                             | Tube         | A213      | TP316      | S31600  | ...                  | ...       | 8         | (14) (26) (28) (31) (36) | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 16Cr-12Ni-2Mo                             | Tube         | A269      | TP316      | S31600  | ...                  | ...       | 8         | (14) (26) (28) (31) (36) | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 16Cr-12Ni-2Mo                             | Tube         | A270      | TP316      | S31600  | ...                  | ...       | 8         | (14) (26) (28)           | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 16Cr-12Ni-2Mo                             | Pipe         | A312      | TP316      | S31600  | ...                  | ...       | 8         | (26) (28)                | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 16Cr-12Ni-2Mo                             | Pipe         | A358      | 316        | S31600  | ...                  | ...       | 8         | (26) (28) (31) (36)      | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 16Cr-12Ni-2Mo                             | Pipe         | A376      | TP316      | S31600  | ...                  | ...       | 8         | (26) (28) (31) (36)      | -425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       | Type/<br>Grade                                     | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------------------------------------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Stainless Steel — Pipes and Tubes (3)(4a) (Cont'd) |              |
| 19.4                                                                       | 18.8 | 18.5 | 18.2 | 18.0 | 17.7 | 17.5 | 17.2 | 16.9 | 13.8  | 10.3  | 7.6   | 5.5   | 4.0   | 3.0   | 2.2   | 1.7   | 1.3   | 1.0   | 0.8   | 309S                                               | A358         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 12.2  | 9.5   | 7.5   | 6.0   | 4.8   | 3.9   | 3.3   | 2.7   | 2.3   | 2.0   | 1.7   | CPF8                                               | A451         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | TP347                                              | A312         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | 347                                                | A358         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | TP347                                              | A376         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | TP347                                              | A409         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | TP348                                              | A312         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | 348                                                | A358         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | TP348                                              | A376         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | TP348                                              | A409         |
| 18.9                                                                       | 18.3 | 17.9 | 17.5 | 17.0 | 16.5 | 16.0 | 15.4 | 14.9 | 11.1  | 8.5   | 6.5   | 5.0   | 3.8   | 2.9   | 2.3   | 1.8   | 1.3   | 0.9   | 0.8   | CPH10                                              | A451         |
| 18.9                                                                       | 18.3 | 17.9 | 17.5 | 17.0 | 16.5 | 16.0 | 15.4 | 14.9 | 11.1  | 8.5   | 6.5   | 5.0   | 3.8   | 2.9   | 2.3   | 1.8   | 1.3   | 0.9   | 0.8   | CPH20                                              | A451         |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 16.7 | 13.8  | 10.3  | 7.6   | 5.5   | 4.0   | 3.0   | 2.2   | 1.7   | 1.3   | 1.0   | 0.8   | TP310H                                             | A312         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | CPF8C                                              | A451         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | TP321                                              | A312         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | TP321                                              | A312         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | 321                                                | A358         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | TP321                                              | A376         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | TP321                                              | A409         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | TP321H                                             | A312         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | TP321H                                             | A312         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | 321H                                               | A358         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | TP321H                                             | A376         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316                                              | A213         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316                                              | A269         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316                                              | A270         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316                                              | A312         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | 316                                                | A358         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316                                              | A376         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                           |              |           |             |         |                          |           |           |                          |                    |                              |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |
|-------------------------------------------|--------------|-----------|-------------|---------|--------------------------|-----------|-----------|--------------------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|
| Nominal Composition                       | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes                    | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Min. Temp. to 100                                                          |      |      |      |
|                                           |              |           |             |         |                          |           |           |                          |                    | Tensile                      | Yield | 200                                                                        | 300  | 400  |      |
| Stainless Steel — Pipes and Tubes (3)(4a) |              |           |             |         |                          |           |           |                          |                    |                              |       |                                                                            |      |      |      |
| 16Cr–12Ni–2Mo                             | Pipe         | A409      | TP316       | S31600  | ...                      | ...       | 8         | (26) (28) (31) (36)      | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 18Cr–13Ni–3Mo                             | Pipe         | A312      | TP317       | S31700  | ...                      | ...       | 8         | (26) (28)                | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 18Cr–13Ni–3Mo                             | Pipe         | A409      | TP317       | S31700  | ...                      | ...       | 8         | (26) (28) (31) (36)      | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 16Cr–12Ni–2Mo                             | Pipe         | A376      | TP316H      | S31609  | ...                      | ...       | 8         | (26) (31) (36)           | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 16Cr–12Ni–2Mo                             | Pipe         | A312      | TP316H      | S31609  | ...                      | ...       | 8         | (26)                     | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 19.3 |
| 18Cr–10Ni–Cb                              | Pipe         | A376      | TP347H      | S34709  | ...                      | ...       | 8         | (30) (36)                | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A312      | TP347       | S34700  | ...                      | ...       | 8         | (28)                     | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A358      | 347         | S34700  | ...                      | ...       | 8         | (28) (30) (36)           | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A376      | TP347       | S34700  | ...                      | ...       | 8         | (28) (30) (36)           | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A409      | TP347       | S34700  | ...                      | ...       | 8         | (28) (30) (36)           | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A312      | TP348       | S34800  | ...                      | ...       | 8         | (28)                     | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A358      | 348         | S34800  | ...                      | ...       | 8         | (28) (30) (36)           | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A376      | TP348       | S34800  | ...                      | ...       | 8         | (28) (30) (36)           | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A409      | TP348       | S34800  | ...                      | ...       | 8         | (28) (30) (36)           | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A312      | TP347H      | S34709  | ...                      | ...       | 8         | ...                      | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                              | Pipe         | A312      | TP348H      | S34809  | ...                      | ...       | 8         | ...                      | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 |
| 18Cr–8Ni                                  | Tube         | A213      | TP304       | S30400  | ...                      | ...       | 8         | (14) (26) (28) (31) (36) | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Tube         | A269      | TP304       | S30400  | ...                      | ...       | 8         | (14) (26) (28) (31) (36) | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Tube         | A270      | TP304       | S30400  | ...                      | ...       | 8         | (14) (26) (28)           | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Pipe         | A312      | TP304       | S30400  | ...                      | ...       | 8         | (26) (28)                | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Pipe         | A358      | 304         | S30400  | ...                      | ...       | 8         | (26) (28) (31) (36)      | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Pipe         | A376      | TP304       | S30400  | ...                      | ...       | 8         | (20) (26) (28) (31) (36) | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Pipe         | A376      | TP304H      | S30409  | ...                      | ...       | 8         | (26) (31) (36)           | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Pipe         | A409      | TP304       | S30400  | ...                      | ...       | 8         | (26) (28) (31) (36)      | –425               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–8Ni                                  | Pipe         | A312      | TP304H      | S30409  | ...                      | ...       | 8         | (26)                     | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 18.6 |
| 18Cr–12Ni–2Mo                             | ...          | A451      | CPF8M       | J92900  | ...                      | ...       | 8         | (26) (28)                | –425               | 70                           | 30    | 20.0                                                                       | 20.0 | 18.9 | 17.0 |
| 44Fe–25Ni–21Cr–Mo                         | Tube         | A249      | ...         | N08904  | ...                      | ...       | 45        | ...                      | –325               | 71                           | 31    | 20.7                                                                       | 20.7 | 20.4 | 18.7 |
| 44Fe–25Ni–21Cr–Mo                         | Pipe         | A312      | ...         | N08904  | ...                      | ...       | 45        | ...                      | –325               | 71                           | 31    | 20.7                                                                       | 20.7 | 20.4 | 18.7 |
| 20Cr–Cu                                   | Tube         | A268      | TP443       | S44300  | ...                      | ...       | a         | (7) (35)                 | –20                | 70                           | 40    | 23.3                                                                       | 23.3 | 23.3 | 23.3 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |        | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|----------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 |        |                |              |
| Stainless Steel — Pipes and Tubes (3)(4a) (Cont'd)                         |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |        |                |              |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316  | A409           |              |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP317  | A312           |              |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP317  | A409           |              |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316H | A376           |              |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | TP316H | A312           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP347H | A376           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP347  | A312           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | 347    | A358           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP347  | A376           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP347  | A409           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP348  | A312           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | 348    | A358           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP348  | A376           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP348  | A409           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP347H | A312           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | TP348H | A312           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304  | A213           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304  | A269           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304  | A270           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304  | A312           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | 304    | A358           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304  | A376           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304H | A376           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304  | A409           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | TP304H | A312           |              |
| 15.8                                                                       | 15.0 | 14.7 | 14.4 | 14.2 | 14.1 | 13.9 | 13.7 | 13.4 | 13.1  | 11.5  | 8.9   | 6.9   | 5.4   | 4.3   | 3.4   | 2.8   | 2.3   | 1.9   | 1.6   | CPF8M  | A451           |              |
| 17.1                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A249           |              |
| 17.1                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A312           |              |
| 23.3                                                                       | 23.3 | 14.6 | 12.5 | 10.7 | 9.2  | 7.9  | 5.9  | 4.0  | 2.5   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | TP443  | A268           |              |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                           |                   |           |             |         |                          |                                     |           |           |                    |                              |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |
|-------------------------------------------|-------------------|-----------|-------------|---------|--------------------------|-------------------------------------|-----------|-----------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|
| Nominal Composition                       | Product Form      | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in.                           | P-No. (5) | Notes     | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Min. Temp. to 100                                                          |      |      |      |
|                                           |                   |           |             |         |                          |                                     |           |           |                    | Tensile                      | Yield | 200                                                                        | 300  | 400  |      |
| Stainless Steel — Pipes and Tubes (3)(4a) |                   |           |             |         |                          |                                     |           |           |                    |                              |       |                                                                            |      |      |      |
| 27Cr                                      | Tube              | A268      | TP446-1     | S44600  | ...                      | ...                                 | 10I       | (35)      | −20                | 70                           | 40    | 23.3                                                                       | 23.3 | 22.5 | 21.9 |
| 12Cr                                      | Wld. pipe         | A1053     | 50          | S41003  | ...                      | ...                                 | 7         | ...       | −20                | 70                           | 50    | 23.3                                                                       | 23.3 | 23.3 | 22.8 |
| 25Cr−8Ni−N                                | ...               | A451      | CPE20N      | J92802  | ...                      | ...                                 | 8         | (35) (39) | −325               | 80                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 |
| 23Cr−4Ni−Mo−Cu−N                          | ...               | A789      | ...         | S32304  | ...                      | ...                                 | 10H       | (25)      | −60                | 87                           | 58    | 29.0                                                                       | 27.9 | 26.1 | 24.7 |
| 23Cr−4Ni−Mo−Cu−N                          | ...               | A790      | ...         | S32304  | ...                      | ...                                 | 10H       | (25)      | −60                | 87                           | 58    | 29.0                                                                       | 27.9 | 26.1 | 24.7 |
| 23Cr−4Ni−Mo−Cu−N                          | Wld. pipe         | A928      | 2304        | S32304  | ...                      | ...                                 | 10H       | (25)      | −60                | 87                           | 58    | 29.0                                                                       | 27.9 | 26.1 | 24.7 |
| 20Cr−18Ni−6Mo                             | Pipe              | A813      | ...         | S31254  | ...                      | ...                                 | 8         | ...       | −325               | 94                           | 44    | 29.3                                                                       | 29.3 | 28.9 | 26.7 |
| 20Cr−18Ni−6Mo                             | Pipe              | A814      | ...         | S31254  | ...                      | ...                                 | 8         | ...       | −325               | 94                           | 44    | 29.3                                                                       | 29.3 | 28.9 | 26.7 |
| 13Cr                                      | ...               | A426      | CPCA15      | J91150  | ...                      | ...                                 | 6         | (10) (35) | −20                | 90                           | 65    | 30.0                                                                       | ...  | ...  | ...  |
| 20Cr−18Ni−6Mo                             | Wld. pipe         | A358      | ...         | S31254  | ...                      | > <sup>3</sup> / <sub>16</sub>      | 8         | ...       | −325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.6 | 27.3 |
| 20Cr−18Ni−6Mo                             | Wld pipe          | A358      | ...         | S31254  | ...                      | ≤ <sup>3</sup> / <sub>16</sub>      | 8         | ...       | −325               | 100                          | 45    | 30.0                                                                       | 30.0 | 29.6 | 27.3 |
| 22Cr−5Ni−3Mo−N                            | ...               | A789      | ...         | S31803  | ...                      | ...                                 | 10H       | (25)      | −60                | 90                           | 65    | 30.0                                                                       | 30.0 | 28.9 | 27.8 |
| 22Cr−5Ni−3Mo−N                            | ...               | A790      | ...         | S31803  | ...                      | ...                                 | 10H       | (25)      | −60                | 90                           | 65    | 30.0                                                                       | 30.0 | 28.9 | 27.8 |
| 22Cr−5Ni−3Mo−N                            | Wld pipe          | A928      | ...         | S31803  | ...                      | ...                                 | 10H       | (25)      | −60                | 90                           | 65    | 30.0                                                                       | 30.0 | 28.9 | 27.8 |
| 20Cr−18Ni−6Mo                             | Tube              | A249      | ...         | S31254  | ...                      | > <sup>3</sup> / <sub>16</sub> thk. | 8         | ...       | −325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.5 | 27.3 |
| 20Cr−18Ni−6Mo                             | Tube              | A249      | ...         | S31254  | ...                      | ≤ <sup>3</sup> / <sub>16</sub> thk. | 8         | ...       | −325               | 98                           | 45    | 30.0                                                                       | 30.0 | 29.5 | 27.3 |
| 20Cr−18Ni−6Mo                             | Pipe              | A312      | ...         | S31254  | ...                      | > <sup>3</sup> / <sub>16</sub> thk. | 8         | ...       | −325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.5 | 27.3 |
| 20Cr−18Ni−6Mo                             | Pipe              | A312      | ...         | S31254  | ...                      | ≤ <sup>3</sup> / <sub>16</sub> thk. | 8         | ...       | −325               | 98                           | 45    | 30.0                                                                       | 30.0 | 29.5 | 27.3 |
| 26Cr−4Ni−Mo                               | ...               | A790      | ...         | S32900  | ...                      | ...                                 | 10H       | (25)      | −20                | 90                           | 70    | 30.0                                                                       | ...  | ...  | ...  |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Smls. & wld. pipe | A312      | ...         | N08367  | ...                      | > <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Wld. pipe         | A358      | ...         | N08367  | ...                      | > <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Wld. pipe         | A813      | ...         | N08367  | ...                      | > <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Wld. pipe         | A814      | ...         | N08367  | ...                      | > <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Smls. & wld. pipe | A312      | ...         | N08367  | ...                      | ≤ <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 29.6 |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Wld. pipe         | A358      | ...         | N08367  | ...                      | ≤ <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 29.6 |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Wld. pipe         | A813      | ...         | N08367  | ...                      | ≤ <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 29.6 |
| 46Fe−24Ni−21Cr−6Mo−Cu−N                   | Wld. pipe         | A814      | ...         | N08367  | ...                      | ≤ <sup>3</sup> / <sub>16</sub>      | 45        | (26)      | −325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 29.6 |
| 21Cr−5Mn−1½Ni−Cu−N                        | Tube              | A789      | ...         | S32101  | ...                      | > <sup>3</sup> / <sub>16</sub>      | 10H       | (25)      | −20                | 94                           | 65    | 31.3                                                                       | 31.3 | 29.8 | 28.5 |
| 21Cr−5Mn−1½Ni−Cu−N                        | Pipe              | A790      | ...         | S32101  | ...                      | > <sup>3</sup> / <sub>16</sub>      | 10H       | (25)      | −20                | 94                           | 65    | 31.3                                                                       | 31.3 | 29.8 | 28.5 |
| 22Cr−5Ni−3Mo−N                            | Tube              | A789      | 2205        | S32205  | ...                      | ...                                 | 10H       | (25)      | −60                | 95                           | 70    | 31.7                                                                       | 31.7 | 30.6 | 29.4 |
| 22Cr−5Ni−3Mo−N                            | Pipe              | A790      | 2205        | S32205  | ...                      | ...                                 | 10H       | (25)      | −60                | 95                           | 70    | 31.7                                                                       | 31.7 | 30.6 | 29.4 |
| 21Cr−5Mn−1½Ni−Cu−N                        | Tube              | A789      | ...         | S32101  | ...                      | ≤ <sup>3</sup> / <sub>16</sub>      | 10H       | (25)      | −20                | 101                          | 77    | 33.7                                                                       | 33.7 | 32.1 | 31.0 |
| 21Cr−5Mn−1½Ni−Cu−N                        | Pipe              | A790      | ...         | S32101  | ...                      | ≤ <sup>3</sup> / <sub>16</sub>      | 10H       | (25)      | −20                | 101                          | 77    | 33.7                                                                       | 33.7 | 32.1 | 31.0 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 |                |              |
| Stainless Steel — Pipes and Tubes (3)(4a) (Cont'd)                         |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |                |              |
| 21.5                                                                       | 20.9 | 20.6 | 20.2 | 19.7 | 19.1 | 18.4 | 17.5 | 16.4 | 15.1  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | TP446-1        | A268         |
| 22.1                                                                       | 21.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 50             | A1053        |
| 26.7                                                                       | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CPE20N         | A451         |
| 22.9                                                                       | 19.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A789         |
| 22.9                                                                       | 19.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A790         |
| 22.9                                                                       | 19.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 2304           | A928         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.8 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A813         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.8 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A814         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CPCA15         | A426         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 22.8 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A358         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 22.8 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A358         |
| 27.2                                                                       | 26.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A789         |
| 27.2                                                                       | 26.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A790         |
| 27.2                                                                       | 26.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A928         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A249         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A249         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A312         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A312         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A790         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A312         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A358         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A813         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A814         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A312         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A358         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A813         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A814         |
| 28.5                                                                       | 28.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A789         |
| 28.5                                                                       | 28.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A790         |
| 28.7                                                                       | 28.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 2205           | A789         |
| 28.7                                                                       | 28.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 2205           | A790         |
| 30.9                                                                       | 30.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A789         |
| 30.9                                                                       | 30.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...            | A790         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                             |                   |           |            |         |                      |             |           |                |                    |                              |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |
|---------------------------------------------|-------------------|-----------|------------|---------|----------------------|-------------|-----------|----------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|
| Nominal Composition                         | Product Form      | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size, in.   | P-No. (5) | Notes          | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Min. Temp. to 100                                                          |      |      |      |
|                                             |                   |           |            |         |                      |             |           |                |                    | Tensile                      | Yield | 200                                                                        | 300  | 400  |      |
| Stainless Steel — Pipes and Tubes (3)(4a)   |                   |           |            |         |                      |             |           |                |                    |                              |       |                                                                            |      |      |      |
| 21Cr-3½Ni-1¾Mo-N                            | ...               | A789      | ...        | S32003  | ...                  | >0.187 thk. | 10H       | (25)           | -60                | 95                           | 65    | 31.7                                                                       | 30.7 | 28.9 | 28.6 |
| 21Cr-3½Ni-1¾Mo-N                            | ...               | A790      | ...        | S32003  | ...                  | >0.187 thk. | 10H       | (25)           | -60                | 95                           | 65    | 31.7                                                                       | 30.7 | 28.9 | 28.6 |
| 21Cr-3½Ni-1¾Mo-N                            | Wld pipe          | A928      | ...        | S32003  | ...                  | >0.187 thk. | 10H       | (25)           | -60                | 95                           | 65    | 31.7                                                                       | 30.7 | 28.9 | 28.6 |
| 22Cr-5Ni-3Mo-N                              | Wld pipe          | A928      | 2205       | S32205  | ...                  | ...         | 10H       | (25)           | -60                | 95                           | 65    | 31.7                                                                       | 31.7 | 30.6 | 29.4 |
| 24Cr-4Ni-3Mn-1.5Mo-N                        | Smls. & wld. tube | A789      | ...        | S82441  | ...                  | ≥0.40 thk.  | 10H       | (25)           | -60                | 99                           | 70    | 32.9                                                                       | 32.9 | 32.9 | 32.9 |
| 24Cr-4Ni-3Mn-1.5Mo-N                        | Smls. & wld. pipe | A790      | ...        | S82441  | ...                  | ≥0.40 thk.  | 10H       | (25)           | -60                | 99                           | 70    | 32.9                                                                       | 32.9 | 32.9 | 32.9 |
| 21Cr-3½Ni-1¾Mo-N                            | ...               | A789      | ...        | S32003  | ...                  | ≤0.187 thk. | 10H       | (25)           | -60                | 100                          | 70    | 33.3                                                                       | 32.3 | 30.4 | 30.1 |
| 21Cr-3½Ni-1¾Mo-N                            | ...               | A790      | ...        | S32003  | ...                  | ≤0.187 thk. | 10H       | (25)           | -60                | 100                          | 70    | 33.3                                                                       | 32.3 | 30.4 | 30.1 |
| 21Cr-3½Ni-1¾Mo-N                            | Wld. pipe         | A928      | ...        | S32003  | ...                  | ≤0.187 thk. | 10H       | (25)           | -60                | 100                          | 70    | 33.3                                                                       | 32.3 | 30.4 | 30.1 |
| 24Cr-4Ni-3Mn-1.5Mo-N                        | Smls. & wld. tube | A789      | ...        | S82441  | ...                  | <0.40 thk.  | 10H       | (25)           | -60                | 107                          | 78    | 35.8                                                                       | 35.8 | 35.8 | 35.8 |
| 24Cr-4Ni-3Mn-1.5Mo-N                        | Smls. & wld. pipe | A790      | ...        | S82441  | ...                  | <0.40 thk.  | 10H       | (25)           | -60                | 107                          | 78    | 35.8                                                                       | 35.8 | 35.8 | 35.8 |
| 25Cr-8Ni-3Mo-W-Cu-N                         | ...               | A789      | ...        | S32760  | ...                  | ...         | 10H       | (25)           | -60                | 109                          | 80    | 36.3                                                                       | 35.9 | 34.4 | 34.0 |
| 25Cr-8Ni-3Mo-W-Cu-N                         | ...               | A790      | ...        | S32760  | ...                  | ...         | 10H       | (25)           | -60                | 109                          | 80    | 36.3                                                                       | 35.9 | 34.4 | 34.0 |
| 29Cr-6.5Ni-2Mo-N                            | Tube              | A789      | ...        | S32906  | ...                  | ≥0.40 thk.  | 10H       | (25)           | -60                | 109                          | 80    | 36.3                                                                       | 36.3 | 34.0 | 33.5 |
| 29Cr-6.5Ni-2Mo-N                            | Pipe              | A790      | ...        | S32906  | ...                  | ≥0.40 thk.  | 10H       | (25)           | -60                | 109                          | 80    | 36.3                                                                       | 36.3 | 34.0 | 33.5 |
| 24Cr-17Ni-6Mn-4½Mo-N                        | ...               | A358      | ...        | S34565  | ...                  | ...         | 8         | (36)           | -325               | 115                          | 60    | 38.3                                                                       | 38.1 | 35.8 | 34.5 |
| 25Cr-7Ni-4Mo-N                              | Smls. & wld. tube | A789      | ...        | S32750  | ...                  | ...         | 10H       | (25)           | -60                | 116                          | 80    | 38.7                                                                       | 38.5 | 36.4 | 35.1 |
| 25Cr-7Ni-4Mo-N                              | Smls. & wld. pipe | A790      | 2507       | S32750  | ...                  | ...         | 10H       | (25)           | -60                | 116                          | 80    | 38.7                                                                       | 38.5 | 36.4 | 35.1 |
| 25Cr-7Ni-4Mo-N                              | Wld. pipe         | A928      | 2507       | S32750  | ...                  | ...         | 10H       | (25)           | -60                | 116                          | 80    | 38.7                                                                       | 38.5 | 36.4 | 35.1 |
| 29Cr-6.5Ni-2Mo-N                            | Tube              | A789      | ...        | S32906  | ...                  | <0.40 thk.  | 10H       | (25)           | -60                | 116                          | 94    | 38.7                                                                       | 38.6 | 36.8 | 35.6 |
| 29Cr-6.5Ni-2Mo-N                            | Pipe              | A790      | ...        | S32906  | ...                  | <0.40 thk.  | 10H       | (25)           | -60                | 116                          | 94    | 38.7                                                                       | 38.6 | 36.8 | 35.6 |
| Stainless Steel — Plates and Sheets (3)(4a) |                   |           |            |         |                      |             |           |                |                    |                              |       |                                                                            |      |      |      |
| 18Cr-11Ni                                   | ...               | A240      | 305        | S30500  | ...                  | ...         | 8         | (26) (36) (39) | -325               | 70                           | 25    | 16.7                                                                       | ...  | ...  | ...  |
| 12Cr-Al                                     | ...               | A240      | 405        | S40500  | ...                  | ...         | 7         | (35)           | -20                | 60                           | 25    | 16.7                                                                       | 15.3 | 14.8 | 14.5 |
| 18Cr-8Ni                                    | ...               | A240      | 304L       | S30403  | ...                  | ...         | 8         | (36)           | -425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.8 |
| 16Cr-12Ni-2Mo                               | ...               | A240      | 316L       | S31603  | ...                  | ...         | 8         | (36)           | -425               | 70                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 15.7 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |      | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|----------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 |      |                |              |
| Stainless Steel — Pipes and Tubes (3)(4a) (Cont'd)                         |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |      |                |              |
| 28.6                                                                       | 28.6 | 28.6 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A789           |              |
| 28.6                                                                       | 28.6 | 28.6 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A790           |              |
| 28.6                                                                       | 28.6 | 28.6 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A928           |              |
| 28.7                                                                       | 28.4 | 28.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | 2205           | A928         |
| 32.9                                                                       | 32.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A789 |                |              |
| 32.9                                                                       | 32.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A790 |                |              |
| 30.1                                                                       | 30.1 | 30.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A789           |              |
| 30.1                                                                       | 30.1 | 30.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A790           |              |
| 30.1                                                                       | 30.1 | 30.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A928           |              |
| 35.8                                                                       | 35.7 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A789           |              |
| 35.8                                                                       | 35.7 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A790           |              |
| 34.0                                                                       | 34.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A789           |              |
| 34.0                                                                       | 34.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A790           |              |
| 33.0                                                                       | 33.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A789           |              |
| 33.0                                                                       | 33.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A790           |              |
| 33.8                                                                       | 33.2 | 33.1 | 32.7 | 32.4 | 32.0 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A358           |              |
| 34.5                                                                       | 34.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A789           |              |
| 34.5                                                                       | 34.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | 2507           | A790         |
| 34.5                                                                       | 34.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | 2507           | A928         |
| 35.2                                                                       | 35.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A789           |              |
| 35.2                                                                       | 35.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | A790           |              |
| Stainless Steel — Plates and Sheets (3)(4a)                                |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |      |                |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | 305            | A240         |
| 14.3                                                                       | 14.0 | 13.8 | 13.5 | 13.1 | 12.6 | 12.0 | 11.3 | 8.4  | 4.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...  | 405            | A240         |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0  | 6.3   | 5.1   | 4.0   | 3.2   | 2.6   | 2.1   | 1.7   | 1.1   | 1.0   | 0.9   | 304L | A240           |              |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8  | 10.8  | 10.2  | 8.8   | 6.4   | 4.7   | 3.5   | 2.5   | 1.8   | 1.3   | 1.0   | 316L | A240           |              |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                      | Product<br>Form           | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size,<br>in.                        | P-No.<br>(5) | Notes                  | Min.<br>Temp.,<br>°F (6) | Specified Min.<br>Strength, ksi |       | Basic Allowable<br>Stress, S, ksi, at<br>Metal Temperature,<br>°F [Notes (1), (4a)] |      |      |      |
|---------------------------------------------|---------------------------|--------------|----------------|------------|--------------------------------|-------------------------------------|--------------|------------------------|--------------------------|---------------------------------|-------|-------------------------------------------------------------------------------------|------|------|------|
|                                             |                           |              |                |            |                                |                                     |              |                        |                          | Tensile                         | Yield | Min.<br>Temp.<br>to 100                                                             | 200  | 300  | 400  |
|                                             |                           |              |                |            |                                |                                     |              |                        |                          |                                 |       |                                                                                     |      |      |      |
| Stainless Steel — Plates and Sheets (3)(4a) |                           |              |                |            |                                |                                     |              |                        |                          |                                 |       |                                                                                     |      |      |      |
| 18Cr–8Ni                                    | ...                       | A240         | 302            | S30200     | ...                            | ...                                 | 8            | (26) (36)              | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 18.6 |
| 12Cr–1Ni                                    | ...                       | A1010        | 40             | S41003     | ...                            | ...                                 | 7            | ...                    | –20                      | 66                              | 40    | 22.0                                                                                | 22.0 | 22.0 | 21.5 |
| 12Cr–1Ni                                    | ...                       | A1010        | 50             | S41003     | ...                            | ...                                 | 7            | ...                    | –20                      | 70                              | 50    | 23.3                                                                                | 23.3 | 23.3 | 22.8 |
| 13Cr                                        | ...                       | A240         | 410S           | S41008     | ...                            | ...                                 | 7            | (35) (50)              | –20                      | 60                              | 30    | 20.0                                                                                | 18.4 | 17.8 | 17.4 |
| 13Cr                                        | ...                       | A240         | 410            | S41000     | ...                            | ...                                 | 6            | (35)                   | –20                      | 65                              | 30    | 20.0                                                                                | 18.4 | 17.8 | 17.4 |
| 15Cr                                        | ...                       | A240         | 429            | S42900     | ...                            | ...                                 | 6            | (35)                   | –20                      | 65                              | 30    | 20.0                                                                                | 18.4 | 17.8 | 17.4 |
| 17Cr                                        | ...                       | A240         | 430            | S43000     | ...                            | ...                                 | 7            | (35)                   | –20                      | 65                              | 30    | 20.0                                                                                | 18.4 | 17.8 | 17.4 |
| 18Cr–13Ni–3Mo                               | ...                       | A240         | 317L           | S31703     | ...                            | ...                                 | 8            | (36)                   | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 18.9 |
| 25Cr–20Ni                                   | ...                       | A240         | 310S           | S31008     | ...                            | ...                                 | 8            | (28) (31)<br>(35) (36) | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                                | Plate,<br>sheet,<br>strip | A240         | 321            | S32100     | ...                            | ...                                 | 8            | (28) (31)<br>(36)      | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 23Cr–12Ni                                   | ...                       | A240         | 309S           | S30908     | ...                            | ...                                 | 8            | (28) (35)<br>(36)      | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                                | ...                       | A240         | 347            | S34700     | ...                            | ...                                 | 8            | (36)                   | –425                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                                | ...                       | A240         | 348            | S34800     | ...                            | ...                                 | 8            | (36)                   | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 25Cr–20Ni                                   | ...                       | A240         | 310H           | S31009     | ...                            | ...                                 | 8            | (29) (35)<br>(39)      | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                                | Plate,<br>sheet,<br>strip | A240         | 321            | S32100     | ...                            | ...                                 | 8            | (28) (30)<br>(36)      | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Ti                                | Plate,<br>sheet,<br>strip | A240         | 321H           | S32109     | ...                            | ...                                 | 8            | (30) (36)              | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 16Cr–12Ni–2Mo                               | ...                       | A240         | 316            | S31600     | ...                            | ...                                 | 8            | (26) (28)<br>(36)      | –425                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 19.3 |
| 18Cr–13Ni–3Mo                               | ...                       | A240         | 317            | S31700     | ...                            | ...                                 | 8            | (26) (28)<br>(36)      | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 19.3 |
| 18Cr–10Ni–Cb                                | ...                       | A240         | 347            | S34700     | ...                            | ...                                 | 8            | (28) (36)              | –425                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 18Cr–10Ni–Cb                                | ...                       | A240         | 348            | S34800     | ...                            | ...                                 | 8            | (28) (36)              | –325                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 20.0 |
| 18Cr–8Ni                                    | ...                       | A240         | 304            | S30400     | ...                            | ...                                 | 8            | (26) (28)<br>(36)      | –425                     | 75                              | 30    | 20.0                                                                                | 20.0 | 20.0 | 18.6 |
| 44Fe–25Ni–21Cr–Mo                           | ...                       | A240         | 904L           | N08904     | ...                            | ...                                 | 45           | ...                    | –325                     | 71                              | 31    | 20.7                                                                                | 20.7 | 20.4 | 18.7 |
| 23Cr–4Ni–Mo–Cu–N                            | ...                       | A240         | 2304           | S32304     | ...                            | ...                                 | 10H          | (25)                   | –60                      | 87                              | 58    | 29.0                                                                                | 27.9 | 26.1 | 24.7 |
| 22Cr–5Ni–3Mo–N                              | ...                       | A240         | ...            | S31803     | ...                            | ...                                 | 10H          | (25)                   | –60                      | 90                              | 65    | 30.0                                                                                | 30.0 | 28.9 | 27.8 |
| 16Cr–4Ni–6Mn                                | ...                       | A240         | 201LN          | S20153     | ...                            | ...                                 | 8            | ...                    | –325                     | 95                              | 45    | 30.0                                                                                | 27.6 | 24.7 | 23.4 |
| 20Cr–18Ni–6Mo                               | ...                       | A240         | ...            | S31254     | ...                            | > <sup>3</sup> / <sub>16</sub> thk. | 8            | ...                    | –325                     | 95                              | 45    | 30.0                                                                                | 30.0 | 29.6 | 27.4 |
| 20Cr–18Ni–6Mo                               | ...                       | A240         | ...            | S31254     | ...                            | ≤ <sup>3</sup> / <sub>16</sub> thk. | 8            | ...                    | –325                     | 98                              | 45    | 30.0                                                                                | 30.0 | 29.6 | 27.4 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 |       |                |              |
| Stainless Steel — Plates and Sheets (3)(4a) (Cont'd)                       |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |                |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 302   | A240           |              |
| 20.8                                                                       | 20.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 40    | A1010          |              |
| 22.1                                                                       | 21.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 50    | A1010          |              |
| 17.2                                                                       | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.3 | 8.8  | 6.4   | 4.4   | 2.9   | 1.8   | 1.0   | ...   | ...   | ...   | ...   | ...   | ...   | 410S  | A240           |              |
| 17.2                                                                       | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.3 | 8.8  | 6.4   | 4.4   | 2.9   | 1.8   | 1.0   | ...   | ...   | ...   | ...   | ...   | ...   | 410   | A240           |              |
| 17.2                                                                       | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.0 | 9.2  | 6.5   | 4.5   | 3.2   | 2.4   | 1.8   | ...   | ...   | ...   | ...   | ...   | ...   | 429   | A240           |              |
| 17.2                                                                       | 16.8 | 16.6 | 16.2 | 15.7 | 15.1 | 14.4 | 12.0 | 9.2  | 6.5   | 4.5   | 3.2   | 2.4   | 1.8   | ...   | ...   | ...   | ...   | ...   | ...   | 430   | A240           |              |
| 17.7                                                                       | 16.9 | 16.5 | 16.2 | 15.8 | 15.5 | 15.2 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 317L  | A240           |              |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 15.9 | 9.9   | 7.1   | 5.0   | 3.6   | 2.5   | 1.5   | 0.8   | 0.5   | 0.4   | 0.3   | 0.2   | 310H  | A240           |              |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 9.6   | 6.9   | 5.0   | 3.6   | 2.6   | 1.7   | 1.1   | 0.8   | 0.5   | 0.3   | 321   | A240           |              |
| 19.4                                                                       | 18.8 | 18.5 | 18.2 | 18.0 | 17.7 | 17.5 | 17.2 | 16.9 | 13.8  | 10.3  | 7.6   | 5.5   | 4.0   | 3.0   | 2.2   | 1.7   | 1.3   | 1.0   | 0.8   | 309S  | A240           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | 347   | A240           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | 348   | A240           |              |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 16.7 | 13.8  | 10.3  | 7.6   | 5.5   | 4.0   | 3.0   | 2.2   | 1.7   | 1.3   | 1.0   | 0.8   | 310H  | A240           |              |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | 321   | A240           |              |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | 321H  | A240           |              |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | 316   | A240           |              |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | 317   | A240           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | 347   | A240           |              |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | 348   | A240           |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.4  | 9.8   | 7.7   | 6.1   | 4.7   | 3.7   | 2.9   | 2.3   | 1.8   | 1.4   | 304   | A240           |              |
| 17.1                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 904L  | A240           |              |
| 22.9                                                                       | 19.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 2304  | A240           |              |
| 27.2                                                                       | 26.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A240           |              |
| 23.0                                                                       | 22.9 | 22.8 | 22.6 | 22.3 | 21.8 | 21.5 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 201LN | A240           |              |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A240           |              |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A240           |              |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                                 |                |           |            |         |                         |                                     |           |                     |                    |         |       |      | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |                   |
|-------------------------------------------------|----------------|-----------|------------|---------|-------------------------|-------------------------------------|-----------|---------------------|--------------------|---------|-------|------|----------------------------------------------------------------------------|------|------|-------------------|
|                                                 |                |           |            |         |                         |                                     |           |                     |                    |         |       |      | Specified Min. Strength, ksi                                               |      |      | Min. Temp. to 100 |
| Nominal Composition                             | Product Form   | Spec. No. | Type/Grade | UNS No. | Class/Condition/ Temper | Size, in.                           | P-No. (5) | Notes               | Min. Temp., °F (6) | Tensile | Yield |      |                                                                            |      |      |                   |
| Stainless Steel — Plates and Sheets (3)(4a)     |                |           |            |         |                         |                                     |           |                     |                    |         |       |      |                                                                            |      |      |                   |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                         | Plate          | A240      | ...        | N08367  | ...                     | > <sup>3</sup> / <sub>16</sub>      | 45        | (26)                | -325               | 95      | 45    | 30.0 | 30.0                                                                       | 29.9 | 28.6 |                   |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                         | Sheet & strip  | A240      | ...        | N08367  | ...                     | ≤ <sup>3</sup> / <sub>16</sub>      | 45        | (26)                | -325               | 100     | 45    | 30.0 | 30.0                                                                       | 30.0 | 29.6 |                   |
| 21Cr-5Mn-1½Ni-Cu-N                              | ...            | A240      | ...        | S32101  | ...                     | > <sup>3</sup> / <sub>16</sub> thk. | 10H       | (25)                | -20                | 94      | 65    | 31.3 | 31.3                                                                       | 29.8 | 28.5 |                   |
| 24Cr-4Ni-3Mn-1.5Mo-N                            | ...            | A240      | ...        | S82441  | ...                     | ≥0.40 thk.                          | 10H       | (25)                | -60                | 99      | 70    | 32.9 | 32.9                                                                       | 32.9 | 32.9 |                   |
| 21Cr-5Mn-1½Ni-Cu-N                              | ...            | A240      | ...        | S32101  | ...                     | ≤ <sup>3</sup> / <sub>16</sub> thk. | 10H       | (25)                | -20                | 101     | 77    | 33.7 | 33.7                                                                       | 32.1 | 31.0 |                   |
| 22Cr-5Ni-3Mo-N                                  | ...            | A240      | 2205       | S32205  | ...                     | ...                                 | 10H       | (25)                | -60                | 95      | 65    | 31.7 | 31.7                                                                       | 30.6 | 29.4 |                   |
| 21Cr-3½Ni-1¾Mo-N                                | ...            | A240      | ...        | S32003  | ...                     | >0.187 thk.                         | 10H       | (25)                | -60                | 95      | 65    | 31.7 | 30.7                                                                       | 28.9 | 28.6 |                   |
| 21Cr-3½Ni-1¾Mo-N                                | ...            | A240      | ...        | S32003  | ...                     | ≤0.187 thk.                         | 10H       | (25)                | -60                | 100     | 70    | 33.3 | 32.3                                                                       | 30.4 | 30.1 |                   |
| 24Cr-4Ni-3Mn-1.5Mo-N                            | ...            | A240      | ...        | S82441  | ...                     | <0.40 thk.                          | 10H       | (25)                | -60                | 107     | 78    | 35.8 | 35.8                                                                       | 35.8 | 35.8 |                   |
| 29Cr-6.5Ni-2Mo-N                                | ...            | A240      | ...        | S32906  | ...                     | ≥0.40 thk.                          | 10H       | (25)                | -60                | 109     | 80    | 36.3 | 36.3                                                                       | 34.5 | 33.5 |                   |
| 29Cr-6.5Ni-2Mo-N                                | ...            | A240      | ...        | S32906  | ...                     | <0.40 thk.                          | 10H       | (25)                | -60                | 116     | 94    | 38.7 | 38.6                                                                       | 36.8 | 35.6 |                   |
| 25Cr-8Ni-3Mo-W-Cu-N                             | ...            | A240      | ...        | S32760  | ...                     | ...                                 | 10H       | (25)                | -60                | 109     | 80    | 36.3 | 36.3                                                                       | 34.8 | 34.0 |                   |
| 25Cr-7Ni-4Mo-N                                  | ...            | A240      | 2507       | S32750  | ...                     | ...                                 | 10H       | (25)                | -60                | 116     | 80    | 38.7 | 38.5                                                                       | 36.4 | 35.1 |                   |
| Stainless Steel — Forgings and Fittings (3)(4a) |                |           |            |         |                         |                                     |           |                     |                    |         |       |      |                                                                            |      |      |                   |
| 18Cr-13Ni-3Mo                                   | ...            | A182      | F317L      | S31703  | ...                     | ≤5 thk.                             | 8         | (9) (21a)           | -325               | 70      | 25    | 16.7 | 16.7                                                                       | 16.7 | 15.7 |                   |
| 18Cr-8Ni                                        | ...            | A182      | F304L      | S30403  | ...                     | ...                                 | 8         | (9) (21a)           | -425               | 70      | 25    | 16.7 | 16.7                                                                       | 16.7 | 15.8 |                   |
| 18Cr-8Ni                                        | ...            | A403      | WP304L     | S30403  | ...                     | ...                                 | 8         | (32) (37)           | -425               | 70      | 25    | 16.7 | 16.7                                                                       | 16.7 | 15.8 |                   |
| 16Cr-12Ni-2Mo                                   | ...            | A182      | F316L      | S31603  | ...                     | ...                                 | 8         | (9) (21a)           | -425               | 70      | 25    | 16.7 | 16.7                                                                       | 16.7 | 15.7 |                   |
| 16Cr-12Ni-2Mo                                   | ...            | A403      | WP316L     | S31603  | ...                     | ...                                 | 8         | (32) (37)           | -425               | 70      | 25    | 16.7 | 16.7                                                                       | 16.7 | 15.7 |                   |
| 18Cr-13Ni-3Mo                                   | ...            | A403      | WP317L     | S31703  | ...                     | ...                                 | 8         | (32) (37)           | -325               | 75      | 30    | 20.0 | 20.0                                                                       | 20.0 | 18.9 |                   |
| 25Cr-20Ni                                       | ...            | A182      | F310       | S31000  | ...                     | ...                                 | 8         | (9) (35) (39)       | -325               | 75      | 30    | 20.0 | 20.0                                                                       | 20.0 | 20.0 |                   |
| 25Cr-20Ni                                       | ...            | A403      | WP310S     | S31008  | ...                     | ...                                 | 8         | (28) (32) (35) (37) | -325               | 75      | 30    | 20.0 | 20.0                                                                       | 20.0 | 20.0 |                   |
| 18Cr-10Ni-Ti                                    | Smls. fittings | A403      | WP321      | S32100  | ...                     | > <sup>3</sup> / <sub>8</sub> thk.  | 8         | (28)                | -325               | 70      | 25    | 16.7 | 16.7                                                                       | 16.7 | 16.7 |                   |
| 18Cr-10Ni-Ti                                    | Forgings       | A182      | F321       | S32100  | ...                     | ...                                 | 8         | (9) (21) (28)       | -325               | 75      | 30    | 20.0 | 20.0                                                                       | 20.0 | 20.0 |                   |
| 18Cr-10Ni-Ti                                    | Smls. fittings | A403      | WP321      | S32100  | ...                     | ≤ <sup>3</sup> / <sub>8</sub> thk.  | 8         | (28)                | -325               | 75      | 30    | 20.0 | 20.0                                                                       | 20.0 | 20.0 |                   |
| 18Cr-10Ni-Ti                                    | Wld. fittings  | A403      | WP321      | S32100  | ...                     | ...                                 | 8         | (28)                | -325               | 75      | 30    | 20.0 | 20.0                                                                       | 20.0 | 20.0 |                   |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |        | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|----------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 |        |                |              |
| Stainless Steel — Plates and Sheets (3)(4a) (Cont'd)                       |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |        |                |              |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 28.5                                                                       | 28.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 32.9                                                                       | 32.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 30.9                                                                       | 30.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 28.7                                                                       | 28.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | 2205           | A240         |
| 28.6                                                                       | 28.6 | 28.6 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    |                | A240         |
| 30.1                                                                       | 30.1 | 30.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 35.8                                                                       | 35.7 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 33.0                                                                       | 33.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 35.2                                                                       | 35.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 33.9                                                                       | 33.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | A240           |              |
| 34.5                                                                       | 34.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | 2507           | A240         |
| Stainless Steel — Forgings and Fittings (3)(4a)                            |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |        |                |              |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | F317L          | A182         |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0  | 6.3   | 5.1   | 4.0   | 3.2   | 2.6   | 2.1   | 1.7   | 1.1   | 1.0   | 0.9   | F304L  | A182           |              |
| 14.7                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 12.6 | 12.3 | 12.0  | 6.3   | 5.1   | 4.0   | 3.2   | 2.6   | 2.1   | 1.7   | 1.1   | 1.0   | 0.9   | WP304L | A403           |              |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8  | 10.8  | 10.2  | 8.8   | 6.4   | 4.7   | 3.5   | 2.5   | 1.8   | 1.3   | 1.0   | F316L  | A182           |              |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.2 | 12.9 | 12.7 | 12.4 | 12.1 | 11.8  | 10.8  | 10.2  | 8.8   | 6.4   | 4.7   | 3.5   | 2.5   | 1.8   | 1.3   | 1.0   | WP316L | A403           |              |
| 17.7                                                                       | 16.9 | 16.5 | 16.2 | 15.8 | 15.5 | 15.2 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | WP317L         | A403         |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 15.9 | 9.9   | 7.1   | 5.0   | 3.6   | 2.5   | 1.5   | 0.8   | 0.5   | 0.4   | 0.3   | 0.2   | F310   | A182           |              |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 15.9 | 9.9   | 7.1   | 5.0   | 3.6   | 2.5   | 1.5   | 0.8   | 0.5   | 0.4   | 0.3   | 0.2   | WP310S | A403           |              |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5  | 9.6   | 6.9   | 5.0   | 3.6   | 2.6   | 1.7   | 1.1   | 0.8   | 0.5   | 0.3   | WP321  | A403           |              |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 9.6   | 6.9   | 5.0   | 3.6   | 2.6   | 1.7   | 1.1   | 0.8   | 0.5   | 0.3   | F321   | A182           |              |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 9.6   | 6.9   | 5.0   | 3.6   | 2.6   | 1.7   | 1.1   | 0.8   | 0.5   | 0.3   | WP321  | A403           |              |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 9.6   | 6.9   | 5.0   | 3.6   | 2.6   | 1.7   | 1.1   | 0.8   | 0.5   | 0.3   | WP321  | A403           |              |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                                 |                |           |             |         |                          |                                    |           |                               |                    |         |       |                   | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |                   |  |
|-------------------------------------------------|----------------|-----------|-------------|---------|--------------------------|------------------------------------|-----------|-------------------------------|--------------------|---------|-------|-------------------|----------------------------------------------------------------------------|------|-------------------|--|
|                                                 |                |           |             |         |                          |                                    |           |                               |                    |         |       |                   | Specified Min. Strength, ksi                                               |      | Min. Temp. to 100 |  |
| Nominal Composition                             | Product Form   | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in.                          | P-No. (5) | Notes                         | Min. Temp., °F (6) | Tensile | Yield | Min. Temp. to 100 | 200                                                                        | 300  | 400               |  |
| Stainless Steel — Forgings and Fittings (3)(4a) |                |           |             |         |                          |                                    |           |                               |                    |         |       |                   |                                                                            |      |                   |  |
| 23Cr–12Ni                                       | ...            | A403      | WP309       | S30900  | ...                      | ...                                | 8         | (28) (32) (35) (37) (39)      | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 25Cr–20Ni                                       | ...            | A182      | F310H       | S31009  | ...                      | ...                                | 8         | (9) (21) (29) (35) (39)       | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 25Cr–20Ni                                       | ...            | A403      | WP310H      | S31009  | ...                      | ...                                | 8         | (28) (29) (32) (35) (37) (39) | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A182      | F347        | S34700  | ...                      | ...                                | 8         | (9) (21)                      | –425               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A403      | WP347       | S34700  | ...                      | ...                                | 8         | (32) (37)                     | –425               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A182      | F348        | S34800  | ...                      | ...                                | 8         | (9) (21)                      | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A403      | WP348       | S34800  | ...                      | ...                                | 8         | (32) (37)                     | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Ti                                    | Smls. fittings | A403      | WP321       | S32100  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (28) (30)                     | –325               | 70      | 25    | 16.7              | 16.7                                                                       | 16.7 | 16.7              |  |
| 18Cr–10Ni–Ti                                    | Smls. fittings | A403      | WP321H      | S32109  | ...                      | > <sup>3</sup> / <sub>8</sub> thk. | 8         | (30)                          | –325               | 70      | 25    | 16.7              | 16.7                                                                       | 16.7 | 16.7              |  |
| 18Cr–10Ni–Ti                                    | Forgings       | A182      | F321        | S32100  | ...                      | ...                                | 8         | (9) (21) (28) (30)            | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Ti                                    | Forgings       | A182      | F321H       | S32109  | ...                      | ...                                | 8         | (9) (21)                      | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Ti                                    | Smls. fittings | A403      | WP321       | S32100  | ...                      | ≤ <sup>3</sup> / <sub>8</sub> thk. | 8         | (28) (30)                     | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Ti                                    | Smls. fittings | A403      | WP321H      | S32109  | ...                      | ≤ <sup>3</sup> / <sub>8</sub> thk. | 8         | (30)                          | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Ti                                    | Wld. fittings  | A403      | WP321       | S32100  | ...                      | ...                                | 8         | (28) (30)                     | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Ti                                    | Wld. fittings  | A403      | WP321H      | S32109  | ...                      | ...                                | 8         | (30)                          | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 16Cr–12Ni–2Mo                                   | ...            | A403      | WP316H      | S31609  | ...                      | ...                                | 8         | (26) (32) (37)                | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 19.3              |  |
| 16Cr–12Ni–2Mo                                   | ...            | A182      | F316H       | S31609  | ...                      | ...                                | 8         | (9) (21) (26)                 | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 19.3              |  |
| 18Cr–10Ni–Cb                                    | ...            | A403      | WP347H      | S34709  | ...                      | ...                                | 8         | (32) (37)                     | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A182      | F347        | S34700  | ...                      | ...                                | 8         | (9) (21) (28)                 | –425               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A403      | WP347       | S34700  | ...                      | ...                                | 8         | (28) (32) (37)                | –425               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A182      | F348        | S34800  | ...                      | ...                                | 8         | (9) (21) (28)                 | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A403      | WP348       | S34800  | ...                      | ...                                | 8         | (28) (32) (37)                | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A182      | F347H       | S34709  | ...                      | ...                                | 8         | (9) (21)                      | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 18Cr–10Ni–Cb                                    | ...            | A182      | F348H       | S34809  | ...                      | ...                                | 8         | (9) (21)                      | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0              |  |
| 16Cr–12Ni–2Mo                                   | ...            | A182      | F316        | S31600  | ...                      | ...                                | 8         | (9) (21) (26) (28)            | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 19.3              |  |
| 16Cr–12Ni–2Mo                                   | ...            | A403      | WP316       | S31600  | ...                      | ...                                | 8         | (26) (28) (32) (37)           | –425               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 19.3              |  |
| 18Cr–13Ni–3Mo                                   | ...            | A403      | WP317       | S31700  | ...                      | ...                                | 8         | (26) (28) (32)                | –325               | 75      | 30    | 20.0              | 20.0                                                                       | 20.0 | 19.3              |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |                |              |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | Type/<br>Grade | Spec.<br>No. |
| Stainless Steel — Forgings and Fittings (3)(4a) (Cont'd)                   |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |                |              |
| 19.4                                                                       | 18.8 | 18.5 | 18.2 | 18.0 | 17.7 | 17.5 | 17.2 | 16.9 | 13.8  | 10.3  | 7.6   | 5.5   | 4.0   | 3.0   | 2.2   | 1.7   | 1.3   | 1.0   | 0.8   | WP309          | A403         |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 16.7 | 13.8  | 10.3  | 7.6   | 5.5   | 4.0   | 3.0   | 2.2   | 1.7   | 1.3   | 1.0   | 0.8   | F310H          | A182         |
| 19.3                                                                       | 18.5 | 18.2 | 17.9 | 17.7 | 17.4 | 17.2 | 16.9 | 16.7 | 13.8  | 10.3  | 7.6   | 5.5   | 4.0   | 3.0   | 2.2   | 1.7   | 1.3   | 1.0   | 0.8   | WP310H         | A403         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | F347           | A182         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | WP347          | A403         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | F348           | A182         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | WP348          | A403         |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | WP321          | A403         |
| 16.1                                                                       | 15.2 | 14.9 | 14.6 | 14.3 | 14.1 | 13.9 | 13.8 | 13.6 | 13.5  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | WP321H         | A403         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | F321           | A182         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | F321H          | A182         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | WP321          | A403         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | WP321H         | A403         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | WP321          | A403         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2  | 12.3  | 9.1   | 6.9   | 5.4   | 4.1   | 3.2   | 2.5   | 1.9   | 1.5   | 1.1   | WP321H         | A403         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | WP316H         | A403         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | F316H          | A182         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | WP347H         | A403         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | F347           | A182         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | WP347          | A403         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | F348           | A182         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | WP348          | A403         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | F347H          | A182         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   | F348H          | A182         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | F316           | A182         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | WP316          | A403         |
| 18.0                                                                       | 17.0 | 16.6 | 16.3 | 16.1 | 15.9 | 15.7 | 15.6 | 15.4 | 15.3  | 15.1  | 12.4  | 9.8   | 7.4   | 5.5   | 4.1   | 3.1   | 2.3   | 1.7   | 1.3   | WP317          | A403         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                                 |              |           |             |         |                          |           |           |                     |                    |                              |       |                   | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |  |
|-------------------------------------------------|--------------|-----------|-------------|---------|--------------------------|-----------|-----------|---------------------|--------------------|------------------------------|-------|-------------------|----------------------------------------------------------------------------|------|------|--|
| Nominal Composition                             | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, in. | P-No. (5) | Notes               | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Min. Temp. to 100 |                                                                            |      |      |  |
|                                                 |              |           |             |         |                          |           |           |                     |                    | Tensile                      | Yield | 200               | 300                                                                        | 400  |      |  |
| Stainless Steel — Forgings and Fittings (3)(4a) |              |           |             |         |                          |           |           |                     |                    |                              |       |                   |                                                                            |      |      |  |
| 18Cr-8Ni                                        | ...          | A182      | F304        | S30400  | ...                      | ...       | 8         | (9) (21) (26) (28)  | -425               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 18.6 |  |
| 18Cr-8Ni                                        | ...          | A403      | WP304       | S30400  | ...                      | ...       | 8         | (26) (28) (32) (37) | -425               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 18.6 |  |
| 18Cr-8Ni                                        | ...          | A403      | WP304H      | S30409  | ...                      | ...       | 8         | (26) (32) (37)      | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 18.6 |  |
| 18Cr-8Ni                                        | ...          | A182      | F304H       | S30409  | ...                      | ...       | 8         | (9) (21) (26)       | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 18.6 |  |
| 44Fe-25Ni-21Cr-Mo                               | ...          | A182      | F904L       | N08904  | ...                      | ...       | 45        | ...                 | -325               | 71                           | 31    | 20.7              | 20.7                                                                       | 20.4 | 18.7 |  |
| 13Cr                                            | ...          | A182      | F6a         | S41000  | 1                        | ...       | 6         | (35)                | -20                | 70                           | 40    | 23.3              | 23.3                                                                       | 22.9 | 22.5 |  |
| 13Cr                                            | ...          | A182      | F6a         | S41000  | 2                        | ...       | 6         | (35)                | -20                | 85                           | 55    | 28.3              | 28.3                                                                       | 27.8 | 27.3 |  |
| 20Cr-18Ni-6Mo                                   | ...          | A182      | F44         | S31254  | ...                      | ...       | 8         | ...                 | -325               | 94                           | 44    | 29.3              | 29.3                                                                       | 28.9 | 26.7 |  |
| 20Cr-18Ni-6Mo                                   | ...          | A403      | WPS31254    | S31254  | ...                      | ...       | 8         | ...                 | -325               | 94                           | 44    | 29.3              | 29.3                                                                       | 28.9 | 26.7 |  |
| 23Cr-4Ni-Mo-Cu-N                                | ...          | A182      | F68         | S32304  | ...                      | ...       | 10H       | (25)                | -60                | 87                           | 58    | 29.0              | 27.9                                                                       | 26.1 | 24.7 |  |
| 22Cr-5Ni-3Mo-N                                  | ...          | A182      | F51         | S31803  | ...                      | ...       | 10H       | (25)                | -60                | 90                           | 65    | 30.0              | 30.0                                                                       | 28.9 | 27.8 |  |
| 22Cr-5Ni-3Mo-N                                  | ...          | A815      | WPS31803    | S31803  | ...                      | ...       | 10H       | (25)                | -60                | 90                           | 65    | 30.0              | 30.0                                                                       | 28.9 | 27.8 |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                         | Forgings     | A182      | F62         | N08367  | ...                      | ...       | 45        | (26)                | -325               | 95                           | 45    | 30.0              | 30.0                                                                       | 29.9 | 28.6 |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                         | Fittings     | A403      | WP6XN       | N08367  | ...                      | ...       | 45        | (26)                | -325               | 95                           | 45    | 30.0              | 30.0                                                                       | 29.9 | 28.6 |  |
| 21Cr-5Mn-1½Ni-Cu-N                              | ...          | A815      | WP32101     | S32101  | ...                      | ...       | 10H       | (25)                | -20                | 94                           | 65    | 31.3              | 31.3                                                                       | 29.8 | 28.5 |  |
| 22Cr-5Ni-3Mo-N                                  | ...          | A182      | F60         | S32205  | ...                      | ...       | 10H       | (25)                | -60                | 95                           | 65    | 31.7              | 31.7                                                                       | 30.6 | 29.4 |  |
| 22Cr-5Ni-3Mo-N                                  | ...          | A815      | WPS32205    | S32205  | ...                      | ...       | 10H       | (25)                | -60                | 95                           | 65    | 31.7              | 31.7                                                                       | 30.6 | 29.4 |  |
| 25Cr-8Ni-3Mo-W-Cu-N                             | ...          | A182      | F55         | S32760  | ...                      | ...       | 10H       | (25)                | -60                | 109                          | 80    | 36.3              | 36.3                                                                       | 34.8 | 34.0 |  |
| 25Cr-8Ni-3Mo-W-Cu-N                             | ...          | A815      | WPS32760    | S32760  | ...                      | ...       | 10H       | (25)                | -60                | 109                          | 80    | 36.3              | 36.3                                                                       | 34.8 | 34.0 |  |
| 25Cr-7Ni-4Mo-N                                  | Forgings     | A182      | F53         | S32750  | ...                      | ≤2        | 10H       | (25)                | -60                | 116                          | 80    | 38.7              | 38.5                                                                       | 36.4 | 35.1 |  |
| 25Cr-7Ni-4Mo-N                                  | Fittings     | A815      | WPS32750    | S32750  | ...                      | ...       | 10H       | (25)                | -60                | 116                          | 80    | 38.7              | 38.5                                                                       | 36.4 | 35.1 |  |
| Stainless Steel — Bar (3)(4a)                   |              |           |             |         |                          |           |           |                     |                    |                              |       |                   |                                                                            |      |      |  |
| 18Cr-8Ni                                        | ...          | A479      | 304         | S30400  | ...                      | ...       | 8         | (26) (28)           | -425               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 18.6 |  |
| 18Cr-8Ni                                        | ...          | A479      | 304H        | S30409  | ...                      | ...       | 8         | (26)                | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 18.7 |  |
| 18Cr-8Ni                                        | ...          | A479      | 304L        | S30403  | ...                      | ...       | 8         | ...                 | -425               | 70                           | 25    | 16.7              | 16.7                                                                       | 16.7 | 15.8 |  |
| 16Cr-12Ni-2Mo                                   | ...          | A479      | 316         | S31600  | ...                      | ...       | 8         | (26) (28)           | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 19.3 |  |
| 16Cr-12Ni-2Mo                                   | ...          | A479      | 316H        | S31609  | ...                      | ...       | 8         | (26)                | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 19.3 |  |
| 16Cr-12Ni-2Mo                                   | ...          | A479      | 316L        | S31603  | ...                      | ...       | 8         | ...                 | -425               | 70                           | 25    | 16.7              | 16.7                                                                       | 16.7 | 15.5 |  |
| 18Cr-10Ni-Ti                                    | Bar          | A479      | 321         | S32100  | ...                      | ...       | 8         | (28)                | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0 |  |
| 18Cr-10Ni-Ti                                    | Bar          | A479      | 321         | S32100  | ...                      | ...       | 8         | (28) (30)           | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0 |  |
| 18Cr-10Ni-Ti                                    | Bar          | A479      | 321H        | S32109  | ...                      | ...       | 8         | (30)                | -325               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0 |  |
| 18Cr-10Ni-Cb                                    | ...          | A479      | 347         | S34700  | ...                      | ...       | 8         | ...                 | -425               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0 |  |
| 18Cr-10Ni-Cb                                    | ...          | A479      | 347         | S34700  | ...                      | ...       | 8         | (28) (30)           | -425               | 75                           | 30    | 20.0              | 20.0                                                                       | 20.0 | 20.0 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|----------------|--------------|
| <b>Stainless Steel — Forgings and Fittings (3)(4a) (Cont'd)</b>            |      |      |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |                |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8  | 7.7  | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | F304           | A182         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8  | 7.7  | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | WP304          | A403         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8  | 7.7  | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | WP304H         | A403         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8  | 7.7  | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | F304H          | A182         |
| 17.1                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F904L          | A182         |
| 22.1                                                                       | 21.6 | 21.2 | 20.6 | 20.0 | 19.2 | 17.2 | 12.3 | 8.8  | 6.4  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F6a Cl. 1      | A182         |
| 26.9                                                                       | 26.2 | 25.7 | 25.1 | 24.3 | 23.3 | 17.2 | 12.3 | 8.8  | 6.4  | 4.4  | 2.9  | 1.8  | 1.0 | ... | ... | ... | ... | ... | ... | F6a Cl. 2      | A182         |
| 25.2                                                                       | 24.1 | 23.8 | 23.6 | 23.4 | 23.2 | 23.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F44            | A182         |
| 25.2                                                                       | 24.1 | 23.8 | 23.6 | 23.4 | 23.2 | 23.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | WPS31254       | A403         |
| 22.9                                                                       | 19.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F68            | A182         |
| 27.2                                                                       | 26.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F51            | A182         |
| 27.2                                                                       | 26.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | WPS31803       | A815         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F62            | A182         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | WP6XN          | A403         |
| 28.5                                                                       | 28.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | WPS32101       | A815         |
| 28.7                                                                       | 28.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F60            | A182         |
| 28.7                                                                       | 28.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | WPS32205       | A815         |
| 33.9                                                                       | 33.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F55            | A182         |
| 33.9                                                                       | 33.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | WPS32760       | A815         |
| 34.5                                                                       | 34.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | F53            | A182         |
| 34.5                                                                       | 34.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | WPS32750       | A815         |
| <b>Stainless Steel — Bar (3)(4a)</b>                                       |      |      |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |                |              |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0 | 12.4 | 9.8  | 7.7  | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | 304            | A479         |
| 17.5                                                                       | 16.4 | 16.2 | 16.0 | 15.6 | 15.2 | 14.9 | 14.6 | 14.4 | 13.8 | 12.2 | 9.7  | 7.7  | 6.0 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | 304H           | A479         |
| 14.8                                                                       | 14.0 | 13.7 | 13.5 | 13.3 | 13.0 | 12.8 | 11.9 | 9.9  | 7.8  | 6.3  | 5.1  | 4.0  | 3.2 | 2.6 | 2.1 | 1.7 | 1.1 | 1.0 | 0.9 | 304L           | A479         |
| 17.9                                                                       | 17.0 | 16.7 | 16.3 | 16.1 | 15.9 | 15.7 | 15.5 | 15.4 | 15.3 | 14.5 | 12.4 | 9.8  | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | 316            | A479         |
| 17.9                                                                       | 17.0 | 16.7 | 16.3 | 16.1 | 15.9 | 15.7 | 15.5 | 15.4 | 15.3 | 14.5 | 12.4 | 9.8  | 7.4 | 5.5 | 4.1 | 3.1 | 2.3 | 1.7 | 1.3 | 316H           | A479         |
| 14.4                                                                       | 13.5 | 13.2 | 12.9 | 12.6 | 12.4 | 12.1 | 11.8 | 11.5 | 11.2 | 10.8 | 10.2 | 8.8  | 6.4 | 4.7 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | 316L           | A479         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 9.6  | 6.9  | 5.0  | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | 321            | A479         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1  | 6.9  | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321            | A479         |
| 19.3                                                                       | 18.3 | 17.8 | 17.5 | 17.2 | 16.9 | 16.7 | 16.5 | 16.4 | 16.2 | 12.3 | 9.1  | 6.9  | 5.4 | 4.1 | 3.2 | 2.5 | 1.9 | 1.5 | 1.1 | 321H           | A479         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 16.0 | 12.1 | 9.1  | 6.1  | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | 347            | A479         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1 | 17.4 | 14.1 | 10.5 | 7.9 | 5.9 | 4.4 | 3.2 | 2.5 | 1.8 | 1.3 | 347            | A479         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                    |              |           |            |         |                      |                                     |           |                         |                    |         |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |            |      |
|------------------------------------|--------------|-----------|------------|---------|----------------------|-------------------------------------|-----------|-------------------------|--------------------|---------|-------|----------------------------------------------------------------------------|------|------------|------|
|                                    |              |           |            |         |                      |                                     |           |                         |                    |         |       | Specified Min. Strength, ksi                                               |      | Min. Temp. |      |
| Nominal Composition                | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size, in.                           | P-No. (5) | Notes                   | Min. Temp., °F (6) | Tensile | Yield | to 100                                                                     | 200  | 300        | 400  |
| Stainless Steel — Bar (3)(4a)      |              |           |            |         |                      |                                     |           |                         |                    |         |       |                                                                            |      |            |      |
| 18Cr-10Ni-Cb                       | ...          | A479      | 347H       | S34709  | ...                  | ...                                 | 8         | ...                     | -325               | 75      | 30    | 20.0                                                                       | 20.0 | 20.0       | 20.0 |
| 44Fe-25Ni-21Cr-Mo                  | ...          | A479      | 904L       | N08904  | ...                  | ...                                 | 45        | ...                     | -325               | 71      | 31    | 20.7                                                                       | 20.7 | 20.4       | 18.7 |
| 22Cr-5Ni-3Mo-N                     | ...          | A479      | ...        | S31803  | ...                  | ...                                 | 10H       | (25)                    | -60                | 90      | 65    | 30.0                                                                       | 30.0 | 28.9       | 27.8 |
| 20Cr-18Ni-6Mo                      | ...          | A479      | ...        | S31254  | ...                  | ...                                 | 8         | ...                     | -325               | 95      | 45    | 30.0                                                                       | 30.0 | 29.5       | 27.3 |
| 46Fe-24Ni-21Cr-6Mo-Cu-N            | ...          | A479      | ...        | N08367  | ...                  | ...                                 | 45        | (26)                    | -325               | 95      | 45    | 30.0                                                                       | 30.0 | 29.9       | 28.6 |
| 21Cr-5Mn-1.5Ni-Cu-N                | ...          | A479      | ...        | S32101  | ...                  | ...                                 | 10H       | (25)                    | -20                | 94      | 65    | 31.3                                                                       | 31.3 | 29.8       | 28.5 |
| 22Cr-5Ni-3Mo-N                     | ...          | A479      | ...        | S32205  | ...                  | ...                                 | 10H       | (25)                    | -60                | 95      | 65    | 31.7                                                                       | 31.7 | 30.6       | 29.4 |
| 24Cr-4Ni-3Mn-1.5Mo-N               | ...          | A479      | ...        | S82441  | ...                  | ≥ <sup>7</sup> / <sub>16</sub> thk. | 10H       | (25)                    | -60                | 99      | 70    | 32.9                                                                       | 32.9 | 32.9       | 32.9 |
| 22Cr-13Ni-5Mn                      | ...          | A479      | XM-19      | S20910  | Annealed             | ...                                 | 8         | ...                     | -325               | 100     | 55    | 33.3                                                                       | 33.1 | 31.4       | 30.4 |
| 24Cr-4Ni-3Mn-1.5Mo-N               | ...          | A479      | ...        | S82441  | ...                  | < <sup>7</sup> / <sub>16</sub> thk. | 10H       | (25)                    | -60                | 107     | 78    | 35.8                                                                       | 35.8 | 35.8       | 35.8 |
| 29Cr-6.5Ni-2Mo-N                   | ...          | A479      | ...        | S32906  | ...                  | ...                                 | 10H       | (25)                    | -60                | 109     | 80    | 36.3                                                                       | 36.3 | 34.5       | 33.5 |
| 25Cr-7Ni-4Mo-N                     | ...          | A479      | ...        | S32750  | ...                  | ≤2 thk.                             | 10H       | (25)                    | -60                | 116     | 80    | 38.7                                                                       | 38.5 | 36.4       | 35.1 |
| Stainless Steel — Castings (3)(4a) |              |           |            |         |                      |                                     |           |                         |                    |         |       |                                                                            |      |            |      |
| 29Ni-20Cr-3Cu-2Mo                  | ...          | A351      | CN7M       | N08007  | ...                  | ...                                 | 45        | (9) (30)                | -325               | 62      | 25    | 16.7                                                                       | ...  | ...        | ...  |
| 35Ni-15Cr-½Mo                      | ...          | A351      | HT30       | N08603  | ...                  | ...                                 | 45        | (36) (39)               | -325               | 65      | 28    | 18.7                                                                       | ...  | ...        | ...  |
| 25Cr-12Ni                          | ...          | A351      | CH8        | J93400  | ...                  | ...                                 | 8         | (9) (31)                | -325               | 65      | 28    | 18.7                                                                       | 18.7 | 18.5       | 18.0 |
| 25Cr-20Ni                          | ...          | A351      | CK20       | J94202  | ...                  | ...                                 | 8         | (9) (27) (31) (35) (39) | -325               | 65      | 28    | 18.7                                                                       | 18.7 | 18.5       | 18.0 |
| 16Cr-14Ni-2Mo                      | ...          | A351      | CF10MC     | ...     | ...                  | ...                                 | 8         | (30)                    | -325               | 70      | 30    | 20.0                                                                       | ...  | ...        | ...  |
| 18Cr-8Ni                           | ...          | A351      | CF3        | J92500  | ...                  | ...                                 | 8         | (9)                     | -425               | 70      | 30    | 20.0                                                                       | 20.0 | 20.0       | 18.6 |
| 18Cr-12Ni-2Mo                      | ...          | A351      | CF3M       | J92800  | ...                  | ...                                 | 8         | (9)                     | -425               | 70      | 30    | 20.0                                                                       | 20.0 | 20.0       | 19.2 |
| 18Cr-8Ni                           | ...          | A351      | CF8        | J92600  | ...                  | ...                                 | 8         | (9) (26) (27) (31)      | -425               | 70      | 30    | 20.0                                                                       | 20.0 | 20.0       | 18.6 |
| 25Cr-12Ni                          | ...          | A351      | CH10       | J93401  | ...                  | ...                                 | 8         | (27) (31) (35)          | -325               | 70      | 30    | 20.0                                                                       | 20.0 | 19.9       | 19.4 |
| 25Cr-12Ni                          | ...          | A351      | CH20       | J93402  | ...                  | ...                                 | 8         | (9) (27) (31) (35) (39) | -325               | 70      | 30    | 20.0                                                                       | 20.0 | 19.9       | 19.4 |
| 18Cr-10Ni-Cb                       | ...          | A351      | CF8C       | J92710  | ...                  | ...                                 | 8         | (9) (28)                | -325               | 70      | 30    | 20.0                                                                       | 20.0 | 20.0       | 19.5 |
| 18Cr-12Ni-2Mo                      | ...          | A351      | CF8M       | J92900  | ...                  | ...                                 | 8         | (9) (26) (27) (30)      | -425               | 70      | 30    | 20.0                                                                       | 20.0 | 20.0       | 18.6 |
| 25Cr-20Ni-½Mo                      | ...          | A351      | HK40       | J94204  | ...                  | ...                                 | 8         | (35) (36) (39)          | -325               | 62      | 35    | 20.7                                                                       | ...  | ...        | ...  |
| 25Cr-20Ni-½Mo                      | ...          | A351      | HK30       | J94203  | ...                  | ...                                 | 8         | (35) (39)               | -325               | 65      | 35    | 21.7                                                                       | ...  | ...        | ...  |
| 18Cr-8Ni                           | ...          | A351      | CF3A       | J92500  | ...                  | ...                                 | 8         | (9) (56)                | -425               | 77      | 35    | 23.3                                                                       | 23.3 | 22.7       | 21.7 |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|--------------|
| <b>Stainless Steel — Bar (3)(4a) (Cont'd)</b>                              |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |                |              |
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 347H           | A479         |
| 20.0                                                                       | 19.3 | 19.0 | 18.7 | 18.5 | 18.3 | 18.2 | 18.1 | 18.1 | 18.1  | 17.4  | 14.1  | 10.5  | 7.9   | 5.9   | 4.4   | 3.2   | 2.5   | 1.8   | 1.3   |                |              |
| 17.1                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 904L           | A479         |
| 27.2                                                                       | 26.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 25.8                                                                       | 24.7 | 24.3 | 24.1 | 23.9 | 23.7 | 23.6 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 27.7                                                                       | 26.2 | 25.7 | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 28.5                                                                       | 28.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 28.7                                                                       | 28.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 32.9                                                                       | 32.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 29.7                                                                       | 29.2 | 29.0 | 28.8 | 28.6 | 28.3 | 27.9 | 27.5 | 27.0 | 26.3  | 25.5  | 20.4  | 13.0  | 8.3   | ...   | ...   | ...   | ...   | ...   | ...   | XM-19          | A479         |
| 35.8                                                                       | 35.7 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 33.0                                                                       | 33.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| 34.5                                                                       | 34.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   |                | A479         |
| <b>Stainless Steel — Castings (3)(4a)</b>                                  |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |                |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CN7M           | A351         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | HT30           | A351         |
| 17.7                                                                       | 17.1 | 16.7 | 16.3 | 15.9 | 15.4 | 14.9 | 14.4 | 13.9 | 11.1  | 8.5   | 6.5   | 5.0   | 3.8   | 2.9   | 2.3   | 1.8   | 1.3   | 0.9   | 0.8   | CH8            | A351         |
| 17.7                                                                       | 17.1 | 16.7 | 16.3 | 15.9 | 15.4 | 14.9 | 14.4 | 13.9 | 11.3  | 9.8   | 8.5   | 7.3   | 6.0   | 4.8   | 3.5   | 2.4   | 1.6   | 1.1   | 0.8   | CK20           | A351         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CF10MC         | A351         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CF3            | A351         |
| 17.9                                                                       | 17.0 | 16.6 | 16.3 | 16.0 | 15.8 | 15.7 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CF3M           | A351         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 12.2  | 9.5   | 7.5   | 6.0   | 4.8   | 3.9   | 3.3   | 2.7   | 2.3   | 2.0   | 1.7   | CF8            | A351         |
| 18.9                                                                       | 18.3 | 17.9 | 17.5 | 17.0 | 16.5 | 15.9 | 15.4 | 14.3 | 11.1  | 8.5   | 6.5   | 5.0   | 3.8   | 2.9   | 2.3   | 1.8   | 1.3   | 0.9   | 0.8   | CH10           | A351         |
| 18.9                                                                       | 18.3 | 17.9 | 17.5 | 17.0 | 16.5 | 15.9 | 15.4 | 14.3 | 11.1  | 8.5   | 6.5   | 5.0   | 3.8   | 2.9   | 2.3   | 1.8   | 1.3   | 0.9   | 0.8   | CH20           | A351         |
| 18.8                                                                       | 18.4 | 18.3 | 18.3 | 18.2 | 18.2 | 18.1 | 18.0 | 18.0 | 16.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | CF8C           | A351         |
| 17.5                                                                       | 16.6 | 16.2 | 15.8 | 15.5 | 15.2 | 14.9 | 14.6 | 14.3 | 14.0  | 12.1  | 9.1   | 6.1   | 4.4   | 3.3   | 2.2   | 1.5   | 1.2   | 0.9   | 0.8   | CF8M           | A351         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | HK40           | A351         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | HK30           | A351         |
| 20.4                                                                       | 19.3 | 18.9 | 18.5 | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CF3A           | A351         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition             | Product<br>Form | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size,<br>in. | P-No.<br>(5) | Notes            | Min.<br>Temp.,<br>°F (6) | Specified Min.<br>Strength, ksi |       | Basic Allowable<br>Stress, S, ksi, at<br>Metal Temperature,<br>°F [Notes (1), (4a)] |      |      |      |
|------------------------------------|-----------------|--------------|----------------|------------|--------------------------------|--------------|--------------|------------------|--------------------------|---------------------------------|-------|-------------------------------------------------------------------------------------|------|------|------|
|                                    |                 |              |                |            |                                |              |              |                  |                          | Tensile                         | Yield | Min.<br>Temp.<br>to 100                                                             | 200  | 300  | 400  |
| Stainless Steel — Castings (3)(4a) |                 |              |                |            |                                |              |              |                  |                          |                                 |       |                                                                                     |      |      |      |
| 18Cr-8Ni                           | ...             | A351         | CF8A           | J92600     | ...                            | ...          | 8            | (9) (26)<br>(56) | -425                     | 77                              | 35    | 23.3                                                                                | 23.3 | 22.7 | 21.7 |
| 25Cr-8Ni-N                         | ...             | A351         | CE20N          | J92802     | ...                            | ...          | 8            | (35) (39)        | -325                     | 80                              | 40    | 26.7                                                                                | 26.7 | 26.7 | 26.7 |
| 12Cr                               | ...             | A217         | CA15           | J91150     | ...                            | ...          | 6            | (35)             | -20                      | 90                              | 65    | 30.0                                                                                | 30.0 | 29.4 | 28.9 |
| 24Cr-10Ni-4Mo-N                    | ...             | A995         | 2A             | J93345     | ...                            | ...          | 10H          | (9)              | -60                      | 95                              | 65    | 31.7                                                                                | 31.6 | 29.3 | 28.2 |
| 25Cr-8Ni-3Mo-W-Cu-N                | ...             | A995         | 6A             | J93380     | ...                            | ...          | 10H          | (9) (25)         | -60                      | 100                             | 65    | 33.3                                                                                | 33.2 | 31.4 | 30.3 |
| 13Cr-4Ni                           | ...             | A487         | CA6NM          | J91540     | A                              | ...          | 6            | (9) (35)         | -20                      | 110                             | 80    | 36.7                                                                                | 36.7 | 35.9 | 35.3 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |     |       |       |       |       |       |       |       |       |       |       |       |                | Type/<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|----------------|--------------|
| 500                                                                        | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 |                |                |              |
| Stainless Steel — Castings (3)(4a)                                         |      |      |      |      |      |      |      |     |       |       |       |       |       |       |       |       |       |       |       |                | (Cont'd)       |              |
| 20.4                                                                       | 19.3 | 18.9 | 18.5 | ...  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CF8A           | A351           |              |
| 26.7                                                                       | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | ... | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CE20N          | A351           |              |
| 28.4                                                                       | 27.7 | 27.2 | 26.5 | 17.5 | 16.8 | 14.9 | 11.0 | 7.6 | 5.0   | 3.3   | 2.3   | 1.5   | 1.0   | ...   | ...   | ...   | ...   | ...   | ...   | CA15           | A217           |              |
| 28.2                                                                       | 28.2 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 2A             | A995           |              |
| 29.8                                                                       | 29.6 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | 6A             | A995           |              |
| 34.8                                                                       | 33.9 | 33.3 | 32.4 | ...  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CA6NM<br>Cl. A | A487           |              |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition                       | Product Form | Spec. No. | UNS No. | Class/Condition/<br>Temper | Size Range, in. | P-No.<br>(5)(7) | Notes          | Min. Temp.,<br>°F (6) | Specified Minimum Strength, ksi |       |
|-------------------------------------------|--------------|-----------|---------|----------------------------|-----------------|-----------------|----------------|-----------------------|---------------------------------|-------|
|                                           |              |           |         |                            |                 |                 |                |                       | Tensile                         | Yield |
| Copper and Copper Alloy — Pipes and Tubes |              |           |         |                            |                 |                 |                |                       |                                 |       |
| 99.95Cu-P                                 | Pipe         | B42       | C10200  | O61                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Pipe         | B42       | C12000  | O61                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Pipe         | B42       | C12200  | O61                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.95Cu-P                                 | Tube         | B75       | C10200  | O50                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.95Cu-P                                 | Tube         | B75       | C10200  | O60                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B75       | C12000  | O50                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B75       | C12000  | O60                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B75       | C12200  | O50                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B75       | C12200  | O60                        | ...             | 31              | ...            | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B68       | C12200  | O50                        | ...             | 31              | (24)           | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B68       | C12200  | O60                        | ...             | 31              | (24)           | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B88       | C12200  | O50                        | ...             | 31              | (24)           | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B88       | C12200  | O60                        | ...             | 31              | (24)           | -452                  | 30                              | 9     |
| 99.9Cu-P                                  | Tube         | B280      | C12200  | O60                        | ...             | 31              | (24)           | -452                  | 30                              | 9     |
| 85Cu-15Zn                                 | Pipe         | B43       | C23000  | O61                        | ...             | 32              | ...            | -452                  | 40                              | 12    |
| 90Cu-10Ni                                 | ...          | B467      | C70600  | W050                       | >4.5 O.D.       | 34              | (14)           | -452                  | 38                              | 13    |
| 90Cu-10Ni                                 | ...          | B467      | C70600  | W061                       | >4.5 O.D.       | 34              | (14)           | -452                  | 38                              | 13    |
| 90Cu-10Ni                                 | ...          | B466      | C70600  | Annealed                   | ...             | 34              | (14)           | -452                  | 38                              | 13    |
| 90Cu-10Ni                                 | ...          | B467      | C70600  | W050                       | ≤4.5 O.D.       | 34              | (14)           | -452                  | 40                              | 15    |
| 90Cu-10Ni                                 | ...          | B467      | C70600  | W061                       | ≤4.5 O.D.       | 34              | (14)           | -452                  | 40                              | 15    |
| 70Cu-30Ni                                 | ...          | B467      | C71500  | W050                       | >4.5 O.D.       | 34              | (14)           | -452                  | 45                              | 15    |
| 70Cu-30Ni                                 | ...          | B467      | C71500  | W061                       | >4.5 O.D.       | 34              | (14)           | -452                  | 45                              | 15    |
| 80Cu-20Ni                                 | ...          | B466      | C71000  | Annealed                   | ≤4.5 O.D.       | 34              | (14)           | -452                  | 45                              | 16    |
| 99.95Cu-P                                 | Pipe         | B42       | C10200  | H55                        | NPS 2½ thru 12  | 31              | (14) (34)      | -452                  | 36                              | 30    |
| 99.9Cu-P                                  | Pipe         | B42       | C12000  | H55                        | NPS 2½ thru 12  | 31              | (14) (34)      | -452                  | 36                              | 30    |
| 99.9Cu-P                                  | Pipe         | B42       | C12200  | H55                        | NPS 2½ thru 12  | 31              | (14) (34)      | -452                  | 36                              | 30    |
| 99.95Cu-P                                 | Tube         | B75       | C10200  | H58                        | ...             | 31              | (14) (34)      | -452                  | 36                              | 30    |
| 99.9Cu-P                                  | Tube         | B75       | C12000  | H58                        | ...             | 31              | (14) (34)      | -452                  | 36                              | 30    |
| 99.9Cu-P                                  | Tube         | B75       | C12200  | H58                        | ...             | 31              | (14) (34)      | -452                  | 36                              | 30    |
| 99.9Cu-P                                  | Tube         | B88       | C12200  | H58                        | ...             | 31              | (14) (24) (34) | -452                  | 36                              | 30    |
| 70Cu-30Ni                                 | ...          | B466      | C71500  | O60                        | ...             | 34              | (14)           | -452                  | 52                              | 18    |
| 70Cu-30Ni                                 | ...          | B467      | C71500  | W050                       | ≤4.5 O.D.       | 34              | (14)           | -452                  | 50                              | 20    |
| 70Cu-30Ni                                 | ...          | B467      | C71500  | W061                       | ≤4.5 O.D.       | 34              | (14)           | -452                  | 50                              | 20    |
| 99.95Cu-P                                 | Pipe         | B42       | C10200  | H80                        | NPS ⅛ thru 2    | 31              | (14) (34)      | -452                  | 45                              | 40    |
| 99.9Cu-P                                  | Pipe         | B42       | C12000  | H80                        | NPS ⅛ thru 2    | 31              | (14) (34)      | -452                  | 45                              | 40    |
| 99.9Cu-P                                  | Pipe         | B42       | C12200  | H80                        | NPS ⅛ thru 2    | 31              | (14) (34)      | -452                  | 45                              | 40    |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Min.<br>Temp.<br>to 100                   | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |      | UNS<br>No. | Spec.<br>No. |
|-------------------------------------------|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------------|--------------|
|                                           | 150                                                                        | 200  | 250  | 300  | 350  | 400  | 450  | 500  | 550  | 600  | 650  | 700  |            |              |
| Copper and Copper Alloy — Pipes and Tubes |                                                                            |      |      |      |      |      |      |      |      |      |      |      |            |              |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C10200     | B42          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12000     | B42          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B42          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C10200     | B75          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C10200     | B75          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12000     | B75          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12000     | B75          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B75          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B75          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B68          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B68          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B88          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B88          |
| 6.0                                       | 5.1                                                                        | 4.9  | 4.8  | 4.7  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B280         |
| 8.0                                       | 7.9                                                                        | 7.9  | 7.9  | 7.9  | 7.0  | 5.0  | 2.0  | ...  | ...  | ...  | ...  | ...  | C23000     | B43          |
| 8.7                                       | 8.4                                                                        | 8.2  | 8.0  | 7.8  | 7.7  | 7.5  | 7.4  | 7.3  | 7.0  | 6.0  | ...  | ...  | C70600     | B467         |
| 8.7                                       | 8.4                                                                        | 8.2  | 8.0  | 7.8  | 7.7  | 7.5  | 7.4  | 7.3  | 7.0  | 6.0  | ...  | ...  | C70600     | B467         |
| 8.7                                       | 8.4                                                                        | 8.2  | 8.0  | 7.8  | 7.7  | 7.5  | 7.4  | 7.3  | 7.0  | 6.0  | ...  | ...  | C70600     | B466         |
| 10.0                                      | 9.7                                                                        | 9.5  | 9.3  | 9.1  | 8.9  | 8.7  | 8.5  | 8.0  | 7.0  | 6.0  | ...  | ...  | C70600     | B467         |
| 10.0                                      | 9.7                                                                        | 9.5  | 9.3  | 9.1  | 8.9  | 8.7  | 8.5  | 8.0  | 7.0  | 6.0  | ...  | ...  | C70600     | B467         |
| 10.0                                      | 9.6                                                                        | 9.4  | 9.2  | 9.0  | 8.8  | 8.6  | 8.4  | 8.2  | 8.1  | 8.0  | 7.9  | 7.8  | C71500     | B467         |
| 10.0                                      | 9.6                                                                        | 9.4  | 9.2  | 9.0  | 8.8  | 8.6  | 8.4  | 8.2  | 8.1  | 8.0  | 7.9  | 7.8  | C71500     | B467         |
| 10.7                                      | 10.6                                                                       | 10.5 | 10.4 | 10.2 | 10.1 | 9.9  | 9.6  | 9.3  | 8.9  | 8.4  | 7.7  | 7.0  | C71000     | B466         |
| 12.0                                      | 11.6                                                                       | 10.9 | 10.4 | 10.0 | 9.8  | 9.5  | ...  | ...  | ...  | ...  | ...  | ...  | C10200     | B42          |
| 12.0                                      | 11.6                                                                       | 10.9 | 10.4 | 10.0 | 9.8  | 9.5  | ...  | ...  | ...  | ...  | ...  | ...  | C12000     | B42          |
| 12.0                                      | 11.6                                                                       | 10.9 | 10.4 | 10.0 | 9.8  | 9.5  | ...  | ...  | ...  | ...  | ...  | ...  | C12200     | B42          |
| 12.0                                      | 11.6                                                                       | 10.9 | 10.4 | 10.0 | 9.8  | 9.5  | ...  | ...  | ...  | ...  | ...  | ...  | C10200     | B75          |
| 12.0                                      | 11.6                                                                       | 10.9 | 10.4 | 10.0 | 9.8  | 9.5  | ...  | ...  | ...  | ...  | ...  | ...  | C12000     | B75          |
| 12.0                                      | 11.6                                                                       | 10.9 | 10.4 | 10.0 | 9.8  | 9.5  | ...  | ...  | ...  | ...  | ...  | ...  | C12200     | B75          |
| 12.0                                      | 11.6                                                                       | 10.9 | 10.4 | 10.0 | 9.8  | 9.5  | ...  | ...  | ...  | ...  | ...  | ...  | C12200     | B88          |
| 12.0                                      | 11.6                                                                       | 11.3 | 11.0 | 10.8 | 10.6 | 10.3 | 10.1 | 9.9  | 9.8  | 9.6  | 9.5  | 9.4  | C71500     | B466         |
| 13.3                                      | 12.9                                                                       | 12.6 | 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.7 | 10.5 | 10.4 | C71500     | B467         |
| 13.3                                      | 12.9                                                                       | 12.6 | 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.7 | 10.5 | 10.4 | C71500     | B467         |
| 15.0                                      | 14.5                                                                       | 13.6 | 13.0 | 12.6 | 12.2 | 4.3  | ...  | ...  | ...  | ...  | ...  | ...  | C10200     | B42          |
| 15.0                                      | 14.5                                                                       | 13.6 | 13.0 | 12.6 | 12.2 | 4.3  | ...  | ...  | ...  | ...  | ...  | ...  | C12000     | B42          |
| 15.0                                      | 14.5                                                                       | 13.6 | 13.0 | 12.6 | 12.2 | 4.3  | ...  | ...  | ...  | ...  | ...  | ...  | C12200     | B42          |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                      | Product<br>Form | Spec.<br>No. | UNS<br>No. | Class/<br>Condition/<br>Temper | Size Range, in. | P-No.<br>(5)(7) | Notes     | Min.<br>Temp.,<br>°F (6) | Specified<br>Minimum<br>Strength, ksi |       |
|---------------------------------------------|-----------------|--------------|------------|--------------------------------|-----------------|-----------------|-----------|--------------------------|---------------------------------------|-------|
|                                             |                 |              |            |                                |                 |                 |           |                          | Tensile                               | Yield |
| Copper and Copper Alloy — Pipes and Tubes   |                 |              |            |                                |                 |                 |           |                          |                                       |       |
| 99.95Cu-P                                   | Tube            | B75          | C10200     | H80                            | ...             | 31              | (14) (34) | -452                     | 45                                    | 40    |
| 99.9Cu-P                                    | Tube            | B75          | C12000     | H80                            | ...             | 31              | (14) (34) | -452                     | 45                                    | 40    |
| 99.9Cu-P                                    | Tube            | B75          | C12200     | H80                            | ...             | 31              | (14) (34) | -452                     | 45                                    | 40    |
| Copper and Copper Alloy — Plates and Sheets |                 |              |            |                                |                 |                 |           |                          |                                       |       |
| 99.95Cu-P                                   | ...             | B152         | C10200     | O25                            | ...             | 31              | (14) (24) | -452                     | 30                                    | 10    |
| 99.95Cu-Ag                                  | ...             | B152         | C10400     | O25                            | ...             | 31              | (14) (24) | -452                     | 30                                    | 10    |
| 99.95Cu-Ag                                  | ...             | B152         | C10500     | O25                            | ...             | 31              | (14) (24) | -452                     | 30                                    | 10    |
| 99.95Cu-Ag                                  | ...             | B152         | C10700     | O25                            | ...             | 31              | (14) (24) | -452                     | 30                                    | 10    |
| 99.9Cu-P                                    | ...             | B152         | C12200     | O25                            | ...             | 31              | (14) (24) | -452                     | 30                                    | 10    |
| 99.9Cu-P                                    | ...             | B152         | C12300     | O25                            | ...             | 31              | (14) (24) | -452                     | 30                                    | 10    |
| 90Cu-10Ni                                   | ...             | B171         | C70600     | ...                            | ≤2.5 thk.       | 34              | (14)      | -452                     | 40                                    | 15    |
| 97Cu-3Si                                    | ...             | B96          | C65500     | O61                            | ...             | 33              | ...       | -452                     | 50                                    | 18    |
| 70Cu-30Ni                                   | ...             | B171         | C71500     | ...                            | ≤2.5 thk.       | 34              | (14)      | -452                     | 50                                    | 20    |
| 90Cu-7Al-3Fe                                | ...             | B169         | C61400     | O25                            | ≤2.0 thk.       | 35              | (13)      | -452                     | 70                                    | 30    |
| 90Cu-7Al-3Fe                                | ...             | B169         | C61400     | O60                            | ≤2.0 thk.       | 35              | (13)      | -452                     | 70                                    | 30    |
| Copper and Copper Alloy — Forgings          |                 |              |            |                                |                 |                 |           |                          |                                       |       |
| 99.9Cu                                      | ...             | B283         | C11000     | ...                            | ...             | 31              | (14)      | -452                     | 33                                    | 11    |
| 97Cu-3Si                                    | ...             | B283         | C65500     | ...                            | ...             | 33              | (14)      | -452                     | 52                                    | 18    |
| 60Cu-38Zn-2Pb                               | ...             | B283         | C37700     | ...                            | ...             | a               | (14)      | -325                     | 58                                    | 23    |
| 60Cu-37Zn-2Pb-Sn                            | ...             | B283         | C48500     | ...                            | ...             | a               | (14)      | -325                     | 62                                    | 24    |
| 60Cu-39Zn-Sn                                | ...             | B283         | C46400     | ...                            | ...             | 32              | (14)      | -425                     | 64                                    | 26    |
| 59Cu-39Zn-Fe-Sn                             | ...             | B283         | C67500     | ...                            | ...             | 32              | (14)      | -325                     | 72                                    | 34    |
| Copper and Copper Alloy — Castings          |                 |              |            |                                |                 |                 |           |                          |                                       |       |
| 85Cu-5Sn-5Zn-5Pb                            | ...             | B62          | C83600     | ...                            | ...             | a               | (9)       | -325                     | 30                                    | 14    |
| 57Cu-20Zn-12Ni-9Pb-2Sn                      | ...             | B584         | C97300     | ...                            | ...             | a               | ...       | -325                     | 30                                    | 15    |
| 64Cu-20Ni-8Zn-4Sn-4Pb                       | ...             | B584         | C97600     | ...                            | ...             | a               | ...       | -325                     | 40                                    | 17    |
| 87Cu-8Sn-4Zn-1Pb                            | ...             | B584         | C92300     | ...                            | ...             | a               | ...       | -325                     | 36                                    | 16    |
| 88Cu-Sn-Zn-Pb                               | ...             | B584         | C92200     | ...                            | ...             | a               | ...       | -325                     | 34                                    | 16    |
| 88Cu-Sn-Zn-Pb                               | ...             | B61          | C92200     | ...                            | ...             | a               | (9)       | -325                     | 34                                    | 16    |
| 88Cu-8Sn-4Zn                                | ...             | B584         | C90300     | ...                            | ...             | b               | ...       | -325                     | 40                                    | 18    |
| 88Cu-10Sn-2Zn                               | ...             | B584         | C90500     | ...                            | ...             | b               | ...       | -325                     | 40                                    | 18    |
| 58Cu-38Zn-1Sn-1Pb-1Fe                       | ...             | B584         | C86400     | ...                            | ...             | a               | (9)       | -325                     | 60                                    | 20    |
| 66Cu-25Ni-5Sn-2Pb-2Zn                       | ...             | B584         | C97800     | ...                            | ...             | a               | ...       | -325                     | 50                                    | 22    |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Min.<br>Temp.<br>to 100                            | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |      | UNS<br>No. | Spec.<br>No. |
|----------------------------------------------------|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------------|--------------|
|                                                    | 150                                                                        | 200  | 250  | 300  | 350  | 400  | 450  | 500  | 550  | 600  | 650  | 700  |            |              |
| Copper and Copper Alloy — Pipes and Tubes (Cont'd) |                                                                            |      |      |      |      |      |      |      |      |      |      |      |            |              |
| 15.0                                               | 14.5                                                                       | 13.6 | 13.0 | 12.6 | 12.2 | 4.3  | ...  | ...  | ...  | ...  | ...  | ...  | C10200     | B75          |
| 15.0                                               | 14.5                                                                       | 13.6 | 13.0 | 12.6 | 12.2 | 4.3  | ...  | ...  | ...  | ...  | ...  | ...  | C12000     | B75          |
| 15.0                                               | 14.5                                                                       | 13.6 | 13.0 | 12.6 | 12.2 | 4.3  | ...  | ...  | ...  | ...  | ...  | ...  | C12200     | B75          |
| Copper and Copper Alloy — Plates and Sheets        |                                                                            |      |      |      |      |      |      |      |      |      |      |      |            |              |
| 6.7                                                | 5.7                                                                        | 5.4  | 5.3  | 5.0  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C10200     | B152         |
| 6.7                                                | 5.7                                                                        | 5.4  | 5.3  | 5.0  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C10400     | B152         |
| 6.7                                                | 5.7                                                                        | 5.4  | 5.3  | 5.0  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C10500     | B152         |
| 6.7                                                | 5.7                                                                        | 5.4  | 5.3  | 5.0  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C10700     | B152         |
| 6.7                                                | 5.7                                                                        | 5.4  | 5.3  | 5.0  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12200     | B152         |
| 6.7                                                | 5.7                                                                        | 5.4  | 5.3  | 5.0  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C12300     | B152         |
| 10.0                                               | 9.7                                                                        | 9.5  | 9.3  | 9.1  | 8.9  | 8.7  | 8.5  | 8.0  | 7.0  | 6.0  | ...  | ...  | C70600     | B171         |
| 12.0                                               | 12.0                                                                       | 11.9 | 11.9 | 11.9 | 10.7 | 6.8  | ...  | ...  | ...  | ...  | ...  | ...  | C65500     | B96          |
| 13.3                                               | 12.9                                                                       | 12.6 | 12.3 | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.7 | 10.5 | 10.4 | C71500     | B171         |
| 20.0                                               | 19.9                                                                       | 19.8 | 19.7 | 19.5 | 19.4 | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...  | C61400     | B169         |
| 20.0                                               | 19.9                                                                       | 19.8 | 19.7 | 19.5 | 19.4 | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...  | C61400     | B169         |
| Copper and Copper Alloy — Forgings                 |                                                                            |      |      |      |      |      |      |      |      |      |      |      |            |              |
| 7.3                                                | 6.2                                                                        | 6.0  | 5.8  | 5.0  | 4.0  | 3.0  | 2.3  | 1.7  | ...  | ...  | ...  | ...  | C11000     | B283         |
| 12.0                                               | 12.0                                                                       | 11.9 | 11.9 | 11.9 | 10.7 | 6.8  | ...  | ...  | ...  | ...  | ...  | ...  | C65500     | B283         |
| 15.3                                               | 14.5                                                                       | 13.9 | 13.3 | 10.5 | 7.5  | 2.0  | ...  | ...  | ...  | ...  | ...  | ...  | C37700     | B283         |
| 16.0                                               | 16.0                                                                       | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | ...  | ...  | ...  | ...  | ...  | ...  | C48500     | B283         |
| 17.3                                               | 17.3                                                                       | 17.3 | 17.3 | 17.1 | 6.3  | 2.5  | ...  | ...  | ...  | ...  | ...  | ...  | C46400     | B283         |
| 22.7                                               | 22.7                                                                       | 22.7 | 22.7 | 22.7 | 22.7 | 22.7 | ...  | ...  | ...  | ...  | ...  | ...  | C67500     | B283         |
| Copper and Copper Alloy — Castings                 |                                                                            |      |      |      |      |      |      |      |      |      |      |      |            |              |
| 9.3                                                | 9.3                                                                        | 9.2  | 8.6  | 8.1  | 7.7  | 7.4  | 7.3  | ...  | ...  | ...  | ...  | ...  | C83600     | B62          |
| 10.0                                               | ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | C97300     | B584         |
| 11.3                                               | 10.1                                                                       | 9.5  | 9.1  | 8.7  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | C97600     | B584         |
| 10.7                                               | 10.7                                                                       | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | ...  | ...  | ...  | ...  | ...  | ...  | C92300     | B584         |
| 10.7                                               | 9.6                                                                        | 9.5  | 9.4  | 9.2  | 8.9  | 8.6  | ...  | ...  | ...  | ...  | ...  | ...  | C92200     | B584         |
| 10.7                                               | 9.6                                                                        | 9.5  | 9.4  | 9.2  | 8.9  | 8.6  | 8.4  | 8.3  | 8.3  | ...  | ...  | ...  | C92200     | B61          |
| 12.0                                               | 12.0                                                                       | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | ...  | ...  | ...  | ...  | ...  | ...  | C90300     | B584         |
| 12.0                                               | 12.0                                                                       | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | ...  | ...  | ...  | ...  | ...  | ...  | C90500     | B584         |
| 13.3                                               | 13.3                                                                       | 13.3 | 13.3 | 13.3 | 13.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | C86400     | B584         |
| 14.7                                               | 14.7                                                                       | 14.7 | 14.7 | 14.7 | 14.7 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | C97800     | B584         |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition             | Product<br>Form | Spec.<br>No. | UNS<br>No. | Class/<br>Condition/<br>Temper | Size Range, in. | P-No.<br>(5)(7) | Notes | Min.<br>Temp.,<br>°F (6) | Specified<br>Minimum<br>Strength, ksi |       |
|------------------------------------|-----------------|--------------|------------|--------------------------------|-----------------|-----------------|-------|--------------------------|---------------------------------------|-------|
|                                    |                 |              |            |                                |                 |                 |       |                          | Tensile                               | Yield |
| Copper and Copper Alloy — Castings |                 |              |            |                                |                 |                 |       |                          |                                       |       |
| 58Cu-39Zn-1Fe-1Al-1Mn              | ...             | B584         | C86500     | ...                            | ...             | b               | ...   | -325                     | 65                                    | 25    |
| 88Cu-9Al-3Fe                       | ...             | B148         | C95200     | ...                            | ...             | 35              | (9)   | -425                     | 65                                    | 25    |
| 89Cu-10Al-1Fe                      | ...             | B148         | C95300     | ...                            | ...             | 35              | (9)   | -425                     | 65                                    | 25    |
| 90Cu-7Al-3Si                       | ...             | B148         | C95600     | ...                            | ...             | 35              | ...   | -325                     | 60                                    | 28    |
| 85Cu-11Al-4Fe                      | ...             | B148         | C95400     | ...                            | ...             | 35              | ...   | -325                     | 75                                    | 30    |
| 58Cu-34Zn-2Fe-2Al-2Mn              | ...             | B584         | C86700     | ...                            | ...             | a               | ...   | -325                     | 80                                    | 32    |
| 82Cu-11Al-4Fe-3Mn                  | ...             | B148         | C95500     | ...                            | ...             | 35              | ...   | -452                     | 90                                    | 40    |
| 63Cu-27Zn-4Al-3Fe-3Mn              | ...             | B584         | C86200     | ...                            | ...             | b               | ...   | -325                     | 90                                    | 45    |
| 61Cu-27Zn-6Al-3Fe-3Mn              | ...             | B584         | C86300     | ...                            | ...             | b               | ...   | -325                     | 110                                   | 60    |
| Copper and Copper Alloy — Rod      |                 |              |            |                                |                 |                 |       |                          |                                       |       |
| 75Cu-21.5Zn-3Si                    | ...             | B371         | C69300     | H02                            | ≤½              | a               | ...   | -325                     | 85                                    | 45    |
| 75Cu-21.5Zn-3Si                    | ...             | B371         | C69300     | H02                            | >½, ≤1          | a               | ...   | -325                     | 75                                    | 35    |
| 75Cu-21.5Zn-3Si                    | ...             | B371         | C69300     | H02                            | >1, ≤2          | a               | ...   | -325                     | 70                                    | 30    |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |     |     |            |              |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-----|-----|------------|--------------|
| Min.<br>Temp.<br>to 100                                                    | 150  | 200  | 250  | 300  | 350  | 400  | 450  | 500  | 550  | 600  | 650 | 700 | UNS<br>No. | Spec.<br>No. |
| Copper and Copper Alloy — Castings (Cont'd)                                |      |      |      |      |      |      |      |      |      |      |     |     |            |              |
| 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | C86500     | B584         |
| 16.7                                                                       | 15.7 | 15.2 | 14.8 | 14.5 | 14.3 | 14.2 | 14.1 | 14.1 | 11.7 | 7.4  | ... | ... | C95200     | B148         |
| 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | ... | ... | C95300     | B148         |
| 18.7                                                                       | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | C95600     | B148         |
| 20.0                                                                       | 19.0 | 18.7 | 18.5 | 18.5 | 18.5 | 18.5 | 16.0 | 13.9 | ...  | ...  | ... | ... | C95400     | B148         |
| 21.3                                                                       | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | ...  | ...  | ...  | ...  | ...  | ... | ... | C86700     | B584         |
| 26.7                                                                       | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | ...  | ...  | ... | ... | C95500     | B148         |
| 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | C86200     | B584         |
| 36.7                                                                       | 36.7 | 36.7 | 36.7 | 36.7 | 36.7 | ...  | ...  | ...  | ...  | ...  | ... | ... | C86300     | B584         |
| Copper and Copper Alloy — Rod                                              |      |      |      |      |      |      |      |      |      |      |     |     |            |              |
| 28.3                                                                       | 25.9 | 25.4 | 25.4 | 25.4 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | C69300     | B371         |
| 23.3                                                                       | 20.2 | 19.8 | 19.8 | 19.8 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | C69300     | B371         |
| 20.0                                                                       | 17.3 | 17.0 | 17.0 | 17.0 | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | C69300     | B371         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition                            | Spec. No. | UNS No. | Class/Condition/<br>Temper  | Size Range, in. | P-No. (5) | Notes | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |  |
|------------------------------------------------|-----------|---------|-----------------------------|-----------------|-----------|-------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|------|------|------|--|
|                                                |           |         |                             |                 |           |       |                    | Tensile                      | Yield | Min. Temp. to 100                                                          |      |      |      |      |      |      |      |  |
|                                                |           |         |                             |                 |           |       |                    |                              |       |                                                                            | 200  | 300  | 400  | 500  | 600  | 650  | 700  |  |
| Nickel and Nickel Alloy — Pipes and Tubes (4a) |           |         |                             |                 |           |       |                    |                              |       |                                                                            |      |      |      |      |      |      |      |  |
| 99.0Ni–Low C                                   | B161      | N02201  | Annealed                    | >5 O.D.         | 41        | ...   | –325               | 50                           | 10    | 6.7                                                                        | 6.4  | 6.3  | 6.3  | 6.3  | 6.3  | 6.2  | 6.2  |  |
| 99.0Ni–Low C                                   | B725      | N02201  | Annealed                    | >5 O.D.         | 41        | ...   | –325               | 50                           | 10    | 6.7                                                                        | 6.4  | 6.3  | 6.3  | 6.3  | 6.3  | 6.2  | 6.2  |  |
| 99.0Ni                                         | B161      | N02200  | Annealed                    | >5 O.D.         | 41        | ...   | –325               | 55                           | 12    | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 8.0  | 8.0  | ...  | ...  |  |
| 99.0Ni                                         | B725      | N02200  | Annealed                    | >5 O.D.         | 41        | ...   | –325               | 55                           | 12    | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 8.0  | 8.0  | ...  | ...  |  |
| 99.0Ni–Low C                                   | B161      | N02201  | Annealed                    | ≤5 O.D.         | 41        | ...   | –325               | 50                           | 12    | 8.0                                                                        | 7.7  | 7.5  | 7.5  | 7.5  | 7.5  | 7.5  | 7.4  |  |
| 99.0Ni–Low C                                   | B725      | N02201  | Annealed                    | ≤5 O.D.         | 41        | ...   | –325               | 50                           | 12    | 8.0                                                                        | 7.7  | 7.5  | 7.5  | 7.5  | 7.5  | 7.5  | 7.4  |  |
| 99.0Ni                                         | B161      | N02200  | Annealed                    | ≤5 O.D.         | 41        | ...   | –325               | 55                           | 15    | 10.0                                                                       | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | ...  | ...  |  |
| 99.0Ni                                         | B725      | N02200  | Annealed                    | ≤5 O.D.         | 41        | ...   | –325               | 55                           | 15    | 10.0                                                                       | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | ...  | ...  |  |
|                                                |           |         |                             |                 |           |       |                    |                              |       |                                                                            |      |      |      |      |      |      |      |  |
| 67Ni–30Cu                                      | B165      | N04400  | Annealed                    | >5 O.D.         | 42        | ...   | –325               | 70                           | 25    | 16.7                                                                       | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 | 13.1 | 13.0 |  |
| 67Ni–30Cu                                      | B725      | N04400  | Annealed                    | >5 O.D.         | 42        | ...   | –325               | 70                           | 25    | 16.7                                                                       | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 | 13.1 | 13.0 |  |
| 33Ni–42Fe–21Cr                                 | B407      | N08800  | H.F. or H.F. ann.           | ...             | 45        | ...   | –325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 |  |
| 72Ni–15Cr–8Fe                                  | B167      | N06600  | H.F. or H.F. ann.           | >5 O.D.         | 43        | ...   | –325               | 75                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 |  |
| 33Ni–42Fe–21Cr                                 | B407      | N08810  | C.D. sol. ann. or H.F. ann. | ...             | 45        | (62)  | –325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 | 16.1 | 15.7 |  |
| 33Ni–42Fe–21Cr                                 | B514      | N08810  | Annealed                    | ...             | 45        | (62)  | –325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 | 16.1 | 15.7 |  |
| 33Ni–42Fe–21Cr–Al–Ti                           | B407      | N08811  | C.D. sol. ann. or H.F. ann. | ...             | 45        | (62)  | –325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 | 16.1 | 15.7 |  |
|                                                |           |         |                             |                 |           |       |                    |                              |       |                                                                            |      |      |      |      |      |      |      |  |
| 67Ni–30Cu                                      | B165      | N04400  | Annealed                    | ≤5 O.D.         | 42        | ...   | –325               | 70                           | 28    | 18.7                                                                       | 16.4 | 15.2 | 14.7 | 14.7 | 14.7 | 14.7 | 14.6 |  |
| 67Ni–30Cu                                      | B725      | N04400  | Annealed                    | ≤5 O.D.         | 42        | ...   | –325               | 70                           | 28    | 18.7                                                                       | 16.4 | 15.2 | 14.7 | 14.7 | 14.7 | 14.7 | 14.6 |  |
| 26Ni–22Cr–5Mo–Ti                               | B619      | N08320  | Sol. ann.                   | ...             | 45        | ...   | –325               | 75                           | 28    | 18.7                                                                       | 18.7 | 18.7 | 18.7 | 18.7 | 18.6 | 18.2 | 17.8 |  |
| 26Ni–22Cr–5Mo–Ti                               | B622      | N08320  | Sol. ann.                   | ...             | 45        | ...   | –325               | 75                           | 28    | 18.7                                                                       | 18.7 | 18.7 | 18.7 | 18.7 | 18.6 | 18.2 | 17.8 |  |
| 99.0Ni–Low C                                   | B161      | N02201  | Str. rel.                   | ...             | 41        | ...   | –325               | 60                           | 30    | 20.0                                                                       | 20.0 | 19.8 | 19.8 | 19.7 | 19.0 | ...  | ...  |  |
| 99.0Ni–Low C                                   | B725      | N02201  | Str. rel.                   | ...             | 41        | ...   | –325               | 60                           | 30    | 20.0                                                                       | 20.0 | 19.8 | 19.8 | 19.7 | 19.0 | ...  | ...  |  |
| 33Ni–42Fe–21Cr                                 | B514      | N08800  | Annealed                    | ...             | 45        | ...   | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 72Ni–15Cr–8Fe                                  | B167      | N06600  | H.F. or H.F. ann.           | ≤5 O.D.         | 43        | ...   | –325               | 80                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 72Ni–15Cr–8Fe                                  | B167      | N06600  | C.D. ann.                   | >5 O.D.         | 43        | ...   | –325               | 80                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |  |
|                                                |           |         |                             |                 |           |       |                    |                              |       |                                                                            |      |      |      |      |      |      |      |  |
| 33Ni–42Fe–21Cr                                 | B407      | N08800  | C.D. ann.                   | ...             | 45        | (61)  | –325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 31Ni–31Fe–29Cr–Mo                              | B668      | N08028  | Sol. ann.                   | ...             | 45        | ...   | –325               | 73                           | 31    | 20.7                                                                       | 20.7 | 20.7 | 20.7 | 20.7 | 19.5 | 18.9 | 18.3 |  |
| 99.0Ni                                         | B161      | N02200  | Str. rel.                   | ...             | 41        | ...   | –325               | 65                           | 40    | 21.7                                                                       | 21.7 | 21.6 | 21.6 | 21.4 | 20.6 | ...  | ...  |  |
| 99.0Ni                                         | B725      | N02200  | Str. rel.                   | ...             | 41        | ...   | –325               | 65                           | 40    | 21.7                                                                       | 21.7 | 21.6 | 21.6 | 21.4 | 20.6 | ...  | ...  |  |
| 35Ni–35Fe–20Cr–Cb                              | B464      | N08020  | Annealed                    | ...             | 45        | ...   | –325               | 80                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |
| 35Ni–35Fe–20Cr–Cb                              | B474      | N08020  | Annealed                    | ...             | 45        | ...   | –325               | 80                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       | UNS<br>No. | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------|--------------|
| 750                                                                        | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 |            |              |
| Nickel and Nickel Alloy — Pipes and Tubes (4a)                             |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |            |              |
| 6.1                                                                        | 6.0  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201     | B161         |
| 6.1                                                                        | 6.0  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201     | B725         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200     | B161         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200     | B725         |
| 7.3                                                                        | 7.2  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201     | B161         |
| 7.3                                                                        | 7.2  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201     | B725         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200     | B161         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200     | B725         |
|                                                                            |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |            |              |
| 12.9                                                                       | 12.7 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400     | B165         |
| 12.9                                                                       | 12.7 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400     | B725         |
| 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.6  | 16.3  | 13.0  | 9.8   | 6.6   | 4.2   | 2.0   | 1.6   | 1.1   | 1.0   | 0.8   | ...   | ...   | ...   | N08800     | B407         |
| 16.7                                                                       | 16.7 | 16.7 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600     | B167         |
| 15.3                                                                       | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 11.6  | 9.3   | 7.4   | 5.9   | 4.7   | 3.8   | 3.0   | 2.4   | 1.9   | 1.4   | 1.1   | 0.86  | N08810     | B407         |
| 15.3                                                                       | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 11.6  | 9.3   | 7.4   | 5.9   | 4.7   | 3.8   | 3.0   | 2.4   | 1.9   | 1.4   | 1.1   | 0.86  | N08810     | B514         |
| 15.3                                                                       | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 12.9  | 10.4  | 8.3   | 6.7   | 5.4   | 4.3   | 3.4   | 2.7   | 2.2   | 1.6   | 1.2   | 0.91  | N08811     | B407         |
|                                                                            |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |            |              |
| 14.5                                                                       | 14.3 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400     | B165         |
| 14.5                                                                       | 14.3 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400     | B725         |
| 17.5                                                                       | 17.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08320     | B619         |
| 17.5                                                                       | 17.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08320     | B622         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201     | B161         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201     | B725         |
| 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 19.9  | 17.0  | 13.0  | 9.8   | 6.6   | 4.2   | 2.0   | 1.6   | 1.1   | 1.0   | 0.8   | ...   | ...   | ...   | N08800     | B514         |
| 20.0                                                                       | 20.0 | 20.0 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600     | B167         |
| 20.0                                                                       | 20.0 | 20.0 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600     | B167         |
|                                                                            |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |            |              |
| 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 19.9  | 17.0  | 13.0  | 9.8   | 6.6   | 4.2   | 2.0   | 1.6   | 1.1   | 1.0   | 0.8   | ...   | ...   | ...   | N08800     | B407         |
| 17.7                                                                       | 17.2 | 16.7 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08028     | B668         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200     | B161         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200     | B725         |
| 23.2                                                                       | 22.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08020     | B464         |
| 23.2                                                                       | 22.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08020     | B474         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                         | Spec.<br>No. | UNS<br>No. | Class/<br>Condition/<br>Temper | Size<br>Range,<br>in. | P-<br>No.<br>(5) | Notes | Min.<br>Temp.,<br>°F (6) | Specified<br>Min.<br>Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal<br>Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |
|------------------------------------------------|--------------|------------|--------------------------------|-----------------------|------------------|-------|--------------------------|------------------------------------|-------|-------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|
|                                                |              |            |                                |                       |                  |       |                          | Tensile                            | Yield | Min.<br>Temp.<br>to 100                                                       | 200  | 300  | 400  | 500  | 600  | 650  | 700  |      |
|                                                |              |            |                                |                       |                  |       |                          |                                    |       |                                                                               |      |      |      |      |      |      |      |      |
| Nickel and Nickel Alloy — Pipes and Tubes (4a) |              |            |                                |                       |                  |       |                          |                                    |       |                                                                               |      |      |      |      |      |      |      |      |
| 35Ni-35Fe-<br>20Cr-Cb                          | B729         | N08020     | Annealed                       | ...                   | 45               | ...   | -325                     | 80                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 42Ni-21.5Cr-<br>3Mo-2.3Cu                      | B163         | N08825     | Annealed                       | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 42Ni-21.5Cr-<br>3Mo-2.3Cu                      | B423         | N08825     | C.D. ann.                      | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 42Ni-21.5Cr-<br>3Mo-2.3Cu                      | B474         | N08825     | Annealed                       | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 42Ni-21.5Cr-<br>3Mo-2.3Cu                      | B704         | N08825     | Annealed                       | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 42Ni-21.5Cr-<br>3Mo-2.3Cu                      | B705         | N08825     | ...                            | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 47Ni-22Cr-<br>19Fe-6Mo                         | B619         | N06007     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 90                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 22.7 | 22.4 | 22.2 |
| 47Ni-22Cr-<br>19Fe-6Mo                         | B622         | N06007     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 90                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 22.7 | 22.4 | 22.2 |
| 40Ni-29Cr-<br>15Fe-5Mo                         | B619         | N06030     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.2 | 22.1 | 21.3 | 20.9 | 20.5 | 20.5 |
| 40Ni-29Cr-<br>15Fe-5Mo                         | B622         | N06030     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.2 | 22.1 | 21.3 | 20.9 | 20.5 | 20.5 |
| 40Ni-29Cr-<br>15Fe-5Mo                         | B626         | N06030     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.2 | 22.1 | 21.3 | 20.9 | 20.5 | 20.5 |
| 72Ni-15Cr-<br>8Fe                              | B167         | N06600     | C.D. ann.                      | ≤5 O.D.               | 43               | ...   | -325                     | 80                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 72Ni-15Cr-<br>8Fe                              | B517         | N06600     | C.D. ann.                      | ...                   | 43               | ...   | -325                     | 80                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 58Ni-29Cr-<br>9Fe                              | B163         | N06690     | C.D. ann.                      | ≤3 O.D.               | 43               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 58Ni-29Cr-<br>9Fe                              | B167         | N06690     | C.D. ann.                      | ≤5 O.D.               | 43               | ...   | -325                     | 85                                 | 35    | 23.3                                                                          | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 37Ni-33Fe-<br>25Cr                             | B163         | N08120     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 90                                 | 40    | 26.7                                                                          | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 | 23.3 | 22.9 | 22.9 |
| 37Ni-33Fe-<br>25Cr                             | B407         | N08120     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 90                                 | 40    | 26.7                                                                          | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 | 23.3 | 22.9 | 22.9 |
| 37Ni-33Fe-<br>25Cr                             | B514         | N08120     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 90                                 | 40    | 26.7                                                                          | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 | 23.3 | 22.9 | 22.9 |
| 37Ni-33Fe-<br>25Cr                             | B515         | N08120     | Sol. ann.                      | ...                   | 45               | ...   | -325                     | 90                                 | 40    | 26.7                                                                          | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 | 23.3 | 22.9 | 22.9 |
| 61Ni-16Mo-<br>16Cr                             | B619         | N06455     | Sol. ann.                      | ...                   | 43               | ...   | -325                     | 100                                | 40    | 26.7                                                                          | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.5 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       | UNS    | Spec. |
|----------------------------------------------------------------------------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|
| 750                                                                        | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | No.    | No.   |
| Nickel and Nickel Alloy — Pipes and Tubes (4a) (Cont'd)                    |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |        |       |
| 23.2                                                                       | 22.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08020 | B729  |
| 23.2                                                                       | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825 | B163  |
| 23.2                                                                       | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825 | B423  |
| 23.2                                                                       | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825 | B474  |
| 23.2                                                                       | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825 | B704  |
| 23.2                                                                       | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825 | B705  |
| 22.0                                                                       | 21.8 | 21.7 | 20.0 | 19.5 | 18.9  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06007 | B619  |
| 22.0                                                                       | 21.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06007 | B622  |
| 20.1                                                                       | 19.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06030 | B619  |
| 20.1                                                                       | 19.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06030 | B622  |
| 20.1                                                                       | 19.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06030 | B626  |
| 23.3                                                                       | 23.3 | 23.3 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600 | B167  |
| 23.3                                                                       | 23.3 | 23.3 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600 | B517  |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06690 | B163  |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06690 | B167  |
| 22.6                                                                       | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4   | N08120 | B163  |
| 22.6                                                                       | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4   | N08120 | B407  |
| 22.6                                                                       | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4   | N08120 | B514  |
| 22.6                                                                       | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4   | N08120 | B515  |
| 26.2                                                                       | 25.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06455 | B619  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition                            | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size Range, in.                | P-No. (5) | Notes        | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |  |
|------------------------------------------------|--------------|-----------|------------|---------|----------------------------|--------------------------------|-----------|--------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|------|--|
|                                                |              |           |            |         |                            |                                |           |              |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 200  | 300  | 400  | 500  | 600  |  |
|                                                |              |           |            |         |                            |                                |           |              |                    |                              |       |                                                                            |      |      |      |      |      |  |
| Nickel and Nickel Alloy — Pipes and Tubes (4a) |              |           |            |         |                            |                                |           |              |                    |                              |       |                                                                            |      |      |      |      |      |  |
| 47Ni-22Cr-9Mo-18Fe                             | ...          | B619      | ...        | N06002  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 40    | 26.7                                                                       | 26.7 | 26.7 | 25.5 | 24.2 |      |  |
| 47Ni-22Cr-9Mo-18Fe                             | ...          | B622      | ...        | N06002  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 25.5 | 24.2 |  |
| 31Ni-33Fe-27Cr-6.5Mo-Cu-N                      | ...          | B619      | ...        | N08031  | Annealed                   | ...                            | 45        | ...          | -325               | 94                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |  |
| 31Ni-33Fe-27Cr-6.5Mo-Cu-N                      | ...          | B622      | ...        | N08031  | Annealed                   | ...                            | 45        | ...          | -325               | 94                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |  |
| 61Ni-16Mo-16Cr                                 | ...          | B622      | ...        | N06455  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 |  |
| 54Ni-16Mo-15Cr                                 | ...          | B619      | ...        | N10276  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |  |
| 54Ni-16Mo-15Cr                                 | ...          | B622      | ...        | N10276  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |  |
| 54Ni-16Mo-15Cr                                 | ...          | B626      | ...        | N10276  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |  |
| 67Ni-30Cu                                      | ...          | B165      | ...        | N04400  | Str. rel.                  | ...                            | 42        | (54)         | -325               | 85                           | 55    | 28.3                                                                       | 28.3 | 28.3 | 28.3 | 28.3 | ...  |  |
| 67Ni-30Cu                                      | ...          | B725      | ...        | N04400  | Str. rel.                  | ...                            | 42        | (54)         | -325               | 85                           | 55    | 28.3                                                                       | 28.3 | 28.3 | 28.3 | 28.3 | ...  |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                        | ...          | B675      | ...        | N08367  | Annealed                   | > <sup>3</sup> / <sub>16</sub> | 45        | ...          | -325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 | 27.7 | 26.2 |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                        | ...          | B690      | ...        | N08367  | Annealed                   | > <sup>3</sup> / <sub>16</sub> | 45        | ...          | -325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 | 27.7 | 26.2 |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                        | ...          | B804      | ...        | N08367  | Annealed                   | > <sup>3</sup> / <sub>16</sub> | 45        | ...          | -325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 | 27.7 | 26.2 |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                        | ...          | B675      | ...        | N08367  | Annealed                   | ≤ <sup>3</sup> / <sub>16</sub> | 45        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 29.6 | 27.7 | 26.2 |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                        | ...          | B690      | ...        | N08367  | Annealed                   | ≤ <sup>3</sup> / <sub>16</sub> | 45        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 29.6 | 27.7 | 26.2 |  |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                        | ...          | B804      | ...        | N08367  | Annealed                   | ≤ <sup>3</sup> / <sub>16</sub> | 45        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 | 27.7 | 26.2 |  |
| 55Ni-21Cr-13.5Mo                               | ...          | B619      | ...        | N06022  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.0 | 27.6 |  |
| 55Ni-21Cr-13.5Mo                               | ...          | B622      | ...        | N06022  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.0 | 27.6 |  |
| 58Ni-33Cr-8Mo                                  | ...          | B619      | ...        | N06035  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |  |
| 58Ni-33Cr-8Mo                                  | ...          | B622      | ...        | N06035  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |  |
| 58Ni-33Cr-8Mo                                  | ...          | B626      | ...        | N06035  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |  |
| 59Ni-23Cr-16Mo                                 | ...          | B619      | ...        | N06059  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |  |
| 59Ni-23Cr-16Mo                                 | ...          | B622      | ...        | N06059  | Sol. ann.                  | ...                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |  |
| 59Ni-23Cr-16Mo                                 | ...          | B626      | ...        | N06059  | Sol. ann.                  | All                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |  |
| 59Ni-23Cr-16Mo-1.6Cu                           | ...          | B619      | ...        | N06200  | Sol. ann.                  | All                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |  |
| 59Ni-23Cr-16Mo-1.6Cu                           | ...          | B622      | ...        | N06200  | Sol. ann.                  | All                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |  |
| 59Ni-23Cr-16Mo-1.6Cu                           | ...          | B626      | ...        | N06200  | Sol. ann.                  | All                            | 43        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |  |
| 62Ni-22Mo-15Cr                                 | ...          | B619      | ...        | N10362  | Sol. ann.                  | All                            | 43        | ...          | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |  |
| 62Ni-22Mo-15Cr                                 | ...          | B622      | ...        | N10362  | Sol. ann.                  | All                            | 43        | ...          | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |  |
| 62Ni-22Mo-15Cr                                 | ...          | B626      | ...        | N10362  | Sol. ann.                  | All                            | 43        | ...          | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |  |
| 62Ni-28Mo-5Fe                                  | ...          | B619      | ...        | N10001  | Sol. ann.                  | ...                            | 44        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |  |
| 62Ni-28Mo-5Fe                                  | ...          | B622      | ...        | N10001  | Sol. ann.                  | ...                            | 44        | ...          | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |  |
| 65Ni-28Mo-2Fe                                  | ...          | B619      | ...        | N10665  | Sol. ann.                  | ...                            | 44        | ...          | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 65Ni-28Mo-2Fe                                  | ...          | B622      | ...        | N10665  | Sol. ann.                  | ...                            | 44        | ...          | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 65Ni-29.5Mo-2Fe-2Cr                            | ...          | B619      | ...        | N10675  | Sol. ann.                  | ...                            | 44        | ...          | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 65Ni-29.5Mo-2Fe-2Cr                            | ...          | B622      | ...        | N10675  | Sol. ann.                  | ...                            | 44        | ...          | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 65Ni-29.5Mo-2Fe-2Cr                            | ...          | B626      | ...        | N10675  | Sol. ann.                  | ...                            | 44        | ...          | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 60Ni-22Cr-9Mo-3.5Cb                            | ...          | B444      | 1          | N06625  | Annealed                   | ...                            | 43        | (64)<br>(70) | -325               | 120                          | 60    | 40.0                                                                       | 40.0 | 39.6 | 39.2 | 38.6 | 37.8 |  |
| 60Ni-22Cr-9Mo-3.5Cb                            | ...          | B705      | 1          | N06625  | Annealed                   | ...                            | 43        | (64)<br>(70) | -325               | 120                          | 60    | 40.0                                                                       | 40.0 | 39.6 | 39.2 | 38.6 | 37.8 |  |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                                                | UNS<br>No. or<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------------------------------------------|------------------------|--------------|
| 650                                                                        | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | Nickel and Nickel Alloy — Pipes and Tubes (4a) |                        |              |
| 23.7                                                                       | 23.3 | 22.9 | 22.7 | 22.5 | 19.6 | 19.5 | 19.3  | 19.3  | 17.5  | 14.1  | 11.3  | 9.3   | 7.7   | 6.1   | 4.8   | 3.8   | 3.0   | ...   | ...   | ...   | N06002                                         | B619                   |              |
| 23.7                                                                       | 23.3 | 22.9 | 22.7 | 22.5 | 19.6 | 19.5 | 19.3  | 19.3  | 17.5  | 14.1  | 11.3  | 9.3   | 7.7   | 6.1   | 4.8   | 3.8   | 3.0   | ...   | ...   | ...   | N06002                                         | B622                   |              |
| 21.7                                                                       | 11.1 | 8.9  | 7.2  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08031                                         | B619                   |              |
| 21.7                                                                       | 11.1 | 8.9  | 7.2  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08031                                         | B622                   |              |
| 26.7                                                                       | 26.5 | 26.1 | 25.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06455                                         | B622                   |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276                                         | B619                   |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276                                         | B622                   |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276                                         | B626                   |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400                                         | B165                   |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400                                         | B725                   |              |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                                         | B675                   |              |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                                         | B690                   |              |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                                         | B804                   |              |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                                         | B675                   |              |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                                         | B690                   |              |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                                         | B804                   |              |
| 27.0                                                                       | 26.5 | 26.1 | 25.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06022                                         | B619                   |              |
| 27.0                                                                       | 26.5 | 26.1 | 25.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06022                                         | B622                   |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035                                         | B619                   |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035                                         | B622                   |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035                                         | B626                   |              |
| 27.5                                                                       | 26.8 | 26.1 | 25.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06059                                         | B619                   |              |
| 27.5                                                                       | 26.8 | 26.1 | 25.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06059                                         | B622                   |              |
| 27.5                                                                       | 26.8 | 26.1 | 25.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06059                                         | B626                   |              |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                                         | B619                   |              |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                                         | B622                   |              |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                                         | B626                   |              |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                                         | B619                   |              |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                                         | B622                   |              |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                                         | B626                   |              |
| 30.0                                                                       | 30.0 | 30.0 | 29.9 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10001                                         | B619                   |              |
| 30.0                                                                       | 30.0 | 30.0 | 29.9 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10001                                         | B622                   |              |
| 34.0                                                                       | 34.0 | 34.0 | 34.0 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10665                                         | B619                   |              |
| 34.0                                                                       | 34.0 | 34.0 | 34.0 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10665                                         | B622                   |              |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                                         | B619                   |              |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                                         | B622                   |              |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                                         | B626                   |              |
| 37.4                                                                       | 37.0 | 36.6 | 36.3 | 36.1 | 35.8 | 35.4 | 31.2  | 31.2  | 23.1  | 21.0  | 13.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06625                                         | B444                   |              |
| 37.4                                                                       | 37.0 | 36.6 | 36.3 | 36.1 | 35.8 | 35.4 | 31.2  | 31.2  | 23.1  | 21.0  | 13.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06625                                         | B705                   |              |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition                              | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size Range, in. | P-No. (5) | Notes     | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |  |
|--------------------------------------------------|--------------|-----------|------------|---------|----------------------|-----------------|-----------|-----------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|------|--|
|                                                  |              |           |            |         |                      |                 |           |           |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 200  | 300  | 400  | 500  | 600  |  |
| Nickel and Nickel Alloy — Pipes and Tubes (4a)   |              |           |            |         |                      |                 |           |           |                    |                              |       |                                                                            |      |      |      |      |      |  |
| 57Ni-22Cr-14W-2Mo-La                             | ...          | B619      | ...        | N06230  | Sol. ann.            | ...             | 43        | ...       | -325               | 110                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |  |
| 57Ni-22Cr-14W-2Mo-La                             | ...          | B622      | ...        | N06230  | Sol. ann.            | ...             | 43        | ...       | -325               | 110                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |  |
| 57Ni-22Cr-14W-2Mo-La                             | ...          | B626      | ...        | N06230  | Sol. ann.            | ...             | 43        | ...       | -325               | 110                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |  |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N                     | ...          | B619      | ...        | R20033  | Sol. ann.            | All             | 45        | ...       | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |  |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N                     | ...          | B622      | ...        | R20033  | Sol. ann.            | All             | 45        | ...       | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |  |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N                     | ...          | B626      | ...        | R20033  | Sol. ann.            | All             | 45        | ...       | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |  |
| Nickel and Nickel Alloy — Plates and Sheets (4a) |              |           |            |         |                      |                 |           |           |                    |                              |       |                                                                            |      |      |      |      |      |  |
| 99.0Ni-Low C                                     | Plate        | B162      | ...        | N02201  | H.R. ann.            | ...             | 41        | ...       | -325               | 50                           | 12    | 8.0                                                                        | 7.7  | 7.5  | 7.5  | 7.5  | 7.5  |  |
| 99.0Ni-Low C                                     | Plate        | B162      | ...        | N02201  | H.R. as R.           | ...             | 41        | ...       | -325               | 50                           | 12    | 8.0                                                                        | 7.7  | 7.5  | 7.5  | 7.5  | 7.5  |  |
| 99.0Ni                                           | Plate        | B162      | ...        | N02200  | H.R. ann.            | ...             | 41        | ...       | -325               | 55                           | 15    | 10.0                                                                       | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |  |
| 99.0Ni                                           | Plate        | B162      | ...        | N02200  | H.R. as R.           | ...             | 41        | ...       | -325               | 55                           | 20    | 13.3                                                                       | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 |  |
| 33Ni-42Fe-21Cr                                   | ...          | B409      | ...        | N08810  | Annealed             | All             | 45        | ...       | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.6 |  |
| 33Ni-42Fe-21Cr-Al-Ti                             | ...          | B409      | ...        | N08811  | Annealed             | All             | 45        | ...       | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |  |
| 26Ni-22Cr-5Mo-Ti                                 | ...          | B620      | ...        | N08320  | Sol. ann.            | All             | 45        | ...       | -325               | 75                           | 28    | 18.7                                                                       | 18.7 | 18.7 | 18.7 | 18.7 | 18.6 |  |
| 67Ni-30Cu                                        | Plate        | B127      | ...        | N04400  | H.R. ann.            | ...             | 42        | ...       | -325               | 70                           | 28    | 18.7                                                                       | 16.4 | 15.2 | 14.7 | 14.7 | 14.7 |  |
| 47Ni-22Cr-19Fe-6Mo                               | ...          | B582      | ...        | N06007  | Sol. ann.            | >3⁄4            | 45        | ...       | -325               | 85                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 19.5 |  |
| 33Ni-42Fe-21Cr                                   | ...          | B409      | ...        | N08800  | Annealed             | All             | 45        | ...       | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 31Ni-31Fe-29Cr-Mo                                | ...          | B709      | ...        | N08028  | Sol. ann.            | ...             | 45        | ...       | -325               | 73                           | 31    | 20.7                                                                       | 20.7 | 20.7 | 20.7 | 20.7 | 19.5 |  |
| 42Ni-21.5Cr-3Mo-2.3Cu                            | ...          | B424      | ...        | N08825  | Annealed             | ...             | 45        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |
| 35Ni-35Fe-20Cr-Cb                                | ...          | B463      | ...        | N08020  | Annealed             | All             | 45        | ...       | -325               | 80                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |
| 40Ni-29Cr-15Fe-5Mo                               | ...          | B582      | ...        | N06030  | Sol. ann.            | All             | 45        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.2 | 22.1 | 21.3 |  |
| 47Ni-22Cr-19Fe-6Mo                               | ...          | B582      | ...        | N06007  | Sol. ann.            | ≤3⁄4            | 45        | ...       | -325               | 90                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 22.7 |  |
| 47Ni-22Cr-9Mo-18Fe                               | ...          | B435      | ...        | N06002  | H.R. sol. ann.       | All             | 43        | ...       | -325               | 95                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 22.3 | 21.2 |  |
| 72Ni-15Cr-8Fe                                    | Plate        | B168      | ...        | N06600  | H.R. ann.            | ...             | 43        | ...       | -325               | 80                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |
| 72Ni-15Cr-8Fe                                    | Plate        | B168      | ...        | N06600  | H.R. as R.           | ...             | 43        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |
| 58Ni-29Cr-9Fe                                    | Plate        | B168      | ...        | N06690  | Annealed             | ≥3⁄16           | 43        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |
| 58Ni-29Cr-9Fe                                    | Sheet        | B168      | ...        | N06690  | Annealed             | 0.018-0.250     | 43        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |  |
| 67Ni-30Cu                                        | Plate        | B127      | ...        | N04400  | H.R. as R.           | ...             | 42        | ...       | -325               | 75                           | 40    | 25.0                                                                       | 25.0 | 24.7 | 23.9 | 23.4 | 23.1 |  |
| 37Ni-33Fe-25Cr                                   | ...          | B409      | ...        | N08120  | Sol. ann.            | All             | 45        | ...       | -325               | 90                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 |  |
| 31Ni-33Fe-27Cr-6.5Mo-Cu-N                        | ...          | B625      | ...        | N08031  | Annealed             | All             | 45        | ...       | -325               | 94                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |  |
| 61Ni-16Mo-16Cr                                   | ...          | B575      | ...        | N06455  | Sol. ann.            | All             | 43        | ...       | -325               | 100                          | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 |  |
| 54Ni-16Mo-15Cr                                   | ...          | B575      | ...        | N10276  | Sol. ann.            | All             | 43        | ...       | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |  |
| 60Ni-22Cr-9Mo-3.5Cb                              | Plate        | B443      | 1          | N06625  | Annealed             | All             | 43        | (64) (70) | -325               | 110                          | 55    | 36.7                                                                       | 36.7 | 36.3 | 35.9 | 35.4 | 34.7 |  |
| 57Ni-22Cr-14W-2Mo-La                             | ...          | B435      | ...        | N06230  | Sol. ann.            | All             | 43        | ...       | -325               | 110                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |  |
| 55Ni-21Cr-13.5Mo                                 | Sheet        | B575      | ...        | N06022  | Sol. ann.            | <3⁄16           | 43        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.0 | 27.6 |  |
| 58Ni-33Cr-8Mo                                    | ...          | B575      | ...        | N06035  | Sol. ann.            | All             | 43        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         | UNS<br>No. or<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|---------------------------------------------------------|------------------------|--------------|
| 650                                                                        | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650  | Nickel and Nickel Alloy — Pipes and Tubes (4a) (Cont'd) |                        |              |
| 29.1                                                                       | 28.7 | 28.4 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2  | 28.2  | 23.2  | 19.0  | 15.6  | 12.9  | 10.6  | 8.5   | 6.7   | 5.3   | 4.1   | 2.9   | 2.1   | 1.5    | N06230                                                  | B619                   |              |
| 29.1                                                                       | 28.7 | 28.4 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2  | 28.2  | 23.2  | 19.0  | 15.6  | 12.9  | 10.6  | 8.5   | 6.7   | 5.3   | 4.1   | 2.9   | 2.1   | 1.5    | N06230                                                  | B622                   |              |
| 29.1                                                                       | 28.7 | 28.4 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2  | 28.2  | 23.2  | 19.0  | 15.6  | 12.9  | 10.6  | 8.5   | 6.7   | 5.3   | 4.1   | 2.9   | 2.1   | 1.5    | N06230                                                  | B626                   |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | R20033                                                  | B619                   |              |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | R20033                                                  | B622                   |              |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    | R20033                                                  | B626                   |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| Nickel and Nickel Alloy — Plates and Sheets (4a)                           |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 7.5                                                                        | 7.4  | 7.4  | 7.2  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201 | B162                                                    |                        |              |
| 7.5                                                                        | 7.4  | 7.4  | 7.2  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201 | B162                                                    |                        |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200 | B162                                                    |                        |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200 | B162                                                    |                        |              |
| 16.2                                                                       | 15.8 | 15.5 | 15.1 | 14.9 | 14.6 | 14.3 | 14.0  | 13.8  | 11.6  | 9.3   | 7.4   | 5.9   | 4.7   | 3.8   | 3.0   | 2.4   | 1.9   | 1.4   | 1.1   | 0.86   | N08810                                                  | B409                   |              |
| 16.1                                                                       | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.7  | 12.9  | 10.4  | 8.3   | 6.7   | 5.4   | 4.3   | 3.4   | 2.7   | 2.2   | 1.6   | 1.2   | 0.91   | N08811                                                  | B409                   |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 18.2                                                                       | 17.8 | 17.5 | 17.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08320 | B620                                                    |                        |              |
| 14.7                                                                       | 14.6 | 14.5 | 14.3 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400 | B127                                                    |                        |              |
| 19.2                                                                       | 19.0 | 18.8 | 18.7 | 18.6 | 18.5 | 18.4 | 18.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06007 | B582                                                    |                        |              |
| 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 19.9  | 17.0  | 13.0  | 9.8   | 6.6   | 4.2   | 2.0   | 1.6   | 1.1   | 1.0   | 0.8   | ...   | ...   | N08800 | B409                                                    |                        |              |
| 18.9                                                                       | 18.3 | 17.7 | 17.2 | 16.7 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08028 | B709                                                    |                        |              |
| 23.3                                                                       | 23.3 | 23.2 | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825 | B424                                                    |                        |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 23.3                                                                       | 23.3 | 23.2 | 22.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08020 | B463                                                    |                        |              |
| 20.9                                                                       | 20.5 | 20.1 | 19.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06030 | B582                                                    |                        |              |
| 22.4                                                                       | 22.2 | 22.0 | 21.8 | 21.7 | 20.0 | 19.5 | 18.9  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06007 | B582                                                    |                        |              |
| 20.7                                                                       | 20.3 | 20.1 | 19.9 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06002 | B435                                                    |                        |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600 | B168                                                    |                        |              |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600 | B168                                                    |                        |              |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06690 | B168                                                    |                        |              |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06690 | B168                                                    |                        |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 22.9                                                                       | 22.7 | 20.0 | 14.5 | 8.5  | 4.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400 | B127                                                    |                        |              |
| 23.3                                                                       | 22.9 | 22.6 | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4    | N08120                                                  | B409                   |              |
| 21.7                                                                       | 21.3 | 20.9 | 20.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08031 | B625                                                    |                        |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 26.7                                                                       | 26.5 | 26.1 | 25.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06455 | B575                                                    |                        |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276 | B575                                                    |                        |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 34.3                                                                       | 33.9 | 33.6 | 33.3 | 33.1 | 32.8 | 32.5 | 31.2  | 31.2  | 23.1  | 21.0  | 13.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06625 | B443                                                    |                        |              |
| 29.1                                                                       | 28.7 | 28.4 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2  | 28.2  | 23.2  | 19.0  | 15.6  | 12.9  | 10.6  | 8.5   | 6.7   | 5.3   | 4.1   | 2.9   | 2.1   | 1.5    | N06230                                                  | B435                   |              |
|                                                                            |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |        |                                                         |                        |              |
| 27.0                                                                       | 26.5 | 26.1 | 25.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06022 | B575                                                    |                        |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035 | B575                                                    |                        |              |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition                                  | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size Range, in. | P-No. (5) | Notes     | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |
|------------------------------------------------------|--------------|-----------|------------|---------|----------------------|-----------------|-----------|-----------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|------|
|                                                      |              |           |            |         |                      |                 |           |           |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 200  | 300  | 400  | 500  | 600  |
| Nickel and Nickel Alloy — Plates and Sheets (4a)     |              |           |            |         |                      |                 |           |           |                    |                              |       |                                                                            |      |      |      |      |      |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                              | ...          | B688      | ...        | N08367  | Annealed             | >3⁄16           | 45        | ...       | -325               | 95                           | 45    | 30.0                                                                       | 30.0 | 29.9 | 28.6 | 27.7 | 26.2 |
| 46Fe-24Ni-21Cr-6Mo-Cu-N                              | ...          | B688      | ...        | N08367  | Annealed             | ≤3⁄16           | 45        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 29.6 | 27.7 | 26.2 |
| 59Ni-23Cr-16Mo                                       | ...          | B575      | ...        | N06059  | Sol. ann.            | All             | 43        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.6 | 28.1 |
| 59Ni-23Cr-16Mo-1.6Cu                                 | ...          | B575      | ...        | N06200  | Sol. ann.            | All             | 43        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |
| 62Ni-22Mo-15Cr                                       | ...          | B575      | ...        | N10362  | Sol. ann.            | All             | 43        | ...       | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |
| 62Ni-28Mo-5Fe                                        | Plate        | B333      | ...        | N10001  | Sol. ann.            | ≥3⁄16, ≤2½      | 44        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| 62Ni-28Mo-5Fe                                        | Sheet        | B333      | ...        | N10001  | Sol. ann.            | <3⁄16           | 44        | ...       | -325               | 115                          | 50    | 33.3                                                                       | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 |
| 65Ni-28Mo-2Fe                                        | ...          | B333      | ...        | N10665  | Sol. ann.            | All             | 44        | ...       | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 65Ni-29.5Mo-2Fe-2Cr                                  | ...          | B333      | ...        | N10675  | Sol. ann.            | All             | 44        | ...       | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N                         | ...          | B625      | ...        | R20033  | Sol. ann.            | All             | 45        | ...       | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |
| Nickel and Nickel Alloy — Forgings and Fittings (4a) |              |           |            |         |                      |                 |           |           |                    |                              |       |                                                                            |      |      |      |      |      |
| 99.0Ni-Low C                                         | ...          | B160      | ...        | N02201  | Annealed             | All             | 41        | (9) (9a)  | -325               | 50                           | 10    | 6.7                                                                        | 6.4  | 6.3  | 6.3  | 6.3  | 6.3  |
| 99.0Ni-Low C                                         | ...          | B366      | ...        | N02201  | Annealed             | All             | 41        | (32) (74) | -325               | 50                           | 10    | 6.7                                                                        | 6.4  | 6.3  | 6.3  | 6.3  | 6.3  |
| 99.0Ni                                               | ...          | B366      | ...        | N02200  | Annealed             | All             | 41        | (32) (74) | -325               | 55                           | 15    | 10.0                                                                       | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 33Ni-42Fe-21Cr                                       | ...          | B564      | ...        | N08810  | Annealed             | ...             | 45        | (9)       | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni-42Fe-21Cr-Al-Ti                                 | ...          | B564      | ...        | N08811  | Annealed             | ...             | 45        | (9)       | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni-42Fe-21Cr                                       | ...          | B366      | ...        | N08810  | Annealed             | All             | 45        | (9) (74)  | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni-42Fe-21Cr-Al-Ti                                 | ...          | B366      | ...        | N08811  | Annealed             | All             | 45        | (9) (74)  | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 67Ni-30Cu                                            | ...          | B564      | ...        | N04400  | Annealed             | ...             | 42        | (9)       | -325               | 70                           | 25    | 16.7                                                                       | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 |
| 67Ni-30Cu                                            | ...          | B366      | ...        | N04400  | Annealed             | All             | 42        | (32) (74) | -325               | 70                           | 25    | 16.7                                                                       | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 |
| 72Ni-15Cr-8Fe                                        | ...          | B366      | ...        | N06600  | Annealed             | All             | 43        | (32) (74) | -325               | 75                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 |
| 40Ni-29Cr-15Fe-5Mo                                   | ...          | B366      | ...        | N06030  | Sol. ann.            | All             | 45        | (74)      | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.2 | 22.1 | 21.3 |
| 40Ni-29Cr-15Fe-5Mo                                   | ...          | B462      | ...        | N06030  | Sol. ann.            | All             | 45        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.2 | 22.1 | 21.3 |
| 33Ni-42Fe-21Cr                                       | ...          | B366      | ...        | N08800  | C.D. ann.            | All             | 45        | (74)      | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 33Ni-42Fe-21Cr                                       | ...          | B564      | ...        | N08800  | Annealed             | ...             | 45        | (9)       | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 35Ni-35Fe-20Cr-Cb                                    | ...          | B366      | ...        | N08020  | Annealed             | All             | 45        | (74)      | -325               | 80                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 35Ni-35Fe-20Cr-Cb                                    | ...          | B462      | ...        | N08020  | Annealed             | ...             | 45        | (9)       | -325               | 80                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 72Ni-15Cr-8Fe                                        | ...          | B564      | ...        | N06600  | Annealed             | All             | 43        | (9)       | -325               | 80                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 42Ni-21.5Cr-3Mo-2.3Cu                                | ...          | B366      | ...        | N08825  | C.D. ann.            | All             | 45        | (74)      | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 42Ni-21.5Cr-3Mo-2.3Cu                                | ...          | B564      | ...        | N08825  | Annealed             | ...             | 45        | ...       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 58Ni-29Cr-9Fe                                        | Forg.        | B564      | ...        | N06690  | Annealed             | All             | 43        | (9)       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 37Ni-33Fe-25Cr                                       | ...          | B366      | ...        | N08120  | Sol. ann.            | All             | 45        | ...       | -325               | 90                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                        |              |
|----------------------------------------------------------------------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------------------|--------------|
| 650                                                                        | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS<br>No. or<br>Grade | Spec.<br>No. |
| Nickel and Nickel Alloy — Plates and Sheets (4a) (Cont'd)                  |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                        |              |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                 | B688         |
| 25.6                                                                       | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08367                 | B688         |
| 27.5                                                                       | 26.7 | 26.1 | 25.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06059                 | B575         |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                 | B575         |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                 | B575         |
| 30.0                                                                       | 30.0 | 30.0 | 29.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10001                 | B333         |
| 33.3                                                                       | 33.3 | 33.3 | 33.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10001                 | B333         |
| 34.0                                                                       | 34.0 | 34.0 | 34.0 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10665                 | B333         |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                 | B333         |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | R20033                 | B625         |
| Nickel and Nickel Alloy — Forgings and Fittings (4a)                       |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                        |              |
| 6.2                                                                        | 6.2  | 6.1  | 6.0  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201                 | B160         |
| 6.2                                                                        | 6.2  | 6.1  | 6.0  | 5.8  | 4.5  | 3.7  | 3.0   | 2.4   | 2.0   | 1.5   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02201                 | B366         |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200                 | B366         |
| 16.1                                                                       | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 11.6  | 9.3   | 7.4   | 5.9   | 4.7   | 3.8   | 3.0   | 2.4   | 1.9   | 1.4   | 1.1   | 0.86  | N08810                 | B564         |
| 16.1                                                                       | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 12.9  | 10.4  | 8.3   | 6.7   | 5.4   | 4.3   | 3.4   | 2.7   | 2.2   | 1.6   | 1.2   | 0.91  | N08811                 | B564         |
| 16.1                                                                       | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 11.6  | 9.3   | 7.4   | 5.9   | 4.7   | 3.8   | 3.0   | 2.4   | 1.9   | 1.4   | 1.1   | 0.86  | N08810                 | B366         |
| 16.1                                                                       | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 12.9  | 10.4  | 8.3   | 6.7   | 5.4   | 4.3   | 3.4   | 2.7   | 2.2   | 1.6   | 1.2   | 0.91  | N08811                 | B366         |
| 13.1                                                                       | 13.0 | 12.9 | 12.7 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400                 | B564         |
| 13.1                                                                       | 13.0 | 12.9 | 12.7 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400                 | B366         |
| 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.5 | 15.9 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600                 | B366         |
| 20.9                                                                       | 20.5 | 20.1 | 19.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06030                 | B366         |
| 20.9                                                                       | 20.5 | 20.1 | 19.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06030                 | B462         |
| 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 19.9  | 17.0  | 13.0  | 9.8   | 6.6   | 4.2   | 2.0   | 1.6   | 1.1   | 1.0   | 0.8   | ...   | ...   | ...   | N08800                 | B366         |
| 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 19.9  | 17.0  | 13.0  | 9.8   | 6.6   | 4.2   | 2.0   | 1.6   | 1.1   | 1.0   | 0.8   | ...   | ...   | ...   | N08800                 | B564         |
| 23.3                                                                       | 23.3 | 23.2 | 22.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08020                 | B366         |
| 23.3                                                                       | 23.3 | 23.2 | 22.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08020                 | B462         |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 16.0 | 10.6 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600                 | B564         |
| 23.3                                                                       | 23.3 | 23.2 | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825                 | B366         |
| 23.3                                                                       | 23.3 | 23.2 | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825                 | B564         |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06690                 | B564         |
| 23.3                                                                       | 22.9 | 22.6 | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4   | N08120                 | B366         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition                                  | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size Range, in. | P-No. (5) | Notes     | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |  |
|------------------------------------------------------|--------------|-----------|------------|---------|----------------------|-----------------|-----------|-----------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|------|--|
|                                                      |              |           |            |         |                      |                 |           |           |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 200  | 300  | 400  | 500  | 600  |  |
|                                                      |              |           |            |         |                      |                 |           |           |                    |                              |       |                                                                            |      |      |      |      |      |  |
| Nickel and Nickel Alloy — Forgings and Fittings (4a) |              |           |            |         |                      |                 |           |           |                    |                              |       |                                                                            |      |      |      |      |      |  |
| 37Ni-33Fe-25Cr                                       | ...          | B564      | ...        | N08120  | Sol. ann.            | All             | 45        | ...       | -325               | 90                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 |  |
| 47Ni-22Cr-9Mo-18Fe                                   | ...          | B366      | ...        | N06002  | Sol. ann.            | All             | 43        | (32)      | -325               | 100                          | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 25.5 | 24.2 |  |
| 31Ni-33Fe-27Cr-6.5Mo-Cu-N                            | ...          | B366      | ...        | N08031  | Sol. ann.            | All             | 45        | (74)      | -325               | 94                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |  |
| 31Ni-33Fe-27Cr-6.5Mo-Cu-N                            | ...          | B564      | ...        | N08031  | Annealed H.W.        | All             | 45        | ...       | -325               | 94                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |  |
| 54Ni-16Mo-15Cr                                       | ...          | B366      | ...        | N10276  | Sol. ann.            | All             | 43        | (74)      | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |  |
| 54Ni-16Mo-15Cr                                       | ...          | B462      | ...        | N10276  | Sol. ann.            | All             | 43        | (9)       | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |  |
| 54Ni-16Mo-15Cr                                       | ...          | B564      | ...        | N10276  | Sol. ann.            | All             | 43        | (9)       | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |  |
| 62Ni-28Mo-5Fe                                        | ...          | B366      | ...        | N10001  | Sol. ann.            | All             | 44        | (32)      | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |  |
| 55Ni-21Cr-13.5Mo                                     | ...          | B366      | ...        | N06022  | Sol. ann.            | All             | 43        | (32) (74) | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.0 | 27.6 |  |
| 55Ni-21Cr-13.5Mo                                     | ...          | B462      | ...        | N06022  | Sol. ann.            | All             | 43        | (9)       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 27.6 |  |
| 55Ni-21Cr-13.5Mo                                     | ...          | B564      | ...        | N06022  | Sol. ann.            | All             | 43        | (9)       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.0 | 27.6 |  |
| 58Ni-33Cr-8Mo                                        | ...          | B366      | ...        | N06035  | Sol. ann.            | All             | 43        | (32) (74) | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |  |
| 58Ni-33Cr-8Mo                                        | ...          | B462      | ...        | N06035  | Sol. ann.            | All             | 43        | (9)       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |  |
| 58Ni-33Cr-8Mo                                        | ...          | B564      | ...        | N06035  | Sol. ann.            | All             | 43        | (9)       | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |  |
| 59Ni-23Cr-16Mo                                       | ...          | B366      | ...        | N06059  | Sol. ann.            | All             | 43        | (74)      | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |  |
| 59Ni-23Cr-16Mo                                       | ...          | B564      | ...        | N06059  | H.W. sol. ann.       | All             | 43        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |  |
| 59Ni-23Cr-16Mo-1.6Cu                                 | ...          | B366      | ...        | N06200  | Sol. ann.            | All             | 43        | (74)      | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |  |
| 59Ni-23Cr-16Mo-1.6Cu                                 | ...          | B462      | ...        | N06200  | Sol. ann.            | All             | 43        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |  |
| 59Ni-23Cr-16Mo-1.6Cu                                 | ...          | B564      | ...        | N06200  | Sol. ann.            | All             | 43        | ...       | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |  |
| 62Ni-22Mo-15Cr                                       | ...          | B366      | ...        | N10362  | Sol. ann.            | All             | 43        | (9)       | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |  |
| 62Ni-22Mo-15Cr                                       | ...          | B462      | ...        | N10362  | Sol. ann.            | All             | 43        | (9)       | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |  |
| 62Ni-22Mo-15Cr                                       | ...          | B564      | ...        | N10362  | Sol. ann.            | All             | 43        | (9)       | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |  |
| 60Ni-22Cr-9Mo-3.5Cb                                  | ...          | B564      | ...        | N06625  | Annealed             | ≤4              | 43        | (9) (64)  | -325               | 120                          | 60    | 40.0                                                                       | 40.0 | 39.6 | 39.2 | 38.6 | 37.8 |  |
| 65Ni-28Mo-2Fe                                        | ...          | B366      | ...        | N10665  | Sol. ann.            | All             | 44        | (74)      | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 65Ni-29.5Mo-2Fe-2Cr                                  | ...          | B366      | ...        | N10675  | Sol. ann.            | All             | 44        | (74)      | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 65Ni-29.5Mo-2Fe-2Cr                                  | ...          | B462      | ...        | N10675  | Sol. ann.            | All             | 44        | ...       | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 65Ni-29.5Mo-2Fe-2Cr                                  | ...          | B564      | ...        | N10675  | Sol. ann.            | All             | 44        | ...       | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |  |
| 57Ni-22Cr-14W-2Mo-La                                 | ...          | B564      | ...        | N06230  | Sol. ann.            | All             | 43        | ...       | -325               | 110                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |  |
| 57Ni-22Cr-14W-2Mo-La                                 | ...          | B366      | ...        | N06230  | Sol. ann.            | All             | 43        | (74)      | -325               | 110                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |  |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N                         | ...          | B366      | ...        | R20033  | Sol. ann.            | All             | 45        | ...       | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |  |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N                         | ...          | B462      | ...        | R20033  | Sol. ann.            | All             | 45        | ...       | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |  |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N                         | ...          | B564      | ...        | R20033  | Sol. ann.            | All             | 45        | ...       | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |  |
| Nickel and Nickel Alloy — Rod and Bar (4a)           |              |           |            |         |                      |                 |           |           |                    |                              |       |                                                                            |      |      |      |      |      |  |
| 99.0Ni                                               | ...          | B160      | ...        | N02200  | H.W.                 | All             | 41        | (9)       | -325               | 60                           | 15    | 10.0                                                                       | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                                                               | UNS<br>No. or<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------------------------------------------------------------|------------------------|--------------|
| 650                                                                        | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | Nickel and Nickel Alloy — Forgings and Fittings (4a) (Cont'd) |                        |              |
| 23.3                                                                       | 22.9 | 22.6 | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4   | N08120                                                        | B564                   |              |
| 23.7                                                                       | 23.3 | 22.9 | 22.7 | 22.5 | 19.6 | 19.5 | 19.3  | 19.3  | 17.5  | 14.1  | 11.3  | 9.3   | 7.7   | 6.1   | 4.8   | 3.8   | 3.0   | ...   | ...   | ...   | N06002                                                        | B366                   |              |
| 21.7                                                                       | 21.3 | 20.9 | 20.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08031                                                        | B366                   |              |
| 21.7                                                                       | 21.3 | 20.9 | 20.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08031                                                        | B564                   |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276                                                        | B366                   |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276                                                        | B462                   |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276                                                        | B564                   |              |
| 30.0                                                                       | 30.0 | 30.0 | 29.9 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10001                                                        | B366                   |              |
| 27.0                                                                       | 26.5 | 26.1 | 25.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06022                                                        | B366                   |              |
| 27.0                                                                       | 26.5 | 26.1 | 25.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06022                                                        | B462                   |              |
| 27.0                                                                       | 26.5 | 26.1 | 25.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06022                                                        | B564                   |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035                                                        | B366                   |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035                                                        | B462                   |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035                                                        | B564                   |              |
| 27.5                                                                       | 26.8 | 26.1 | 25.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06059                                                        | B366                   |              |
| 27.5                                                                       | 26.8 | 26.1 | 25.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06059                                                        | B564                   |              |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                                                        | B366                   |              |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                                                        | B462                   |              |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                                                        | B564                   |              |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                                                        | B366                   |              |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                                                        | B462                   |              |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                                                        | B564                   |              |
| 37.4                                                                       | 37.0 | 36.6 | 36.3 | 36.1 | 35.8 | 35.4 | 31.2  | 31.2  | 23.1  | 21.0  | 13.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06625                                                        | B564                   |              |
| 34.0                                                                       | 34.0 | 34.0 | 34.0 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10665                                                        | B366                   |              |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                                                        | B366                   |              |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                                                        | B462                   |              |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                                                        | B564                   |              |
| 29.1                                                                       | 28.7 | 28.4 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2  | 28.2  | 23.2  | 19.0  | 15.6  | 12.9  | 10.6  | 8.5   | 6.7   | 5.3   | 4.1   | 2.9   | 2.1   | 1.5   | N06230                                                        | B564                   |              |
| 29.1                                                                       | 28.7 | 28.4 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2  | 28.2  | 23.2  | 19.0  | 15.6  | 12.9  | 10.6  | 8.5   | 6.7   | 5.3   | 4.1   | 2.9   | 2.1   | 1.5   | N06230                                                        | B366                   |              |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | R20033                                                        | B366                   |              |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | R20033                                                        | B462                   |              |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | R20033                                                        | B564                   |              |
| Nickel and Nickel Alloy — Rod and Bar (4a)                                 |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                                                               |                        |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200                                                        | B160                   |              |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition                        | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size Range, in.                                | P-No. (5) | Notes               | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |
|--------------------------------------------|--------------|-----------|------------|---------|----------------------|------------------------------------------------|-----------|---------------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|------|
|                                            |              |           |            |         |                      |                                                |           |                     |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 200  | 300  | 400  | 500  | 600  |
|                                            |              |           |            |         |                      |                                                |           |                     |                    |                              |       |                                                                            |      |      |      |      |      |
| Nickel and Nickel Alloy — Rod and Bar (4a) |              |           |            |         |                      |                                                |           |                     |                    |                              |       |                                                                            |      |      |      |      |      |
| 99.0Ni                                     | ...          | B160      | ...        | N02200  | Annealed             | All                                            | 41        | (9)                 | -325               | 55                           | 15    | 10.0                                                                       | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| 67Ni-30Cu                                  | ...          | B164      | ...        | N04400  | Ann. forg.           | All                                            | 42        | (13)                | -325               | 70                           | 25    | 16.7                                                                       | 14.6 | 13.6 | 13.2 | 13.1 | 13.1 |
| 33Ni-42Fe-21Cr                             | Bar          | B408      | ...        | N08810  | Sol. tr. or ann.     | ...                                            | 45        | ...                 | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni-42Fe-21Cr-Al-Ti                       | Bar          | B408      | ...        | N08811  | Sol. tr. or ann.     | ...                                            | 45        | ...                 | -325               | 65                           | 25    | 16.7                                                                       | 16.7 | 16.7 | 16.7 | 16.7 | 16.5 |
| 33Ni-42Fe-21Cr                             | Bar          | B408      | ...        | N08800  | H.F.                 | ...                                            | 45        | ...                 | -325               | 75                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| 26Ni-22Cr-5Mo-Ti                           | ...          | B621      | ...        | N08320  | Sol. ann.            | All                                            | 45        | ...                 | -325               | 75                           | 28    | 18.7                                                                       | 18.7 | 18.7 | 18.7 | 18.7 | 18.6 |
| 47Ni-22Cr-19Fe-6Mo                         | ...          | B581      | ...        | N06007  | Sol. ann.            | > <sup>3</sup> / <sub>4</sub>                  | 45        | ...                 | -325               | 85                           | 30    | 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 19.5 |
| 42Ni-21.5Cr-3Mo-2.3Cu                      | ...          | B425      | ...        | N08825  | Annealed             | ...                                            | 45        | ...                 | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 58Ni-29Cr-9Fe                              | Bar          | B166      | ...        | N06690  | H.R.                 | >3                                             | 43        | ...                 | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 58Ni-29Cr-9Fe                              | Bar          | B166      | ...        | N06690  | H.R or C.D. ann.     | All                                            | 43        | ...                 | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 47Ni-22Cr-19Fe-6Mo                         | ...          | B581      | ...        | N06007  | Sol. ann.            | ≤ <sup>3</sup> / <sub>4</sub>                  | 45        | ...                 | -325               | 90                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 22.7 |
| 40Ni-29Cr-15Fe-5Mo                         | ...          | B581      | ...        | N06030  | Sol. ann.            | All                                            | 45        | ...                 | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 23.2 | 22.1 | 21.3 |
| 37Ni-33Fe-25Cr                             | ...          | B408      | ...        | N08120  | Sol. ann.            | All                                            | 45        | ...                 | -325               | 90                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 25.1 | 24.4 |
| 31Ni-33Fe-27Cr-6.5Mo-Cu-N                  | ...          | B649      | ...        | N08031  | Annealed             | All                                            | 45        | ...                 | -325               | 94                           | 40    | 26.7                                                                       | 26.7 | 26.7 | 24.7 | 23.3 | 22.2 |
| 67Ni-30Cu                                  | ...          | B164      | ...        | N04400  | H.W.                 | All except hex. >2 <sup>1</sup> / <sub>8</sub> | 42        | ...                 | -325               | 80                           | 40    | 26.7                                                                       | 25.8 | 24.8 | 23.9 | 23.4 | 23.1 |
| 58Ni-33Cr-8Mo                              | ...          | B574      | ...        | N06035  | Sol. ann.            | All                                            | 43        | (9)                 | -325               | 85                           | 35    | 23.3                                                                       | 23.3 | 23.3 | 22.2 | 20.6 | 19.7 |
| 61Ni-16Mo-16Cr                             | ...          | B574      | ...        | N06455  | Sol. ann.            | All                                            | 43        | (9)                 | -325               | 100                          | 40    | 26.7                                                                       | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 |
| 54Ni-16Mo-15Cr                             | ...          | B574      | ...        | N10276  | Sol. ann.            | All                                            | 43        | ...                 | -325               | 100                          | 41    | 27.3                                                                       | 27.3 | 27.3 | 27.3 | 26.9 | 25.2 |
| 62Ni-22Mo-15Cr                             | ...          | B574      | ...        | N10362  | Sol. ann.            | All                                            | 43        | (9)                 | -325               | 105                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.9 | 27.7 |
| 60Ni-22Cr-9Mo-3.5Cb                        | ...          | B446      | 1          | N06625  | Annealed             | >4 to 10                                       | 43        | (9)<br>(64)<br>(70) | -325               | 110                          | 50    | 33.3                                                                       | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 |
| 60Ni-22Cr-9Mo-3.5Cb                        | ...          | B446      | 1          | N06625  | Annealed             | ≤4                                             | 43        | (9)<br>(64)<br>(70) | -325               | 120                          | 60    | 40.0                                                                       | 40.0 | 40.0 | 40.0 | 38.3 | 38.0 |
| 57Ni-22Cr-14W-2Mo-La                       | ...          | B572      | ...        | N06230  | Sol. ann.            | All                                            | 43        | ...                 | -325               | 110                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 30.0 | 29.6 |
| 59Ni-23Cr-16Mo                             | ...          | B574      | ...        | N06059  | Sol. ann.            | All                                            | 43        | ...                 | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 29.7 | 28.2 |
| 59Ni-23Cr-16Mo-1.6Cu                       | ...          | B574      | ...        | N06200  | Sol. ann.            | All                                            | 43        | ...                 | -325               | 100                          | 45    | 30.0                                                                       | 30.0 | 30.0 | 30.0 | 28.6 | 26.9 |
| 65Ni-29.5Mo-2Fe-2Cr                        | ...          | B335      | ...        | N10675  | Sol. ann.            | All                                            | 44        | ...                 | -325               | 110                          | 51    | 34.0                                                                       | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N               | ...          | B649      | ...        | R20033  | Sol. ann.            | All                                            | 45        | ...                 | -325               | 109                          | 55    | 36.3                                                                       | 30.9 | 28.1 | 26.1 | 24.7 | 23.8 |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                                                     | UNS<br>No. or<br>Grade | Spec.<br>No. |
|----------------------------------------------------------------------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----------------------------------------------------|------------------------|--------------|
| 650                                                                        | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | Nickel and Nickel Alloy — Rod and Bar (4a) (Cont'd) |                        |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N02200                                              | B160                   |              |
| 13.1                                                                       | 13.0 | 12.9 | 12.7 | 11.0 | 8.0  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400                                              | B164                   |              |
| 16.1                                                                       | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.8  | 11.6  | 9.3   | 7.4   | 5.9   | 4.7   | 3.8   | 3.0   | 2.4   | 1.9   | 1.4   | 1.1   | 0.86  | N08810                                              | B408                   |              |
| 16.1                                                                       | 15.7 | 15.3 | 15.0 | 14.7 | 14.5 | 14.2 | 14.0  | 13.7  | 12.9  | 10.4  | 8.3   | 6.7   | 5.4   | 4.3   | 3.4   | 2.7   | 2.2   | 1.6   | 1.2   | 0.91  | N08811                                              | B408                   |              |
| 20.0                                                                       | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 19.9  | 17.0  | 13.0  | 9.8   | 6.6   | 4.2   | 2.0   | 1.6   | 1.1   | 1.0   | 0.8   | ...   | ...   | ...   | N08800                                              | B408                   |              |
| 18.2                                                                       | 17.8 | 17.5 | 17.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08320                                              | B621                   |              |
| 19.2                                                                       | 19.0 | 18.8 | 18.7 | 18.6 | 18.5 | 18.4 | 18.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06007                                              | B581                   |              |
| 23.3                                                                       | 23.3 | 23.2 | 23.0 | 22.9 | 22.8 | 22.6 | 22.3  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08825                                              | B425                   |              |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06690                                              | B166                   |              |
| 23.3                                                                       | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06690                                              | B166                   |              |
| 22.4                                                                       | 22.2 | 22.0 | 21.8 | 21.7 | 20.0 | 19.5 | 18.9  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06007                                              | B581                   |              |
| 20.9                                                                       | 20.5 | 20.1 | 19.7 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06030                                              | B581                   |              |
| 23.3                                                                       | 22.9 | 22.6 | 22.4 | 22.2 | 22.1 | 22.0 | 21.9  | 21.9  | 17.9  | 14.2  | 12.3  | 9.4   | 7.6   | 6.2   | 5.0   | 4.0   | 3.2   | 2.6   | 2.0   | 1.4   | N08120                                              | B408                   |              |
| 21.7                                                                       | 21.3 | 20.9 | 20.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N08031                                              | B649                   |              |
| 22.9                                                                       | 22.7 | 20.0 | 14.5 | 8.5  | 4.0  | 1.9  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400                                              | B164                   |              |
| 19.4                                                                       | 19.2 | 19.0 | 18.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06035                                              | B574                   |              |
| 26.7                                                                       | 26.5 | 26.1 | 25.8 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06455                                              | B574                   |              |
| 24.6                                                                       | 24.0 | 23.5 | 23.1 | 22.8 | 22.6 | 22.4 | 22.3  | 18.5  | 15.0  | 12.2  | 9.8   | 7.8   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10276                                              | B574                   |              |
| 27.3                                                                       | 27.0 | 26.7 | 26.4 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10362                                              | B574                   |              |
| 33.3                                                                       | 33.3 | 33.3 | 33.3 | 33.1 | 32.8 | 32.5 | 31.2  | 31.2  | 23.1  | 21.0  | 13.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06625                                              | B446                   |              |
| 37.7                                                                       | 37.4 | 37.4 | 37.4 | 37.4 | 37.4 | 37.4 | 37.4  | 37.4  | 37.4  | 27.7  | 21.0  | 13.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06625                                              | B446                   |              |
| 29.1                                                                       | 28.7 | 28.4 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2  | 28.2  | 23.2  | 19.0  | 15.6  | 12.9  | 10.6  | 8.5   | 6.7   | 5.3   | 4.1   | 2.9   | 2.1   | 1.5   | N06230                                              | B572                   |              |
| 27.5                                                                       | 26.8 | 26.1 | 25.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06059                                              | B574                   |              |
| 26.2                                                                       | 25.7 | 25.4 | 25.2 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06200                                              | B574                   |              |
| 34.0                                                                       | 34.0 | 33.9 | 33.5 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10675                                              | B335                   |              |
| 23.5                                                                       | 23.1 | 22.9 | 22.6 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | R20033                                              | B649                   |              |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal<br>Composition                  | Product<br>Form | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condi-<br>tion/<br>Temper | Size<br>Range,<br>in. | P-<br>No.<br>(5) | Notes   | Min.<br>Temp.,<br>°F (6) | Specified<br>Min.<br>Strength, ksi |       | Basic Allowable<br>Stress, S, ksi, at Metal<br>Temperature,<br>°F [Notes (1), (4a)] |      |      |      |      |      |  |
|-----------------------------------------|-----------------|--------------|----------------|------------|-------------------------------------|-----------------------|------------------|---------|--------------------------|------------------------------------|-------|-------------------------------------------------------------------------------------|------|------|------|------|------|--|
|                                         |                 |              |                |            |                                     |                       |                  |         |                          | Tensile                            | Yield | Min.<br>Temp.<br>to<br>100                                                          | 200  | 300  | 400  | 500  | 600  |  |
|                                         |                 |              |                |            |                                     |                       |                  |         |                          |                                    |       |                                                                                     |      |      |      |      |      |  |
| Nickel and Nickel Alloy — Castings (4a) |                 |              |                |            |                                     |                       |                  |         |                          |                                    |       |                                                                                     |      |      |      |      |      |  |
| 59Ni-22Cr-14Mo-4Fe-3W                   | ...             | A494         | CX2MW          | N26022     | ...                                 | ...                   | 43               | (9)     | -325                     | 80                                 | 45    | 26.7                                                                                | 26.7 | 26.7 | 26.7 | 26.7 | ...  |  |
| 53Ni-17Mo-16Cr-6Fe-5W                   | ...             | A494         | CW12-MW        | N30002     | ...                                 | ...                   | a                | (7) (9) | -325                     | 72                                 | 40    | 24.0                                                                                | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |  |
| 56Ni-19Mo-18Cr-2Fe                      | ...             | A494         | CW6M           | N30107     | ...                                 | ...                   | 44               | (9)     | -325                     | 72                                 | 40    | 24.0                                                                                | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                        |              |
|----------------------------------------------------------------------------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------------------|--------------|
| 650                                                                        | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 | UNS<br>No. or<br>Grade | Spec.<br>No. |
| Nickel and Nickel Alloy — Castings (4a)                                    |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                        |              |
| ...                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CX2MW                  | A494         |
| 24.0                                                                       | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 22.8  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CW12M-<br>W            | A494         |
| 24.0                                                                       | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 22.8  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | CW6M                   | A494         |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition                                      | Product Form      | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | P-No.<br>(5) | Notes | Min. Temp.,<br>°F (6) | Specified Min. Strength, ksi |       |
|----------------------------------------------------------|-------------------|-----------|------------|---------|----------------------------|--------------|-------|-----------------------|------------------------------|-------|
|                                                          |                   |           |            |         |                            |              |       |                       | Tensile                      | Yield |
| Titanium and Titanium Alloy — Pipes and Tubes            |                   |           |            |         |                            |              |       |                       |                              |       |
| Ti                                                       | Smls. & wld. tube | B338      | 1          | R50250  | Annealed                   | 51           | ...   | −75                   | 35                           | 20    |
| Ti                                                       | Smls. pipe        | B861      | 1          | R50250  | Annealed                   | 51           | ...   | −75                   | 35                           | 20    |
| Ti                                                       | Wld. pipe         | B862      | 1          | R50250  | Annealed                   | 51           | ...   | −75                   | 35                           | 20    |
| Ti                                                       | Smls. & wld. tube | B338      | 2          | R50400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti                                                       | Smls. pipe        | B861      | 2          | R50400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti                                                       | Wld. pipe         | B862      | 2          | R50400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti                                                       | Smls. & wld. tube | B338      | 3          | R50550  | Annealed                   | 52           | ...   | −75                   | 65                           | 55    |
| Ti                                                       | Smls. pipe        | B861      | 3          | R50550  | Annealed                   | 52           | ...   | −75                   | 65                           | 55    |
| Ti                                                       | Wld. pipe         | B862      | 3          | R50550  | Annealed                   | 52           | ...   | −75                   | 65                           | 55    |
| Ti-Pd                                                    | Smls. & wld. tube | B338      | 7          | R52400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti-Pd                                                    | Smls. pipe        | B861      | 7          | R52400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti-Pd                                                    | Wld. pipe         | B862      | 7          | R52400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti-0.3Mo-0.8Ni                                           | Smls. & wld. tube | B338      | 12         | R53400  | Annealed                   | 52           | ...   | −75                   | 70                           | 50    |
| Ti-0.3Mo-0.8Ni                                           | Smls. pipe        | B861      | 12         | R53400  | Annealed                   | 52           | ...   | −75                   | 70                           | 50    |
| Ti-0.3Mo-0.8Ni                                           | Wld. pipe         | B862      | 12         | R53400  | Annealed                   | 52           | ...   | −75                   | 70                           | 50    |
| Titanium and Titanium Alloy — Plates, Sheets, and Strips |                   |           |            |         |                            |              |       |                       |                              |       |
| Ti                                                       | ...               | B265      | 1          | R50250  | Annealed                   | 51           | ...   | −75                   | 35                           | 20    |
| Ti                                                       | ...               | B265      | 2          | R50400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti                                                       | ...               | B265      | 3          | R50550  | Annealed                   | 52           | ...   | −75                   | 65                           | 55    |
| Ti-Pd                                                    | ...               | B265      | 7          | R52400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti-0.3Mo-0.8Ni                                           | ...               | B265      | 12         | R53400  | Annealed                   | 52           | ...   | −75                   | 70                           | 50    |
| Titanium and Titanium Alloy — Forgings and Fittings      |                   |           |            |         |                            |              |       |                       |                              |       |
| Ti                                                       | Fittings          | B363      | WPT1       | R50250  | Annealed                   | 51           | ...   | −75                   | 35                           | 20    |
| Ti                                                       | Forgings          | B381      | F-1        | R50250  | Annealed                   | 51           | ...   | −75                   | 35                           | 20    |
| Ti                                                       | Fittings          | B363      | WPT2       | R50400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti                                                       | Forgings          | B381      | F-2        | R50400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti                                                       | Fittings          | B363      | WPT3       | R50550  | Annealed                   | 52           | ...   | −75                   | 65                           | 55    |
| Ti                                                       | Forgings          | B381      | F-3        | R50550  | Annealed                   | 52           | ...   | −75                   | 65                           | 55    |
| Ti-Pd                                                    | Fittings          | B363      | WPT7       | R52400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti-Pd                                                    | Forgings          | B381      | F-7        | R52400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti-0.3Mo-0.8Ni                                           | Fittings          | B363      | WPT12      | R53400  | Annealed                   | 52           | ...   | −75                   | 70                           | 50    |
| Ti-0.3Mo-0.8Ni                                           | Forgings          | B381      | F-12       | R53400  | Annealed                   | 52           | ...   | −75                   | 70                           | 50    |
| Titanium and Titanium Alloy — Bars                       |                   |           |            |         |                            |              |       |                       |                              |       |
| Ti                                                       | ...               | B348      | 1          | R50250  | Annealed                   | 51           | ...   | −75                   | 35                           | 20    |
| Ti                                                       | ...               | B348      | 2          | R50400  | Annealed                   | 51           | ...   | −75                   | 50                           | 40    |
| Ti                                                       | ...               | B348      | 3          | R50550  | Annealed                   | 52           | ...   | −75                   | 65                           | 55    |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-----|-----|---------|-----------|
| Min.<br>Temp.<br>to 100                                                    | 150  | 200  | 250  | 300  | 350  | 400  | 450  | 500  | 550  | 600  | 650 | 700 | UNS No. | Spec. No. |
| Titanium and Titanium Alloy — Pipes and Tubes                              |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 11.7                                                                       | 10.7 | 9.3  | 8.2  | 7.2  | 6.3  | 5.5  | 4.7  | 4.2  | 3.8  | 3.5  | ... | ... | R50250  | B338      |
| 11.7                                                                       | 10.7 | 9.3  | 8.2  | 7.2  | 6.3  | 5.5  | 4.7  | 4.2  | 3.8  | 3.5  | ... | ... | R50250  | B861      |
| 11.7                                                                       | 10.7 | 9.3  | 8.2  | 7.2  | 6.3  | 5.5  | 4.7  | 4.2  | 3.8  | 3.5  | ... | ... | R50250  | B862      |
|                                                                            |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R50400  | B338      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R50400  | B861      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R50400  | B862      |
|                                                                            |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | 9.3  | 8.6  | ... | ... | R50550  | B338      |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | 9.3  | 8.6  | ... | ... | R50550  | B861      |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | 9.3  | 8.6  | ... | ... | R50550  | B862      |
|                                                                            |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R52400  | B338      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R52400  | B861      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R52400  | B862      |
|                                                                            |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 23.3                                                                       | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400  | B338      |
| 23.3                                                                       | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400  | B861      |
| 23.3                                                                       | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400  | B862      |
| Titanium and Titanium Alloy — Plates, Sheets, and Strips                   |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 11.7                                                                       | 10.7 | 9.3  | 8.2  | 7.2  | 6.3  | 5.5  | 4.7  | 4.2  | 3.8  | 3.5  | ... | ... | R50250  | B265      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R50400  | B265      |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | 9.3  | 8.6  | ... | ... | R50550  | B265      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R52400  | B265      |
| 23.3                                                                       | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400  | B265      |
| Titanium and Titanium Alloy — Forgings and Fittings                        |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 11.7                                                                       | 10.7 | 9.3  | 8.2  | 7.2  | 6.3  | 5.5  | 4.7  | 4.2  | 3.8  | 3.5  | ... | ... | R50250  | B363      |
| 11.7                                                                       | 10.7 | 9.3  | 8.2  | 7.2  | 6.3  | 5.5  | 4.7  | 4.2  | 3.8  | 3.5  | ... | ... | R50250  | B381      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R50400  | B363      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R50400  | B381      |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | 9.3  | 8.6  | ... | ... | R50550  | B363      |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | 9.3  | 8.6  | ... | ... | R50550  | B381      |
|                                                                            |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R52400  | B363      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R52400  | B381      |
| 23.3                                                                       | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400  | B363      |
| 23.3                                                                       | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ... | ... | R53400  | B381      |
| Titanium and Titanium Alloy — Bars                                         |      |      |      |      |      |      |      |      |      |      |     |     |         |           |
| 11.7                                                                       | 10.7 | 9.3  | 8.2  | 7.2  | 6.3  | 5.5  | 4.7  | 4.2  | 3.8  | 3.5  | ... | ... | R50250  | B348      |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ... | ... | R50400  | B348      |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | 9.3  | 8.6  | ... | ... | R50550  | B348      |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                                   |                     |              |           |            |         |                            |           |           | Specified Min. Strength, ksi |         |       |
|---------------------------------------------------|---------------------|--------------|-----------|------------|---------|----------------------------|-----------|-----------|------------------------------|---------|-------|
| Nominal Composition                               |                     | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | P-No. (5) | Notes     | Min. Temp., °F (6)           | Tensile | Yield |
| Titanium and Titanium Alloy — Bars                |                     |              |           |            |         |                            |           |           |                              |         |       |
| Ti-Pd                                             | ...                 |              | B348      | 7          | R52400  | Annealed                   | 51        | ...       | -75                          | 50      | 40    |
| Ti-0.3Mo-0.8Ni                                    | ...                 |              | B348      | 12         | R53400  | Annealed                   | 52        | ...       | -75                          | 70      | 50    |
| Titanium and Titanium Alloy — Castings            |                     |              |           |            |         |                            |           |           |                              |         |       |
| Ti                                                | ...                 |              | B367      | C-2        | R52550  | ...                        | 51        | (14) (44) | -75                          | 50      | 40    |
| Ti                                                | ...                 |              | B367      | C-3        | R52550  | ...                        | 52        | (14) (44) | -75                          | 65      | 55    |
| Ti-Pd                                             | ...                 |              | B367      | C-7        | R52700  | ...                        | 51        | (14) (44) | -75                          | 50      | 40    |
| Zirconium and Zirconium Alloy — Pipes and Tubes   |                     |              |           |            |         |                            |           |           |                              |         |       |
| 99.2Zr                                            | Smls. & wld. tube   |              | B523      | ...        | R60702  |                            | 61        | ...       | -75                          | 55      | 30    |
| 99.2Zr                                            | Smls. & wld. tube   |              | B658      | ...        | R60702  |                            | 61        | ...       | -75                          | 55      | 30    |
| 95.5Zr + 2.5Nb                                    | Smls. & wld. pipe   |              | B658      | ...        | R60705  |                            | 62        | (73)      | -75                          | 80      | 55    |
| Zirconium and Zirconium Alloy — Plates and Sheets |                     |              |           |            |         |                            |           |           |                              |         |       |
| 99.2Zr                                            | Plate, sheet, strip |              | B551      | ...        | R60702  |                            | 61        | ...       | -75                          | 55      | 30    |
| 95.5Zr + 2.5Nb                                    | Plate, sheet, strip |              | B551      | ...        | R60705  |                            | 62        | (73)      | -75                          | 80      | 55    |
| Zirconium and Zirconium Alloy — Forgings and Bar  |                     |              |           |            |         |                            |           |           |                              |         |       |
| 99.2Zr                                            | Forgings            |              | B493      | ...        | R60702  |                            | 61        | ...       | -75                          | 55      | 30    |
| 99.2Zr                                            | Bar, wire           |              | B550      | ...        | R60702  |                            | 61        | ...       | -75                          | 55      | 30    |
| 95.5Zr + 2.5Nb                                    | Forgings            |              | B493      | ...        | R60705  |                            | 62        | (73)      | -75                          | 70      | 55    |
| 95.5Zr + 2.5Nb                                    | Bar, wire           |              | B550      | ...        | R60705  |                            | 62        | (73)      | -75                          | 80      | 55    |



**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |      |      |      |      |      |      |      |      |         |           |
|----------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|---------|-----------|
| Min.<br>Temp.<br>to 100                                                    | 150  | 200  | 250  | 300  | 350  | 400  | 450  | 500  | 550  | 600  | 650  | 700  | UNS No. | Spec. No. |
| Titanium and Titanium Alloy — Bars (Cont'd)                                |      |      |      |      |      |      |      |      |      |      |      |      |         |           |
| 16.7                                                                       | 15.6 | 14.5 | 13.3 | 12.1 | 11.2 | 10.3 | 9.6  | 8.9  | 8.2  | 7.6  | ...  | ...  | R52400  | B348      |
| 23.3                                                                       | 22.6 | 21.8 | 20.4 | 18.9 | 17.8 | 16.7 | 16.0 | 15.2 | 14.8 | 14.4 | ...  | ...  | R53400  | B348      |
| Titanium and Titanium Alloy — Castings                                     |      |      |      |      |      |      |      |      |      |      |      |      |         |           |
| 16.7                                                                       | 15.2 | 13.8 | 12.6 | 11.4 | 10.4 | 9.5  | 8.7  | 7.9  | ...  | ...  | ...  | ...  | R52550  | B367      |
| 21.7                                                                       | 20.0 | 18.4 | 16.6 | 14.9 | 13.5 | 12.1 | 11.0 | 9.9  | ...  | ...  | ...  | ...  | R52550  | B367      |
| 16.7                                                                       | 15.2 | 13.8 | 12.6 | 11.4 | 10.4 | 9.5  | 8.7  | 7.9  | ...  | ...  | ...  | ...  | R52700  | B367      |
| Zirconium and Zirconium Alloy — Pipes and Tubes                            |      |      |      |      |      |      |      |      |      |      |      |      |         |           |
| 18.3                                                                       | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3  | 8.3  | 7.4  | 6.6  | 6.0  | 5.6  | 5.2  | R60702  | B523      |
| 18.3                                                                       | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3  | 8.3  | 7.4  | 6.6  | 6.0  | 5.6  | 5.2  | R60702  | B658      |
| 26.7                                                                       | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705  | B658      |
| Zirconium and Zirconium Alloy — Plates and Sheets                          |      |      |      |      |      |      |      |      |      |      |      |      |         |           |
| 18.3                                                                       | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3  | 8.3  | 7.4  | 6.6  | 6.0  | 5.6  | 5.2  | R60702  | B551      |
| 26.7                                                                       | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705  | B551      |
| Zirconium and Zirconium Alloy — Forgings and Bar                           |      |      |      |      |      |      |      |      |      |      |      |      |         |           |
| 18.3                                                                       | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3  | 8.3  | 7.4  | 6.6  | 6.0  | 5.6  | 5.2  | R60702  | B493      |
| 18.3                                                                       | 17.2 | 15.4 | 13.6 | 12.0 | 10.6 | 9.3  | 8.3  | 7.4  | 6.6  | 6.0  | 5.6  | 5.2  | R60702  | B550      |
| 23.3                                                                       | 21.3 | 19.3 | 17.8 | 16.5 | 15.5 | 14.6 | 13.8 | 13.1 | 12.6 | 12.2 | 11.8 | 11.5 | R60705  | B493      |
| 26.7                                                                       | 24.4 | 22.1 | 20.4 | 18.9 | 17.7 | 16.7 | 15.8 | 15.0 | 14.4 | 13.9 | 13.5 | 13.2 | R60705  | B550      |

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                           |           |             |         |                          |                              |           |           |                    | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |     |     |     |  |
|-------------------------------------------|-----------|-------------|---------|--------------------------|------------------------------|-----------|-----------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|-----|-----|-----|--|
|                                           |           |             |         |                          |                              |           |           |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 150  | 200  | 250  | 300 | 350 | 400 |  |
| Nominal Composition                       | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes     | Min. Temp., °F (6) |                              |       |                                                                            |      |      |      |     |     |     |  |
| Aluminum Alloy — Seamless Pipes and Tubes |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| Al-Mn-Cu                                  | B210      | Alclad 3003 | A83003  | O                        | ...                          | 21        | (14) (33) | -452               | 13                           | 4.5   | 3.0                                                                        | 2.9  | 2.8  | 2.7  | 2.5 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B210      | Alclad 3003 | A83003  | H112                     | ...                          | 21        | (14) (33) | -452               | 13                           | 4.5   | 3.0                                                                        | 2.9  | 2.8  | 2.7  | 2.5 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B241      | Alclad 3003 | A83003  | O                        | ...                          | 21        | (14) (33) | -452               | 13                           | 4.5   | 3.0                                                                        | 2.9  | 2.8  | 2.7  | 2.5 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B241      | Alclad 3003 | A83003  | H112                     | ...                          | 21        | (14) (33) | -452               | 13                           | 4.5   | 3.0                                                                        | 2.9  | 2.8  | 2.7  | 2.5 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B210      | Alclad 3003 | A83003  | H14                      | ...                          | 21        | (14) (33) | -452               | 19                           | 16    | 6.3                                                                        | 6.3  | 6.3  | 6.1  | 4.3 | 3.0 | 2.3 |  |
| Al-Mn-Cu                                  | B210      | Alclad 3003 | A83003  | H18                      | ...                          | 21        | (14) (33) | -452               | 26                           | 23    | 8.7                                                                        | 8.7  | 8.7  | 8.4  | 4.3 | 3.0 | 2.3 |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| 99.60Al                                   | B210      | 1060        | A91060  | O                        | ...                          | 21        | (14) (33) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2 | 1.1 | 0.8 |  |
| 99.60Al                                   | B210      | 1060        | A91060  | H112                     | ...                          | 21        | (14) (33) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2 | 1.1 | 0.8 |  |
| 99.60Al                                   | B210      | 1060        | A91060  | H113                     | ...                          | 21        | (14) (33) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2 | 1.1 | 0.8 |  |
| 99.60Al                                   | B241      | 1060        | A91060  | O                        | ...                          | 21        | (14) (33) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2 | 1.1 | 0.8 |  |
| 99.60Al                                   | B241      | 1060        | A91060  | H112                     | ...                          | 21        | (14) (33) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2 | 1.1 | 0.8 |  |
| 99.60Al                                   | B241      | 1060        | A91060  | H113                     | ...                          | 21        | (14) (33) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2 | 1.1 | 0.8 |  |
| 99.60Al                                   | B210      | 1060        | A91060  | H14                      | ...                          | 21        | (14) (33) | -452               | 12                           | 10    | 4.0                                                                        | 4.0  | 4.0  | 4.0  | 2.7 | 1.8 | 1.1 |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| 99.0Al-Cu                                 | B241      | 1100        | A91100  | O                        | ...                          | 21        | (14) (33) | -452               | 11                           | 3     | 2.0                                                                        | 2.0  | 2.0  | 1.9  | 1.7 | 1.3 | 1.0 |  |
| 99.0Al-Cu                                 | B241      | 1100        | A91100  | H112                     | ...                          | 21        | (14) (33) | -452               | 11                           | 3     | 2.0                                                                        | 2.0  | 2.0  | 1.9  | 1.7 | 1.3 | 1.0 |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| 99.0Al-Cu                                 | B210      | 1100        | A91100  | H113                     | ...                          | 21        | (14) (33) | -452               | 11                           | 3.5   | 2.3                                                                        | 2.3  | 2.3  | 2.3  | 1.7 | 1.3 | 1.0 |  |
| 99.0Al-Cu                                 | B210      | 1100        | A91100  | H14                      | ...                          | 21        | (14) (33) | -452               | 16                           | 14    | 5.3                                                                        | 5.3  | 5.3  | 4.9  | 2.8 | 1.9 | 1.1 |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| Al-Mn-Cu                                  | B210      | 3003        | A93003  | O                        | ...                          | 21        | (14) (33) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B210      | 3003        | A93003  | H112                     | ...                          | 21        | (14) (33) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B241      | 3003        | A93003  | O                        | ...                          | 21        | (14) (33) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B241      | 3003        | A93003  | H112                     | ...                          | 21        | (14) (33) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B491      | 3003        | A93003  | O                        | ...                          | 21        | (14) (33) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7 | 1.9 | 1.5 |  |
| Al-Mn-Cu                                  | B491      | 3003        | A93003  | H112                     | ...                          | 21        | (14) (33) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7 | 1.9 | 1.5 |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| Al-Mn-Cu                                  | B210      | 3003        | A93003  | H14                      | ...                          | 21        | (14) (33) | -452               | 20                           | 17    | 6.7                                                                        | 6.7  | 6.5  | 4.8  | 4.3 | 3.0 | 2.3 |  |
| Al-Mn-Cu                                  | B210      | 3003        | A93003  | H18                      | ...                          | 21        | (14) (33) | -452               | 27                           | 24    | 9.0                                                                        | 9.0  | 8.7  | 8.0  | 5.3 | 3.5 | 2.5 |  |
| Al-Mn-Cu                                  | B241      | 3003        | A93003  | H18                      | ...                          | 21        | (14) (33) | -452               | 27                           | 24    | 9.0                                                                        | 9.0  | 8.7  | 8.0  | 5.3 | 3.5 | 2.5 |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| Al-2.5Mg                                  | B210      | 5052        | A95052  | O                        | ...                          | 22        | (14)      | -452               | 25                           | 10    | 6.7                                                                        | 6.7  | 6.7  | 6.6  | 6.1 | 4.1 | 2.3 |  |
| Al-2.5Mg                                  | B241      | 5052        | A95052  | O                        | ...                          | 22        | (14)      | -452               | 25                           | 10    | 6.7                                                                        | 6.7  | 6.7  | 6.6  | 6.1 | 4.1 | 2.3 |  |
| Al-2.5Mg                                  | B210      | 5052        | A95052  | H32                      | ...                          | 22        | (14) (33) | -452               | 31                           | 23    | 10.3                                                                       | 10.3 | 10.3 | 10.3 | 6.1 | 4.1 | 2.3 |  |
| Al-2.5Mg                                  | B210      | 5052        | A95052  | H34                      | ...                          | 22        | (14) (33) | -452               | 34                           | 26    | 11.3                                                                       | 11.3 | 11.3 | 11.3 | 6.1 | 4.1 | 2.3 |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| Al-4.4Mg-Mn                               | B210      | 5083        | A95083  | O                        | ...                          | 25        | (33)      | -452               | 39                           | 16    | 10.7                                                                       | 10.7 | ...  | ...  | ... | ... | ... |  |
| Al-4.4Mg-Mn                               | B210      | 5083        | A95083  | H112                     | ...                          | 25        | (33)      | -452               | 39                           | 16    | 10.7                                                                       | 10.7 | ...  | ...  | ... | ... | ... |  |
| Al-4.4Mg-Mn                               | B241      | 5083        | A95083  | O                        | ...                          | 25        | (33)      | -452               | 39                           | 16    | 10.7                                                                       | 10.7 | ...  | ...  | ... | ... | ... |  |
| Al-4.4Mg-Mn                               | B241      | 5083        | A95083  | H112                     | ...                          | 25        | (33)      | -452               | 39                           | 16    | 10.7                                                                       | 10.7 | ...  | ...  | ... | ... | ... |  |
|                                           |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |     |     |     |  |
| Al-4.0Mg-Mn                               | B210      | 5086        | A95086  | O                        | ...                          | 25        | (33)      | -452               | 35                           | 14    | 9.3                                                                        | 9.3  | ...  | ...  | ... | ... | ... |  |
| Al-4.0Mg-Mn                               | B210      | 5086        | A95086  | H112                     | ...                          | 25        | (33)      | -452               | 35                           | 14    | 9.3                                                                        | 9.3  | ...  | ...  | ... | ... | ... |  |
| Al-4.0Mg-Mn                               | B241      | 5086        | A95086  | O                        | ...                          | 25        | (33)      | -452               | 35                           | 14    | 9.3                                                                        | 9.3  | ...  | ...  | ... | ... | ... |  |
| Al-4.0Mg-Mn                               | B241      | 5086        | A95086  | H112                     | ...                          | 25        | (33)      | -452               | 35                           | 14    | 9.3                                                                        | 9.3  | ...  | ...  | ... | ... | ... |  |
| Al-4.0Mg-Mn                               | B210      | 5086        | A95086  | H32                      | ...                          | 25        | (33)      | -452               | 40                           | 28    | 13.3                                                                       | 13.3 | ...  | ...  | ... | ... | ... |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for **Appendix A** Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition                                | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes     | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |     |     |  |
|----------------------------------------------------|-----------|-------------|---------|--------------------------|------------------------------|-----------|-----------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|-----|-----|--|
|                                                    |           |             |         |                          |                              |           |           |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 150  | 200  | 250  | 300  | 350 | 400 |  |
| Aluminum Alloy — Seamless Pipes and Tubes (Cont'd) |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |      |     |     |  |
| Al-4.0Mg-Mn                                        | B210      | 5086        | A95086  | H34                      | ...                          | 25        | (33)      | -452               | 44                           | 34    | 14.7                                                                       | 14.7 | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                           | B210      | 5154        | A95154  | O                        | ...                          | 22        | ...       | -452               | 30                           | 11    | 7.3                                                                        | 7.3  | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                           | B210      | 5154        | A95154  | H34                      | ...                          | 22        | (33)      | -452               | 39                           | 29    | 13.3                                                                       | 13.0 | ...  | ...  | ...  | ... | ... |  |
| Al-2.7Mg-Mn                                        | B241      | 5454        | A95454  | O                        | ...                          | 22        | (33)      | -452               | 31                           | 12    | 8.0                                                                        | 8.0  | 8.0  | 7.4  | 5.5  | 4.1 | 3.0 |  |
| Al-2.7Mg-Mn                                        | B241      | 5454        | A95454  | H112                     | ...                          | 22        | (33)      | -452               | 31                           | 12    | 8.0                                                                        | 8.0  | 8.0  | 7.4  | 5.5  | 4.1 | 3.0 |  |
| Al-5.1Mg-Mn                                        | B210      | 5456        | A95456  | O                        | ...                          | 25        | (33)      | -452               | 41                           | 19    | 12.7                                                                       | 12.7 | ...  | ...  | ...  | ... | ... |  |
| Al-5.1Mg-Mn                                        | B210      | 5456        | A95456  | H112                     | ...                          | 25        | (33)      | -452               | 41                           | 19    | 12.7                                                                       | 12.7 | ...  | ...  | ...  | ... | ... |  |
| Al-5.1Mg-Mn                                        | B241      | 5456        | A95456  | O                        | ...                          | 25        | (33)      | -452               | 41                           | 19    | 12.7                                                                       | 12.7 | ...  | ...  | ...  | ... | ... |  |
| Al-5.1Mg-Mn                                        | B241      | 5456        | A95456  | H112                     | ...                          | 25        | (33)      | -452               | 41                           | 19    | 12.7                                                                       | 12.7 | ...  | ...  | ...  | ... | ... |  |
| Al-Mg-Si-Cu                                        | B210      | 6061        | A96061  | T4 wld.                  | ...                          | 23        | (22) (63) | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                        | B210      | 6061        | A96061  | T6 wld.                  | ...                          | 23        | (22) (63) | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                        | B241      | 6061        | A96061  | T4 wld.                  | ...                          | 23        | (22) (63) | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                        | B241      | 6061        | A96061  | T6 wld.                  | ...                          | 23        | (22) (63) | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                        | B241      | 6061        | A96061  | T4                       | ...                          | 23        | (33) (63) | -452               | 26                           | 16    | 8.7                                                                        | 8.7  | 8.7  | 8.7  | 8.3  | 7.4 | 5.2 |  |
| Al-Mg-Si-Cu                                        | B210      | 6061        | A96061  | T4                       | ...                          | 23        | (33)      | -452               | 30                           | 16    | 10.0                                                                       | 10.0 | 10.0 | 9.9  | 9.5  | 8.4 | 5.2 |  |
| Al-Mg-Si-Cu                                        | B241      | 6061        | A96061  | T6                       | ...                          | 23        | (33) (63) | -452               | 38                           | 35    | 12.7                                                                       | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |  |
| Al-Mg-Si-Cu                                        | B210      | 6061        | A96061  | T6                       | ...                          | 23        | (33)      | -452               | 42                           | 35    | 14.0                                                                       | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |  |
| Al-Mg-Si                                           | B210      | 6063        | A96063  | T4 wld.                  | ...                          | 23        | ...       | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                           | B210      | 6063        | A96063  | T5 wld.                  | ...                          | 23        | ...       | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                           | B210      | 6063        | A96063  | T6 wld.                  | ...                          | 23        | ...       | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                           | B241      | 6063        | A96063  | T4 wld.                  | ...                          | 23        | ...       | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                           | B241      | 6063        | A96063  | T5 wld.                  | ...                          | 23        | ...       | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                           | B241      | 6063        | A96063  | T6 wld.                  | ...                          | 23        | ...       | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                           | B241      | 6063        | A96063  | T4                       | ≤0.500                       | 23        | (33)      | -452               | 19                           | 10    | 6.3                                                                        | 6.3  | 6.3  | 6.3  | 5.8  | 3.9 | 1.5 |  |
| Al-Mg-Si                                           | B210      | 6063        | A96063  | T4                       | ...                          | 23        | (33)      | -452               | 22                           | 10    | 6.7                                                                        | 6.5  | 6.5  | 6.3  | 6.3  | 4.5 | 1.7 |  |
| Al-Mg-Si                                           | B241      | 6063        | A96063  | T5                       | ≤0.500                       | 23        | (33)      | -452               | 22                           | 16    | 7.3                                                                        | 7.3  | 7.3  | 7.3  | 7.1  | 3.8 | 2.0 |  |
| Al-Mg-Si                                           | B241      | 6063        | A96063  | T6                       | ...                          | 23        | (33)      | -452               | 30                           | 25    | 10.0                                                                       | 10.0 | 10.0 | 9.1  | 7.2  | 3.4 | 2.0 |  |
| Al-Mg-Si                                           | B210      | 6063        | A96063  | T6                       | ...                          | 23        | (33)      | -452               | 33                           | 28    | 11.0                                                                       | 11.0 | 11.0 | 9.6  | 7.3  | 3.8 | 2.0 |  |
| Aluminum Alloy — Structural Tubes                  |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |      |     |     |  |
| Al-Mn-Cu                                           | B221      | Alclad 3003 | A83003  | O                        | ...                          | 21        | (33) (69) | -452               | 13                           | 4.5   | 3.0                                                                        | 2.9  | 2.8  | 2.7  | 2.5  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                           | B221      | Alclad 3003 | A83003  | H112                     | ...                          | 21        | (33) (69) | -452               | 13                           | 4.5   | 3.0                                                                        | 2.9  | 2.8  | 2.7  | 2.5  | 1.9 | 1.5 |  |
| 99.0Al                                             | B221      | 1060        | A91060  | O                        | ...                          | 21        | (33) (69) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2  | 1.1 | 0.8 |  |
| 99.0Al                                             | B221      | 1060        | A91060  | H112                     | ...                          | 21        | (33) (69) | -452               | 8.5                          | 2.5   | 1.7                                                                        | 1.7  | 1.6  | 1.4  | 1.2  | 1.1 | 0.8 |  |
| 99.0Al-Cu                                          | B221      | 1100        | A91100  | O                        | ...                          | 21        | (33) (69) | -452               | 11                           | 3     | 2.0                                                                        | 2.0  | 2.0  | 1.9  | 1.7  | 1.3 | 1.0 |  |
| 99.0Al-Cu                                          | B221      | 1100        | A91100  | H112                     | ...                          | 21        | (33) (69) | -452               | 11                           | 3     | 2.0                                                                        | 2.0  | 2.0  | 1.9  | 1.7  | 1.3 | 1.0 |  |
| Al-Mn-Cu                                           | B221      | 3003        | A93003  | O                        | ...                          | 21        | (33) (69) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                           | B221      | 3003        | A93003  | H112                     | ...                          | 21        | (33) (69) | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

|                                            |           |             |         |                         |                              |           |                |                    | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |     |     |  |
|--------------------------------------------|-----------|-------------|---------|-------------------------|------------------------------|-----------|----------------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|-----|-----|--|
|                                            |           |             |         |                         |                              |           |                |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 150  | 200  | 250  | 300  | 350 | 400 |  |
| Nominal Composition                        | Spec. No. | Type/Grade  | UNS No. | Class/Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes          | Min. Temp., °F (6) |                              |       |                                                                            |      |      |      |      |     |     |  |
| Aluminum Alloy — Structural Tubes (Cont'd) |           |             |         |                         |                              |           |                |                    |                              |       |                                                                            |      |      |      |      |     |     |  |
| Al-2.5Mg                                   | B221      | 5052        | A95052  | O                       | ...                          | 22        | (69)           | -452               | 25                           | 10    | 6.7                                                                        | 6.7  | 6.6  | 6.1  | 4.1  | 2.3 |     |  |
| Al-4.4Mg-Mn                                | B221      | 5083        | A95083  | O                       | ...                          | 25        | (69)           | -452               | 39                           | 16    | 10.7                                                                       | 10.7 | ...  | ...  | ...  | ... |     |  |
| Al-4.0Mg-Mn                                | B221      | 5086        | A95086  | O                       | ...                          | 25        | (69)           | -452               | 35                           | 14    | 9.3                                                                        | 9.3  | ...  | ...  | ...  | ... |     |  |
| Al-3.5Mg                                   | B221      | 5154        | A95154  | O                       | ...                          | 22        | (69)           | -452               | 30                           | 11    | 7.3                                                                        | 7.3  | ...  | ...  | ...  | ... |     |  |
| Al-2.7Mg-Mn                                | B221      | 5454        | A95454  | O                       | ...                          | 22        | (69)           | -452               | 31                           | 12    | 8.0                                                                        | 8.0  | 8.0  | 7.4  | 5.5  | 4.1 | 3.0 |  |
| Al-5.1Mg-Mn                                | B221      | 5456        | A95456  | O                       | ...                          | 25        | (69)           | -452               | 41                           | 19    | 12.7                                                                       | 12.7 | ...  | ...  | ...  | ... |     |  |
| Al-Mg-Si-Cu                                | B221      | 6061        | A96061  | T4 wld.                 | ...                          | 23        | (22) (63) (69) | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                | B221      | 6061        | A96061  | T6 wld.                 | ...                          | 23        | (22) (63) (69) | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                | B221      | 6061        | A96061  | T4                      | ...                          | 23        | (33) (63) (69) | -452               | 26                           | 16    | 8.7                                                                        | 8.7  | 8.7  | 8.7  | 8.3  | 7.4 | 5.2 |  |
| Al-Mg-Si-Cu                                | B221      | 6061        | A96061  | T6                      | ...                          | 23        | (33) (63) (69) | -452               | 38                           | 35    | 12.7                                                                       | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |  |
| Al-Mg-Si                                   | B221      | 6063        | A96063  | T4 wld.                 | ...                          | 23        | (69)           | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                   | B221      | 6063        | A96063  | T5 wld.                 | ...                          | 23        | (69)           | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                   | B221      | 6063        | A96063  | T6 wld.                 | ...                          | 23        | (69)           | -452               | 17                           | ...   | 5.7                                                                        | 5.7  | 5.6  | 5.3  | 4.8  | 3.8 | 2.0 |  |
| Al-Mg-Si                                   | B221      | 6063        | A96063  | T4                      | ≤0.500                       | 23        | (13) (33) (69) | -452               | 19                           | 10    | 6.3                                                                        | 6.3  | 6.3  | 6.3  | 5.8  | 3.9 | 1.5 |  |
| Al-Mg-Si                                   | B221      | 6063        | A96063  | T5                      | ≤0.500                       | 23        | (13) (33) (69) | -452               | 22                           | 16    | 7.3                                                                        | 7.3  | 7.3  | 7.3  | 7.1  | 3.8 | 2.0 |  |
| Al-Mg-Si                                   | B221      | 6063        | A96063  | T6                      | ...                          | 23        | (33) (69)      | -452               | 30                           | 25    | 10.0                                                                       | 10.0 | 10.0 | 9.1  | 7.2  | 3.4 | 2.0 |  |
| Aluminum Alloy — Plates and Sheets         |           |             |         |                         |                              |           |                |                    |                              |       |                                                                            |      |      |      |      |     |     |  |
| Al-Mn-Cu                                   | B209      | Alclad 3003 | A83003  | O                       | 0.006-0.499                  | 21        | (66)           | -452               | 13                           | 4.5   | 3.0                                                                        | 2.9  | 2.8  | 2.7  | 2.5  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                   | B209      | Alclad 3003 | A83003  | O                       | 0.500-3.000                  | 21        | (68)           | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                   | B209      | Alclad 3003 | A83003  | H112                    | 0.500-2.000                  | 21        | (33) (66)      | -452               | 15                           | 6     | 4.0                                                                        | 3.9  | 3.7  | 3.6  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                   | B209      | Alclad 3003 | A83003  | H12                     | 0.017-0.499                  | 21        | (33) (66)      | -452               | 16                           | 11    | 5.3                                                                        | 5.3  | 5.2  | 4.9  | 4.3  | 3.0 | 2.3 |  |
| Al-Mn-Cu                                   | B209      | Alclad 3003 | A83003  | H12                     | 0.500-2.000                  | 21        | (33) (68)      | -452               | 17                           | 12    | 5.7                                                                        | 5.7  | 5.7  | 5.7  | 4.3  | 3.0 | 2.3 |  |
| Al-Mn-Cu                                   | B209      | Alclad 3003 | A83003  | H14                     | 0.009-0.499                  | 21        | (33) (66)      | -452               | 19                           | 16    | 6.3                                                                        | 6.3  | 6.3  | 6.1  | 4.3  | 3.0 | 2.3 |  |
| Al-Mn-Cu                                   | B209      | Alclad 3003 | A83003  | H14                     | 0.500-1.000                  | 21        | (33) (68)      | -452               | 20                           | 17    | 6.7                                                                        | 6.7  | 6.7  | 6.5  | 4.3  | 3.0 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | O                       | 0.006-0.499                  | 22        | (66)           | -452               | 21                           | 8     | 5.3                                                                        | 5.3  | 5.3  | 5.3  | 5.3  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | O                       | 0.500-3.000                  | 22        | (68)           | -452               | 22                           | 8.5   | 5.7                                                                        | 5.6  | 5.6  | 5.6  | 5.6  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | H112                    | 0.250-0.499                  | 22        | (33) (66)      | -452               | 22                           | 8.5   | 5.7                                                                        | 5.6  | 5.6  | 5.6  | 5.6  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | H112                    | 0.500-3.000                  | 22        | (33) (68)      | -452               | 23                           | 9     | 6.0                                                                        | 6.0  | 6.0  | 6.0  | 5.7  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | H32                     | 0.017-0.499                  | 22        | (33) (66)      | -452               | 27                           | 20    | 9.0                                                                        | 9.0  | 9.0  | 9.0  | 5.7  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | H32                     | 0.500-2.000                  | 22        | (33) (68)      | -452               | 28                           | 21    | 9.3                                                                        | 9.3  | 9.3  | 9.3  | 5.7  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | H34                     | 0.009-0.499                  | 22        | (33) (66)      | -452               | 31                           | 24    | 10.3                                                                       | 10.3 | 10.3 | 10.3 | 5.7  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                   | B209      | Alclad 3004 | A83004  | H34                     | 0.500-1.000                  | 22        | (33) (68)      | -452               | 32                           | 25    | 10.7                                                                       | 10.7 | 10.7 | 10.7 | 5.7  | 3.8 | 2.3 |  |
| Al-Mg-Si-Cu                                | B209      | Alclad 6061 | A86061  | T4 wld.                 | ...                          | 23        | (22) (63)      | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                | B209      | Alclad 6061 | A86061  | T6 wld.                 | ...                          | 23        | (22) (63)      | -452               | 24                           | ...   | 8.0                                                                        | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                | B209      | Alclad 6061 | A86061  | T4                      | ...                          | 23        | (33) (66)      | -452               | 27                           | 14    | 9.0                                                                        | 9.0  | 9.0  | 8.9  | 8.6  | 7.6 | 5.2 |  |
| Al-Mg-Si-Cu                                | B209      | Alclad 6061 | A86061  | T451                    | 0.250-0.499                  | 23        | (33) (66)      | -452               | 27                           | 14    | 9.0                                                                        | 9.0  | 9.0  | 8.9  | 8.6  | 7.6 | 5.2 |  |
| Al-Mg-Si-Cu                                | B209      | Alclad 6061 | A86061  | T451                    | 0.500-3.000                  | 23        | (33) (68)      | -452               | 30                           | 16    | 9.0                                                                        | 9.0  | 9.0  | 8.9  | 8.5  | 8.4 | 5.2 |  |

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition                         | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size or Thickness Range, in. | P-No. (5) | Notes     | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] |      |      |      |      |     |     |  |
|---------------------------------------------|-----------|-------------|---------|--------------------------|------------------------------|-----------|-----------|--------------------|------------------------------|-------|----------------------------------------------------------------------------|------|------|------|------|-----|-----|--|
|                                             |           |             |         |                          |                              |           |           |                    | Tensile                      | Yield | Min. Temp. to 100                                                          | 150  | 200  | 250  | 300  | 350 | 400 |  |
| Aluminum Alloy — Plates and Sheets (Cont'd) |           |             |         |                          |                              |           |           |                    |                              |       |                                                                            |      |      |      |      |     |     |  |
| Al-Mg-Si-Cu                                 | B209      | Alclad 6061 | A86061  | T6                       | ...                          | 23        | (33) (66) | -452               | 38                           | 32    | 12.7                                                                       | 12.7 | 12.7 | 12.3 | 10.6 | 8.1 | 5.2 |  |
| Al-Mg-Si-Cu                                 | B209      | Alclad 6061 | A86061  | T651                     | 0.250-0.499                  | 23        | (33) (66) | -452               | 38                           | 32    | 12.7                                                                       | 12.7 | 12.7 | 12.3 | 10.6 | 8.1 | 5.2 |  |
| Al-Mg-Si-Cu                                 | B209      | Alclad 6061 | A86061  | T651                     | 0.500-4.000                  | 23        | (33) (68) | -452               | 42                           | 35    | 14.0                                                                       | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |  |
| 99.60Al                                     | B209      | 1060        | A91060  | O                        | ...                          | 21        | ...       | -452               | 8                            | 2.5   | 1.7                                                                        | 1.6  | 1.6  | 1.4  | 1.2  | 1.1 | 0.8 |  |
| 99.60Al                                     | B209      | 1060        | A91060  | H112                     | 0.500-1.000                  | 21        | (13) (33) | -452               | 10                           | 5     | 3.3                                                                        | 3.2  | 2.9  | 2.5  | 2.0  | 1.5 | 0.9 |  |
| 99.60Al                                     | B209      | 1060        | A91060  | H12                      | ...                          | 21        | (33)      | -452               | 11                           | 9     | 3.7                                                                        | 3.7  | 3.4  | 3.1  | 2.7  | 1.8 | 1.1 |  |
| 99.60Al                                     | B209      | 1060        | A91060  | H14                      | ...                          | 21        | (33)      | -452               | 12                           | 10    | 4.0                                                                        | 4.0  | 4.0  | 4.0  | 2.7  | 1.8 | 1.1 |  |
| 99.0Al-Cu                                   | B209      | 1100        | A91100  | O                        | ...                          | 21        | ...       | -452               | 11                           | 3.5   | 2.3                                                                        | 2.3  | 2.3  | 2.3  | 1.7  | 1.3 | 1.0 |  |
| 99.0Al-Cu                                   | B209      | 1100        | A91100  | H112                     | 0.500-2.000                  | 21        | (13) (33) | -452               | 12                           | 5     | 3.3                                                                        | 3.3  | 3.3  | 3.2  | 2.4  | 1.7 | 1.0 |  |
| 99.0Al-Cu                                   | B209      | 1100        | A91100  | H12                      | ...                          | 21        | (33)      | -452               | 14                           | 11    | 4.7                                                                        | 4.7  | 4.6  | 3.8  | 2.8  | 1.9 | 1.1 |  |
| 99.0Al-Cu                                   | B209      | 1100        | A91100  | H14                      | ...                          | 21        | (33)      | -452               | 16                           | 14    | 5.3                                                                        | 5.3  | 5.3  | 4.9  | 2.8  | 1.9 | 1.1 |  |
| Al-Mn-Cu                                    | B209      | 3003        | A93003  | O                        | ...                          | 21        | ...       | -452               | 14                           | 5     | 3.3                                                                        | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                    | B209      | 3003        | A93003  | H112                     | 0.500-2.000                  | 21        | (13) (33) | -452               | 15                           | 6     | 4.0                                                                        | 3.9  | 3.7  | 3.6  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                    | B209      | 3003        | A93003  | H12                      | ...                          | 21        | (33)      | -452               | 17                           | 12    | 5.7                                                                        | 5.7  | 5.6  | 5.2  | 4.3  | 3.0 | 2.3 |  |
| Al-Mn-Cu                                    | B209      | 3003        | A93003  | H14                      | ...                          | 21        | (33)      | -452               | 20                           | 17    | 6.7                                                                        | 6.7  | 6.7  | 6.5  | 4.3  | 3.0 | 2.3 |  |
| Al-Mn-Mg                                    | B209      | 3004        | A93004  | O                        | ...                          | 22        | ...       | -452               | 22                           | 8.5   | 5.7                                                                        | 5.7  | 5.7  | 5.7  | 5.7  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                    | B209      | 3004        | A93004  | H112                     | ...                          | 22        | (33)      | -452               | 23                           | 9     | 6.0                                                                        | 6.0  | 6.0  | 6.0  | 5.8  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                    | B209      | 3004        | A93004  | H32                      | ...                          | 22        | (33)      | -452               | 28                           | 21    | 9.3                                                                        | 9.3  | 9.3  | 9.3  | 5.7  | 3.8 | 2.3 |  |
| Al-Mn-Mg                                    | B209      | 3004        | A93004  | H34                      | ...                          | 22        | (33)      | -452               | 32                           | 25    | 10.7                                                                       | 10.7 | 10.7 | 10.7 | 5.7  | 3.8 | 2.3 |  |
| Al-1.5Mg                                    | B209      | 5050        | A95050  | O                        | ...                          | 21        | ...       | -452               | 18                           | 6     | 4.0                                                                        | 4.0  | 4.0  | 4.0  | 4.0  | 2.8 | 1.4 |  |
| Al-1.5Mg                                    | B209      | 5050        | A95050  | H112                     | ...                          | 21        | (33)      | -452               | 20                           | 8     | 5.3                                                                        | 5.3  | 5.3  | 5.2  | 5.2  | 2.8 | 1.4 |  |
| Al-1.5Mg                                    | B209      | 5050        | A95050  | H32                      | ...                          | 21        | (33)      | -452               | 22                           | 16    | 7.3                                                                        | 7.3  | 7.3  | 7.3  | 5.3  | 2.8 | 1.4 |  |
| Al-1.5Mg                                    | B209      | 5050        | A95050  | H34                      | ...                          | 21        | (33)      | -452               | 25                           | 20    | 8.3                                                                        | 8.3  | 8.3  | 7.8  | 5.3  | 2.8 | 1.4 |  |
| Al-2.5Mg                                    | B209      | 5052        | A95052  | O                        | ...                          | 22        | ...       | -452               | 25                           | 9.5   | 6.3                                                                        | 6.3  | 6.3  | 6.2  | 6.1  | 4.1 | 2.3 |  |
| Al-2.5Mg                                    | B209      | 5052        | A95052  | H112                     | 0.500-3.000                  | 22        | (13) (33) | -452               | 25                           | 9.5   | 6.3                                                                        | 6.3  | 6.3  | 6.3  | 6.1  | 4.1 | 2.3 |  |
| Al-2.5Mg                                    | B209      | 5052        | A95052  | H32                      | ...                          | 22        | (33)      | -452               | 31                           | 23    | 10.3                                                                       | 10.3 | 10.3 | 10.3 | 6.1  | 4.1 | 2.3 |  |
| Al-2.5Mg                                    | B209      | 5052        | A95052  | H34                      | ...                          | 22        | (33)      | -452               | 34                           | 26    | 11.3                                                                       | 11.3 | 11.3 | 11.3 | 6.1  | 4.1 | 2.3 |  |
| Al-4.4Mg-Mn                                 | B209      | 5083        | A95083  | O                        | 0.051-1.500                  | 25        | (13)      | -452               | 40                           | 18    | 12.0                                                                       | 12.0 | ...  | ...  | ...  | ... | ... |  |
| Al-4.4Mg-Mn                                 | B209      | 5083        | A95083  | H32                      | 0.188-1.500                  | 25        | (13) (33) | -452               | 44                           | 31    | 14.7                                                                       | 14.7 | ...  | ...  | ...  | ... | ... |  |
| Al-4.0Mg-Mn                                 | B209      | 5086        | A95086  | O                        | ...                          | 25        | ...       | -452               | 35                           | 14    | 9.3                                                                        | 9.3  | ...  | ...  | ...  | ... | ... |  |
| Al-4.0Mg-Mn                                 | B209      | 5086        | A95086  | H112                     | 0.500-1.000                  | 25        | (13) (33) | -452               | 35                           | 16    | 9.3                                                                        | 9.3  | ...  | ...  | ...  | ... | ... |  |
| Al-4.0Mg-Mn                                 | B209      | 5086        | A95086  | H32                      | ...                          | 25        | (33)      | -452               | 40                           | 28    | 13.3                                                                       | 13.3 | ...  | ...  | ...  | ... | ... |  |
| Al-4.0Mg-Mn                                 | B209      | 5086        | A95086  | H34                      | ...                          | 25        | (33)      | -452               | 44                           | 34    | 14.7                                                                       | 14.7 | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                    | B209      | 5154        | A95154  | O                        | ...                          | 22        | ...       | -452               | 30                           | 11    | 7.3                                                                        | 7.3  | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                    | B209      | 5154        | A95154  | H112                     | 0.500-3.000                  | 22        | (13) (33) | -452               | 30                           | 11    | 7.3                                                                        | 7.3  | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                    | B209      | 5154        | A95154  | H32                      | ...                          | 22        | (33)      | -452               | 36                           | 26    | 12.0                                                                       | 12.0 | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                    | B209      | 5154        | A95154  | H34                      | ...                          | 22        | (33)      | -452               | 39                           | 29    | 13.0                                                                       | 13.0 | ...  | ...  | ...  | ... | ... |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                      | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size or<br>Thickness<br>Range, in. | P-<br>No.<br>(5) | Notes                          | Min.<br>Temp.,<br>°F (6) | Specified<br>Min.<br>Strength, ksi |       | Basic Allowable Stress, S, ksi, at<br>Metal Temperature, °F [Notes (1),<br>(4a)] |      |      |      |      |     |     |  |
|---------------------------------------------|--------------|----------------|------------|--------------------------------|------------------------------------|------------------|--------------------------------|--------------------------|------------------------------------|-------|----------------------------------------------------------------------------------|------|------|------|------|-----|-----|--|
|                                             |              |                |            |                                |                                    |                  |                                |                          | Tensile                            | Yield | Min.<br>Temp.<br>to<br>100                                                       | 150  | 200  | 250  | 300  | 350 | 400 |  |
|                                             |              |                |            |                                |                                    |                  |                                |                          |                                    |       |                                                                                  |      |      |      |      |     |     |  |
| Aluminum Alloy — Plates and Sheets (Cont'd) |              |                |            |                                |                                    |                  |                                |                          |                                    |       |                                                                                  |      |      |      |      |     |     |  |
| Al-3.5Mg                                    | B209         | 5254           | A95254     | O                              | ...                                | 22               | ...                            | -452                     | 30                                 | 11    | 7.3                                                                              | 7.3  | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                    | B209         | 5254           | A95254     | H112                           | 0.500-3.000                        | 22               | (13) (33)                      | -452                     | 30                                 | 11    | 7.3                                                                              | 7.3  | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                    | B209         | 5254           | A95254     | H32                            | ...                                | 22               | (33)                           | -452                     | 36                                 | 26    | 12.0                                                                             | 12.0 | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                    | B209         | 5254           | A95254     | H34                            | ...                                | 22               | (33)                           | -452                     | 39                                 | 29    | 13.0                                                                             | 13.0 | ...  | ...  | ...  | ... | ... |  |
| Al-2.7Mg-Mn                                 | B209         | 5454           | A95454     | O                              | ...                                | 22               | ...                            | -452                     | 31                                 | 12    | 8.0                                                                              | 8.0  | 8.0  | 7.4  | 5.5  | 4.1 | 3.0 |  |
| Al-2.7Mg-Mn                                 | B209         | 5454           | A95454     | H112                           | 0.500-3.000                        | 22               | (13) (33)                      | -452                     | 31                                 | 12    | 8.0                                                                              | 8.0  | 8.0  | 7.4  | 5.5  | 4.1 | 3.0 |  |
| Al-2.7Mg-Mn                                 | B209         | 5454           | A95454     | H32                            | ...                                | 22               | (33)                           | -452                     | 36                                 | 26    | 12.0                                                                             | 12.0 | 12.0 | 7.5  | 5.5  | 4.1 | 3.0 |  |
| Al-2.7Mg-Mn                                 | B209         | 5454           | A95454     | H34                            | ...                                | 22               | (33)                           | -452                     | 39                                 | 29    | 13.0                                                                             | 13.0 | 13.0 | 7.5  | 5.5  | 4.1 | 3.0 |  |
| Al-5.1Mg-Mn                                 | B209         | 5456           | A95456     | O                              | 0.051-1.500                        | 25               | (13)                           | -452                     | 42                                 | 19    | 12.7                                                                             | 12.7 | ...  | ...  | ...  | ... | ... |  |
| Al-5.1Mg-Mn                                 | B209         | 5456           | A95456     | H32                            | 0.188-0.499                        | 25               | (13) (33)                      | -452                     | 46                                 | 33    | 15.3                                                                             | 15.3 | ...  | ...  | ...  | ... | ... |  |
| Al-2.5Mg                                    | B209         | 5652           | A95652     | O                              | ...                                | 22               | ...                            | -452                     | 25                                 | 9.5   | 6.3                                                                              | 6.3  | 6.3  | 6.2  | 6.1  | 4.1 | 2.3 |  |
| Al-2.5Mg                                    | B209         | 5652           | A95652     | H112                           | 0.500-3.000                        | 22               | (13) (33)                      | -452                     | 25                                 | 9.5   | 6.3                                                                              | 6.3  | 6.3  | 6.3  | 6.1  | 4.1 | 2.3 |  |
| Al-2.5Mg                                    | B209         | 5652           | A95652     | H32                            | ...                                | 22               | (33)                           | -452                     | 31                                 | 23    | 10.3                                                                             | 10.3 | 10.3 | 10.3 | 6.1  | 4.1 | 2.3 |  |
| Al-2.5Mg                                    | B209         | 5652           | A95652     | H34                            | ...                                | 22               | (33)                           | -452                     | 34                                 | 26    | 11.3                                                                             | 11.3 | 11.3 | 11.3 | 6.1  | 4.1 | 2.3 |  |
| Al-Mg-Si-Cu                                 | B209         | 6061           | A96061     | T4 wld.                        | ...                                | 23               | (22) (63)                      | -452                     | 24                                 | ...   | 8.0                                                                              | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                 | B209         | 6061           | A96061     | T6 wld.                        | ...                                | 23               | (22) (63)                      | -452                     | 24                                 | ...   | 8.0                                                                              | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                 | B209         | 6061           | A96061     | T4                             | ...                                | 23               | (33) (63)                      | -452                     | 30                                 | 16    | 10.0                                                                             | 10.0 | 10.0 | 9.9  | 9.5  | 8.4 | 5.2 |  |
| Al-Mg-Si-Cu                                 | B209         | 6061           | A96061     | T6                             | ...                                | 23               | (33)                           | -452                     | 42                                 | 35    | 14.0                                                                             | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |  |
| Al-Mg-Si-Cu                                 | B209         | 6061           | A96061     | T651                           | 0.250-4.000                        | 23               | (13) (33)                      | -452                     | 42                                 | 35    | 14.0                                                                             | 14.0 | 14.0 | 13.6 | 11.7 | 8.9 | 5.2 |  |
| Aluminum Alloy — Forgings and Fittings      |              |                |            |                                |                                    |                  |                                |                          |                                    |       |                                                                                  |      |      |      |      |     |     |  |
| Al-Mn-Cu                                    | B361         | WP Alclad 3003 | A83003     | O                              | ...                                | 21               | (13) (14)<br>(32) (33)<br>(66) | -452                     | 13                                 | 4.5   | 3.0                                                                              | 2.9  | 2.8  | 2.7  | 2.5  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                    | B361         | WP Alclad 3003 | A83003     | H112                           | ...                                | 21               | (13) (14)<br>(32) (33)<br>(66) | -452                     | 13                                 | 4.5   | 3.0                                                                              | 2.9  | 2.8  | 2.7  | 2.5  | 1.9 | 1.5 |  |
| 99.60Al                                     | B361         | WP1060         | A91060     | O                              | ...                                | 21               | (13) (14)<br>(32) (33)         | -452                     | 8                                  | 2.5   | 1.7                                                                              | 1.6  | 1.6  | 1.4  | 1.2  | 1.1 | 0.8 |  |
| 99.60Al                                     | B361         | WP1060         | A91060     | H112                           | ...                                | 21               | (13) (14)<br>(32) (33)         | -452                     | 8                                  | 2.5   | 1.7                                                                              | 1.6  | 1.6  | 1.4  | 1.2  | 1.1 | 0.8 |  |
| 99.0Al-Cu                                   | B361         | WP1100         | A91100     | O                              | ...                                | 21               | (13) (14)<br>(32) (33)         | -452                     | 11                                 | 3     | 2.0                                                                              | 2.0  | 2.0  | 1.9  | 1.7  | 1.3 | 1.0 |  |
| 99.0Al-Cu                                   | B361         | WP1100         | A91100     | H112                           | ...                                | 21               | (13) (14)<br>(32) (33)         | -452                     | 11                                 | 3     | 2.0                                                                              | 2.0  | 2.0  | 1.9  | 1.7  | 1.3 | 1.0 |  |
| Al-Mn-Cu                                    | B247         | 3003           | A93003     | H112                           | ...                                | 21               | (9) (45)                       | -452                     | 14                                 | 5     | 3.3                                                                              | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                    | B247         | 3003           | A93003     | H112 wld.                      | ...                                | 21               | (9) (45)                       | -452                     | 14                                 | 5     | 3.3                                                                              | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                    | B361         | WP3003         | A93003     | O                              | ...                                | 21               | (13) (14)<br>(32) (33)         | -452                     | 14                                 | 5     | 3.3                                                                              | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                    | B361         | WP3003         | A93003     | H112                           | ...                                | 21               | (13) (14)<br>(32) (33)         | -452                     | 14                                 | 5     | 3.3                                                                              | 3.2  | 3.1  | 3.0  | 2.7  | 1.9 | 1.5 |  |
| Al-Mn-Cu                                    | B247         | 5083           | A95083     | O                              | ...                                | 25               | (9) (32)<br>(33)               | -452                     | 39                                 | 16    | 10.7                                                                             | 10.7 | ...  | ...  | ...  | ... | ... |  |
| Al-Mn-Cu                                    | B247         | 5083           | A95083     | H112                           | ...                                | 25               | (9) (32)<br>(33)               | -452                     | 39                                 | 16    | 10.7                                                                             | 10.7 | ...  | ...  | ...  | ... | ... |  |
| Al-Mn-Cu                                    | B247         | 5083           | A95083     | H112 wld.                      | ...                                | 25               | (9) (32)<br>(33)               | -452                     | 39                                 | 16    | 10.7                                                                             | 10.7 | ...  | ...  | ...  | ... | ... |  |

**Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix A](#) Tables; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition                          | Spec.<br>No. | Type/<br>Grade | UNS<br>No. | Class/<br>Condition/<br>Temper | Size or<br>Thickness<br>Range, in. | P-<br>No.<br>(5) | Notes                  | Min.<br>Temp.,<br>°F (6) | Specified<br>Min.<br>Strength, ksi |       | Basic Allowable Stress, S, ksi, at<br>Metal Temperature, °F [Notes (1),<br>(4a)] |      |      |      |      |     |     |  |
|-------------------------------------------------|--------------|----------------|------------|--------------------------------|------------------------------------|------------------|------------------------|--------------------------|------------------------------------|-------|----------------------------------------------------------------------------------|------|------|------|------|-----|-----|--|
|                                                 |              |                |            |                                |                                    |                  |                        |                          | Tensile                            | Yield | Min.<br>Temp.<br>to<br>100                                                       | 150  | 200  | 250  | 300  | 350 | 400 |  |
|                                                 |              |                |            |                                |                                    |                  |                        |                          |                                    |       |                                                                                  |      |      |      |      |     |     |  |
| Aluminum Alloy — Forgings and Fittings (Cont'd) |              |                |            |                                |                                    |                  |                        |                          |                                    |       |                                                                                  |      |      |      |      |     |     |  |
| Al-4.4Mg-Mn                                     | B361         | WP5083         | A95083     | O                              | ...                                | 25               | (13) (32)<br>(33)      | -452                     | 39                                 | 16    | 10.7                                                                             | 10.7 | ...  | ...  | ...  | ... | ... |  |
| Al-4.4Mg-Mn                                     | B361         | WP5083         | A95083     | H112                           | ...                                | 25               | (13) (32)<br>(33)      | -452                     | 39                                 | 16    | 10.7                                                                             | 10.7 | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                        | B361         | WP5154         | A95154     | O                              | ...                                | 22               | (32) (33)              | -452                     | 30                                 | 11    | 7.3                                                                              | 7.3  | ...  | ...  | ...  | ... | ... |  |
| Al-3.5Mg                                        | B361         | WP5154         | A95154     | H112                           | ...                                | 22               | (32) (33)              | -452                     | 30                                 | 11    | 7.3                                                                              | 7.3  | ...  | ...  | ...  | ... | ... |  |
| Al-Mg-Si-Cu                                     | B247         | 6061           | A96061     | T6 wld.                        | ...                                | 23               | (9) (22)               | -452                     | 24                                 | ...   | 8.0                                                                              | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                     | B361         | WP6061         | A96061     | T4 wld.                        | ...                                | 23               | (22) (32)<br>(63)      | -452                     | 24                                 | ...   | 8.0                                                                              | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                     | B361         | WP6061         | A96061     | T6 wld.                        | ...                                | 23               | (22) (32)<br>(63)      | -452                     | 24                                 | ...   | 8.0                                                                              | 8.0  | 8.0  | 8.0  | 7.7  | 6.9 | 5.1 |  |
| Al-Mg-Si-Cu                                     | B361         | WP6061         | A96061     | T4                             | ...                                | 23               | (13) (32)<br>(33) (63) | -452                     | 26                                 | 16    | 8.7                                                                              | 8.7  | 8.7  | 8.7  | 8.3  | 7.4 | 5.2 |  |
| Al-Mg-Si-Cu                                     | B247         | 6061           | A96061     | T6                             | ...                                | 23               | (9) (33)               | -452                     | 38                                 | 35    | 12.7                                                                             | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |  |
| Al-Mg-Si-Cu                                     | B361         | WP6061         | A96061     | T6                             | ...                                | 23               | (13) (32)<br>(33) (63) | -452                     | 38                                 | 35    | 12.7                                                                             | 12.7 | 12.7 | 12.3 | 10.5 | 8.1 | 5.2 |  |
| Al-Mg-Si                                        | B361         | WP6063         | A96063     | T4 wld.                        | ...                                | 23               | (32)                   | -452                     | 17                                 | ...   | 5.7                                                                              | 5.7  | 5.7  | 5.7  | 5.5  | 3.8 | 2.0 |  |
| Al-Mg-Si                                        | B361         | WP6063         | A96063     | T6 wld.                        | ...                                | 23               | (32)                   | -452                     | 17                                 | ...   | 5.7                                                                              | 5.7  | 5.7  | 5.7  | 5.5  | 3.8 | 2.0 |  |
| Al-Mg-Si                                        | B361         | WP6063         | A96063     | T4                             | ...                                | 23               | (13) (32)<br>(33)      | -452                     | 18                                 | 9     | 6.0                                                                              | 5.9  | 5.8  | 5.7  | 5.5  | 3.7 | 1.4 |  |
| Al-Mg-Si                                        | B361         | WP6063         | A96063     | T6                             | ...                                | 23               | (13) (32)<br>(33)      | -452                     | 30                                 | 25    | 10.0                                                                             | 10.0 | 10.0 | 9.1  | 7.2  | 3.4 | 2.0 |  |
| Aluminum Alloy — Castings                       |              |                |            |                                |                                    |                  |                        |                          |                                    |       |                                                                                  |      |      |      |      |     |     |  |
| Al-Si-Mg                                        | B26          | 356.0          | A03560     | T71                            | ...                                | 26               | (9) (43)               | -452                     | 25                                 | 18    | 8.3                                                                              | 8.3  | 8.3  | 8.1  | 7.3  | 5.5 | 2.4 |  |
| Al-Si-Mg                                        | B26          | 356.0          | A03560     | T6                             | ...                                | 26               | (9) (43)               | -452                     | 30                                 | 20    | 10.0                                                                             | 10.0 | 10.0 | 8.4  | ...  | ... | ... |  |
| Al-Si                                           | B26          | 443.0          | A04430     | F                              | ...                                | ...              | (9) (43)               | -452                     | 17                                 | 7     | 4.7                                                                              | 4.7  | 4.7  | 4.7  | 4.7  | 4.7 | 3.5 |  |



(20)

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Notes         | Min. Temp., °C (6) | Min. Tensile Strgth., MPa | Min. Yield Strgth., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------|-----------|------------|---------|----------------------|---------------|--------------------|---------------------------|-------------------------|--------------------|
| 1        | Fe                  | Castings     | A126      | A          | F11501  | ...                  | (8e) (9) (48) | -29                | 145                       | ...                     | 204                |
| 2        | Fe                  | Castings     | A48       | 150        | F11401  | ...                  | (8e) (48)     | -29                | 150                       | ...                     | 204                |
| 3        | Fe                  | Castings     | A278      | 150        | F11401  | ...                  | (8e) (48)     | -29                | 150                       | ...                     | 204                |
| 4        | Fe                  | Castings     | A48       | 175        | F11701  | ...                  | (8e) (48)     | -29                | 175                       | ...                     | 204                |
| 5        | Fe                  | Castings     | A278      | 175        | F11701  | ...                  | (8e) (48)     | -29                | 175                       | ...                     | 204                |
| 6        | Fe                  | Castings     | A48       | 200        | F12101  | ...                  | (8e) (48)     | -29                | 200                       | ...                     | 204                |
| 7        | Fe                  | Castings     | A278      | 200        | F12101  | ...                  | (8e) (48)     | -29                | 200                       | ...                     | 204                |
| 8        | Fe                  | Castings     | A126      | B          | F12102  | ...                  | (8e) (9) (48) | -29                | 214                       | ...                     | 204                |
| 9        | Fe                  | Castings     | A48       | 225        | ...     | ...                  | (8e) (48)     | -29                | 225                       | ...                     | 204                |
| 10       | Fe                  | Castings     | A278      | 225        | ...     | ...                  | (8e) (48)     | -29                | 225                       | ...                     | 204                |
| 11       | Fe                  | Castings     | A48       | 250        | F12401  | ...                  | (8e) (9) (48) | -29                | 250                       | ...                     | 204                |
| 12       | Fe                  | Castings     | A278      | 250        | F12401  | ...                  | (8e) (53)     | -29                | 250                       | ...                     | 343                |
| 13       | Fe                  | Castings     | A48       | 275        | F12801  | ...                  | (8e) (48)     | -29                | 275                       | ...                     | 204                |
| 14       | Fe                  | Castings     | A278      | 275        | F12803  | ...                  | (8e) (53)     | -29                | 275                       | ...                     | 204                |
| 15       | Fe                  | Castings     | A48       | 375        | ...     | ...                  | (8e) (48)     | -29                | 375                       | ...                     | 204                |
| 16       | Fe                  | Castings     | A278      | 380        | F13801  | ...                  | (8e) (53)     | -29                | 380                       | ...                     | 204                |
| 17       | Fe                  | Castings     | A197      | ...        | F22000  | ...                  | (8e) (9)      | -29                | 275                       | 200                     | 343                |
| 18       | Fe                  | Castings     | A126      | C          | F12802  | ...                  | (8e) (9) (48) | -29                | 283                       | ...                     | 204                |
| 19       | Fe                  | Castings     | A48       | 300        | F13101  | ...                  | (8e) (48)     | -29                | 300                       | ...                     | 204                |
| 20       | Fe                  | Castings     | A278      | 300        | F13101  | ...                  | (8e) (53)     | -29                | 300                       | ...                     | 343                |
| 21       | Fe                  | Castings     | A48       | 325        | ...     | ...                  | (8e) (48)     | -29                | 325                       | ...                     | 204                |
| 22       | Fe                  | Castings     | A278      | 325        | ...     | ...                  | (8e) (53)     | -29                | 325                       | ...                     | 204                |
| 23       | Fe                  | Castings     | A47       | 22010      | F22200  | ...                  | (8e) (9)      | -29                | 340                       | 220                     | 343                |
| 24       | Fe                  | Castings     | A48       | 350        | F13501  | ...                  | (8e) (48)     | -29                | 350                       | ...                     | 204                |
| 25       | Fe                  | Castings     | A278      | 350        | F13502  | ...                  | (8e) (53)     | -29                | 350                       | ...                     | 343                |
| 26       | Fe                  | Castings     | A48       | 400        | F14101  | ...                  | (8e) (48)     | -29                | 400                       | ...                     | 204                |
| 27       | Fe                  | Castings     | A278      | 415        | F14102  | ...                  | (8e) (53)     | -29                | 415                       | ...                     | 204                |
| 28       | Fe                  | Castings     | A395      | 60-40-18   | F32800  | ...                  | (8d) (9)      | -29                | 415                       | 275                     | 343                |
| 29       | Fe                  | Castings     | A536      | 65-45-12   | F33100  | ...                  | (8d) (9)      | -29                | 448                       | 310                     | 260                |
| 30       | Fe                  | Castings     | A571      | D-2M       | F43010  | 3                    | (8d)          | -29                | 450                       | 205                     | 40                 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | Min. Temp. to 40                                                              | 65   | 100  | 125  | 150  | 175  | 200  | 225  | 250  | 275  | 300  | 325  | 350  |
| 1        | 13.8                                                                          | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | ...  | ...  | ...  | ...  | ...  |
| 2        | 15.0                                                                          | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | ...  | ...  | ...  | ...  | ...  |
| 3        | 15.0                                                                          | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | ...  | ...  | ...  | ...  | ...  |
| 4        | 17.5                                                                          | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | ...  | ...  | ...  | ...  | ...  |
| 5        | 17.5                                                                          | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | ...  | ...  | ...  | ...  | ...  |
| 6        | 20.0                                                                          | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ...  | ...  | ...  | ...  |
| 7        | 20.0                                                                          | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ...  | ...  | ...  | ...  |
| 8        | 20.7                                                                          | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | ...  | ...  | ...  | ...  | ...  |
| 9        | 22.5                                                                          | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | ...  | ...  | ...  | ...  | ...  |
| 10       | 22.5                                                                          | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | ...  | ...  | ...  | ...  | ...  |
| 11       | 25.0                                                                          | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  |
| 12       | 25.0                                                                          | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 |
| 13       | 27.5                                                                          | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | ...  | ...  | ...  | ...  | ...  |
| 14       | 27.5                                                                          | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | ...  | ...  | ...  | ...  | ...  |
| 15       | 37.5                                                                          | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | ...  | ...  | ...  | ...  | ...  |
| 16       | 38.0                                                                          | 38.0 | 38.0 | 38.0 | 38.0 | 38.0 | 38.0 | 38.0 | ...  | ...  | ...  | ...  | ...  |
| 17       | 55.2                                                                          | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 |
| 18       | 27.6                                                                          | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | ...  | ...  | ...  | ...  | ...  |
| 19       | 30.0                                                                          | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | ...  | ...  | ...  | ...  | ...  |
| 20       | 30.0                                                                          | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 |
| 21       | 32.5                                                                          | 32.5 | 32.5 | 32.5 | 32.5 | 32.5 | 32.5 | 32.5 | ...  | ...  | ...  | ...  | ...  |
| 22       | 32.5                                                                          | 32.5 | 32.5 | 32.5 | 32.5 | 32.5 | 32.5 | 32.5 | ...  | ...  | ...  | ...  | ...  |
| 23       | 68.0                                                                          | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 | 68.0 |
| 24       | 35.0                                                                          | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | ...  | ...  | ...  | ...  | ...  |
| 25       | 35.0                                                                          | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 41.4 | 41.4 | 41.4 | 41.4 | 41.4 |
| 26       | 37.5                                                                          | 37.5 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | ...  | ...  | ...  | ...  | ...  |
| 27       | 41.5                                                                          | 41.5 | 41.5 | 41.5 | 41.5 | 41.5 | 41.5 | 41.5 | ...  | ...  | ...  | ...  | ...  |
| 28       | 137                                                                           | 133  | 128  | 125  | 122  | 119  | 116  | 112  | 109  | 106  | 103  | 98.0 | 93.5 |
| 29       | 149                                                                           | 149  | 149  | 149  | 149  | 149  | 148  | 148  | 148  | 147  | ...  | ...  | ...  |
| 30       | 137                                                                           | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Cond./Temper | Size, mm | P-No. (5) | Notes          | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------|-----------|------------|---------|--------------------|----------|-----------|----------------|--------------------|------------------------|----------------------|--------------------|
| 1        | Carbon steel        | Pipe & tube  | A134      | A285A      | K01700  | ...                | ...      | 1         | (8b) (57)      | B                  | 310                    | 165                  | 482                |
| 2        | Carbon steel        | Pipe & tube  | A672      | A45        | K01700  | ...                | ...      | 1         | (57) (59) (67) | B                  | 310                    | 165                  | 593                |
| 3        | Carbon steel        | Pipe & tube  | API 5L    | A25        | ...     | ...                | ...      | 1         | (8a) (77)      | -29                | 310                    | 172                  | 204                |
| 4        | Carbon steel        | Pipe & tube  | API 5L    | A25        | ...     | ...                | ...      | 1         | (57) (59) (77) | B                  | 310                    | 172                  | 204                |
| 5        | Carbon steel        | Pipe & tube  | A179      | ...        | K01200  | ...                | ...      | 1         | (57) (59)      | -29                | 324                    | 179                  | 593                |
| 6        | Carbon steel        | Pipe & tube  | A53       | A          | K02504  | ...                | ...      | 1         | (8a)           | -7                 | 331                    | 207                  | 204                |
| 7        | Carbon steel        | Pipe & tube  | A139      | A          | ...     | ...                | ...      | 1         | (8b)           | A                  | 331                    | 207                  | 149                |
| 8        | Carbon steel        | Pipe & tube  | A587      | ...        | K11500  | ...                | ...      | 1         | (57) (59)      | -29                | 331                    | 207                  | 454                |
| 9        | Carbon steel        | Pipe & tube  | A53       | A          | K02504  | ...                | ...      | 1         | (57) (59)      | B                  | 331                    | 207                  | 593                |
| 10       | Carbon steel        | Pipe & tube  | A106      | A          | K02501  | ...                | ...      | 1         | (57)           | B                  | 331                    | 207                  | 593                |
| 11       | Carbon steel        | Pipe & tube  | A135      | A          | ...     | ...                | ...      | 1         | (57) (59)      | B                  | 331                    | 207                  | 593                |
| 12       | Carbon steel        | Pipe & tube  | A369      | FPA        | K02501  | ...                | ...      | 1         | (57)           | B                  | 331                    | 207                  | 593                |
| 13       | Carbon steel        | Pipe & tube  | API 5L    | A          | ...     | ...                | ...      | 1         | (57) (59)      | B                  | 331                    | 207                  | 593                |
| 14       | Carbon steel        | Pipe & tube  | A134      | A285B      | K02200  | ...                | ...      | 1         | (8b) (57)      | B                  | 345                    | 186                  | 482                |
| 15       | Carbon steel        | Pipe & tube  | A672      | A50        | K02200  | ...                | ...      | 1         | (57) (59) (67) | B                  | 345                    | 186                  | 593                |
| 16       | Carbon steel        | Pipe & tube  | A134      | A285C      | K02801  | ...                | ...      | 1         | (8b) (57)      | A                  | 379                    | 207                  | 482                |
| 17       | Carbon steel        | Pipe & tube  | A524      | II         | K02104  | ...                | ...      | 1         | (57)           | -29                | 379                    | 207                  | 538                |
| 18       | Carbon steel        | Pipe & tube  | A333      | 1          | K03008  | ...                | ...      | 1         | (57) (59)      | -46                | 379                    | 207                  | 593                |
| 19       | Carbon steel        | Pipe & tube  | A334      | 1          | K03008  | ...                | ...      | 1         | (57) (59)      | -46                | 379                    | 207                  | 593                |
| 20       | Carbon steel        | Pipe & tube  | A671      | CA55       | K02801  | ...                | ...      | 1         | (59) (67)      | A                  | 379                    | 207                  | 593                |
| 21       | Carbon steel        | Pipe & tube  | A672      | A55        | K02801  | ...                | ...      | 1         | (57) (59) (67) | A                  | 379                    | 207                  | 593                |
| 22       | Carbon steel        | Pipe & tube  | A672      | C55        | K01800  | ...                | ...      | 1         | (57) (67)      | C                  | 379                    | 207                  | 593                |
| 23       | Carbon steel        | Pipe & tube  | A671      | CC60       | K02100  | ...                | ...      | 1         | (57) (67)      | C                  | 414                    | 221                  | 538                |
| 24       | Carbon steel        | Pipe & tube  | A671      | CB60       | K02401  | ...                | ...      | 1         | (57) (67)      | B                  | 414                    | 221                  | 593                |
| 25       | Carbon steel        | Pipe & tube  | A672      | B60        | K02401  | ...                | ...      | 1         | (57) (67)      | B                  | 414                    | 221                  | 593                |
| 26       | Carbon steel        | Pipe & tube  | A672      | C60        | K02100  | ...                | ...      | 1         | (57) (67)      | C                  | 414                    | 221                  | 593                |
| 27       | Carbon steel        | Pipe & tube  | A139      | B          | K03003  | ...                | ...      | 1         | (8b)           | A                  | 414                    | 241                  | 149                |
| 28       | Carbon steel        | Pipe & tube  | A135      | B          | K03018  | ...                | ...      | 1         | (57) (59)      | B                  | 414                    | 241                  | 538                |
| 29       | Carbon steel        | Pipe & tube  | A524      | I          | K02104  | ...                | ...      | 1         | (57)           | -29                | 414                    | 241                  | 538                |
| 30       | Carbon steel        | Pipe & tube  | A53       | B          | K03005  | ...                | ...      | 1         | (57) (59)      | B                  | 414                    | 241                  | 593                |
| 31       | Carbon steel        | Pipe & tube  | A106      | B          | K03006  | ...                | ...      | 1         | (57)           | B                  | 414                    | 241                  | 593                |
| 32       | Carbon steel        | Pipe & tube  | A333      | 6          | K03006  | ...                | ...      | 1         | (57)           | -46                | 414                    | 241                  | 593                |
| 33       | Carbon steel        | Pipe & tube  | A334      | 6          | K03006  | ...                | ...      | 1         | (57)           | -46                | 414                    | 241                  | 593                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | Min. Temp. to 40                                                              | 65  | 100 | 150  | 200  | 250  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  |
| 1        | 103                                                                           | 103 | 101 | 97.5 | 94.6 | 90.8 | 86.1 | 83.6 | 81.1 | 78.6 | 73.3 | 64.0 | 55.8 | 43.9 | 40.7 | ...  | ...  | ...  | ...  |
| 2        | 103                                                                           | 103 | 101 | 97.5 | 94.6 | 90.8 | 86.1 | 83.6 | 81.1 | 78.6 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 3        | 103                                                                           | 103 | 103 | 102  | 98.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 4        | 103                                                                           | 103 | 103 | 102  | 98.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 5        | 108                                                                           | 108 | 108 | 106  | 102  | 98.3 | 93.3 | 90.6 | 87.8 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 6        | 110                                                                           | 110 | 110 | 110  | 110  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 7        | 110                                                                           | 110 | 110 | 110  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 8        | 110                                                                           | 110 | 110 | 110  | 110  | 110  | 108  | 105  | 97.0 | 84.3 | 73.3 | 64.0 | 55.8 | 54.5 | ...  | ...  | ...  | ...  | ...  |
| 9        | 110                                                                           | 110 | 110 | 110  | 110  | 110  | 108  | 105  | 97.0 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 10       | 110                                                                           | 110 | 110 | 110  | 110  | 110  | 108  | 105  | 97.0 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 11       | 110                                                                           | 110 | 110 | 110  | 110  | 110  | 108  | 105  | 97.0 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 12       | 110                                                                           | 110 | 110 | 110  | 110  | 110  | 108  | 105  | 97.0 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 13       | 110                                                                           | 110 | 110 | 110  | 110  | 110  | 108  | 105  | 97.0 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 14       | 115                                                                           | 115 | 113 | 110  | 106  | 102  | 96.9 | 94.1 | 91.2 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 40.7 | ...  | ...  | ...  | ...  |
| 15       | 115                                                                           | 115 | 113 | 110  | 106  | 102  | 96.9 | 94.1 | 91.2 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 16       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | ...  | ...  | ...  | ...  |
| 17       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | 21.9 | 12.7 | ...  | ...  |
| 18       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 19       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 20       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 21       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 22       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 23       | 138                                                                           | 138 | 134 | 130  | 126  | 121  | 115  | 111  | 108  | 105  | 88.9 | 75.3 | 62.7 | 45.5 | 31.6 | 21.9 | 12.7 | ...  | ...  |
| 24       | 138                                                                           | 138 | 134 | 130  | 126  | 121  | 115  | 111  | 108  | 105  | 88.9 | 75.3 | 62.7 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 25       | 138                                                                           | 138 | 134 | 130  | 126  | 121  | 115  | 111  | 108  | 105  | 88.9 | 75.3 | 62.7 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 26       | 138                                                                           | 138 | 134 | 130  | 126  | 121  | 115  | 111  | 108  | 105  | 88.9 | 75.3 | 62.7 | 45.5 | 31.6 | 21.9 | 12.7 | 9.40 | 6.89 |
| 27       | 138                                                                           | 138 | 138 | 138  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 28       | 138                                                                           | 138 | 138 | 138  | 138  | 132  | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 17.2 | ...  | ...  |
| 29       | 138                                                                           | 138 | 138 | 138  | 138  | 132  | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 17.2 | ...  | ...  |
| 30       | 138                                                                           | 138 | 138 | 138  | 138  | 132  | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 31       | 138                                                                           | 138 | 138 | 138  | 138  | 132  | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 32       | 138                                                                           | 138 | 138 | 138  | 138  | 132  | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 33       | 138                                                                           | 138 | 138 | 138  | 138  | 132  | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Cond./Temper | Size, mm | P-No. (5) | Notes               | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------|-----------|------------|---------|--------------------|----------|-----------|---------------------|--------------------|------------------------|----------------------|--------------------|
| 34       | Carbon steel        | Pipe & tube  | A369      | FPB        | K03006  | ...                | ...      | 1         | (57)                | -29                | 414                    | 241                  | 593                |
| 35       | Carbon steel        | Pipe & tube  | A381      | Y35        | ...     | ...                | ...      | 1         | ...                 | A                  | 414                    | 241                  | 593                |
| 36       | Carbon steel        | Pipe & tube  | API 5L    | B          | ...     | ...                | ...      | 1         | (57) (59) (77)      | B                  | 414                    | 241                  | 593                |
| 37       | Carbon steel        | Pipe & tube  | A139      | C          | K03004  | ...                | ...      | 1         | (8b)                | A                  | 414                    | 290                  | 149                |
| 38       | Carbon steel        | Pipe & tube  | A139      | D          | K03010  | ...                | ...      | 1         | (8b)                | A                  | 414                    | 317                  | 149                |
| 39       | Carbon steel        | Pipe & tube  | API 5L    | X42        | ...     | ...                | ...      | 1         | (55) (77)           | A                  | 414                    | 290                  | 204                |
| 40       | Carbon steel        | Pipe & tube  | A381      | Y42        | ...     | ...                | ...      | 1         | ...                 | A                  | 414                    | 290                  | 204                |
| 41       | Carbon steel        | Pipe & tube  | A381      | Y48        | ...     | ...                | ...      | 1         | ...                 | A                  | 427                    | 331                  | 343                |
| 42       | Carbon steel        | Pipe & tube  | API 5L    | X46        | ...     | ...                | ...      | 1         | (55) (77)           | A                  | 434                    | 317                  | 204                |
| 43       | Carbon steel        | Pipe & tube  | A381      | Y46        | ...     | ...                | ...      | 1         | ...                 | A                  | 434                    | 317                  | 204                |
| 44       | Carbon steel        | Pipe & tube  | A381      | Y50        | ...     | ...                | ...      | 1         | ...                 | A                  | 441                    | 345                  | 343                |
| 45       | Carbon steel        | Pipe & tube  | A671      | CC65       | K02403  | ...                | ...      | 1         | (57) (67)           | B                  | 448                    | 241                  | 538                |
| 46       | Carbon steel        | Pipe & tube  | A671      | CB65       | K02800  | ...                | ...      | 1         | (57) (67)           | A                  | 448                    | 241                  | 593                |
| 47       | Carbon steel        | Pipe & tube  | A672      | B65        | K02800  | ...                | ...      | 1         | (57) (67)           | A                  | 448                    | 241                  | 593                |
| 48       | Carbon steel        | Pipe & tube  | A672      | C65        | K02403  | ...                | ...      | 1         | (57) (67)           | B                  | 448                    | 241                  | 593                |
| 49       | Carbon steel        | Pipe & tube  | A139      | E          | K03012  | ...                | ...      | 1         | (8b)                | A                  | 455                    | 359                  | 149                |
| 50       | Carbon steel        | Pipe & tube  | API 5L    | X52        | ...     | ...                | ...      | 1         | (55) (77)           | A                  | 455                    | 359                  | 204                |
| 51       | Carbon steel        | Pipe & tube  | A381      | Y52        | ...     | ...                | ...      | 1         | ...                 | A                  | 455                    | 359                  | 204                |
| 52       | Carbon steel        | Pipe & tube  | A671      | CC70       | K02700  | ...                | ...      | 1         | (57) (67)           | B                  | 483                    | 262                  | 538                |
| 53       | Carbon steel        | Pipe & tube  | A671      | CB70       | K03101  | ...                | ...      | 1         | (57) (67)           | A                  | 483                    | 262                  | 593                |
| 54       | Carbon steel        | Pipe & tube  | A672      | B70        | K03101  | ...                | ...      | 1         | (57) (67)           | A                  | 483                    | 262                  | 593                |
| 55       | Carbon steel        | Pipe & tube  | A672      | C70        | K02700  | ...                | ...      | 1         | (57) (67)           | B                  | 483                    | 262                  | 593                |
| 56       | Carbon steel        | Pipe & tube  | A106      | C          | K03501  | ...                | ...      | 1         | (57)                | B                  | 483                    | 276                  | 427                |
| 57       | Carbon steel        | Pipe & tube  | A671      | CD70       | K12437  | ...                | ≤64      | 1         | (67)                | D                  | 483                    | 345                  | 371                |
| 58       | Carbon steel        | Pipe & tube  | A672      | D70        | K12437  | ...                | ≤64      | 1         | (67)                | D                  | 483                    | 345                  | 371                |
| 59       | Carbon steel        | Pipe & tube  | A691      | CMSH-70    | K12437  | ...                | ≤64      | 1         | (67)                | D                  | 483                    | 345                  | 371                |
| 60       | Carbon steel        | Pipe & tube  | API 5L    | X56        | ...     | ...                | ...      | 1         | (51) (55) (71) (77) | A                  | 490                    | 386                  | 204                |
| 61       | Carbon steel        | Pipe & tube  | A381      | Y56        | ...     | ...                | ...      | 1         | (51) (55) (71)      | A                  | 490                    | 386                  | 204                |
| 62       | Carbon steel        | Pipe & tube  | A671      | CK75       | K02803  | ...                | >25      | 1         | (57) (67)           | A                  | 517                    | 276                  | 593                |
| 63       | Carbon steel        | Pipe & tube  | A672      | N75        | K02803  | ...                | >25      | 1         | (57) (67)           | A                  | 517                    | 276                  | 593                |
| 64       | Carbon steel        | Pipe & tube  | A691      | CMS-75     | K02803  | ...                | >25      | 1         | (57) (67)           | A                  | 517                    | 276                  | 593                |
| 65       | Carbon steel        | Pipe & tube  | A671      | CK75       | K02803  | ...                | ≤25      | 1         | (57) (67)           | A                  | 517                    | 290                  | 371                |
| 66       | Carbon steel        | Pipe & tube  | A672      | N75        | K02803  | ...                | ≤25      | 1         | (57) (67)           | A                  | 517                    | 290                  | 371                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |     |     |     |     |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|
|          | Min. Temp. to 40                                                              | 65  | 100 | 150 | 200 | 250 | 300 | 325 | 350 | 375 | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  |
| 34       | 138                                                                           | 138 | 138 | 138 | 138 | 132 | 126 | 122 | 118 | 113 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 35       | 138                                                                           | 138 | 138 | 138 | 138 | 132 | 126 | 122 | 118 | 113 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 36       | 138                                                                           | 138 | 138 | 138 | 138 | 132 | 126 | 122 | 118 | 113 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 37       | 138                                                                           | 138 | 138 | 138 | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 38       | 138                                                                           | 138 | 138 | 138 | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 39       | 138                                                                           | 138 | 138 | 138 | 138 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 40       | 138                                                                           | 138 | 138 | 138 | 138 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 41       | 142                                                                           | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 129 | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 42       | 145                                                                           | 145 | 145 | 145 | 145 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 43       | 145                                                                           | 145 | 145 | 145 | 145 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 44       | 147                                                                           | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 129 | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 45       | 149                                                                           | 149 | 147 | 142 | 138 | 132 | 126 | 122 | 118 | 113 | 95.0 | 79.6 | 63.2 | 45.3 | 31.7 | 21.9 | 12.7 | ...  | ...  |
| 46       | 149                                                                           | 149 | 147 | 142 | 138 | 132 | 126 | 122 | 118 | 113 | 95.0 | 79.6 | 63.2 | 45.3 | 31.7 | 21.9 | 12.7 | 9.40 | 6.89 |
| 47       | 149                                                                           | 149 | 147 | 142 | 138 | 132 | 126 | 122 | 118 | 113 | 95.0 | 79.6 | 63.2 | 45.3 | 31.7 | 21.9 | 12.7 | 9.40 | 6.89 |
| 48       | 149                                                                           | 149 | 147 | 142 | 138 | 132 | 126 | 122 | 118 | 113 | 95.0 | 79.6 | 63.2 | 45.3 | 31.7 | 21.9 | 12.7 | 9.40 | 6.89 |
| 49       | 152                                                                           | 152 | 152 | 152 | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 50       | 152                                                                           | 152 | 152 | 152 | 152 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 51       | 152                                                                           | 152 | 152 | 152 | 152 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 52       | 161                                                                           | 161 | 159 | 154 | 150 | 144 | 136 | 132 | 128 | 122 | 101  | 83.8 | 67.1 | 51.0 | 33.6 | 21.3 | 12.9 | ...  | ...  |
| 53       | 161                                                                           | 161 | 159 | 154 | 150 | 144 | 136 | 132 | 128 | 122 | 101  | 83.8 | 67.1 | 51.0 | 33.6 | 21.3 | 12.9 | 9.40 | 6.89 |
| 54       | 161                                                                           | 161 | 159 | 154 | 150 | 144 | 136 | 132 | 128 | 122 | 101  | 83.8 | 67.1 | 51.0 | 33.6 | 21.3 | 12.9 | 9.40 | 6.89 |
| 55       | 161                                                                           | 161 | 159 | 154 | 150 | 144 | 136 | 132 | 128 | 122 | 101  | 83.8 | 67.1 | 51.0 | 33.6 | 21.3 | 12.9 | 9.40 | 6.89 |
| 56       | 161                                                                           | 161 | 161 | 161 | 158 | 151 | 144 | 139 | 135 | 122 | 101  | 83.8 | 82.7 | ...  | ...  | ...  | ...  | ...  | ...  |
| 57       | 161                                                                           | 161 | 161 | 157 | 156 | 156 | 156 | 154 | 148 | 126 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 58       | 161                                                                           | 161 | 161 | 157 | 156 | 156 | 156 | 154 | 148 | 126 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 59       | 161                                                                           | 161 | 161 | 157 | 156 | 156 | 156 | 154 | 148 | 126 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 60       | 163                                                                           | 163 | 163 | 163 | 163 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 61       | 163                                                                           | 163 | 163 | 163 | 163 | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 62       | 172                                                                           | 172 | 168 | 163 | 158 | 151 | 144 | 139 | 135 | 131 | 107  | 88.0 | 67.3 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |
| 63       | 172                                                                           | 172 | 168 | 163 | 158 | 151 | 144 | 139 | 135 | 131 | 107  | 88.0 | 67.3 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |
| 64       | 172                                                                           | 172 | 168 | 163 | 158 | 151 | 144 | 139 | 135 | 131 | 107  | 88.0 | 67.3 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |
| 65       | 172                                                                           | 172 | 172 | 171 | 165 | 159 | 151 | 146 | 142 | 131 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 66       | 172                                                                           | 172 | 172 | 171 | 165 | 159 | 151 | 146 | 142 | 131 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form             | Spec. No. | Type/Grade   | UNS No. | Class/Cond./Temper | Size, mm | P-No. (5) | Notes               | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------------------|-----------|--------------|---------|--------------------|----------|-----------|---------------------|--------------------|------------------------|----------------------|--------------------|
| 67       | Carbon steel        | Pipe & tube              | A691      | CMS-75       | K02803  | ...                | ≤25      | 1         | (57) (67)           | A                  | 517                    | 290                  | 371                |
| 68       | Carbon steel        | Pipe & tube              | API 5L    | X60          | ...     | ...                | ...      | 1         | (51) (55) (71) (77) | A                  | 517                    | 414                  | 204                |
| 69       | Carbon steel        | Pipe & tube              | API 5L    | X65          | ...     | ...                | ...      | 1         | (51) (55) (71) (77) | A                  | 531                    | 448                  | 204                |
| 70       | Carbon steel        | Pipe & tube              | API 5L    | X70          | ...     | ...                | ...      | 1         | (51) (55) (71) (77) | A                  | 565                    | 483                  | 204                |
| 71       | Carbon steel        | Pipe & tube              | API 5L    | X80          | ...     | ...                | ...      | 1         | (51) (55) (71) (77) | A                  | 621                    | 552                  | 204                |
| 72       | Carbon steel        | Pipe & tube              | A381      | Y60          | ...     | ...                | ...      | 1         | (51) (71)           | A                  | 517                    | 414                  | 204                |
| 73       | Carbon steel        | Structural pipe          | A134      | A1011SS30    | K02502  | ...                | ...      | 1         | (8a) (8c)           | -29                | 338                    | 207                  | 204                |
| 74       | Carbon steel        | Structural pipe          | A134      | A1011SS33    | K02502  | ...                | ...      | 1         | (8a) (8c)           | -29                | 359                    | 228                  | 204                |
| 75       | Carbon steel        | Structural pipe          | A134      | A1011SS36-T1 | K02502  | ...                | ...      | 1         | (8a) (8c)           | -29                | 365                    | 248                  | 204                |
| 76       | Carbon steel        | Structural pipe          | A134      | A1011SS40    | K02502  | ...                | ...      | 1         | (8a) (8c)           | -29                | 379                    | 276                  | 204                |
| 77       | Carbon steel        | Structural pipe          | A134      | A36          | K02600  | ...                | ...      | 1         | (8a) (8c)           | -29                | 400                    | 248                  | 204                |
| 78       | Carbon steel        | Structural pipe          | A134      | A283D        | K02702  | ...                | ...      | 1         | (8a) (8c)           | -29                | 414                    | 228                  | 149                |
| 79       | Carbon steel        | Structural pipe          | A134      | A1011SS45    | K02507  | ...                | ...      | 1         | (8a) (8c)           | -29                | 414                    | 310                  | 204                |
| 80       | Carbon steel        | Structural pipe          | A134      | A1011SS50    | K02507  | ...                | ...      | 1         | (8a) (8c)           | -29                | 448                    | 345                  | 204                |
| 81       | Carbon steel        | Plate, bar, shps., sheet | A285      | A            | K01700  | ...                | ...      | 1         | (57) (59)           | B                  | 310                    | 165                  | 593                |
| 82       | Carbon steel        | Plate, bar, shps., sheet | A285      | B            | K02200  | ...                | ...      | 1         | (57) (59)           | B                  | 345                    | 186                  | 593                |
| 83       | Carbon steel        | Plate, bar, shps., sheet | A516      | 55           | K01800  | ...                | ...      | 1         | (57)                | C                  | 379                    | 207                  | 454                |
| 84       | Carbon steel        | Plate, bar, shps., sheet | A285      | C            | K02801  | ...                | ...      | 1         | (57) (59)           | A                  | 379                    | 207                  | 593                |
| 85       | Carbon steel        | Plate, bar, shps., sheet | A516      | 60           | K02100  | ...                | ...      | 1         | (57)                | C                  | 414                    | 221                  | 454                |
| 86       | Carbon steel        | Plate, bar, shps., sheet | A515      | 60           | K02401  | ...                | ...      | 1         | (57)                | B                  | 414                    | 221                  | 538                |
| 87       | Carbon steel        | Plate, bar, shps., sheet | A696      | B            | K03200  | ...                | ...      | 1         | (57)                | A                  | 415                    | 240                  | 371                |
| 88       | Carbon steel        | Plate, bar, shps., sheet | A516      | 65           | K02403  | ...                | ...      | 1         | (57)                | B                  | 448                    | 241                  | 454                |
| 89       | Carbon steel        | Plate, bar, shps., sheet | A515      | 65           | K02800  | ...                | ...      | 1         | (57)                | A                  | 448                    | 241                  | 538                |
| 90       | Carbon steel        | Plate, bar, shps., sheet | A516      | 70           | K02700  | ...                | ...      | 1         | (57)                | B                  | 483                    | 262                  | 454                |
| 91       | Carbon steel        | Plate, bar, shps., sheet | A515      | 70           | K03101  | ...                | ...      | 1         | (57)                | A                  | 483                    | 262                  | 538                |
| 92       | Carbon steel        | Plate, bar, shps., sheet | A696      | C            | K03200  | ...                | ...      | 1         | (57)                | A                  | 485                    | 275                  | 371                |
| 93       | Carbon steel        | Plate, bar, shps., sheet | A537      | ...          | K12437  | 1                  | ≤64      | 1         | ...                 | D                  | 483                    | 345                  | 371                |
| 94       | Carbon steel        | Plate, bar, shps., sheet | A299      | A            | K02803  | ...                | >25      | 1         | (57)                | A                  | 517                    | 276                  | 593                |
| 95       | Carbon steel        | Plate, bar, shps., sheet | A299      | A            | K02803  | ...                | ≤25      | 1         | (57)                | A                  | 517                    | 290                  | 593                |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | Min. Temp. to 40                                                              | 65  | 100 | 150  | 200  | 250  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  |
| 67       | 172                                                                           | 172 | 172 | 171  | 165  | 159  | 151  | 146  | 142  | 131  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 68       | 172                                                                           | 172 | 172 | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 69       | 177                                                                           | 177 | 177 | 177  | 177  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 70       | 188                                                                           | 188 | 188 | 188  | 188  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 71       | 207                                                                           | 207 | 207 | 207  | 207  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 72       | 172                                                                           | 172 | 172 | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 73       | 104                                                                           | 104 | 104 | 104  | 104  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 74       | 110                                                                           | 110 | 110 | 110  | 110  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 75       | 112                                                                           | 112 | 112 | 112  | 112  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 76       | 116                                                                           | 116 | 116 | 116  | 116  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 77       | 123                                                                           | 123 | 123 | 123  | 123  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 78       | 127                                                                           | 127 | 127 | 123  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 79       | 127                                                                           | 127 | 127 | 127  | 127  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 80       | 137                                                                           | 137 | 137 | 137  | 137  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 81       | 103                                                                           | 103 | 101 | 97.5 | 94.6 | 90.8 | 86.1 | 83.6 | 81.1 | 78.6 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 82       | 115                                                                           | 115 | 113 | 110  | 106  | 102  | 96.9 | 94.1 | 91.2 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 83       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.1 | 75.4 | 62.6 | 45.5 | 31.6 | 21.9 | 12.7 | ...  | ...  |
| 84       | 126                                                                           | 126 | 126 | 122  | 118  | 113  | 108  | 105  | 101  | 98.3 | 89.0 | 75.3 | 62.1 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 85       | 138                                                                           | 138 | 134 | 130  | 126  | 121  | 115  | 111  | 108  | 105  | 88.9 | 75.3 | 62.7 | 45.5 | 31.6 | 21.9 | 12.7 | ...  | ...  |
| 86       | 138                                                                           | 138 | 134 | 130  | 126  | 121  | 115  | 111  | 108  | 105  | 88.9 | 75.3 | 62.7 | 45.5 | 31.6 | 21.9 | 12.7 | ...  | ...  |
| 87       | 138                                                                           | 138 | 138 | 138  | 138  | 132  | 125  | 122  | 118  | 115  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 88       | 149                                                                           | 149 | 147 | 142  | 138  | 132  | 126  | 122  | 118  | 113  | 95.0 | 79.6 | 63.2 | 45.3 | 31.7 | 21.9 | 12.7 | ...  | ...  |
| 89       | 149                                                                           | 149 | 147 | 142  | 138  | 132  | 126  | 122  | 118  | 113  | 95.0 | 79.6 | 63.2 | 45.3 | 31.7 | 21.9 | 12.7 | ...  | ...  |
| 90       | 161                                                                           | 161 | 159 | 154  | 150  | 144  | 136  | 132  | 128  | 122  | 101  | 83.8 | 67.1 | 51.0 | 33.6 | 21.3 | 12.9 | ...  | ...  |
| 91       | 161                                                                           | 161 | 159 | 154  | 150  | 144  | 136  | 132  | 128  | 122  | 101  | 83.8 | 67.1 | 51.0 | 33.6 | 21.3 | 12.9 | ...  | ...  |
| 92       | 161                                                                           | 161 | 161 | 161  | 158  | 151  | 144  | 139  | 135  | 131  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 93       | 161                                                                           | 161 | 161 | 157  | 156  | 156  | 156  | 154  | 148  | 126  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 94       | 172                                                                           | 172 | 168 | 163  | 158  | 151  | 144  | 139  | 135  | 131  | 107  | 88.0 | 67.3 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |
| 95       | 172                                                                           | 172 | 172 | 171  | 165  | 159  | 151  | 146  | 142  | 131  | 107  | 88.0 | 67.3 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form        | Spec. No. | Type/Grade | UNS No. | Class/Cond./Temper | Size, mm | P-No. (5) | Notes         | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|---------------------|-----------|------------|---------|--------------------|----------|-----------|---------------|--------------------|------------------------|----------------------|--------------------|
| 96       | Carbon steel        | Struct. sht., strip | A10-11    | SS30       | K02502  | ...                | ...      | 1         | (8c) (57)     | A                  | 338                    | 207                  | 399                |
| 97       | Carbon steel        | Struct. sht., strip | A10-11    | SS33       | K02502  | ...                | ...      | 1         | (8c) (57)     | A                  | 359                    | 228                  | 399                |
| 98       | Carbon steel        | Struct. sht., strip | A10-11    | SS36-T1    | K02502  | ...                | ...      | 1         | (8c) (57)     | A                  | 365                    | 248                  | 399                |
| 99       | Carbon steel        | Structural plate    | A283      | C          | K02401  | ...                | ...      | 1         | (8c) (57)     | A                  | 379                    | 207                  | 399                |
| 100      | Carbon steel        | Struct. sht., strip | A10-11    | SS40       | K02502  | ...                | ...      | 1         | (8c) (57)     | A                  | 379                    | 276                  | 399                |
| 101      | Carbon steel        | Structural steel    | A36       | ...        | K02600  | ...                | ...      | 1         | (8c)          | A                  | 400                    | 248                  | 371                |
| 102      | Carbon steel        | Structural plate    | A283      | D          | K02702  | ...                | ...      | 1         | (8c) (57)     | A                  | 414                    | 228                  | 399                |
| 103      | Carbon steel        | Struct. sht., strip | A10-11    | SS45       | K02507  | ...                | ...      | 1         | (8c) (57)     | A                  | 414                    | 310                  | 399                |
| 104      | Carbon steel        | Struct. sht., strip | A10-11    | SS50       | K02507  | ...                | ...      | 1         | (8c) (57)     | A                  | 448                    | 344                  | 399                |
| 105      | Carbon steel        | Structural shapes   | A992      | ...        | ...     | ...                | ...      | 1         | (8c) (57)     | A                  | 448                    | 344                  | 427                |
| 106      | Carbon steel        | Forgings & fittings | A350      | LF1        | K03009  | ...                | ...      | 1         | (9) (57) (59) | -29                | 414                    | 207                  | 538                |
| 107      | Carbon steel        | Forgings & fittings | A181      | ...        | K03502  | 60                 | ...      | 1         | (9) (57) (59) | A                  | 414                    | 207                  | 593                |
| 108      | Carbon steel        | Forgings & fittings | A420      | WPL6       | K03006  | ...                | ...      | 1         | (57)          | -46                | 414                    | 241                  | 538                |
| 109      | Carbon steel        | Forgings & fittings | A234      | WPB        | K03006  | ...                | ...      | 1         | (57) (59)     | B                  | 414                    | 241                  | 593                |
| 110      | Carbon steel        | Forgings & fittings | A694      | F42        | K03014  | ...                | ...      | 1         | (9)           | -29                | 415                    | 290                  | 260                |
| 111      | Carbon steel        | Forgings & fittings | A707      | L1         | K02302  | 1                  | ...      | 1         | (9)           | -29                | 415                    | 290                  | 260                |
| 112      | Carbon steel        | Forgings & fittings | A707      | L2         | K03301  | 1                  | ...      | 1         | (9)           | -46                | 415                    | 290                  | 260                |
| 113      | Carbon steel        | Forgings & fittings | A707      | L3         | K12510  | 1                  | ...      | 1         | (9)           | -46                | 415                    | 290                  | 260                |
| 114      | Carbon steel        | Forgings & fittings | A860      | WPHY 42    | ...     | ...                | ...      | 1         | ...           | -46                | 415                    | 290                  | 260                |
| 115      | Carbon steel        | Forgings & fittings | A694      | F46        | K03014  | ...                | ...      | 1         | (9)           | -29                | 435                    | 317                  | 260                |
| 116      | Carbon steel        | Forgings & fittings | A860      | WPHY 46    | ...     | ...                | ...      | 1         | ...           | -46                | 435                    | 317                  | 260                |
| 117      | Carbon steel        | Forgings & fittings | A694      | F52        | K03014  | ...                | ...      | 1         | (9)           | -29                | 455                    | 360                  | 260                |
| 118      | Carbon steel        | Forgings & fittings | A707      | L1         | K02302  | 2                  | ...      | 1         | (9)           | -29                | 455                    | 360                  | 260                |
| 119      | Carbon steel        | Forgings & fittings | A707      | L2         | K03301  | 2                  | ...      | 1         | (9)           | -46                | 455                    | 360                  | 260                |
| 120      | Carbon steel        | Forgings & fittings | A707      | L3         | K12510  | 2                  | ...      | 1         | (9)           | -46                | 455                    | 360                  | 260                |
| 121      | Carbon steel        | Forgings & fittings | A860      | WPHY 52    | ...     | ...                | ...      | 1         | ...           | -46                | 455                    | 360                  | 260                |
| 122      | Carbon steel        | Forgings & fittings | A350      | LF2        | K03011  | 1                  | ...      | 1         | (9) (57)      | -46                | 483                    | 248                  | 538                |
| 123      | Carbon steel        | Forgings & fittings | A350      | LF2        | K03011  | 2                  | ...      | 1         | (9) (57)      | -18                | 483                    | 248                  | 538                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | Min. Temp. to 40                                                              | 65  | 100 | 150 | 200 | 250 | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  |
| 96       | 104                                                                           | 104 | 104 | 104 | 104 | 104 | 99.4 | 96.6 | 89.2 | 77.6 | 67.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 97       | 110                                                                           | 110 | 110 | 110 | 110 | 110 | 109  | 106  | 89.2 | 77.6 | 67.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 98       | 112                                                                           | 112 | 112 | 112 | 112 | 112 | 112  | 112  | 89.2 | 77.6 | 67.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 99       | 116                                                                           | 116 | 116 | 112 | 109 | 104 | 99.4 | 96.6 | 92.9 | 90.4 | 82.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 100      | 116                                                                           | 116 | 116 | 116 | 116 | 116 | 116  | 116  | 114  | 96.6 | 82.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 101      | 123                                                                           | 123 | 123 | 123 | 123 | 123 | 119  | 115  | 112  | 99.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 102      | 127                                                                           | 127 | 127 | 123 | 120 | 115 | 109  | 106  | 102  | 99.4 | 88.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 103      | 127                                                                           | 127 | 127 | 127 | 127 | 127 | 127  | 127  | 124  | 104  | 88.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 104      | 137                                                                           | 137 | 137 | 137 | 137 | 137 | 137  | 137  | 124  | 104  | 88.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 105      | 137                                                                           | 137 | 137 | 137 | 137 | 137 | 137  | 137  | 117  | 105  | 87.5 | 73.2 | 58.1 | ...  | ...  | ...  | ...  | ...  | ...  |
| 106      | 138                                                                           | 130 | 126 | 122 | 118 | 113 | 108  | 105  | 101  | 98.3 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 17.2 | ...  | ...  |
| 107      | 138                                                                           | 130 | 126 | 122 | 118 | 113 | 108  | 105  | 101  | 98.3 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 108      | 138                                                                           | 138 | 138 | 138 | 138 | 132 | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 17.2 | ...  | ...  |
| 109      | 138                                                                           | 138 | 138 | 138 | 138 | 132 | 126  | 122  | 118  | 113  | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 110      | 138                                                                           | 138 | 138 | 138 | 138 | 137 | 132  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 111      | 138                                                                           | 138 | 138 | 138 | 138 | 137 | 132  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 112      | 138                                                                           | 138 | 138 | 138 | 138 | 137 | 132  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 113      | 138                                                                           | 138 | 138 | 138 | 138 | 137 | 132  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 114      | 138                                                                           | 138 | 138 | 138 | 138 | 137 | 132  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 115      | 145                                                                           | 145 | 145 | 145 | 145 | 145 | 144  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 116      | 145                                                                           | 145 | 145 | 145 | 145 | 145 | 144  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 117      | 150                                                                           | 150 | 150 | 150 | 150 | 150 | 150  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 118      | 150                                                                           | 150 | 150 | 150 | 150 | 150 | 150  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 119      | 150                                                                           | 150 | 150 | 150 | 150 | 150 | 150  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 120      | 150                                                                           | 150 | 150 | 150 | 150 | 150 | 150  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 121      | 150                                                                           | 150 | 150 | 150 | 150 | 150 | 150  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 122      | 161                                                                           | 156 | 151 | 146 | 142 | 136 | 129  | 125  | 122  | 118  | 101  | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 | 17.2 | ...  | ...  |
| 123      | 161                                                                           | 156 | 151 | 146 | 142 | 136 | 129  | 125  | 122  | 118  | 101  | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 | 17.2 | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form        | Spec. No. | Type/Grade | UNS No. | Class/Cond./Temper | Size, mm | P-No. (5) | Notes         | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|---------------------|-----------|------------|---------|--------------------|----------|-----------|---------------|--------------------|------------------------|----------------------|--------------------|
| 124      | Carbon steel        | Forgings & fittings | A105      | ...        | K03504  | ...                | ...      | 1         | (9) (57) (59) | -29                | 483                    | 248                  | 593                |
| 125      | Carbon steel        | Forgings & fittings | A181      | ...        | K03502  | 70                 | ...      | 1         | (9) (57) (59) | A                  | 483                    | 248                  | 593                |
| 126      | Carbon steel        | Forgings & fittings | A234      | WPC        | K03501  | ...                | ...      | 1         | (57) (59)     | B                  | 483                    | 276                  | 427                |
| 127      | Carbon steel        | Forgings & fittings | A694      | F56        | K03014  | ...                | ...      | 1         | (9)           | -29                | 490                    | 385                  | 260                |
| 128      | Carbon steel        | Forgings & fittings | A694      | F60        | K03014  | ...                | ...      | 1         | (9)           | -29                | 515                    | 415                  | 260                |
| 129      | Carbon steel        | Forgings & fittings | A707      | L2         | K03301  | 3                  | ...      | 1         | (9)           | -46                | 515                    | 415                  | 260                |
| 130      | Carbon steel        | Forgings & fittings | A707      | L3         | K12510  | 3                  | ...      | 1         | (9)           | -46                | 515                    | 415                  | 260                |
| 131      | Carbon steel        | Forgings & fittings | A860      | WPHY 60    | ...     | ...                | ...      | 1         | ...           | -46                | 515                    | 415                  | 260                |
| 132      | Carbon steel        | Forgings & fittings | A694      | F65        | K03014  | ...                | ...      | 1         | (9)           | -29                | 530                    | 450                  | 260                |
| 133      | Carbon steel        | Forgings & fittings | A860      | WPHY 65    | ...     | ...                | ...      | 1         | ...           | -46                | 530                    | 450                  | 260                |
| 134      | Carbon steel        | Forgings & fittings | A694      | F70        | K03014  | ...                | ...      | 1         | (9) (79)      | ...                | 565                    | 485                  | 204                |
| 135      | Carbon steel        | Forgings & fittings | A860      | WPHY 70    | ...     | ...                | ...      | 1         | ...           | -46                | 565                    | 485                  | 204                |
| 136      | Carbon steel        | Castings            | A216      | WCA        | J02502  | ...                | ...      | 1         | (57)          | -29                | 414                    | 207                  | 593                |
| 137      | Carbon steel        | Castings            | A352      | LCB        | J03003  | ...                | ...      | 1         | (9) (57)      | -46                | 448                    | 241                  | 593                |
| 138      | Carbon steel        | Castings            | A352      | LCC        | J02505  | ...                | ...      | 1         | (9)           | -46                | 483                    | 276                  | 371                |
| 139      | Carbon steel        | Castings            | A216      | WCB        | J03002  | ...                | ...      | 1         | (9) (57)      | -29                | 483                    | 248                  | 593                |
| 140      | Carbon steel        | Castings            | A216      | WCC        | J02503  | ...                | ...      | 1         | (9) (57)      | -29                | 483                    | 276                  | 538                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |     |     |     |      |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|
|          | Min. Temp. to 40                                                              | 65  | 100 | 150 | 200 | 250 | 300 | 325 | 350 | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  |
| 124      | 161                                                                           | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118  | 101  | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |
| 125      | 161                                                                           | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118  | 101  | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |
| 126      | 161                                                                           | 161 | 161 | 161 | 158 | 151 | 144 | 139 | 135 | 122  | 101  | 83.8 | 82.7 | ...  | ...  | ...  | ...  | ...  | ...  |
| 127      | 163                                                                           | 163 | 163 | 163 | 163 | 163 | 163 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 128      | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 129      | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 130      | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 131      | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 132      | 177                                                                           | 177 | 177 | 177 | 177 | 177 | 177 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 133      | 177                                                                           | 177 | 177 | 177 | 177 | 177 | 177 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 134      | 188                                                                           | 188 | 188 | 188 | 188 | 188 | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 135      | 188                                                                           | 188 | 188 | 188 | 188 | 188 | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 136      | 138                                                                           | 130 | 126 | 122 | 118 | 113 | 108 | 105 | 101 | 98.3 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | 21.4 | 14.2 | 9.40 | 6.89 |
| 137      | 149                                                                           | 149 | 147 | 142 | 138 | 132 | 126 | 122 | 118 | 113  | 95.1 | 79.5 | 64.4 | 47.7 | 32.5 | 21.4 | 14.2 | 9.40 | 6.89 |
| 138      | 161                                                                           | 161 | 161 | 161 | 158 | 151 | 139 | 137 | 136 | 132  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 139      | 161                                                                           | 156 | 151 | 146 | 142 | 136 | 129 | 125 | 122 | 118  | 101  | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 | 14.2 | 9.40 | 6.89 |
| 140      | 161                                                                           | 161 | 161 | 161 | 158 | 151 | 144 | 139 | 135 | 122  | 101  | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 | 17.2 | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temp | Size, mm | P-No. (5) | Notes               | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------|-----------|------------|---------|----------------------|----------|-----------|---------------------|--------------------|------------------------|----------------------|--------------------|
| 1        | ½Cr-½Mo             | Pipe         | A335      | P2         | K11547  | ...                  | ...      | 3         | ...                 | -29                | 379                    | 207                  | 538                |
| 2        | ½Cr-½Mo             | Pipe         | A691      | ½CR        | K12143  | ...                  | ...      | 3         | (11) (67)           | -29                | 379                    | 228                  | 538                |
| 3        | C-½Mo               | Pipe         | A335      | P1         | K11522  | ...                  | ...      | 3         | (58)                | -29                | 379                    | 207                  | 593                |
| 4        | C-½Mo               | Pipe         | A369      | FP1        | K11522  | ...                  | ...      | 3         | (58)                | -29                | 379                    | 207                  | 593                |
| 5        | ½Cr-½Mo             | Pipe         | A369      | FP2        | K11547  | ...                  | ...      | 3         | ...                 | -29                | 379                    | 207                  | 593                |
| 6        | 1Cr-½Mo             | Pipe         | A691      | 1CR        | K11757  | ...                  | ...      | 4         | (11) (67)           | -29                | 379                    | 228                  | 649                |
| 7        | ½Cr-½Mo             | Pipe         | A426      | CP2        | J11547  | ...                  | ...      | 3         | (10)                | -29                | 414                    | 207                  | 593                |
| 8        | 1½Si-½Mo            | Pipe         | A335      | P15        | K11578  | ...                  | ...      | 3         | ...                 | -29                | 414                    | 207                  | 593                |
| 9        | C-½Mo-Si            | Pipe         | A426      | CP15       | J11522  | ...                  | ...      | 3         | (10)                | -29                | 414                    | 207                  | 593                |
| 10       | 1Cr-½Mo             | Pipe         | A426      | CP12       | J11562  | ...                  | ...      | 4         | (10)                | -29                | 414                    | 207                  | 649                |
| 11       | 5Cr-1½Si-½Mo        | Pipe         | A426      | CP5b       | J51545  | ...                  | ...      | 5B        | (10)                | -29                | 414                    | 207                  | 649                |
| 12       | 3Cr-Mo              | Pipe         | A426      | CP21       | J31545  | ...                  | ...      | 5A        | (10)                | -29                | 414                    | 207                  | 649                |
| 13       | ¾Cr-¾Ni-Cu-Al       | Pipe         | A333      | 4          | K11267  | ...                  | ...      | 4         | ...                 | -101               | 414                    | 241                  | 40                 |
| 14       | 2Cr-½Mo             | Pipe         | A369      | FP3b       | K21509  | ...                  | ...      | 4         | ...                 | -29                | 414                    | 207                  | 649                |
| 15       | 1Cr-½Mo             | Pipe         | A335      | P12        | K11562  | ...                  | ...      | 4         | ...                 | -29                | 414                    | 221                  | 649                |
| 16       | 1Cr-½Mo             | Pipe         | A369      | FP12       | K11562  | ...                  | ...      | 4         | ...                 | -29                | 414                    | 221                  | 649                |
| 17       | 1¼Cr-½Mo-Si         | Pipe         | A335      | P11        | K11597  | ...                  | ...      | 4         | ...                 | -29                | 414                    | 207                  | 649                |
| 18       | 1¼Cr-½Mo-Si         | Pipe         | A369      | FP11       | K11597  | ...                  | ...      | 4         | ...                 | -29                | 414                    | 207                  | 649                |
| 19       | 1¼Cr-½Mo-Si         | Pipe         | A691      | 1¼CR       | K11789  | ...                  | ...      | 4         | (11) (67)           | -29                | 414                    | 241                  | 649                |
| 20       | 5Cr-½Mo             | Pipe         | A691      | 5CR        | K41545  | ...                  | ...      | 5B        | (11) (67)           | -29                | 414                    | 207                  | 649                |
| 21       | 5Cr-½Mo             | Pipe         | A335      | P5         | K41545  | ...                  | ...      | 5B        | ...                 | -29                | 414                    | 207                  | 649                |
| 22       | 5Cr-½Mo-Si          | Pipe         | A335      | P5b        | K51545  | ...                  | ...      | 5B        | ...                 | -29                | 414                    | 207                  | 649                |
| 23       | 5Cr-½Mo-Ti          | Pipe         | A335      | P5c        | K41245  | ...                  | ...      | 5B        | ...                 | -29                | 414                    | 207                  | 649                |
| 24       | 5Cr-½Mo             | Pipe         | A369      | FP5        | K41545  | ...                  | ...      | 5B        | ...                 | -29                | 414                    | 207                  | 649                |
| 25       | 9Cr-1Mo             | Pipe         | A335      | P9         | K90941  | ...                  | ...      | 5B        | ...                 | -29                | 414                    | 207                  | 649                |
| 26       | 9Cr-1Mo             | Pipe         | A369      | FP9        | K90941  | ...                  | ...      | 5B        | ...                 | -29                | 414                    | 207                  | 649                |
| 27       | 9Cr-1Mo             | Pipe         | A691      | 9CR        | K90941  | ...                  | ...      | 5B        | (11) (67)           | -29                | 414                    | 207                  | 649                |
| 28       | 3Cr-1Mo             | Pipe         | A335      | P21        | K31545  | ...                  | ...      | 5A        | ...                 | -29                | 414                    | 207                  | 649                |
| 29       | 3Cr-1Mo             | Pipe         | A369      | FP21       | K31545  | ...                  | ...      | 5A        | ...                 | -29                | 414                    | 207                  | 649                |
| 30       | 3Cr-1Mo             | Pipe         | A691      | 3CR        | K31545  | ...                  | ...      | 5A        | (11) (67)           | -29                | 414                    | 207                  | 649                |
| 31       | 2¼Cr-1Mo            | Pipe         | A691      | 2¼CR       | K21590  | ...                  | ...      | 5A        | (11) (67) (72) (75) | -29                | 414                    | 207                  | 649                |
| 32       | 2¼Cr-1Mo            | Pipe         | A369      | FP22       | K21590  | ...                  | ...      | 5A        | (72) (75)           | -29                | 414                    | 207                  | 649                |
| 33       | 2¼Cr-1Mo            | Pipe         | A335      | P22        | K21590  | ...                  | ...      | 5A        | (72) (75)           | -29                | 414                    | 207                  | 649                |
| 34       | 2Ni-1Cu             | Pipe         | A333      | 9          | K22035  | ...                  | ...      | 9A        | ...                 | -73                | 434                    | 317                  | 40                 |
| 35       | 2Ni-1Cu             | Pipe         | A334      | 9          | K22035  | ...                  | ...      | 9A        | ...                 | -73                | 434                    | 317                  | 40                 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |     |     |     |     |     |     |     |     |     |      |      |      |      |      |      |      |      |      |      |  |  |  |
|----------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|--|--|--|
|          | Min. Temp. to 40                                                              | 65  | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  | 625  | 650  |  |  |  |
| 1        | 126                                                                           | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103  | 100  | 97.1 | 74.4 | 49.9 | 40.7 | ...  | ...  | ...  | ...  |  |  |  |
| 2        | 126                                                                           | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 125 | 123 | 121 | 119 | 116 | 114  | 110  | 107  | 74.4 | 49.9 | 40.7 | ...  | ...  | ...  | ...  |  |  |  |
| 3        | 126                                                                           | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103  | 100  | 97.1 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 4        | 126                                                                           | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103  | 100  | 97.1 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 5        | 126                                                                           | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103  | 100  | 97.1 | 93.5 | 49.9 | 34.7 | 23.9 | 17.2 | ...  | ...  |  |  |  |
| 6        | 126                                                                           | 126 | 123 | 122 | 122 | 122 | 122 | 121 | 120 | 118 | 116 | 115 | 114 | 112 | 110 | 109  | 106  | 104  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |
| 7        | 138                                                                           | 133 | 129 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103  | 100  | 97.1 | 74.4 | 49.9 | 34.3 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 8        | 138                                                                           | 133 | 129 | 127 | 125 | 124 | 122 | 121 | 120 | 118 | 117 | 115 | 114 | 112 | 110 | 107  | 103  | 88.4 | 74.7 | 53.7 | 35.6 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 9        | 138                                                                           | 133 | 129 | 127 | 125 | 124 | 122 | 121 | 120 | 118 | 117 | 115 | 114 | 112 | 110 | 107  | 103  | 88.4 | 74.7 | 53.7 | 35.6 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 10       | 138                                                                           | 129 | 124 | 120 | 117 | 115 | 112 | 110 | 109 | 107 | 106 | 105 | 103 | 102 | 100 | 98.7 | 96.8 | 94.6 | 92.0 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |
| 11       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 12       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |  |  |  |
| 13       | 138                                                                           | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |      |  |  |  |
| 14       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 118  | 74.7 | 53.3 | 36.0 | 24.6 | 15.5 | 9.21 | 6.89 |  |  |  |
| 15       | 138                                                                           | 138 | 132 | 128 | 125 | 122 | 120 | 118 | 116 | 114 | 113 | 112 | 110 | 109 | 107 | 105  | 103  | 101  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |
| 16       | 138                                                                           | 138 | 132 | 128 | 125 | 122 | 120 | 118 | 116 | 114 | 113 | 112 | 110 | 109 | 107 | 105  | 103  | 101  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |
| 17       | 138                                                                           | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |  |
| 18       | 138                                                                           | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |  |
| 19       | 138                                                                           | 138 | 138 | 138 | 138 | 138 | 136 | 134 | 131 | 129 | 127 | 125 | 123 | 121 | 119 | 116  | 113  | 104  | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |  |
| 20       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 21       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 22       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 23       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 24       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 25       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |  |  |
| 26       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |  |  |
| 27       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |  |  |
| 28       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |  |  |  |
| 29       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |  |  |  |
| 30       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |  |  |  |
| 31       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |  |  |  |
| 32       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |  |  |  |
| 33       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |  |  |  |
| 34       | 145                                                                           | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |      |  |  |  |
| 35       | 145                                                                           | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |      |  |  |  |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temper | Size, mm | P-No. (5) | Notes          | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------|-----------|------------|---------|------------------------|----------|-----------|----------------|--------------------|------------------------|----------------------|--------------------|
| 36       | 2¼Ni                | Pipe         | A333      | 7          | K21903  | ...                    | ...      | 9A        | ...            | -73                | 448                    | 241                  | 593                |
| 37       | 2¼Ni                | Pipe         | A334      | 7          | K21903  | ...                    | ...      | 9A        | ...            | -73                | 448                    | 241                  | 593                |
| 38       | 3½Ni                | Pipe         | A333      | 3          | K31918  | ...                    | ...      | 9B        | ...            | -101               | 448                    | 241                  | 593                |
| 39       | 3½Ni                | Pipe         | A334      | 3          | K31918  | ...                    | ...      | 9B        | ...            | -101               | 448                    | 241                  | 593                |
| 40       | C-½Mo               | Pipe         | A426      | CP1        | J12521  | ...                    | ...      | 3         | (10) (58)      | -29                | 448                    | 241                  | 593                |
| 41       | C-½Mo               | Pipe         | A672      | L65        | K11820  | ...                    | ...      | 3         | (11) (58) (67) | -29                | 448                    | 255                  | 593                |
| 42       | C-½Mo               | Pipe         | A691      | CM-65      | K11820  | ...                    | ...      | 3         | (11) (58) (67) | -29                | 448                    | 255                  | 593                |
| 43       | 2¼Ni                | Pipe         | A671      | CFB70      | K22103  | ...                    | ...      | 9A        | (11) (65) (67) | -29                | 483                    | 276                  | 40                 |
| 44       | 3½Ni                | Pipe         | A671      | CFE70      | K32018  | ...                    | ...      | 9B        | (11) (65) (67) | -29                | 483                    | 276                  | 40                 |
| 45       | C-½Mo               | Pipe         | A672      | L70        | K12020  | ...                    | ...      | 3         | (11) (58) (67) | -29                | 483                    | 276                  | 593                |
| 46       | C-½Mo               | Pipe         | A691      | CM-70      | K12020  | ...                    | ...      | 3         | (11) (58) (67) | -29                | 483                    | 276                  | 593                |
| 47       | 1¼Cr-½Mo            | Pipe         | A426      | CP11       | J12072  | ...                    | ...      | 4         | (10)           | -29                | 483                    | 276                  | 649                |
| 48       | 2¼Cr-1Mo            | Pipe         | A426      | CP22       | J21890  | ...                    | ...      | 5A        | (10) (72)      | -29                | 483                    | 276                  | 649                |
| 49       | C-½Mo               | Pipe         | A672      | L75        | K12320  | ...                    | ...      | 3         | (11) (58) (67) | -29                | 517                    | 296                  | 593                |
| 50       | C-½Mo               | Pipe         | A691      | CM-75      | K12320  | ...                    | ...      | 3         | (11) (58) (67) | -29                | 517                    | 296                  | 593                |
| 51       | 9Cr-1Mo-V           | Pipe         | A335      | P91        | K90901  | ...                    | ≤75      | 15E       | ...            | -29                | 586                    | 414                  | 649                |
| 52       | 9Cr-1Mo-V           | Pipe         | A691      | 91         | K90901  | ...                    | ≤75      | 15E       | (11) (67)      | -29                | 586                    | 414                  | 649                |
| 53       | 5Cr-½Mo             | Pipe         | A426      | CP5        | J42045  | ...                    | ...      | 5B        | (10)           | -29                | 621                    | 414                  | 649                |
| 54       | 9Cr-1Mo             | Pipe         | A426      | CP9        | J82090  | ...                    | ...      | 5B        | (10)           | -29                | 621                    | 414                  | 649                |
| 55       | 9Ni                 | Pipe         | A333      | 8          | K81340  | ...                    | ...      | 11A       | (47)           | -196               | 689                    | 517                  | 93                 |
| 56       | 9Ni                 | Pipe         | A334      | 8          | K81340  | ...                    | ...      | 11A       | ...            | -196               | 689                    | 517                  | 93                 |
| 57       | ½Cr-½Mo             | Plate        | A387      | 2          | K12143  | 1                      | ...      | 3         | ...            | -29                | 379                    | 228                  | 538                |
| 58       | 1Cr-½Mo             | Plate        | A387      | 12         | K11757  | 1                      | ...      | 4         | ...            | -29                | 379                    | 228                  | 649                |
| 59       | 9Cr-1Mo             | Plate        | A387      | 9          | K90941  | 1                      | ...      | 5B        | ...            | -29                | 414                    | 207                  | 649                |
| 60       | 1¼Cr-½Mo-Si         | Plate        | A387      | 11         | K11789  | 1                      | ...      | 4         | ...            | -29                | 414                    | 241                  | 649                |
| 61       | 5Cr-½Mo             | Plate        | A387      | 5          | K41545  | 1                      | ...      | 5B        | ...            | -29                | 414                    | 207                  | 649                |
| 62       | 3Cr-1Mo             | Plate        | A387      | 21         | K31545  | 1                      | ...      | 5A        | ...            | -29                | 414                    | 207                  | 649                |
| 63       | 2¼Cr-1Mo            | Plate        | A387      | 22         | K21590  | 1                      | ...      | 5A        | (72)           | -29                | 414                    | 207                  | 649                |
| 64       | 2¼Ni                | Plate        | A203      | A          | K21703  | ...                    | ...      | 9A        | (12) (65)      | -29                | 448                    | 255                  | 538                |
| 65       | 3½Ni                | Plate        | A203      | D          | K31718  | ...                    | ...      | 9B        | (12) (65)      | -29                | 448                    | 255                  | 538                |
| 66       | C-½Mo               | Plate        | A204      | A          | K11820  | ...                    | ...      | 3         | (58)           | -29                | 448                    | 255                  | 593                |
| 67       | 1Cr-½Mo             | Plate        | A387      | 12         | K11757  | 2                      | ...      | 4         | ...            | -29                | 448                    | 276                  | 649                |
| 68       | 2¼Ni                | Plate        | A203      | B          | K22103  | ...                    | ...      | 9A        | (12) (65)      | -29                | 483                    | 276                  | 538                |
| 69       | 3½Ni                | Plate        | A203      | E          | K32018  | ...                    | ...      | 9B        | (12) (65)      | -29                | 483                    | 276                  | 538                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |     |     |     |     |     |     |     |     |      |      |      |      |      |      |      |      |      |      |      |  |  |
|----------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|--|--|
|          | Min. Temp. to 40                                                              | 65  | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  | 625  | 650  |  |  |
| 36       | 149                                                                           | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.40 | 6.89 | ...  | ...  |  |  |
| 37       | 149                                                                           | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.40 | 6.89 | ...  | ...  |  |  |
| 38       | 149                                                                           | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.48 | 7.06 | ...  | ...  |  |  |
| 39       | 149                                                                           | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | 107 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 14.2 | 9.48 | 7.06 | ...  | ...  |  |  |
| 40       | 149                                                                           | 149 | 149 | 148 | 145 | 143 | 140 | 138 | 137 | 135 | 133 | 131 | 129 | 126 | 123  | 120  | 117  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 41       | 149                                                                           | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 144 | 142 | 140 | 138 | 136 | 133 | 131  | 127  | 124  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 42       | 149                                                                           | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 144 | 142 | 140 | 138 | 136 | 133 | 131  | 127  | 124  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 43       | 161                                                                           | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |
| 44       | 161                                                                           | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |
| 45       | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141  | 138  | 134  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 46       | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141  | 138  | 134  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 47       | 161                                                                           | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136  | 133  | 130  | 104  | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |
| 48       | 161                                                                           | 161 | 160 | 157 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156  | 156  | 156  | 119  | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |  |  |
| 49       | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | 170 | 168 | 165 | 163 | 161 | 158 | 155 | 152  | 148  | 144  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 50       | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | 170 | 168 | 165 | 163 | 161 | 158 | 155 | 152  | 148  | 144  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 51       | 195                                                                           | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178  | 172  | 165  | 156  | 147  | 137  | 115  | 87.0 | 64.7 | 45.1 | 29.6 |  |  |
| 52       | 195                                                                           | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178  | 172  | 165  | 156  | 147  | 137  | 115  | 87.0 | 64.7 | 45.1 | 29.6 |  |  |
| 53       | 207                                                                           | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182  | 176  | 169  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |
| 54       | 207                                                                           | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182  | 176  | 169  | 160  | 87.5 | 61.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |  |
| 55       | 230                                                                           | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |
| 56       | 230                                                                           | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |
| 57       | 126                                                                           | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 125 | 123 | 121 | 119 | 116  | 114  | 110  | 107  | 74.4 | 49.9 | 40.7 | ...  | ...  | ...  | ...  |  |  |
| 58       | 126                                                                           | 126 | 123 | 122 | 122 | 122 | 122 | 121 | 120 | 118 | 116 | 115 | 114 | 112 | 110  | 109  | 106  | 104  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |
| 59       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110  | 106  | 103  | 98.3 | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |  |
| 60       | 138                                                                           | 138 | 138 | 138 | 138 | 138 | 136 | 134 | 131 | 129 | 127 | 125 | 123 | 121 | 119  | 116  | 113  | 104  | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |
| 61       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110  | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |
| 62       | 138                                                                           | 130 | 126 | 123 | 121 | 119 | 117 | 116 | 115 | 114 | 112 | 111 | 110 | 109 | 107  | 105  | 103  | 89.2 | 68.8 | 54.2 | 43.4 | 34.0 | 25.1 | 17.1 | 10.3 |  |  |
| 63       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123  | 122  | 121  | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |  |  |
| 64       | 149                                                                           | 149 | 149 | 149 | 149 | 148 | 146 | 143 | 140 | 136 | 131 | 126 | 120 | 113 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 17.2 | ...  | ...  | ...  | ...  |  |  |
| 65       | 149                                                                           | 149 | 149 | 149 | 149 | 148 | 146 | 143 | 140 | 136 | 131 | 126 | 120 | 113 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 17.2 | ...  | ...  | ...  | ...  |  |  |
| 66       | 149                                                                           | 149 | 149 | 149 | 149 | 149 | 148 | 146 | 144 | 142 | 140 | 138 | 136 | 133 | 131  | 127  | 124  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |
| 67       | 149                                                                           | 149 | 146 | 144 | 144 | 144 | 144 | 144 | 144 | 143 | 141 | 139 | 138 | 136 | 134  | 132  | 129  | 126  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |
| 68       | 161                                                                           | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 130 | 113 | 95.1 | 79.5 | 64.4 | 48.8 | 35.4 | 22.6 | 17.2 | ...  | ...  | ...  | ...  |  |  |
| 69       | 161                                                                           | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 130 | 122 | 101  | 83.8 | 66.8 | 49.2 | 35.4 | 22.6 | 17.2 | ...  | ...  | ...  | ...  |  |  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temper | Size, mm | P-No. (5) | Notes         | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------|-----------|------------|---------|------------------------|----------|-----------|---------------|--------------------|------------------------|----------------------|--------------------|
| 70       | ½Cr-½Mo             | Plate        | A387      | 2          | K12143  | 2                      | ...      | 3         | ...           | -29                | 483                    | 310                  | 538                |
| 71       | C-½Mo               | Plate        | A204      | B          | K12020  | ...                    | ...      | 3         | (58)          | -29                | 483                    | 276                  | 593                |
| 72       | Mn-½Mo              | Plate        | A302      | A          | K12021  | ...                    | ...      | 3         | ...           | -29                | 517                    | 310                  | 538                |
| 73       | C-½Mo               | Plate        | A204      | C          | K12320  | ...                    | ...      | 3         | (58)          | -29                | 517                    | 296                  | 593                |
| 74       | 1¼Cr-½Mo-Si         | Plate        | A387      | 11         | K11789  | 2                      | ...      | 4         | ...           | -29                | 517                    | 310                  | 649                |
| 75       | 5Cr-½Mo             | Plate        | A387      | 5          | K41545  | 2                      | ...      | 5B        | ...           | -29                | 517                    | 310                  | 649                |
| 76       | 3Cr-1Mo             | Plate        | A387      | 21         | K31545  | 2                      | ...      | 5A        | ...           | -29                | 517                    | 310                  | 649                |
| 77       | 2¼Cr-1Mo            | Plate        | A387      | 22         | K21590  | 2                      | ...      | 5A        | (72)          | -29                | 517                    | 310                  | 649                |
| 78       | Mn-½Mo              | Plate        | A302      | B          | K12022  | ...                    | ...      | 3         | ...           | -29                | 552                    | 345                  | 538                |
| 79       | Mn-½Mo-½Ni          | Plate        | A302      | C          | K12039  | ...                    | ...      | 3         | ...           | -29                | 552                    | 345                  | 538                |
| 80       | Mn-½Mo-¾Ni          | Plate        | A302      | D          | K12054  | ...                    | ...      | 3         | ...           | -29                | 552                    | 345                  | 538                |
| 81       | 9Cr-1Mo-V           | Plate        | A387      | 91         | K90901  | 2                      | ≤75      | 15E       | ...           | -29                | 586                    | 414                  | 649                |
| 82       | 8Ni                 | Plate        | A553      | II         | K71340  | ...                    | ...      | 11A       | (47)          | -171               | 689                    | 586                  | 40                 |
| 83       | 5Ni-¼Mo             | Plate        | A645      | A          | K41583  | ...                    | ...      | 11A       | ...           | -171               | 655                    | 448                  | 93                 |
| 84       | 9Ni                 | Plate        | A553      | I          | K81340  | ...                    | ...      | 11A       | (47)          | -196               | 689                    | 586                  | 93                 |
| 85       | 9Ni                 | Plate        | A353      | ...        | K81340  | ...                    | ...      | 11A       | (47)          | -196               | 689                    | 517                  | 93                 |
| 86       | C-½Mo               | Forg. & ftg. | A234      | WP1        | K12821  | ...                    | ...      | 3         | (58)          | -29                | 379                    | 207                  | 593                |
| 87       | 1Cr-½Mo             | Forg. & ftg. | A182      | F12        | K11562  | 1                      | ...      | 4         | (9)           | -29                | 414                    | 221                  | 649                |
| 88       | 1Cr-½Mo             | Forg. & ftg. | A234      | WP12       | K12062  | 1                      | ...      | 4         | ...           | -29                | 414                    | 221                  | 649                |
| 89       | 1¼Cr-½Mo-Si         | Forg. & ftg. | A182      | F11        | K11597  | 1                      | ...      | 4         | (9)           | -29                | 414                    | 207                  | 649                |
| 90       | 1¼Cr-½Mo-Si         | Forg. & ftg. | A234      | WP11       | K11597  | 1                      | ...      | 4         | ...           | -29                | 414                    | 207                  | 649                |
| 91       | 2¼Cr-1Mo            | Forg. & ftg. | A182      | F22        | K21590  | 1                      | ...      | 5A        | (9) (72) (75) | -29                | 414                    | 207                  | 649                |
| 92       | 2¼Cr-1Mo            | Forg. & ftg. | A234      | WP22       | K21590  | 1                      | ...      | 5A        | (72)          | -29                | 414                    | 207                  | 649                |
| 93       | 5Cr-½Mo             | Forg. & ftg. | A234      | WP5        | K41545  | ...                    | ...      | 5B        | ...           | -29                | 414                    | 207                  | 649                |
| 94       | 9Cr-1Mo             | Forg. & ftg. | A234      | WP9        | K90941  | ...                    | ...      | 5B        | ...           | -29                | 414                    | 207                  | 649                |
| 95       | 3½Ni                | Forg. & ftg. | A420      | WPL3       | K31918  | ...                    | ...      | 9B        | ...           | -101               | 448                    | 241                  | 343                |
| 96       | 3½Ni                | Forg. & ftg. | A350      | LF3        | K32025  | ...                    | ...      | 9B        | (9)           | -101               | 483                    | 259                  | 343                |
| 97       | ½Cr-½Mo             | Forg. & ftg. | A182      | F2         | K12122  | ...                    | ...      | 3         | (9)           | -29                | 483                    | 276                  | 538                |
| 98       | C-½Mo               | Forg. & ftg. | A182      | F1         | K12822  | ...                    | ...      | 3         | (9) (58)      | -29                | 483                    | 276                  | 593                |
| 99       | 1Cr-½Mo             | Forg. & ftg. | A182      | F12        | K11564  | 2                      | ...      | 4         | (9)           | -29                | 483                    | 276                  | 649                |
| 100      | 1Cr-½Mo             | Forg. & ftg. | A234      | WP12       | K12062  | 2                      | ...      | 4         | ...           | -29                | 483                    | 276                  | 649                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |     |     |     |     |     |     |     |     |     |      |      |      |      |      |      |      |      |      |      |  |  |  |
|----------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|--|--|--|
|          | Min. Temp. to 40                                                              | 65  | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  | 625  | 650  |  |  |  |
| 70       | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 159 | 155  | 151  | 146  | 93.5 | 49.9 | 40.7 | ...  | ...  | ...  | ...  |  |  |  |
| 71       | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138  | 134  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 72       | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 171 | 168 | 165 | 160  | 154  | 104  | 68.0 | 42.3 | 33.1 | ...  | ...  | ...  | ...  |  |  |  |
| 73       | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | 170 | 168 | 165 | 163 | 161 | 158 | 155 | 152 | 148  | 144  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 74       | 172                                                                           | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 169 | 166 | 164 | 161 | 159 | 156 | 153 | 149  | 146  | 104  | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |  |
| 75       | 172                                                                           | 172 | 171 | 169 | 167 | 166 | 165 | 165 | 165 | 164 | 164 | 162 | 159 | 156 | 130 | 126  | 104  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 76       | 172                                                                           | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167  | 167  | 98.2 | 73.5 | 54.7 | 40.6 | 29.2 | 20.6 | 15.2 | 8.96 |  |  |  |
| 77       | 172                                                                           | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167  | 167  | 119  | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |  |  |  |
| 78       | 184                                                                           | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 183 | 178  | 172  | 104  | 68.0 | 42.3 | 33.1 | ...  | ...  | ...  | ...  |  |  |  |
| 79       | 184                                                                           | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 183 | 178  | 172  | 104  | 68.0 | 42.3 | 33.1 | ...  | ...  | ...  | ...  |  |  |  |
| 80       | 184                                                                           | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 183 | 178  | 172  | 104  | 68.0 | 42.3 | 33.1 | ...  | ...  | ...  | ...  |  |  |  |
| 81       | 195                                                                           | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172  | 165  | 156  | 147  | 137  | 115  | 87.0 | 64.7 | 45.1 | 29.6 |  |  |  |
| 82       | 230                                                                           | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |  |
| 83       | 218                                                                           | 218 | 218 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |  |
| 84       | 230                                                                           | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |  |
| 85       | 230                                                                           | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |  |
| 86       | 126                                                                           | 126 | 126 | 126 | 124 | 122 | 120 | 119 | 117 | 115 | 114 | 112 | 110 | 108 | 106 | 103  | 100  | 97.1 | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 87       | 138                                                                           | 129 | 124 | 120 | 117 | 115 | 112 | 110 | 109 | 107 | 106 | 105 | 103 | 102 | 100 | 98.7 | 96.8 | 94.6 | 92.0 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |
| 88       | 138                                                                           | 138 | 132 | 128 | 125 | 122 | 120 | 118 | 116 | 114 | 113 | 112 | 110 | 109 | 107 | 105  | 103  | 101  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |
| 89       | 138                                                                           | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |  |
| 90       | 138                                                                           | 131 | 126 | 124 | 121 | 119 | 116 | 115 | 113 | 111 | 109 | 107 | 106 | 104 | 102 | 99.6 | 97.2 | 94.5 | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |  |  |
| 91       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |  |  |  |
| 92       | 138                                                                           | 132 | 128 | 126 | 125 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 124 | 123 | 122  | 121  | 99.6 | 80.9 | 63.3 | 47.5 | 34.2 | 23.5 | 15.3 | 9.65 |  |  |  |
| 93       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |  |  |
| 94       | 138                                                                           | 129 | 124 | 122 | 120 | 119 | 119 | 118 | 118 | 117 | 117 | 116 | 114 | 112 | 110 | 106  | 103  | 98.3 | 87.5 | 61.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |  |  |
| 95       | 149                                                                           | 149 | 147 | 144 | 142 | 140 | 138 | 135 | 132 | 128 | 124 | 119 | 113 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |  |
| 96       | 161                                                                           | 160 | 157 | 155 | 152 | 150 | 148 | 145 | 142 | 137 | 133 | 128 | 122 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |  |  |
| 97       | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138  | 134  | 129  | 93.5 | 49.9 | 40.7 | ...  | ...  | ...  | ...  |  |  |  |
| 98       | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 158 | 156 | 154 | 152 | 149 | 147 | 144 | 141 | 138  | 134  | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |  |  |
| 99       | 161                                                                           | 161 | 157 | 155 | 155 | 153 | 150 | 147 | 145 | 143 | 141 | 139 | 138 | 136 | 134 | 132  | 129  | 126  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |
| 100      | 161                                                                           | 161 | 157 | 155 | 155 | 153 | 150 | 147 | 145 | 143 | 141 | 139 | 138 | 136 | 134 | 132  | 129  | 126  | 92.1 | 61.1 | 40.4 | 26.4 | 17.4 | 11.6 | 7.58 |  |  |  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/ Temper | Size, mm | P-No. (5) | Notes    | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C |
|----------|---------------------|--------------|-----------|------------|---------|-------------------------|----------|-----------|----------|--------------------|------------------------|----------------------|--------------------|
| 101      | 1¼Cr-½Mo-Si         | Forg. & ftg. | A182      | F11        | K11572  | 2                       | ...      | 4         | (9)      | -29                | 483                    | 276                  | 649                |
| 102      | 1¼Cr-½Mo-Si         | Forg. & ftg. | A234      | WP11       | K11572  | 2                       | ...      | 4         | ...      | -29                | 483                    | 276                  | 649                |
| 103      | 5Cr-½Mo             | Forg. & ftg. | A182      | F5         | K41545  | ...                     | ...      | 5B        | (9)      | -29                | 483                    | 276                  | 649                |
| 104      | 3Cr-1Mo             | Forg. & ftg. | A182      | F21        | K31545  | ...                     | ...      | 5A        | (9)      | -29                | 517                    | 310                  | 649                |
| 105      | 2¼Cr-1Mo            | Forg. & ftg. | A182      | F22        | K21590  | 3                       | ...      | 5A        | (9) (72) | -29                | 517                    | 310                  | 649                |
| 106      | 2¼Cr-1Mo            | Forg. & ftg. | A234      | WP22       | K21590  | 3                       | ...      | 5A        | (72)     | -29                | 517                    | 310                  | 649                |
| 107      | 9Cr-1Mo             | Forg. & ftg. | A182      | F9         | K90941  | ...                     | ...      | 5B        | (9)      | -29                | 586                    | 379                  | 649                |
| 108      | 9Cr-1Mo-V           | Forg. & ftg. | A182      | F91        | K90901  | ...                     | ≤75      | 15E       | ...      | -29                | 586                    | 414                  | 649                |
| 109      | 9Cr-1Mo-V           | Forg. & ftg. | A234      | WP91       | K90901  | ...                     | ≤75      | 15E       | ...      | -29                | 586                    | 414                  | 649                |
| 110      | 5Cr-½Mo             | Forg. & ftg. | A182      | F5a        | K42544  | ...                     | ...      | 5B        | (9)      | -29                | 621                    | 448                  | 649                |
| 111      | 9Ni                 | Forg. & ftg. | A420      | WPL8       | K81340  | ...                     | ...      | 11A       | (47)     | -196               | 689                    | 517                  | 93                 |
| 112      | C-½Mo               | Castings     | A352      | LC1        | J12522  | ...                     | ...      | 3         | (9) (58) | -59                | 448                    | 241                  | 371                |
| 113      | C-½Mo               | Castings     | A217      | WC1        | J12524  | ...                     | ...      | 3         | (9) (58) | -29                | 448                    | 241                  | 593                |
| 114      | 2½Ni                | Castings     | A352      | LC2        | J22500  | ...                     | ...      | 9A        | (9)      | -73                | 483                    | 276                  | 343                |
| 115      | 3½Ni                | Castings     | A352      | LC3        | J31550  | ...                     | ...      | 9B        | (9)      | -101               | 483                    | 276                  | 343                |
| 116      | 1Ni-½Cr-½Mo         | Castings     | A217      | WC4        | J12082  | ...                     | ...      | 4         | (9)      | -29                | 483                    | 276                  | 538                |
| 117      | ¾Ni-1Mo-¾Cr         | Castings     | A217      | WC5        | J22000  | ...                     | ...      | 4         | (9)      | -29                | 483                    | 276                  | 593                |
| 118      | 1¼Cr-½Mo            | Castings     | A217      | WC6        | J12072  | ...                     | ...      | 4         | (9)      | -29                | 483                    | 276                  | 649                |
| 119      | 2¼Cr-1Mo            | Castings     | A217      | WC9        | J21890  | ...                     | ...      | 5A        | (9)      | -29                | 483                    | 276                  | 649                |
| 120      | 5Cr-½Mo             | Castings     | A217      | C5         | J42045  | ...                     | ...      | 5B        | (9)      | -29                | 621                    | 414                  | 649                |
| 121      | 9Cr-1Mo             | Castings     | A217      | C12        | J82090  | ...                     | ...      | 5B        | (9)      | -29                | 621                    | 414                  | 649                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated**

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |      |      |      |      |      |      |      |      |  |
|----------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|--|
|          | Min. Temp. to 40                                                              | 65  | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475  | 500  | 525  | 550  | 575  | 600  | 625  | 650  |  |
| 101      | 161                                                                           | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136 | 133 | 130 | 104  | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |
| 102      | 161                                                                           | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136 | 133 | 130 | 104  | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |
| 103      | 161                                                                           | 161 | 160 | 157 | 156 | 155 | 155 | 155 | 154 | 154 | 153 | 151 | 149 | 146 | 142 | 137 | 131 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |
| 104      | 172                                                                           | 172 | 172 | 169 | 168 | 167 | 166 | 166 | 165 | 165 | 164 | 164 | 162 | 161 | 158 | 155 | 152 | 98.2 | 73.5 | 54.7 | 40.6 | 29.2 | 20.6 | 15.2 | 8.96 |  |
| 105      | 172                                                                           | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 119  | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |  |
| 106      | 172                                                                           | 172 | 171 | 168 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 167 | 119  | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |  |
| 107      | 195                                                                           | 195 | 194 | 191 | 189 | 188 | 188 | 188 | 187 | 187 | 186 | 184 | 181 | 177 | 172 | 166 | 159 | 151  | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |
| 108      | 195                                                                           | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172 | 165 | 156  | 147  | 137  | 115  | 87.0 | 64.7 | 45.1 | 29.6 |  |
| 109      | 195                                                                           | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 194 | 193 | 192 | 190 | 187 | 183 | 178 | 172 | 165 | 156  | 147  | 137  | 115  | 87.0 | 64.7 | 45.1 | 29.6 |  |
| 110      | 207                                                                           | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |
| 111      | 230                                                                           | 230 | 230 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |
| 112      | 149                                                                           | 149 | 149 | 148 | 145 | 143 | 140 | 138 | 137 | 135 | 133 | 131 | 129 | 127 | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |
| 113      | 149                                                                           | 149 | 149 | 148 | 145 | 143 | 140 | 138 | 137 | 135 | 133 | 131 | 129 | 126 | 123 | 120 | 117 | 109  | 68.0 | 42.3 | 30.5 | 23.2 | 16.5 | ...  | ...  |  |
| 114      | 161                                                                           | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 131 | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |
| 115      | 161                                                                           | 161 | 161 | 161 | 161 | 160 | 158 | 155 | 151 | 147 | 142 | 136 | 131 | ... | ... | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |  |
| 116      | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 159 | 158 | 156 | 154 | 152 | 149 | 146 | 142 | 137 | 131  | 74.4 | 49.9 | 40.7 | ...  | ...  | ...  | ...  |  |
| 117      | 161                                                                           | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 159 | 158 | 156 | 154 | 152 | 149 | 146 | 142 | 137 | 131  | 74.4 | 49.9 | 34.3 | 23.2 | 16.5 | ...  | ...  |  |
| 118      | 161                                                                           | 161 | 161 | 161 | 161 | 158 | 155 | 153 | 150 | 148 | 146 | 143 | 141 | 138 | 136 | 133 | 130 | 104  | 73.7 | 52.0 | 36.3 | 25.2 | 17.6 | 12.3 | 8.27 |  |
| 119      | 161                                                                           | 161 | 160 | 157 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 119  | 88.4 | 64.0 | 44.6 | 30.0 | 19.7 | 12.8 | 8.27 |  |
| 120      | 207                                                                           | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 80.6 | 61.7 | 46.4 | 34.7 | 25.5 | 17.8 | 11.4 | 6.89 |  |
| 121      | 207                                                                           | 207 | 205 | 202 | 200 | 199 | 199 | 199 | 198 | 198 | 196 | 194 | 191 | 187 | 182 | 176 | 169 | 160  | 83.2 | 60.2 | 42.9 | 29.9 | 20.6 | 14.4 | 10.3 |  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form      | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|----------|---------------------|-------------------|-----------|-------------|---------|--------------------------|----------|-----------|
| 1        | 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321       | S32100  | ...                      | >10      | 8         |
| 2        | 18Cr-10Ni-Ti        | Smls. pipe        | A376      | TP321       | S32100  | ...                      | >10      | 8         |
| 3        | 18Cr-8Ni            | Tube              | A213      | TP304L      | S30403  | ...                      | ...      | 8         |
| 4        | 18Cr-8Ni            | Tube              | A269      | TP304L      | S30403  | ...                      | ...      | 8         |
| 5        | 18Cr-8Ni            | Tube              | A270      | TP304L      | S30403  | ...                      | ...      | 8         |
| 6        | 18Cr-8Ni            | Smls. & wld. pipe | A312      | TP304L      | S30403  | ...                      | ...      | 8         |
| 7        | 18Cr-8Ni            | Wld. pipe         | A358      | 304L        | S30403  | ...                      | ...      | 8         |
| 8        | 16Cr-12Ni-2Mo       | Tube              | A213      | TP316L      | S31603  | ...                      | ...      | 8         |
| 9        | 16Cr-12Ni-2Mo       | Tube              | A269      | TP316L      | S31603  | ...                      | ...      | 8         |
| 10       | 16Cr-12Ni-2Mo       | Tube              | A270      | TP316L      | S31603  | ...                      | ...      | 8         |
| 11       | 16Cr-12Ni-2Mo       | Smls. & wld. pipe | A312      | TP316L      | S31603  | ...                      | ...      | 8         |
| 12       | 16Cr-12Ni-2Mo       | Wld. pipe         | A358      | 316L        | S31603  | ...                      | ...      | 8         |
| 13       | 16Cr-12Ni-2Mo-Ti    | Tube              | A213      | TP316Ti     | S31635  | ...                      | ...      | 8         |
| 14       | 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321       | S32100  | ...                      | >10      | 8         |
| 15       | 18Cr-10Ni-Ti        | Smls. pipe        | A376      | TP321       | S32100  | ...                      | >10      | 8         |
| 16       | 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321H      | S32109  | ...                      | >10      | 8         |
| 17       | 18Cr-10Ni-Ti        | Smls. pipe        | A376      | TP321H      | S32109  | ...                      | >10      | 8         |
| 18       | 25Cr-12Ni           | Pipe & tube       | A451      | CPH8        | J93400  | ...                      | ...      | 8         |
| 19       | 25Cr-20Ni           | Pipe & tube       | A451      | CPK20       | J94202  | ...                      | ...      | 8         |
| 20       | 11Cr-Ti             | Tube              | A268      | TP409       | S40900  | ...                      | ...      | 7         |
| 21       | 18Cr-Ti             | Tube              | A268      | TP430Ti     | S43036  | ...                      | ...      | 7         |
| 22       | 16Cr-14Ni-2Mo       | Pipe & tube       | A451      | CPF10MC     | J92971  | ...                      | ...      | 8         |
| 23       | 12Cr-Al             | Tube              | A268      | TP405       | S40500  | ...                      | ...      | 7         |
| 24       | 13Cr                | Tube              | A268      | TP410       | S41000  | ...                      | ...      | 6         |
| 25       | 17Cr                | Tube              | A268      | TP430       | S43000  | ...                      | ...      | 7         |
| 26       | 18Cr-13Ni-3Mo       | Smls. & wld. pipe | A312      | TP317L      | S31703  | ...                      | ...      | 8         |
| 27       | 25Cr-20Ni           | Smls. & wld. pipe | A312      | TP310S      | S31008  | ...                      | ...      | 8         |
| 28       | 25Cr-20Ni           | Wld. pipe         | A358      | 310S        | S31008  | ...                      | ...      | 8         |
| 29       | 25Cr-20Ni           | Pipe              | A409      | TP310S      | S31008  | ...                      | ...      | 8         |
| 30       | 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321       | S32100  | ...                      | ≤10      | 8         |
| 31       | 18Cr-10Ni-Ti        | Wld. pipe         | A312      | TP321       | S32100  | ...                      | ...      | 8         |
| 32       | 18Cr-10Ni-Ti        | Wld. pipe         | A358      | 321         | S32100  | ...                      | ...      | 8         |
| 33       | 18Cr-10Ni-Ti        | Smls. pipe        | A376      | TP321       | S32100  | ...                      | ≤10      | 8         |
| 34       | 18Cr-10Ni-Ti        | Wld. pipe         | A409      | TP321       | S32100  | ...                      | ...      | 8         |
| 35       | 23Cr-12Ni           | Smls. & wld. pipe | A312      | TP309       | ...     | ...                      | ...      | 8         |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes               | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |                            |                          |                    |                  |     |     |     |     |     |     |
|----------|---------------------|-------------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------------|-----|-----|-----|-----|-----|-----|
|          |                     | Min. Temp., °C (6)                                                                  | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 |     |     |     |     |     |     |
|          |                     |                                                                                     |                            |                          |                    |                  | 65  | 100 | 125 | 150 | 175 | 200 |
| 1        | (28)                | -254                                                                                | 485                        | 170                      | 816                | 115              | 115 | 115 | 115 | 115 | 115 | 115 |
| 2        | (28) (36)           | -254                                                                                | 485                        | 170                      | 816                | 115              | 115 | 115 | 115 | 115 | 115 | 115 |
| 3        | (14) (36)           | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 114 | 110 |
| 4        | (14) (36)           | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 114 | 110 |
| 5        | (14)                | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 114 | 110 |
| 6        | ...                 | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 114 | 110 |
| 7        | (36)                | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 114 | 110 |
| 8        | (14) (36)           | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 113 | 109 |
| 9        | (14) (36)           | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 113 | 109 |
| 10       | (14)                | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 113 | 109 |
| 11       | ...                 | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 113 | 109 |
| 12       | (36)                | -254                                                                                | 483                        | 172                      | 816                | 115              | 115 | 115 | 115 | 115 | 113 | 109 |
| 13       | (30)                | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 134 |
| 14       | (28) (30)           | -254                                                                                | 485                        | 170                      | 816                | 115              | 115 | 115 | 115 | 115 | 115 | 115 |
| 15       | (28) (30) (36)      | -254                                                                                | 485                        | 170                      | 816                | 115              | 115 | 115 | 115 | 115 | 115 | 115 |
| 16       | (30)                | -198                                                                                | 485                        | 170                      | 816                | 115              | 115 | 115 | 115 | 115 | 115 | 115 |
| 17       | (30) (36)           | -198                                                                                | 485                        | 170                      | 816                | 115              | 115 | 115 | 115 | 115 | 115 | 115 |
| 18       | (26) (28) (35)      | -198                                                                                | 448                        | 193                      | 816                | 129              | 129 | 129 | 129 | 127 | 125 | 124 |
| 19       | (12) (28) (35) (39) | -198                                                                                | 448                        | 193                      | 816                | 129              | 129 | 129 | 129 | 127 | 125 | 124 |
| 20       | (35)                | -29                                                                                 | 414                        | 207                      | 40                 | 138              | ... | ... | ... | ... | ... | ... |
| 21       | (35) (49)           | -29                                                                                 | 414                        | 276                      | 40                 | 138              | ... | ... | ... | ... | ... | ... |
| 22       | (28)                | -198                                                                                | 483                        | 207                      | 40                 | 138              | ... | ... | ... | ... | ... | ... |
| 23       | (35)                | -29                                                                                 | 414                        | 207                      | 538                | 138              | 138 | 138 | 137 | 135 | 134 | 133 |
| 24       | (35)                | -29                                                                                 | 414                        | 207                      | 649                | 138              | 138 | 138 | 137 | 135 | 134 | 133 |
| 25       | (35) (49)           | -29                                                                                 | 414                        | 241                      | 649                | 138              | 138 | 138 | 137 | 135 | 134 | 133 |
| 26       | ...                 | -198                                                                                | 517                        | 207                      | 454                | 138              | 138 | 138 | 138 | 138 | 136 | 131 |
| 27       | (28) (35)           | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 28       | (28) (35) (36)      | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 29       | (28) (31) (35) (36) | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 30       | (28)                | -254                                                                                | 515                        | 205                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 31       | (28)                | -254                                                                                | 515                        | 205                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 32       | (28) (36)           | -254                                                                                | 515                        | 205                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 33       | (28) (36)           | -254                                                                                | 515                        | 205                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 34       | (28) (36)           | -254                                                                                | 515                        | 205                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 35       | (28) (35) (39)      | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|-----|------|------|------|------|------|------|------|------|------|------|------|
|          | 225                                                                                         | 250 | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  |
| 1        | 115                                                                                         | 112 | 109  | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 2        | 115                                                                                         | 112 | 109  | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 3        | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 4        | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 5        | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 6        | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 7        | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 8        | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 9        | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 10       | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 11       | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 12       | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 13       | 129                                                                                         | 124 | 120  | 117  | 115  | 113  | 112  | 111  | 110  | 109  | 108  | 107  | 106  |
| 14       | 115                                                                                         | 112 | 109  | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 15       | 115                                                                                         | 112 | 109  | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 16       | 115                                                                                         | 112 | 109  | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 17       | 115                                                                                         | 112 | 109  | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6 |
| 18       | 124                                                                                         | 123 | 121  | 119  | 117  | 115  | 112  | 109  | 106  | 103  | 100  | 96.9 | 93.7 |
| 19       | 124                                                                                         | 123 | 121  | 119  | 117  | 115  | 112  | 109  | 106  | 103  | 100  | 96.9 | 93.7 |
| 20       | ...                                                                                         | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 21       | ...                                                                                         | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 22       | ...                                                                                         | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 23       | 132                                                                                         | 131 | 130  | 129  | 127  | 124  | 121  | 118  | 114  | 109  | 103  | 70.1 | 38.8 |
| 24       | 132                                                                                         | 131 | 130  | 129  | 127  | 124  | 121  | 118  | 114  | 109  | 92.5 | 68.4 | 51.1 |
| 25       | 132                                                                                         | 131 | 130  | 129  | 127  | 124  | 121  | 118  | 114  | 109  | 88.7 | 69.8 | 52.6 |
| 26       | 127                                                                                         | 123 | 120  | 118  | 115  | 113  | 111  | 109  | 107  | 105  | 103  | ...  | ...  |
| 27       | 137                                                                                         | 134 | 131  | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | 84.9 |
| 28       | 137                                                                                         | 134 | 131  | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | 84.9 |
| 29       | 137                                                                                         | 134 | 131  | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | 84.9 |
| 30       | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 31       | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 32       | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 33       | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 34       | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 35       | 138                                                                                         | 135 | 133  | 131  | 129  | 127  | 125  | 124  | 122  | 121  | 119  | 117  | 108  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 550                                                                                         | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  |
| 1        | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 2        | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 3        | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 4        | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 5        | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 6        | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 7        | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 8        | 80.8                                                                                        | 79.3 | 77.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 9        | 80.8                                                                                        | 79.3 | 77.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 10       | 80.8                                                                                        | 79.3 | 77.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 11       | 80.8                                                                                        | 79.3 | 77.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 12       | 80.8                                                                                        | 73.0 | 67.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 13       | 106                                                                                         | 101  | 80.3 | 65.5 | 50.4 | 38.6 | 29.6 | 23.0 | 17.7 | 13.4 | 10.4 | 8.05 |
| 14       | 92.7                                                                                        | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 15       | 92.7                                                                                        | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 16       | 92.7                                                                                        | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 17       | 92.7                                                                                        | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 18       | 68.1                                                                                        | 53.5 | 42.1 | 33.2 | 25.9 | 20.3 | 16.5 | 13.2 | 10.1 | 7.35 | 5.89 | 5.52 |
| 19       | 73.2                                                                                        | 64.4 | 56.5 | 49.0 | 41.0 | 33.5 | 25.4 | 18.3 | 12.8 | 9.01 | 6.59 | 5.52 |
| 20       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 21       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 22       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 23       | 27.6                                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 24       | 37.4                                                                                        | 26.3 | 17.8 | 11.4 | 6.89 | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 25       | 38.1                                                                                        | 27.6 | 20.6 | 15.9 | 12.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 26       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 27       | 59.0                                                                                        | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 28       | 59.0                                                                                        | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 29       | 59.0                                                                                        | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 30       | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 31       | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 32       | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 33       | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 34       | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 35       | 83.7                                                                                        | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form      | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|---------------------|-------------------|-----------|------------|---------|----------------------------|----------|-----------|
| 36       | 23Cr-12Ni           | Wld. pipe         | A358      | 309S       | S30908  | ...                        | ...      | 8         |
| 37       | 18Cr-8Ni            | Pipe & tube       | A451      | CPF8       | J92600  | ...                        | ...      | 8         |
| 38       | 18Cr-10Ni-Cb        | Smls. & wld. pipe | A312      | TP347      | S34700  | ...                        | ...      | 8         |
| 39       | 18Cr-10Ni-Cb        | Wld. pipe         | A358      | 347        | S34700  | ...                        | ...      | 8         |
| 40       | 18Cr-10Ni-Cb        | Pipe              | A376      | TP347      | S34700  | ...                        | ...      | 8         |
| 41       | 18Cr-10Ni-Cb        | Pipe              | A409      | TP347      | S34700  | ...                        | ...      | 8         |
| 42       | 18Cr-10Ni-Cb        | Smls. & wld. pipe | A312      | TP348      | S34800  | ...                        | ...      | 8         |
| 43       | 18Cr-10Ni-Cb        | Wld. pipe         | A358      | 348        | S34800  | ...                        | ...      | 8         |
| 44       | 18Cr-10Ni-Cb        | Pipe              | A376      | TP348      | S34800  | ...                        | ...      | 8         |
| 45       | 18Cr-10Ni-Cb        | Pipe              | A409      | TP348      | S34800  | ...                        | ...      | 8         |
| 46       | 25Cr-12Ni           | Pipe & tube       | A451      | CPH10      | J93402  | ...                        | ...      | 8         |
| 47       | 25Cr-12Ni           | Pipe & tube       | A451      | CPH20      | J93402  | ...                        | ...      | 8         |
| 48       | 25Cr-20Ni           | Smls. & wld. pipe | A312      | TP310H     | S31009  | ...                        | ...      | 8         |
| 49       | 18Cr-10Ni-Cb        | Pipe & tube       | A451      | CPF8C      | J92710  | ...                        | ...      | 8         |
| 50       | 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321      | S32100  | ...                        | ≤10      | 8         |
| 51       | 18Cr-10Ni-Ti        | Wld. pipe         | A312      | TP321      | S32100  | ...                        | ...      | 8         |
| 52       | 18Cr-10Ni-Ti        | Wld. pipe         | A358      | 321        | S32100  | ...                        | ...      | 8         |
| 53       | 18Cr-10Ni-Ti        | Smls. pipe        | A376      | TP321      | S32100  | ...                        | ≤10      | 8         |
| 54       | 18Cr-10Ni-Ti        | Wld. pipe         | A409      | TP321      | S32100  | ...                        | ...      | 8         |
| 55       | 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321H     | S32109  | ...                        | ≤10      | 8         |
| 56       | 18Cr-10Ni-Ti        | Wld. pipe         | A312      | TP321H     | S32109  | ...                        | ...      | 8         |
| 57       | 18Cr-10Ni-Ti        | Wld. pipe         | A358      | 321H       | S32109  | ...                        | ...      | 8         |
| 58       | 18Cr-10Ni-Ti        | Smls. pipe        | A376      | TP321H     | S32109  | ...                        | ≤10      | 8         |
| 59       | 16Cr-12Ni-2Mo       | Tube              | A213      | TP316      | S31600  | ...                        | ...      | 8         |
| 60       | 16Cr-12Ni-2Mo       | Tube              | A269      | TP316      | S31600  | ...                        | ...      | 8         |
| 61       | 16Cr-12Ni-2Mo       | Tube              | A270      | TP316      | S31600  | ...                        | ...      | 8         |
| 62       | 16Cr-12Ni-2Mo       | Smls. & wld. pipe | A312      | TP316      | S31600  | ...                        | ...      | 8         |
| 63       | 16Cr-12Ni-2Mo       | Wld. pipe         | A358      | 316        | S31600  | ...                        | ...      | 8         |
| 64       | 16Cr-12Ni-2Mo       | Pipe              | A376      | TP316      | S31600  | ...                        | ...      | 8         |
| 65       | 16Cr-12Ni-2Mo       | Pipe              | A409      | TP316      | S31600  | ...                        | ...      | 8         |
| 66       | 18Cr-13Ni-3Mo       | Smls. & wld. pipe | A312      | TP317      | S31700  | ...                        | ...      | 8         |
| 67       | 18Cr-13Ni-3Mo       | Pipe              | A409      | TP317      | S31700  | ...                        | ...      | 8         |
| 68       | 16Cr-12Ni-2Mo       | Pipe              | A376      | TP316H     | S31609  | ...                        | ...      | 8         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes                    | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |     |     |
|----------|--------------------------|--------------------|----------------------------|--------------------------|--------------------|-------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|
|          |                          |                    |                            |                          |                    | Min. Temp. to 40                                                                    | 65  | 100 | 125 | 150 | 175 | 200 |
|          |                          |                    |                            |                          |                    |                                                                                     |     |     |     |     |     |     |
| 36       | (28) (31) (35) (36)      | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 37       | (26) (28)                | -254               | 483                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 134 | 129 |
| 38       | ...                      | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 39       | (30) (36)                | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 40       | (30) (36)                | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 41       | (30) (36)                | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 42       | ...                      | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 43       | (30) (36)                | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 44       | (30) (36)                | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 45       | (30) (36)                | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 46       | (12) (14) (28) (35) (39) | -198               | 483                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 137 | 135 | 134 |
| 47       | (12) (14) (28) (35) (39) | -198               | 483                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 137 | 135 | 134 |
| 48       | (29) (35) (39)           | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 49       | (28)                     | -198               | 483                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 134 | 129 |
| 50       | (28) (30)                | -254               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 51       | (28) (30)                | -254               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 52       | (28) (30) (36)           | -254               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 53       | (28) (30) (36)           | -254               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 54       | (28) (30) (36)           | -254               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 55       | (30)                     | -198               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 56       | (30)                     | -198               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 57       | (30) (36)                | -198               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 58       | (30) (36)                | -198               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 59       | (14) (26) (28) (31) (36) | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 60       | (14) (26) (28) (31) (36) | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 61       | (14) (26) (28)           | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 62       | (26) (28)                | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 63       | (26) (28) (31) (36)      | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 64       | (26) (28) (31) (36)      | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 65       | (26) (28) (31) (36)      | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 66       | (26) (28)                | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 67       | (26) (28) (31) (36)      | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 68       | (26) (31) (36)           | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |     |     |     |     |     |     |      |             |
|----------|---------------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-------------|
|          | 225                                                                                         | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500  | 525         |
| 36       | 138                                                                                         | 135 | 133 | 131 | 129 | 127 | 125 | 124 | 122 | 121 | 119 | 117  | <b>108</b>  |
| 37       | 125                                                                                         | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | <b>94.4</b> |
| 38       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 39       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 40       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 41       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 42       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 43       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 44       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 45       | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127 | 126 | 126 | 125 | 125  | 125         |
| 46       | 133                                                                                         | 131 | 129 | 128 | 125 | 123 | 120 | 117 | 114 | 111 | 107 | 104  | 100         |
| 47       | 133                                                                                         | 131 | 129 | 128 | 125 | 123 | 120 | 117 | 114 | 111 | 107 | 104  | 100         |
| 48       | 137                                                                                         | 134 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 119 | 117 | 116  | <b>108</b>  |
| 49       | 125                                                                                         | 122 | 119 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 99.1 | 97.3        |
| 50       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 51       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 52       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 53       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 54       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 55       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 56       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 57       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 58       | 138                                                                                         | 135 | 131 | 128 | 125 | 122 | 120 | 119 | 117 | 115 | 114 | 113  | 112         |
| 59       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 60       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 61       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 62       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 63       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 64       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 65       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 66       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 67       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |
| 68       | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111 | 110 | 109 | 108 | 107  | 106         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 550                                                                                         | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  |
| 36       | 83.7                                                                                        | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 37       | 75.3                                                                                        | 60.4 | 49.0 | 40.1 | 32.8 | 27.2 | 23.4 | 19.6 | 16.8 | 14.7 | 12.8 | 11.7 |
| 38       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 39       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 40       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 41       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 42       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 43       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 44       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 45       | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 46       | 68.1                                                                                        | 53.5 | 42.1 | 33.2 | 25.9 | 20.3 | 16.5 | 13.2 | 10.1 | 7.35 | 5.89 | 5.52 |
| 47       | 68.1                                                                                        | 53.5 | 42.1 | 33.2 | 25.9 | 20.3 | 16.5 | 13.2 | 10.1 | 7.35 | 5.89 | 5.52 |
| 48       | 83.7                                                                                        | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 49       | 95.5                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 50       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 51       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 52       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 53       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 54       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 55       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 56       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 57       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 58       | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 59       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 60       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 61       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 62       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 63       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 64       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 65       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 66       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 67       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 68       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form      | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|---------------------|-------------------|-----------|------------|---------|----------------------------|----------|-----------|
| 69       | 16Cr-12Ni-2Mo       | Smls. & wld. pipe | A312      | TP316H     | S31609  | ...                        | ...      | 8         |
| 70       | 18Cr-10Ni-Cb        | Pipe              | A376      | TP347H     | S34709  | ...                        | ...      | 8         |
| 71       | 18Cr-10Ni-Cb        | Smls. & wld. pipe | A312      | TP347      | S34700  | ...                        | ...      | 8         |
| 72       | 18Cr-10Ni-Cb        | Wld. pipe         | A358      | 347        | S34700  | ...                        | ...      | 8         |
| 73       | 18Cr-10Ni-Cb        | Pipe              | A376      | TP347      | S34700  | ...                        | ...      | 8         |
| 74       | 18Cr-10Ni-Cb        | Pipe              | A409      | TP347      | S34700  | ...                        | ...      | 8         |
| 75       | 18Cr-10Ni-Cb        | Smls. & wld. pipe | A312      | TP348      | S34800  | ...                        | ...      | 8         |
| 76       | 18Cr-10Ni-Cb        | Wld. pipe         | A358      | 348        | S34800  | ...                        | ...      | 8         |
| 77       | 18Cr-10Ni-Cb        | Pipe              | A376      | TP348      | S34800  | ...                        | ...      | 8         |
| 78       | 18Cr-10Ni-Cb        | Pipe              | A409      | TP348      | S34800  | ...                        | ...      | 8         |
| 79       | 18Cr-10Ni-Cb        | Smls. & wld. pipe | A312      | TP347H     | S34709  | ...                        | ...      | 8         |
| 80       | 18Cr-10Ni-Cb        | Smls. & wld. pipe | A312      | TP348H     | S34809  | ...                        | ...      | 8         |
| 81       | 18Cr-8Ni            | Tube              | A213      | TP304      | S30400  | ...                        | ...      | 8         |
| 82       | 18Cr-8Ni            | Tube              | A269      | TP304      | S30400  | ...                        | ...      | 8         |
| 83       | 18Cr-8Ni            | Tube              | A270      | TP304      | S30400  | ...                        | ...      | 8         |
| 84       | 18Cr-8Ni            | Smls. & wld. pipe | A312      | TP304      | S30400  | ...                        | ...      | 8         |
| 85       | 18Cr-8Ni            | Wld. pipe         | A358      | 304        | S30400  | ...                        | ...      | 8         |
| 86       | 18Cr-8Ni            | Pipe              | A376      | TP304      | S30400  | ...                        | ...      | 8         |
| 87       | 18Cr-8Ni            | Pipe              | A376      | TP304H     | S30409  | ...                        | ...      | 8         |
| 88       | 18Cr-8Ni            | Pipe              | A409      | TP304      | S30400  | ...                        | ...      | 8         |
| 89       | 18Cr-8Ni            | Smls. & wld. pipe | A312      | TP304H     | S30409  | ...                        | ...      | 8         |
| 90       | 18Cr-12Ni-2Mo       | Pipe & tube       | A451      | CPF8M      | J92900  | ...                        | ...      | 8         |
| 91       | 44Fe-25Ni-21Cr-Mo   | Wld. tube         | A249      | ...        | N08904  | ...                        | ...      | 45        |
| 92       | 44Fe-25Ni-21Cr-Mo   | Smls. & wld. pipe | A312      | ...        | N08904  | ...                        | ...      | 45        |
| 93       | 20Cr-Cu             | Tube              | A268      | TP443      | S44300  | ...                        | ...      | a         |
| 94       | 27Cr                | Tube              | A268      | TP446-1    | S44600  | ...                        | ...      | 10I       |
| 95       | 12Cr                | Wld. pipe         | A1053     | 50         | S41003  | ...                        | ...      | 7         |
| 96       | 25Cr-8Ni-N          | Pipe & tube       | A451      | CPE20N     | J92802  | ...                        | ...      | 8         |
| 97       | 23Cr-4Ni-Mo-Cu-N    | Smls. & wld. tube | A789      | ...        | S32304  | ...                        | ...      | 10H       |
| 98       | 23Cr-4Ni-Mo-Cu-N    | Smls. & wld. pipe | A790      | ...        | S32304  | ...                        | ...      | 10H       |
| 99       | 23Cr-4Ni-Mo-Cu-N    | Pipe & tube       | A928      | 2304       | S32304  | ...                        | ...      | 10H       |
| 100      | 20Cr-18Ni-6Mo       | Pipe & tube       | A813      | ...        | S31254  | ...                        | ...      | 8         |
| 101      | 20Cr-18Ni-6Mo       | Pipe & tube       | A814      | ...        | S31254  | ...                        | ...      | 8         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes                    | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |                            |                          |                    |                  |     |     |     |     |     |     |
|----------|--------------------------|-------------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------------|-----|-----|-----|-----|-----|-----|
|          |                          | Min. Temp., °C (6)                                                                  | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 |     |     |     |     |     |     |
|          |                          |                                                                                     |                            |                          |                    |                  | 65  | 100 | 125 | 150 | 175 | 200 |
| 69       | (26)                     | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 134 |
| 70       | (30) (36)                | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 71       | (28)                     | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 72       | (28) (30) (36)           | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 73       | (28) (30) (36)           | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 74       | (28) (30) (36)           | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 75       | (28)                     | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 76       | (28) (30) (36)           | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 77       | (28) (30) (36)           | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 78       | (28) (30) (36)           | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 79       | ...                      | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 80       | ...                      | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 81       | (14) (26) (28) (31) (36) | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 82       | (14) (26) (28) (31) (36) | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 83       | (14) (26) (28)           | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 84       | (26) (28)                | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 85       | (26) (28) (31) (36)      | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 86       | (20) (26) (28) (31) (36) | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 87       | (26) (31) (36)           | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 88       | (26) (28) (31) (36)      | -254                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 89       | (26)                     | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 90       | (26) (28)                | -254                                                                                | 483                        | 207                      | 816                | 138              | 138 | 138 | 138 | 130 | 124 | 118 |
| 91       | (26)                     | -198                                                                                | 490                        | 220                      | 260                | 143              | 143 | 143 | 143 | 141 | 135 | 130 |
| 92       | (26)                     | -198                                                                                | 490                        | 220                      | 260                | 143              | 143 | 143 | 143 | 141 | 135 | 130 |
| 93       | (7) (35)                 | -29                                                                                 | 483                        | 276                      | 538                | 161              | 161 | 161 | 161 | 161 | 161 | 161 |
| 94       | (35)                     | -29                                                                                 | 483                        | 276                      | 538                | 161              | 161 | 161 | 158 | 155 | 153 | 152 |
| 95       | ...                      | -29                                                                                 | 485                        | 350                      | 316                | 162              | 162 | 162 | 162 | 162 | 161 | 159 |
| 96       | (35) (39)                | -198                                                                                | 552                        | 276                      | 482                | 184              | 184 | 184 | 184 | 184 | 184 | 184 |
| 97       | (25)                     | -51                                                                                 | 600                        | 400                      | 316                | 200              | 200 | 191 | 185 | 180 | 175 | 171 |
| 98       | (25)                     | -51                                                                                 | 600                        | 400                      | 316                | 200              | 200 | 191 | 185 | 180 | 175 | 171 |
| 99       | (25)                     | -51                                                                                 | 600                        | 400                      | 316                | 200              | 200 | 191 | 185 | 180 | 175 | 171 |
| 100      | ...                      | -198                                                                                | 650                        | 300                      | 454                | 202              | 202 | 202 | 202 | 199 | 192 | 185 |
| 101      | ...                      | -198                                                                                | 650                        | 300                      | 454                | 202              | 202 | 202 | 202 | 199 | 192 | 185 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|-----|-----|-----|-----|------|------|------|------|------|------|------|------|
|          | 225                                                                                         | 250 | 275 | 300 | 325 | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  |
| 69       | 129                                                                                         | 125 | 122 | 119 | 116 | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106  |
| 70       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125  |
| 71       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125  |
| 72       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 73       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 74       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 75       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 76       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 77       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 78       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 79       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125  |
| 80       | 138                                                                                         | 138 | 137 | 135 | 132 | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125  |
| 81       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 82       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 83       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 84       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 85       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 86       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 87       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 88       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 89       | 125                                                                                         | 122 | 119 | 116 | 113 | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 90       | 114                                                                                         | 110 | 107 | 104 | 102 | 101  | 99.3 | 98.1 | 97.0 | 95.9 | 94.7 | 93.3 | 91.5 |
| 91       | 125                                                                                         | 120 | 116 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 92       | 125                                                                                         | 120 | 116 | ... | ... | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 93       | 161                                                                                         | 161 | 161 | 161 | 161 | 97.0 | 84.3 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | 21.4 |
| 94       | 150                                                                                         | 149 | 147 | 145 | 144 | 141  | 139  | 136  | 132  | 128  | 122  | 116  | 109  |
| 95       | 156                                                                                         | 154 | 152 | 149 | 146 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 96       | 184                                                                                         | 184 | 184 | 184 | 184 | 184  | 184  | 184  | 184  | 184  | 184  | 184  | ...  |
| 97       | 166                                                                                         | 161 | 153 | 143 | 111 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 98       | 166                                                                                         | 161 | 153 | 143 | 111 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 99       | 166                                                                                         | 161 | 153 | 143 | 111 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 100      | 180                                                                                         | 175 | 171 | 168 | 165 | 164  | 162  | 161  | 160  | 159  | 158  | ...  | ...  |
| 101      | 180                                                                                         | 175 | 171 | 168 | 165 | 164  | 162  | 161  | 160  | 159  | 158  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 550                                                                                         | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  |
| 69       | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 70       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 71       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 72       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 73       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 74       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 75       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 76       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 77       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 78       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 79       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 80       | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 81       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 82       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 83       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 84       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 85       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 86       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 87       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 88       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 89       | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 90       | 89.1                                                                                        | 72.7 | 57.7 | 46.0 | 36.9 | 30.1 | 24.3 | 20.3 | 17.0 | 14.3 | 12.1 | 11.0 |
| 91       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 92       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 93       | 17.2                                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 94       | 104                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 95       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 96       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 97       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 98       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 99       | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 100      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 101      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition     | Product Form      | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|-------------------------|-------------------|-----------|------------|---------|----------------------------|----------|-----------|
| 102      | 13Cr                    | Pipe & tube       | A426      | CPCA15     | J91150  | ...                        | ...      | 6         |
| 103      | 20Cr-18Ni-6Mo           | Wld. pipe         | A358      | ...        | S31254  | ...                        | >5.0     | 8         |
| 104      | 20Cr-18Ni-6Mo           | Wld. pipe         | A358      | ...        | S31254  | ...                        | ≤5.0     | 8         |
| 105      | 22Cr-5Ni-3Mo-N          | Smls. & wld. tube | A789      | ...        | S31803  | ...                        | ...      | 10H       |
| 106      | 22Cr-5Ni-3Mo-N          | Smls. & wld. pipe | A790      | ...        | S31803  | ...                        | ...      | 10H       |
| 107      | 22Cr-5Ni-3Mo-N          | Pipe & tube       | A928      | ...        | S31803  | ...                        | ...      | 10H       |
| 108      | 20Cr-18Ni-6Mo           | Pipe & tube       | A249      | ...        | S31254  | ...                        | >5.00    | 8         |
| 109      | 20Cr-18Ni-6Mo           | Pipe & tube       | A249      | ...        | S31254  | ...                        | ≤5.00    | 8         |
| 110      | 20Cr-18Ni-6Mo           | Pipe & tube       | A312      | ...        | S31254  | ...                        | >5.00    | 8         |
| 111      | 20Cr-18Ni-6Mo           | Pipe & tube       | A312      | ...        | S31254  | ...                        | ≤5.00    | 8         |
| 112      | 26Cr-4Ni-Mo             | Smls. & wld. pipe | A790      | ...        | S32900  | ...                        | ...      | 10H       |
| 113      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Smls. & wld. pipe | A312      | ...        | N08367  | ...                        | >5.0     | 45        |
| 114      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Wld. pipe         | A358      | ...        | N08367  | ...                        | >5.0     | 45        |
| 115      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Wld. pipe         | A813      | ...        | N08367  | ...                        | >5.0     | 45        |
| 116      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Wld. pipe         | A814      | ...        | N08367  | ...                        | >5.0     | 45        |
| 117      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Smls. & wld. pipe | A312      | ...        | N08367  | ...                        | ≤5.0     | 45        |
| 118      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Wld. pipe         | A358      | ...        | N08367  | ...                        | ≤5.0     | 45        |
| 119      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Wld. pipe         | A813      | ...        | N08367  | ...                        | ≤5.0     | 45        |
| 120      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Wld. pipe         | A814      | ...        | N08367  | ...                        | ≤5.0     | 45        |
| 121      | 21Cr-5Mn-1½Ni-Cu-N      | Smls. & wld. tube | A789      | ...        | S32101  | ...                        | >5.0     | 10H       |
| 122      | 21Cr-5Mn-1½Ni-Cu-N      | Smls. & wld. pipe | A790      | ...        | S32101  | ...                        | >5.0     | 10H       |
| 123      | 24Cr-4Ni-3Mn-1.5Mo-N    | Smls. & wld. tube | A789      | ...        | S82441  | ...                        | ≥10.0    | 10H       |
| 124      | 24Cr-4Ni-3Mn-1.5Mo-N    | Smls. & wld. pipe | A790      | ...        | S82441  | ...                        | ≥10.0    | 10H       |
| 125      | 21Cr-5Mn-1½Ni-Cu-N      | Smls. & wld. tube | A789      | ...        | S32101  | ...                        | ≤5.0     | 10H       |
| 126      | 21Cr-5Mn-1½Ni-Cu-N      | Smls. & wld. pipe | A790      | ...        | S32101  | ...                        | ≤5.0     | 10H       |
| 127      | 21Cr-3½Ni-1¾Mo-N        | Smls. & wld. tube | A789      | ...        | S32003  | ...                        | >5.00    | 10H       |
| 128      | 21Cr-3½Ni-1¾Mo-N        | Smls. & wld. pipe | A790      | ...        | S32003  | ...                        | >5.00    | 10H       |
| 129      | 21Cr-3½Ni-1¾Mo-N        | Pipe & tube       | A928      | ...        | S32003  | ...                        | >5.00    | 10H       |
| 130      | 22Cr-5Ni-3Mo-N          | Pipe & tube       | A928      | 2205       | S32205  | ...                        | ...      | 10H       |
| 131      | 21Cr-3½Ni-1¾Mo-N        | Smls. & wld. tube | A789      | ...        | S32003  | ...                        | ≤5.00    | 10H       |
| 132      | 21Cr-3½Ni-1¾Mo-N        | Smls. & wld. pipe | A790      | ...        | S32003  | ...                        | ≤5.00    | 10H       |
| 133      | 21Cr-3½Ni-1¾Mo-N        | Pipe & tube       | A928      | ...        | S32003  | ...                        | ≤5.00    | 10H       |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes     | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |                            |                          |                    |                  |     |     |     |     |     |     |
|----------|-----------|-------------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------------|-----|-----|-----|-----|-----|-----|
|          |           | Min. Temp., °C (6)                                                                  | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 |     |     |     |     |     |     |
|          |           |                                                                                     |                            |                          |                    |                  | 65  | 100 | 125 | 150 | 175 | 200 |
| 102      | (10) (35) | -29                                                                                 | 621                        | 448                      | 40                 | 207              | ... | ... | ... | ... | ... | ... |
| 103      | ...       | -198                                                                                | 655                        | 310                      | 475                | 207              | 207 | 207 | 207 | 203 | 196 | 189 |
| 104      | ...       | -198                                                                                | 690                        | 310                      | 475                | 207              | 207 | 207 | 207 | 203 | 196 | 189 |
| 105      | (25)      | -51                                                                                 | 621                        | 448                      | 316                | 207              | 207 | 207 | 204 | 199 | 196 | 193 |
| 106      | (25)      | -51                                                                                 | 621                        | 448                      | 316                | 207              | 207 | 207 | 204 | 199 | 196 | 193 |
| 107      | (25)      | -51                                                                                 | 621                        | 448                      | 316                | 207              | 207 | 207 | 204 | 199 | 196 | 193 |
| 108      | ...       | -198                                                                                | 655                        | 310                      | 454                | 207              | 207 | 207 | 207 | 203 | 196 | 190 |
| 109      | ...       | -198                                                                                | 675                        | 310                      | 454                | 207              | 207 | 207 | 207 | 203 | 196 | 190 |
| 110      | ...       | -198                                                                                | 655                        | 310                      | 454                | 207              | 207 | 207 | 207 | 203 | 196 | 190 |
| 111      | ...       | -198                                                                                | 675                        | 310                      | 454                | 207              | 207 | 207 | 207 | 203 | 196 | 190 |
| 112      | (25)      | -29                                                                                 | 621                        | 483                      | 40                 | 207              | ... | ... | ... | ... | ... | ... |
| 113      | (26)      | -198                                                                                | 655                        | 310                      | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 |
| 114      | (26)      | -198                                                                                | 655                        | 310                      | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 |
| 115      | (26)      | -198                                                                                | 655                        | 310                      | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 |
| 116      | (26)      | -198                                                                                | 655                        | 310                      | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 |
| 117      | (26)      | -198                                                                                | 690                        | 310                      | 427                | 207              | 207 | 207 | 207 | 207 | 207 | 205 |
| 118      | (26)      | -198                                                                                | 690                        | 310                      | 427                | 207              | 207 | 207 | 207 | 207 | 207 | 205 |
| 119      | (26)      | -198                                                                                | 690                        | 310                      | 427                | 207              | 207 | 207 | 207 | 207 | 207 | 205 |
| 120      | (26)      | -198                                                                                | 690                        | 310                      | 427                | 207              | 207 | 207 | 207 | 207 | 207 | 205 |
| 121      | (25)      | -29                                                                                 | 650                        | 450                      | 316                | 217              | 217 | 215 | 211 | 206 | 203 | 199 |
| 122      | (25)      | -29                                                                                 | 650                        | 450                      | 316                | 217              | 217 | 215 | 211 | 206 | 203 | 199 |
| 123      | (25)      | -51                                                                                 | 680                        | 480                      | 316                | 227              | 227 | 227 | 227 | 227 | 227 | 227 |
| 124      | (25)      | -51                                                                                 | 680                        | 480                      | 316                | 227              | 227 | 227 | 227 | 227 | 227 | 227 |
| 125      | (25)      | -29                                                                                 | 700                        | 530                      | 316                | 233              | 233 | 231 | 227 | 222 | 219 | 215 |
| 126      | (25)      | -29                                                                                 | 700                        | 530                      | 316                | 233              | 233 | 231 | 227 | 222 | 219 | 215 |
| 127      | (25)      | -51                                                                                 | 655                        | 450                      | 343                | 218              | 218 | 210 | 203 | 199 | 197 | 197 |
| 128      | (25)      | -51                                                                                 | 655                        | 450                      | 343                | 218              | 218 | 210 | 203 | 199 | 197 | 197 |
| 129      | (25)      | -51                                                                                 | 655                        | 450                      | 343                | 218              | 218 | 210 | 203 | 199 | 197 | 197 |
| 130      | (25)      | -51                                                                                 | 655                        | 450                      | 343                | 218              | 218 | 218 | 215 | 210 | 206 | 203 |
| 131      | (25)      | -51                                                                                 | 690                        | 485                      | 343                | 230              | 230 | 221 | 214 | 209 | 207 | 207 |
| 132      | (25)      | -51                                                                                 | 690                        | 485                      | 343                | 230              | 230 | 221 | 214 | 209 | 207 | 207 |
| 133      | (25)      | -51                                                                                 | 690                        | 485                      | 343                | 230              | 230 | 221 | 214 | 209 | 207 | 207 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |     |     |     |     |     |     |     |     |
|----------|---------------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|          | 225                                                                                         | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 102      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 103      | 184                                                                                         | 179 | 175 | 172 | 169 | 167 | 165 | 165 | 164 | 163 | 161 | ... | ... |
| 104      | 184                                                                                         | 179 | 175 | 172 | 169 | 167 | 165 | 165 | 164 | 163 | 161 | ... | ... |
| 105      | 190                                                                                         | 188 | 187 | 186 | 185 | ... | ... | ... | ... | ... | ... | ... | ... |
| 106      | 190                                                                                         | 188 | 187 | 186 | 185 | ... | ... | ... | ... | ... | ... | ... | ... |
| 107      | 190                                                                                         | 188 | 187 | 186 | 185 | ... | ... | ... | ... | ... | ... | ... | ... |
| 108      | 184                                                                                         | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | ... | ... |
| 109      | 184                                                                                         | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | ... | ... |
| 110      | 184                                                                                         | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | ... | ... |
| 111      | 184                                                                                         | 179 | 175 | 172 | 169 | 167 | 166 | 165 | 164 | 163 | 161 | ... | ... |
| 112      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 113      | 195                                                                                         | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 114      | 195                                                                                         | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 115      | 195                                                                                         | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 116      | 195                                                                                         | 192 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 117      | 199                                                                                         | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 118      | 199                                                                                         | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 119      | 199                                                                                         | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 120      | 199                                                                                         | 194 | 188 | 184 | 179 | 176 | 173 | 170 | 167 | 166 | ... | ... | ... |
| 121      | 199                                                                                         | 199 | 199 | 199 | 199 | ... | ... | ... | ... | ... | ... | ... | ... |
| 122      | 199                                                                                         | 199 | 199 | 199 | 199 | ... | ... | ... | ... | ... | ... | ... | ... |
| 123      | 227                                                                                         | 227 | 227 | 227 | 227 | ... | ... | ... | ... | ... | ... | ... | ... |
| 124      | 227                                                                                         | 227 | 227 | 227 | 227 | ... | ... | ... | ... | ... | ... | ... | ... |
| 125      | 214                                                                                         | 214 | 214 | 214 | 214 | ... | ... | ... | ... | ... | ... | ... | ... |
| 126      | 214                                                                                         | 214 | 214 | 214 | 214 | ... | ... | ... | ... | ... | ... | ... | ... |
| 127      | 197                                                                                         | 197 | 197 | 197 | 197 | 197 | ... | ... | ... | ... | ... | ... | ... |
| 128      | 197                                                                                         | 197 | 197 | 197 | 197 | 197 | ... | ... | ... | ... | ... | ... | ... |
| 129      | 197                                                                                         | 197 | 197 | 197 | 197 | 197 | ... | ... | ... | ... | ... | ... | ... |
| 130      | 201                                                                                         | 199 | 197 | 196 | 196 | 195 | ... | ... | ... | ... | ... | ... | ... |
| 131      | 207                                                                                         | 207 | 207 | 207 | 207 | 207 | ... | ... | ... | ... | ... | ... | ... |
| 132      | 207                                                                                         | 207 | 207 | 207 | 207 | 207 | ... | ... | ... | ... | ... | ... | ... |
| 133      | 207                                                                                         | 207 | 207 | 207 | 207 | 207 | ... | ... | ... | ... | ... | ... | ... |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |     |     |     |     |     |     |     |
|----------|---------------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|          | 550                                                                                         | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 102      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 103      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 104      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 105      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 106      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 107      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 108      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 109      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 110      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 111      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 112      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 113      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 114      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 115      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 116      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 117      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 118      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 119      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 120      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 121      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 122      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 123      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 124      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 125      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 126      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 127      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 128      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 129      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 130      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 131      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 132      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 133      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition                | Product Form        | Spec. No. | Type/Grade | UNS No. | Class/<br>Condition/<br>Temper | Size,<br>mm | P-No.<br>(5) |
|----------|------------------------------------|---------------------|-----------|------------|---------|--------------------------------|-------------|--------------|
| 134      | 24Cr-4Ni-3Mn-1.5Mo-N               | Smls. & wld. tube   | A789      | ...        | S82441  | ...                            | <10.0       | 10H          |
| 135      | 24Cr-4Ni-3Mn-1.5Mo-N               | Smls. & wld. pipe   | A790      | ...        | S82441  | ...                            | <10.0       | 10H          |
| 136      | 25Cr-8Ni-3Mo-W-Cu-N                | Smls. & wld. tube   | A789      | ...        | S32760  | ...                            | ...         | 10H          |
| 137      | 25Cr-8Ni-3Mo-W-Cu-N                | Smls. & wld. pipe   | A790      | ...        | S32760  | ...                            | ...         | 10H          |
| 138      | 29Cr-6.5Ni-2Mo-N                   | Smls. & wld. tube   | A789      | ...        | S32906  | ...                            | ≥10         | 10H          |
| 139      | 29Cr-6.5Ni-2Mo-N                   | Smls. & wld. pipe   | A790      | ...        | S32906  | ...                            | ≥10         | 10H          |
| 140      | 24Cr-17Ni-6Mn-4 $\frac{1}{2}$ Mo-N | Pipe & tube         | A358      | ...        | S34565  | ...                            | ...         | 8            |
| 141      | 25Cr-7Ni-4Mo-N                     | Smls. & wld. tube   | A789      | ...        | S32750  | ...                            | ...         | 10H          |
| 142      | 25Cr-7Ni-4Mo-N                     | Smls. & wld. pipe   | A790      | 2507       | S32750  | ...                            | ...         | 10H          |
| 143      | 25Cr-7Ni-4Mo-N                     | Pipe & tube         | A928      | 2507       | S32750  | ...                            | ...         | 10H          |
| 144      | 29Cr-6.5Ni-2Mo-N                   | Smls. & wld. tube   | A789      | ...        | S32906  | ...                            | <10         | 10H          |
| 145      | 29Cr-6.5Ni-2Mo-N                   | Smls. & wld. pipe   | A790      | ...        | S32906  | ...                            | <10         | 10H          |
| 146      | 18Cr-11Ni                          | Plate & sheet       | A240      | 305        | S30500  | ...                            | ...         | 8            |
| 147      | 12Cr-Al                            | Plate & sheet       | A240      | 405        | S40500  | ...                            | ...         | 7            |
| 148      | 18Cr-8Ni                           | Plate & sheet       | A240      | 304L       | S30403  | ...                            | ...         | 8            |
| 149      | 16Cr-12Ni-2Mo                      | Plate & sheet       | A240      | 316L       | S31603  | ...                            | ...         | 8            |
| 150      | 18Cr-8Ni                           | Plate & sheet       | A240      | 302        | S30200  | ...                            | ...         | 8            |
| 151      | 12Cr-1Ni                           | Plate, sheet, strip | A1010     | 40         | S41003  | ...                            | ...         | 7            |
| 152      | 12Cr-1Ni                           | Plate, sheet, strip | A1010     | 50         | S41003  | ...                            | ...         | 7            |
| 153      | 13Cr                               | Plate & sheet       | A240      | 410S       | S41008  | ...                            | ...         | 7            |
| 154      | 13Cr                               | Plate & sheet       | A240      | 410        | S41000  | ...                            | ...         | 6            |
| 155      | 15Cr                               | Plate & sheet       | A240      | 429        | S42900  | ...                            | ...         | 6            |
| 156      | 17Cr                               | Plate & sheet       | A240      | 430        | S43000  | ...                            | ...         | 7            |
| 157      | 18Cr-13Ni-3Mo                      | Plate & sheet       | A240      | 317L       | S31703  | ...                            | ...         | 8            |
| 158      | 25Cr-20Ni                          | Plate & sheet       | A240      | 310S       | S31008  | ...                            | ...         | 8            |
| 159      | 18Cr-10Ni-Ti                       | Plate, sheet, strip | A240      | 321        | S32100  | ...                            | ...         | 8            |
| 160      | 23Cr-12Ni                          | Plate & sheet       | A240      | 309S       | S30908  | ...                            | ...         | 8            |
| 161      | 18Cr-10Ni-Cb                       | Plate & sheet       | A240      | 347        | S34700  | ...                            | ...         | 8            |
| 162      | 18Cr-10Ni-Cb                       | Plate & sheet       | A240      | 348        | S34800  | ...                            | ...         | 8            |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes               | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |     |     |
|----------|---------------------|--------------------|----------------------------|--------------------------|--------------------|-------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|
|          |                     |                    |                            |                          |                    | Min. Temp. to 40                                                                    | 65  | 100 | 125 | 150 | 175 | 200 |
|          |                     |                    |                            |                          |                    |                                                                                     |     |     |     |     |     |     |
| 134      | (25)                | -51                | 740                        | 540                      | 316                | 247                                                                                 | 247 | 247 | 247 | 247 | 247 | 247 |
| 135      | (25)                | -51                | 740                        | 540                      | 316                | 247                                                                                 | 247 | 247 | 247 | 247 | 247 | 247 |
| 136      | (25)                | -51                | 750                        | 550                      | 316                | 250                                                                                 | 250 | 248 | 243 | 238 | 236 | 234 |
| 137      | (25)                | -51                | 750                        | 550                      | 316                | 250                                                                                 | 250 | 248 | 243 | 238 | 236 | 234 |
| 138      | (25)                | -51                | 750                        | 550                      | 316                | 251                                                                                 | 251 | 249 | 243 | 238 | 235 | 231 |
| 139      | (25)                | -51                | 750                        | 550                      | 316                | 251                                                                                 | 251 | 249 | 243 | 238 | 235 | 231 |
| 140      | (36)                | -198               | 795                        | 415                      | 427                | 264                                                                                 | 264 | 260 | 253 | 247 | 242 | 238 |
| 141      | (25)                | -51                | 800                        | 550                      | 316                | 267                                                                                 | 265 | 264 | 257 | 251 | 247 | 243 |
| 142      | (25)                | -51                | 800                        | 550                      | 316                | 267                                                                                 | 265 | 264 | 257 | 251 | 247 | 243 |
| 143      | (25)                | -51                | 800                        | 552                      | 316                | 267                                                                                 | 265 | 264 | 257 | 251 | 247 | 243 |
| 144      | (25)                | -51                | 800                        | 650                      | 316                | 267                                                                                 | 267 | 265 | 259 | 253 | 250 | 246 |
| 145      | (25)                | -51                | 800                        | 650                      | 316                | 267                                                                                 | 267 | 265 | 259 | 253 | 250 | 246 |
| 146      | (26) (36) (39)      | -198               | 483                        | 172                      | 40                 | 115                                                                                 | ... | ... | ... | ... | ... | ... |
| 147      | (35)                | -29                | 414                        | 172                      | 538                | 115                                                                                 | 109 | 105 | 103 | 102 | 101 | 100 |
| 148      | (36)                | -254               | 483                        | 172                      | 816                | 115                                                                                 | 115 | 115 | 115 | 115 | 114 | 110 |
| 149      | (36)                | -254               | 483                        | 172                      | 816                | 115                                                                                 | 115 | 115 | 115 | 115 | 113 | 109 |
| 150      | (26) (36)           | -198               | 517                        | 207                      | 538                | 138                                                                                 | 138 | 138 | 138 | 138 | 134 | 129 |
| 151      | ...                 | -29                | 455                        | 275                      | 316                | 152                                                                                 | 152 | 152 | 152 | 152 | 151 | 149 |
| 152      | ...                 | -29                | 485                        | 350                      | 316                | 162                                                                                 | 162 | 162 | 162 | 162 | 161 | 159 |
| 153      | (35) (50)           | -29                | 414                        | 207                      | 649                | 138                                                                                 | 130 | 126 | 124 | 122 | 121 | 120 |
| 154      | (35)                | -29                | 448                        | 207                      | 649                | 138                                                                                 | 130 | 126 | 124 | 122 | 121 | 120 |
| 155      | (35)                | -29                | 448                        | 207                      | 649                | 138                                                                                 | 130 | 126 | 124 | 122 | 121 | 120 |
| 156      | (35)                | -29                | 448                        | 207                      | 649                | 138                                                                                 | 130 | 126 | 124 | 122 | 121 | 120 |
| 157      | (36)                | -198               | 517                        | 207                      | 454                | 138                                                                                 | 138 | 138 | 138 | 138 | 136 | 131 |
| 158      | (28) (31) (35) (36) | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 159      | (28) (31) (36)      | -198               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 160      | (28) (35) (36)      | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 161      | (36)                | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 162      | (36)                | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |             |             |             |
|----------|---------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|-------------|-------------|-------------|
|          | 225                                                                                         | 250  | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475         | 500         | 525         |
| 134      | 247                                                                                         | 247  | 247  | 247  | 247  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 135      | 247                                                                                         | 247  | 247  | 247  | 247  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 136      | 233                                                                                         | 233  | 233  | 233  | 233  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 137      | 233                                                                                         | 233  | 233  | 233  | 233  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 138      | 230                                                                                         | 228  | 228  | 228  | 228  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 139      | 230                                                                                         | 228  | 228  | 228  | 228  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 140      | 235                                                                                         | 234  | 232  | 231  | 229  | 228  | 226  | 223  | 221  | 218  | ...         | ...         | ...         |
| 141      | 241                                                                                         | 238  | 237  | 237  | 236  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 142      | 241                                                                                         | 238  | 237  | 237  | 236  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 143      | 241                                                                                         | 238  | 237  | 237  | 236  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 144      | 245                                                                                         | 243  | 243  | 242  | 242  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 145      | 245                                                                                         | 243  | 243  | 242  | 242  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 146      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 147      | 99.7                                                                                        | 99.1 | 98.4 | 97.5 | 96.2 | 94.7 | 92.6 | 90.1 | 87.0 | 83.4 | 79.2        | <b>70.1</b> | <b>38.8</b> |
| 148      | 106                                                                                         | 103  | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3        | 85.6        | 83.7        |
| 149      | 106                                                                                         | 103  | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9        | 84.2        | 82.5        |
| 150      | 125                                                                                         | 122  | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101         | 99.1        | 97.3        |
| 151      | 147                                                                                         | 145  | 142  | 140  | 137  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 152      | 156                                                                                         | 154  | 152  | 149  | 146  | ...  | ...  | ...  | ...  | ...  | ...         | ...         | ...         |
| 153      | 120                                                                                         | 119  | 118  | 117  | 115  | 114  | 111  | 108  | 104  | 100  | <b>92.5</b> | <b>68.4</b> | <b>51.1</b> |
| 154      | 120                                                                                         | 119  | 118  | 117  | 115  | 114  | 111  | 108  | 104  | 100  | <b>92.5</b> | <b>68.4</b> | <b>51.1</b> |
| 155      | 120                                                                                         | 119  | 118  | 117  | 115  | 114  | 111  | 108  | 104  | 100  | <b>88.7</b> | <b>69.8</b> | <b>52.6</b> |
| 156      | 120                                                                                         | 119  | 118  | 117  | 115  | 114  | 111  | 108  | 104  | 100  | <b>88.7</b> | <b>69.8</b> | <b>52.6</b> |
| 157      | 127                                                                                         | 123  | 120  | 118  | 115  | 113  | 111  | 109  | 107  | 105  | 103         | ...         | ...         |
| 158      | 137                                                                                         | 134  | 131  | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117         | 116         | <b>84.9</b> |
| 159      | 138                                                                                         | 135  | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114         | 113         | 112         |
| 160      | 138                                                                                         | 135  | 133  | 131  | 129  | 127  | 125  | 124  | 122  | 121  | 119         | 117         | <b>108</b>  |
| 161      | 138                                                                                         | 138  | 137  | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125         | 125         | 125         |
| 162      | 138                                                                                         | 138  | 137  | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125         | 125         | 125         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |             |             |             |             |             |             |             |             |             |             |             |
|----------|---------------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|          | 550                                                                                         | 575         | 600         | 625         | 650         | 675         | 700         | 725         | 750         | 775         | 800         | 825         |
| 134      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 135      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 136      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 137      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 138      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 139      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 140      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 141      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 142      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 143      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 144      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 145      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 146      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 147      | <b>27.6</b>                                                                                 | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 148      | <b>81.4</b>                                                                                 | <b>40.4</b> | <b>33.2</b> | <b>26.7</b> | <b>21.9</b> | <b>18.2</b> | <b>15.0</b> | <b>12.4</b> | <b>8.87</b> | <b>7.20</b> | <b>6.58</b> | <b>6.21</b> |
| 149      | <b>80.8</b>                                                                                 | <b>73.0</b> | <b>67.9</b> | <b>58.0</b> | <b>43.6</b> | <b>33.0</b> | <b>25.3</b> | <b>18.8</b> | <b>14.0</b> | <b>10.4</b> | <b>7.99</b> | <b>6.89</b> |
| 150      | 96.4                                                                                        | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 151      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 152      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 153      | <b>37.4</b>                                                                                 | <b>26.3</b> | <b>17.8</b> | <b>11.4</b> | <b>6.89</b> | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 154      | <b>37.4</b>                                                                                 | <b>26.3</b> | <b>17.8</b> | <b>11.4</b> | <b>6.89</b> | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 155      | <b>38.1</b>                                                                                 | <b>27.6</b> | <b>20.6</b> | <b>15.9</b> | <b>12.4</b> | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 156      | <b>38.1</b>                                                                                 | <b>27.6</b> | <b>20.6</b> | <b>15.9</b> | <b>12.4</b> | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 157      | ...                                                                                         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 158      | <b>59.0</b>                                                                                 | <b>43.5</b> | <b>31.9</b> | <b>23.6</b> | <b>16.9</b> | <b>10.7</b> | <b>6.10</b> | <b>3.90</b> | <b>2.99</b> | <b>2.36</b> | <b>1.73</b> | <b>1.38</b> |
| 159      | <b>88.7</b>                                                                                 | <b>59.2</b> | <b>44.0</b> | <b>32.9</b> | <b>24.5</b> | <b>18.3</b> | <b>12.5</b> | <b>8.49</b> | <b>6.19</b> | <b>4.28</b> | <b>2.75</b> | <b>1.74</b> |
| 160      | <b>83.7</b>                                                                                 | <b>64.0</b> | <b>48.5</b> | <b>36.3</b> | <b>27.3</b> | <b>21.0</b> | <b>15.9</b> | <b>12.5</b> | <b>9.87</b> | <b>7.65</b> | <b>5.97</b> | <b>5.17</b> |
| 161      | <b>97.6</b>                                                                                 | <b>75.9</b> | <b>57.2</b> | <b>40.2</b> | <b>30.3</b> | <b>23.2</b> | <b>16.2</b> | <b>11.4</b> | <b>8.97</b> | <b>7.08</b> | <b>5.89</b> | <b>5.52</b> |
| 162      | <b>97.6</b>                                                                                 | <b>75.9</b> | <b>57.2</b> | <b>40.2</b> | <b>30.3</b> | <b>23.2</b> | <b>16.2</b> | <b>11.4</b> | <b>8.97</b> | <b>7.08</b> | <b>5.89</b> | <b>5.52</b> |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition     | Product Form        | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|----------|-------------------------|---------------------|-----------|-------------|---------|--------------------------|----------|-----------|
| 163      | 25Cr-20Ni               | Plate & sheet       | A240      | 310H        | S31009  | ...                      | ...      | 8         |
| 164      | 18Cr-10Ni-Ti            | Plate, sheet, strip | A240      | 321         | S32100  | ...                      | ...      | 8         |
| 165      | 18Cr-10Ni-Ti            | Plate, sheet, strip | A240      | 321H        | S32109  | ...                      | ...      | 8         |
| 166      | 16Cr-12Ni-2Mo           | Plate & sheet       | A240      | 316         | S31600  | ...                      | ...      | 8         |
| 167      | 18Cr-13Ni-3Mo           | Plate & sheet       | A240      | 317         | S31700  | ...                      | ...      | 8         |
| 168      | 18Cr-10Ni-Cb            | Plate & sheet       | A240      | 347         | S34700  | ...                      | ...      | 8         |
| 169      | 18Cr-10Ni-Cb            | Plate & sheet       | A240      | 348         | S34800  | ...                      | ...      | 8         |
| 170      | 18Cr-8Ni                | Plate & sheet       | A240      | 304         | S30400  | ...                      | ...      | 8         |
| 171      | 44Fe-25Ni-21Cr-Mo       | Plate & sheet       | A240      | 904L        | N08904  | ...                      | ...      | 45        |
| 172      | 23Cr-4Ni-Mo-Cu-N        | Plate & sheet       | A240      | 2304        | S32304  | ...                      | ...      | 10H       |
| 173      | 22Cr-5Ni-3Mo-N          | Plate & sheet       | A240      | ...         | S31803  | ...                      | ...      | 10H       |
| 174      | 16Cr-4Ni-6Mn            | Plate & sheet       | A240      | 201LN       | S20153  | ...                      | ...      | 8         |
| 175      | 20Cr-18Ni-6Mo           | Plate               | A240      | ...         | S31254  | ...                      | >5.0     | 8         |
| 176      | 20Cr-18Ni-6Mo           | Sheet               | A240      | ...         | S31254  | ...                      | ≤5.0     | 8         |
| 177      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Plate               | A240      | ...         | N08367  | ...                      | >5.0     | 45        |
| 178      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Sheet & strip       | A240      | ...         | N08367  | ...                      | ≤5.0     | 45        |
| 179      | 21Cr-5Mn-1.5Ni-Cu-N     | Plate & sheet       | A240      | ...         | S32101  | ...                      | >5.0     | 10H       |
| 180      | 24Cr-4Ni-3Mn-1.5Mo-N    | Plate & sheet       | A240      | ...         | S82441  | ...                      | ≥10.0    | 10H       |
| 181      | 21Cr-5Mn-1.5Ni-Cu-N     | Plate & sheet       | A240      | ...         | S32101  | ...                      | ≤5.0     | 10H       |
| 182      | 21Cr-3½Ni-1¾Mo-N        | Plate & sheet       | A240      | ...         | S32003  | ...                      | >5.00    | 10H       |
| 183      | 21Cr-3½Ni-1¾Mo-N        | Plate & sheet       | A240      | ...         | S32003  | ...                      | ≤5.00    | 10H       |
| 184      | 24Cr-4Ni-3Mn-1.5Mo-N    | Plate & sheet       | A240      | ...         | S82441  | ...                      | <10.0    | 10H       |
| 185      | 29Cr-6.5Ni-2Mo-N        | Plate & sheet       | A240      | ...         | S32906  | ...                      | ≥10.0    | 10H       |
| 186      | 29Cr-6.5Ni-2Mo-N        | Plate & sheet       | A240      | ...         | S32906  | ...                      | ≤10.0    | 10H       |
| 187      | 25Cr-8Ni-3Mo-W-Cu-N     | Plate & sheet       | A240      | ...         | S32760  | ...                      | ...      | 10H       |
| 188      | 25Cr-7Ni-4Mo-N          | Plate & sheet       | A240      | 2507        | S32750  | ...                      | ...      | 10H       |
| 189      | 18Cr-13Ni-3Mo           | Forgings & fittings | A182      | F317L       | S31703  | ...                      | ≤125     | 8         |
| 190      | 18Cr-8Ni                | Forgings & fittings | A182      | F304L       | S30403  | ...                      | ...      | 8         |
| 191      | 18Cr-8Ni                | Forgings & fittings | A403      | WP304L      | S30403  | ...                      | ...      | 8         |
| 192      | 16Cr-12Ni-2Mo           | Forgings & fittings | A182      | F316L       | S31603  | ...                      | ...      | 8         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes          | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |     |     |
|----------|----------------|--------------------|----------------------------|--------------------------|--------------------|-------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|
|          |                |                    |                            |                          |                    | Min. Temp. to 40                                                                    | 65  | 100 | 125 | 150 | 175 | 200 |
| 163      | (29) (35) (39) | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 164      | (28) (30) (36) | -198               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 165      | (30) (36)      | -198               | 515                        | 205                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 166      | (26) (28) (36) | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 167      | (26) (28) (36) | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 134 |
| 168      | (28) (36)      | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 169      | (28) (36)      | -198               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 138 | 138 |
| 170      | (26) (28) (36) | -254               | 517                        | 207                      | 816                | 138                                                                                 | 138 | 138 | 138 | 138 | 134 | 129 |
| 171      | (26)           | -198               | 490                        | 220                      | 260                | 143                                                                                 | 143 | 143 | 143 | 141 | 135 | 130 |
| 172      | (25)           | -51                | 600                        | 400                      | 316                | 200                                                                                 | 200 | 191 | 185 | 180 | 175 | 171 |
| 173      | (25)           | -51                | 620                        | 450                      | 316                | 207                                                                                 | 207 | 207 | 204 | 199 | 196 | 193 |
| 174      | ...            | -198               | 655                        | 310                      | 454                | 207                                                                                 | 206 | 187 | 177 | 170 | 165 | 162 |
| 175      | ...            | -254               | 655                        | 310                      | 454                | 207                                                                                 | 207 | 207 | 207 | 203 | 196 | 190 |
| 176      | ...            | -254               | 690                        | 310                      | 454                | 207                                                                                 | 207 | 207 | 207 | 203 | 196 | 190 |
| 177      | (26)           | -198               | 655                        | 310                      | 427                | 207                                                                                 | 207 | 207 | 207 | 206 | 202 | 198 |
| 178      | (26)           | -198               | 690                        | 310                      | 427                | 207                                                                                 | 207 | 207 | 207 | 207 | 207 | 205 |
| 179      | (25)           | -29                | 650                        | 450                      | 316                | 217                                                                                 | 217 | 217 | 211 | 206 | 203 | 199 |
| 180      | (25)           | -51                | 680                        | 480                      | 316                | 227                                                                                 | 227 | 227 | 227 | 227 | 227 | 227 |
| 181      | (25)           | -29                | 700                        | 530                      | 316                | 233                                                                                 | 233 | 231 | 227 | 222 | 219 | 215 |
| 182      | (25)           | -51                | 655                        | 450                      | 343                | 218                                                                                 | 218 | 210 | 203 | 199 | 197 | 197 |
| 183      | (25)           | -51                | 690                        | 485                      | 343                | 230                                                                                 | 230 | 221 | 214 | 209 | 207 | 207 |
| 184      | (25)           | -51                | 740                        | 540                      | 316                | 247                                                                                 | 247 | 247 | 247 | 247 | 247 | 247 |
| 185      | (25)           | -51                | 750                        | 550                      | 316                | 251                                                                                 | 251 | 249 | 243 | 238 | 235 | 231 |
| 186      | (25)           | -51                | 800                        | 650                      | 316                | 267                                                                                 | 267 | 265 | 259 | 253 | 250 | 246 |
| 187      | (25)           | -51                | 750                        | 550                      | 316                | 250                                                                                 | 250 | 248 | 243 | 238 | 236 | 234 |
| 188      | (25)           | -51                | 800                        | 550                      | 316                | 267                                                                                 | 265 | 264 | 257 | 251 | 247 | 243 |
| 189      | (9) (21a)      | -198               | 483                        | 172                      | 454                | 115                                                                                 | 115 | 115 | 115 | 115 | 113 | 109 |
| 190      | (9) (21a)      | -254               | 483                        | 172                      | 816                | 115                                                                                 | 115 | 115 | 115 | 115 | 114 | 110 |
| 191      | (32) (37)      | -254               | 483                        | 172                      | 816                | 115                                                                                 | 115 | 115 | 115 | 115 | 114 | 110 |
| 192      | (9) (21a)      | -254               | 483                        | 172                      | 816                | 115                                                                                 | 115 | 115 | 115 | 115 | 113 | 109 |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |      |      |      |      |      |      |      |      |      |      |            |
|----------|---------------------------------------------------------------------------------------------|-----|------|------|------|------|------|------|------|------|------|------|------------|
|          | 225                                                                                         | 250 | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525        |
| 163      | 137                                                                                         | 134 | 131  | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | <b>108</b> |
| 164      | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112        |
| 165      | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112        |
| 166      | 129                                                                                         | 125 | 122  | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106        |
| 167      | 129                                                                                         | 125 | 122  | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106        |
| 168      | 138                                                                                         | 138 | 137  | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125        |
| 169      | 138                                                                                         | 138 | 137  | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125        |
| 170      | 125                                                                                         | 122 | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3       |
| 171      | 125                                                                                         | 120 | 116  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 172      | 166                                                                                         | 161 | 153  | 143  | 111  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 173      | 190                                                                                         | 188 | 187  | 186  | 185  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 174      | 160                                                                                         | 159 | 158  | 158  | 158  | 157  | 156  | 154  | 152  | 149  | 146  | ...  | ...        |
| 175      | 184                                                                                         | 179 | 175  | 172  | 169  | 167  | 166  | 165  | 164  | 163  | 161  | ...  | ...        |
| 176      | 184                                                                                         | 179 | 175  | 172  | 169  | 167  | 166  | 165  | 164  | 163  | 161  | ...  | ...        |
| 177      | 195                                                                                         | 192 | 188  | 184  | 179  | 176  | 173  | 170  | 167  | 166  | ...  | ...  | ...        |
| 178      | 199                                                                                         | 194 | 188  | 184  | 179  | 176  | 173  | 170  | 167  | 166  | ...  | ...  | ...        |
| 179      | 199                                                                                         | 199 | 199  | 199  | 199  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 180      | 227                                                                                         | 227 | 227  | 227  | 227  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 181      | 214                                                                                         | 214 | 214  | 214  | 214  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 182      | 197                                                                                         | 197 | 197  | 197  | 197  | 197  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 183      | 207                                                                                         | 207 | 207  | 207  | 207  | 207  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 184      | 247                                                                                         | 247 | 247  | 247  | 247  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 185      | 230                                                                                         | 228 | 228  | 228  | 228  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 186      | 245                                                                                         | 243 | 243  | 242  | 242  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 187      | 233                                                                                         | 233 | 233  | 233  | 233  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 188      | 241                                                                                         | 238 | 237  | 237  | 236  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...        |
| 189      | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | ...  | ...        |
| 190      | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7       |
| 191      | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7       |
| 192      | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5       |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 550                                                                                         | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  |
| 163      | 83.7                                                                                        | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 164      | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 165      | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 166      | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 167      | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 168      | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 169      | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 170      | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 171      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 172      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 173      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 174      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 175      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 176      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 177      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 178      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 179      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 180      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 181      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 182      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 183      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 184      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 185      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 186      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 187      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 188      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 189      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 190      | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 191      | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 192      | 80.8                                                                                        | 73.0 | 67.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form        | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temper | Size, mm | P-No. (5) |
|----------|---------------------|---------------------|-----------|------------|---------|------------------------|----------|-----------|
| 193      | 16Cr-12Ni-2Mo       | Forgings & fittings | A403      | WP316L     | S31603  | ...                    | ...      | 8         |
| 194      | 18Cr-13Ni-3Mo       | Forgings & fittings | A403      | WP317L     | S31703  | ...                    | ...      | 8         |
| 195      | 25Cr-20Ni           | Forgings & fittings | A182      | F310       | S31000  | ...                    | ...      | 8         |
| 196      | 25Cr-20Ni           | Forgings & fittings | A403      | WP310S     | S31008  | ...                    | ...      | 8         |
| 197      | 18Cr-10Ni-Ti        | Smls. fittings      | A403      | WP321      | S32100  | ...                    | >10      | 8         |
| 198      | 18Cr-10Ni-Ti        | Forgings            | A182      | F321       | S32100  | ...                    | ...      | 8         |
| 199      | 18Cr-10Ni-Ti        | Smls. fittings      | A403      | WP321      | S32100  | ...                    | ≤10      | 8         |
| 200      | 18Cr-10Ni-Ti        | Wld. fittings       | A403      | WP321      | S32100  | ...                    | ...      | 8         |
| 201      | 23Cr-12Ni           | Forgings & fittings | A403      | WP309      | S30900  | ...                    | ...      | 8         |
| 202      | 25Cr-20Ni           | Forgings & fittings | A182      | F310H      | S31009  | ...                    | ...      | 8         |
| 203      | 25Cr-20Ni           | Forgings & fittings | A403      | WP310H     | S31009  | ...                    | ...      | 8         |
| 204      | 18Cr-10Ni-Cb        | Forgings & fittings | A182      | F347       | S34700  | ...                    | ...      | 8         |
| 205      | 18Cr-10Ni-Cb        | Forgings & fittings | A403      | WP347      | S34700  | ...                    | ...      | 8         |
| 206      | 18Cr-10Ni-Cb        | Forgings & fittings | A182      | F348       | S34800  | ...                    | ...      | 8         |
| 207      | 18Cr-10Ni-Cb        | Forgings & fittings | A403      | WP348      | S34800  | ...                    | ...      | 8         |
| 208      | 18Cr-10Ni-Ti        | Smls. fittings      | A403      | WP321      | S32100  | ...                    | >10      | 8         |
| 209      | 18Cr-10Ni-Ti        | Smls. fittings      | A403      | WP321H     | S32109  | ...                    | >10      | 8         |
| 210      | 18Cr-10Ni-Ti        | Forgings            | A182      | F321       | S32100  | ...                    | ...      | 8         |
| 211      | 18Cr-10Ni-Ti        | Forgings            | A182      | F321H      | S32109  | ...                    | ...      | 8         |
| 212      | 18Cr-10Ni-Ti        | Smls. fittings      | A403      | WP321      | S32100  | ...                    | ≤10      | 8         |
| 213      | 18Cr-10Ni-Ti        | Smls. fittings      | A403      | WP321H     | S32109  | ...                    | ≤10      | 8         |
| 214      | 18Cr-10Ni-Ti        | Wld. fittings       | A403      | WP321      | S32100  | ...                    | ...      | 8         |
| 215      | 18Cr-10Ni-Ti        | Wld. fittings       | A403      | WP321H     | S32109  | ...                    | ...      | 8         |
| 216      | 16Cr-12Ni-2Mo       | Forgings & fittings | A403      | WP316H     | S31609  | ...                    | ...      | 8         |
| 217      | 16Cr-12Ni-2Mo       | Forgings & fittings | A182      | F316H      | S31609  | ...                    | ...      | 8         |
| 218      | 18Cr-10Ni-Cb        | Forgings & fittings | A403      | WP347H     | S34709  | ...                    | ...      | 8         |
| 219      | 18Cr-10Ni-Cb        | Forgings & fittings | A182      | F347       | S34700  | ...                    | ...      | 8         |
| 220      | 18Cr-10Ni-Cb        | Forgings & fittings | A403      | WP347      | S34700  | ...                    | ...      | 8         |
| 221      | 18Cr-10Ni-Cb        | Forgings & fittings | A182      | F348       | S34800  | ...                    | ...      | 8         |
| 222      | 18Cr-10Ni-Cb        | Forgings & fittings | A403      | WP348      | S34800  | ...                    | ...      | 8         |
| 223      | 18Cr-10Ni-Cb        | Forgings & fittings | A182      | F347H      | S34709  | ...                    | ...      | 8         |
| 224      | 18Cr-10Ni-Cb        | Forgings & fittings | A182      | F348H      | S34809  | ...                    | ...      | 8         |
| 225      | 16Cr-12Ni-2Mo       | Forgings & fittings | A182      | F316       | S31600  | ...                    | ...      | 8         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes                    | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |                            |                          |                    |            |     |     |     |     |     |     |
|----------|--------------------------|-------------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------|-----|-----|-----|-----|-----|-----|
|          |                          | Min. Temp., °C (6)                                                                  | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. |     |     |     |     |     |     |
|          |                          |                                                                                     |                            |                          |                    | to 40      | 65  | 100 | 125 | 150 | 175 | 200 |
| 193      | (32) (37)                | -254                                                                                | 483                        | 172                      | 816                | 115        | 115 | 115 | 115 | 115 | 113 | 109 |
| 194      | (32) (37)                | -198                                                                                | 517                        | 207                      | 454                | 138        | 138 | 138 | 138 | 138 | 136 | 131 |
| 195      | (9) (35) (39)            | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 196      | (28) (32) (35) (37)      | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 197      | (28)                     | -198                                                                                | 485                        | 170                      | 816                | 115        | 115 | 115 | 115 | 115 | 115 | 115 |
| 198      | (9) (21) (28)            | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 199      | (28)                     | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 200      | (28)                     | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 201      | (28) (32) (35) (37) (39) | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 202      | (9) (21) (29) (35) (39)  | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 203      | (29) (32) (35) (37) (39) | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 204      | (9) (21)                 | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 205      | (32) (37)                | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 206      | (9) (21)                 | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 207      | (32) (37)                | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 208      | (28) (30)                | -198                                                                                | 485                        | 170                      | 816                | 115        | 115 | 115 | 115 | 115 | 115 | 115 |
| 209      | (30)                     | -198                                                                                | 485                        | 170                      | 816                | 115        | 115 | 115 | 115 | 115 | 115 | 115 |
| 210      | (9) (21) (28) (30)       | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 211      | (9) (21)                 | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 212      | (28) (30)                | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 213      | (30)                     | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 214      | (28) (30)                | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 215      | (30)                     | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 216      | (26) (32) (37)           | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 134 |
| 217      | (9) (21) (26)            | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 134 |
| 218      | (32) (37)                | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 219      | (9) (21) (28)            | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 220      | (28) (32) (37)           | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 221      | (9) (21) (28)            | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 222      | (28) (32) (37)           | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 223      | (9) (21)                 | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 224      | (9) (21)                 | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 225      | (9) (21) (26) (28)       | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 134 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |      |      |      |      |      |      |      |      |      |             |
|----------|---------------------------------------------------------------------------------------------|-----|-----|------|------|------|------|------|------|------|------|------|-------------|
|          | 225                                                                                         | 250 | 275 | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525         |
| 193      | 106                                                                                         | 103 | 100 | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5        |
| 194      | 127                                                                                         | 123 | 120 | 118  | 115  | 113  | 111  | 109  | 107  | 105  | 103  | ...  | ...         |
| 195      | 137                                                                                         | 134 | 131 | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | <b>84.9</b> |
| 196      | 137                                                                                         | 134 | 131 | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | <b>84.9</b> |
| 197      | 115                                                                                         | 112 | 109 | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6        |
| 198      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 199      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 200      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 201      | 138                                                                                         | 135 | 133 | 131  | 129  | 127  | 125  | 124  | 122  | 121  | 119  | 117  | <b>108</b>  |
| 202      | 137                                                                                         | 134 | 131 | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | <b>108</b>  |
| 203      | 137                                                                                         | 134 | 131 | 129  | 127  | 125  | 123  | 122  | 120  | 119  | 117  | 116  | <b>108</b>  |
| 204      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125         |
| 205      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125         |
| 206      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125         |
| 207      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125         |
| 208      | 115                                                                                         | 112 | 109 | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6        |
| 209      | 115                                                                                         | 112 | 109 | 106  | 104  | 102  | 100  | 99.0 | 97.0 | 96.3 | 95.3 | 94.4 | 93.6        |
| 210      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 211      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 212      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 213      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 214      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 215      | 138                                                                                         | 135 | 131 | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112         |
| 216      | 129                                                                                         | 125 | 122 | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106         |
| 217      | 129                                                                                         | 125 | 122 | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106         |
| 218      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125         |
| 219      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125         |
| 220      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125         |
| 221      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125         |
| 222      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125         |
| 223      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125         |
| 224      | 138                                                                                         | 138 | 137 | 135  | 132  | 130  | 129  | 127  | 126  | 126  | 125  | 125  | 125         |
| 225      | 129                                                                                         | 125 | 122 | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 550                                                                                 | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  |
| 193      | 80.8                                                                                | 73.0 | 67.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 194      | ...                                                                                 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 195      | 59.0                                                                                | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 196      | 59.0                                                                                | 43.5 | 31.9 | 23.6 | 16.9 | 10.7 | 6.10 | 3.90 | 2.99 | 2.36 | 1.73 | 1.38 |
| 197      | 88.7                                                                                | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 198      | 88.7                                                                                | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 199      | 88.7                                                                                | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 200      | 88.7                                                                                | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 201      | 83.7                                                                                | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 202      | 83.7                                                                                | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 203      | 83.7                                                                                | 64.0 | 48.5 | 36.3 | 27.3 | 21.0 | 15.9 | 12.5 | 9.87 | 7.65 | 5.97 | 5.17 |
| 204      | 97.6                                                                                | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 205      | 97.6                                                                                | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 206      | 97.6                                                                                | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 207      | 97.6                                                                                | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 208      | 92.7                                                                                | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 209      | 92.7                                                                                | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 210      | 100                                                                                 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 211      | 100                                                                                 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 212      | 100                                                                                 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 213      | 100                                                                                 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 214      | 100                                                                                 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 215      | 100                                                                                 | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 216      | 105                                                                                 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 217      | 105                                                                                 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 218      | 125                                                                                 | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 219      | 125                                                                                 | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 220      | 125                                                                                 | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 221      | 125                                                                                 | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 222      | 125                                                                                 | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 223      | 125                                                                                 | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 224      | 125                                                                                 | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 225      | 105                                                                                 | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition     | Product Form        | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm | P-No. (5) |
|----------|-------------------------|---------------------|-----------|-------------|---------|--------------------------|----------|-----------|
| 226      | 16Cr-12Ni-2Mo           | Forgings & fittings | A403      | WP316       | S31600  | ...                      | ...      | 8         |
| 227      | 18Cr-13Ni-3Mo           | Forgings & fittings | A403      | WP317       | S31700  | ...                      | ...      | 8         |
| 228      | 18Cr-8Ni                | Forgings & fittings | A182      | F304        | S30400  | ...                      | ...      | 8         |
| 229      | 18Cr-8Ni                | Forgings & fittings | A403      | WP304       | S30400  | ...                      | ...      | 8         |
| 230      | 18Cr-8Ni                | Forgings & fittings | A403      | WP304H      | S30409  | ...                      | ...      | 8         |
| 231      | 18Cr-8Ni                | Forgings & fittings | A182      | F304H       | S30409  | ...                      | ...      | 8         |
| 232      | 44Fe-25Ni-21Cr-Mo       | Forgings            | A182      | F904L       | N08904  | ...                      | ...      | 45        |
| 233      | 13Cr                    | Forgings & fittings | A182      | F6a         | S41000  | 1                        | ...      | 6         |
| 234      | 13Cr                    | Forgings & fittings | A182      | F6a         | S41000  | 2                        | ...      | 6         |
| 235      | 20Cr-18Ni-6Mo           | Forgings            | A182      | F44         | S31254  | ...                      | ...      | 8         |
| 236      | 20Cr-18Ni-6Mo           | Fittings            | A403      | WPS31254    | S31254  | ...                      | ...      | 8         |
| 237      | 23Cr-4Ni-Mo-Cu-N        | Forgings            | A182      | F68         | S32304  | ...                      | ...      | 10H       |
| 238      | 22Cr-5Ni-3Mo-N          | Forgings            | A182      | F51         | S31803  | ...                      | ...      | 10H       |
| 239      | 22Cr-5Ni-3Mo-N          | Fittings            | A815      | WPS31803    | S31803  | ...                      | ...      | 10H       |
| 240      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Forgings            | A182      | F62         | N08367  | ...                      | ...      | 45        |
| 241      | 46Fe-24Ni-21Cr-6Mo-Cu-N | Fittings            | A403      | WP6XN       | N08367  | ...                      | ...      | 45        |
| 242      | 21Cr-5Mn-1½Ni-Cu-N      | Fittings            | A815      | WPS32101    | S32101  | ...                      | ...      | 10H       |
| 243      | 25Cr-8Ni-3Mo-W-Cu-N     | Forgings & fittings | A182      | F55         | S32760  | ...                      | ...      | 10H       |
| 244      | 25Cr-8Ni-3Mo-W-Cu-N     | Forgings & fittings | A815      | WPS32760    | S32760  | ...                      | ...      | 10H       |
| 245      | 25Cr-7Ni-4Mo-N          | Forgings & fittings | A182      | F53         | S32750  | ...                      | ≤50      | 10H       |
| 246      | 25Cr-7Ni-4Mo-N          | Forgings & fittings | A815      | WPS32750    | S32750  | ...                      | ...      | 10H       |
| 247      | 18Cr-8Ni                | Bar                 | A479      | 304         | S30400  | ...                      | ...      | 8         |
| 248      | 18Cr-8Ni                | Bar                 | A479      | 304H        | S30409  | ...                      | ...      | 8         |
| 249      | 18Cr-8Ni                | Bar                 | A479      | 304L        | S30403  | ...                      | ...      | 8         |
| 250      | 16Cr-12Ni-2Mo           | Bar                 | A479      | 316         | S31600  | ...                      | ...      | 8         |
| 251      | 16Cr-12Ni-2Mo           | Bar                 | A479      | 316H        | S31609  | ...                      | ...      | 8         |
| 252      | 16Cr-12Ni-2Mo           | Bar                 | A479      | 316L        | S31603  | ...                      | ...      | 8         |
| 253      | 18Cr-10Ni-Ti            | Bar                 | A479      | 321         | S32100  | ...                      | ...      | 8         |
| 254      | 18Cr-10Ni-Ti            | Bar                 | A479      | 321         | S32100  | ...                      | ...      | 8         |
| 255      | 18Cr-10Ni-Ti            | Bar                 | A479      | 321H        | S32109  | ...                      | ...      | 8         |
| 256      | 18Cr-10Ni-Cb            | Bar                 | A479      | 347         | S34700  | ...                      | ...      | 8         |
| 257      | 18Cr-10Ni-Cb            | Bar                 | A479      | 347         | S34700  | ...                      | ...      | 8         |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes               | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |                            |                          |                    |            |     |     |     |     |     |     |
|----------|---------------------|-------------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------|-----|-----|-----|-----|-----|-----|
|          |                     | Min. Temp., °C (6)                                                                  | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. |     |     |     |     |     |     |
|          |                     |                                                                                     |                            |                          |                    | to 40      | 65  | 100 | 125 | 150 | 175 | 200 |
| 226      | (26) (28) (32) (37) | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 134 |
| 227      | (26) (28) (32)      | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 134 |
| 228      | (9) (21) (26) (28)  | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 134 | 129 |
| 229      | (26) (28) (32) (37) | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 134 | 129 |
| 230      | (26) (32) (37)      | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 134 | 129 |
| 231      | (9) (21) (26)       | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 134 | 129 |
| 232      | (26)                | -198                                                                                | 490                        | 220                      | 260                | 143        | 143 | 143 | 143 | 141 | 135 | 130 |
| 233      | (35)                | -29                                                                                 | 483                        | 276                      | 538                | 161        | 161 | 161 | 160 | 158 | 156 | 155 |
| 234      | (35)                | -29                                                                                 | 586                        | 379                      | 649                | 195        | 195 | 195 | 194 | 191 | 190 | 188 |
| 235      | ...                 | -198                                                                                | 650                        | 300                      | 454                | 202        | 202 | 202 | 202 | 199 | 192 | 185 |
| 236      | ...                 | -198                                                                                | 650                        | 300                      | 454                | 202        | 202 | 202 | 202 | 199 | 192 | 185 |
| 237      | (25)                | -51                                                                                 | 600                        | 400                      | 316                | 200        | 200 | 191 | 185 | 180 | 175 | 171 |
| 238      | (25)                | -51                                                                                 | 620                        | 450                      | 316                | 207        | 207 | 207 | 204 | 199 | 196 | 193 |
| 239      | (25)                | -51                                                                                 | 620                        | 450                      | 316                | 207        | 207 | 207 | 204 | 199 | 196 | 193 |
| 240      | (26)                | -198                                                                                | 655                        | 310                      | 427                | 207        | 207 | 207 | 207 | 206 | 202 | 198 |
| 241      | (26)                | -198                                                                                | 655                        | 310                      | 427                | 207        | 207 | 207 | 207 | 206 | 202 | 198 |
| 242      | (25)                | -29                                                                                 | 650                        | 450                      | 316                | 217        | 217 | 215 | 211 | 206 | 203 | 199 |
| 243      | (25)                | -51                                                                                 | 750                        | 550                      | 316                | 250        | 250 | 248 | 243 | 238 | 236 | 234 |
| 244      | (25)                | -51                                                                                 | 750                        | 550                      | 316                | 250        | 250 | 248 | 243 | 238 | 236 | 234 |
| 245      | (25)                | -51                                                                                 | 800                        | 550                      | 316                | 267        | 265 | 264 | 257 | 251 | 247 | 243 |
| 246      | (25)                | -51                                                                                 | 800                        | 550                      | 316                | 267        | 265 | 264 | 257 | 251 | 247 | 243 |
| 247      | (26) (28)           | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 134 | 129 |
| 248      | (26)                | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 134 | 129 |
| 249      | ...                 | -254                                                                                | 483                        | 172                      | 816                | 115        | 115 | 115 | 115 | 115 | 114 | 110 |
| 250      | (26) (28)           | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 134 |
| 251      | (26)                | -198                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 134 |
| 252      | ...                 | -254                                                                                | 483                        | 172                      | 816                | 115        | 115 | 115 | 115 | 115 | 113 | 109 |
| 253      | (28)                | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 254      | (28) (30)           | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 255      | (30)                | -198                                                                                | 515                        | 205                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 256      | ...                 | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |
| 257      | (28) (30)           | -254                                                                                | 517                        | 207                      | 816                | 138        | 138 | 138 | 138 | 138 | 138 | 138 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|-----|------|------|------|------|------|------|------|------|------|------|------|
|          | 225                                                                                         | 250 | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  |
| 226      | 129                                                                                         | 125 | 122  | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106  |
| 227      | 129                                                                                         | 125 | 122  | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106  |
| 228      | 125                                                                                         | 122 | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 229      | 125                                                                                         | 122 | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 230      | 125                                                                                         | 122 | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 231      | 125                                                                                         | 122 | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 232      | 125                                                                                         | 120 | 116  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 233      | 154                                                                                         | 153 | 152  | 150  | 148  | 145  | 142  | 137  | 133  | 125  | 92.5 | 68.4 | 51.1 |
| 234      | 187                                                                                         | 186 | 184  | 182  | 180  | 176  | 172  | 167  | 161  | 125  | 92.5 | 68.4 | 51.1 |
| 235      | 180                                                                                         | 175 | 171  | 168  | 165  | 164  | 162  | 161  | 160  | 159  | 158  | ...  | ...  |
| 236      | 180                                                                                         | 175 | 171  | 168  | 165  | 164  | 162  | 161  | 160  | 159  | 158  | ...  | ...  |
| 237      | 166                                                                                         | 161 | 153  | 143  | 111  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 238      | 190                                                                                         | 188 | 187  | 186  | 185  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 239      | 190                                                                                         | 188 | 187  | 186  | 185  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 240      | 195                                                                                         | 192 | 188  | 184  | 179  | 176  | 173  | 170  | 167  | 166  | ...  | ...  | ...  |
| 241      | 195                                                                                         | 192 | 188  | 184  | 179  | 176  | 173  | 170  | 167  | 166  | ...  | ...  | ...  |
| 242      | 199                                                                                         | 199 | 199  | 199  | 199  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 243      | 233                                                                                         | 233 | 233  | 233  | 233  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 244      | 233                                                                                         | 233 | 233  | 233  | 233  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 245      | 241                                                                                         | 238 | 237  | 237  | 236  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 246      | 241                                                                                         | 238 | 237  | 237  | 236  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 247      | 125                                                                                         | 122 | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 248      | 125                                                                                         | 122 | 119  | 116  | 113  | 111  | 109  | 107  | 105  | 103  | 101  | 99.1 | 97.3 |
| 249      | 106                                                                                         | 103 | 99.9 | 97.7 | 95.7 | 94.1 | 92.6 | 91.3 | 90.0 | 88.7 | 87.3 | 85.6 | 83.7 |
| 250      | 129                                                                                         | 125 | 122  | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106  |
| 251      | 129                                                                                         | 125 | 122  | 119  | 116  | 114  | 112  | 111  | 110  | 109  | 108  | 107  | 106  |
| 252      | 106                                                                                         | 103 | 100  | 98.1 | 96.1 | 94.3 | 92.6 | 90.9 | 89.3 | 87.6 | 85.9 | 84.2 | 82.5 |
| 253      | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 254      | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 255      | 138                                                                                         | 135 | 131  | 128  | 125  | 122  | 120  | 119  | 117  | 115  | 114  | 113  | 112  |
| 256      | 138                                                                                         | 138 | 137  | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |
| 257      | 138                                                                                         | 138 | 137  | 135  | 132  | 130  | 128  | 127  | 126  | 126  | 125  | 125  | 125  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 550                                                                                         | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  |
| 226      | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 227      | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 228      | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 229      | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 230      | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 231      | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 232      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 233      | 44.1                                                                                        | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 234      | 37.4                                                                                        | 26.3 | 17.8 | 11.4 | 6.89 | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 235      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 236      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 237      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 238      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 239      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 240      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 241      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 242      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 243      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 244      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 245      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 246      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 247      | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 248      | 95.5                                                                                        | 78.9 | 63.8 | 51.6 | 41.6 | 32.9 | 26.5 | 21.3 | 17.2 | 14.1 | 11.2 | 9.65 |
| 249      | 81.4                                                                                        | 40.4 | 33.2 | 26.7 | 21.9 | 18.2 | 15.0 | 12.4 | 8.87 | 7.20 | 6.58 | 6.21 |
| 250      | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 251      | 105                                                                                         | 97.8 | 80.8 | 65.0 | 50.4 | 38.6 | 29.6 | 23.0 | 17.4 | 13.3 | 10.4 | 8.96 |
| 252      | 80.8                                                                                        | 73.0 | 67.9 | 58.0 | 43.6 | 33.0 | 25.3 | 18.8 | 14.0 | 10.4 | 7.99 | 6.89 |
| 253      | 88.7                                                                                        | 59.2 | 44.0 | 32.9 | 24.5 | 18.3 | 12.5 | 8.49 | 6.19 | 4.28 | 2.75 | 1.74 |
| 254      | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 255      | 100                                                                                         | 76.5 | 58.7 | 46.0 | 36.8 | 28.7 | 23.0 | 18.4 | 14.5 | 11.5 | 9.02 | 6.83 |
| 256      | 97.6                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 257      | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition         | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/<br>Condition/<br>Temper | Size,<br>mm | P-No.<br>(5) |
|----------|-----------------------------|--------------|-----------|-------------|---------|--------------------------------|-------------|--------------|
| 258      | 18Cr-10Ni-Cb                | Bar          | A479      | 347H        | S34709  | ...                            | ...         | 8            |
| 259      | 44Fe-25Ni-21Cr-Mo           | Bar          | A479      | 904L        | N08904  | ...                            | ...         | 45           |
| 260      | 22Cr-5Ni-3Mo-N              | Bar          | A479      | ...         | S31803  | ...                            | ...         | 10H          |
| 261      | 20Cr-18Ni-6Mo               | Bar          | A479      | ...         | S31254  | ...                            | ...         | 8            |
| 262      | 46Fe-24Ni-21Cr-6Mo-Cu-N     | Bar          | A479      | ...         | N08367  | ...                            | ...         | 45           |
| 263      | 21Cr-5Mn-1.5Ni-Cu-N         | Bar          | A479      | ...         | S32101  | ...                            | ...         | 10H          |
| 264      | 24Cr-4Ni-3Mn-1.5Mo-N        | Bar          | A479      | ...         | S82441  | ...                            | ≥11.0       | 10H          |
| 265      | 22Cr-13Ni-5Mn               | Bar          | A479      | XM-19       | S20910  | Annealed                       | ...         | 8            |
| 266      | 24Cr-4Ni-3Mn-1.5Mo-N        | Bar          | A479      | ...         | S82441  | ...                            | <11.0       | 10H          |
| 267      | 29Cr-6.5Ni-2Mo-N            | Bar          | A479      | ...         | S32906  | ...                            | ...         | 10H          |
| 268      | 25Cr-7Ni-4Mo-N              | Bar          | A479      | ...         | S32750  | ...                            | ≤50         | 10H          |
| 269      | 29Ni-20Cr-3Cu-2Mo           | Castings     | A351      | CN7M        | N08007  | ...                            | ...         | 45           |
| 270      | 35Ni-15Cr- $\frac{1}{2}$ Mo | Castings     | A351      | HT30        | N08603  | ...                            | ...         | 45           |
| 271      | 25Cr-12Ni                   | Castings     | A351      | CH8         | J93400  | ...                            | ...         | 8            |
| 272      | 25Cr-20Ni                   | Castings     | A351      | CK20        | J94202  | ...                            | ...         | 8            |
| 273      | 16Cr-14Ni-2Mo               | Castings     | A351      | CF10MC      | ...     | ...                            | ...         | 8            |
| 274      | 18Cr-8Ni                    | Castings     | A351      | CF3         | J92500  | ...                            | ...         | 8            |
| 275      | 18Cr-12Ni-2Mo               | Castings     | A351      | CF3M        | J92800  | ...                            | ...         | 8            |
| 276      | 18Cr-8Ni                    | Castings     | A351      | CF8         | J92600  | ...                            | ...         | 8            |
| 277      | 25Cr-12Ni                   | Castings     | A351      | CH10        | J93401  | ...                            | ...         | 8            |
| 278      | 25Cr-12Ni                   | Castings     | A351      | CH20        | J93402  | ...                            | ...         | 8            |
| 279      | 18Cr-10Ni-Cb                | Castings     | A351      | CF8C        | J92710  | ...                            | ...         | 8            |
| 280      | 18Cr-12Ni-2Mo               | Castings     | A351      | CF8M        | J92900  | ...                            | ...         | 8            |
| 281      | 25Cr-20Ni- $\frac{1}{2}$ Mo | Castings     | A351      | HK40        | J94204  | ...                            | ...         | 8            |
| 282      | 25Cr-20Ni- $\frac{1}{2}$ Mo | Castings     | A351      | HK30        | J94203  | ...                            | ...         | 8            |
| 283      | 18Cr-8Ni                    | Castings     | A351      | CF3A        | J92500  | ...                            | ...         | 8            |
| 284      | 18Cr-8Ni                    | Castings     | A351      | CF8A        | J92600  | ...                            | ...         | 8            |
| 285      | 25Cr-8Ni-N                  | Castings     | A351      | CE20N       | J92802  | ...                            | ...         | 8            |
| 286      | 12Cr                        | Castings     | A217      | CA15        | J91150  | ...                            | ...         | 6            |
| 287      | 24Cr-10Ni-4Mo-N             | Castings     | A995      | 2A          | J93345  | ...                            | ...         | 10H          |
| 288      | 25Cr-8Ni-3Mo-W-Cu-N         | Castings     | A995      | 6A          | J93380  | ...                            | ...         | 10H          |
| 289      | 13Cr-4Ni                    | Castings     | A487      | CA6NM       | J91540  | ...                            | ...         | 6            |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes                   | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |                            |                          |                    |                  |     |     |     |     |     |     |
|----------|-------------------------|-------------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------------|-----|-----|-----|-----|-----|-----|
|          |                         | Min. Temp., °C (6)                                                                  | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. to 40 |     |     |     |     |     |     |
|          |                         |                                                                                     |                            |                          |                    |                  | 65  | 100 | 125 | 150 | 175 | 200 |
| 258      | ...                     | -198                                                                                | 517                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 138 |
| 259      | (26)                    | -198                                                                                | 490                        | 220                      | 260                | 143              | 143 | 143 | 143 | 141 | 135 | 130 |
| 260      | (25)                    | -51                                                                                 | 620                        | 450                      | 316                | 207              | 207 | 207 | 204 | 199 | 196 | 193 |
| 261      | ...                     | -198                                                                                | 655                        | 310                      | 454                | 207              | 207 | 207 | 207 | 203 | 196 | 190 |
| 262      | (26)                    | -198                                                                                | 655                        | 310                      | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 |
| 263      | (25)                    | -29                                                                                 | 650                        | 450                      | 316                | 217              | 217 | 215 | 211 | 206 | 203 | 199 |
| 264      | (25)                    | -51                                                                                 | 680                        | 480                      | 316                | 227              | 227 | 227 | 227 | 227 | 227 | 227 |
| 265      | ...                     | -198                                                                                | 690                        | 380                      | 649                | 230              | 230 | 227 | 221 | 217 | 213 | 210 |
| 266      | (25)                    | -51                                                                                 | 740                        | 540                      | 316                | 247              | 247 | 247 | 247 | 247 | 247 | 247 |
| 267      | (25)                    | -51                                                                                 | 750                        | 550                      | 316                | 251              | 251 | 249 | 243 | 238 | 235 | 231 |
| 268      | (25)                    | -51                                                                                 | 800                        | 550                      | 316                | 267              | 265 | 264 | 257 | 251 | 247 | 243 |
| 269      | (9) (30)                | -198                                                                                | 427                        | 172                      | 40                 | 115              | ... | ... | ... | ... | ... | ... |
| 270      | (36) (39)               | -198                                                                                | 448                        | 193                      | 40                 | 129              | ... | ... | ... | ... | ... | ... |
| 271      | (9) (31)                | -198                                                                                | 448                        | 193                      | 816                | 129              | 129 | 129 | 129 | 127 | 125 | 124 |
| 272      | (9) (27) (31) (35) (39) | -198                                                                                | 448                        | 193                      | 816                | 129              | 129 | 129 | 129 | 127 | 125 | 124 |
| 273      | (30)                    | -198                                                                                | 483                        | 207                      | 40                 | 138              | ... | ... | ... | ... | ... | ... |
| 274      | (9)                     | -254                                                                                | 483                        | 207                      | 427                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 275      | (9)                     | -254                                                                                | 483                        | 207                      | 454                | 138              | 138 | 138 | 138 | 138 | 138 | 133 |
| 276      | (9) (26) (27) (31)      | -254                                                                                | 483                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 277      | (27) (31) (35)          | -198                                                                                | 483                        | 207                      | 816                | 138              | 138 | 138 | 138 | 137 | 136 | 134 |
| 278      | (9) (27) (31) (35) (39) | -198                                                                                | 483                        | 207                      | 816                | 138              | 138 | 138 | 138 | 137 | 136 | 134 |
| 279      | (9) (28)                | -198                                                                                | 485                        | 205                      | 816                | 138              | 138 | 138 | 138 | 138 | 138 | 135 |
| 280      | (9) (26) (27) (30)      | -254                                                                                | 483                        | 207                      | 816                | 138              | 138 | 138 | 138 | 138 | 134 | 129 |
| 281      | (35) (36) (39)          | -198                                                                                | 427                        | 241                      | 40                 | 142              | ... | ... | ... | ... | ... | ... |
| 282      | (35) (39)               | -198                                                                                | 448                        | 241                      | 40                 | 149              | ... | ... | ... | ... | ... | ... |
| 283      | (9) (56)                | -254                                                                                | 531                        | 241                      | 371                | 161              | 161 | 161 | 160 | 156 | 153 | 151 |
| 284      | (9) (26) (56)           | -254                                                                                | 531                        | 241                      | 371                | 161              | 161 | 161 | 160 | 156 | 153 | 151 |
| 285      | (35) (39)               | -198                                                                                | 552                        | 276                      | 482                | 184              | 184 | 184 | 184 | 184 | 184 | 184 |
| 286      | (35)                    | -29                                                                                 | 621                        | 448                      | 649                | 207              | 207 | 207 | 205 | 203 | 201 | 199 |
| 287      | (9)                     | -51                                                                                 | 655                        | 448                      | 316                | 218              | 218 | 216 | 208 | 201 | 197 | 195 |
| 288      | (9) (25)                | -51                                                                                 | 689                        | 448                      | 316                | 230              | 230 | 227 | 221 | 216 | 212 | 209 |
| 289      | (9) (35)                | -29                                                                                 | 758                        | 552                      | 371                | 253              | 253 | 253 | 251 | 248 | 245 | 244 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |     |     |     |     |     |     |            |            |            |             |             |             |
|----------|---------------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|------------|------------|------------|-------------|-------------|-------------|
|          | 225                                                                                         | 250 | 275 | 300 | 325 | 350 | 375 | 400        | 425        | 450        | 475         | 500         | 525         |
| 258      | 138                                                                                         | 138 | 137 | 135 | 132 | 130 | 128 | 127        | 126        | 126        | 125         | 125         | 125         |
| 259      | 125                                                                                         | 120 | 116 | ... | ... | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 260      | 190                                                                                         | 188 | 187 | 186 | 185 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 261      | 184                                                                                         | 179 | 175 | 172 | 169 | 167 | 166 | 165        | 164        | 163        | 161         | ...         | ...         |
| 262      | 195                                                                                         | 192 | 188 | 184 | 179 | 176 | 173 | 170        | 167        | 166        | ...         | ...         | ...         |
| 263      | 199                                                                                         | 199 | 199 | 199 | 199 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 264      | 227                                                                                         | 227 | 227 | 227 | 227 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 265      | 207                                                                                         | 205 | 204 | 202 | 201 | 200 | 199 | 197        | 195        | 193        | 191         | 188         | 183         |
| 266      | 247                                                                                         | 247 | 247 | 247 | 247 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 267      | 230                                                                                         | 228 | 228 | 228 | 228 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 268      | 241                                                                                         | 238 | 237 | 237 | 236 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 269      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 270      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 271      | 124                                                                                         | 123 | 121 | 119 | 117 | 115 | 112 | 109        | 106        | 103        | 100         | 96.9        | 93.7        |
| 272      | 124                                                                                         | 123 | 121 | 119 | 117 | 115 | 112 | 109        | 106        | 103        | 100         | 96.9        | 93.7        |
| 273      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 274      | 125                                                                                         | 122 | 119 | 116 | 113 | 111 | 109 | 107        | 105        | 103        | ...         | ...         | ...         |
| 275      | 129                                                                                         | 125 | 122 | 119 | 116 | 114 | 112 | 111        | 109        | 108        | 107         | ...         | ...         |
| 276      | 125                                                                                         | 122 | 119 | 116 | 113 | 111 | 109 | 107        | 105        | 103        | 101         | 99.1        | <b>94.4</b> |
| 277      | 132                                                                                         | 131 | 130 | 128 | 125 | 123 | 120 | 117        | 114        | 110        | 107         | 104         | 101         |
| 278      | 132                                                                                         | 131 | 130 | 128 | 125 | 123 | 120 | 117        | 114        | 110        | 107         | 104         | 101         |
| 279      | 132                                                                                         | 130 | 128 | 127 | 127 | 126 | 126 | 126        | 125        | 125        | 124         | 124         | 124         |
| 280      | 125                                                                                         | 122 | 119 | 116 | 113 | 111 | 109 | 107        | 105        | 103        | 101         | 99.1        | 97.3        |
| 281      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 282      | ...                                                                                         | ... | ... | ... | ... | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 283      | 146                                                                                         | 142 | 138 | 135 | 132 | 130 | 127 | ...        | ...        | ...        | ...         | ...         | ...         |
| 284      | 146                                                                                         | 142 | 138 | 135 | 132 | 130 | 127 | ...        | ...        | ...        | ...         | ...         | ...         |
| 285      | 184                                                                                         | 184 | 184 | 184 | 184 | 184 | 184 | 184        | 184        | 184        | 184         | 184         | ...         |
| 286      | 198                                                                                         | 197 | 195 | 193 | 190 | 187 | 182 | <b>120</b> | <b>116</b> | <b>105</b> | <b>82.1</b> | <b>59.9</b> | <b>41.8</b> |
| 287      | 194                                                                                         | 194 | 194 | 194 | 194 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 288      | 207                                                                                         | 206 | 205 | 204 | 204 | ... | ... | ...        | ...        | ...        | ...         | ...         | ...         |
| 289      | 242                                                                                         | 240 | 238 | 236 | 232 | 228 | 224 | ...        | ...        | ...        | ...         | ...         | ...         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 550                                                                                         | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  |
| 258      | 125                                                                                         | 112  | 90.6 | 69.6 | 53.8 | 41.4 | 31.8 | 24.0 | 18.8 | 14.6 | 10.9 | 8.96 |
| 259      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 260      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 261      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 262      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 263      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 264      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 265      | 179                                                                                         | 174  | 132  | 83.6 | 56.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 266      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 267      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 268      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 269      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 270      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 271      | 68.1                                                                                        | 53.5 | 42.1 | 33.2 | 25.9 | 20.3 | 16.5 | 13.2 | 10.1 | 7.35 | 5.89 | 5.52 |
| 272      | 73.2                                                                                        | 64.4 | 56.5 | 49.0 | 41.0 | 33.5 | 25.4 | 18.3 | 12.8 | 9.01 | 6.59 | 5.52 |
| 273      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 274      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 275      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 276      | 75.3                                                                                        | 60.4 | 49.0 | 40.1 | 32.8 | 27.2 | 23.4 | 19.6 | 16.8 | 14.7 | 12.8 | 11.7 |
| 277      | 68.2                                                                                        | 53.7 | 42.1 | 33.2 | 25.9 | 20.3 | 16.4 | 13.3 | 10.2 | 7.25 | 5.74 | 5.33 |
| 278      | 68.2                                                                                        | 53.7 | 42.1 | 33.2 | 25.9 | 20.3 | 16.4 | 13.3 | 10.2 | 7.25 | 5.74 | 5.33 |
| 279      | 98.3                                                                                        | 77.2 | 57.7 | 39.9 | 30.0 | 23.2 | 16.3 | 11.2 | 8.93 | 7.08 | 5.77 | 5.32 |
| 280      | 95.5                                                                                        | 75.9 | 57.2 | 40.2 | 30.3 | 23.2 | 16.2 | 11.4 | 8.97 | 7.08 | 5.89 | 5.52 |
| 281      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 282      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 283      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 284      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 285      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 286      | 28.7                                                                                        | 20.1 | 14.3 | 9.77 | 6.89 | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 287      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 288      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 289      | ...                                                                                         | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form | Spec. No. | UNS No. | Class/Condition/ Temper | Size, mm       | P-No. (5)(7) | Notes          | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa |
|----------|---------------------|--------------|-----------|---------|-------------------------|----------------|--------------|----------------|--------------------|------------------------|----------------------|
| 1        | 99.95Cu-P           | Pipe         | B42       | C10200  | 061                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 2        | 99.9Cu-P            | Pipe         | B42       | C12000  | 061                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 3        | 99.9Cu-P            | Pipe         | B42       | C12200  | 061                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 4        | 99.95Cu-P           | Tube         | B75       | C10200  | 050                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 5        | 99.95Cu-P           | Tube         | B75       | C10200  | 060                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 6        | 99.9Cu-P            | Tube         | B75       | C12000  | 050                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 7        | 99.9Cu-P            | Tube         | B75       | C12000  | 060                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 8        | 99.9Cu-P            | Tube         | B75       | C12200  | 050                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 9        | 99.9Cu-P            | Tube         | B75       | C12200  | 060                     | ...            | 31           | ...            | -269               | 207                    | 62                   |
| 10       | 99.9Cu-P            | Tube         | B68       | C12200  | 050                     | ...            | 31           | (24)           | -269               | 207                    | 62                   |
| 11       | 99.9Cu-P            | Tube         | B68       | C12200  | 060                     | ...            | 31           | (24)           | -269               | 207                    | 62                   |
| 12       | 99.9Cu-P            | Tube         | B88       | C12200  | 050                     | ...            | 31           | (24)           | -269               | 207                    | 62                   |
| 13       | 99.9Cu-P            | Tube         | B88       | C12200  | 060                     | ...            | 31           | (24)           | -269               | 207                    | 62                   |
| 14       | 99.9Cu-P            | Tube         | B280      | C12200  | 060                     | ...            | 31           | (24)           | -269               | 207                    | 62                   |
| 15       | 85Cu-15Zn           | Pipe         | B43       | C23000  | 061                     | ...            | 32           | ...            | -269               | 276                    | 83                   |
| 16       | 90Cu-10Ni           | Pipe & tube  | B467      | C70600  | W050                    | >114 O.D.      | 34           | (14)           | -269               | 262                    | 90                   |
| 17       | 90Cu-10Ni           | Pipe & tube  | B467      | C70600  | W061                    | >114 O.D.      | 34           | (14)           | -269               | 262                    | 90                   |
| 18       | 90Cu-10Ni           | Pipe & tube  | B466      | C70600  | Annealed                | ...            | 34           | (14)           | -269               | 262                    | 90                   |
| 19       | 90Cu-10Ni           | Pipe & tube  | B467      | C70600  | W050                    | ≤114 O.D.      | 34           | (14)           | -269               | 276                    | 103                  |
| 20       | 90Cu-10Ni           | Pipe & tube  | B467      | C70600  | W061                    | ≤114 O.D.      | 34           | (14)           | -269               | 276                    | 103                  |
| 21       | 70Cu-30Ni           | Pipe & tube  | B467      | C71500  | W050                    | >114 O.D.      | 34           | (14)           | -269               | 310                    | 103                  |
| 22       | 70Cu-30Ni           | Pipe & tube  | B467      | C71500  | W061                    | >114 O.D.      | 34           | (14)           | -269               | 310                    | 103                  |
| 23       | 80Cu-20Ni           | Pipe & tube  | B466      | C71000  | Annealed                | ≤114 O.D.      | 34           | (14)           | -269               | 310                    | 110                  |
| 24       | 99.95Cu-P           | Pipe         | B42       | C10200  | H55                     | DN 64 thru 300 | 31           | (14) (34)      | -269               | 248                    | 207                  |
| 25       | 99.9Cu-P            | Pipe         | B42       | C12000  | H55                     | DN 64 thru 300 | 31           | (14) (34)      | -269               | 248                    | 207                  |
| 26       | 99.9Cu-P            | Pipe         | B42       | C12200  | H55                     | DN 64 thru 300 | 31           | (14) (34)      | -269               | 248                    | 207                  |
| 27       | 99.95Cu-P           | Tube         | B75       | C10200  | H58                     | ...            | 31           | (14) (34)      | -269               | 248                    | 207                  |
| 28       | 99.9Cu-P            | Tube         | B75       | C12000  | H58                     | ...            | 31           | (14) (34)      | -269               | 248                    | 207                  |
| 29       | 99.9Cu-P            | Tube         | B75       | C12200  | H58                     | ...            | 31           | (14) (34)      | -269               | 248                    | 207                  |
| 30       | 99.9Cu-P            | Tube         | B88       | C12200  | H58                     | ...            | 31           | (14) (24) (34) | -269               | 248                    | 207                  |
| 31       | 70Cu-30Ni           | Pipe & tube  | B466      | C71500  | 060                     | ...            | 34           | (14)           | -269               | 359                    | 124                  |
| 32       | 70Cu-30Ni           | Pipe & tube  | B467      | C71500  | W050                    | ≤114 O.D.      | 34           | (14)           | -269               | 345                    | 138                  |
| 33       | 70Cu-30Ni           | Pipe & tube  | B467      | C71500  | W061                    | ≤114 O.D.      | 34           | (14)           | -269               | 345                    | 138                  |
| 34       | 99.95Cu-P           | Pipe         | B42       | C10200  | H80                     | DN 6 thru 50   | 31           | (14) (34)      | -269               | 310                    | 276                  |
| 35       | 99.9Cu-P            | Pipe         | B42       | C12000  | H80                     | DN 6 thru 50   | 31           | (14) (34)      | -269               | 310                    | 276                  |
| 36       | 99.9Cu-P            | Pipe         | B42       | C12200  | H80                     | DN 6 thru 50   | 31           | (14) (34)      | -269               | 310                    | 276                  |
| 37       | 99.95Cu-P           | Tube         | B75       | C10200  | H80                     | ...            | 31           | (14) (34)      | -269               | 310                    | 276                  |
| 38       | 99.9Cu-P            | Tube         | B75       | C12000  | H80                     | ...            | 31           | (14) (34)      | -269               | 310                    | 276                  |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |             |             |             |             |             |             |             |             |             |
|----------|--------------------|-------------------------------------------------------------------------------|------|------|------|------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|          |                    | Min. Temp. to 40                                                              | 65   | 100  | 125  | 150  | 175         | 200         | 225         | 250         | 275         | 300         | 325         | 350         | 375         |
| 1        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 2        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 3        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 4        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 5        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 6        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 7        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 8        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 9        | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 10       | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 11       | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 12       | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 13       | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 14       | 260                | 41.4                                                                          | 34.9 | 33.5 | 32.9 | 32.2 | <b>28.0</b> | <b>21.7</b> | <b>16.7</b> | <b>12.9</b> | <b>11.6</b> | ...         | ...         | ...         | ...         |
| 15       | 232                | 55.2                                                                          | 54.7 | 54.7 | 54.7 | 54.7 | 54.7        | <b>36.4</b> | <b>17.5</b> | <b>13.8</b> | ...         | ...         | ...         | ...         | ...         |
| 16       | 316                | 59.8                                                                          | 58.0 | 56.1 | 54.9 | 53.8 | 52.9        | 52.0        | 51.2        | 50.4        | 49.7        | <b>45.1</b> | <b>39.3</b> | ...         | ...         |
| 17       | 316                | 59.8                                                                          | 58.0 | 56.1 | 54.9 | 53.8 | 52.9        | 52.0        | 51.2        | 50.4        | 49.7        | <b>45.1</b> | <b>39.3</b> | ...         | ...         |
| 18       | 316                | 59.8                                                                          | 58.0 | 56.1 | 54.9 | 53.8 | 52.9        | 52.0        | 51.2        | 50.4        | 49.7        | <b>45.1</b> | <b>39.3</b> | ...         | ...         |
| 19       | 316                | 68.9                                                                          | 67.0 | 65.1 | 63.7 | 62.4 | 61.1        | 60.0        | 59.1        | 58.3        | <b>51.3</b> | <b>45.1</b> | <b>39.3</b> | ...         | ...         |
| 20       | 316                | 68.9                                                                          | 67.0 | 65.1 | 63.7 | 62.4 | 61.1        | 60.0        | 59.1        | 58.3        | <b>51.3</b> | <b>45.1</b> | <b>39.3</b> | ...         | ...         |
| 21       | 371                | 68.9                                                                          | 66.6 | 64.6 | 63.2 | 61.9 | 60.7        | 59.5        | 58.4        | 57.4        | <b>56.2</b> | <b>55.5</b> | <b>54.9</b> | <b>54.3</b> | <b>53.8</b> |
| 22       | 371                | 68.9                                                                          | 66.6 | 64.6 | 63.2 | 61.9 | 60.7        | 59.5        | 58.4        | 57.4        | <b>56.2</b> | <b>55.5</b> | <b>54.9</b> | <b>54.3</b> | <b>53.8</b> |
| 23       | 371                | 73.5                                                                          | 72.8 | 72.1 | 71.4 | 70.6 | 69.6        | 68.3        | 66.6        | 64.7        | 62.4        | 60.0        | <b>56.2</b> | <b>51.9</b> | <b>48.3</b> |
| 24       | 204                | 82.7                                                                          | 80.0 | 74.1 | 71.3 | 69.2 | 67.4        | 65.7        | 65.3        | ...         | ...         | ...         | ...         | ...         | ...         |
| 25       | 204                | 82.7                                                                          | 80.0 | 74.1 | 71.3 | 69.2 | 67.4        | 65.7        | 65.3        | ...         | ...         | ...         | ...         | ...         | ...         |
| 26       | 204                | 82.7                                                                          | 80.0 | 74.1 | 71.3 | 69.2 | 67.4        | 65.7        | 65.3        | ...         | ...         | ...         | ...         | ...         | ...         |
| 27       | 204                | 82.7                                                                          | 80.0 | 74.1 | 71.3 | 69.2 | 67.4        | 65.7        | 65.3        | ...         | ...         | ...         | ...         | ...         | ...         |
| 28       | 204                | 82.7                                                                          | 80.0 | 74.1 | 71.3 | 69.2 | 67.4        | 65.7        | 65.3        | ...         | ...         | ...         | ...         | ...         | ...         |
| 29       | 204                | 82.7                                                                          | 80.0 | 74.1 | 71.3 | 69.2 | 67.4        | 65.7        | 65.3        | ...         | ...         | ...         | ...         | ...         | ...         |
| 30       | 204                | 82.7                                                                          | 80.0 | 74.1 | 71.3 | 69.2 | 67.4        | 65.7        | 65.3        | ...         | ...         | ...         | ...         | ...         | ...         |
| 31       | 371                | 82.7                                                                          | 79.8 | 77.5 | 75.9 | 74.3 | 72.9        | 71.5        | 70.2        | 68.9        | 67.8        | 66.8        | 65.9        | 65.3        | 64.8        |
| 32       | 371                | 91.9                                                                          | 88.7 | 86.1 | 84.3 | 82.6 | 81.0        | 79.4        | 78.0        | 76.6        | 75.3        | 74.2        | 73.2        | 72.5        | 71.7        |
| 33       | 371                | 91.9                                                                          | 88.7 | 86.1 | 84.3 | 82.6 | 81.0        | 79.4        | 78.0        | 76.6        | 75.3        | 74.2        | 73.2        | 72.5        | 71.7        |
| 34       | 204                | 103                                                                           | 100  | 92.6 | 89.1 | 86.5 | 84.3        | <b>35.8</b> | <b>29.6</b> | ...         | ...         | ...         | ...         | ...         | ...         |
| 35       | 204                | 103                                                                           | 100  | 92.6 | 89.1 | 86.5 | 84.3        | <b>35.8</b> | <b>29.6</b> | ...         | ...         | ...         | ...         | ...         | ...         |
| 36       | 204                | 103                                                                           | 100  | 92.6 | 89.1 | 86.5 | 84.3        | <b>35.8</b> | <b>29.6</b> | ...         | ...         | ...         | ...         | ...         | ...         |
| 37       | 204                | 103                                                                           | 100  | 92.6 | 89.1 | 86.5 | 84.3        | <b>35.8</b> | <b>29.6</b> | ...         | ...         | ...         | ...         | ...         | ...         |
| 38       | 204                | 103                                                                           | 100  | 92.6 | 89.1 | 86.5 | 84.3        | <b>35.8</b> | <b>29.6</b> | ...         | ...         | ...         | ...         | ...         | ...         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition    | Product Form  | Spec. No. | UNS No. | Class/Condition/Temp | Size, mm | P-No. (5)(7) | Notes     | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa |
|----------|------------------------|---------------|-----------|---------|----------------------|----------|--------------|-----------|--------------------|------------------------|----------------------|
| 39       | 99.9Cu-P               | Tube          | B75       | C12200  | H80                  | ...      | 31           | (14) (34) | -269               | 310                    | 276                  |
| 40       | 99.95Cu-P              | Plate & sheet | B152      | C10200  | O25                  | ...      | 31           | (14) (24) | -269               | 207                    | 69                   |
| 41       | 99.95Cu-Ag             | Plate & sheet | B152      | C10400  | O25                  | ...      | 31           | (14) (24) | -269               | 207                    | 69                   |
| 42       | 99.95Cu-Ag             | Plate & sheet | B152      | C10500  | O25                  | ...      | 31           | (14) (24) | -269               | 207                    | 69                   |
| 43       | 99.95Cu-Ag             | Plate & sheet | B152      | C10700  | O25                  | ...      | 31           | (14) (24) | -269               | 207                    | 69                   |
| 44       | 99.9Cu-P               | Plate & sheet | B152      | C12200  | O25                  | ...      | 31           | (14) (24) | -269               | 207                    | 69                   |
| 45       | 99.9Cu-P               | Plate & sheet | B152      | C12300  | O25                  | ...      | 31           | (14) (24) | -269               | 207                    | 69                   |
| 46       | 90Cu-10Ni              | Plate & sheet | B171      | C70600  | ...                  | ≤64 thk. | 34           | (14)      | -269               | 276                    | 103                  |
| 47       | 97Cu-3Si               | Plate & sheet | B96       | C65500  | O61                  | ...      | 33           | ...       | -269               | 345                    | 124                  |
| 48       | 70Cu-30Ni              | Plate & sheet | B171      | C71500  | ...                  | ≤64 thk. | 34           | (14)      | -269               | 345                    | 138                  |
| 49       | 90Cu-7Al-3Fe           | Plate & sheet | B169      | C61400  | O25                  | ≤50 thk. | 35           | (13)      | -269               | 483                    | 207                  |
| 50       | 90Cu-7Al-3Fe           | Plate & sheet | B169      | C61400  | O60                  | ≤50 thk. | 35           | (13)      | -269               | 483                    | 207                  |
| 51       | 99.9Cu                 | Forgings      | B283      | C11000  | ...                  | ...      | 31           | (14)      | -269               | 228                    | 76                   |
| 52       | 97Cu-3Si               | Forgings      | B283      | C65500  | ...                  | ...      | 33           | (14)      | -269               | 359                    | 124                  |
| 53       | 60Cu-38Zn-2Pb          | Forgings      | B283      | C37700  | ...                  | ...      | a            | (14)      | -198               | 400                    | 159                  |
| 54       | 60Cu-37Zn-2Pb-Sn       | Forgings      | B283      | C48500  | ...                  | ...      | a            | (14)      | -198               | 427                    | 165                  |
| 55       | 60Cu-39Zn-Sn           | Forgings      | B283      | C46400  | ...                  | ...      | 32           | (14)      | -254               | 441                    | 179                  |
| 56       | 59Cu-39Zn-Fe-Sn        | Forgings      | B283      | C67500  | ...                  | ...      | 32           | (14)      | -198               | 496                    | 234                  |
| 57       | 85Cu-5Sn-5Zn-5Pb       | Castings      | B62       | C83600  | ...                  | ...      | a            | (9)       | -198               | 207                    | 97                   |
| 58       | 57Cu-20Zn-12Ni-9Pb-2Sn | Castings      | B584      | C97300  | ...                  | ...      | a            | ...       | -198               | 207                    | 103                  |
| 59       | 64Cu-20Ni-8Zn-4Sn-4Pb  | Castings      | B584      | C97600  | ...                  | ...      | a            | ...       | -198               | 276                    | 117                  |
| 60       | 87Cu-8Sn-4Zn-1Pb       | Castings      | B584      | C92300  | ...                  | ...      | a            | ...       | -198               | 248                    | 110                  |
| 61       | 88Cu-Sn-Zn-Pb          | Castings      | B584      | C92200  | ...                  | ...      | a            | ...       | -198               | 234                    | 110                  |
| 62       | 88Cu-Sn-Zn-Pb          | Castings      | B61       | C92200  | ...                  | ...      | a            | (9)       | -198               | 234                    | 110                  |
| 63       | 88Cu-8Sn-4Zn           | Castings      | B584      | C90300  | ...                  | ...      | b            | ...       | -198               | 276                    | 124                  |
| 64       | 88Cu-10Sn-2Zn          | Castings      | B584      | C90500  | ...                  | ...      | b            | ...       | -198               | 276                    | 124                  |
| 65       | 58Cu-38Zn-1Sn-1Pb-1Fe  | Castings      | B584      | C86400  | ...                  | ...      | a            | (9)       | -198               | 414                    | 138                  |
| 66       | 66Cu-25Ni-5Sn-2Pb-2Zn  | Castings      | B584      | C97800  | ...                  | ...      | a            | ...       | -198               | 345                    | 152                  |
| 67       | 58Cu-39Zn-1Fe-1Al-1Mn  | Castings      | B584      | C86500  | ...                  | ...      | b            | ...       | -198               | 448                    | 172                  |
| 68       | 88Cu-9Al-3Fe           | Castings      | B148      | C95200  | ...                  | ...      | 35           | (9)       | -254               | 448                    | 172                  |
| 69       | 89Cu-10Al-1Fe          | Castings      | B148      | C95300  | ...                  | ...      | 35           | (9)       | -254               | 448                    | 172                  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|--------------------|-------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|          |                    | Min. Temp. to 40                                                              | 65   | 100  | 125  | 150  | 175  | 200  | 225  | 250  | 275  | 300  | 325  | 350  | 375  |
| 39       | 204                | 103                                                                           | 100  | 92.6 | 89.1 | 86.5 | 84.3 | 35.8 | 29.6 | ...  | ...  | ...  | ...  | ...  | ...  |
| 40       | 260                | 46.0                                                                          | 39.1 | 37.1 | 36.5 | 34.2 | 28.0 | 21.7 | 16.7 | 12.9 | 11.6 | ...  | ...  | ...  | ...  |
| 41       | 260                | 46.0                                                                          | 39.1 | 37.1 | 36.5 | 34.2 | 28.0 | 21.7 | 16.7 | 12.9 | 11.6 | ...  | ...  | ...  | ...  |
| 42       | 260                | 46.0                                                                          | 39.1 | 37.1 | 36.5 | 34.2 | 28.0 | 21.7 | 16.7 | 12.9 | 11.6 | ...  | ...  | ...  | ...  |
| 43       | 260                | 46.0                                                                          | 39.1 | 37.1 | 36.5 | 34.2 | 28.0 | 21.7 | 16.7 | 12.9 | 11.6 | ...  | ...  | ...  | ...  |
| 44       | 260                | 46.0                                                                          | 39.1 | 37.1 | 36.5 | 34.2 | 28.0 | 21.7 | 16.7 | 12.9 | 11.6 | ...  | ...  | ...  | ...  |
| 45       | 260                | 46.0                                                                          | 39.1 | 37.1 | 36.5 | 34.2 | 28.0 | 21.7 | 16.7 | 12.9 | 11.6 | ...  | ...  | ...  | ...  |
| 46       | 316                | 68.9                                                                          | 67.0 | 65.1 | 63.7 | 62.4 | 61.1 | 60.0 | 59.1 | 58.3 | 51.3 | 45.1 | 39.3 | ...  | ...  |
| 47       | 204                | 82.7                                                                          | 82.7 | 82.7 | 82.7 | 82.7 | 75.4 | 50.8 | 31.9 | ...  | ...  | ...  | ...  | ...  | ...  |
| 48       | 371                | 91.9                                                                          | 88.7 | 86.1 | 84.3 | 82.6 | 81.0 | 79.4 | 78.0 | 76.6 | 75.3 | 74.2 | 73.2 | 72.5 | 71.7 |
| 49       | 260                | 138                                                                           | 137  | 136  | 135  | 135  | 134  | 133  | 131  | 130  | 130  | ...  | ...  | ...  | ...  |
| 50       | 260                | 138                                                                           | 137  | 136  | 135  | 135  | 134  | 133  | 131  | 130  | 130  | ...  | ...  | ...  | ...  |
| 51       | 260                | 50.6                                                                          | 42.8 | 40.8 | 40.2 | 34.2 | 28.0 | 21.7 | 16.7 | 12.9 | 11.6 | ...  | ...  | ...  | ...  |
| 52       | 204                | 82.7                                                                          | 82.7 | 82.7 | 82.7 | 82.7 | 75.4 | 50.8 | 31.9 | ...  | ...  | ...  | ...  | ...  | ...  |
| 53       | 204                | 106                                                                           | 99.8 | 94.5 | 91.1 | 71.4 | 52.8 | 17.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  |
| 54       | 204                | 110                                                                           | 110  | 110  | 110  | 110  | 110  | 110  | 110  | ...  | ...  | ...  | ...  | ...  | ...  |
| 55       | 204                | 120                                                                           | 120  | 120  | 120  | 118  | 118  | 20.0 | 17.2 | ...  | ...  | ...  | ...  | ...  | ...  |
| 56       | 204                | 156                                                                           | 156  | 156  | 156  | 156  | 156  | 156  | 156  | ...  | ...  | ...  | ...  | ...  | ...  |
| 57       | 232                | 64.4                                                                          | 64.4 | 62.6 | 59.1 | 55.7 | 53.0 | 51.2 | 50.3 | 50.1 | ...  | ...  | ...  | ...  | ...  |
| 58       | 40                 | 68.9                                                                          | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 59       | 149                | 78.1                                                                          | 69.6 | 64.9 | 62.5 | 60.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 60       | 204                | 73.5                                                                          | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | ...  | ...  | ...  | ...  | ...  | ...  |
| 61       | 204                | 73.5                                                                          | 66.4 | 65.3 | 64.6 | 63.3 | 61.5 | 59.6 | 58.1 | ...  | ...  | ...  | ...  | ...  | ...  |
| 62       | 288                | 73.5                                                                          | 66.4 | 65.3 | 64.6 | 63.3 | 61.5 | 59.6 | 58.1 | 57.5 | 57.5 | 57.3 | ...  | ...  | ...  |
| 63       | 204                | 82.7                                                                          | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | ...  | ...  | ...  | ...  | ...  | ...  |
| 64       | 204                | 82.7                                                                          | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | 82.7 | ...  | ...  | ...  | ...  | ...  | ...  |
| 65       | 177                | 91.9                                                                          | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 66       | 177                | 101                                                                           | 101  | 101  | 101  | 101  | 101  | 101  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 67       | 177                | 115                                                                           | 115  | 115  | 115  | 115  | 115  | 115  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 68       | 316                | 115                                                                           | 108  | 104  | 102  | 99.8 | 98.6 | 97.8 | 97.5 | 97.4 | 97.4 | 65.9 | 43.7 | ...  | ...  |
| 69       | 316                | 115                                                                           | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition   | Product Form | Spec. No. | UNS No. | Class/Condition/ Temper | Size, mm | P-No. (5)(7) | Notes | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa |
|----------|-----------------------|--------------|-----------|---------|-------------------------|----------|--------------|-------|--------------------|------------------------|----------------------|
| 70       | 90Cu-7Al-3Si          | Castings     | B148      | C95600  | ...                     | ...      | 35           | ...   | -198               | 414                    | 193                  |
| 71       | 85Cu-11Al-4Fe         | Castings     | B148      | C95400  | ...                     | ...      | 35           | ...   | -198               | 517                    | 207                  |
| 72       | 58Cu-34Zn-2Fe-2Al-2Mn | Castings     | B584      | C86700  | ...                     | ...      | a            | ...   | -198               | 552                    | 221                  |
| 73       | 82Cu-11Al-4Fe-3Mn     | Castings     | B148      | C95500  | ...                     | ...      | 35           | ...   | -269               | 621                    | 276                  |
| 74       | 63Cu-27Zn-4Al-3Fe-3Mn | Castings     | B584      | C86200  | ...                     | ...      | b            | ...   | -198               | 621                    | 310                  |
| 75       | 61Cu-27Zn-6Al-3Fe-3Mn | Castings     | B584      | C86300  | ...                     | ...      | b            | ...   | -198               | 758                    | 414                  |
| 76       | 75Cu-21.5Zn-3Si       | Rod          | B371      | C69300  | H02                     | ≤12      | a            | ...   | -198               | 585                    | 310                  |
| 77       | 75Cu-21.5Zn-3Si       | Rod          | B371      | C69300  | H02                     | >12, ≤25 | a            | ...   | -198               | 515                    | 240                  |
| 78       | 75Cu-21.5Zn-3Si       | Rod          | B371      | C69300  | H02                     | >25, ≤50 | a            | ...   | -198               | 480                    | 205                  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Max. Use Temp., °C | Min. Temp. to 40 | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |     |     |     |     |      |     |     |     |     |
|----------|--------------------|------------------|-------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|
|          |                    |                  | 65                                                                            | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275  | 300 | 325 | 350 | 375 |
| 70       | 40                 | 129              | ...                                                                           | ... | ... | ... | ... | ... | ... | ... | ...  | ... | ... | ... | ... |
| 71       | 260                | 138              | 131                                                                           | 128 | 128 | 128 | 128 | 128 | 128 | 101 | 95.8 | ... | ... | ... | ... |
| 72       | 177                | 147              | 147                                                                           | 147 | 147 | 147 | 147 | 147 | ... | ... | ...  | ... | ... | ... | ... |
| 73       | 260                | 184              | 184                                                                           | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184  | ... | ... | ... | ... |
| 74       | 177                | 207              | 207                                                                           | 207 | 207 | 207 | 207 | 207 | ... | ... | ...  | ... | ... | ... | ... |
| 75       | 177                | 253              | 253                                                                           | 253 | 253 | 253 | 253 | 253 | ... | ... | ...  | ... | ... | ... | ... |
| 76       | 149                | 195              | 179                                                                           | 176 | 176 | 176 | ... | ... | ... | ... | ...  | ... | ... | ... | ... |
| 77       | 149                | 161              | 139                                                                           | 137 | 137 | 137 | ... | ... | ... | ... | ...  | ... | ... | ... | ... |
| 78       | 149                | 138              | 119                                                                           | 117 | 117 | 117 | ... | ... | ... | ... | ...  | ... | ... | ... | ... |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition   | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper        | Size, mm | P-No. (5) |
|----------|-----------------------|--------------|-----------|------------|---------|-----------------------------------|----------|-----------|
| 1        | 99.0Ni-Low C          | Pipe & tube  | B161      | ...        | N02201  | Annealed                          | >125     | 41        |
| 2        | 99.0Ni-Low C          | Pipe & tube  | B725      | ...        | N02201  | Annealed                          | >125     | 41        |
| 3        | 99.0Ni                | Pipe & tube  | B161      | ...        | N02200  | Annealed                          | >125     | 41        |
| 4        | 99.0Ni                | Pipe & tube  | B725      | ...        | N02200  | Annealed                          | >125     | 41        |
| 5        | 99.0Ni-Low C          | Pipe & tube  | B161      | ...        | N02201  | Annealed                          | ≤125     | 41        |
| 6        | 99.0Ni-Low C          | Pipe & tube  | B725      | ...        | N02201  | Annealed                          | ≤125     | 41        |
| 7        | 99.0Ni                | Pipe & tube  | B161      | ...        | N02200  | Annealed                          | ≤125     | 41        |
| 8        | 99.0Ni                | Pipe & tube  | B725      | ...        | N02200  | Annealed                          | ≤125     | 41        |
| 9        | 67Ni-30Cu             | Pipe & tube  | B165      | ...        | N04400  | Annealed                          | >125     | 42        |
| 10       | 67Ni-30Cu             | Pipe & tube  | B725      | ...        | N04400  | Annealed                          | >125     | 42        |
| 11       | 33Ni-42Fe-21Cr        | Pipe & tube  | B407      | ...        | N08800  | H.F. or H.F.<br>ann.              | ...      | 45        |
| 12       | 72Ni-15Cr-8Fe         | Pipe & tube  | B167      | ...        | N06600  | H.F. or H.F.<br>ann.              | >125     | 43        |
| 13       | 33Ni-42Fe-21Cr        | Pipe & tube  | B407      | ...        | N08810  | C.D. sol. ann.<br>or H.F.<br>ann. | ...      | 45        |
| 14       | 33Ni-42Fe-21Cr        | Pipe & tube  | B514      | ...        | N08810  | Annealed                          | ...      | 45        |
| 15       | 33Ni-42Fe-21Cr-Al-Ti  | Pipe & tube  | B407      | ...        | N08811  | C.D. sol. ann.<br>or H.F.<br>ann. | ...      | 45        |
| 16       | 67Ni-30Cu             | Pipe & tube  | B165      | ...        | N04400  | Annealed                          | ≤125     | 42        |
| 17       | 67Ni-30Cu             | Pipe & tube  | B725      | ...        | N04400  | Annealed                          | ≤125     | 42        |
| 18       | 26Ni-22Cr-5Mo-Ti      | Pipe & tube  | B619      | ...        | N08320  | Sol. ann.                         | ...      | 45        |
| 19       | 26Ni-22Cr-5Mo-Ti      | Pipe & tube  | B622      | ...        | N08320  | Sol. ann.                         | ...      | 45        |
| 20       | 99.0Ni-Low C          | Pipe & tube  | B161      | ...        | N02201  | Str. rel.                         | ...      | 41        |
| 21       | 99.0Ni-Low C          | Pipe & tube  | B725      | ...        | N02201  | Str. rel.                         | ...      | 41        |
| 22       | 33Ni-42Fe-21Cr        | Pipe & tube  | B514      | ...        | N08800  | Annealed                          | ...      | 45        |
| 23       | 72Ni-15Cr-8Fe         | Pipe & tube  | B167      | ...        | N06600  | H.F. or H.F.<br>ann.              | ≤125     | 43        |
| 24       | 72Ni-15Cr-8Fe         | Pipe & tube  | B167      | ...        | N06600  | C.D. ann.                         | >125     | 43        |
| 25       | 33Ni-42Fe-21Cr        | Pipe & tube  | B407      | ...        | N08800  | C.D. ann.                         | ...      | 45        |
| 26       | 31Ni-31Fe-29Cr-Mo     | Pipe & tube  | B668      | ...        | N08028  | Sol. ann.                         | ...      | 45        |
| 27       | 99.0Ni                | Pipe & tube  | B161      | ...        | N02200  | Str. rel.                         | ...      | 41        |
| 28       | 99.0Ni                | Pipe & tube  | B725      | ...        | N02200  | Str. rel.                         | ...      | 41        |
| 29       | 35Ni-35Fe-20Cr-Cb     | Pipe & tube  | B464      | ...        | N08020  | Annealed                          | ...      | 45        |
| 30       | 35Ni-35Fe-20Cr-Cb     | Pipe & tube  | B474      | ...        | N08020  | Annealed                          | ...      | 45        |
| 31       | 35Ni-35Fe-20Cr-Cb     | Pipe & tube  | B729      | ...        | N08020  | Annealed                          | ...      | 45        |
| 32       | 42Ni-21.5Cr-3Mo-2.3Cu | Smls. tube   | B163      | ...        | N08825  | Annealed                          | ...      | 45        |
| 33       | 42Ni-21.5Cr-3Mo-2.3Cu | Pipe & tube  | B423      | ...        | N08825  | C.D. ann.                         | ...      | 45        |
| 34       | 42Ni-21.5Cr-3Mo-2.3Cu | Pipe & tube  | B474      | ...        | N08825  | Annealed                          | ...      | 45        |
| 35       | 42Ni-21.5Cr-3Mo-2.3Cu | Wld. tube    | B704      | ...        | N08825  | Annealed                          | ...      | 45        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                        |                      |                    |                  |      |      |      |      |      |      |      |      |
|----------|-------|----------------------------------------------------------------------------------|------------------------|----------------------|--------------------|------------------|------|------|------|------|------|------|------|------|
|          |       | Min. Temp., °C (6)                                                               | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 |      |      |      |      |      |      |      |      |
|          |       |                                                                                  |                        |                      |                    |                  | 65   | 100  | 125  | 150  | 175  | 200  | 225  | 250  |
| 1        | ...   | -198                                                                             | 345                    | 69                   | 649                | 46.0             | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 2        | ...   | -198                                                                             | 345                    | 69                   | 649                | 46.0             | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 3        | ...   | -198                                                                             | 379                    | 83                   | 316                | 55.2             | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 |
| 4        | ...   | -198                                                                             | 379                    | 83                   | 316                | 55.2             | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 | 55.2 |
| 5        | ...   | -198                                                                             | 345                    | 83                   | 649                | 55.2             | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 6        | ...   | -198                                                                             | 345                    | 83                   | 649                | 55.2             | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 7        | ...   | -198                                                                             | 379                    | 103                  | 316                | 68.9             | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 8        | ...   | -198                                                                             | 379                    | 103                  | 316                | 68.9             | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 9        | ...   | -198                                                                             | 483                    | 172                  | 482                | 115              | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 10       | ...   | -198                                                                             | 483                    | 172                  | 482                | 115              | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 11       | ...   | -198                                                                             | 448                    | 172                  | 816                | 115              | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 12       | ...   | -198                                                                             | 517                    | 172                  | 649                | 115              | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 13       | (62)  | -198                                                                             | 448                    | 172                  | 899                | 115              | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 14       | (62)  | -198                                                                             | 448                    | 172                  | 899                | 115              | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 15       | (62)  | -198                                                                             | 448                    | 172                  | 899                | 115              | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 16       | ...   | -198                                                                             | 483                    | 193                  | 482                | 129              | 119  | 112  | 108  | 105  | 103  | 102  | 101  | 101  |
| 17       | ...   | -198                                                                             | 483                    | 193                  | 482                | 129              | 119  | 112  | 108  | 105  | 103  | 102  | 101  | 101  |
| 18       | ...   | -198                                                                             | 517                    | 193                  | 427                | 129              | 129  | 129  | 129  | 129  | 129  | 129  | 129  | 129  |
| 19       | ...   | -198                                                                             | 517                    | 193                  | 427                | 129              | 129  | 129  | 129  | 129  | 129  | 129  | 129  | 129  |
| 20       | ...   | -198                                                                             | 414                    | 207                  | 316                | 138              | 138  | 138  | 137  | 137  | 137  | 137  | 137  | 136  |
| 21       | ...   | -198                                                                             | 414                    | 207                  | 316                | 138              | 138  | 138  | 137  | 137  | 137  | 137  | 137  | 136  |
| 22       | ...   | -198                                                                             | 517                    | 207                  | 816                | 138              | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 23       | ...   | -198                                                                             | 552                    | 207                  | 649                | 138              | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 24       | ...   | -198                                                                             | 552                    | 207                  | 649                | 138              | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 25       | (61)  | -198                                                                             | 517                    | 207                  | 816                | 138              | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 26       | ...   | -198                                                                             | 505                    | 215                  | 454                | 143              | 143  | 143  | 143  | 143  | 143  | 143  | 143  | 143  |
| 27       | ...   | -198                                                                             | 448                    | 276                  | 316                | 149              | 149  | 149  | 149  | 149  | 149  | 149  | 149  | 148  |
| 28       | ...   | -198                                                                             | 448                    | 276                  | 316                | 149              | 149  | 149  | 149  | 149  | 149  | 149  | 149  | 148  |
| 29       | ...   | -198                                                                             | 552                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 30       | ...   | -198                                                                             | 552                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 31       | ...   | -198                                                                             | 552                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 32       | ...   | -198                                                                             | 585                    | 240                  | 538                | 161              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 33       | ...   | -198                                                                             | 585                    | 240                  | 538                | 161              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 34       | ...   | -198                                                                             | 585                    | 240                  | 538                | 161              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 35       | ...   | -198                                                                             | 585                    | 240                  | 538                | 161              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | 275                                                                                   | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  |
| 1        | 43.2                                                                                  | 43.2 | 43.1 | 42.9 | 42.6 | 42.1 | 41.5 | 40.7 | 33.1 | 27.4 | 22.8 | 18.7 | 15.6 |
| 2        | 43.2                                                                                  | 43.2 | 43.1 | 42.9 | 42.6 | 42.1 | 41.5 | 40.7 | 33.1 | 27.4 | 22.8 | 18.7 | 15.6 |
| 3        | 55.2                                                                                  | 55.2 | 55.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 4        | 55.2                                                                                  | 55.2 | 55.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 5        | 51.6                                                                                  | 51.6 | 51.6 | 51.5 | 51.2 | 50.7 | 49.9 | 41.4 | 33.1 | 27.4 | 22.8 | 18.7 | 15.6 |
| 6        | 51.6                                                                                  | 51.6 | 51.6 | 51.5 | 51.2 | 50.7 | 49.9 | 41.4 | 33.1 | 27.4 | 22.8 | 18.7 | 15.6 |
| 7        | 68.9                                                                                  | 68.9 | 68.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 8        | 68.9                                                                                  | 68.9 | 68.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 9        | 90.4                                                                                  | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 79.7 | 59.9 | 55.2 | ...  | ...  | ...  |
| 10       | 90.4                                                                                  | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 79.7 | 59.9 | 55.2 | ...  | ...  | ...  |
| 11       | 115                                                                                   | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 113  | 107  |
| 12       | 115                                                                                   | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 84.8 | 58.4 | 39.7 | 27.0 |
| 13       | 115                                                                                   | 115  | 113  | 110  | 108  | 106  | 104  | 102  | 100  | 98.6 | 97.1 | 95.7 | 91.8 |
| 14       | 115                                                                                   | 115  | 113  | 110  | 108  | 106  | 104  | 102  | 100  | 98.6 | 97.1 | 95.7 | 91.8 |
| 15       | 115                                                                                   | 115  | 113  | 110  | 108  | 106  | 104  | 102  | 100  | 98.6 | 97.1 | 95.7 | 92.5 |
| 16       | 101                                                                                   | 101  | 101  | 101  | 100  | 99.6 | 98.6 | 79.7 | 59.9 | 55.2 | ...  | ...  | ...  |
| 17       | 101                                                                                   | 101  | 101  | 101  | 100  | 99.6 | 98.6 | 79.7 | 59.9 | 55.2 | ...  | ...  | ...  |
| 18       | 129                                                                                   | 129  | 127  | 125  | 122  | 121  | 119  | 119  | ...  | ...  | ...  | ...  | ...  |
| 19       | 129                                                                                   | 129  | 127  | 125  | 122  | 121  | 119  | 119  | ...  | ...  | ...  | ...  | ...  |
| 20       | 135                                                                                   | 133  | 130  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 21       | 135                                                                                   | 133  | 130  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 22       | 138                                                                                   | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 136  | 107  |
| 23       | 138                                                                                   | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 84.8 | 58.4 | 39.7 | 27.0 |
| 24       | 138                                                                                   | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 84.8 | 58.4 | 39.7 | 27.0 |
| 25       | 138                                                                                   | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 136  | 107  |
| 26       | 140                                                                                   | 137  | 133  | 130  | 125  | 122  | 119  | 116  | 113  | ...  | ...  | ...  | ...  |
| 27       | 146                                                                                   | 144  | 141  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 28       | 146                                                                                   | 144  | 141  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 29       | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 157  | 156  | ...  | ...  | ...  | ...  | ...  |
| 30       | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 157  | 156  | ...  | ...  | ...  | ...  | ...  |
| 31       | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 157  | 156  | ...  | ...  | ...  | ...  | ...  |
| 32       | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 159  | 158  | 157  | 156  | 155  | 153  | ...  |
| 33       | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 159  | 158  | 157  | 156  | 155  | 153  | ...  |
| 34       | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 159  | 158  | 157  | 156  | 155  | 153  | ...  |
| 35       | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 159  | 158  | 157  | 156  | 155  | 153  | ...  |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | 600                                                                                   | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  | 850  | 875  | 900  |
| 1        | 12.9                                                                                  | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 2        | 12.9                                                                                  | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 3        | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 4        | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 5        | 12.9                                                                                  | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 6        | 12.9                                                                                  | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 7        | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 8        | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 9        | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 10       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 11       | 83.8                                                                                  | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ...  | ...  | ...  |
| 12       | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 13       | 75.7                                                                                  | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 14       | 75.7                                                                                  | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 15       | 84.5                                                                                  | 69.5 | 56.7 | 46.8 | 38.5 | 31.5 | 25.5 | 20.7 | 17.0 | 13.9 | 11.2 | 9.33 | 7.58 |
| 16       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 17       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 18       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 19       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 20       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 21       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 22       | 83.8                                                                                  | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ...  | ...  | ...  |
| 23       | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 24       | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 25       | 83.8                                                                                  | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ...  | ...  | ...  |
| 26       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 27       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 28       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 29       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 30       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 31       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 32       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 33       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 34       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 35       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition       | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/ Temper | Size, mm | P-No. (5) |
|----------|---------------------------|--------------|-----------|------------|---------|-------------------------|----------|-----------|
| 36       | 42Ni-21.5Cr-3Mo-2.3Cu     | Pipe & tube  | B705      | ...        | N08825  | Annealed                | ...      | 45        |
| 37       | 47Ni-22Cr-19Fe-6Mo        | Pipe & tube  | B619      | ...        | N06007  | Sol. ann.               | ...      | 45        |
| 38       | 47Ni-22Cr-19Fe-6Mo        | Pipe & tube  | B622      | ...        | N06007  | Sol. ann.               | ...      | 45        |
| 39       | 40Ni-29Cr-15Fe-5Mo        | Pipe & tube  | B619      | ...        | N06030  | Sol. ann.               | ...      | 45        |
| 40       | 40Ni-29Cr-15Fe-5Mo        | Pipe & tube  | B622      | ...        | N06030  | Sol. ann.               | ...      | 45        |
| 41       | 40Ni-29Cr-15Fe-5Mo        | Pipe & tube  | B626      | ...        | N06030  | Sol. ann.               | ...      | 45        |
| 42       | 72Ni-15Cr-8Fe             | Pipe & tube  | B167      | ...        | N06600  | C.D. ann.               | ≤125     | 43        |
| 43       | 72Ni-15Cr-8Fe             | Pipe & tube  | B517      | ...        | N06600  | C.D. ann.               | ...      | 43        |
| 44       | 58Ni-29Cr-9Fe             | Tube         | B163      | ...        | N06690  | Annealed                | ≤75      | 43        |
| 45       | 58Ni-29Cr-9Fe             | Pipe & tube  | B167      | ...        | N06690  | C.D. ann.               | ≤125     | 43        |
| 46       | 37Ni-33Fe-25Cr            | Pipe & tube  | B163      | ...        | N08120  | Sol. ann.               | ...      | 45        |
| 47       | 37Ni-33Fe-25Cr            | Pipe & tube  | B407      | ...        | N08120  | Sol. ann.               | ...      | 45        |
| 48       | 37Ni-33Fe-25Cr            | Pipe & tube  | B514      | ...        | N08120  | Sol. ann.               | ...      | 45        |
| 49       | 37Ni-33Fe-25Cr            | Pipe & tube  | B515      | ...        | N08120  | Sol. ann.               | ...      | 45        |
| 50       | 61Ni-16Mo-16Cr            | Pipe & tube  | B619      | ...        | N06455  | Sol. ann.               | ...      | 43        |
| 51       | 47Ni-22Cr-9Mo-18Fe        | Pipe & tube  | B619      | ...        | N06002  | Sol. ann.               | ...      | 43        |
| 52       | 47Ni-22Cr-9Mo-18Fe        | Pipe & tube  | B622      | ...        | N06002  | Sol. ann.               | ...      | 43        |
| 53       | 31Ni-33Fe-27Cr-6.5Mo-Cu-N | Pipe & tube  | B619      | ...        | N08031  | Annealed                | ...      | 45        |
| 54       | 31Ni-33Fe-27Cr-6.5Mo-Cu-N | Pipe & tube  | B622      | ...        | N08031  | Annealed                | ...      | 45        |
| 55       | 61Ni-16Mo-16Cr            | Pipe & tube  | B622      | ...        | N06455  | Sol. ann.               | ...      | 43        |
| 56       | 54Ni-16Mo-15Cr            | Pipe & tube  | B619      | ...        | N10276  | Sol. ann.               | ...      | 43        |
| 57       | 54Ni-16Mo-15Cr            | Pipe & tube  | B622      | ...        | N10276  | Sol. ann.               | ...      | 43        |
| 58       | 54Ni-16Mo-15Cr            | Pipe & tube  | B626      | ...        | N10276  | Sol. ann.               | ...      | 43        |
| 59       | 67Ni-30Cu                 | Pipe & tube  | B165      | ...        | N04400  | Str. rel.               | ...      | 42        |
| 60       | 67Ni-30Cu                 | Pipe & tube  | B725      | ...        | N04400  | Str. rel.               | ...      | 42        |
| 61       | 46Fe-24Ni-21Cr-6Mo-Cu-N   | Pipe & tube  | B675      | ...        | N08367  | Annealed                | >5       | 45        |
| 62       | 46Fe-24Ni-21Cr-6Mo-Cu-N   | Pipe & tube  | B690      | ...        | N08367  | Annealed                | >5       | 45        |
| 63       | 46Fe-24Ni-21Cr-6Mo-Cu-N   | Pipe & tube  | B804      | ...        | N08367  | Annealed                | >5       | 45        |
| 64       | 46Fe-24Ni-21Cr-6Mo-Cu-N   | Pipe & tube  | B675      | ...        | N08367  | Annealed                | ≤5       | 45        |
| 65       | 46Fe-24Ni-21Cr-6Mo-Cu-N   | Pipe & tube  | B690      | ...        | N08367  | Annealed                | ≤5       | 45        |
| 66       | 46Fe-24Ni-21Cr-6Mo-Cu-N   | Pipe & tube  | B804      | ...        | N08367  | Annealed                | ≤5       | 45        |
| 67       | 55Ni-21Cr-13.5Mo          | Pipe & tube  | B619      | ...        | N06022  | Sol. ann.               | ...      | 43        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                        |                      |                    |                  |     |     |     |     |     |     |     |     |
|----------|-------|----------------------------------------------------------------------------------|------------------------|----------------------|--------------------|------------------|-----|-----|-----|-----|-----|-----|-----|-----|
|          |       | Min. Temp., °C (6)                                                               | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 |     |     |     |     |     |     |     |     |
|          |       |                                                                                  |                        |                      |                    |                  | 65  | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
| 36       | ...   | -198                                                                             | 585                    | 240                  | 538                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 37       | ...   | -198                                                                             | 621                    | 241                  | 538                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 38       | ...   | -198                                                                             | 621                    | 241                  | 427                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 39       | ...   | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 157 | 154 |
| 40       | ...   | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 157 | 154 |
| 41       | ...   | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 157 | 154 |
| 42       | ...   | -198                                                                             | 552                    | 241                  | 649                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 43       | ...   | -198                                                                             | 552                    | 241                  | 649                | 161              | 161 | 161 | 161 | 161 | 161 | 161 | 161 | 161 |
| 44       | ...   | -198                                                                             | 586                    | 241                  | 482                | 160              | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 45       | ...   | -198                                                                             | 586                    | 240                  | 482                | 160              | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| 46       | ...   | -198                                                                             | 621                    | 276                  | 899                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 47       | ...   | -198                                                                             | 621                    | 276                  | 899                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 48       | ...   | -198                                                                             | 621                    | 276                  | 899                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 49       | ...   | -198                                                                             | 621                    | 276                  | 899                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 180 | 175 |
| 50       | ...   | -198                                                                             | 689                    | 276                  | 427                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |
| 51       | ...   | -198                                                                             | 689                    | 276                  | 816                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 178 |
| 52       | ...   | -198                                                                             | 689                    | 276                  | 816                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 178 |
| 53       | ...   | -198                                                                             | 648                    | 276                  | 427                | 184              | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 54       | ...   | -198                                                                             | 648                    | 276                  | 427                | 184              | 184 | 184 | 184 | 184 | 177 | 171 | 166 | 162 |
| 55       | ...   | -198                                                                             | 689                    | 276                  | 427                | 184              | 184 | 184 | 184 | 184 | 184 | 184 | 184 | 184 |
| 56       | ...   | -198                                                                             | 689                    | 283                  | 677                | 188              | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 57       | ...   | -198                                                                             | 689                    | 283                  | 677                | 188              | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 58       | ...   | -198                                                                             | 689                    | 283                  | 677                | 188              | 188 | 188 | 188 | 188 | 188 | 188 | 188 | 187 |
| 59       | (54)  | -198                                                                             | 586                    | 379                  | 260                | 195              | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 |
| 60       | (54)  | -198                                                                             | 586                    | 379                  | 260                | 195              | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 |
| 61       | ...   | -198                                                                             | 655                    | 310                  | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 | 195 | 192 |
| 62       | ...   | -198                                                                             | 655                    | 310                  | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 | 195 | 192 |
| 63       | ...   | -198                                                                             | 655                    | 310                  | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 | 195 | 192 |
| 64       | ...   | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 | 195 | 192 |
| 65       | ...   | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 | 195 | 192 |
| 66       | ...   | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207 | 207 | 206 | 202 | 198 | 195 | 192 |
| 67       | ...   | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207 | 207 | 207 | 207 | 207 | 204 | 202 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |     |             |             |             |             |     |             |             |             |             |
|----------|---------------------------------------------------------------------------------------|-----|-----|-----|-------------|-------------|-------------|-------------|-----|-------------|-------------|-------------|-------------|
|          | 275                                                                                   | 300 | 325 | 350 | 375         | 400         | 425         | 450         | 475 | 500         | 525         | 550         | 575         |
| 36       | 161                                                                                   | 161 | 161 | 161 | 161         | 160         | 159         | 158         | 157 | 156         | 155         | 153         | ...         |
| 37       | 160                                                                                   | 158 | 156 | 154 | 153         | 152         | 151         | 150         | 149 | <b>136</b>  | <b>132</b>  | <b>130</b>  | ...         |
| 38       | 160                                                                                   | 158 | 156 | 154 | 153         | 152         | 151         | 150         | ... | ...         | ...         | ...         | ...         |
| 39       | 151                                                                                   | 148 | 146 | 143 | 141         | 138         | 136         | 136         | ... | ...         | ...         | ...         | ...         |
| 40       | 151                                                                                   | 148 | 146 | 143 | 141         | 138         | 136         | 136         | ... | ...         | ...         | ...         | ...         |
| 41       | 151                                                                                   | 148 | 146 | 143 | 141         | 138         | 136         | 136         | ... | ...         | ...         | ...         | ...         |
| 42       | 161                                                                                   | 161 | 161 | 161 | 161         | 161         | 161         | 161         | 161 | <b>84.8</b> | <b>58.4</b> | <b>39.7</b> | <b>27.0</b> |
| 43       | 161                                                                                   | 161 | 161 | 161 | 161         | 161         | 161         | 161         | 161 | <b>84.8</b> | <b>58.4</b> | <b>39.7</b> | <b>27.0</b> |
| 44       | 160                                                                                   | 160 | 160 | 160 | 160         | 160         | 160         | 160         | 160 | 160         | ...         | ...         | ...         |
| 45       | 160                                                                                   | 160 | 160 | 160 | 160         | 160         | 160         | 160         | 160 | 160         | ...         | ...         | ...         |
| 46       | 170                                                                                   | 166 | 163 | 160 | 158         | 156         | 154         | 153         | 153 | 152         | 151         | 151         | 151         |
| 47       | 170                                                                                   | 166 | 163 | 160 | 158         | 156         | 154         | 153         | 153 | 152         | 151         | 151         | 151         |
| 48       | 170                                                                                   | 166 | 163 | 160 | 158         | 156         | 154         | 153         | 153 | 152         | 151         | 151         | 151         |
| 49       | 170                                                                                   | 166 | 163 | 160 | 158         | 156         | 154         | 153         | 153 | 152         | 151         | 151         | 151         |
| 50       | 184                                                                                   | 184 | 184 | 184 | 183         | 180         | 178         | 178         | ... | ...         | ...         | ...         | ...         |
| 51       | 173                                                                                   | 169 | 165 | 162 | 160         | 158         | 157         | 155         | 154 | <b>135</b>  | <b>134</b>  | <b>133</b>  | <b>129</b>  |
| 52       | 173                                                                                   | 169 | 165 | 162 | 160         | 158         | 157         | 155         | 154 | <b>135</b>  | <b>134</b>  | <b>133</b>  | <b>129</b>  |
| 53       | 158                                                                                   | 155 | 152 | 149 | <b>74.2</b> | <b>61.1</b> | <b>50.3</b> | <b>49.6</b> | ... | ...         | ...         | ...         | ...         |
| 54       | 158                                                                                   | 155 | 152 | 149 | <b>74.2</b> | <b>61.1</b> | <b>50.3</b> | <b>49.6</b> | ... | ...         | ...         | ...         | ...         |
| 55       | 184                                                                                   | 184 | 184 | 184 | 182         | 180         | 178         | 178         | ... | ...         | ...         | ...         | ...         |
| 56       | 183                                                                                   | 177 | 172 | 169 | 165         | 162         | 159         | 157         | 156 | 155         | 154         | <b>143</b>  | <b>118</b>  |
| 57       | 183                                                                                   | 177 | 172 | 169 | 165         | 162         | 159         | 157         | 156 | 155         | 154         | <b>143</b>  | <b>118</b>  |
| 58       | 183                                                                                   | 177 | 172 | 169 | 165         | 162         | 159         | 157         | 156 | 155         | 154         | <b>143</b>  | <b>118</b>  |
| 59       | 195                                                                                   | ... | ... | ... | ...         | ...         | ...         | ...         | ... | ...         | ...         | ...         | ...         |
| 60       | 195                                                                                   | ... | ... | ... | ...         | ...         | ...         | ...         | ... | ...         | ...         | ...         | ...         |
| 61       | 188                                                                                   | 183 | 179 | 176 | 173         | 170         | 168         | 167         | ... | ...         | ...         | ...         | ...         |
| 62       | 188                                                                                   | 183 | 179 | 176 | 173         | 170         | 168         | 167         | ... | ...         | ...         | ...         | ...         |
| 63       | 188                                                                                   | 183 | 179 | 176 | 173         | 170         | 168         | 167         | ... | ...         | ...         | ...         | ...         |
| 64       | 188                                                                                   | 183 | 179 | 176 | 173         | 170         | 168         | 167         | ... | ...         | ...         | ...         | ...         |
| 65       | 188                                                                                   | 183 | 179 | 176 | 173         | 170         | 168         | 167         | ... | ...         | ...         | ...         | ...         |
| 66       | 188                                                                                   | 183 | 179 | 176 | 173         | 170         | 168         | 167         | ... | ...         | ...         | ...         | ...         |
| 67       | 197                                                                                   | 193 | 189 | 185 | 182         | 180         | 177         | 177         | ... | ...         | ...         | ...         | ...         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |     |
|----------|---------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|-----|
|          | 600                                                                                   | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  | 850  | 875  | 900 |
| 36       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 37       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 38       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 39       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 40       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 41       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 42       | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 43       | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 44       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 45       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 46       | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 47       | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 48       | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 49       | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8 |
| 50       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 51       | 115                                                                                   | 94.2 | 77.3 | 64.9 | 54.7 | 44.7 | 36.1 | 29.2 | 23.6 | 20.7 | ...  | ...  | ... |
| 52       | 115                                                                                   | 94.2 | 77.3 | 64.9 | 54.7 | 44.7 | 36.1 | 29.2 | 23.6 | 20.7 | ...  | ...  | ... |
| 53       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 54       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 55       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 56       | 99.1                                                                                  | 81.6 | 67.0 | 54.6 | 42.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 57       | 99.1                                                                                  | 81.6 | 67.0 | 54.6 | 42.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 58       | 99.1                                                                                  | 81.6 | 67.0 | 54.6 | 42.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 59       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 60       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 61       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 62       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 63       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 64       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 65       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 66       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |
| 67       | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition          | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|------------------------------|--------------|-----------|------------|---------|----------------------------|----------|-----------|
| 68       | 55Ni-21Cr-13.5Mo             | Pipe & tube  | B622      | ...        | N06022  | Sol. ann.                  | ...      | 43        |
| 69       | 58Ni-33Cr-8Mo                | Pipe & tube  | B619      | ...        | N06035  | Sol. ann.                  | ...      | 43        |
| 70       | 58Ni-33Cr-8Mo                | Pipe & tube  | B622      | ...        | N06035  | Sol. ann.                  | ...      | 43        |
| 71       | 58Ni-33Cr-8Mo                | Pipe & tube  | B626      | ...        | N06035  | Sol. ann.                  | ...      | 43        |
| 72       | 59Ni-23Cr-16Mo               | Pipe & tube  | B619      | ...        | N06059  | Sol. ann.                  | ...      | 43        |
| 73       | 59Ni-23Cr-16Mo               | Pipe & tube  | B622      | ...        | N06059  | Sol. ann.                  | ...      | 43        |
| 74       | 59Ni-23Cr-16Mo               | Wld. tube    | B626      | ...        | N06059  | Sol. ann.                  | All      | 43        |
| 75       | 59Ni-23Cr-16Mo-1.6Cu         | Pipe & tube  | B619      | ...        | N06200  | Sol. ann.                  | All      | 43        |
| 76       | 59Ni-23Cr-16Mo-1.6Cu         | Pipe & tube  | B622      | ...        | N06200  | Sol. ann.                  | All      | 43        |
| 77       | 59Ni-23Cr-16Mo-1.6Cu         | Pipe & tube  | B626      | ...        | N06200  | Sol. ann.                  | All      | 43        |
| 78       | 62Ni-22Mo-15Cr               | Pipe & tube  | B619      | ...        | N10362  | Sol. ann.                  | All      | 43        |
| 79       | 62Ni-22Mo-15Cr               | Pipe & tube  | B622      | ...        | N10362  | Sol. ann.                  | All      | 43        |
| 80       | 62Ni-22Mo-15Cr               | Pipe & tube  | B626      | ...        | N10362  | Sol. ann.                  | All      | 43        |
| 81       | 62Ni-28Mo-5Fe                | Pipe & tube  | B619      | ...        | N10001  | Sol. ann.                  | ...      | 44        |
| 82       | 62Ni-28Mo-5Fe                | Pipe & tube  | B622      | ...        | N10001  | Sol. ann.                  | ...      | 44        |
| 83       | 65Ni-28Mo-2Fe                | Pipe & tube  | B619      | ...        | N10665  | Sol. ann.                  | ...      | 44        |
| 84       | 65Ni-28Mo-2Fe                | Pipe & tube  | B622      | ...        | N10665  | Sol. ann.                  | ...      | 44        |
| 85       | 65Ni-29.5Mo-2Fe-2Cr          | Pipe & tube  | B619      | ...        | N10675  | Sol. ann.                  | ...      | 44        |
| 86       | 65Ni-29.5Mo-2Fe-2Cr          | Pipe & tube  | B622      | ...        | N10675  | Sol. ann.                  | ...      | 44        |
| 87       | 65Ni-29.5Mo-2Fe-2Cr          | Pipe & tube  | B626      | ...        | N10675  | Sol. ann.                  | ...      | 44        |
| 88       | 60Ni-22Cr-9Mo-3.5Cb          | Pipe & tube  | B444      | 1          | N06625  | Annealed                   | ...      | 43        |
| 89       | 60Ni-22Cr-9Mo-3.5Cb          | Pipe & tube  | B705      | 1          | N06625  | Annealed                   | ...      | 43        |
| 90       | 57Ni-22Cr-14W-2Mo-La         | Pipe & tube  | B619      | ...        | N06230  | Sol. ann.                  | ...      | 43        |
| 91       | 57Ni-22Cr-14W-2Mo-La         | Pipe & tube  | B622      | ...        | N06230  | Sol. ann.                  | ...      | 43        |
| 92       | 57Ni-22Cr-14W-2Mo-La         | Pipe & tube  | B626      | ...        | N06230  | Sol. ann.                  | ...      | 43        |
| 93       | 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N | Pipe         | B619      | ...        | R20033  | Sol. ann.                  | ...      | 45        |
| 94       | 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N | Pipe & tube  | B622      | ...        | R20033  | Sol. ann.                  | ...      | 45        |
| 95       | 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N | Tube         | B626      | ...        | R20033  | Sol. ann.                  | ...      | 45        |
| 96       | 99.0Ni-Low C                 | Plate        | B162      | ...        | N02201  | H.R. ann.                  | ...      | 41        |
| 97       | 99.0Ni-Low C                 | Plate        | B162      | ...        | N02201  | H.R. as R.                 | ...      | 41        |
| 98       | 99.0Ni                       | Plate        | B162      | ...        | N02200  | H.R. ann.                  | ...      | 41        |
| 99       | 99.0Ni                       | Plate        | B162      | ...        | N02200  | H.R. as R.                 | ...      | 41        |
| 100      | 33Ni-42Fe-21Cr               | Pl. & sht.   | B409      | ...        | N08810  | Annealed                   | All      | 45        |
| 101      | 33Ni-42Fe-21Cr-Al-Ti         | Pl. & sht.   | B409      | ...        | N08811  | Annealed                   | All      | 45        |
| 102      | 26Ni-22Cr-5Mo-Ti             | Pl. & sht.   | B620      | ...        | N08320  | Sol. ann.                  | All      | 45        |
| 103      | 67Ni-30Cu                    | Plate        | B127      | ...        | N04400  | H.R. ann.                  | ...      | 42        |
| 104      | 47Ni-22Cr-19Fe-6Mo           | Pl. & sht.   | B582      | ...        | N06007  | Sol. ann.                  | >19      | 45        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes     | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                        |                      |                    |                  |      |      |      |      |      |      |      |      |
|----------|-----------|----------------------------------------------------------------------------------|------------------------|----------------------|--------------------|------------------|------|------|------|------|------|------|------|------|
|          |           | Min. Temp., °C (6)                                                               | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 |      |      |      |      |      |      |      |      |
|          |           |                                                                                  |                        |                      |                    |                  | 65   | 100  | 125  | 150  | 175  | 200  | 225  | 250  |
| 68       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 204  | 202  |
| 69       | ...       | -198                                                                             | 586                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | 154  | 149  | 144  |
| 70       | ...       | -198                                                                             | 586                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | 154  | 149  | 144  |
| 71       | ...       | -198                                                                             | 586                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | 154  | 149  | 144  |
| 72       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 206  |
| 73       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 206  |
| 74       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 206  |
| 75       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 200  |
| 76       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 200  |
| 77       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 200  |
| 78       | ...       | -198                                                                             | 725                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 204  | 202  | 199  |
| 79       | ...       | -198                                                                             | 725                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 204  | 202  | 199  |
| 80       | ...       | -198                                                                             | 725                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 204  | 202  | 199  |
| 81       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 82       | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 83       | ...       | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234  | 234  | 234  |
| 84       | ...       | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234  | 234  | 234  |
| 85       | ...       | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234  | 234  | 234  |
| 86       | ...       | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234  | 234  | 234  |
| 87       | ...       | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234  | 234  | 234  |
| 88       | (64) (70) | -198                                                                             | 827                    | 414                  | 649                | 276              | 276  | 276  | 274  | 273  | 272  | 270  | 269  | 267  |
| 89       | (64) (70) | -198                                                                             | 827                    | 414                  | 649                | 276              | 276  | 276  | 274  | 273  | 272  | 270  | 269  | 267  |
| 90       | ...       | -198                                                                             | 758                    | 310                  | 899                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 91       | ...       | -198                                                                             | 758                    | 310                  | 899                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 92       | ...       | -198                                                                             | 758                    | 310                  | 899                | 207              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 93       | ...       | -198                                                                             | 750                    | 380                  | 427                | 250              | 231  | 209  | 200  | 193  | 187  | 181  | 176  | 172  |
| 94       | ...       | -198                                                                             | 750                    | 380                  | 427                | 250              | 231  | 209  | 200  | 193  | 187  | 181  | 176  | 172  |
| 95       | ...       | -198                                                                             | 750                    | 380                  | 427                | 250              | 231  | 209  | 200  | 193  | 187  | 181  | 176  | 172  |
| 96       | ...       | -198                                                                             | 345                    | 83                   | 649                | 55.2             | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 97       | ...       | -198                                                                             | 345                    | 83                   | 649                | 55.2             | 53.8 | 52.8 | 52.3 | 51.9 | 51.7 | 51.6 | 51.6 | 51.6 |
| 98       | ...       | -198                                                                             | 379                    | 103                  | 316                | 68.9             | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 99       | ...       | -198                                                                             | 379                    | 138                  | 316                | 91.9             | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 | 91.9 |
| 100      | ...       | -198                                                                             | 448                    | 172                  | 899                | 115              | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 101      | ...       | -198                                                                             | 448                    | 172                  | 899                | 115              | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 102      | ...       | -198                                                                             | 517                    | 193                  | 427                | 129              | 129  | 129  | 129  | 129  | 129  | 129  | 129  | 129  |
| 103      | ...       | -198                                                                             | 483                    | 193                  | 482                | 129              | 119  | 112  | 108  | 105  | 103  | 102  | 101  | 101  |
| 104      | ...       | -198                                                                             | 586                    | 207                  | 538                | 138              | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |            |            |            |            |            |            |             |             |             |             |             |             |
|----------|---------------------------------------------------------------------------------------|------------|------------|------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|
|          | 275                                                                                   | 300        | 325        | 350        | 375        | 400        | 425        | 450         | 475         | 500         | 525         | 550         | 575         |
| 68       | 197                                                                                   | 193        | 189        | 185        | 182        | 180        | 177        | 177         | ...         | ...         | ...         | ...         | ...         |
| 69       | <b>140</b>                                                                            | <b>137</b> | <b>135</b> | <b>133</b> | <b>132</b> | <b>131</b> | <b>129</b> | <b>128</b>  | ...         | ...         | ...         | ...         | ...         |
| 70       | <b>140</b>                                                                            | <b>137</b> | <b>135</b> | <b>133</b> | <b>132</b> | <b>131</b> | <b>129</b> | <b>128</b>  | ...         | ...         | ...         | ...         | ...         |
| 71       | <b>140</b>                                                                            | <b>137</b> | <b>135</b> | <b>133</b> | <b>132</b> | <b>131</b> | <b>129</b> | <b>128</b>  | ...         | ...         | ...         | ...         | ...         |
| 72       | 202                                                                                   | 197        | 192        | 188        | 184        | 180        | 176        | 176         | ...         | ...         | ...         | ...         | ...         |
| 73       | 202                                                                                   | 197        | 192        | 188        | 184        | 180        | 176        | 176         | ...         | ...         | ...         | ...         | ...         |
| 74       | 202                                                                                   | 197        | 192        | 188        | 184        | 180        | 176        | 176         | ...         | ...         | ...         | ...         | ...         |
| 75       | <b>194</b>                                                                            | <b>188</b> | <b>184</b> | <b>180</b> | <b>177</b> | <b>175</b> | <b>174</b> | <b>173</b>  | ...         | ...         | ...         | ...         | ...         |
| 76       | <b>194</b>                                                                            | <b>188</b> | <b>184</b> | <b>180</b> | <b>177</b> | <b>175</b> | <b>174</b> | <b>173</b>  | ...         | ...         | ...         | ...         | ...         |
| 77       | <b>194</b>                                                                            | <b>188</b> | <b>184</b> | <b>180</b> | <b>177</b> | <b>175</b> | <b>174</b> | <b>173</b>  | ...         | ...         | ...         | ...         | ...         |
| 78       | 197                                                                                   | 193        | 190        | 188        | 186        | 184        | 182        | 180         | ...         | ...         | ...         | ...         | ...         |
| 79       | 197                                                                                   | 193        | 190        | 188        | 186        | 184        | 182        | 180         | ...         | ...         | ...         | ...         | ...         |
| 80       | 197                                                                                   | 193        | 190        | 188        | 186        | 184        | 182        | 180         | ...         | ...         | ...         | ...         | ...         |
| 81       | 207                                                                                   | 207        | 207        | 207        | 207        | 207        | 206        | 206         | ...         | ...         | ...         | ...         | ...         |
| 82       | 207                                                                                   | 207        | 207        | 207        | 207        | 207        | 206        | 206         | ...         | ...         | ...         | ...         | ...         |
| 83       | 234                                                                                   | 234        | 234        | 234        | 234        | 234        | 234        | 234         | ...         | ...         | ...         | ...         | ...         |
| 84       | 234                                                                                   | 234        | 234        | 234        | 234        | 234        | 234        | 234         | ...         | ...         | ...         | ...         | ...         |
| 85       | 234                                                                                   | 234        | 234        | 234        | 234        | <b>233</b> | <b>231</b> | <b>230</b>  | ...         | ...         | ...         | ...         | ...         |
| 86       | 234                                                                                   | 234        | 234        | 234        | 234        | <b>233</b> | <b>231</b> | <b>230</b>  | ...         | ...         | ...         | ...         | ...         |
| 87       | 234                                                                                   | 234        | 234        | 234        | 234        | <b>233</b> | <b>231</b> | <b>230</b>  | ...         | ...         | ...         | ...         | ...         |
| 88       | 265                                                                                   | 262        | 260        | 257        | 255        | 252        | 251        | 249         | 247         | 245         | 242         | <b>215</b>  | <b>194</b>  |
| 89       | 265                                                                                   | 262        | 260        | 257        | 255        | 252        | 251        | 249         | 247         | 245         | 242         | <b>215</b>  | <b>194</b>  |
| 90       | 207                                                                                   | 207        | 203        | 199        | 197        | 196        | 195        | 195         | 195         | 195         | 195         | 195         | 183         |
| 91       | 207                                                                                   | 207        | 203        | 199        | 197        | 196        | 195        | 195         | 195         | 195         | 195         | 195         | 183         |
| 92       | 207                                                                                   | 207        | 203        | 199        | 197        | 196        | 195        | 195         | 195         | 195         | 195         | 195         | 183         |
| 93       | 169                                                                                   | 165        | 163        | 161        | 159        | 157        | 156        | 155         | ...         | ...         | ...         | ...         | ...         |
| 94       | 169                                                                                   | 165        | 163        | 161        | 159        | 157        | 156        | 155         | ...         | ...         | ...         | ...         | ...         |
| 95       | 169                                                                                   | 165        | 163        | 161        | 159        | 157        | 156        | 155         | ...         | ...         | ...         | ...         | ...         |
| 96       | 51.6                                                                                  | 51.6       | 51.6       | 51.5       | 51.2       | 50.7       | 49.9       | <b>41.4</b> | <b>33.1</b> | <b>27.4</b> | <b>22.8</b> | <b>18.7</b> | <b>15.6</b> |
| 97       | 51.6                                                                                  | 51.6       | 51.6       | 51.5       | 51.2       | 50.7       | 49.9       | <b>41.4</b> | <b>33.1</b> | <b>27.4</b> | <b>22.8</b> | <b>18.7</b> | <b>15.6</b> |
| 98       | 68.9                                                                                  | 68.9       | 68.9       | ...        | ...        | ...        | ...        | ...         | ...         | ...         | ...         | ...         | ...         |
| 99       | 91.9                                                                                  | 91.9       | 91.9       | ...        | ...        | ...        | ...        | ...         | ...         | ...         | ...         | ...         | ...         |
| 100      | 115                                                                                   | 115        | 113        | 110        | 108        | 105        | 104        | 102         | 100         | 98.6        | 97.1        | 95.9        | <b>91.8</b> |
| 101      | 115                                                                                   | 115        | 113        | 110        | 108        | 105        | 104        | 102         | 100         | 98.6        | 97.1        | 96.1        | <b>94.1</b> |
| 102      | 129                                                                                   | 129        | 127        | 125        | 122        | 121        | 119        | 119         | ...         | ...         | ...         | ...         | ...         |
| 103      | 101                                                                                   | 101        | 101        | 101        | 100        | 99.6       | 98.6       | <b>79.7</b> | <b>59.9</b> | <b>55.2</b> | ...         | ...         | ...         |
| 104      | 138                                                                                   | 135        | 134        | 132        | 131        | 130        | 129        | 128         | 128         | 127         | 127         | 126         | ...         |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, $S$ , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|----------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | 600                                                                              | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  | 850  | 875  | 900  |
| 68       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 69       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 70       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 71       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 72       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 73       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 74       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 75       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 76       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 77       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 78       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 79       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 80       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 81       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 82       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 83       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 84       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 85       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 86       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 87       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 88       | 156                                                                              | 136  | 91.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 89       | 156                                                                              | 136  | 91.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 90       | 153                                                                              | 128  | 107  | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 91       | 153                                                                              | 128  | 107  | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 92       | 153                                                                              | 128  | 107  | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 93       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 94       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 95       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 96       | 12.9                                                                             | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 97       | 12.9                                                                             | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 98       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 99       | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 100      | 75.7                                                                             | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 101      | 85.5                                                                             | 69.3 | 56.8 | 46.8 | 38.6 | 31.5 | 25.5 | 20.6 | 17.1 | 13.8 | 10.7 | 7.98 | 6.20 |
| 102      | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 103      | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 104      | ...                                                                              | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition              | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|----------------------------------|--------------|-----------|------------|---------|----------------------------|----------|-----------|
| 105      | 33Ni-42Fe-21Cr                   | Pl. & sht.   | B409      | ...        | N08800  | Annealed                   | All      | 45        |
| 106      | 31Ni-31Fe-29Cr-Mo                | Pl. & sht.   | B709      | ...        | N08028  | Sol. ann.                  | All      | 45        |
| 107      | 42Ni-21.5Cr-3Mo-2.3Cu            | Plate        | B424      | ...        | N08825  | Annealed                   | ...      | 45        |
| 108      | 35Ni-35Fe-20Cr-Cb                | Pl. & sht.   | B463      | ...        | N08020  | Annealed                   | All      | 45        |
| 109      | 40Ni-29Cr-15Fe-5Mo               | Pl. & sht.   | B582      | ...        | N06030  | Sol. ann.                  | All      | 45        |
| 110      | 47Ni-22Cr-19Fe-6Mo               | Pl. & sht.   | B582      | ...        | N06007  | Sol. ann.                  | ≤19      | 45        |
| 111      | 47Ni-22Cr-9Mo-18Fe               | Pl. & sht.   | B435      | ...        | N06002  | H.R sol. ann.              | All      | 43        |
| 112      | 72Ni-15Cr-8Fe                    | Plate        | B168      | ...        | N06600  | H.R. ann.                  | ...      | 43        |
| 113      | 72Ni-15Cr-8Fe                    | Plate        | B168      | ...        | N06600  | H.R. as R.                 | ...      | 43        |
| 114      | 58Ni-29Cr-9Fe                    | Plate        | B168      | ...        | N06690  | Annealed                   | ≥5       | 43        |
| 115      | 58Ni-29Cr-9Fe                    | Sheet        | B168      | ...        | N06690  | H.R. ann. or<br>C.R. ann.  | 0.5 to 6 | 43        |
| 116      | 67Ni-30Cu                        | Plate        | B127      | ...        | N04400  | H.R. as R.                 | ...      | 42        |
| 117      | 37Ni-33Fe-25Cr                   | Pl. & sht.   | B409      | ...        | N08120  | Sol. ann.                  | All      | 45        |
| 118      | 31Ni-33Fe-27Cr-6.5Mo-<br>Cu-N    | Pl. & sht.   | B625      | ...        | N08031  | Annealed                   | All      | 45        |
| 119      | 61Ni-16Mo-16Cr                   | Pl. & sht.   | B575      | ...        | N06455  | Sol. ann.                  | All      | 43        |
| 120      | 54Ni-16Mo-15Cr                   | Pl. & sht.   | B575      | ...        | N10276  | Sol. ann.                  | All      | 43        |
| 121      | 60Ni-22Cr-9Mo-3.5Cb              | Plate        | B443      | 1          | N06625  | Annealed                   | All      | 43        |
| 122      | 57Ni-22Cr-14W-2Mo-La             | Pl. & sht.   | B435      | ...        | N06230  | Sol. ann.                  | All      | 43        |
| 123      | 55Ni-21Cr-13.5Mo                 | Sheet        | B575      | ...        | N06022  | Sol. ann.                  | <5       | 43        |
| 124      | 58Ni-33Cr-8Mo                    | Pl. & sht.   | B575      | ...        | N06035  | Sol. ann.                  | All      | 43        |
| 125      | 46Fe-24Ni-21Cr-6Mo-<br>Cu-N      | Pl. & sht.   | B688      | ...        | N08367  | Annealed                   | >5       | 45        |
| 126      | 46Fe-24Ni-21Cr-6Mo-<br>Cu-N      | Pl. & sht.   | B688      | ...        | N08367  | Annealed                   | ≤5       | 45        |
| 127      | 59Ni-23Cr-16Mo                   | Pl. & sht.   | B575      | ...        | N06059  | Sol. ann.                  | All      | 43        |
| 128      | 59Ni-23Cr-16Mo-1.6Cu             | Pl. & sht.   | B575      | ...        | N06200  | Sol. ann.                  | All      | 43        |
| 129      | 62Ni-22Mo-15Cr                   | Pl. & sht.   | B575      | ...        | N10362  | Sol. ann.                  | All      | 43        |
| 130      | 62Ni-28Mo-5Fe                    | Plate        | B333      | ...        | N10001  | Sol. ann.                  | ≥5, ≤64  | 44        |
| 131      | 62Ni-28Mo-5Fe                    | Sheet        | B333      | ...        | N10001  | Sol. ann.                  | ≤5       | 44        |
| 132      | 65Ni-28Mo-2Fe                    | Pl. & sht.   | B333      | ...        | N10665  | Sol. ann.                  | All      | 44        |
| 133      | 65Ni-29.5Mo-2Fe-2Cr              | Pl. & sht.   | B333      | ...        | N10675  | Sol. ann.                  | All      | 44        |
| 134      | 33Cr-31Ni-32Fe-1.5Mo-<br>0.6Cu-N | Pl. & sht.   | B625      | ...        | R20033  | Sol. ann.                  | ...      | 45        |
| 135      | 99.0Ni-Low C                     | Forg. & ftg. | B160      | ...        | N02201  | Annealed                   | All      | 41        |
| 136      | 99.0Ni-Low C                     | Forg. & ftg. | B366      | ...        | N02201  | Annealed                   | All      | 41        |
| 137      | 99.0Ni                           | Forg. & ftg. | B366      | ...        | N02200  | Annealed                   | All      | 41        |
| 138      | 99.0Ni                           | Forg. & ftg. | B564      | ...        | N02200  | Annealed                   | All      | 41        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes     | Min. Temp., °C (6) | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |      |      |      |      |      |      |      |      |
|----------|-----------|--------------------|------------------------|----------------------|--------------------|----------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|
|          |           |                    |                        |                      |                    | Min. Temp. to 40                                                                 | 65   | 100  | 125  | 150  | 175  | 200  | 225  | 250  |
| 105      | ...       | -198               | 517                    | 207                  | 816                | 138                                                                              | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 106      | ...       | -198               | 505                    | 215                  | 454                | 143                                                                              | 143  | 143  | 143  | 143  | 143  | 143  | 143  | 143  |
| 107      | (9)       | -198               | 585                    | 240                  | 538                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 108      | ...       | -198               | 552                    | 241                  | 427                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 109      | ...       | -198               | 586                    | 241                  | 427                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 161  | 157  | 154  |
| 110      | ...       | -198               | 621                    | 241                  | 538                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 111      | ...       | -198               | 655                    | 241                  | 427                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 156  |
| 112      | ...       | -198               | 552                    | 241                  | 649                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 113      | ...       | -198               | 586                    | 241                  | 649                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 114      | ...       | -198               | 586                    | 240                  | 482                | 160                                                                              | 160  | 160  | 160  | 160  | 160  | 160  | 160  | 160  |
| 115      | ...       | -198               | 586                    | 240                  | 482                | 160                                                                              | 160  | 160  | 160  | 160  | 160  | 160  | 160  | 160  |
| 116      | ...       | -198               | 517                    | 276                  | 482                | 172                                                                              | 172  | 172  | 171  | 170  | 168  | 165  | 164  | 162  |
| 117      | ...       | -198               | 621                    | 276                  | 899                | 184                                                                              | 184  | 184  | 184  | 184  | 184  | 184  | 180  | 175  |
| 118      | ...       | -198               | 648                    | 276                  | 427                | 184                                                                              | 184  | 184  | 184  | 184  | 177  | 171  | 166  | 162  |
| 119      | ...       | -198               | 689                    | 276                  | 427                | 184                                                                              | 184  | 184  | 184  | 184  | 184  | 184  | 184  | 184  |
| 120      | ...       | -198               | 689                    | 283                  | 677                | 188                                                                              | 188  | 188  | 188  | 188  | 188  | 188  | 188  | 187  |
| 121      | (64) (70) | -198               | 758                    | 379                  | 649                | 253                                                                              | 253  | 253  | 251  | 250  | 249  | 248  | 247  | 245  |
| 122      | ...       | -198               | 758                    | 310                  | 899                | 207                                                                              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 123      | ...       | -198               | 689                    | 310                  | 427                | 207                                                                              | 207  | 207  | 207  | 207  | 207  | 207  | 204  | 202  |
| 124      | ...       | -198               | 586                    | 241                  | 427                | 161                                                                              | 161  | 161  | 161  | 161  | 161  | 154  | 149  | 144  |
| 125      | ...       | -198               | 655                    | 310                  | 427                | 207                                                                              | 207  | 207  | 207  | 206  | 202  | 198  | 195  | 192  |
| 126      | ...       | -198               | 689                    | 310                  | 427                | 207                                                                              | 207  | 207  | 207  | 207  | 207  | 206  | 199  | 193  |
| 127      | ...       | -198               | 689                    | 310                  | 427                | 207                                                                              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 206  |
| 128      | ...       | -198               | 689                    | 310                  | 427                | 207                                                                              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 200  |
| 129      | ...       | -198               | 725                    | 310                  | 427                | 207                                                                              | 207  | 207  | 207  | 207  | 207  | 204  | 202  | 199  |
| 130      | ...       | -198               | 689                    | 310                  | 427                | 207                                                                              | 207  | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 131      | ...       | -198               | 793                    | 345                  | 427                | 230                                                                              | 230  | 230  | 230  | 230  | 230  | 230  | 230  | 230  |
| 132      | ...       | -198               | 758                    | 352                  | 427                | 234                                                                              | 234  | 234  | 234  | 234  | 234  | 234  | 234  | 234  |
| 133      | ...       | -198               | 758                    | 352                  | 427                | 234                                                                              | 234  | 234  | 234  | 234  | 234  | 234  | 234  | 234  |
| 134      | ...       | -198               | 750                    | 380                  | 427                | 250                                                                              | 231  | 209  | 200  | 193  | 187  | 181  | 176  | 172  |
| 135      | (9) (9a)  | -198               | 345                    | 69                   | 649                | 46.0                                                                             | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 136      | (32) (74) | -198               | 345                    | 69                   | 649                | 46.0                                                                             | 44.7 | 43.9 | 43.6 | 43.3 | 43.2 | 43.2 | 43.2 | 43.2 |
| 137      | (32) (74) | -198               | 380                    | 105                  | 260                | 70.0                                                                             | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 |
| 138      | (9)       | -198               | 379                    | 103                  | 316                | 68.9                                                                             | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, $S$ , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |            |            |            |            |            |            |             |             |             |             |             |             |
|----------|----------------------------------------------------------------------------------|------------|------------|------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|
|          | 275                                                                              | 300        | 325        | 350        | 375        | 400        | 425        | 450         | 475         | 500         | 525         | 550         | 575         |
| 105      | 138                                                                              | 138        | 138        | 138        | 138        | 138        | 138        | 138         | 138         | 138         | 138         | 136         | <b>107</b>  |
| 106      | <b>140</b>                                                                       | <b>137</b> | <b>133</b> | <b>130</b> | <b>125</b> | <b>122</b> | <b>119</b> | <b>116</b>  | <b>113</b>  | ...         | ...         | ...         | ...         |
| 107      | 161                                                                              | 161        | 161        | 161        | 161        | 160        | 159        | 158         | 157         | 156         | 155         | 153         | ...         |
| 108      | 161                                                                              | 161        | 161        | 161        | 161        | 160        | 157        | 156         | ...         | ...         | ...         | ...         | ...         |
| 109      | <b>151</b>                                                                       | <b>148</b> | <b>146</b> | <b>143</b> | <b>141</b> | <b>138</b> | <b>136</b> | <b>136</b>  | ...         | ...         | ...         | ...         | ...         |
| 110      | 160                                                                              | 158        | 156        | 154        | 153        | 152        | 151        | 150         | 149         | <b>136</b>  | <b>132</b>  | <b>130</b>  | ...         |
| 111      | 152                                                                              | 148        | 145        | 142        | 140        | 138        | 137        | 137         | ...         | ...         | ...         | ...         | ...         |
| 112      | 161                                                                              | 161        | 161        | 161        | 161        | 161        | 161        | 161         | 161         | <b>84.8</b> | <b>58.4</b> | <b>39.7</b> | <b>27.0</b> |
| 113      | 161                                                                              | 161        | 161        | 161        | 161        | 161        | 161        | 161         | 161         | <b>84.8</b> | <b>58.4</b> | <b>39.7</b> | <b>27.0</b> |
| 114      | 160                                                                              | 160        | 160        | 160        | 160        | 160        | 160        | 160         | 160         | 160         | ...         | ...         | ...         |
| 115      | 160                                                                              | 160        | 160        | 160        | 160        | 160        | 160        | 160         | 160         | 160         | ...         | ...         | ...         |
| 116      | 161                                                                              | 160        | 159        | 158        | 156        | <b>136</b> | <b>102</b> | <b>63.8</b> | <b>33.5</b> | <b>27.6</b> | ...         | ...         | ...         |
| 117      | 170                                                                              | 166        | 163        | 160        | 158        | 156        | 154        | 153         | 153         | 152         | 151         | 151         | 151         |
| 118      | 158                                                                              | 155        | 152        | 149        | 146        | 144        | 141        | 140         | ...         | ...         | ...         | ...         | ...         |
| 119      | 184                                                                              | 184        | 184        | 184        | 182        | 180        | 178        | 176         | ...         | ...         | ...         | ...         | ...         |
| 120      | 183                                                                              | 177        | 172        | 169        | 165        | 162        | 159        | 157         | 156         | 155         | 154         | <b>143</b>  | <b>118</b>  |
| 121      | <b>243</b>                                                                       | <b>241</b> | <b>238</b> | <b>236</b> | <b>233</b> | <b>231</b> | <b>230</b> | <b>228</b>  | <b>227</b>  | <b>225</b>  | <b>222</b>  | <b>215</b>  | <b>194</b>  |
| 122      | 207                                                                              | 207        | 203        | 199        | 197        | 196        | 195        | 195         | 195         | 195         | 195         | 195         | 183         |
| 123      | 197                                                                              | 193        | 189        | 185        | 182        | 180        | 177        | 177         | ...         | ...         | ...         | ...         | ...         |
| 124      | <b>140</b>                                                                       | <b>137</b> | <b>135</b> | <b>133</b> | <b>132</b> | <b>131</b> | <b>129</b> | <b>128</b>  | ...         | ...         | ...         | ...         | ...         |
| 125      | 188                                                                              | 183        | 179        | 176        | 173        | 170        | 168        | 167         | ...         | ...         | ...         | ...         | ...         |
| 126      | 188                                                                              | 183        | 179        | 176        | 173        | 170        | 168        | 167         | ...         | ...         | ...         | ...         | ...         |
| 127      | 202                                                                              | 197        | 192        | 188        | 184        | 180        | 176        | 176         | ...         | ...         | ...         | ...         | ...         |
| 128      | <b>194</b>                                                                       | <b>188</b> | <b>184</b> | <b>180</b> | <b>177</b> | <b>175</b> | <b>174</b> | <b>173</b>  | ...         | ...         | ...         | ...         | ...         |
| 129      | 197                                                                              | 193        | 190        | 188        | 186        | 184        | 182        | 180         | ...         | ...         | ...         | ...         | ...         |
| 130      | 207                                                                              | 207        | 207        | 207        | 207        | 207        | 206        | 206         | ...         | ...         | ...         | ...         | ...         |
| 131      | 230                                                                              | 230        | 230        | 230        | 230        | 230        | 229        | 229         | ...         | ...         | ...         | ...         | ...         |
| 132      | 234                                                                              | 234        | 234        | 234        | 234        | 234        | 234        | 234         | ...         | ...         | ...         | ...         | ...         |
| 133      | <b>234</b>                                                                       | <b>234</b> | <b>234</b> | <b>234</b> | <b>234</b> | <b>233</b> | <b>231</b> | <b>230</b>  | ...         | ...         | ...         | ...         | ...         |
| 134      | 169                                                                              | 165        | 163        | 161        | 159        | 157        | 156        | 155         | ...         | ...         | ...         | ...         | ...         |
| 135      | 43.2                                                                             | 43.2       | 43.1       | 42.9       | 42.6       | 42.1       | 41.5       | 40.7        | <b>33.1</b> | <b>27.4</b> | <b>22.8</b> | <b>18.7</b> | <b>15.6</b> |
| 136      | 43.2                                                                             | 43.2       | 43.1       | 42.9       | 42.6       | 42.1       | 41.5       | 40.7        | <b>33.1</b> | <b>27.4</b> | <b>22.8</b> | <b>18.7</b> | <b>15.6</b> |
| 137      | 70.0                                                                             | ...        | ...        | ...        | ...        | ...        | ...        | ...         | ...         | ...         | ...         | ...         | ...         |
| 138      | 68.9                                                                             | 68.9       | 68.9       | ...        | ...        | ...        | ...        | ...         | ...         | ...         | ...         | ...         | ...         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | 600                                                                                   | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  | 850  | 875  | 900  |
| 105      | 83.8                                                                                  | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ...  | ...  | ...  |
| 106      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 107      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 108      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 109      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 110      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 111      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 112      | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 113      | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 114      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 115      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 116      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 117      | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8  |
| 118      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 119      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 120      | 99.1                                                                                  | 81.6 | 67.0 | 54.6 | 42.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 121      | 156                                                                                   | 136  | 91.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 122      | 153                                                                                   | 128  | 107  | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 123      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 124      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 125      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 126      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 127      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 128      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 129      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 130      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 131      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 132      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 133      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 134      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 135      | 12.9                                                                                  | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 136      | 12.9                                                                                  | 10.0 | 8.27 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 137      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 138      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition       | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|---------------------------|--------------|-----------|------------|---------|----------------------------|----------|-----------|
| 139      | 33Ni-42Fe-21Cr            | Forg. & ftg. | B564      | ...        | N08810  | Annealed                   | ...      | 45        |
| 140      | 33Ni-42Fe-21Cr-Al-Ti      | Forg. & ftg. | B564      | ...        | N08811  | Annealed                   | ...      | 45        |
| 141      | 33Ni-42Fe-21Cr            | Fittings     | B366      | ...        | N08810  | Annealed                   | All      | 45        |
| 142      | 33Ni-42Fe-21Cr-Al-Ti      | Fittings     | B366      | ...        | N08811  | Annealed                   | All      | 45        |
| 143      | 67Ni-30Cu                 | Forg. & ftg. | B564      | ...        | N04400  | Annealed                   | ...      | 42        |
| 144      | 67Ni-30Cu                 | Forg. & ftg. | B366      | ...        | N04400  | Annealed                   | All      | 42        |
| 145      | 72Ni-15Cr-8Fe             | Forg. & ftg. | B366      | ...        | N06600  | Annealed                   | All      | 43        |
| 146      | 40Ni-29Cr-15Fe-5Mo        | Forg. & ftg. | B366      | ...        | N06030  | Sol. ann.                  | All      | 45        |
| 147      | 40Ni-29Cr-15Fe-5Mo        | Forg. & ftg. | B462      | ...        | N06030  | Sol. ann.                  | All      | 45        |
| 148      | 33Ni-42Fe-21Cr            | Forg. & ftg. | B366      | ...        | N08800  | C.D. ann.                  | All      | 45        |
| 149      | 33Ni-42Fe-21Cr            | Forg. & ftg. | B564      | ...        | N08800  | Annealed                   | ...      | 45        |
| 150      | 35Ni-35Fe-20Cr-Cb         | Forg. & ftg. | B366      | ...        | N08020  | Annealed                   | All      | 45        |
| 151      | 35Ni-35Fe-20Cr-Cb         | Forg. & ftg. | B462      | ...        | N08020  | Annealed                   | ...      | 45        |
| 152      | 72Ni-15Cr-8Fe             | Forg. & ftg. | B564      | ...        | N06600  | Annealed                   | All      | 43        |
| 153      | 42Ni-21.5Cr-3Mo-2.3Cu     | Fittings     | B366      | ...        | N08825  | C.D. ann.                  | All      | 45        |
| 154      | 42Ni-21.5Cr-3Mo-2.3Cu     | Forgings     | B564      | ...        | N08825  | Annealed                   | ...      | 45        |
| 155      | 58Ni-29Cr-9Fe             | Forgings     | B564      | ...        | N06690  | Annealed                   | All      | 43        |
| 156      | 37Ni-33Fe-25Cr            | Fittings     | B366      | ...        | N08120  | Sol. ann.                  | All      | 45        |
| 157      | 37Ni-33Fe-25Cr            | Forgings     | B564      | ...        | N08120  | Sol. ann.                  | All      | 45        |
| 158      | 47Ni-22Cr-9Mo-18Fe        | Forg. & ftg. | B366      | ...        | N06002  | Sol. ann.                  | All      | 43        |
| 159      | 31Ni-33Fe-27Cr-6.5Mo-Cu-N | Forg. & ftg. | B366      | ...        | N08031  | Sol. ann.                  | All      | 45        |
| 160      | 31Ni-33Fe-27Cr-6.5Mo-Cu-N | Forg. & ftg. | B564      | ...        | N08031  | Annealed H.W.              | All      | 45        |
| 161      | 54Ni-16Mo-15Cr            | Forg. & ftg. | B366      | ...        | N10276  | Sol. ann.                  | All      | 43        |
| 162      | 54Ni-16Mo-15Cr            | Forg. & ftg. | B462      | ...        | N10276  | Sol. ann.                  | All      | 43        |
| 163      | 54Ni-16Mo-15Cr            | Forg. & ftg. | B564      | ...        | N10276  | Sol. ann.                  | All      | 43        |
| 164      | 62Ni-28Mo-5Fe             | Forg. & ftg. | B366      | ...        | N10001  | Sol. ann.                  | All      | 44        |
| 165      | 55Ni-21Cr-13.5Mo          | Forg. & ftg. | B366      | ...        | N06022  | Sol. ann.                  | All      | 43        |
| 166      | 55Ni-21Cr-13.5Mo          | Forg. & ftg. | B462      | ...        | N06022  | Sol. ann.                  | All      | 43        |
| 167      | 55Ni-21Cr-13.5Mo          | Forg. & ftg. | B564      | ...        | N06022  | Sol. ann.                  | All      | 43        |
| 168      | 58Ni-33Cr-8Mo             | Forg. & ftg. | B366      | ...        | N06035  | Sol. ann.                  | All      | 43        |
| 169      | 58Ni-33Cr-8Mo             | Forg. & ftg. | B462      | ...        | N06035  | Sol. ann.                  | All      | 43        |
| 170      | 58Ni-33Cr-8Mo             | Forg. & ftg. | B564      | ...        | N06035  | Sol. ann.                  | All      | 43        |
| 171      | 59Ni-23Cr-16Mo            | Forg. & ftg. | B366      | ...        | N06059  | Sol. ann.                  | All      | 43        |
| 172      | 59Ni-23Cr-16Mo            | Forg. & ftg. | B564      | ...        | N06059  | H.W. sol. ann.             | All      | 43        |
| 173      | 59Ni-23Cr-16Mo-1.6Cu      | Forg. & ftg. | B366      | ...        | N06200  | Sol. ann.                  | All      | 43        |
| 174      | 59Ni-23Cr-16Mo-1.6Cu      | Forg. & ftg. | B462      | ...        | N06200  | Sol. ann.                  | All      | 43        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes     | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                        |                      |                    |                  |     |      |      |      |      |      |      |      |
|----------|-----------|----------------------------------------------------------------------------------|------------------------|----------------------|--------------------|------------------|-----|------|------|------|------|------|------|------|
|          |           | Min. Temp., °C (6)                                                               | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 |     |      |      |      |      |      |      |      |
|          |           |                                                                                  |                        |                      |                    |                  | 65  | 100  | 125  | 150  | 175  | 200  | 225  | 250  |
| 139      | (9)       | -198                                                                             | 448                    | 172                  | 899                | 115              | 115 | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 140      | (9)       | -198                                                                             | 448                    | 172                  | 899                | 115              | 115 | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 141      | (9) (74)  | -198                                                                             | 450                    | 170                  | 899                | 115              | 115 | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 142      | (9) (74)  | -198                                                                             | 450                    | 170                  | 899                | 115              | 115 | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 143      | (9)       | -198                                                                             | 483                    | 172                  | 482                | 115              | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 144      | (32) (74) | -198                                                                             | 483                    | 172                  | 482                | 115              | 106 | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 | 90.4 |
| 145      | (32) (74) | -198                                                                             | 517                    | 172                  | 649                | 115              | 115 | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| 146      | (74)      | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161  | 161  | 161  | 161  | 161  | 157  | 154  |
| 147      | ...       | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161  | 161  | 161  | 161  | 161  | 157  | 154  |
| 148      | (74)      | -198                                                                             | 517                    | 207                  | 816                | 138              | 138 | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 149      | (9)       | -198                                                                             | 517                    | 207                  | 816                | 138              | 138 | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 150      | (74)      | -198                                                                             | 552                    | 241                  | 427                | 161              | 161 | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 151      | (9)       | -198                                                                             | 552                    | 241                  | 427                | 161              | 161 | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 152      | (9)       | -198                                                                             | 552                    | 241                  | 649                | 161              | 161 | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 153      | (9) (74)  | -198                                                                             | 585                    | 240                  | 538                | 161              | 161 | 161  | 161  | 161  | 161  | 161  | 161  | 161  |
| 154      | (9)       | -198                                                                             | 585                    | 240                  | 538                | 160              | 160 | 160  | 160  | 160  | 160  | 160  | 160  | 160  |
| 155      | (9)       | -198                                                                             | 586                    | 241                  | 482                | 160              | 160 | 160  | 160  | 160  | 160  | 160  | 160  | 160  |
| 156      | ...       | -198                                                                             | 621                    | 276                  | 899                | 184              | 184 | 184  | 184  | 184  | 184  | 184  | 180  | 175  |
| 157      | ...       | -198                                                                             | 621                    | 276                  | 899                | 184              | 184 | 184  | 184  | 184  | 184  | 184  | 180  | 175  |
| 158      | (32)      | -198                                                                             | 689                    | 276                  | 816                | 184              | 184 | 184  | 184  | 184  | 184  | 184  | 184  | 178  |
| 159      | (74)      | -198                                                                             | 648                    | 276                  | 427                | 184              | 184 | 184  | 184  | 184  | 177  | 171  | 166  | 162  |
| 160      | ...       | -198                                                                             | 648                    | 276                  | 427                | 184              | 184 | 184  | 184  | 184  | 177  | 171  | 166  | 162  |
| 161      | (74)      | -198                                                                             | 689                    | 283                  | 677                | 188              | 188 | 188  | 188  | 188  | 188  | 188  | 188  | 187  |
| 162      | (9)       | -198                                                                             | 689                    | 283                  | 677                | 188              | 188 | 188  | 188  | 188  | 188  | 188  | 188  | 187  |
| 163      | (9)       | -198                                                                             | 689                    | 283                  | 677                | 188              | 188 | 188  | 188  | 188  | 188  | 188  | 188  | 187  |
| 164      | (32)      | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 165      | (32) (74) | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 204  | 202  |
| 166      | (9)       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 204  | 202  |
| 167      | (9)       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 204  | 202  |
| 168      | (32) (74) | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161  | 161  | 161  | 161  | 154  | 149  | 144  |
| 169      | (9)       | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161  | 161  | 161  | 161  | 154  | 149  | 144  |
| 170      | (9)       | -198                                                                             | 586                    | 241                  | 427                | 161              | 161 | 161  | 161  | 161  | 161  | 154  | 149  | 144  |
| 171      | (74)      | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 207  | 206  |
| 172      | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 207  | 206  |
| 173      | (74)      | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 207  | 200  |
| 174      | ...       | -198                                                                             | 689                    | 310                  | 427                | 207              | 207 | 207  | 207  | 207  | 207  | 207  | 207  | 200  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |            |            |            |            |            |            |             |             |             |             |             |             |
|----------|---------------------------------------------------------------------------------------|------------|------------|------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|
|          | 275                                                                                   | 300        | 325        | 350        | 375        | 400        | 425        | 450         | 475         | 500         | 525         | 550         | 575         |
| 139      | 115                                                                                   | 115        | 113        | 110        | 108        | 105        | 104        | 102         | 100         | 98.6        | 97.1        | 95.9        | 91.8        |
| 140      | 115                                                                                   | 115        | 113        | 110        | 108        | 105        | 104        | 102         | 100         | 98.7        | 97.1        | 96.1        | 94.1        |
| 141      | 115                                                                                   | 115        | 113        | 110        | 108        | 105        | 104        | 102         | 100         | 98.6        | 97.1        | 95.9        | 91.8        |
| 142      | 115                                                                                   | 115        | 113        | 110        | 108        | 105        | 104        | 102         | 100         | 98.7        | 97.1        | 96.1        | 94.1        |
| 143      | 90.4                                                                                  | 90.4       | 90.4       | 90.4       | 89.8       | 89.0       | 88.0       | <b>79.7</b> | <b>59.9</b> | <b>55.2</b> | ...         | ...         | ...         |
| 144      | 90.4                                                                                  | 90.4       | 90.4       | 90.4       | 89.8       | 89.0       | 88.0       | <b>79.7</b> | <b>59.9</b> | <b>55.2</b> | ...         | ...         | ...         |
| 145      | 115                                                                                   | 115        | 115        | 115        | 115        | 115        | 115        | 115         | 115         | <b>84.8</b> | <b>58.4</b> | <b>39.7</b> | <b>27.0</b> |
| 146      | <b>151</b>                                                                            | <b>148</b> | <b>146</b> | <b>143</b> | <b>141</b> | <b>138</b> | <b>136</b> | <b>136</b>  | ...         | ...         | ...         | ...         | ...         |
| 147      | <b>151</b>                                                                            | <b>148</b> | <b>146</b> | <b>143</b> | <b>141</b> | <b>138</b> | <b>136</b> | <b>136</b>  | ...         | ...         | ...         | ...         | ...         |
| 148      | 138                                                                                   | 138        | 138        | 138        | 138        | 138        | 138        | 138         | 138         | 138         | 138         | 136         | <b>107</b>  |
| 149      | 138                                                                                   | 138        | 138        | 138        | 138        | 138        | 138        | 138         | 138         | 138         | 138         | 136         | <b>107</b>  |
| 150      | 161                                                                                   | 161        | 161        | 161        | 161        | 160        | 157        | 156         | ...         | ...         | ...         | ...         | ...         |
| 151      | 161                                                                                   | 161        | 161        | 161        | 161        | 160        | 157        | 156         | ...         | ...         | ...         | ...         | ...         |
| 152      | 161                                                                                   | 161        | 161        | 161        | 161        | 161        | 161        | 161         | 161         | <b>84.8</b> | <b>58.4</b> | <b>39.7</b> | <b>27.0</b> |
| 153      | 161                                                                                   | 161        | 161        | 161        | 161        | 160        | 159        | 158         | 157         | 156         | 155         | 153         | ...         |
| 154      | 160                                                                                   | 160        | 160        | 160        | 160        | 159        | 158        | 157         | 156         | 156         | 154         | 151         | ...         |
| 155      | 160                                                                                   | 160        | 160        | 160        | 160        | 160        | 160        | 160         | 160         | 160         | ...         | ...         | ...         |
| 156      | 170                                                                                   | 166        | 163        | 160        | 158        | 156        | 154        | 153         | 153         | 152         | 151         | 151         | 151         |
| 157      | 170                                                                                   | 166        | 163        | 160        | 158        | 156        | 154        | 153         | 153         | 152         | 151         | 151         | 151         |
| 158      | 173                                                                                   | 169        | 165        | 162        | 160        | 158        | 157        | 155         | 154         | <b>135</b>  | <b>134</b>  | <b>133</b>  | <b>129</b>  |
| 159      | 158                                                                                   | 155        | 152        | 149        | 146        | 144        | 141        | 141         | ...         | ...         | ...         | ...         | ...         |
| 160      | 158                                                                                   | 155        | 152        | 149        | 146        | 144        | 141        | 141         | ...         | ...         | ...         | ...         | ...         |
| 161      | 183                                                                                   | 177        | 172        | 169        | 165        | 162        | 159        | 157         | 156         | 155         | 154         | <b>143</b>  | <b>118</b>  |
| 162      | 183                                                                                   | 177        | 172        | 169        | 165        | 162        | 159        | 157         | 156         | 155         | 154         | <b>143</b>  | <b>118</b>  |
| 163      | 183                                                                                   | 177        | 172        | 169        | 165        | 162        | 159        | 157         | 156         | 155         | 154         | <b>143</b>  | <b>118</b>  |
| 164      | 207                                                                                   | 207        | 207        | 207        | 207        | 207        | 206        | 206         | ...         | ...         | ...         | ...         | ...         |
| 165      | 197                                                                                   | 193        | 189        | 185        | 182        | 180        | 177        | 177         | ...         | ...         | ...         | ...         | ...         |
| 166      | 197                                                                                   | 193        | 189        | 185        | 182        | 180        | 177        | 177         | ...         | ...         | ...         | ...         | ...         |
| 167      | 197                                                                                   | 193        | 189        | 185        | 182        | 180        | 177        | 177         | ...         | ...         | ...         | ...         | ...         |
| 168      | <b>140</b>                                                                            | <b>137</b> | <b>135</b> | <b>133</b> | <b>132</b> | <b>131</b> | <b>129</b> | <b>128</b>  | ...         | ...         | ...         | ...         | ...         |
| 169      | <b>140</b>                                                                            | <b>137</b> | <b>135</b> | <b>133</b> | <b>132</b> | <b>131</b> | <b>129</b> | <b>128</b>  | ...         | ...         | ...         | ...         | ...         |
| 170      | <b>140</b>                                                                            | <b>137</b> | <b>135</b> | <b>133</b> | <b>132</b> | <b>131</b> | <b>129</b> | <b>128</b>  | ...         | ...         | ...         | ...         | ...         |
| 171      | 202                                                                                   | 197        | 192        | 188        | 184        | 180        | 176        | 176         | ...         | ...         | ...         | ...         | ...         |
| 172      | 202                                                                                   | 197        | 192        | 188        | 184        | 180        | 176        | 176         | ...         | ...         | ...         | ...         | ...         |
| 173      | <b>194</b>                                                                            | <b>188</b> | <b>184</b> | <b>180</b> | <b>177</b> | <b>175</b> | <b>174</b> | <b>173</b>  | ...         | ...         | ...         | ...         | ...         |
| 174      | <b>194</b>                                                                            | <b>188</b> | <b>184</b> | <b>180</b> | <b>177</b> | <b>175</b> | <b>174</b> | <b>173</b>  | ...         | ...         | ...         | ...         | ...         |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | 600                                                                                   | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  | 850  | 875  | 900  |
| 139      | 75.7                                                                                  | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 140      | 85.5                                                                                  | 69.3 | 56.8 | 46.8 | 38.6 | 31.5 | 25.5 | 20.6 | 17.1 | 13.8 | 10.2 | 7.98 | 6.20 |
| 141      | 75.7                                                                                  | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 142      | 85.5                                                                                  | 69.3 | 56.8 | 46.8 | 38.6 | 31.5 | 25.5 | 20.6 | 17.1 | 13.8 | 10.2 | 7.98 | 6.20 |
| 143      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 144      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 145      | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 146      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 147      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 148      | 83.8                                                                                  | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ...  | ...  | ...  |
| 149      | 83.8                                                                                  | 63.9 | 44.7 | 29.8 | 15.5 | 11.7 | 8.68 | 7.20 | 6.25 | 5.11 | ...  | ...  | ...  |
| 150      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 151      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 152      | 19.2                                                                                  | 15.0 | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 153      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 154      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 155      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 156      | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8  |
| 157      | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8  |
| 158      | 115                                                                                   | 94.2 | 77.3 | 64.9 | 54.7 | 44.7 | 36.1 | 29.2 | 23.6 | 19.1 | ...  | ...  | ...  |
| 159      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 160      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 161      | 99.1                                                                                  | 81.6 | 67.0 | 54.6 | 42.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 162      | 99.1                                                                                  | 81.6 | 67.0 | 54.6 | 42.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 163      | 99.1                                                                                  | 81.6 | 67.0 | 54.6 | 42.2 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 164      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 165      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 166      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 167      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 168      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 169      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 170      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 171      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 172      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 173      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 174      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition          | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm           | P-No. (5) |
|----------|------------------------------|--------------|-----------|------------|---------|----------------------------|--------------------|-----------|
| 175      | 59Ni-23Cr-16Mo-1.6Cu         | Forg. & ftg. | B564      | ...        | N06200  | Sol. ann.                  | All                | 43        |
| 176      | 62Ni-22Mo-15Cr               | Fittings     | B366      | ...        | N10362  | Sol. ann.                  | All                | 43        |
| 177      | 62Ni-22Mo-15Cr               | Forgings     | B462      | ...        | N10362  | Sol. ann.                  | All                | 43        |
| 178      | 62Ni-22Mo-15Cr               | Forgings     | B564      | ...        | N10362  | Sol. ann.                  | All                | 43        |
| 179      | 60Ni-22Cr-9Mo-3.5Cb          | Forg. & ftg. | B564      | ...        | N06625  | Annealed                   | ≤100               | 43        |
| 180      | 65Ni-28Mo-2Fe                | Forg. & ftg. | B366      | ...        | N10665  | Sol. ann.                  | All                | 44        |
| 181      | 65Ni-29.5Mo-2Fe-2Cr          | Forg. & ftg. | B366      | ...        | N10675  | Sol. ann.                  | All                | 44        |
| 182      | 65Ni-29.5Mo-2Fe-2Cr          | Forg. & ftg. | B462      | ...        | N10675  | Sol. ann.                  | All                | 44        |
| 183      | 65Ni-29.5Mo-2Fe-2Cr          | Forg. & ftg. | B564      | ...        | N10675  | Sol. ann.                  | All                | 44        |
| 184      | 57Ni-22Cr-14W-2Mo-La         | Forg. & ftg. | B564      | ...        | N06230  | Sol. ann.                  | All                | 43        |
| 185      | 57Ni-22Cr-14W-2Mo-La         | Forg. & ftg. | B366      | ...        | N06230  | Sol. ann.                  | All                | 43        |
| 186      | 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N | Fittings     | B366      | ...        | R20033  | Sol. ann.                  | ...                | 45        |
| 187      | 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N | Fittings     | B462      | ...        | R20033  | Sol. ann.                  | ...                | 45        |
| 188      | 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N | Forgings     | B564      | ...        | R20033  | Sol. ann.                  | ...                | 45        |
| 189      | 99.0Ni                       | Rod & bar    | B160      | ...        | N02200  | H.W.                       | All                | 41        |
| 190      | 99.0Ni                       | Rod & bar    | B160      | ...        | N02200  | Annealed                   | All                | 41        |
| 191      | 67Ni-30Cu                    | Rod & bar    | B164      | ...        | N04400  | Ann. forg.                 | All                | 42        |
| 192      | 33Ni-42Fe-21Cr               | Rod & bar    | B408      | ...        | N08810  | Sol. trt. or ann.          | ...                | 45        |
| 193      | 33Ni-42Fe-21Cr-Al-Ti         | Rod & bar    | B408      | ...        | N08811  | Annealed                   | ...                | 45        |
| 194      | 33Ni-42Fe-21Cr               | Rod & bar    | B408      | ...        | N08800  | Annealed                   | ...                | 45        |
| 195      | 26Ni-22Cr-5Mo-Ti             | Rod & bar    | B621      | ...        | N08320  | Sol. ann.                  | All                | 45        |
| 196      | 47Ni-22Cr-19Fe-6Mo           | Rod & bar    | B581      | ...        | N06007  | Sol. ann.                  | >19                | 45        |
| 197      | 42Ni-21.5Cr-3Mo-2.3Cu        | Rod & bar    | B425      | ...        | N08825  | Annealed                   | ...                | 45        |
| 198      | 58Ni-29Cr-9Fe                | Rod & bar    | B166      | ...        | N06690  | H.R.                       | >75                | 43        |
| 199      | 58Ni-29Cr-9Fe                | Rod & bar    | B166      | ...        | N06690  | H.R. ann. or C.D. ann.     | All                | 43        |
| 200      | 47Ni-22Cr-19Fe-6Mo           | Rod & bar    | B581      | ...        | N06007  | Sol. ann.                  | ≤19                | 45        |
| 201      | 40Ni-29Cr-15Fe-5Mo           | Rod & bar    | B581      | ...        | N06030  | Sol. ann.                  | All                | 45        |
| 202      | 31Ni-33Fe-27Cr-6.5Mo-Cu-N    | Rod & bar    | B649      | ...        | N08031  | Annealed                   | All                | 45        |
| 203      | 67Ni-30Cu                    | Rod & bar    | B164      | ...        | N04400  | H.W.                       | All except hex >54 | 42        |
| 204      | 58Ni-33Cr-8Mo                | Rod & bar    | B574      | ...        | N06035  | Sol. ann.                  | All                | 43        |
| 205      | 37Ni-33Fe-25Cr               | Rod & bar    | B408      | ...        | N08120  | Sol. ann.                  | All                | 45        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes    | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                        |                      |                    |                  |      |      |      |      |      |            |            |            |
|----------|----------|----------------------------------------------------------------------------------|------------------------|----------------------|--------------------|------------------|------|------|------|------|------|------------|------------|------------|
|          |          | Min. Temp., °C (6)                                                               | Min. Tensile Str., MPa | Min. Yield Str., MPa | Max. Use Temp., °C | Min. Temp. to 40 |      |      |      |      |      |            |            |            |
|          |          |                                                                                  |                        |                      |                    |                  | 65   | 100  | 125  | 150  | 175  | 200        | 225        | 250        |
| 175      | ...      | -198                                                                             | 689                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 207        | <b>207</b> | <b>200</b> |
| 176      | ...      | -198                                                                             | 725                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 204        | 202        | 199        |
| 177      | ...      | -198                                                                             | 725                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 204        | 202        | 199        |
| 178      | ...      | -198                                                                             | 725                    | 310                  | 427                | 207              | 207  | 207  | 207  | 207  | 207  | 204        | 202        | 199        |
| 179      | (9) (64) | -198                                                                             | 827                    | 414                  | 649                | 276              | 276  | 276  | 274  | 273  | 272  | 270        | 269        | 267        |
| 180      | (74)     | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234        | 234        | 234        |
| 181      | (74)     | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234        | 234        | 234        |
| 182      | ...      | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234        | 234        | 234        |
| 183      | ...      | -198                                                                             | 758                    | 352                  | 427                | 234              | 234  | 234  | 234  | 234  | 234  | 234        | 234        | 234        |
| 184      | ...      | -198                                                                             | 758                    | 310                  | 899                | 207              | 207  | 207  | 207  | 207  | 207  | 207        | 207        | 207        |
| 185      | (74)     | -198                                                                             | 758                    | 310                  | 899                | 207              | 207  | 207  | 207  | 207  | 207  | 207        | 207        | 207        |
| 186      | ...      | -198                                                                             | 750                    | 380                  | 427                | 250              | 231  | 209  | 200  | 193  | 187  | 181        | 176        | 172        |
| 187      | ...      | -198                                                                             | 750                    | 380                  | 427                | 250              | 231  | 209  | 200  | 193  | 187  | 181        | 176        | 172        |
| 188      | ...      | -198                                                                             | 750                    | 380                  | 427                | 250              | 231  | 209  | 200  | 193  | 187  | 181        | 176        | 172        |
| 189      | (9)      | -198                                                                             | 414                    | 103                  | 316                | 68.9             | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9       | 68.9       | 68.9       |
| 190      | (9)      | -198                                                                             | 379                    | 103                  | 316                | 68.9             | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9       | 68.9       | 68.9       |
| 191      | (13)     | -198                                                                             | 483                    | 172                  | 482                | 115              | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9       | 90.4       | 90.4       |
| 192      | (9)      | -198                                                                             | 450                    | 170                  | 899                | 115              | 115  | 115  | 115  | 115  | 115  | 115        | 115        | 115        |
| 193      | (9)      | -198                                                                             | 450                    | 170                  | 899                | 115              | 115  | 115  | 115  | 115  | 115  | 115        | 115        | 115        |
| 194      | (9)      | -198                                                                             | 515                    | 205                  | 816                | 138              | 138  | 138  | 138  | 138  | 138  | 138        | 138        | 138        |
| 195      | ...      | -198                                                                             | 517                    | 193                  | 427                | 129              | 129  | 129  | 129  | 129  | 129  | 129        | 129        | 129        |
| 196      | ...      | -198                                                                             | 586                    | 207                  | 538                | 138              | 138  | 138  | 138  | 138  | 138  | 138        | 138        | 138        |
| 197      | (9)      | -198                                                                             | 585                    | 240                  | 538                | 161              | 161  | 161  | 161  | 161  | 161  | 161        | 161        | 161        |
| 198      | ...      | -198                                                                             | 585                    | 240                  | 482                | 160              | 160  | 160  | 160  | 160  | 160  | 160        | 160        | 160        |
| 199      | ...      | -198                                                                             | 586                    | 240                  | 482                | 160              | 160  | 160  | 160  | 160  | 160  | 160        | 160        | 160        |
| 200      | ...      | -198                                                                             | 621                    | 241                  | 538                | 161              | 161  | 161  | 161  | 161  | 161  | 161        | 161        | 161        |
| 201      | ...      | -198                                                                             | 586                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | 161        | <b>157</b> | <b>154</b> |
| 202      | ...      | -198                                                                             | 648                    | 276                  | 427                | 184              | 184  | 184  | 184  | 184  | 177  | 171        | 166        | 162        |
| 203      | ...      | -198                                                                             | 552                    | 276                  | 510                | 184              | 182  | 177  | 174  | 171  | 168  | 165        | 164        | 162        |
| 204      | (9)      | -198                                                                             | 586                    | 241                  | 427                | 161              | 161  | 161  | 161  | 161  | 161  | <b>154</b> | <b>149</b> | <b>144</b> |
| 205      | ...      | -198                                                                             | 621                    | 276                  | 899                | 184              | 184  | 184  | 184  | 184  | 184  | 184        | 180        | 175        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | 275                                                                                   | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  |
| 175      | 194                                                                                   | 188  | 184  | 180  | 177  | 175  | 174  | 173  | ...  | ...  | ...  | ...  | ...  |
| 176      | 197                                                                                   | 193  | 190  | 188  | 186  | 184  | 182  | 180  | ...  | ...  | ...  | ...  | ...  |
| 177      | 197                                                                                   | 193  | 190  | 188  | 186  | 184  | 182  | 180  | ...  | ...  | ...  | ...  | ...  |
| 178      | 197                                                                                   | 193  | 190  | 188  | 186  | 184  | 182  | 180  | ...  | ...  | ...  | ...  | ...  |
| 179      | 265                                                                                   | 262  | 260  | 257  | 255  | 252  | 251  | 249  | 247  | 245  | 242  | 215  | 194  |
| 180      | 234                                                                                   | 234  | 234  | 234  | 234  | 234  | 234  | 234  | ...  | ...  | ...  | ...  | ...  |
| 181      | 234                                                                                   | 234  | 234  | 234  | 234  | 233  | 231  | 230  | ...  | ...  | ...  | ...  | ...  |
| 182      | 234                                                                                   | 234  | 234  | 234  | 234  | 233  | 231  | 230  | ...  | ...  | ...  | ...  | ...  |
| 183      | 234                                                                                   | 234  | 234  | 234  | 234  | 233  | 231  | 230  | ...  | ...  | ...  | ...  | ...  |
| 184      | 207                                                                                   | 207  | 203  | 199  | 197  | 196  | 195  | 195  | 195  | 195  | 195  | 195  | 183  |
| 185      | 207                                                                                   | 207  | 203  | 199  | 197  | 196  | 195  | 195  | 195  | 195  | 195  | 195  | 183  |
| 186      | 169                                                                                   | 165  | 163  | 161  | 159  | 157  | 156  | 155  | ...  | ...  | ...  | ...  | ...  |
| 187      | 169                                                                                   | 165  | 163  | 161  | 159  | 157  | 156  | 155  | ...  | ...  | ...  | ...  | ...  |
| 188      | 169                                                                                   | 165  | 163  | 161  | 159  | 157  | 156  | 155  | ...  | ...  | ...  | ...  | ...  |
| 189      | 68.9                                                                                  | 68.9 | 68.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 190      | 68.9                                                                                  | 68.9 | 68.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 191      | 90.4                                                                                  | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 79.7 | 59.9 | 55.2 | ...  | ...  | ...  |
| 192      | 115                                                                                   | 115  | 113  | 110  | 108  | 105  | 104  | 102  | 100  | 98.6 | 97.1 | 95.9 | 91.8 |
| 193      | 115                                                                                   | 115  | 113  | 110  | 108  | 105  | 104  | 102  | 100  | 98.7 | 97.1 | 96.1 | 94.1 |
| 194      | 138                                                                                   | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 137  | 131  | 108  |
| 195      | 129                                                                                   | 129  | 127  | 125  | 122  | 121  | 119  | 119  | ...  | ...  | ...  | ...  | ...  |
| 196      | 138                                                                                   | 135  | 134  | 132  | 131  | 130  | 129  | 128  | 128  | 127  | 127  | 126  | ...  |
| 197      | 161                                                                                   | 161  | 161  | 161  | 161  | 160  | 159  | 158  | 157  | 156  | 155  | 153  | ...  |
| 198      | 160                                                                                   | 160  | 160  | 160  | 160  | 160  | 160  | 160  | 160  | 160  | ...  | ...  | ...  |
| 199      | 160                                                                                   | 160  | 160  | 160  | 160  | 160  | 160  | 160  | 160  | 160  | ...  | ...  | ...  |
| 200      | 160                                                                                   | 158  | 156  | 154  | 153  | 152  | 151  | 150  | 149  | 136  | 132  | 130  | ...  |
| 201      | 151                                                                                   | 148  | 146  | 143  | 141  | 138  | 136  | 136  | ...  | ...  | ...  | ...  | ...  |
| 202      | 158                                                                                   | 155  | 152  | 149  | 146  | 144  | 141  | 141  | ...  | ...  | ...  | ...  | ...  |
| 203      | 161                                                                                   | 160  | 159  | 158  | 156  | 136  | 102  | 63.8 | 33.5 | 17.0 | 13.0 | ...  | ...  |
| 204      | 140                                                                                   | 137  | 135  | 133  | 132  | 131  | 129  | 128  | ...  | ...  | ...  | ...  | ...  |
| 205      | 170                                                                                   | 166  | 163  | 160  | 158  | 156  | 154  | 153  | 153  | 152  | 151  | 151  | 151  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |      |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|          | 600                                                                                   | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  | 825  | 850  | 875  | 900  |
| 175      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 176      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 177      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 178      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 179      | 156                                                                                   | 136  | 91.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 180      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 181      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 182      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 183      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 184      | 153                                                                                   | 128  | 107  | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 185      | 153                                                                                   | 128  | 107  | 89.7 | 74.7 | 61.9 | 50.8 | 41.1 | 32.6 | 25.2 | 18.9 | 13.8 | 10.2 |
| 186      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 187      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 188      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 189      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 190      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 191      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 192      | 75.7                                                                                  | 62.6 | 50.6 | 41.2 | 33.6 | 27.7 | 22.6 | 18.3 | 15.0 | 11.9 | 9.03 | 7.35 | 5.86 |
| 193      | 85.5                                                                                  | 69.3 | 56.8 | 46.8 | 38.6 | 31.5 | 25.5 | 20.6 | 17.1 | 13.8 | 10.2 | 7.98 | 6.20 |
| 194      | 85.0                                                                                  | 64.4 | 44.8 | 30.0 | 15.5 | 11.3 | 8.82 | 6.98 | 6.43 | 5.00 | ...  | ...  | ...  |
| 195      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 196      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 197      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 198      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 199      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 200      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 201      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 202      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 203      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 204      | ...                                                                                   | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 205      | 117                                                                                   | 96.2 | 79.3 | 65.6 | 54.4 | 45.0 | 37.2 | 30.6 | 25.1 | 20.5 | 16.5 | 13.0 | 9.8  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition          | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm      | P-No. (5) |
|----------|------------------------------|--------------|-----------|------------|---------|----------------------------|---------------|-----------|
| 206      | 61Ni-16Mo-16Cr               | Rod & bar    | B574      | ...        | N06455  | Sol. ann.                  | All           | 43        |
| 207      | 54Ni-16Mo-15Cr               | Rod & bar    | B574      | ...        | N10276  | Sol. ann.                  | All           | 43        |
| 208      | 62Ni-22Mo-15Cr               | Rod & bar    | B574      | ...        | N10362  | Sol. ann.                  | All           | 43        |
| 209      | 60Ni-22Cr-9Mo-3.5Cb          | Rod & bar    | B446      | 1          | N06625  | Annealed                   | >100,<br>≤250 | 43        |
| 210      | 60Ni-22Cr-9Mo-3.5Cb          | Rod & bar    | B446      | 1          | N06625  | Annealed                   | ≤100          | 43        |
| 211      | 57Ni-22Cr-14W-2Mo-La         | Rod & bar    | B572      | ...        | N06230  | Sol. ann.                  | All           | 43        |
| 212      | 59Ni-23Cr-16Mo               | Rod & bar    | B574      | ...        | N06059  | Sol. ann.                  | All           | 43        |
| 213      | 59Ni-23Cr-16Mo-1.6Cu         | Rod & bar    | B574      | ...        | N06200  | Sol. ann.                  | All           | 43        |
| 214      | 65Ni-29.5Mo-2Fe-2Cr          | Rod & bar    | B335      | ...        | N10675  | Sol. ann.                  | All           | 44        |
| 215      | 33Cr-31Ni-32Fe-1.5Mo-0.6Cu-N | Rod          | B649      | ...        | R20033  | Sol. ann.                  | ...           | 45        |
| 216      | 59Ni-22Cr-14Mo-4Fe-3W        | Castings     | A494      | CX2MW      | N26022  | ...                        | ...           | 43        |
| 217      | 53Ni-17Mo-16Cr-6Fe-5W        | Castings     | A494      | CW12MW     | N30002  | ...                        | ...           | a         |
| 218      | 56Ni-19Mo-18Cr-2Fe           | Castings     | A494      | CW6M       | N30107  | ...                        | ...           | 44        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes            | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                                 |                               |                             |                           |     |     |     |     |     |     |            |            |
|----------|------------------|----------------------------------------------------------------------------------|---------------------------------|-------------------------------|-----------------------------|---------------------------|-----|-----|-----|-----|-----|-----|------------|------------|
|          |                  | Min.<br>Temp.,<br>°C (6)                                                         | Min.<br>Tensile<br>Str.,<br>MPa | Min.<br>Yield<br>Str.,<br>MPa | Max.<br>Use<br>Temp.,<br>°C | Min.<br>Temp.<br>to<br>40 |     |     |     |     |     |     |            |            |
|          |                  |                                                                                  |                                 |                               |                             |                           | 65  | 100 | 125 | 150 | 175 | 200 | 225        | 250        |
| 206      | (9)              | -198                                                                             | 689                             | 276                           | 427                         | 184                       | 184 | 184 | 184 | 184 | 184 | 184 | 184        | 184        |
| 207      | ...              | -198                                                                             | 689                             | 283                           | 677                         | 188                       | 188 | 188 | 188 | 188 | 188 | 188 | 188        | 187        |
| 208      | ...              | -198                                                                             | 725                             | 310                           | 427                         | 207                       | 207 | 207 | 207 | 207 | 207 | 204 | 202        | 199        |
| 209      | (9) (64)<br>(70) | -198                                                                             | 758                             | 345                           | 649                         | 230                       | 230 | 230 | 230 | 230 | 230 | 230 | 230        | 230        |
| 210      | (9) (64)<br>(70) | -198                                                                             | 827                             | 414                           | 649                         | 276                       | 276 | 276 | 274 | 273 | 272 | 270 | 269        | 267        |
| 211      | ...              | -198                                                                             | 758                             | 310                           | 899                         | 207                       | 207 | 207 | 207 | 207 | 207 | 207 | 207        | 207        |
| 212      | ...              | -198                                                                             | 689                             | 310                           | 427                         | 207                       | 207 | 207 | 207 | 207 | 207 | 207 | 207        | 206        |
| 213      | ...              | -198                                                                             | 689                             | 310                           | 427                         | 207                       | 207 | 207 | 207 | 207 | 207 | 207 | <b>207</b> | <b>200</b> |
| 214      | ...              | -198                                                                             | 758                             | 352                           | 427                         | 234                       | 234 | 234 | 234 | 234 | 234 | 234 | 234        | 234        |
| 215      | ...              | -198                                                                             | 750                             | 380                           | 427                         | 250                       | 231 | 209 | 200 | 193 | 187 | 181 | 176        | 172        |
| 216      | (7) (9)          | -198                                                                             | 550                             | 310                           | 260                         | 184                       | 184 | 184 | 184 | 184 | 184 | 184 | 184        | 184        |
| 217      | (7) (9)          | -198                                                                             | 495                             | 275                           | 538                         | 165                       | 165 | 165 | 165 | 165 | 165 | 165 | 165        | 165        |
| 218      | (7) (9)          | -198                                                                             | 495                             | 275                           | 538                         | 165                       | 165 | 165 | 165 | 165 | 165 | 165 | 165        | 165        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |            |            |            |            |            |            |            |     |     |     |            |            |
|----------|---------------------------------------------------------------------------------------|------------|------------|------------|------------|------------|------------|------------|-----|-----|-----|------------|------------|
|          | 275                                                                                   | 300        | 325        | 350        | 375        | 400        | 425        | 450        | 475 | 500 | 525 | 550        | 575        |
| 206      | 184                                                                                   | 184        | 184        | 184        | 182        | 180        | 178        | 178        | ... | ... | ... | ...        | ...        |
| 207      | 183                                                                                   | 177        | 172        | 169        | 165        | 162        | 159        | 157        | 156 | 155 | 154 | <b>143</b> | <b>118</b> |
| 208      | 197                                                                                   | 193        | 190        | 188        | 186        | 184        | 182        | 180        | ... | ... | ... | ...        | ...        |
| 209      | 230                                                                                   | 230        | 230        | 230        | 230        | 230        | 230        | 228        | 227 | 225 | 222 | <b>215</b> | <b>194</b> |
| 210      | 265                                                                                   | 262        | 260        | 257        | 255        | 252        | 251        | 249        | 247 | 245 | 242 | <b>215</b> | <b>194</b> |
| 211      | 207                                                                                   | 207        | 203        | 199        | 197        | 196        | 195        | 195        | 195 | 195 | 195 | 195        | 183        |
| 212      | 202                                                                                   | 197        | 192        | 188        | 184        | 180        | 176        | 176        | ... | ... | ... | ...        | ...        |
| 213      | <b>194</b>                                                                            | <b>188</b> | <b>184</b> | <b>180</b> | <b>177</b> | <b>175</b> | <b>174</b> | <b>173</b> | ... | ... | ... | ...        | ...        |
| 214      | 234                                                                                   | 234        | 234        | 234        | 234        | <b>233</b> | <b>231</b> | <b>230</b> | ... | ... | ... | ...        | ...        |
| 215      | 169                                                                                   | 165        | 163        | 161        | 159        | 157        | 156        | 155        | ... | ... | ... | ...        | ...        |
| 216      | 184                                                                                   | ...        | ...        | ...        | ...        | ...        | ...        | ...        | ... | ... | ... | ...        | ...        |
| 217      | 165                                                                                   | 165        | 165        | 165        | 165        | 165        | 165        | 165        | 165 | 165 | 165 | 157        | ...        |
| 218      | 165                                                                                   | 165        | 165        | 165        | 165        | 165        | 165        | 165        | 165 | 165 | 165 | 157        | ...        |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, <i>S</i> , MPa, at Metal Temperature, °C [Notes (1) and (4b)] |             |             |             |             |             |             |             |             |             |             |             |             |
|----------|---------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|          | 600                                                                                   | 625         | 650         | 675         | 700         | 725         | 750         | 775         | 800         | 825         | 850         | 875         | 900         |
| 206      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 207      | <b>99.1</b>                                                                           | <b>81.6</b> | <b>67.0</b> | <b>54.6</b> | <b>42.2</b> | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 208      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 209      | <b>156</b>                                                                            | <b>136</b>  | <b>91.0</b> | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 210      | <b>156</b>                                                                            | <b>136</b>  | <b>91.0</b> | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 211      | <b>153</b>                                                                            | <b>128</b>  | <b>107</b>  | <b>89.7</b> | <b>74.7</b> | <b>61.9</b> | <b>50.8</b> | <b>41.1</b> | <b>32.6</b> | <b>25.2</b> | <b>18.9</b> | <b>13.8</b> | <b>10.2</b> |
| 212      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 213      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 214      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 215      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 216      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 217      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| 218      | ...                                                                                   | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form        | Spec. No. | Type/Grade | UNS No. | Class/Condition/ Temper | P-No. (5) | Notes     | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa |
|----------|---------------------|---------------------|-----------|------------|---------|-------------------------|-----------|-----------|--------------------|----------------------------|--------------------------|
| 1        | Ti                  | Smls. & wld. tube   | B338      | 1          | R50250  | Annealed                | 51        | ...       | -59                | 240                        | 138                      |
| 2        | Ti                  | Smls. pipe          | B861      | 1          | R50250  | Annealed                | 51        | ...       | -59                | 240                        | 138                      |
| 3        | Ti                  | Wld. pipe           | B862      | 1          | R50250  | Annealed                | 51        | ...       | -59                | 240                        | 138                      |
| 4        | Ti                  | Smls. & wld. tube   | B338      | 2          | R50400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 5        | Ti                  | Smls. pipe          | B861      | 2          | R50400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 6        | Ti                  | Wld. pipe           | B862      | 2          | R50400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 7        | Ti                  | Smls. & wld. tube   | B338      | 3          | R50550  | Annealed                | 52        | ...       | -59                | 450                        | 380                      |
| 8        | Ti                  | Smls. pipe          | B861      | 3          | R50550  | Annealed                | 52        | ...       | -59                | 450                        | 380                      |
| 9        | Ti                  | Wld. pipe           | B862      | 3          | R50550  | Annealed                | 52        | ...       | -59                | 450                        | 380                      |
| 10       | Ti-Pd               | Smls. & wld. tube   | B338      | 7          | R52400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 11       | Ti-Pd               | Smls. pipe          | B861      | 7          | R52400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 12       | Ti-Pd               | Wld. pipe           | B862      | 7          | R52400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 13       | Ti-0.3Mo-0.8Ni      | Smls. & wld. tube   | B338      | 12         | R53400  | Annealed                | 52        | ...       | -59                | 485                        | 345                      |
| 14       | Ti-0.3Mo-0.8Ni      | Smls. pipe          | B861      | 12         | R53400  | Annealed                | 52        | ...       | -59                | 485                        | 345                      |
| 15       | Ti-0.3Mo-0.8Ni      | Wld. pipe           | B862      | 12         | R53400  | Annealed                | 52        | ...       | -59                | 485                        | 345                      |
| 16       | Ti                  | Plate, sheet, strip | B265      | 1          | R50250  | Annealed                | 51        | ...       | -59                | 240                        | 138                      |
| 17       | Ti                  | Plate, sheet, strip | B265      | 2          | R50400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 18       | Ti                  | Plate, sheet, strip | B265      | 3          | R50550  | Annealed                | 52        | ...       | -59                | 450                        | 380                      |
| 19       | Ti-Pd               | Plate, sheet, strip | B265      | 7          | R52400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 20       | Ti-0.3Mo-0.8Ni      | Plate, sheet, strip | B265      | 12         | R53400  | Annealed                | 52        | ...       | -59                | 485                        | 345                      |
| 21       | Ti                  | Fittings            | B363      | WPT1       | R50250  | Annealed                | 51        | ...       | -59                | 240                        | 138                      |
| 22       | Ti                  | Forgings            | B381      | F-1        | R50250  | Annealed                | 51        | ...       | -59                | 240                        | 138                      |
| 23       | Ti                  | Fittings            | B363      | WPT2       | R50400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 24       | Ti                  | Forgings            | B381      | F-2        | R50400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 25       | Ti                  | Fittings            | B363      | WPT3       | R50550  | Annealed                | 52        | ...       | -59                | 450                        | 380                      |
| 26       | Ti                  | Forgings            | B381      | F-3        | R50550  | Annealed                | 52        | ...       | -59                | 450                        | 380                      |
| 27       | Ti-Pd               | Fittings            | B363      | WPT7       | R52400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 28       | Ti-Pd               | Forgings            | B381      | F-7        | R52400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 29       | Ti-0.3Mo-0.8Ni      | Fittings            | B363      | WPT12      | R53400  | Annealed                | 52        | ...       | -59                | 485                        | 345                      |
| 30       | Ti-0.3Mo-0.8Ni      | Forgings            | B381      | F-12       | R53400  | Annealed                | 52        | ...       | -59                | 485                        | 345                      |
| 31       | Ti                  | Bar                 | B348      | 1          | R50250  | Annealed                | 51        | ...       | -59                | 240                        | 138                      |
| 32       | Ti                  | Bar                 | B348      | 2          | R50400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 33       | Ti                  | Bar                 | B348      | 3          | R50550  | Annealed                | 52        | ...       | -59                | 450                        | 380                      |
| 34       | Ti-Pd               | Bar                 | B348      | 7          | R52400  | Annealed                | 51        | ...       | -59                | 345                        | 275                      |
| 35       | Ti-0.3Mo-0.8Ni      | Bar                 | B348      | 12         | R53400  | Annealed                | 52        | ...       | -59                | 485                        | 345                      |
| 36       | Ti                  | Castings            | B367      | C-2        | R52550  | ...                     | 51        | (14) (44) | -59                | 345                        | 275                      |
| 37       | Ti                  | Castings            | B367      | C-3        | R52550  | ...                     | 52        | (14) (44) | -59                | 450                        | 380                      |
| 38       | Ti-Pd               | Castings            | B367      | C-7        | R52700  | ...                     | 51        | (14) (44) | -59                | 345                        | 275                      |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                  |      |      |      |      |      |      |      |      |      |      |      |
|----------|----------------------------------------------------------------------------------|------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | Max. Use Temp., °C                                                               | Min. Temp. to 40 | 65   | 100  | 125  | 150  | 175  | 200  | 225  | 250  | 275  | 300  | 325  |
|          |                                                                                  |                  |      |      |      |      |      |      |      |      |      |      |      |
| 1        | 316                                                                              | 80.3             | 73.8 | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 2        | 316                                                                              | 80.3             | 73.8 | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 3        | 316                                                                              | 80.3             | 73.8 | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 4        | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 5        | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 6        | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 7        | 316                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 66.2 | 61.7 | 57.7 |
| 8        | 316                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 66.2 | 61.7 | 57.7 |
| 9        | 316                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 66.2 | 61.7 | 57.7 |
| 10       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 11       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 12       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 13       | 316                                                                              | 161              | 156  | 148  | 139  | 130  | 123  | 116  | 111  | 106  | 104  | 101  | 98.3 |
| 14       | 316                                                                              | 161              | 156  | 148  | 139  | 130  | 123  | 116  | 111  | 106  | 104  | 101  | 98.3 |
| 15       | 316                                                                              | 161              | 156  | 148  | 139  | 130  | 123  | 116  | 111  | 106  | 104  | 101  | 98.3 |
| 16       | 316                                                                              | 80.3             | 73.8 | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 17       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 18       | 316                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 66.2 | 61.7 | 57.7 |
| 19       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 20       | 316                                                                              | 161              | 156  | 148  | 139  | 130  | 123  | 116  | 111  | 106  | 104  | 101  | 98.3 |
| 21       | 316                                                                              | 80.3             | 73.8 | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 22       | 316                                                                              | 80.3             | 73.8 | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 23       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 24       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 25       | 316                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 66.2 | 61.7 | 57.7 |
| 26       | 316                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 66.2 | 61.7 | 57.7 |
| 27       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 28       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 29       | 316                                                                              | 161              | 156  | 148  | 139  | 130  | 123  | 116  | 111  | 106  | 104  | 101  | 98.3 |
| 30       | 316                                                                              | 161              | 156  | 148  | 139  | 130  | 123  | 116  | 111  | 106  | 104  | 101  | 98.3 |
| 31       | 316                                                                              | 80.3             | 73.8 | 62.4 | 55.5 | 49.4 | 43.4 | 38.3 | 33.9 | 30.2 | 27.3 | 25.2 | 23.7 |
| 32       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 33       | 316                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 66.2 | 61.7 | 57.7 |
| 34       | 316                                                                              | 115              | 108  | 98.3 | 90.7 | 83.0 | 77.5 | 72.0 | 67.3 | 62.7 | 58.7 | 54.7 | 50.7 |
| 35       | 316                                                                              | 161              | 156  | 148  | 139  | 130  | 123  | 116  | 111  | 106  | 104  | 101  | 98.3 |
| 36       | 260                                                                              | 115              | 106  | 92.7 | 85.3 | 78.0 | 72.2 | 66.3 | 61.5 | 56.7 | 52.0 | ...  | ...  |
| 37       | 260                                                                              | 149              | 139  | 124  | 113  | 102  | 93.3 | 84.7 | 77.7 | 70.7 | 65.3 | ...  | ...  |
| 38       | 260                                                                              | 115              | 106  | 92.7 | 85.3 | 78.0 | 72.2 | 66.3 | 61.5 | 56.7 | 52.0 | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form        | Spec. No. | UNS No. | P-No. (5) | Notes | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C |
|----------|---------------------|---------------------|-----------|---------|-----------|-------|--------------------|----------------------------|--------------------------|--------------------|
| 1        | 99.2Zr              | Smls. & wld. tube   | B523      | R60702  | 61        | ...   | -59                | 380                        | 205                      | 371                |
| 2        | 99.2Zr              | Smls. & wld. pipe   | B658      | R60702  | 61        | ...   | -59                | 380                        | 205                      | 371                |
| 3        | 95.5Zr + 2.5Nb      | Smls. & wld. pipe   | B658      | R60705  | 62        | (73)  | -59                | 550                        | 380                      | 371                |
| 4        | 99.2Zr              | Plate, sheet, strip | B551      | R60702  | 61        | ...   | -59                | 380                        | 205                      | 371                |
| 5        | 95.5Zr + 2.5Nb      | Plate, sheet, strip | B551      | R60705  | 62        | (73)  | -59                | 550                        | 380                      | 371                |
| 6        | 99.2Zr              | Forgings            | B493      | R60702  | 61        | ...   | -59                | 380                        | 205                      | 371                |
| 7        | 99.2Zr              | Bar, wire           | B550      | R60702  | 61        | ...   | -59                | 380                        | 205                      | 371                |
| 8        | 95.5Zr + 2.5Nb      | Forgings            | B493      | R60705  | 62        | (73)  | -59                | 485                        | 380                      | 380                |
| 9        | 95.5Zr + 2.5Nb      | Bar, wire           | B550      | R60705  | 62        | (73)  | -59                | 550                        | 380                      | 371                |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] |     |     |      |      |      |      |      |      |      |      |      |      |      |
|----------|-------------------------------------------------------------------------------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|
|          | Min. Temp. to 40                                                              | 65  | 100 | 125  | 150  | 175  | 200  | 225  | 250  | 275  | 300  | 325  | 350  | 375  |
| 1        | 126                                                                           | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 2        | 126                                                                           | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 3        | 184                                                                           | 169 | 149 | 139  | 130  | 123  | 116  | 111  | 106  | 101  | 97.6 | 94.6 | 92.4 | 91.0 |
| 4        | 126                                                                           | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 5        | 184                                                                           | 169 | 149 | 139  | 130  | 123  | 116  | 111  | 106  | 101  | 97.6 | 94.6 | 92.4 | 91.0 |
| 6        | 126                                                                           | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 7        | 126                                                                           | 119 | 103 | 92.4 | 82.5 | 73.6 | 65.7 | 58.8 | 52.8 | 47.8 | 43.7 | 40.4 | 37.8 | 36.1 |
| 8        | 161                                                                           | 148 | 130 | 122  | 114  | 108  | 101  | 97.1 | 92.7 | 88.4 | 85.4 | 82.8 | 80.8 | 79.6 |
| 9        | 184                                                                           | 169 | 149 | 139  | 130  | 123  | 116  | 111  | 106  | 101  | 97.6 | 94.6 | 92.4 | 91.0 |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form      | Spec. No. | Type/Grade  | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|---------------------|-------------------|-----------|-------------|---------|----------------------------|----------|-----------|
| 1        | Al-Mn-Cu            | Smls. pipe & tube | B210      | Alclad 3003 | A83003  | O                          | ...      | 21        |
| 2        | Al-Mn-Cu            | Smls. pipe & tube | B210      | Alclad 3003 | A83003  | H112                       | ...      | 21        |
| 3        | Al-Mn-Cu            | Smls. pipe & tube | B241      | Alclad 3003 | A83003  | O                          | ...      | 21        |
| 4        | Al-Mn-Cu            | Smls. pipe & tube | B241      | Alclad 3003 | A83003  | H112                       | ...      | 21        |
| 5        | Al-Mn-Cu            | Smls. pipe & tube | B210      | Alclad 3003 | A83003  | H14                        | ...      | 21        |
| 6        | Al-Mn-Cu            | Smls. pipe & tube | B210      | Alclad 3003 | A83003  | H18                        | ...      | 21        |
| 7        | 99.60Al             | Smls. pipe & tube | B210      | 1060        | A91060  | O                          | ...      | 21        |
| 8        | 99.60Al             | Smls. pipe & tube | B210      | 1060        | A91060  | H112                       | ...      | 21        |
| 9        | 99.60Al             | Smls. pipe & tube | B210      | 1060        | A91060  | H113                       | ...      | 21        |
| 10       | 99.60Al             | Smls. pipe & tube | B241      | 1060        | A91060  | O                          | ...      | 21        |
| 11       | 99.60Al             | Smls. pipe & tube | B241      | 1060        | A91060  | H112                       | ...      | 21        |
| 12       | 99.60Al             | Smls. pipe & tube | B241      | 1060        | A91060  | H113                       | ...      | 21        |
| 13       | 99.60Al             | Smls. pipe & tube | B210      | 1060        | A91060  | H14                        | ...      | 21        |
| 14       | 99.0Al-Cu           | Smls. pipe & tube | B241      | 1100        | A91100  | O                          | ...      | 21        |
| 15       | 99.0Al-Cu           | Smls. pipe & tube | B241      | 1100        | A91100  | H112                       | ...      | 21        |
| 16       | 99.0Al-Cu           | Smls. pipe & tube | B210      | 1100        | A91100  | H113                       | ...      | 21        |
| 17       | 99.0Al-Cu           | Smls. pipe & tube | B210      | 1100        | A91100  | H14                        | ...      | 21        |
| 18       | Al-Mn-Cu            | Smls. pipe & tube | B210      | 3003        | A93003  | O                          | ...      | 21        |
| 19       | Al-Mn-Cu            | Smls. pipe & tube | B210      | 3003        | A93003  | H112                       | ...      | 21        |
| 20       | Al-Mn-Cu            | Smls. pipe & tube | B241      | 3003        | A93003  | O                          | ...      | 21        |
| 21       | Al-Mn-Cu            | Smls. pipe & tube | B241      | 3003        | A93003  | H112                       | ...      | 21        |
| 22       | Al-Mn-Cu            | Smls. pipe & tube | B491      | 3003        | A93003  | O                          | ...      | 21        |
| 23       | Al-Mn-Cu            | Smls. pipe & tube | B491      | 3003        | A93003  | H112                       | ...      | 21        |
| 24       | Al-Mn-Cu            | Smls. pipe & tube | B210      | 3003        | A93003  | H14                        | ...      | 21        |
| 25       | Al-Mn-Cu            | Smls. pipe & tube | B210      | 3003        | A93003  | H18                        | ...      | 21        |
| 26       | Al-Mn-Cu            | Smls. pipe & tube | B241      | 3003        | A93003  | H18                        | ...      | 21        |
| 27       | Al-2.5Mg            | Smls. pipe & tube | B210      | 5052        | A95052  | O                          | ...      | 22        |
| 28       | Al-2.5Mg            | Smls. pipe & tube | B241      | 5052        | A95052  | O                          | ...      | 22        |
| 29       | Al-2.5Mg            | Smls. pipe & tube | B210      | 5052        | A95052  | H32                        | ...      | 22        |
| 30       | Al-2.5Mg            | Smls. pipe & tube | B210      | 5052        | A95052  | H34                        | ...      | 22        |
| 31       | Al-4.4Mg-Mn         | Smls. pipe & tube | B210      | 5083        | A95083  | O                          | ...      | 25        |
| 32       | Al-4.4Mg-Mn         | Smls. pipe & tube | B210      | 5083        | A95083  | H112                       | ...      | 25        |
| 33       | Al-4.4Mg-Mn         | Smls. pipe & tube | B241      | 5083        | A95083  | O                          | ...      | 25        |
| 34       | Al-4.4Mg-Mn         | Smls. pipe & tube | B241      | 5083        | A95083  | H112                       | ...      | 25        |
| 35       | Al-4.0Mg-Mn         | Smls. pipe & tube | B210      | 5086        | A95086  | O                          | ...      | 25        |
| 36       | Al-4.0Mg-Mn         | Smls. pipe & tube | B210      | 5086        | A95086  | H112                       | ...      | 25        |
| 37       | Al-4.0Mg-Mn         | Smls. pipe & tube | B241      | 5086        | A95086  | O                          | ...      | 25        |
| 38       | Al-4.0Mg-Mn         | Smls. pipe & tube | B241      | 5086        | A95086  | H112                       | ...      | 25        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes     | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                            |                          |                    |            |      |      |      |      |      |      |      |
|----------|-----------|----------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------|------|------|------|------|------|------|------|
|          |           | Min. Temp., °C (6)                                                               | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. |      |      |      |      |      |      |      |
|          |           |                                                                                  |                            |                          |                    | to 40      | 65   | 100  | 125  | 150  | 175  | 200  | 225  |
| 1        | (14) (33) | -269                                                                             | 90                         | 31                       | 204                | 20.7       | 19.9 | 19.3 | 18.4 | 17.3 | 13.6 | 10.9 | 10.5 |
| 2        | (14) (33) | -269                                                                             | 90                         | 31                       | 204                | 20.7       | 19.9 | 19.3 | 18.4 | 17.3 | 13.6 | 10.9 | 10.5 |
| 3        | (14) (33) | -269                                                                             | 90                         | 31                       | 204                | 20.7       | 19.9 | 19.3 | 18.4 | 17.3 | 13.6 | 10.9 | 10.5 |
| 4        | (14) (33) | -269                                                                             | 90                         | 31                       | 204                | 20.7       | 19.9 | 19.3 | 18.4 | 17.3 | 13.6 | 10.9 | 10.5 |
| 5        | (14) (33) | -269                                                                             | 131                        | 110                      | 204                | 43.7       | 43.7 | 43.7 | 41.7 | 29.0 | 21.1 | 16.7 | 16.1 |
| 6        | (14) (33) | -269                                                                             | 179                        | 159                      | 204                | 59.8       | 59.8 | 59.8 | 57.0 | 29.0 | 21.1 | 16.7 | 16.1 |
| 7        | (14) (33) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5 | 10.9 | 9.8  | 8.8  | 7.5  | 5.8  | 5.5  |
| 8        | (14) (33) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5 | 10.9 | 9.8  | 8.8  | 7.5  | 5.8  | 5.5  |
| 9        | (14) (33) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5 | 10.9 | 9.8  | 8.8  | 7.5  | 5.8  | 5.5  |
| 10       | (14) (33) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5 | 10.9 | 9.8  | 8.8  | 7.5  | 5.8  | 5.5  |
| 11       | (14) (33) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5 | 10.9 | 9.8  | 8.8  | 7.5  | 5.8  | 5.5  |
| 12       | (14) (33) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5 | 10.9 | 9.8  | 8.8  | 7.5  | 5.8  | 5.5  |
| 13       | (14) (33) | -269                                                                             | 83                         | 69                       | 204                | 27.6       | 27.6 | 27.6 | 26.6 | 18.1 | 12.7 | 8.4  | 7.8  |
| 14       | (14) (33) | -269                                                                             | 76                         | 21                       | 204                | 13.8       | 13.8 | 13.7 | 13.2 | 11.8 | 9.3  | 7.2  | 6.9  |
| 15       | (14) (33) | -269                                                                             | 76                         | 21                       | 204                | 13.8       | 13.8 | 13.7 | 13.2 | 11.8 | 9.3  | 7.2  | 6.9  |
| 16       | (14) (33) | -269                                                                             | 76                         | 24                       | 204                | 16.1       | 16.1 | 16.0 | 15.6 | 11.8 | 9.3  | 7.2  | 6.9  |
| 17       | (14) (33) | -269                                                                             | 110                        | 97                       | 204                | 36.8       | 36.8 | 36.1 | 33.1 | 19.0 | 13.6 | 8.5  | 7.8  |
| 18       | (14) (33) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1 | 21.4 | 20.5 | 18.2 | 13.6 | 10.9 | 10.5 |
| 19       | (14) (33) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1 | 21.4 | 20.5 | 18.2 | 13.6 | 10.9 | 10.5 |
| 20       | (14) (33) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1 | 21.4 | 20.5 | 18.2 | 13.6 | 10.9 | 10.5 |
| 21       | (14) (33) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1 | 21.4 | 20.5 | 18.2 | 13.6 | 10.9 | 10.5 |
| 22       | (14) (33) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1 | 21.4 | 20.5 | 18.2 | 13.6 | 10.9 | 10.5 |
| 23       | (14) (33) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1 | 21.4 | 20.5 | 18.2 | 13.6 | 10.9 | 10.5 |
| 24       | (14) (33) | -269                                                                             | 138                        | 117                      | 204                | 46.0       | 46.0 | 46.0 | 43.9 | 29.0 | 21.1 | 16.7 | 16.1 |
| 25       | (14) (33) | -269                                                                             | 186                        | 165                      | 204                | 62.1       | 62.1 | 60.3 | 52.1 | 36.1 | 24.5 | 18.0 | 17.0 |
| 26       | (14) (33) | -269                                                                             | 186                        | 165                      | 204                | 62.1       | 62.1 | 60.3 | 52.1 | 36.1 | 24.5 | 18.0 | 17.0 |
| 27       | (14)      | -269                                                                             | 172                        | 69                       | 204                | 46.0       | 46.0 | 46.0 | 45.9 | 41.6 | 28.8 | 17.6 | 16.1 |
| 28       | (14)      | -269                                                                             | 172                        | 69                       | 204                | 46.0       | 46.0 | 46.0 | 45.9 | 41.6 | 28.8 | 17.6 | 16.1 |
| 29       | (14) (33) | -269                                                                             | 214                        | 159                      | 204                | 71.2       | 71.2 | 71.2 | 71.0 | 41.6 | 28.8 | 17.6 | 16.1 |
| 30       | (14) (33) | -269                                                                             | 234                        | 179                      | 204                | 78.1       | 78.1 | 78.1 | 78.1 | 41.6 | 28.8 | 17.6 | 16.1 |
| 31       | (33)      | -269                                                                             | 269                        | 110                      | 65                 | 73.5       | 73.5 | ...  | ...  | ...  | ...  | ...  | ...  |
| 32       | (33)      | -269                                                                             | 269                        | 110                      | 65                 | 73.5       | 73.5 | ...  | ...  | ...  | ...  | ...  | ...  |
| 33       | (33)      | -269                                                                             | 269                        | 110                      | 65                 | 73.5       | 73.5 | ...  | ...  | ...  | ...  | ...  | ...  |
| 34       | (33)      | -269                                                                             | 269                        | 110                      | 65                 | 73.5       | 73.5 | ...  | ...  | ...  | ...  | ...  | ...  |
| 35       | (33)      | -269                                                                             | 241                        | 97                       | 65                 | 64.4       | 64.4 | ...  | ...  | ...  | ...  | ...  | ...  |
| 36       | (33)      | -269                                                                             | 241                        | 97                       | 65                 | 64.4       | 64.4 | ...  | ...  | ...  | ...  | ...  | ...  |
| 37       | (33)      | -269                                                                             | 241                        | 97                       | 65                 | 64.4       | 64.4 | ...  | ...  | ...  | ...  | ...  | ...  |
| 38       | (33)      | -269                                                                             | 241                        | 97                       | 65                 | 64.4       | 64.4 | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form      | Spec. No. | Type/Grade  | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|---------------------|-------------------|-----------|-------------|---------|----------------------------|----------|-----------|
| 39       | Al-4.0Mg-Mn         | Smls. pipe & tube | B210      | 5086        | A95086  | H32                        | ...      | 25        |
| 40       | Al-4.0Mg-Mn         | Smls. pipe & tube | B210      | 5086        | A95086  | H34                        | ...      | 25        |
| 41       | Al-3.5Mg            | Smls. pipe & tube | B210      | 5154        | A95154  | 0                          | ...      | 22        |
| 42       | Al-3.5Mg            | Smls. pipe & tube | B210      | 5154        | A95154  | H34                        | ...      | 22        |
| 43       | Al-2.7Mg-Mn         | Smls. pipe & tube | B241      | 5454        | A95454  | 0                          | ...      | 22        |
| 44       | Al-2.7Mg-Mn         | Smls. pipe & tube | B241      | 5454        | A95454  | H112                       | ...      | 22        |
| 45       | Al-5.1Mg-Mn         | Smls. pipe & tube | B210      | 5456        | A95456  | 0                          | ...      | 25        |
| 46       | Al-5.1Mg-Mn         | Smls. pipe & tube | B210      | 5456        | A95456  | H112                       | ...      | 25        |
| 47       | Al-5.1Mg-Mn         | Smls. pipe & tube | B241      | 5456        | A95456  | 0                          | ...      | 25        |
| 48       | Al-5.1Mg-Mn         | Smls. pipe & tube | B241      | 5456        | A95456  | H112                       | ...      | 25        |
| 49       | Al-Mg-Si-Cu         | Smls. pipe & tube | B210      | 6061        | A96061  | T4 wld.                    | ...      | 23        |
| 50       | Al-Mg-Si-Cu         | Smls. pipe & tube | B210      | 6061        | A96061  | T6 wld.                    | ...      | 23        |
| 51       | Al-Mg-Si-Cu         | Smls. pipe & tube | B241      | 6061        | A96061  | T4 wld.                    | ...      | 23        |
| 52       | Al-Mg-Si-Cu         | Smls. pipe & tube | B241      | 6061        | A96061  | T6 wld.                    | ...      | 23        |
| 53       | Al-Mg-Si-Cu         | Smls. pipe & tube | B241      | 6061        | A96061  | T4                         | ...      | 23        |
| 54       | Al-Mg-Si-Cu         | Smls. pipe & tube | B210      | 6061        | A96061  | T4                         | ...      | 23        |
| 55       | Al-Mg-Si-Cu         | Smls. pipe & tube | B241      | 6061        | A96061  | T6                         | ...      | 23        |
| 56       | Al-Mg-Si-Cu         | Smls. pipe & tube | B210      | 6061        | A96061  | T6                         | ...      | 23        |
| 57       | Al-Mg-Si            | Smls. pipe & tube | B210      | 6063        | A96063  | T4 wld.                    | ...      | 23        |
| 58       | Al-Mg-Si            | Smls. pipe & tube | B210      | 6063        | A96063  | T5 wld.                    | ...      | 23        |
| 59       | Al-Mg-Si            | Smls. pipe & tube | B210      | 6063        | A96063  | T6 wld.                    | ...      | 23        |
| 60       | Al-Mg-Si            | Smls. pipe & tube | B241      | 6063        | A96063  | T4 wld.                    | ...      | 23        |
| 61       | Al-Mg-Si            | Smls. pipe & tube | B241      | 6063        | A96063  | T5 wld.                    | ...      | 23        |
| 62       | Al-Mg-Si            | Smls. pipe & tube | B241      | 6063        | A96063  | T6 wld.                    | ...      | 23        |
| 63       | Al-Mg-Si            | Smls. pipe & tube | B241      | 6063        | A96063  | T4                         | ≤13      | 23        |
| 64       | Al-Mg-Si            | Smls. pipe & tube | B210      | 6063        | A96063  | T4                         | ...      | 23        |
| 65       | Al-Mg-Si            | Smls. pipe & tube | B241      | 6063        | A96063  | T5                         | ≤13      | 23        |
| 66       | Al-Mg-Si            | Smls. pipe & tube | B241      | 6063        | A96063  | T6                         | ...      | 23        |
| 67       | Al-Mg-Si            | Smls. pipe & tube | B210      | 6063        | A96063  | T6                         | ...      | 23        |
| 68       | Al-Mn-Cu            | Structural tube   | B221      | Alclad 3003 | A83003  | 0                          | ...      | 21        |
| 69       | Al-Mn-Cu            | Structural tube   | B221      | Alclad 3003 | A83003  | H112                       | ...      | 21        |
| 70       | 99.0Al              | Structural tube   | B221      | 1060        | A91060  | 0                          | ...      | 21        |
| 71       | 99.0Al              | Structural tube   | B221      | 1060        | A91060  | H112                       | ...      | 21        |
| 72       | 99.0Al-Cu           | Structural tube   | B221      | 1100        | A91100  | 0                          | ...      | 21        |
| 73       | 99.0Al-Cu           | Structural tube   | B221      | 1100        | A91100  | H112                       | ...      | 21        |
| 74       | Al-Mn-Cu            | Structural tube   | B221      | 3003        | A93003  | 0                          | ...      | 21        |
| 75       | Al-Mn-Cu            | Structural tube   | B221      | 3003        | A93003  | H112                       | ...      | 21        |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes     | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                            |                          |                    |            |       |      |             |             |             |             |             |
|----------|-----------|----------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------|-------|------|-------------|-------------|-------------|-------------|-------------|
|          |           | Min. Temp., °C (6)                                                               | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. |       |      |             |             |             |             |             |
|          |           |                                                                                  |                            |                          |                    | to 40      | 65    | 100  | 125         | 150         | 175         | 200         | 225         |
| 39       | (33)      | -269                                                                             | 276                        | 193                      | 65                 | 91.9       | 91.9  | ...  | ...         | ...         | ...         | ...         | ...         |
| 40       | (33)      | -269                                                                             | 303                        | 234                      | 65                 | 101.1      | 101.1 | ...  | ...         | ...         | ...         | ...         | ...         |
| 41       | ...       | -269                                                                             | 207                        | 76                       | 65                 | 50.6       | 50.6  | ...  | ...         | ...         | ...         | ...         | ...         |
| 42       | (33)      | -269                                                                             | 269                        | 200                      | 65                 | 89.6       | 89.6  | ...  | ...         | ...         | ...         | ...         | ...         |
| 43       | (33)      | -269                                                                             | 214                        | 83                       | 204                | 55.2       | 55.2  | 55.2 | <b>48.9</b> | <b>37.5</b> | <b>28.6</b> | <b>21.7</b> | <b>20.7</b> |
| 44       | (33)      | -269                                                                             | 214                        | 83                       | 204                | 55.2       | 55.2  | 55.2 | <b>48.9</b> | <b>37.5</b> | <b>28.6</b> | <b>21.7</b> | <b>20.7</b> |
| 45       | (33)      | -269                                                                             | 283                        | 131                      | 65                 | 87.3       | 87.3  | ...  | ...         | ...         | ...         | ...         | ...         |
| 46       | (33)      | -269                                                                             | 283                        | 131                      | 65                 | 87.3       | 87.3  | ...  | ...         | ...         | ...         | ...         | ...         |
| 47       | (33)      | -269                                                                             | 283                        | 131                      | 65                 | 87.3       | 87.3  | ...  | ...         | ...         | ...         | ...         | ...         |
| 48       | (33)      | -269                                                                             | 283                        | 131                      | 65                 | 87.3       | 87.3  | ...  | ...         | ...         | ...         | ...         | ...         |
| 49       | (22) (63) | -269                                                                             | 165                        | ...                      | 204                | 55.2       | 55.2  | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 50       | (22) (63) | -269                                                                             | 165                        | ...                      | 204                | 55.2       | 55.2  | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 51       | (22) (63) | -269                                                                             | 165                        | ...                      | 204                | 55.2       | 55.2  | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 52       | (22) (63) | -269                                                                             | 165                        | ...                      | 204                | 55.2       | 55.2  | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 53       | (33) (63) | -269                                                                             | 179                        | 110                      | 204                | 59.8       | 59.8  | 59.8 | 58.9        | 56.3        | 50.2        | 38.3        | 35.9        |
| 54       | (33)      | -269                                                                             | 207                        | 110                      | 204                | 68.9       | 68.9  | 68.9 | 67.8        | 64.8        | 57.9        | <b>40.2</b> | <b>35.9</b> |
| 55       | (33) (63) | -269                                                                             | 262                        | 241                      | 204                | 87.3       | 87.3  | 87.3 | 83.6        | 72.3        | 57.2        | <b>40.2</b> | <b>35.9</b> |
| 56       | (33)      | -269                                                                             | 290                        | 241                      | 204                | 96.5       | 96.5  | 96.5 | 92.5        | 79.9        | 63.1        | <b>40.2</b> | <b>35.9</b> |
| 57       | ...       | -269                                                                             | 117                        | ...                      | 204                | 39.1       | 39.1  | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 58       | ...       | -269                                                                             | 117                        | ...                      | 204                | 39.1       | 39.1  | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 59       | ...       | -269                                                                             | 117                        | ...                      | 204                | 39.1       | 39.1  | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 60       | ...       | -269                                                                             | 117                        | ...                      | 204                | 39.1       | 39.1  | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 61       | ...       | -269                                                                             | 117                        | ...                      | 204                | 39.1       | 39.1  | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 62       | ...       | -269                                                                             | 117                        | ...                      | 204                | 39.1       | 39.1  | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 63       | (33)      | -269                                                                             | 131                        | 69                       | 204                | 43.7       | 43.7  | 43.7 | 43.7        | 43.7        | 35.8        | 23.9        | 10.3        |
| 64       | (33)      | -269                                                                             | 152                        | 69                       | 204                | 46.0       | 45.8  | 45.8 | 45.5        | 45.5        | 41.5        | 27.7        | 12.0        |
| 65       | (33)      | -269                                                                             | 152                        | 110                      | 204                | 50.6       | 50.6  | 48.7 | 46.6        | 41.4        | <b>27.5</b> | <b>15.3</b> | <b>13.8</b> |
| 66       | (33)      | -269                                                                             | 207                        | 172                      | 204                | 68.9       | 68.9  | 67.7 | 59.0        | 45.9        | <b>27.5</b> | <b>15.3</b> | <b>49.3</b> |
| 67       | (33)      | -269                                                                             | 228                        | 193                      | 204                | 75.8       | 75.8  | 74.8 | <b>64.0</b> | <b>49.2</b> | <b>27.5</b> | <b>15.3</b> | <b>13.8</b> |
| 68       | (33) (69) | -269                                                                             | 90                         | 31                       | 204                | 20.7       | 19.9  | 19.3 | 18.4        | 17.3        | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 69       | (33) (69) | -269                                                                             | 90                         | 31                       | 204                | 20.7       | 19.9  | 19.3 | 18.4        | 17.3        | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 70       | (33) (69) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5  | 10.9 | 9.8         | 8.8         | <b>7.5</b>  | <b>5.8</b>  | <b>5.5</b>  |
| 71       | (33) (69) | -269                                                                             | 59                         | 17                       | 204                | 11.5       | 11.5  | 10.9 | 9.8         | 8.8         | <b>7.5</b>  | <b>5.8</b>  | <b>5.5</b>  |
| 72       | (33) (69) | -269                                                                             | 76                         | 21                       | 204                | 13.8       | 13.8  | 13.7 | 13.2        | <b>11.8</b> | <b>9.3</b>  | <b>7.2</b>  | <b>6.9</b>  |
| 73       | (33) (69) | -269                                                                             | 76                         | 21                       | 204                | 13.8       | 13.8  | 13.7 | 13.2        | <b>11.8</b> | <b>9.3</b>  | <b>7.2</b>  | <b>6.9</b>  |
| 74       | (33) (69) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1  | 21.4 | 20.5        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 75       | (33) (69) | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1  | 21.4 | 20.5        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form    | Spec. No. | Type/Grade  | UNS No. | Class/Condition/<br>Temper | Size, mm   | P-No. (5) |
|----------|---------------------|-----------------|-----------|-------------|---------|----------------------------|------------|-----------|
| 76       | Al-2.5Mg            | Structural tube | B221      | 5052        | A95052  | O                          | ...        | 22        |
| 77       | Al-4.4Mg-Mn         | Structural tube | B221      | 5083        | A95083  | O                          | ...        | 25        |
| 78       | Al-4.0Mg-Mn         | Structural tube | B221      | 5086        | A95086  | O                          | ...        | 25        |
| 79       | Al-3.5Mg            | Structural tube | B221      | 5154        | A95154  | O                          | ...        | 22        |
| 80       | Al-2.7Mg-Mn         | Structural tube | B221      | 5454        | A95454  | O                          | ...        | 22        |
| 81       | Al-5.1Mg-Mn         | Structural tube | B221      | 5456        | A95456  | O                          | ...        | 25        |
| 82       | Al-Mg-Si-Cu         | Structural tube | B221      | 6061        | A96061  | T4 wld.                    | ...        | 23        |
| 83       | Al-Mg-Si-Cu         | Structural tube | B221      | 6061        | A96061  | T6 wld.                    | ...        | 23        |
| 84       | Al-Mg-Si-Cu         | Structural tube | B221      | 6061        | A96061  | T4                         | ...        | 23        |
| 85       | Al-Mg-Si-Cu         | Structural tube | B221      | 6061        | A96061  | T6                         | ...        | 23        |
| 86       | Al-Mg-Si            | Structural tube | B221      | 6063        | A96063  | T4 wld.                    | ...        | 23        |
| 87       | Al-Mg-Si            | Structural tube | B221      | 6063        | A96063  | T5 wld.                    | ...        | 23        |
| 88       | Al-Mg-Si            | Structural tube | B221      | 6063        | A96063  | T6 wld.                    | ...        | 23        |
| 89       | Al-Mg-Si            | Structural tube | B221      | 6063        | A96063  | T4                         | ≤13        | 23        |
| 90       | Al-Mg-Si            | Structural tube | B221      | 6063        | A96063  | T5                         | ≤13        | 23        |
| 91       | Al-Mg-Si            | Structural tube | B221      | 6063        | A96063  | T6                         | ...        | 23        |
| 92       | Al-Mn-Cu            | Plate & sheet   | B209      | Alclad 3003 | A83003  | O                          | ≥0.15, <13 | 21        |
| 93       | Al-Mn-Cu            | Plate & sheet   | B209      | Alclad 3003 | A83003  | O                          | ≥13, ≤75   | 21        |
| 94       | Al-Mn-Cu            | Plate & sheet   | B209      | Alclad 3003 | A83003  | H112                       | ≥13, ≤50   | 21        |
| 95       | Al-Mn-Cu            | Plate & sheet   | B209      | Alclad 3003 | A83003  | H12                        | ≥0.43, <13 | 21        |
| 96       | Al-Mn-Cu            | Plate & sheet   | B209      | Alclad 3003 | A83003  | H12                        | ≥13, ≤50   | 21        |
| 97       | Al-Mn-Cu            | Plate & sheet   | B209      | Alclad 3003 | A83003  | H14                        | ≥0.23, <13 | 21        |
| 98       | Al-Mn-Cu            | Plate & sheet   | B209      | Alclad 3003 | A83003  | H14                        | ≥13, ≤25   | 21        |
| 99       | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | O                          | ≥0.15, <13 | 22        |
| 100      | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | O                          | ≥13, ≤75   | 22        |
| 101      | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | H112                       | ≥6, <13    | 22        |
| 102      | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | H112                       | ≥13, ≤75   | 22        |
| 103      | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | H32                        | ≥0.43, <13 | 22        |
| 104      | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | H32                        | ≥13, ≤50   | 22        |
| 105      | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | H34                        | ≥0.23, <13 | 22        |
| 106      | Al-Mn-Mg            | Plate & sheet   | B209      | Alclad 3004 | A83004  | H34                        | ≥13, ≤25   | 22        |
| 107      | Al-Mg-Si-Cu         | Plate & sheet   | B209      | Alclad 6061 | A86061  | T4 wld.                    | ...        | 23        |
| 108      | Al-Mg-Si-Cu         | Plate & sheet   | B209      | Alclad 6061 | A86061  | T6 wld.                    | ...        | 23        |
| 109      | Al-Mg-Si-Cu         | Plate & sheet   | B209      | Alclad 6061 | A86061  | T4                         | ...        | 23        |
| 110      | Al-Mg-Si-Cu         | Plate & sheet   | B209      | Alclad 6061 | A86061  | T451                       | ≥6, <13    | 23        |
| 111      | Al-Mg-Si-Cu         | Plate & sheet   | B209      | Alclad 6061 | A86061  | T451                       | ≥13, ≤75   | 23        |
| 112      | Al-Mg-Si-Cu         | Plate & sheet   | B209      | Alclad 6061 | A86061  | T6                         | ...        | 23        |
| 113      | Al-Mg-Si-Cu         | Plate & sheet   | B209      | Alclad 6061 | A86061  | T651                       | ≥6, <13    | 23        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes          | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |      |      |             |             |             |             |             |
|----------|----------------|--------------------|----------------------------|--------------------------|--------------------|----------------------------------------------------------------------------------|------|------|-------------|-------------|-------------|-------------|-------------|
|          |                |                    |                            |                          |                    | Min. Temp. to 40                                                                 | 65   | 100  | 125         | 150         | 175         | 200         | 225         |
| 76       | (69)           | -269               | 172                        | 69                       | 204                | 46.0                                                                             | 46.0 | 46.0 | 45.9        | <b>41.6</b> | <b>28.8</b> | <b>17.6</b> | <b>16.1</b> |
| 77       | (69)           | -269               | 269                        | 110                      | 65                 | 73.5                                                                             | 73.5 | ...  | ...         | ...         | ...         | ...         | ...         |
| 78       | (69)           | -269               | 241                        | 97                       | 65                 | 64.4                                                                             | 64.4 | ...  | ...         | ...         | ...         | ...         | ...         |
| 79       | (69)           | -269               | 207                        | 76                       | 65                 | 50.6                                                                             | 50.6 | ...  | ...         | ...         | ...         | ...         | ...         |
| 80       | (69)           | -269               | 214                        | 83                       | 204                | 55.2                                                                             | 55.2 | 55.2 | <b>48.9</b> | <b>37.5</b> | <b>28.6</b> | <b>21.7</b> | <b>20.7</b> |
| 81       | (69)           | -269               | 283                        | 131                      | 65                 | 87.3                                                                             | 87.3 | ...  | ...         | ...         | ...         | ...         | ...         |
| 82       | (22) (63) (69) | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2 | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 83       | (22) (63) (69) | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2 | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 84       | (33) (63) (69) | -269               | 179                        | 110                      | 204                | 59.8                                                                             | 59.8 | 59.8 | 58.9        | 56.3        | 50.2        | 38.3        | 35.9        |
| 85       | (33) (63) (69) | -269               | 262                        | 241                      | 204                | 87.3                                                                             | 87.3 | 87.3 | 83.6        | 72.3        | 57.2        | <b>40.2</b> | <b>35.9</b> |
| 86       | (69)           | -269               | 117                        | ...                      | 204                | 39.1                                                                             | 39.1 | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 87       | (69)           | -269               | 117                        | ...                      | 204                | 39.1                                                                             | 39.1 | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 88       | (69)           | -269               | 117                        | ...                      | 204                | 39.1                                                                             | 39.1 | 37.9 | 35.9        | 32.1        | 25.7        | 17.6        | 13.8        |
| 89       | (13) (33) (69) | -269               | 131                        | 69                       | 204                | 43.7                                                                             | 43.7 | 43.7 | 43.7        | 43.7        | 35.8        | 23.9        | 10.3        |
| 90       | (13) (33) (69) | -269               | 152                        | 110                      | 204                | 50.6                                                                             | 50.6 | 48.7 | 46.6        | 41.4        | <b>27.5</b> | <b>15.3</b> | <b>13.8</b> |
| 91       | (33) (69)      | -269               | 207                        | 172                      | 204                | 68.9                                                                             | 68.9 | 67.7 | 59.0        | 45.9        | <b>27.5</b> | <b>15.3</b> | <b>49.3</b> |
| 92       | (66)           | -269               | 90                         | 31                       | 204                | 20.7                                                                             | 19.9 | 19.3 | 18.4        | 17.3        | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 93       | (68)           | -269               | 97                         | 34                       | 204                | 23.0                                                                             | 22.2 | 21.3 | 20.4        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 94       | (33) (66)      | -269               | 103                        | 41                       | 204                | 27.6                                                                             | 26.6 | 25.6 | 24.4        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 95       | (33) (66)      | -269               | 110                        | 76                       | 204                | 36.8                                                                             | 36.8 | 35.9 | 33.7        | <b>29.0</b> | <b>21.1</b> | <b>16.7</b> | <b>16.1</b> |
| 96       | (33) (68)      | -269               | 117                        | 83                       | 204                | 39.1                                                                             | 39.1 | 39.1 | 39.1        | <b>29.0</b> | <b>21.1</b> | <b>16.7</b> | <b>16.1</b> |
| 97       | (33) (66)      | -269               | 131                        | 110                      | 204                | 43.7                                                                             | 43.7 | 43.7 | 41.7        | <b>29.0</b> | <b>21.1</b> | <b>16.7</b> | <b>16.1</b> |
| 98       | (33) (68)      | -269               | 138                        | 117                      | 204                | 46.0                                                                             | 46.0 | 46.0 | 43.9        | <b>29.0</b> | <b>21.1</b> | <b>16.7</b> | <b>16.1</b> |
| 99       | (66)           | -269               | 145                        | 55                       | 204                | 36.8                                                                             | 36.8 | 36.8 | 36.8        | 36.8        | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 100      | (68)           | -269               | 152                        | 59                       | 204                | 39.1                                                                             | 39.1 | 39.1 | 39.1        | <b>38.9</b> | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 101      | (33) (66)      | -269               | 152                        | 59                       | 204                | 39.1                                                                             | 39.1 | 39.1 | 39.1        | <b>38.9</b> | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 102      | (33) (68)      | -269               | 159                        | 62                       | 204                | 41.4                                                                             | 41.4 | 41.4 | 41.4        | <b>38.9</b> | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 103      | (33) (66)      | -269               | 186                        | 138                      | 204                | 62.1                                                                             | 62.1 | 62.1 | <b>60.4</b> | <b>38.9</b> | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 104      | (33) (68)      | -269               | 193                        | 145                      | 204                | 64.4                                                                             | 64.4 | 64.4 | <b>60.4</b> | <b>38.9</b> | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 105      | (33) (66)      | -269               | 214                        | 165                      | 204                | 71.2                                                                             | 71.2 | 71.2 | 71.2        | <b>38.9</b> | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 106      | (33) (68)      | -269               | 221                        | 172                      | 204                | 73.5                                                                             | 73.5 | 73.5 | 73.5        | <b>38.9</b> | <b>26.9</b> | <b>17.4</b> | <b>16.1</b> |
| 107      | (22) (63)      | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2 | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 108      | (22) (63)      | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2 | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 109      | (33) (66)      | -269               | 186                        | 97                       | 204                | 62.1                                                                             | 62.1 | 62.1 | 61.0        | 58.3        | 52.1        | 39.7        | 35.9        |
| 110      | (33) (66)      | -269               | 186                        | 97                       | 204                | 62.1                                                                             | 62.1 | 62.1 | 61.0        | 58.3        | 52.1        | 39.7        | 35.9        |
| 111      | (33) (68)      | -269               | 207                        | 110                      | 204                | 68.9                                                                             | 68.9 | 68.9 | 67.8        | 64.8        | 57.9        | <b>40.2</b> | <b>35.9</b> |
| 112      | (33) (66)      | -269               | 262                        | 221                      | 204                | 87.3                                                                             | 87.3 | 87.3 | 83.8        | 72.3        | 57.2        | <b>40.2</b> | <b>35.9</b> |
| 113      | (33) (66)      | -269               | 262                        | 221                      | 204                | 87.3                                                                             | 87.3 | 87.3 | 83.8        | 72.3        | 57.2        | <b>40.2</b> | <b>35.9</b> |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form  | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size, mm  | P-No. (5) |
|----------|---------------------|---------------|-----------|-------------|---------|--------------------------|-----------|-----------|
| 114      | Al-Mg-Si-Cu         | Plate & sheet | B209      | Alclad 6061 | A86061  | T651                     | ≥13, ≤100 | 23        |
| 115      | 99.60Al             | Plate & sheet | B209      | 1060        | A91060  | O                        | ...       | 21        |
| 116      | 99.60Al             | Plate & sheet | B209      | 1060        | A91060  | H112                     | ≥13, ≤25  | 21        |
| 117      | 99.60Al             | Plate & sheet | B209      | 1060        | A91060  | H12                      | ...       | 21        |
| 118      | 99.60Al             | Plate & sheet | B209      | 1060        | A91060  | H14                      | ...       | 21        |
| 119      | 99.0Al-Cu           | Plate & sheet | B209      | 1100        | A91100  | O                        | ...       | 21        |
| 120      | 99.0Al-Cu           | Plate & sheet | B209      | 1100        | A91100  | H112                     | ≥13, ≤50  | 21        |
| 121      | 99.0Al-Cu           | Plate & sheet | B209      | 1100        | A91100  | H12                      | ...       | 21        |
| 122      | 99.0Al-Cu           | Plate & sheet | B209      | 1100        | A91100  | H14                      | ...       | 21        |
| 123      | Al-Mn-Cu            | Plate & sheet | B209      | 3003        | A93003  | O                        | ...       | 21        |
| 124      | Al-Mn-Cu            | Plate & sheet | B209      | 3003        | A93003  | H112                     | ≥13, ≤50  | 21        |
| 125      | Al-Mn-Cu            | Plate & sheet | B209      | 3003        | A93003  | H12                      | ...       | 21        |
| 126      | Al-Mn-Cu            | Plate & sheet | B209      | 3003        | A93003  | H14                      | ...       | 21        |
| 127      | Al-Mn-Mg            | Plate & sheet | B209      | 3004        | A93004  | O                        | ...       | 22        |
| 128      | Al-Mn-Mg            | Plate & sheet | B209      | 3004        | A93004  | H112                     | ...       | 22        |
| 129      | Al-Mn-Mg            | Plate & sheet | B209      | 3004        | A93004  | H32                      | ...       | 22        |
| 130      | Al-Mn-Mg            | Plate & sheet | B209      | 3004        | A93004  | H34                      | ...       | 22        |
| 131      | Al-1.5Mg            | Plate & sheet | B209      | 5050        | A95050  | O                        | ...       | 21        |
| 132      | Al-1.5Mg            | Plate & sheet | B209      | 5050        | A95050  | H112                     | ...       | 21        |
| 133      | Al-1.5Mg            | Plate & sheet | B209      | 5050        | A95050  | H32                      | ...       | 21        |
| 134      | Al-1.5Mg            | Plate & sheet | B209      | 5050        | A95050  | H34                      | ...       | 21        |
| 135      | Al-2.5Mg            | Plate & sheet | B209      | 5052        | A95052  | O                        | ...       | 22        |
| 136      | Al-2.5Mg            | Plate & sheet | B209      | 5052        | A95052  | H112                     | ≥13, ≤75  | 22        |
| 137      | Al-2.5Mg            | Plate & sheet | B209      | 5052        | A95052  | H32                      | ...       | 22        |
| 138      | Al-2.5Mg            | Plate & sheet | B209      | 5052        | A95052  | H34                      | ...       | 22        |
| 139      | Al-4.4Mg-Mn         | Plate & sheet | B209      | 5083        | A95083  | O                        | ≥1.3, ≤38 | 25        |
| 140      | Al-4.4Mg-Mn         | Plate & sheet | B209      | 5083        | A95083  | H32                      | ≥5, ≤38   | 25        |
| 141      | Al-4.0Mg-Mn         | Plate & sheet | B209      | 5086        | A95086  | O                        | ...       | 25        |
| 142      | Al-4.0Mg-Mn         | Plate & sheet | B209      | 5086        | A95086  | H112                     | ≥13, ≤25  | 25        |
| 143      | Al-4.0Mg-Mn         | Plate & sheet | B209      | 5086        | A95086  | H32                      | ...       | 25        |
| 144      | Al-4.0Mg-Mn         | Plate & sheet | B209      | 5086        | A95086  | H34                      | ...       | 25        |
| 145      | Al-3.5Mg            | Plate & sheet | B209      | 5154        | A95154  | O                        | ...       | 22        |
| 146      | Al-3.5Mg            | Plate & sheet | B209      | 5154        | A95154  | H112                     | ≥13, ≤75  | 22        |
| 147      | Al-3.5Mg            | Plate & sheet | B209      | 5154        | A95154  | H32                      | ...       | 22        |
| 148      | Al-3.5Mg            | Plate & sheet | B209      | 5154        | A95154  | H34                      | ...       | 22        |
| 149      | Al-3.5Mg            | Plate & sheet | B209      | 5254        | A95254  | O                        | ...       | 22        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes     | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |                            |                          |                    |            |       |      |      |      |      |      |      |
|----------|-----------|----------------------------------------------------------------------------------|----------------------------|--------------------------|--------------------|------------|-------|------|------|------|------|------|------|
|          |           | Min. Temp., °C (6)                                                               | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Min. Temp. |       |      |      |      |      |      |      |
|          |           |                                                                                  |                            |                          |                    | to 40      | 65    | 100  | 125  | 150  | 175  | 200  | 225  |
| 114      | (33) (68) | -269                                                                             | 290                        | 241                      | 204                | 96.5       | 96.5  | 96.5 | 92.5 | 79.9 | 63.1 | 40.2 | 35.9 |
| 115      | ...       | -269                                                                             | 55                         | 17                       | 204                | 11.5       | 11.5  | 10.9 | 9.8  | 8.8  | 7.5  | 5.8  | 5.5  |
| 116      | (13) (33) | -269                                                                             | 69                         | 34                       | 204                | 23.0       | 21.8  | 19.1 | 17.0 | 15.0 | 11.8 | 7.5  | 5.9  |
| 117      | (33)      | -269                                                                             | 76                         | 62                       | 204                | 25.3       | 25.3  | 23.1 | 21.0 | 18.1 | 12.7 | 8.4  | 7.8  |
| 118      | (33)      | -269                                                                             | 83                         | 69                       | 204                | 27.6       | 27.6  | 27.6 | 26.6 | 18.1 | 12.7 | 8.4  | 7.8  |
| 119      | ...       | -269                                                                             | 76                         | 24                       | 204                | 16.1       | 16.1  | 16.0 | 15.6 | 11.8 | 9.3  | 7.2  | 6.9  |
| 120      | (13) (33) | -269                                                                             | 83                         | 34                       | 204                | 23.0       | 23.0  | 22.7 | 21.6 | 16.3 | 11.8 | 7.5  | 6.9  |
| 121      | (33)      | -269                                                                             | 97                         | 76                       | 204                | 32.2       | 32.2  | 31.3 | 25.2 | 19.0 | 13.6 | 8.5  | 7.8  |
| 122      | (33)      | -269                                                                             | 110                        | 97                       | 204                | 36.8       | 36.8  | 36.1 | 33.1 | 19.0 | 13.6 | 8.5  | 7.8  |
| 123      | ...       | -269                                                                             | 97                         | 34                       | 204                | 23.0       | 22.1  | 21.4 | 20.5 | 18.2 | 13.6 | 10.9 | 10.5 |
| 124      | (13) (33) | -269                                                                             | 103                        | 41                       | 204                | 27.6       | 26.6  | 25.6 | 24.4 | 18.2 | 13.6 | 10.9 | 10.5 |
| 125      | (33)      | -269                                                                             | 117                        | 83                       | 204                | 39.1       | 39.1  | 38.1 | 35.8 | 29.0 | 21.1 | 16.7 | 16.1 |
| 126      | (33)      | -269                                                                             | 138                        | 117                      | 204                | 46.0       | 46.0  | 46.0 | 43.9 | 29.0 | 21.1 | 16.7 | 16.1 |
| 127      | ...       | -269                                                                             | 152                        | 59                       | 204                | 39.1       | 39.1  | 39.1 | 39.0 | 38.9 | 26.9 | 17.4 | 16.1 |
| 128      | (33)      | -269                                                                             | 159                        | 62                       | 204                | 41.4       | 41.4  | 41.4 | 41.4 | 38.9 | 26.9 | 17.4 | 16.1 |
| 129      | (33)      | -269                                                                             | 193                        | 145                      | 204                | 64.4       | 64.4  | 64.4 | 60.4 | 38.9 | 26.9 | 17.4 | 16.1 |
| 130      | (33)      | -269                                                                             | 221                        | 172                      | 204                | 73.5       | 73.5  | 73.5 | 73.5 | 38.9 | 26.9 | 17.4 | 16.1 |
| 131      | ...       | -269                                                                             | 124                        | 41                       | 204                | 27.6       | 27.6  | 27.5 | 27.5 | 27.5 | 20.1 | 10.8 | 9.7  |
| 132      | (33)      | -269                                                                             | 138                        | 55                       | 204                | 36.8       | 36.7  | 36.7 | 36.6 | 35.8 | 20.1 | 10.8 | 9.7  |
| 133      | (33)      | -269                                                                             | 152                        | 110                      | 204                | 50.6       | 50.6  | 50.6 | 50.6 | 35.8 | 20.1 | 10.8 | 9.7  |
| 134      | (33)      | -269                                                                             | 172                        | 138                      | 204                | 57.5       | 57.5  | 57.5 | 57.5 | 35.8 | 20.1 | 10.8 | 9.7  |
| 135      | ...       | -269                                                                             | 172                        | 65                       | 204                | 43.7       | 43.7  | 43.7 | 43.6 | 41.6 | 28.8 | 17.6 | 16.1 |
| 136      | (13) (33) | -269                                                                             | 172                        | 65                       | 204                | 43.7       | 43.7  | 43.7 | 43.6 | 41.6 | 28.8 | 17.6 | 16.1 |
| 137      | (33)      | -269                                                                             | 214                        | 159                      | 204                | 71.2       | 71.2  | 71.2 | 71.0 | 41.6 | 28.8 | 17.6 | 16.1 |
| 138      | (33)      | -269                                                                             | 234                        | 179                      | 204                | 78.1       | 78.1  | 78.1 | 78.1 | 41.6 | 28.8 | 17.6 | 16.1 |
| 139      | (13)      | -269                                                                             | 276                        | 124                      | 65                 | 82.7       | 82.7  | ...  | ...  | ...  | ...  | ...  | ...  |
| 140      | (13) (33) | -269                                                                             | 303                        | 214                      | 65                 | 101.1      | 101.1 | ...  | ...  | ...  | ...  | ...  | ...  |
| 141      | ...       | -269                                                                             | 241                        | 97                       | 65                 | 64.4       | 64.4  | ...  | ...  | ...  | ...  | ...  | ...  |
| 142      | (13) (33) | -269                                                                             | 241                        | 110                      | 65                 | 73.5       | 73.5  | ...  | ...  | ...  | ...  | ...  | ...  |
| 143      | (33)      | -269                                                                             | 276                        | 193                      | 65                 | 91.9       | 91.9  | ...  | ...  | ...  | ...  | ...  | ...  |
| 144      | (33)      | -269                                                                             | 303                        | 234                      | 65                 | 101.1      | 101.1 | ...  | ...  | ...  | ...  | ...  | ...  |
| 145      | ...       | -269                                                                             | 207                        | 76                       | 65                 | 50.6       | 50.4  | ...  | ...  | ...  | ...  | ...  | ...  |
| 146      | (13) (33) | -269                                                                             | 207                        | 76                       | 65                 | 50.6       | 50.4  | ...  | ...  | ...  | ...  | ...  | ...  |
| 147      | (33)      | -269                                                                             | 248                        | 179                      | 65                 | 82.7       | 82.7  | ...  | ...  | ...  | ...  | ...  | ...  |
| 148      | (33)      | -269                                                                             | 269                        | 200                      | 65                 | 89.6       | 89.6  | ...  | ...  | ...  | ...  | ...  | ...  |
| 149      | ...       | -269                                                                             | 207                        | 76                       | 65                 | 50.6       | 50.4  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form        | Spec. No. | Type/Grade     | UNS No. | Class/Condition/<br>Temper | Size, mm  | P-No. (5) |
|----------|---------------------|---------------------|-----------|----------------|---------|----------------------------|-----------|-----------|
| 150      | Al-3.5Mg            | Plate & sheet       | B209      | 5254           | A95254  | H112                       | ≥13, ≤75  | 22        |
| 151      | Al-3.5Mg            | Plate & sheet       | B209      | 5254           | A95254  | H32                        | ...       | 22        |
| 152      | Al-3.5Mg            | Plate & sheet       | B209      | 5254           | A95254  | H34                        | ...       | 22        |
| 153      | Al-2.7Mg-Mn         | Plate & sheet       | B209      | 5454           | A95454  | O                          | ...       | 22        |
| 154      | Al-2.7Mg-Mn         | Plate & sheet       | B209      | 5454           | A95454  | H112                       | ≥13, ≤75  | 22        |
| 155      | Al-2.7Mg-Mn         | Plate & sheet       | B209      | 5454           | A95454  | H32                        | ...       | 22        |
| 156      | Al-2.7Mg-Mn         | Plate & sheet       | B209      | 5454           | A95454  | H34                        | ...       | 22        |
| 157      | Al-5.1Mg-Mn         | Plate & sheet       | B209      | 5456           | A95456  | O                          | ≥1.3, ≤38 | 25        |
| 158      | Al-5.1Mg-Mn         | Plate & sheet       | B209      | 5456           | A95456  | H32                        | ≥5, <13   | 25        |
| 159      | Al-2.5Mg            | Plate & sheet       | B209      | 5652           | A95652  | O                          | ...       | 22        |
| 160      | Al-2.5Mg            | Plate & sheet       | B209      | 5652           | A95652  | H112                       | ≥13, ≤75  | 22        |
| 161      | Al-2.5Mg            | Plate & sheet       | B209      | 5652           | A95652  | H32                        | ...       | 22        |
| 162      | Al-2.5Mg            | Plate & sheet       | B209      | 5652           | A95652  | H34                        | ...       | 22        |
| 163      | Al-Mg-Si-Cu         | Plate & sheet       | B209      | 6061           | A96061  | T4 wld.                    | ...       | 23        |
| 164      | Al-Mg-Si-Cu         | Plate & sheet       | B209      | 6061           | A96061  | T6 wld.                    | ...       | 23        |
| 165      | Al-Mg-Si-Cu         | Plate & sheet       | B209      | 6061           | A96061  | T4                         | ...       | 23        |
| 166      | Al-Mg-Si-Cu         | Plate & sheet       | B209      | 6061           | A96061  | T6                         | ...       | 23        |
| 167      | Al-Mg-Si-Cu         | Plate & sheet       | B209      | 6061           | A96061  | T651                       | ≥6, ≤100  | 23        |
| 168      | Al-Mn-Cu            | Forgings & fittings | B361      | WP Alclad 3003 | A83003  | O                          | ...       | 21        |
| 169      | Al-Mn-Cu            | Forgings & fittings | B361      | WP Alclad 3003 | A83003  | H112                       | ...       | 21        |
| 170      | 99.60Al             | Forgings & fittings | B361      | WP1060         | A91060  | O                          | ...       | 21        |
| 171      | 99.60Al             | Forgings & fittings | B361      | WP1060         | A91060  | H112                       | ...       | 21        |
| 172      | 99.0Al-Cu           | Forgings & fittings | B361      | WP1100         | A91100  | O                          | ...       | 21        |
| 173      | 99.0Al-Cu           | Forgings & fittings | B361      | WP1100         | A91100  | H112                       | ...       | 21        |
| 174      | Al-Mn-Cu            | Forgings & fittings | B247      | 3003           | A93003  | H112                       | ...       | 21        |
| 175      | Al-Mn-Cu            | Forgings & fittings | B247      | 3003           | A93003  | H112 wld.                  | ...       | 21        |
| 176      | Al-Mn-Cu            | Forgings & fittings | B361      | WP3003         | A93003  | O                          | ...       | 21        |
| 177      | Al-Mn-Cu            | Forgings & fittings | B361      | WP3003         | A93003  | H112                       | ...       | 21        |
| 178      | Al-Mn-Cu            | Forgings & fittings | B247      | 5083           | A95083  | O                          | ...       | 25        |
| 179      | Al-Mn-Cu            | Forgings & fittings | B247      | 5083           | A95083  | H112                       | ...       | 25        |
| 180      | Al-Mn-Cu            | Forgings & fittings | B247      | 5083           | A95083  | H112 wld.                  | ...       | 25        |
| 181      | Al-4.4Mg-Mn         | Forgings & fittings | B361      | WP5083         | A95083  | O                          | ...       | 25        |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes                       | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |       |      |             |             |             |             |             |
|----------|-----------------------------|--------------------|----------------------------|--------------------------|--------------------|----------------------------------------------------------------------------------|-------|------|-------------|-------------|-------------|-------------|-------------|
|          |                             |                    |                            |                          |                    | Min. Temp. to 40                                                                 | 65    | 100  | 125         | 150         | 175         | 200         | 225         |
| 150      | (13) (33)                   | -269               | 207                        | 76                       | 65                 | 50.6                                                                             | 50.4  | ...  | ...         | ...         | ...         | ...         | ...         |
| 151      | (33)                        | -269               | 248                        | 179                      | 65                 | 82.7                                                                             | 82.7  | ...  | ...         | ...         | ...         | ...         | ...         |
| 152      | (33)                        | -269               | 269                        | 200                      | 65                 | 89.6                                                                             | 89.6  | ...  | ...         | ...         | ...         | ...         | ...         |
| 153      | ...                         | -269               | 214                        | 83                       | 204                | 55.2                                                                             | 55.2  | 55.2 | <b>48.9</b> | <b>37.5</b> | <b>28.6</b> | <b>21.7</b> | <b>20.7</b> |
| 154      | (13) (33)                   | -269               | 214                        | 83                       | 204                | 55.2                                                                             | 55.2  | 55.2 | <b>48.9</b> | <b>37.5</b> | <b>28.6</b> | <b>21.7</b> | <b>20.7</b> |
| 155      | (33)                        | -269               | 248                        | 179                      | 204                | 82.7                                                                             | 82.7  | 82.7 | <b>49.5</b> | <b>37.5</b> | <b>28.6</b> | <b>21.7</b> | <b>20.7</b> |
| 156      | (33)                        | -269               | 269                        | 200                      | 204                | 89.6                                                                             | 89.6  | 89.6 | <b>49.5</b> | <b>37.5</b> | <b>28.6</b> | <b>21.7</b> | <b>20.7</b> |
| 157      | (13)                        | -269               | 290                        | 131                      | 65                 | 87.3                                                                             | 87.3  | ...  | ...         | ...         | ...         | ...         | ...         |
| 158      | (13) (33)                   | -269               | 317                        | 228                      | 65                 | 105.7                                                                            | 105.7 | ...  | ...         | ...         | ...         | ...         | ...         |
| 159      | ...                         | -269               | 172                        | 65                       | 204                | 43.7                                                                             | 43.7  | 43.7 | 43.6        | <b>41.6</b> | <b>28.8</b> | <b>17.6</b> | <b>16.1</b> |
| 160      | (13) (33)                   | -269               | 172                        | 65                       | 204                | 43.7                                                                             | 43.7  | 43.7 | 43.6        | <b>41.6</b> | <b>28.8</b> | <b>17.6</b> | <b>16.1</b> |
| 161      | (33)                        | -269               | 214                        | 159                      | 204                | 71.2                                                                             | 71.2  | 71.2 | 71.0        | <b>41.6</b> | <b>28.8</b> | <b>17.6</b> | <b>16.1</b> |
| 162      | (33)                        | -269               | 234                        | 179                      | 204                | 78.1                                                                             | 78.1  | 78.1 | 78.1        | <b>41.6</b> | <b>28.8</b> | <b>17.6</b> | <b>16.1</b> |
| 163      | (22) (63)                   | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2  | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 164      | (22) (63)                   | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2  | 55.2 | 54.3        | 52.0        | 46.3        | 35.3        | 34.8        |
| 165      | (33) (63)                   | -269               | 207                        | 110                      | 204                | 68.9                                                                             | 68.9  | 68.9 | 67.8        | 64.8        | 57.9        | <b>40.2</b> | <b>35.9</b> |
| 166      | (33)                        | -269               | 290                        | 241                      | 204                | 96.5                                                                             | 96.5  | 96.5 | 92.5        | 79.9        | 63.1        | <b>40.2</b> | <b>35.9</b> |
| 167      | (13) (33)                   | -269               | 290                        | 241                      | 204                | 96.5                                                                             | 96.5  | 96.5 | 92.5        | 79.9        | 63.1        | <b>40.2</b> | <b>35.9</b> |
| 168      | (13) (14) (32)<br>(33) (66) | -269               | 90                         | 31                       | 204                | 20.7                                                                             | 19.9  | 19.3 | 18.4        | 17.3        | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 169      | (13) (14) (32)<br>(33) (66) | -269               | 90                         | 31                       | 204                | 20.7                                                                             | 19.9  | 19.3 | 18.4        | 17.3        | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 170      | (13) (14) (32)<br>(33)      | -269               | 55                         | 17                       | 204                | 11.5                                                                             | 11.5  | 10.9 | 9.8         | 8.8         | <b>7.5</b>  | <b>5.8</b>  | <b>5.5</b>  |
| 171      | (13) (14) (32)<br>(33)      | -269               | 55                         | 17                       | 204                | 11.5                                                                             | 11.5  | 10.9 | 9.8         | 8.8         | <b>7.5</b>  | <b>5.8</b>  | <b>5.5</b>  |
| 172      | (13) (14) (32)<br>(33)      | -269               | 76                         | 21                       | 204                | 13.8                                                                             | 13.8  | 13.7 | 13.2        | <b>11.8</b> | <b>9.3</b>  | <b>7.2</b>  | <b>6.9</b>  |
| 173      | (13) (14) (32)<br>(33)      | -269               | 76                         | 21                       | 204                | 13.8                                                                             | 13.8  | 13.7 | 13.2        | <b>11.8</b> | <b>9.3</b>  | <b>7.2</b>  | <b>6.9</b>  |
| 174      | (9) (45)                    | -269               | 97                         | 34                       | 204                | 23.0                                                                             | 22.1  | 21.4 | 20.5        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 175      | (9) (45)                    | -269               | 97                         | 34                       | 204                | 23.0                                                                             | 22.1  | 21.4 | 20.5        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 176      | (13) (14) (32)<br>(33)      | -269               | 97                         | 34                       | 204                | 23.0                                                                             | 22.1  | 21.4 | 20.5        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 177      | (13) (14) (32)<br>(33)      | -269               | 97                         | 34                       | 204                | 23.0                                                                             | 22.1  | 21.4 | 20.5        | <b>18.2</b> | <b>13.6</b> | <b>10.9</b> | <b>10.5</b> |
| 178      | (9) (32) (33)               | -269               | 268                        | 110                      | 65                 | 73.5                                                                             | 73.5  | ...  | ...         | ...         | ...         | ...         | ...         |
| 179      | (9) (32) (33)               | -269               | 268                        | 110                      | 65                 | 73.5                                                                             | 73.5  | ...  | ...         | ...         | ...         | ...         | ...         |
| 180      | (9) (32) (33)               | -269               | 268                        | 110                      | 65                 | 73.5                                                                             | 73.5  | ...  | ...         | ...         | ...         | ...         | ...         |
| 181      | (13) (32) (33)              | -269               | 269                        | 110                      | 65                 | 73.5                                                                             | 73.5  | ...  | ...         | ...         | ...         | ...         | ...         |

**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Nominal Composition | Product Form        | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size, mm | P-No. (5) |
|----------|---------------------|---------------------|-----------|------------|---------|----------------------------|----------|-----------|
| 182      | Al-4.4Mg-Mn         | Forgings & fittings | B361      | WP5083     | A95083  | H112                       | ...      | 25        |
| 183      | Al-3.5Mg            | Forgings & fittings | B361      | WP5154     | A95154  | O                          | ...      | 22        |
| 184      | Al-3.5Mg            | Forgings & fittings | B361      | WP5154     | A95154  | H112                       | ...      | 22        |
| 185      | Al-Mg-Si-Cu         | Forgings & fittings | B247      | 6061       | A96061  | T6 wld.                    | ...      | 23        |
| 186      | Al-Mg-Si-Cu         | Forgings & fittings | B361      | WP6061     | A96061  | T4 wld.                    | ...      | 23        |
| 187      | Al-Mg-Si-Cu         | Forgings & fittings | B361      | WP6061     | A96061  | T6 wld.                    | ...      | 23        |
| 188      | Al-Mg-Si-Cu         | Forgings & fittings | B361      | WP6061     | A96061  | T4                         | ...      | 23        |
| 189      | Al-Mg-Si-Cu         | Forgings & fittings | B247      | 6061       | A96061  | T6                         | ...      | 23        |
| 190      | Al-Mg-Si-Cu         | Forgings & fittings | B361      | WP6061     | A96061  | T6                         | ...      | 23        |
| 191      | Al-Mg-Si            | Forgings & fittings | B361      | WP6063     | A96063  | T4 wld.                    | ...      | 23        |
| 192      | Al-Mg-Si            | Forgings & fittings | B361      | WP6063     | A96063  | T6 wld.                    | ...      | 23        |
| 193      | Al-Mg-Si            | Forgings & fittings | B361      | WP6063     | A96063  | T4                         | ...      | 23        |
| 194      | Al-Mg-Si            | Forgings & fittings | B361      | WP6063     | A96063  | T6                         | ...      | 23        |
| 195      | Al-Si-Mg            | Castings            | B26       | 356.0      | A03560  | T71                        | ...      | 26        |
| 196      | Al-Si-Mg            | Castings            | B26       | 356.0      | A03560  | T6                         | ...      | 26        |
| 197      | Al-Si               | Castings            | B26       | 443.0      | A04430  | F                          | ...      | ...       |



**Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

| Line No. | Notes               | Min. Temp., °C (6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Basic Allowable Stress, S, MPa, at Metal Temperature, °C<br>[Notes (1) and (4b)] |      |      |      |      |      |      |      |
|----------|---------------------|--------------------|----------------------------|--------------------------|--------------------|----------------------------------------------------------------------------------|------|------|------|------|------|------|------|
|          |                     |                    |                            |                          |                    | Min. Temp. to 40                                                                 | 65   | 100  | 125  | 150  | 175  | 200  | 225  |
|          |                     |                    |                            |                          |                    |                                                                                  |      |      |      |      |      |      |      |
| 182      | (13) (32) (33)      | -269               | 269                        | 110                      | 65                 | 73.5                                                                             | 73.5 | ...  | ...  | ...  | ...  | ...  | ...  |
| 183      | (32) (33)           | -269               | 207                        | 76                       | 65                 | 50.6                                                                             | 50.6 | ...  | ...  | ...  | ...  | ...  | ...  |
| 184      | (32) (33)           | -269               | 207                        | 76                       | 65                 | 50.6                                                                             | 50.6 | ...  | ...  | ...  | ...  | ...  | ...  |
| 185      | (9) (22)            | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2 | 55.2 | 54.3 | 52.0 | 46.3 | 35.3 | 34.8 |
| 186      | (22) (32) (63)      | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2 | 55.2 | 54.3 | 52.0 | 46.3 | 35.3 | 34.8 |
| 187      | (22) (32) (63)      | -269               | 165                        | ...                      | 204                | 55.2                                                                             | 55.2 | 55.2 | 54.3 | 52.0 | 46.3 | 35.3 | 34.8 |
| 188      | (13) (32) (33) (63) | -269               | 179                        | 110                      | 204                | 59.8                                                                             | 59.8 | 59.8 | 58.9 | 56.3 | 50.2 | 38.3 | 35.9 |
| 189      | (9) (33)            | -269               | 262                        | 241                      | 204                | 87.3                                                                             | 87.3 | 87.3 | 83.6 | 72.3 | 57.2 | 40.2 | 35.9 |
| 190      | (13) (32) (33) (63) | -269               | 262                        | 241                      | 204                | 87.3                                                                             | 87.3 | 87.3 | 83.6 | 72.3 | 57.2 | 40.2 | 35.9 |
| 191      | (32)                | -269               | 117                        | ...                      | 204                | 39.1                                                                             | 39.1 | 37.6 | 36.0 | 32.0 | 24.7 | 15.3 | 13.8 |
| 192      | (32)                | -269               | 117                        | ...                      | 204                | 39.1                                                                             | 39.1 | 37.6 | 36.0 | 32.0 | 24.7 | 15.3 | 13.8 |
| 193      | (13) (32) (33)      | -269               | 124                        | 62                       | 204                | 41.4                                                                             | 41.3 | 41.3 | 41.0 | 41.0 | 33.9 | 22.6 | 9.8  |
| 194      | (13) (32) (33)      | -269               | 207                        | 172                      | 204                | 68.9                                                                             | 68.9 | 67.7 | 59.0 | 45.9 | 27.5 | 15.3 | 13.8 |
| 195      | (9) (43)            | -269               | 172                        | 124                      | 204                | 57.5                                                                             | 57.5 | 57.5 | 55.0 | 49.8 | 38.6 | 18.9 | 16.5 |
| 196      | (9) (43)            | -269               | 207                        | 138                      | 121                | 68.9                                                                             | 68.9 | 68.9 | 57.9 | ...  | ...  | ...  | ...  |
| 197      | (9) (43)            | -269               | 117                        | 48                       | 204                | 32.0                                                                             | 32.0 | 32.0 | 32.0 | 32.0 | 32.0 | 32.0 | 24.1 |

**Table A-1A Basic Casting Quality Factors,  $E_c$** 

These quality factors are determined in accordance with [para. 302.3.3\(b\)](#). See also [para. 302.3.3\(c\)](#) and [Table 302.3.3C](#) for increased quality factors applicable in special cases. Specifications are ASTM.

| Spec. No.                               | Description                                | $E_c$ [Note (2)] | Appendix A<br>Notes |
|-----------------------------------------|--------------------------------------------|------------------|---------------------|
| <b>Iron</b>                             |                                            |                  |                     |
| A47                                     | Malleable iron castings                    | 1.00             | (9)                 |
| A48                                     | Gray iron castings                         | 1.00             | (9)                 |
| A126                                    | Gray iron castings                         | 1.00             | (9)                 |
| A197                                    | Cupola malleable iron castings             | 1.00             | (9)                 |
| A278                                    | Gray iron castings                         | 1.00             | (9)                 |
| A395                                    | Ductile and ferritic ductile iron castings | 0.80             | (9), (40)           |
| A536                                    | Ductile iron castings                      | 0.80             | (9), (40)           |
| A571                                    | Austenitic ductile iron castings           | 0.80             | (9), (40)           |
| <b>Carbon Steel</b>                     |                                            |                  |                     |
| A216                                    | Carbon steel castings                      | 0.80             | (9), (40)           |
| A352                                    | Ferritic steel castings                    | 0.80             | (9), (40)           |
| <b>Low and Intermediate Alloy Steel</b> |                                            |                  |                     |
| A217                                    | Martensitic stainless and alloy castings   | 0.80             | (9), (40)           |
| A352                                    | Ferritic steel castings                    | 0.80             | (9), (40)           |
| A426                                    | Centrifugally cast pipe                    | 1.00             | (10)                |
| <b>Stainless Steel</b>                  |                                            |                  |                     |
| A351                                    | Austenitic steel castings                  | 0.80             | (9), (40)           |
| A451                                    | Centrifugally cast pipe                    | 0.90             | (10), (40)          |
| A487                                    | Steel castings                             | 0.80             | (9), (40)           |
| <b>Copper and Copper Alloy</b>          |                                            |                  |                     |
| B61                                     | Steam bronze castings                      | 0.80             | (9), (40)           |
| B62                                     | Composition bronze castings                | 0.80             | (9), (40)           |
| B148                                    | Al-bronze and Si-Al-bronze castings        | 0.80             | (9), (40)           |
| B584                                    | Copper alloy castings                      | 0.80             | (9), (40)           |
| <b>Nickel and Nickel Alloy</b>          |                                            |                  |                     |
| A494                                    | Nickel and nickel alloy castings           | 0.80             | (9), (40)           |
| <b>Aluminum Alloy</b>                   |                                            |                  |                     |
| B26, Temper F                           | Aluminum alloy castings                    | 1.00             | (9), (10)           |
| B26, Temper T6, T71                     | Aluminum alloy castings                    | 0.80             | (9), (40)           |
| <b>Titanium and Titanium Alloy</b>      |                                            |                  |                     |
| B367                                    | Titanium and titanium alloy castings       | 0.80             | (9), (40)           |

**Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes,  $E_j$** 

(20)

These quality factors are determined in accordance with [para. 302.3.4\(a\)](#). See also [para. 302.3.4\(b\)](#) and [Table 302.3.4](#) for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

| Spec. No.                               | Class (or Type)    | Description                                                                 | $E_j$<br>[Note (2)] | Appendix A<br>Notes |
|-----------------------------------------|--------------------|-----------------------------------------------------------------------------|---------------------|---------------------|
| <b>Carbon Steel</b>                     |                    |                                                                             |                     |                     |
| API 5L                                  | ...                | Seamless pipe                                                               | 1.00                | ...                 |
|                                         |                    | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         |                    | Electric resistance welded pipe                                             | 0.85                | ...                 |
|                                         |                    | Electric fusion welded pipe, double butt seam                               | 0.95                | ...                 |
|                                         |                    | Continuous welded (furnace butt welded) pipe                                | 0.60                | ...                 |
| A53                                     | Type S             | Seamless pipe                                                               | 1.00                | ...                 |
|                                         | Type E             | Electric resistance welded pipe                                             | 0.85                | ...                 |
|                                         | Type F             | Furnace butt welded pipe                                                    | 0.60                | ...                 |
| A106                                    | ...                | Seamless pipe                                                               | 1.00                | ...                 |
| A134                                    | ...                | Electric fusion welded pipe, single butt, straight or spiral (helical) seam | 0.80                | ...                 |
| A135                                    | ...                | Electric resistance welded pipe                                             | 0.85                | ...                 |
| A139                                    | ...                | Electric fusion welded pipe, straight or spiral (helical) seam              | 0.80                | ...                 |
| A179                                    | ...                | Seamless tube                                                               | 1.00                | ...                 |
| A333                                    | ...                | Seamless pipe                                                               | 1.00                | ...                 |
|                                         |                    | Electric resistance welded pipe                                             | 0.85                | ...                 |
| A334                                    | ...                | Seamless tube                                                               | 1.00                | ...                 |
| A369                                    | ...                | Seamless pipe                                                               | 1.00                | ...                 |
| A381                                    | ...                | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         |                    | Electric fusion welded pipe, spot radiographed                              | 0.90                | (19)                |
|                                         |                    | Electric fusion welded pipe, as manufactured                                | 0.85                | ...                 |
| A524                                    | ...                | Seamless pipe                                                               | 1.00                | ...                 |
| A587                                    | ...                | Electric resistance welded pipe                                             | 0.85                | ...                 |
| A671                                    | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam                               | 0.85                | ...                 |
| A672                                    | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam                               | 0.85                | ...                 |
| A691                                    | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam                               | 0.85                | ...                 |
| <b>Low and Intermediate Alloy Steel</b> |                    |                                                                             |                     |                     |
| A333                                    | ...                | Seamless pipe                                                               | 1.00                | ...                 |
|                                         |                    | Electric resistance welded pipe                                             | 0.85                | (78)                |
| A334                                    | ...                | Seamless tube                                                               | 1.00                | ...                 |
| A335                                    | ...                | Seamless pipe                                                               | 1.00                | ...                 |
| A369                                    | ...                | Seamless pipe                                                               | 1.00                | ...                 |
| A671                                    | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam                               | 0.85                | (78)                |
| A672                                    | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam                               | 0.85                | (78)                |
| A691                                    | 12, 22, 32, 42, 52 | Electric fusion welded pipe, 100% radiographed                              | 1.00                | ...                 |
|                                         | 13, 23, 33, 43, 53 | Electric fusion welded pipe, double butt seam                               | 0.85                | (78)                |

**Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes,  $E_j$  (Cont'd)**

These quality factors are determined in accordance with [para. 302.3.4\(a\)](#). See also [para. 302.3.4\(b\)](#) and [Table 302.3.4](#) for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

| Spec. No.                      | Class (or Type) | Description                                    | $E_j$<br>[Note (2)] | Appendix A<br>Notes |
|--------------------------------|-----------------|------------------------------------------------|---------------------|---------------------|
| <b>Stainless Steel</b>         |                 |                                                |                     |                     |
| A249                           | ...             | Electric fusion welded tube, single butt seam  | 0.80                | ...                 |
| A268                           | ...             | Seamless tube                                  | 1.00                | ...                 |
|                                |                 | Electric fusion welded tube, double butt seam  | 0.85                | ...                 |
|                                |                 | Electric fusion welded tube, single butt seam  | 0.80                | ...                 |
| A269                           | ...             | Seamless tube                                  | 1.00                | ...                 |
|                                |                 | Electric fusion welded tube, double butt seam  | 0.85                | ...                 |
|                                |                 | Electric fusion welded tube, single butt seam  | 0.80                | ...                 |
| A270                           | ...             | Seamless tube                                  | 1.00                | ...                 |
|                                |                 | Electric fusion welded tube, double butt seam  | 0.85                | ...                 |
|                                |                 | Electric fusion welded tube, single butt seam  | 0.80                | ...                 |
| A312                           | ...             | Seamless pipe                                  | 1.00                | ...                 |
|                                |                 | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
|                                |                 | Electric fusion welded pipe, single butt seam  | 0.80                | ...                 |
|                                |                 | Electric fusion welded pipe, 100% radiographed | 1.00                | (46)                |
| A358                           | 1, 3, 4         | Electric fusion welded pipe, 100% radiographed | 1.00                | ...                 |
|                                | 5               | Electric fusion welded pipe, spot radiographed | 0.90                | ...                 |
|                                | 2               | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
| A376                           | ...             | Seamless pipe                                  | 1.00                | ...                 |
| A409                           | ...             | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
|                                |                 | Electric fusion welded pipe, single butt seam  | 0.80                | ...                 |
| A789                           | ...             | Seamless tube                                  | 1.00                | ...                 |
|                                |                 | Electric fusion welded tube, 100% radiographed | 1.00                | ...                 |
|                                |                 | Electric fusion welded tube, double butt       | 0.85                | ...                 |
|                                |                 | Electric fusion welded tube, single butt       | 0.80                | ...                 |
| A790                           | ...             | Seamless pipe                                  | 1.00                | ...                 |
|                                |                 | Electric fusion welded pipe, 100% radiographed | 1.00                | ...                 |
|                                |                 | Electric fusion welded pipe, double butt       | 0.85                | ...                 |
|                                |                 | Electric fusion welded pipe, single butt       | 0.80                | ...                 |
| A813                           | DW              | Electric fusion welded pipe, double butt       | 0.85                | ...                 |
|                                | SW              | Electric fusion welded pipe, single butt       | 0.80                | ...                 |
| A814                           | DW              | Electric fusion welded pipe, double butt       | 0.85                | ...                 |
|                                | SW              | Electric fusion welded pipe, single butt       | 0.80                | ...                 |
| A928                           | 1, 3, 4         | Electric fusion welded pipe, 100% radiographed | 1.00                | ...                 |
|                                | 5               | Electric fusion welded pipe, spot radiographed | 0.90                | ...                 |
|                                | 2               | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
| <b>Copper and Copper Alloy</b> |                 |                                                |                     |                     |
| B42                            | ...             | Seamless pipe                                  | 1.00                | ...                 |
| B43                            | ...             | Seamless pipe                                  | 1.00                | ...                 |
| B68                            | ...             | Seamless tube                                  | 1.00                | ...                 |
| B75                            | ...             | Seamless tube                                  | 1.00                | ...                 |
| B88                            | ...             | Seamless water tube                            | 1.00                | ...                 |

**Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes,  $E_j$  (Cont'd)**

These quality factors are determined in accordance with [para. 302.3.4\(a\)](#). See also [para. 302.3.4\(b\)](#) and [Table 302.3.4](#) for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

| Spec. No.                               | Class (or Type) | Description                                    | $E_j$<br>[Note (2)] | Appendix A<br>Notes |
|-----------------------------------------|-----------------|------------------------------------------------|---------------------|---------------------|
| <b>Copper and Copper Alloy (Cont'd)</b> |                 |                                                |                     |                     |
| B280                                    | ...             | Seamless tube                                  | 1.00                | ...                 |
| B466                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B467                                    | ...             | Electric resistance welded pipe                | 0.85                | ...                 |
|                                         |                 | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
|                                         |                 | Electric fusion welded pipe, single butt seam  | 0.80                | ...                 |
| <b>Nickel and Nickel Alloy</b>          |                 |                                                |                     |                     |
| B161                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B163                                    | ...             | Seamless tube                                  | 1.00                | ...                 |
| B165                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B167                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B407                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B444                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B464                                    | ...             | Welded pipe                                    | 0.80                | ...                 |
| B474                                    | 1, 3, 4         | Welded pipe, 100% radiographed                 | 1.00                | ...                 |
|                                         | 2               | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
| B514                                    | ...             | Welded pipe                                    | 0.80                | ...                 |
| B515                                    | ...             | Welded tube                                    | 0.80                | ...                 |
| B619                                    | ...             | Electric resistance welded pipe                | 0.85                | ...                 |
|                                         |                 | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
|                                         |                 | Electric fusion welded pipe, single butt seam  | 0.80                | ...                 |
| B622                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B626                                    | All             | Electric resistance welded tube                | 0.85                | ...                 |
|                                         |                 | Electric fusion welded tube, double butt seam  | 0.85                | ...                 |
|                                         |                 | Electric fusion welded tube, single butt seam  | 0.80                | ...                 |
| B668                                    | All             | Seamless pipe and tube                         | 1.00                | ...                 |
| B675                                    | All             | Welded pipe                                    | 0.80                | ...                 |
| B690                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B704                                    | ...             | Welded tube                                    | 0.80                | ...                 |
| B705                                    | ...             | Welded pipe                                    | 0.80                | ...                 |
| B725                                    | ...             | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
|                                         |                 | Electric fusion welded pipe, single butt seam  | 0.80                | ...                 |
| B729                                    | ...             | Seamless pipe and tube                         | 1.00                | ...                 |
| B804                                    | 1, 3, 5         | Welded pipe, 100% radiographed                 | 1.00                | ...                 |
|                                         | 2, 4            | Welded pipe, double fusion welded              | 0.85                | ...                 |
|                                         | 6               | Welded pipe, single fusion welded              | 0.80                | ...                 |
| <b>Titanium and Titanium Alloy</b>      |                 |                                                |                     |                     |
| B338                                    | ...             | Seamless tube                                  | 1.00                | ...                 |
|                                         |                 | Electric fusion welded tube, 100% radiographed | 1.00                | ...                 |

**Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes,  $E_j$  (Cont'd)**

These quality factors are determined in accordance with [para. 302.3.4\(a\)](#). See also [para. 302.3.4\(b\)](#) and [Table 302.3.4](#) for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

| Spec. No.                                   | Class (or Type) | Description                                    | $E_j$<br>[Note (2)] | Appendix A<br>Notes |
|---------------------------------------------|-----------------|------------------------------------------------|---------------------|---------------------|
| <b>Titanium and Titanium Alloy (Cont'd)</b> |                 |                                                |                     |                     |
|                                             |                 | Electric fusion welded tube, double butt seam  | 0.85                | ...                 |
|                                             |                 | Electric fusion welded tube, single butt seam  | 0.80                | ...                 |
| B861                                        | ...             | Seamless pipe                                  | 1.00                | ...                 |
| B862                                        | ...             | Electric fusion welded pipe, 100% radiographed | 1.00                | ...                 |
|                                             |                 | Electric fusion welded pipe, double butt seam  | 0.85                | ...                 |
|                                             |                 | Electric fusion welded pipe, single butt seam  | 0.80                | ...                 |
| <b>Zirconium and Zirconium Alloy</b>        |                 |                                                |                     |                     |
| B523                                        | ...             | Seamless tube                                  | 1.00                | ...                 |
|                                             |                 | Electric fusion welded tube                    | 0.80                | ...                 |
| B658                                        | ...             | Seamless pipe                                  | 1.00                | ...                 |
|                                             |                 | Electric fusion welded pipe                    | 0.80                | ...                 |
| <b>Aluminum Alloy</b>                       |                 |                                                |                     |                     |
| B210                                        | ...             | Seamless tube                                  | 1.00                | ...                 |
| B241                                        | ...             | Seamless pipe and tube                         | 1.00                | ...                 |

TABLE STARTS ON NEXT PAGE

(20)

**Table A-2 Design Stress Values for Bolting Materials**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal Composition | Product Form   | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size Range,<br>Dia., in. | Notes     | Min. Temp.,<br>°F (6) | Specified Min. Strength, ksi |       | Design Stress, ksi, at Metal Temperature, °F [Note (1)] |      |      |      |      |  |
|---------------------|----------------|-----------|------------|---------|----------------------------|--------------------------|-----------|-----------------------|------------------------------|-------|---------------------------------------------------------|------|------|------|------|--|
|                     |                |           |            |         |                            |                          |           |                       | Tensile                      | Yield | Min. Temp. to 100                                       | 200  | 300  | 400  | 500  |  |
| ...                 | Bolts          | A675      | 45         | D40450  | ...                        | ...                      | (8f) (8g) | -20                   | 45                           | 22.5  | 11.3                                                    | 11.3 | 11.3 | 11.3 | 11.3 |  |
| ...                 | Bolts          | A675      | 50         | D40500  | ...                        | ...                      | (8f) (8g) | -20                   | 50                           | 25    | 12.5                                                    | 12.5 | 12.5 | 12.5 | 12.5 |  |
| ...                 | Bolts          | A675      | 55         | D40550  | ...                        | ...                      | (8f) (8g) | -20                   | 55                           | 27.5  | 13.8                                                    | 13.8 | 13.8 | 13.8 | 13.8 |  |
| ...                 | Bolts          | A307      | B          | ...     | ...                        | ...                      | (8f) (8g) | -20                   | 60                           | ...   | 15.0                                                    | 15.0 | 15.0 | 15.0 | 15.0 |  |
| ...                 | Bolts          | A675      | 60         | D40600  | ...                        | ...                      | (8f) (8g) | -20                   | 60                           | 30    | 15.0                                                    | 15.0 | 15.0 | 15.0 | 15.0 |  |
| ...                 | Bolts          | A675      | 65         | D40650  | ...                        | ...                      | (8g)      | -20                   | 65                           | 32.5  | 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 |  |
| ...                 | Bolts          | A675      | 70         | D40700  | ...                        | ...                      | (8g)      | -20                   | 70                           | 35    | 17.5                                                    | 17.5 | 17.5 | 17.5 | 17.5 |  |
| ...                 | Bolts          | A675      | 80         | D40800  | ...                        | ...                      | (8g)      | -20                   | 80                           | 40    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| ...                 | Bolts          | F3125     | A325       | K02706  | ...                        | ...                      | (8g)      | -20                   | 120                          | 92    | 23.0                                                    | 23.0 | 23.0 | 23.0 | 23.0 |  |
| ...                 | Nuts           | A194      | 1          | K01503  | ...                        | ...                      | (42)      | -20                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| ...                 | Nuts           | A194      | 2          | K04002  | ...                        | ...                      | (42)      | -55                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| ...                 | Nuts           | A194      | 2H         | K04002  | ...                        | ...                      | (42)      | -55                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| ...                 | Nuts           | A194      | 2HM        | K04002  | ...                        | ...                      | (42)      | -55                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| ...                 | Nuts, hvy. hex | A563      | A          | K05802  | ...                        | ...                      | (42b)     | -20                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| Alloy Steel         |                |           |            |         |                            |                          |           |                       |                              |       |                                                         |      |      |      |      |  |
| Cr-1⁄5Mo            | Bolts          | A193      | B7M        | G41400  | ...                        | ≤4                       | ...       | -55                   | 100                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| Cr-1⁄5Mo            | Bolts          | A320      | L7M        | G41400  | ...                        | ≤2½                      | ...       | -100                  | 100                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 5Cr                 | Bolts          | A193      | B5         | S50100  | ...                        | ≤4                       | (15)      | -20                   | 100                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| Cr-Mo-V             | Bolts          | A193      | B16        | K14072  | ...                        | >2½, ≤4                  | (15)      | -20                   | 110                          | 95    | 22.0                                                    | 22.0 | 22.0 | 22.0 | 22.0 |  |
| Alloy steel         | Bolts          | A354      | BC         | K04100  | ...                        | >2½, ≤4                  | (15)      | 0                     | 115                          | 99    | 23.0                                                    | 23.0 | 23.0 | 23.0 | 23.0 |  |
| Cr-Mo               | Bolts          | A193      | B7         | G41400  | ...                        | >2½, ≤4                  | (15)      | -40                   | 115                          | 95    | 23.0                                                    | 23.0 | 23.0 | 23.0 | 23.0 |  |
| Ni-Cr-Mo            | Bolts          | A320      | L43        | G43400  | ...                        | ≤4                       | (15)      | -150                  | 125                          | 105   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Cr-Mo               | Bolts          | A320      | L7         | G41400  | ...                        | ≤2½                      | (15)      | -150                  | 125                          | 105   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Cr-Mo               | Bolts          | A320      | L7A        | G40370  | ...                        | ≤2½                      | (15)      | -150                  | 125                          | 105   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Cr-Mo               | Bolts          | A320      | L7B        | G41370  | ...                        | ≤2½                      | (15)      | -150                  | 125                          | 105   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Cr-Mo               | Bolts          | A320      | L7C        | G87400  | ...                        | ≤2½                      | (15)      | -150                  | 125                          | 105   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Cr-Mo               | Bolts          | A193      | B7         | G41400  | ...                        | ≤2½                      | ...       | -55                   | 125                          | 105   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Cr-Mo-V             | Bolts          | A193      | B16        | K14072  | ...                        | ≤2½                      | (15)      | -20                   | 125                          | 105   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Alloy steel         | Bolts          | A354      | BC         | K04100  | ...                        | ≤2½                      | (15)      | 0                     | 125                          | 109   | 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 |  |
| Alloy steel         | Bolts          | A354      | BD         | K04100  | ...                        | ≤4                       | (15)      | -20                   | 150                          | 130   | 30.0                                                    | 30.0 | 30.0 | 30.0 | 30.0 |  |
| 5Cr                 | Nuts           | A194      | 3          | S50100  | ...                        | ...                      | (42)      | -20                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| Cr-Mo               | Nuts           | A194      | 7          | G41400  | ...                        | ...                      | (42)      | -55                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| Cr-Mo               | Nuts           | A194      | 7L         | G41400  | ...                        | ...                      | (42)      | -150                  | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| Cr-Mo               | Nuts           | A194      | 7M         | G41400  | ...                        | ...                      | (42)      | -55                   | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| Cr-Mo               | Nuts           | A194      | 7ML        | G41400  | ...                        | ...                      | (42)      | -100                  | ...                          | ...   | ...                                                     | ...  | ...  | ...  | ...  |  |
| Stainless Steel     |                |           |            |         |                            |                          |           |                       |                              |       |                                                         |      |      |      |      |  |
| 16Cr-12Ni-2Mo       | Bolts          | A193      | B8M        | S31600  | 2                          | >1¼, ≤1½                 | (15) (60) | -325                  | 90                           | 50    | 18.8                                                    | 17.3 | 15.6 | 14.3 | 13.3 |  |
| 16Cr-12Ni-2Mo       | Bolts          | A320      | B8M        | S31600  | 2                          | >1¼, ≤1½                 | (15) (60) | -325                  | 90                           | 50    | 18.8                                                    | 17.3 | 15.6 | 14.3 | 13.3 |  |



**Table A-2 Design Stress Values for Bolting Materials**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |     | Type/<br>Grade | Spec.<br>No. |
|---------------------------------------------------------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|----------------|--------------|
| 600                                                     | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 |     |                |              |
| 11.3                                                    | 11.1 | 10.7 | 10.4 | 9.2  | 7.9  | 5.9  | 4.0  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 45             | A675         |
| 12.5                                                    | 12.4 | 11.9 | 10.7 | 9.2  | 7.9  | 5.9  | 4.0  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 50             | A675         |
| 13.8                                                    | 13.6 | 13.1 | 12.7 | 10.8 | 8.7  | 5.9  | 4.0  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 55             | A675         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B              | A307         |
| 15.0                                                    | 14.8 | 14.3 | 13.8 | 11.4 | 8.7  | 5.9  | 4.0  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 60             | A675         |
| 16.3                                                    | 16.1 | 15.5 | 13.9 | 11.4 | 9.0  | 6.3  | 4.0  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 65             | A675         |
| 17.5                                                    | 17.3 | 16.7 | 14.8 | 12.0 | 9.3  | 6.7  | 4.0  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 70             | A675         |
| 20.0                                                    | 19.8 | 19.1 | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 80             | A675         |
| 23.0                                                    | 23.0 | 23.0 | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | A325           | F3125        |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 1              | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 2              | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 2H             | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 2HM            | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | A              | A563         |
| Alloy Steel                                             |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |     |                |              |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 18.5 | 16.3 | 12.5 | 8.5  | 4.5   | 2.4   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B7M            | A193         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 18.5 | 16.3 | 12.5 | 8.5  | 4.5   | 2.4   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | L7M            | A320         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 14.3 | 10.9 | 8.0  | 5.8   | 4.2   | 2.9   | 1.8   | 1.0   | 0.6   | ...   | ...   | ...   | ...   | ...   | ... | B5             | A193         |
| 22.0                                                    | 22.0 | 22.0 | 22.0 | 22.0 | 21.0 | 18.5 | 15.3 | 11.0  | 6.3   | 2.8   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B16            | A193         |
| 23.0                                                    | 23.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | BC             | A354         |
| 23.0                                                    | 23.0 | 23.0 | 23.0 | 20.0 | 16.3 | 12.5 | 8.5  | 4.5   | 2.4   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B7             | A193         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | L43            | A320         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | L7             | A320         |
| 25.0                                                    | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | L7A            | A320         |
| 25.0                                                    | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | L7B            | A320         |
| 25.0                                                    | 25.0 | 25.0 | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | L7C            | A320         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 | 21.0 | 17.0 | 12.5 | 8.5   | 4.5   | 2.4   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B7             | A193         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 | 23.5 | 20.5 | 16.0 | 11.0  | 6.3   | 2.8   | 1.2   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B16            | A193         |
| 25.0                                                    | 25.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | BC             | A354         |
| 30.0                                                    | 30.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | BD             | A354         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 3              | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 7              | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 7L             | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 7M             | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | 7ML            | A194         |
| Stainless Steel                                         |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |     |                |              |
| 12.6                                                    | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5  | 12.5  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B8M Cl. 2      | A193         |
| 12.6                                                    | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5  | 12.5  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ... | B8M Cl. 2      | A320         |

**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., in. | Notes          | Min. Temp., °F (6) | Specified Min. Strength, ksi |       | Design Stress, ksi, at Metal Temperature, °F [Note (1)] |      |      |      |      |  |
|---------------------|--------------|-----------|-------------|---------|--------------------------|-----------------------|----------------|--------------------|------------------------------|-------|---------------------------------------------------------|------|------|------|------|--|
|                     |              |           |             |         |                          |                       |                |                    | Tensile                      | Yield | Min. Temp. to 100                                       | 200  | 300  | 400  | 500  |  |
|                     |              |           |             |         |                          |                       |                |                    |                              |       |                                                         |      |      |      |      |  |
| Stainless Steel     |              |           |             |         |                          |                       |                |                    |                              |       |                                                         |      |      |      |      |  |
| 18Cr-8Ni            | Bolts        | A193      | B8          | S30400  | 2                        | >1¼, ≤1½              | (15) (60)      | -325               | 100                          | 50    | 18.8                                                    | 16.7 | 15.0 | 13.8 | 12.9 |  |
| 18Cr-8Ni            | Bolts        | A320      | B8          | S30400  | 2                        | >1¼, ≤1½              | (15) (60)      | -325               | 100                          | 50    | 18.8                                                    | 16.7 | 15.0 | 13.8 | 12.9 |  |
| 18Cr-10Ni-Cb        | Bolts        | A193      | B8C         | ...     | 2                        | >1¼, ≤1½              | (15) (60)      | -325               | 100                          | 50    | 18.8                                                    | 17.9 | 16.5 | 15.5 | 15.0 |  |
| 18Cr-10Ni-Cb        | Bolts        | A320      | B8C         | S34700  | 2                        | >1¼, ≤1½              | (15) (60)      | -325               | 100                          | 50    | 18.8                                                    | 17.9 | 16.5 | 15.5 | 15.0 |  |
| 18Cr-10Ni-Ti        | Bolts        | A193      | B8T         | S32100  | 2                        | >1¼, ≤1½              | (15) (60)      | -325               | 100                          | 50    | 18.8                                                    | 17.8 | 16.5 | 15.3 | 14.3 |  |
| 18Cr-10Ni-Ti        | Bolts        | A320      | B8T         | S32100  | 2                        | >1¼, ≤1½              | (15) (60)      | -325               | 100                          | 50    | 18.8                                                    | 17.8 | 16.5 | 15.3 | 14.3 |  |
| 18Cr-9Ni            | Bolts        | A320      | B8F         | S30300  | 1                        | ...                   | (8f) (15) (39) | -325               | 75                           | 30    | 18.8                                                    | 16.7 | 15.0 | 13.8 | 12.9 |  |
|                     |              |           |             |         |                          |                       |                |                    |                              |       |                                                         |      |      |      |      |  |
| 19Cr-9Ni            | Bolts        | A453      | 651B        | ...     | ...                      | >3                    | (15) (35)      | -20                | 95                           | 50    | 23.8                                                    | 23.4 | 22.1 | 21.3 | 20.8 |  |
| 19Cr-9Ni            | Bolts        | A453      | 651B        | ...     | ...                      | ≤3                    | (15) (35)      | -20                | 95                           | 60    | 23.8                                                    | 23.4 | 22.1 | 21.3 | 20.8 |  |
| 19Cr-9Ni            | Bolts        | A453      | 651A        | ...     | ...                      | >3                    | (15) (35)      | -20                | 100                          | 60    | 23.8                                                    | 23.4 | 22.1 | 21.3 | 20.8 |  |
| 19Cr-9Ni            | Bolts        | A453      | 651A        | ...     | ...                      | ≤3                    | (15) (35)      | -20                | 100                          | 70    | 23.8                                                    | 23.4 | 22.1 | 21.3 | 20.8 |  |
|                     |              |           |             |         |                          |                       |                |                    |                              |       |                                                         |      |      |      |      |  |
| 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M         | S31600  | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 17.3 | 16.3 | 16.3 | 16.3 |  |
| 16Cr-12Ni-2Mo       | Bolts        | A320      | B8M         | S31600  | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 17.3 | 16.3 | 16.3 | 16.3 |  |
| 18Cr-10Ni-Cb        | Bolts        | A193      | B8C         | ...     | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 17.9 | 16.5 | 16.3 | 16.3 |  |
| 18Cr-10Ni-Cb        | Bolts        | A320      | B8C         | S34700  | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 17.9 | 16.5 | 16.3 | 16.3 |  |
| 18Cr-8Ni            | Bolts        | A193      | B8          | S30400  | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 16.7 | 16.3 | 16.3 | 16.3 |  |
| 18Cr-8Ni            | Bolts        | A320      | B8          | S30400  | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 16.7 | 16.3 | 16.3 | 16.3 |  |
| 18Cr-10Ni-Ti        | Bolts        | A193      | B8T         | S32100  | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 17.8 | 16.5 | 16.3 | 16.3 |  |
| 18Cr-10Ni-Ti        | Bolts        | A320      | B8T         | S32100  | 2                        | >1, ≤1¼               | (15) (60)      | -325               | 105                          | 65    | 18.8                                                    | 17.8 | 16.5 | 16.3 | 16.3 |  |
|                     |              |           |             |         |                          |                       |                |                    |                              |       |                                                         |      |      |      |      |  |
| 18Cr-10Ni-Ti        | Bolts        | A193      | B8T         | S32100  | 1                        | ...                   | (8f) (15) (28) | -325               | 75                           | 30    | 18.8                                                    | 17.8 | 16.5 | 15.3 | 14.3 |  |
| 18Cr-8Ni            | Bolts        | A193      | B8          | S30400  | 1                        | ...                   | (8f) (15) (28) | -425               | 75                           | 30    | 18.8                                                    | 16.7 | 15.0 | 13.8 | 12.9 |  |
| 18Cr-8Ni            | Bolts        | A320      | B8          | S30400  | 1                        | ...                   | (8f) (15) (28) | -425               | 75                           | 30    | 18.8                                                    | 16.7 | 15.0 | 13.8 | 12.9 |  |
| 18Cr-10Ni-Cb        | Bolts        | A193      | B8C         | ...     | 1                        | ...                   | (8f) (15) (28) | -425               | 75                           | 30    | 18.8                                                    | 17.9 | 16.5 | 15.5 | 15.0 |  |
| 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M         | S31600  | 1                        | ...                   | (8f) (15) (28) | -325               | 75                           | 30    | 18.8                                                    | 17.3 | 15.6 | 14.3 | 13.3 |  |
|                     |              |           |             |         |                          |                       |                |                    |                              |       |                                                         |      |      |      |      |  |
| 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M         | S31600  | 2                        | >¾, ≤1                | (15) (60)      | -325               | 100                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 16Cr-12Ni-2Mo       | Bolts        | A320      | B8M         | S31600  | 2                        | >¾, ≤1                | (15) (60)      | -325               | 100                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 18Cr-10Ni-Cb        | Bolts        | A193      | B8C         | ...     | 2                        | >¾, ≤1                | (15) (60)      | -325               | 115                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 18Cr-10Ni-Cb        | Bolts        | A320      | B8C         | S34700  | 2                        | >¾, ≤1                | (15) (60)      | -325               | 115                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 18Cr-8Ni            | Bolts        | A193      | B8          | S30400  | 2                        | >¾, ≤1                | (15) (60)      | -325               | 115                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 18Cr-8Ni            | Bolts        | A320      | B8          | S30400  | 2                        | >¾, ≤1                | (15) (60)      | -325               | 115                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 18Cr-10Ni-Ti        | Bolts        | A193      | B8T         | S32100  | 2                        | >¾, ≤1                | (15) (60)      | -325               | 115                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
| 18Cr-10Ni-Ti        | Bolts        | A320      | B8T         | S32100  | 2                        | >¾, ≤1                | (15) (60)      | -325               | 115                          | 80    | 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 |  |
|                     |              |           |             |         |                          |                       |                |                    |                              |       |                                                         |      |      |      |      |  |
| 12Cr                | Bolts        | A437      | B4C         | S42200  | ...                      | ...                   | (35)           | -20                | 115                          | 85    | 21.3                                                    | 21.3 | 21.3 | 21.3 | 21.3 |  |
| 13Cr                | Bolts        | A193      | B6          | S41000  | ...                      | ≤4                    | (15) (35)      | -20                | 110                          | 85    | 21.3                                                    | 21.3 | 21.3 | 21.3 | 21.3 |  |

**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     | Type/<br>Grade           | Spec.<br>No. |
|---------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------------------------|--------------|
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     | Stainless Steel (Cont'd) |              |
| 12.5                                                    | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A193         |
| 12.5                                                    | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A320         |
| 14.3                                                    | 14.0 | 13.8 | 13.7 | 13.6 | 13.5 | 13.4 | 13.4 | 13.4 | 12.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A193         |
| 14.3                                                    | 14.0 | 13.8 | 13.7 | 13.6 | 13.5 | 13.4 | 13.4 | 13.4 | 12.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A320         |
| 13.5                                                    | 13.2 | 13.0 | 12.7 | 12.6 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A193         |
| 13.5                                                    | 13.2 | 13.0 | 12.7 | 12.6 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A320         |
| 12.3                                                    | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8F Cl. 1                | A320         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 20.5                                                    | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651B                     | A453         |
| 20.5                                                    | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651B                     | A453         |
| 20.5                                                    | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651A                     | A453         |
| 20.5                                                    | 20.4 | 20.3 | 20.2 | 20.0 | 19.7 | 19.3 | 18.9 | 18.2 | 17.5 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 651A                     | A453         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2                | A193         |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2                | A320         |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A193         |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A320         |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A193         |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A320         |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A193         |
| 16.3                                                    | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A320         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 13.5                                                    | 13.2 | 13.0 | 12.7 | 12.6 | 12.4 | 12.3 | 12.1 | 12.0 | 9.6  | 6.9  | 5.0 | 3.6 | 2.6 | 1.7 | 1.1 | 0.8 | 0.5 | 0.3 | ... | B8T Cl. 1                | A193         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 12.3                                                    | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.6 | 10.4 | 10.1 | 9.8  | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | ... | B8 Cl. 1                 | A193         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 12.3                                                    | 12.0 | 11.7 | 11.5 | 11.2 | 11.0 | 10.8 | 10.6 | 10.4 | 10.1 | 9.8  | 7.7 | 6.1 | 4.7 | 3.7 | 2.9 | 2.3 | 1.8 | 1.4 | ... | B8 Cl. 1                 | A320         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 14.3                                                    | 14.0 | 13.8 | 13.7 | 13.6 | 13.5 | 13.4 | 13.4 | 13.4 | 12.1 | 9.1  | 6.1 | 4.4 | 3.3 | 2.2 | 1.5 | 1.2 | 0.9 | 0.8 | ... | B8C Cl. 1                | A193         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 12.6                                                    | 12.3 | 12.1 | 11.9 | 11.8 | 11.6 | 11.5 | 11.4 | 11.3 | 11.2 | 11.1 | 9.8 | 7.4 | 5.6 | 4.2 | 3.2 | 2.4 | 1.8 | 1.4 | ... | B8M Cl. 1                | A193         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2                | A193         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2                | A320         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A193         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A320         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A193         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A320         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A193         |
| 20.0                                                    | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A320         |
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |                          |              |
| 21.3                                                    | 21.3 | 21.3 | 21.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B4C                      | A437         |
| 21.3                                                    | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 20.2 | 18.7 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B6                       | A193         |

**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal<br>Composition | Product<br>Form | Spec.<br>No. | Type/<br>Grade | UNS No. | Class/<br>Condition/<br>Temper | Size Range,<br>Dia., in.      | Notes     | Min.<br>Temp.,<br>°F (6) | Specified Min.<br>Strength, ksi |       | Design Stress, ksi, at<br>Metal Temperature,<br>°F [Note (1)] |      |      |      |      |  |
|------------------------|-----------------|--------------|----------------|---------|--------------------------------|-------------------------------|-----------|--------------------------|---------------------------------|-------|---------------------------------------------------------------|------|------|------|------|--|
|                        |                 |              |                |         |                                |                               |           |                          | Tensile                         | Yield | Min.<br>Temp.<br>to 100                                       | 200  | 300  | 400  | 500  |  |
| Stainless Steel        |                 |              |                |         |                                |                               |           |                          |                                 |       |                                                               |      |      |      |      |  |
| 14Cr-24Ni              | Bolts           | A453         | 660            | S66286  | A                              | ...                           | (15) (35) | -325                     | 130                             | 85    | 21.3                                                          | 21.3 | 21.3 | 21.3 | 21.3 |  |
| 14Cr-24Ni              | Bolts           | A453         | 660            | S66286  | B                              | ...                           | (15) (35) | -325                     | 130                             | 85    | 21.3                                                          | 21.3 | 21.3 | 21.3 | 21.3 |  |
|                        |                 |              |                |         |                                |                               |           |                          |                                 |       |                                                               |      |      |      |      |  |
| 16Cr-12Ni-2Mo          | Bolts           | A193         | B8M            | S31600  | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 110                             | 95    | 22.0                                                          | 22.0 | 22.0 | 22.0 | 22.0 |  |
| 16Cr-12Ni-2Mo          | Bolts           | A320         | B8M            | S31600  | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 110                             | 95    | 22.0                                                          | 22.0 | 22.0 | 22.0 | 22.0 |  |
|                        |                 |              |                |         |                                |                               |           |                          |                                 |       |                                                               |      |      |      |      |  |
| 18Cr-10Ni-Cb           | Bolts           | A193         | B8C            | ...     | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 125                             | 100   | 25.0                                                          | 25.0 | 25.0 | 25.0 | 25.0 |  |
| 18Cr-10Ni-Cb           | Bolts           | A320         | B8C            | S34700  | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 125                             | 100   | 25.0                                                          | 25.0 | 25.0 | 25.0 | 25.0 |  |
| 18Cr-8Ni               | Bolts           | A193         | B8             | S30400  | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 125                             | 100   | 25.0                                                          | 25.0 | 25.0 | 25.0 | 25.0 |  |
| 18Cr-8Ni               | Bolts           | A320         | B8             | S30400  | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 125                             | 100   | 25.0                                                          | 25.0 | 25.0 | 25.0 | 25.0 |  |
| 18Cr-10Ni-Ti           | Bolts           | A193         | B8T            | S32100  | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 125                             | 100   | 25.0                                                          | 25.0 | 25.0 | 25.0 | 25.0 |  |
| 18Cr-10Ni-Ti           | Bolts           | A320         | B8T            | S32100  | 2                              | ≤ <sup>3</sup> / <sub>4</sub> | (15) (60) | -325                     | 125                             | 100   | 25.0                                                          | 25.0 | 25.0 | 25.0 | 25.0 |  |
|                        |                 |              |                |         |                                |                               |           |                          |                                 |       |                                                               |      |      |      |      |  |
| 12Cr                   | Bolts           | A437         | B4B            | S42225  | ...                            | ...                           | (35)      | -20                      | 145                             | 105   | 26.3                                                          | 26.3 | 26.3 | 26.3 | 26.3 |  |
| 12Cr                   | Nuts            | A194         | 6              | S41000  | ...                            | ...                           | (35) (42) | -20                      | ...                             | ...   | ...                                                           | ...  | ...  | ...  | ...  |  |
| 18Cr-9Ni               | Nuts            | A194         | 8FA            | S30300  | ...                            | ...                           | (42)      | -20                      | ...                             | ...   | ...                                                           | ...  | ...  | ...  | ...  |  |
|                        |                 |              |                |         |                                |                               |           |                          |                                 |       |                                                               |      |      |      |      |  |
| 16Cr-12Ni-2Mo          | Nuts            | A194         | 8MA            | S31600  | ...                            | ...                           | (42)      | -325                     | ...                             | ...   | ...                                                           | ...  | ...  | ...  | ...  |  |
| 18Cr-10Ni-Ti           | Nuts            | A194         | 8TA            | S32100  | ...                            | ...                           | (42)      | -325                     | ...                             | ...   | ...                                                           | ...  | ...  | ...  | ...  |  |
|                        |                 |              |                |         |                                |                               |           |                          |                                 |       |                                                               |      |      |      |      |  |
| 18Cr-8Ni               | Nuts            | A194         | 8              | S30400  | ...                            | ...                           | (42)      | -425                     | ...                             | ...   | ...                                                           | ...  | ...  | ...  | ...  |  |
| 18Cr-8Ni               | Nuts            | A194         | 8A             | S30400  | ...                            | ...                           | (42)      | -425                     | ...                             | ...   | ...                                                           | ...  | ...  | ...  | ...  |  |
| 18Cr-10Ni-Cb           | Nuts            | A194         | 8CA            | S34700  | ...                            | ...                           | (42)      | -425                     | ...                             | ...   | ...                                                           | ...  | ...  | ...  | ...  |  |

**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     | Type/<br>Grade           | Spec.<br>No. |
|---------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------------------------|--------------|
|                                                         |      |      |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     | Stainless Steel (Cont'd) |              |
| 21.3                                                    | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 660 Cl. A                | A453         |
| 21.3                                                    | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 660 Cl. B                | A453         |
| 22.0                                                    | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2                | A193         |
| 22.0                                                    | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8M Cl. 2                | A320         |
| 24.6                                                    | 24.5 | 24.5 | 24.5 | 24.5 | 24.5 | 24.5 | 24.4 | 24.2 | 23.9 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A193         |
| 24.6                                                    | 24.5 | 24.5 | 24.5 | 24.5 | 24.5 | 24.5 | 24.4 | 24.2 | 23.9 | 23.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8C Cl. 2                | A320         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 24.7 | 23.9 | 22.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A193         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 24.7 | 23.9 | 22.9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8 Cl. 2                 | A320         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A193         |
| 25.0                                                    | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | B8T Cl. 2                | A320         |
| 26.3                                                    | 26.3 | 26.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | B4B                      | A437         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 6                        | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8FA                      | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8MA                      | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8TA                      | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8                        | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8A                       | A194         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8CA                      | A194         |

**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal<br>Composition  | Product<br>Form | Spec.<br>No. | Type/<br>Grade | UNS No. | Class/<br>Condition/<br>Temper | Size<br>Range,<br>Dia., in. | Notes     | Min.<br>Temp.,<br>°F (6) | Specified Min.<br>Strength, ksi |       | Design Stress,<br>ksi, at Metal<br>Temperature, °F<br>[Note (1)] |      |      |  |
|-------------------------|-----------------|--------------|----------------|---------|--------------------------------|-----------------------------|-----------|--------------------------|---------------------------------|-------|------------------------------------------------------------------|------|------|--|
|                         |                 |              |                |         |                                |                             |           |                          | Tensile                         | Yield | Min.<br>Temp.<br>to 100                                          | 200  | 300  |  |
|                         |                 |              |                |         |                                |                             |           |                          |                                 |       |                                                                  |      |      |  |
| Copper and Copper Alloy |                 |              |                |         |                                |                             |           |                          |                                 |       |                                                                  |      |      |  |
| Naval brass             | Bolts           | B21          | ...            | C46400  | O60                            | ...                         | (8f)      | -325                     | 50                              | 20    | 12.5                                                             | 12.5 | 12.5 |  |
| Naval brass             | Bolts           | B21          | ...            | C48200  | O60                            | ...                         | (8f)      | -325                     | 50                              | 20    | 12.5                                                             | 12.5 | 12.5 |  |
| Naval brass             | Bolts           | B21          | ...            | C48500  | O60                            | ...                         | (8f)      | -325                     | 50                              | 20    | 12.5                                                             | 12.5 | 12.5 |  |
| Cu                      | Bolts           | B187         | ...            | C10200  | O60                            | ...                         | (8f)      | -325                     | 30                              | 10    | 6.7                                                              | 5.4  | 5.0  |  |
| Cu                      | Bolts           | B187         | ...            | C11000  | O60                            | ...                         | (8f)      | -325                     | 30                              | 10    | 6.7                                                              | 5.4  | 5.0  |  |
| Cu                      | Bolts           | B187         | ...            | C12000  | O60                            | ...                         | (8f)      | -325                     | 30                              | 10    | 6.7                                                              | 5.4  | 5.0  |  |
| Cu                      | Bolts           | B187         | ...            | C12200  | O60                            | ...                         | (8f)      | -325                     | 30                              | 10    | 6.7                                                              | 5.4  | 5.0  |  |
| Cu-Si                   | Bolts           | B98          | ...            | C65100  | O60                            | ...                         | (8f) (52) | -325                     | 40                              | 12    | 8.0                                                              | 8.0  | 7.1  |  |
| Cu-Si                   | Bolts           | B98          | ...            | C65500  | O60                            | ...                         | (8f) (52) | -325                     | 52                              | 15    | 10.0                                                             | 10.0 | 10.0 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C66100  | O60                            | ...                         | (8f) (52) | -325                     | 52                              | 15    | 10.0                                                             | 10.0 | 10.0 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C65500  | H01                            | ...                         | (8f)      | -325                     | 55                              | 24    | 10.0                                                             | 10.0 | 10.0 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C66100  | H01                            | ...                         | (8f)      | -325                     | 55                              | 24    | 10.0                                                             | 10.0 | 10.0 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C65500  | H02                            | <2                          | ...       | -325                     | 70                              | 38    | 10.0                                                             | 10.0 | 10.0 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C66100  | H02                            | <2                          | ...       | -325                     | 70                              | 38    | 10.0                                                             | 10.0 | 10.0 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C65100  | H06                            | >1, <1½                     | ...       | -325                     | 75                              | 40    | 10.0                                                             | 10.0 | 10.0 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C65100  | H06                            | >½, ≤1                      | ...       | -325                     | 75                              | 45    | 11.3                                                             | 11.3 | 11.3 |  |
| Cu-Si                   | Bolts           | B98          | ...            | C65100  | H06                            | ≤½                          | ...       | -325                     | 85                              | 55    | 13.8                                                             | 13.8 | 13.8 |  |
| Al-Si-bronze            | Bolts           | B150         | ...            | C64200  | HR50                           | >1, ≤2                      | ...       | -325                     | 80                              | 42    | 16.7                                                             | 13.9 | 13.4 |  |
| Al-Si-bronze            | Bolts           | B150         | ...            | C64200  | HR50                           | >½, ≤1                      | ...       | -325                     | 85                              | 42    | 16.7                                                             | 13.9 | 13.4 |  |
| Al-Si-bronze            | Bolts           | B150         | ...            | C64200  | HR50                           | ≤½                          | ...       | -325                     | 90                              | 42    | 16.7                                                             | 13.9 | 13.4 |  |
| Al-bronze               | Bolts           | B150         | ...            | C61400  | HR50                           | >1, ≤2                      | ...       | -325                     | 70                              | 32    | 17.5                                                             | 17.5 | 17.5 |  |
| Al-bronze               | Bolts           | B150         | ...            | C61400  | HR50                           | >½, ≤1                      | ...       | -325                     | 75                              | 35    | 17.5                                                             | 17.5 | 17.5 |  |
| Al-bronze               | Bolts           | B150         | ...            | C61400  | HR50                           | ≤½                          | ...       | -325                     | 80                              | 40    | 18.0                                                             | 18.0 | 18.0 |  |
| Al-bronze               | Bolts           | B150         | ...            | C63000  | HR50                           | >2, ≤3                      | ...       | -325                     | 85                              | 42.5  | 21.3                                                             | 21.3 | 21.0 |  |
| Al-bronze               | Bolts           | B150         | ...            | C63000  | M20                            | >3, ≤4                      | ...       | -325                     | 85                              | 42.5  | 20.0                                                             | 19.6 | 19.1 |  |
| Al-bronze               | Bolts           | B150         | ...            | C63000  | HR50                           | >1, ≤2                      | ...       | -325                     | 90                              | 45    | 22.5                                                             | 22.5 | 22.5 |  |
| Al-bronze               | Bolts           | B150         | ...            | C63000  | HR50                           | ≥½, ≤1                      | ...       | -325                     | 100                             | 50    | 22.5                                                             | 22.5 | 22.5 |  |
| Nickel and Nickel Alloy |                 |              |                |         |                                |                             |           |                          |                                 |       |                                                                  |      |      |  |
| Low C-Ni                | Bolts           | B160         | ...            | N02201  | Hot fin./ann.                  | ...                         | (8f)      | -325                     | 50                              | 10    | 6.7                                                              | 6.4  | 6.3  |  |
| Ni                      | Bolts           | B160         | ...            | N02200  | Hot fin.                       | ...                         | (8f)      | -325                     | 60                              | 15    | 10.0                                                             | 10.0 | 10.0 |  |
| Ni                      | Bolts           | B160         | ...            | N02200  | Annealed                       | ...                         | (8f)      | -325                     | 55                              | 15    | 10.0                                                             | 10.0 | 10.0 |  |
| Ni                      | Bolts           | B160         | ...            | N02200  | Cold drawn                     | ...                         | ...       | -325                     | 65                              | 40    | 10.0                                                             | 10.0 | 10.0 |  |
| Ni-Cu                   | Bolts           | B164         | ...            | N04400  | C.D./str. rel.                 | ...                         | (54)      | -325                     | 84                              | 50    | 16.7                                                             | 14.6 | 13.6 |  |
| Ni-Cu                   | Bolts           | B164         | ...            | N04405  | Cold drawn                     | ...                         | (54)      | -325                     | 85                              | 50    | 16.7                                                             | 14.6 | 13.6 |  |
| Ni-Cu                   | Bolts           | B164         | ...            | N04400  | Cold drawn                     | ...                         | (54)      | -325                     | 85                              | 55    | 16.7                                                             | 14.6 | 13.8 |  |
| Ni-Cu                   | Bolts           | B164         | ...            | N04400  | Annealed                       | ...                         | (8f)      | -325                     | 70                              | 25    | 16.7                                                             | 14.6 | 13.6 |  |
| Ni-Cu                   | Bolts           | B164         | ...            | N04405  | Annealed                       | ...                         | (8f)      | -325                     | 70                              | 25    | 16.7                                                             | 14.6 | 13.6 |  |

**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     | UNS<br>No. | Spec.<br>No. |
|---------------------------------------------------------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------------|--------------|
| <b>Copper and Copper Alloy</b>                          |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |            |              |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C46400     | B21          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C48200     | B21          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C48500     | B21          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C10200     | B187         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C11000     | B187         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C12000     | B187         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C12200     | B187         |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65500     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C66100     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65500     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C66100     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65500     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C66100     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100     | B98          |
| ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C65100     | B98          |
| 10.8                                                    | 5.2  | 1.7  | 1.2  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C64200     | B150         |
| 10.8                                                    | 5.2  | 1.7  | 1.2  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C64200     | B150         |
| 10.8                                                    | 5.2  | 1.7  | 1.2  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C64200     | B150         |
| 17.2                                                    | 16.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C61400     | B150         |
| 17.2                                                    | 16.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C61400     | B150         |
| 17.7                                                    | 16.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C61400     | B150         |
| 20.7                                                    | 19.4 | 12.0 | 8.6  | 6.0  | 4.2  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000     | B150         |
| 18.8                                                    | 17.6 | 12.0 | 8.6  | 6.0  | 4.2  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000     | B150         |
| 22.5                                                    | 21.1 | 12.0 | 8.6  | 6.0  | 4.2  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000     | B150         |
| 22.5                                                    | 21.1 | 12.0 | 8.6  | 6.0  | 4.2  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | C63000     | B150         |
| <b>Nickel and Nickel Alloy</b>                          |      |      |      |      |      |      |      |      |     |     |     |     |     |     |     |     |     |            |              |
| 6.2                                                     | 6.2  | 6.2  | 6.2  | 6.2  | 6.1  | 6.0  | 5.8  | 4.5  | 3.7 | 3.0 | 2.4 | 2.0 | 1.5 | 1.2 | 1.0 | ... | ... | N02201     | B160         |
| 10.0                                                    | 10.0 | 10.0 | 10.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200     | B160         |
| 10.0                                                    | 10.0 | 10.0 | 10.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200     | B160         |
| 10.0                                                    | 10.0 | 10.0 | 10.0 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | N02200     | B160         |
| 13.2                                                    | 13.1 | 13.1 | 13.1 | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400     | B164         |
| 13.2                                                    | 13.1 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04405     | B164         |
| 13.8                                                    | 13.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... | ... | N04400     | B164         |
| 13.2                                                    | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2 | ... | ... | ... | ... | ... | ... | ... | ... | N04400     | B164         |
| 13.2                                                    | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2 | ... | ... | ... | ... | ... | ... | ... | ... | N04405     | B164         |

**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Nominal<br>Composition  | Product<br>Form   | Spec.<br>No. | Type/<br>Grade | UNS No. | Class/<br>Condition/<br>Temper | Size<br>Range,<br>Dia., in.                                     | Notes             | Min.<br>Temp.,<br>°F (6) | Specified Min. |       | Design Stress,<br>ksi, at Metal |      |      |
|-------------------------|-------------------|--------------|----------------|---------|--------------------------------|-----------------------------------------------------------------|-------------------|--------------------------|----------------|-------|---------------------------------|------|------|
|                         |                   |              |                |         |                                |                                                                 |                   |                          | Strength, ksi  |       | Temperature, °F<br>[Note (1)]   |      |      |
|                         |                   |              |                |         |                                |                                                                 |                   |                          | Tensile        | Yield | Min.<br>Temp.<br>to 100         | 200  | 300  |
| Nickel and Nickel Alloy |                   |              |                |         |                                |                                                                 |                   |                          |                |       |                                 |      |      |
| Ni-Cu                   | Rod               | B164         | ...            | N04405  | Hot fin.                       | ≤3                                                              | ...               | -325                     | 75             | 35    | 16.7                            | 14.6 | 13.6 |
| Ni-Cu                   | Hex               | B164         | ...            | N04400  | Hot fin.                       | ≥2 <sup>1</sup> / <sub>8</sub> , ≤4                             | (8f)              | -325                     | 75             | 30    | 16.7                            | 14.6 | 13.6 |
| Ni-Cu                   | All except<br>hex | B164         | ...            | N04400  | Hot fin.                       | >2 <sup>1</sup> / <sub>8</sub>                                  | ...               | -325                     | 80             | 40    | 16.7                            | 14.6 | 13.6 |
| Ni-Cr-Fe                | Rod               | B166         | ...            | N06600  | Cold drawn                     | ≤3                                                              | (41) (54)         | -325                     | 105            | 80    | 20.0                            | 20.0 | 20.0 |
| Ni-Cr-Fe                | Rod               | B166         | ...            | N06600  | Hot fin.                       | ≤3                                                              | ...               | -325                     | 90             | 40    | 16.7                            | 15.9 | 15.2 |
| Ni-Cr-Fe                | Bolts             | B166         | ...            | N06600  | Annealed                       | ...                                                             | ...               | -325                     | 80             | 35    | 16.7                            | 15.9 | 15.2 |
| Ni-Cr-Fe                | Rod               | B166         | ...            | N06600  | Hot fin.                       | >3                                                              | ...               | -325                     | 85             | 35    | 16.7                            | 15.9 | 15.2 |
| Ni-Mo                   | Bolts             | B335         | ...            | N10001  | Annealed                       | ...                                                             | ...               | -325                     | 100            | 46    | 25.0                            | 25.0 | 25.0 |
| Ni-Mo-Cr                | Bolts             | B574         | ...            | N10276  | Sol. ann.                      | ...                                                             | ...               | -325                     | 100            | 41    | 25.0                            | 24.9 | 23.0 |
| Aluminum Alloy          |                   |              |                |         |                                |                                                                 |                   |                          |                |       |                                 |      |      |
| ...                     | Bolts             | B211         | 6061           | 6061    | T6, T651<br>wld.               | ≥ <sup>1</sup> / <sub>8</sub> , ≤8                              | (8f) (43)<br>(63) | -452                     | 24             | ...   | 4.8                             | 4.8  | 4.8  |
| ...                     | Bolts             | B211         | 6061           | 6061    | T6, T651                       | ≥ <sup>1</sup> / <sub>8</sub> , ≤8                              | (43) (63)         | -452                     | 42             | 35    | 8.4                             | 8.4  | 8.4  |
| ...                     | Bolts             | B211         | 2024           | 2024    | T4                             | >6 <sup>1</sup> / <sub>2</sub> , ≤8                             | (43) (63)         | -452                     | 58             | 38    | 9.5                             | 9.5  | 9.5  |
| ...                     | Bolts             | B211         | 2024           | 2024    | T4                             | >4 <sup>1</sup> / <sub>2</sub> , ≤6 <sup>1</sup> / <sub>2</sub> | (43) (63)         | -452                     | 62             | 40    | 10.0                            | 10.0 | 10.0 |
| ...                     | Bolts             | B211         | 2024           | 2024    | T4                             | ≥ <sup>1</sup> / <sub>2</sub> , ≤4 <sup>1</sup> / <sub>2</sub>  | (43) (63)         | -452                     | 62             | 42    | 10.5                            | 10.5 | 10.3 |
| ...                     | Bolts             | B211         | 2024           | 2024    | T4                             | ≥ <sup>1</sup> / <sub>8</sub> , < <sup>1</sup> / <sub>2</sub>   | (43) (63)         | -452                     | 62             | 45    | 11.3                            | 11.3 | 10.3 |
| ...                     | Bolts             | B211         | 2014           | 2014    | T6, T651                       | ≥ <sup>1</sup> / <sub>8</sub> , ≤8                              | (43) (63)         | -452                     | 65             | 55    | 13.0                            | 13.0 | 12.4 |



**Table A-2 Design Stress Values for Bolting Materials (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, ksi, at Metal Temperature, °F [Note (1)] |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |        | UNS<br>No. | Spec.<br>No. |
|---------------------------------------------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|--------|------------|--------------|
| 400                                                     | 500  | 600  | 650  | 700  | 750  | 800  | 850  | 900  | 950  | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 |        |            |              |
| Nickel and Nickel Alloy (Cont'd)                        |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |        |            |              |
| 13.2                                                    | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04405 | B164       |              |
| 13.2                                                    | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400 | B164       |              |
| 13.2                                                    | 13.1 | 13.1 | 13.1 | 13.0 | 12.9 | 12.7 | 12.6 | 12.5 | 9.2  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N04400 | B164       |              |
| 20.0                                                    | 20.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N06600 | B166       |              |
| 14.6                                                    | 14.0 | 13.5 | 13.3 | 13.1 | 12.9 | 12.7 | 12.5 | 12.4 | 10.0 | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | 1.8   | ...   | N06600 | B166       |              |
| 14.6                                                    | 14.0 | 13.5 | 13.3 | 13.1 | 12.9 | 12.7 | 12.5 | 12.4 | 9.2  | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | 1.8   | ...   | N06600 | B166       |              |
| 14.6                                                    | 14.0 | 13.5 | 13.3 | 13.1 | 12.9 | 12.7 | 12.5 | 12.4 | 9.2  | 7.0   | 4.5   | 3.0   | 2.2   | 2.0   | 1.8   | ...   | N06600 | B166       |              |
| 24.6                                                    | 24.3 | 23.6 | 23.3 | 23.0 | 22.8 | 22.6 | 22.5 | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | N10001 | B335       |              |
| 21.3                                                    | 19.9 | 18.7 | 18.2 | 17.8 | 17.4 | 17.1 | 16.9 | 16.7 | 16.6 | 16.5  | 16.5  | ...   | ...   | ...   | ...   | ...   | N10276 | B574       |              |
| Aluminum Alloy                                          |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |        |            |              |
| 3.6                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A96061 | B211       |              |
| 4.8                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A96061 | B211       |              |
| 4.2                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A92024 | B211       |              |
| 4.5                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A92024 | B211       |              |
| 4.5                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A92024 | B211       |              |
| 4.5                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A92024 | B211       |              |
| 4.3                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | A92014 | B211       |              |

(20)

**Table A-2M Design Stress Values for Bolting Materials (SI Units)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade  | UNS No. | Class/Condition/<br>Temper | Size Range,<br>Dia., mm | Notes        |
|----------|---------------------|--------------|-----------|-------------|---------|----------------------------|-------------------------|--------------|
| 1        | Carbon steel        | Bolts        | A675      | 45          | D40450  | ...                        | ...                     | (8f) (8g)    |
| 2        | Carbon steel        | Bolts        | A675      | 50          | D40500  | ...                        | ...                     | (8f) (8g)    |
| 3        | Carbon steel        | Bolts        | A675      | 55          | D40550  | ...                        | ...                     | (8f) (8g)    |
| 4        | Carbon steel        | Bolts        | A307      | B           | ...     | ...                        | ...                     | (8f) (8g)    |
| 5        | Carbon steel        | Bolts        | A675      | 60          | D40600  | ...                        | ...                     | (8f) (8g)    |
| 6        | Carbon steel        | Bolts        | A675      | 65          | D40650  | ...                        | ...                     | (8g)         |
| 7        | Carbon steel        | Bolts        | A675      | 70          | D40700  | ...                        | ...                     | (8g)         |
| 8        | Carbon steel        | Bolts        | A675      | 80          | D40800  | ...                        | ...                     | (8g)         |
| 9        | Carbon steel        | Bolts        | F3125     | A325        | K02706  | ...                        | ...                     | (8g)         |
| 10       | Carbon steel        | Nuts         | A194      | 1           | K01503  | ...                        | ...                     | (42)         |
| 11       | Carbon steel        | Nuts         | A194      | 2, 2H       | K04002  | ...                        | ...                     | (42)         |
| 12       | Carbon steel        | Nuts         | A194      | 2HM         | K04002  | ...                        | ...                     | (42)         |
| 13       | Carbon steel        | Nuts         | A563      | A, hvy. hex | K05802  | ...                        | ...                     | (42b)        |
| 14       | Cr-0.2Mo            | Bolts        | A193      | B7M         | G41400  | ...                        | ≤100                    | ...          |
| 15       | Cr-0.2Mo            | Bolts        | A320      | L7M         | G41400  | ...                        | ≤64                     | ...          |
| 16       | 5Cr                 | Bolts        | A193      | B5          | S50100  | ...                        | ≤100                    | (15)         |
| 17       | Cr-Mo-V             | Bolts        | A193      | B16         | K14072  | ...                        | >64, ≤100               | (15)         |
| 18       | Alloy steel         | Bolts        | A354      | BC          | ...     | ...                        | >64, ≤100               | (15)         |
| 19       | Cr-Mo               | Bolts        | A193      | B7          | G41400  | ...                        | >64, ≤100               | (15)         |
| 20       | Ni-Cr-Mo            | Bolts        | A320      | L43         | G43400  | ...                        | ≤100                    | (15)         |
| 21       | Cr-Mo               | Bolts        | A320      | L7          | G41400  | ...                        | ≤64                     | (15)         |
| 22       | Cr-Mo               | Bolts        | A320      | L7A         | G40370  | ...                        | ≤64                     | (15)         |
| 23       | Cr-Mo               | Bolts        | A320      | L7B         | G41370  | ...                        | ≤64                     | (15)         |
| 24       | Cr-Mo               | Bolts        | A320      | L7C         | G87400  | ...                        | ≤64                     | (15)         |
| 25       | Cr-Mo               | Bolts        | A193      | B7          | G41400  | ...                        | ≤64                     | ...          |
| 26       | Cr-Mo-V             | Bolts        | A193      | B16         | K14072  | ...                        | ≤64                     | (15)         |
| 27       | Alloy steel         | Bolts        | A354      | BC          | ...     | ...                        | ≤64                     | (15)         |
| 28       | Alloy steel         | Bolts        | A354      | BD          | ...     | ...                        | ≤100                    | (15)         |
| 29       | 5Cr                 | Nuts         | A194      | 3           | S50100  | ...                        | ...                     | (42)         |
| 30       | Cr-Mo               | Nuts         | A194      | 7           | G41400  | ...                        | ...                     | (42)         |
| 31       | Cr-Mo               | Nuts         | A194      | 7L          | G41400  | ...                        | ...                     | (42)         |
| 32       | Cr-Mo               | Nuts         | A194      | 7M          | G41400  | ...                        | ...                     | (42)         |
| 33       | Cr-Mo               | Nuts         | A194      | 7ML         | G41400  | ...                        | ...                     | (42)         |
| 34       | 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M         | S31600  | 2                          | >32, ≤38                | (15)<br>(60) |
| 35       | 16Cr-12Ni-2Mo       | Bolts        | A320      | B8M         | S31600  | 2                          | >32, ≤38                | (15)<br>(60) |
| 36       | 18Cr-8Ni            | Bolts        | A193      | B8          | S30400  | 2                          | >32, ≤38                | (15)<br>(60) |

**Table A-2M Design Stress Values for Bolting Materials (SI Units)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C<br>(6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |      |      |
|----------|-----------------------|----------------------------|--------------------------|--------------------|---------------------------------------------------------|------|------|------|------|------|------|------|
|          |                       |                            |                          |                    | Min. Temp. to 40                                        | 65   | 100  | 125  | 150  | 175  | 200  | 225  |
| 1        | -29                   | 310                        | 155                      | 482                | 77.6                                                    | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 | 77.6 |
| 2        | -29                   | 345                        | 172                      | 482                | 86.2                                                    | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 3        | -29                   | 379                        | 190                      | 482                | 94.8                                                    | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 | 94.8 |
| 4        | -29                   | 414                        | ...                      | 260                | 103                                                     | 103  | 103  | 103  | 103  | 103  | 103  | 103  |
| 5        | -29                   | 414                        | 207                      | 482                | 103                                                     | 103  | 103  | 103  | 103  | 103  | 103  | 103  |
| 6        | -29                   | 448                        | 224                      | 538                | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 7        | -29                   | 483                        | 241                      | 538                | 121                                                     | 121  | 121  | 121  | 121  | 121  | 121  | 121  |
| 8        | -29                   | 552                        | 276                      | 343                | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 9        | -29                   | 825                        | 635                      | 343                | 159                                                     | 159  | 159  | 159  | 159  | 159  | 159  | 159  |
| 10       | -29                   | ...                        | ...                      | 40                 | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 11       | -48                   | ...                        | ...                      | 40                 | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 12       | -48                   | ...                        | ...                      | 40                 | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 13       | -29                   | ...                        | ...                      | 40                 | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 14       | -48                   | 689                        | 552                      | 538                | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 15       | -73                   | 689                        | 552                      | 538                | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 16       | -29                   | 689                        | 552                      | 649                | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 17       | -29                   | 758                        | 655                      | 593                | 152                                                     | 152  | 152  | 152  | 152  | 152  | 152  | 152  |
| 18       | -18                   | 793                        | 683                      | 343                | 159                                                     | 159  | 159  | 159  | 159  | 159  | 159  | 159  |
| 19       | -40                   | 793                        | 655                      | 538                | 159                                                     | 159  | 159  | 159  | 159  | 159  | 159  | 159  |
| 20       | -101                  | 862                        | 724                      | 371                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 21       | -101                  | 862                        | 724                      | 371                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 22       | -101                  | 862                        | 724                      | 343                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 23       | -101                  | 862                        | 724                      | 343                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 24       | -101                  | 862                        | 724                      | 343                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 25       | -48                   | 862                        | 724                      | 538                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 26       | -29                   | 862                        | 724                      | 593                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 27       | -18                   | 862                        | 752                      | 343                | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  |
| 28       | -29                   | 1034                       | 896                      | 343                | 207                                                     | 207  | 207  | 207  | 207  | 207  | 207  | 207  |
| 29       | -29                   | ...                        | ...                      | 40                 | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 30       | -48                   | ...                        | ...                      | 593                | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 31       | -101                  | ...                        | ...                      | 593                | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 32       | -48                   | ...                        | ...                      | 593                | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 33       | -73                   | ...                        | ...                      | 593                | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 34       | -198                  | 621                        | 345                      | 538                | 129                                                     | 126  | 118  | 112  | 107  | 103  | 99.1 | 95.8 |
| 35       | -198                  | 621                        | 345                      | 538                | 129                                                     | 126  | 118  | 112  | 107  | 103  | 99.1 | 95.8 |
| 36       | -198                  | 689                        | 345                      | 538                | 129                                                     | 123  | 113  | 108  | 103  | 99.0 | 95.6 | 92.7 |

**Table A-2M Design Stress Values for Bolting Materials (SI Units)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 250                                                     | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  |
| 1        | 77.6                                                    | 77.6 | 77.6 | 77.6 | 76.0 | 73.7 | 71.5 | 64.0 | 55.8 | 43.9 | 31.7 | ...  |
| 2        | 86.2                                                    | 86.2 | 86.2 | 86.2 | 84.5 | 81.9 | 73.3 | 64.0 | 55.8 | 43.9 | 31.7 | ...  |
| 3        | 94.8                                                    | 94.8 | 94.8 | 94.8 | 92.9 | 90.1 | 87.4 | 75.3 | 62.1 | 45.0 | 31.7 | ...  |
| 4        | 103                                                     | 103  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 5        | 103                                                     | 103  | 103  | 103  | 101  | 98.3 | 95.1 | 79.5 | 62.6 | 45.0 | 31.7 | ...  |
| 6        | 112                                                     | 112  | 112  | 112  | 110  | 106  | 95.1 | 79.5 | 64.4 | 47.7 | 32.5 | 21.4 |
| 7        | 121                                                     | 121  | 121  | 121  | 118  | 115  | 101  | 83.8 | 66.8 | 50.3 | 33.2 | 21.4 |
| 8        | 138                                                     | 138  | 138  | 138  | 135  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 9        | 159                                                     | 159  | 159  | 159  | 159  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 10       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 11       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 12       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 13       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 14       | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 115  | 92.3 | 67.3 | 41.6 |
| 15       | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 115  | 92.3 | 67.3 | 41.6 |
| 16       | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 80.6 | 61.7 | 46.4 |
| 17       | 152                                                     | 152  | 152  | 152  | 152  | 152  | 152  | 152  | 148  | 132  | 113  | 88.3 |
| 18       | 159                                                     | 159  | 159  | 159  | 159  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 19       | 159                                                     | 159  | 159  | 159  | 159  | 159  | 159  | 159  | 116  | 92.3 | 67.3 | 41.6 |
| 20       | 172                                                     | 172  | 172  | 172  | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  |
| 21       | 172                                                     | 172  | 172  | 172  | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  |
| 22       | 172                                                     | 172  | 172  | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 23       | 172                                                     | 172  | 172  | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 24       | 172                                                     | 172  | 172  | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 25       | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  | 121  | 93.4 | 67.3 | 41.6 |
| 26       | 172                                                     | 172  | 172  | 172  | 172  | 172  | 172  | 172  | 166  | 146  | 121  | 90.1 |
| 27       | 172                                                     | 172  | 172  | 172  | 172  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 28       | 207                                                     | 207  | 207  | 207  | 207  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 29       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 30       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 31       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 32       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 33       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 34       | 92.8                                                    | 90.3 | 88.1 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 35       | 92.8                                                    | 90.3 | 88.1 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 36       | 90.1                                                    | 87.9 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |

**Table A-2M Design Stress Values for Bolting Materials (SI Units)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |     |     |     |     |     |     |     |     |
|---------------------------------------------------------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Line No.                                                | 550  | 575  | 600  | 625  | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 1                                                       | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 2                                                       | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 3                                                       | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 4                                                       | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 5                                                       | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 6                                                       | 14.2 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 7                                                       | 14.2 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 8                                                       | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 9                                                       | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 10                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 11                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 12                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 13                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 14                                                      | 23.5 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 15                                                      | 23.5 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 16                                                      | 34.7 | 25.5 | 17.8 | 11.4 | 6.7 | ... | ... | ... | ... | ... | ... | ... |
| 17                                                      | 59.3 | 33.0 | 15.9 | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 18                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 19                                                      | 23.5 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 20                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 21                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 22                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 23                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 24                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 25                                                      | 23.5 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 26                                                      | 59.3 | 33.0 | 15.9 | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 27                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 28                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 29                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 30                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 31                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 32                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 33                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 34                                                      | 86.2 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 35                                                      | 86.2 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 36                                                      | 86.2 | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temper | Size Range, Dia., mm | Notes             |
|----------|---------------------|--------------|-----------|------------|---------|------------------------|----------------------|-------------------|
| 37       | 18Cr-8Ni            | Bolts        | A320      | B8         | S30400  | 2                      | >32, ≤38             | (15)<br>(60)      |
| 38       | 18Cr-10Ni-Cb        | Bolts        | A193      | B8C        | ...     | 2                      | >32, ≤38             | (15)<br>(60)      |
| 39       | 18Cr-10Ni-Cb        | Bolts        | A320      | B8C        | S34700  | 2                      | >32, ≤38             | (15)<br>(60)      |
| 40       | 18Cr-10Ni-Ti        | Bolts        | A193      | B8T        | S32100  | 2                      | >32, ≤38             | (15)<br>(60)      |
| 41       | 18Cr-10Ni-Ti        | Bolts        | A320      | B8T        | S32100  | 2                      | >32, ≤38             | (15)<br>(60)      |
| 42       | 18Cr-9Ni            | Bolts        | A320      | B8F        | S30300  | 1                      | ...                  | (8f) (15)<br>(39) |
| 43       | 19Cr-9Ni            | Bolts        | A453      | 651B       | ...     | ...                    | >75                  | (15)<br>(35)      |
| 44       | 19Cr-9Ni            | Bolts        | A453      | 651B       | ...     | ...                    | ≤75                  | (15)<br>(35)      |
| 45       | 19Cr-9Ni            | Bolts        | A453      | 651A       | ...     | ...                    | >75                  | (15)<br>(35)      |
| 46       | 19Cr-9Ni            | Bolts        | A453      | 651A       | ...     | ...                    | ≤75                  | (15)<br>(35)      |
| 47       | 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M        | S31600  | 2                      | >25, ≤32             | (15)<br>(60)      |
| 48       | 16Cr-12Ni-2Mo       | Bolts        | A320      | B8M        | S31600  | 2                      | >25, ≤32             | (15)<br>(60)      |
| 49       | 18Cr-10Ni-Cb        | Bolts        | A193      | B8C        | ...     | 2                      | >25, ≤32             | (15)<br>(60)      |
| 50       | 18Cr-10Ni-Cb        | Bolts        | A320      | B8C        | S34700  | 2                      | >25, ≤32             | (15)<br>(60)      |
| 51       | 18Cr-8Ni            | Bolts        | A193      | B8         | S30400  | 2                      | >25, ≤32             | (15)<br>(60)      |
| 52       | 18Cr-8Ni            | Bolts        | A320      | B8         | S30400  | 2                      | >25, ≤32             | (15)<br>(60)      |
| 53       | 18Cr-10Ni-Ti        | Bolts        | A193      | B8T        | S32100  | 2                      | >25, ≤32             | (15)<br>(60)      |
| 54       | 18Cr-10Ni-Ti        | Bolts        | A320      | B8T        | S32100  | 2                      | >25, ≤32             | (15)<br>(60)      |
| 55       | 18Cr-10Ni-Ti        | Bolts        | A193      | B8T        | S32100  | 1                      | ...                  | (8f) (15)<br>(28) |
| 56       | 18Cr-8Ni            | Bolts        | A193      | B8         | S30400  | 1                      | ...                  | (8f) (15)<br>(28) |
| 57       | 18Cr-8Ni            | Bolts        | A320      | B8         | S30400  | 1                      | ...                  | (8f) (15)<br>(28) |
| 58       | 18Cr-10Ni-Cb        | Bolts        | A193      | B8C        | ...     | 1                      | ...                  | (8f) (15)<br>(28) |
| 59       | 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M        | S31600  | 1                      | ...                  | (8f) (15)<br>(28) |
| 60       | 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M        | S31600  | 2                      | >19, ≤25             | (15)<br>(60)      |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C<br>(6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |     |     |     |     |      |      |      |
|----------|-----------------------|----------------------------|--------------------------|--------------------|---------------------------------------------------------|-----|-----|-----|-----|------|------|------|
|          |                       |                            |                          |                    | Min. Temp. to 40                                        | 65  | 100 | 125 | 150 | 175  | 200  | 225  |
| 37       | -198                  | 689                        | 345                      | 538                | 129                                                     | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |
| 38       | -198                  | 689                        | 345                      | 538                | 129                                                     | 129 | 122 | 117 | 113 | 110  | 108  | 105  |
| 39       | -198                  | 689                        | 345                      | 538                | 129                                                     | 129 | 122 | 117 | 113 | 110  | 108  | 105  |
| 40       | -198                  | 689                        | 345                      | 538                | 129                                                     | 129 | 121 | 118 | 114 | 110  | 106  | 103  |
| 41       | -198                  | 689                        | 345                      | 538                | 129                                                     | 129 | 121 | 118 | 114 | 110  | 106  | 103  |
| 42       | -198                  | 517                        | 207                      | 427                | 129                                                     | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |
| 43       | -29                   | 655                        | 345                      | 538                | 164                                                     | 164 | 160 | 156 | 152 | 149  | 147  | 145  |
| 44       | -29                   | 655                        | 414                      | 538                | 164                                                     | 164 | 160 | 156 | 152 | 149  | 147  | 145  |
| 45       | -29                   | 689                        | 414                      | 538                | 164                                                     | 164 | 160 | 156 | 152 | 149  | 147  | 145  |
| 46       | -29                   | 689                        | 483                      | 538                | 164                                                     | 164 | 160 | 156 | 152 | 149  | 147  | 145  |
| 47       | -198                  | 724                        | 448                      | 538                | 129                                                     | 126 | 118 | 112 | 112 | 112  | 112  | 112  |
| 48       | -198                  | 724                        | 448                      | 538                | 129                                                     | 126 | 118 | 112 | 112 | 112  | 112  | 112  |
| 49       | -198                  | 724                        | 448                      | 538                | 129                                                     | 129 | 122 | 117 | 113 | 112  | 112  | 112  |
| 50       | -198                  | 724                        | 448                      | 538                | 129                                                     | 129 | 122 | 117 | 113 | 112  | 112  | 112  |
| 51       | -198                  | 724                        | 448                      | 538                | 129                                                     | 123 | 113 | 112 | 112 | 112  | 112  | 112  |
| 52       | -198                  | 724                        | 448                      | 538                | 129                                                     | 123 | 113 | 112 | 112 | 112  | 112  | 112  |
| 53       | -198                  | 724                        | 448                      | 538                | 129                                                     | 129 | 121 | 118 | 114 | 112  | 112  | 112  |
| 54       | -198                  | 724                        | 448                      | 538                | 129                                                     | 129 | 121 | 118 | 114 | 112  | 112  | 112  |
| 55       | -198                  | 517                        | 207                      | 816                | 129                                                     | 129 | 121 | 118 | 114 | 110  | 106  | 103  |
| 56       | -254                  | 517                        | 207                      | 816                | 129                                                     | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |
| 57       | -254                  | 517                        | 207                      | 816                | 129                                                     | 123 | 113 | 108 | 103 | 99.0 | 95.6 | 92.7 |
| 58       | -254                  | 517                        | 207                      | 816                | 129                                                     | 129 | 122 | 117 | 113 | 110  | 108  | 105  |
| 59       | -198                  | 517                        | 207                      | 816                | 129                                                     | 126 | 118 | 112 | 107 | 103  | 99.1 | 95.8 |
| 60       | -198                  | 689                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138  | 138  | 138  |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 250                                                     | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  |
| 37       | 90.1                                                    | 87.9 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 | 86.2 |
| 38       | 104                                                     | 102  | 99.9 | 98.0 | 96.4 | 95.2 | 94.2 | 93.5 | 93.0 | 92.7 | 92.6 | 92.4 |
| 39       | 104                                                     | 102  | 99.9 | 98.0 | 96.4 | 95.2 | 94.2 | 93.5 | 93.0 | 92.7 | 92.6 | 92.4 |
| 40       | 100                                                     | 97.2 | 94.7 | 92.6 | 90.8 | 89.2 | 87.8 | 86.6 | 86.2 | 86.2 | 86.2 | 86.2 |
| 41       | 100                                                     | 97.2 | 94.7 | 92.6 | 90.8 | 89.2 | 87.8 | 86.6 | 86.2 | 86.2 | 86.2 | 86.2 |
| 42       | 90.1                                                    | 87.9 | 85.8 | 84.0 | 82.3 | 80.6 | 79.1 | 77.6 | 76.2 | ...  | ...  | ...  |
| 43       | 144                                                     | 143  | 142  | 141  | 141  | 140  | 139  | 138  | 136  | 134  | 131  | 128  |
| 44       | 144                                                     | 143  | 142  | 141  | 141  | 140  | 139  | 138  | 136  | 134  | 131  | 128  |
| 45       | 144                                                     | 143  | 142  | 141  | 141  | 140  | 139  | 138  | 136  | 134  | 131  | 128  |
| 46       | 144                                                     | 143  | 142  | 141  | 141  | 140  | 139  | 138  | 136  | 134  | 131  | 128  |
| 47       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 48       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 49       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 50       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 51       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 52       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 53       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 54       | 112                                                     | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  | 112  |
| 55       | 99.9                                                    | 97.2 | 94.7 | 92.6 | 90.8 | 89.2 | 87.8 | 86.6 | 85.6 | 84.7 | 84.0 | 83.2 |
| 56       | 90.1                                                    | 87.9 | 85.8 | 84.0 | 82.3 | 80.6 | 79.1 | 77.6 | 76.2 | 74.8 | 73.4 | 72.1 |
| 57       | 90.1                                                    | 87.9 | 85.8 | 84.0 | 82.3 | 80.6 | 79.1 | 77.6 | 76.2 | 74.8 | 73.4 | 72.1 |
| 58       | 104                                                     | 102  | 99.9 | 98.0 | 96.4 | 95.2 | 94.2 | 93.5 | 93.0 | 92.7 | 92.6 | 92.4 |
| 59       | 92.8                                                    | 90.3 | 88.1 | 86.2 | 84.6 | 83.3 | 82.2 | 81.2 | 80.4 | 79.7 | 79.0 | 78.4 |
| 60       | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  | 138  |



**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |             |             |             |             |             |             |             |             |             |            |
|---------------------------------------------------------|------|------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|
| Line No.                                                | 550  | 575  | 600         | 625         | 650         | 675         | 700         | 725         | 750         | 775         | 800         | 825        |
| 37                                                      | 86.2 | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 38                                                      | 92.2 | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 39                                                      | 92.2 | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 40                                                      | 86.2 | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 41                                                      | 86.2 | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 42                                                      | ...  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 43                                                      | 124  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 44                                                      | 124  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 45                                                      | 124  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 46                                                      | 124  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 47                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 48                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 49                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 50                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 51                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 52                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 53                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 54                                                      | 112  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |
| 55                                                      | 82.4 | 59.2 | 44.0        | 32.9        | 24.5        | 18.3        | 12.5        | 8.5         | 6.2         | 4.3         | 2.8         | 1.7        |
| 56                                                      | 70.7 | 69.4 | <b>63.8</b> | <b>51.6</b> | <b>41.6</b> | <b>32.9</b> | <b>26.5</b> | <b>21.3</b> | <b>17.2</b> | <b>14.1</b> | <b>11.2</b> | <b>8.8</b> |
| 57                                                      | 70.7 | 69.4 | 63.8        | 51.6        | 41.6        | 32.9        | 26.5        | 21.3        | 17.2        | 14.1        | 11.2        | 8.8        |
| 58                                                      | 92.2 | 75.9 | 57.2        | 40.2        | 30.3        | 23.2        | 16.2        | 11.4        | 9.0         | 7.1         | 5.9         | 5.3        |
| 59                                                      | 77.7 | 76.9 | 75.9        | 65.0        | 50.5        | 39.2        | 30.4        | 23.6        | 18.4        | 14.3        | 11.1        | 8.6        |
| 60                                                      | 138  | ...  | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...        |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/ Grade | UNS No. | Class/ Condition/ Temper | Size Range, Dia., mm | Notes        |
|----------|---------------------|--------------|-----------|-------------|---------|--------------------------|----------------------|--------------|
| 61       | 16Cr-12Ni-2Mo       | Bolts        | A320      | B8M         | S31600  | 2                        | >19, ≤25             | (15)<br>(60) |
| 62       | 18Cr-10Ni-Cb        | Bolts        | A193      | B8C         | ...     | 2                        | >19, ≤25             | (15)<br>(60) |
| 63       | 18Cr-10Ni-Cb        | Bolts        | A320      | B8C         | S34700  | 2                        | >19, ≤25             | (15)<br>(60) |
| 64       | 18Cr-8Ni            | Bolts        | A193      | B8          | S30400  | 2                        | >19, ≤25             | (15)<br>(60) |
| 65       | 18Cr-8Ni            | Bolts        | A320      | B8          | S30400  | 2                        | >19, ≤25             | (15)<br>(60) |
| 66       | 18Cr-10Ni-Ti        | Bolts        | A193      | B8T         | S32100  | 2                        | >19, ≤25             | (15)<br>(60) |
| 67       | 18Cr-10Ni-Ti        | Bolts        | A320      | B8T         | S32100  | 2                        | >19, ≤25             | (15)<br>(60) |
| 68       | 12Cr                | Bolts        | A437      | B4C         | S42200  | ...                      | ...                  | (35)         |
| 69       | 13Cr                | Bolts        | A193      | B6          | S41000  | ...                      | ≤100                 | (15)<br>(35) |
| 70       | 14Cr-24Ni           | Bolts        | A453      | 660         | S66286  | A                        | ...                  | (15)<br>(35) |
| 71       | 14Cr-24Ni           | Bolts        | A453      | 660         | S66286  | B                        | ...                  | (15)<br>(35) |
| 72       | 16Cr-12Ni-2Mo       | Bolts        | A193      | B8M         | S31600  | 2                        | ≤19                  | (15)<br>(60) |
| 73       | 16Cr-12Ni-2Mo       | Bolts        | A320      | B8M         | S31600  | 2                        | ≤19                  | (15)<br>(60) |
| 74       | 18Cr-10Ni-Cb        | Bolts        | A193      | B8C         | ...     | 2                        | ≤19                  | (15)<br>(60) |
| 75       | 18Cr-10Ni-Cb        | Bolts        | A320      | B8C         | S34700  | 2                        | ≤19                  | (15)<br>(60) |
| 76       | 18Cr-8Ni            | Bolts        | A193      | B8          | S30400  | 2                        | ≤19                  | (15)<br>(60) |
| 77       | 18Cr-8Ni            | Bolts        | A320      | B8          | S30400  | 2                        | ≤19                  | (15)<br>(60) |
| 78       | 18Cr-10Ni-Ti        | Bolts        | A193      | B8T         | S32100  | 2                        | ≤19                  | (15)<br>(60) |
| 79       | 18Cr-10Ni-Ti        | Bolts        | A320      | B8T         | S32100  | 2                        | ≤19                  | (15)<br>(60) |
| 80       | 12Cr                | Bolts        | A437      | B4B         | S42225  | ...                      | ...                  | (35)         |
| 81       | 12Cr                | Nuts         | A194      | 6           | S41000  | ...                      | ...                  | (35)<br>(42) |
| 82       | 18Cr-9Ni            | Nuts         | A194      | 8FA         | S30300  | ...                      | ...                  | (42)         |
| 83       | 16Cr-12Ni-2Mo       | Nuts         | A194      | 8MA         | S31600  | ...                      | ...                  | (42)         |
| 84       | 18Cr-10Ni-Ti        | Nuts         | A194      | 8TA         | S32100  | ...                      | ...                  | (42)         |
| 85       | 18Cr-8Ni            | Nuts         | A194      | 8           | S30400  | ...                      | ...                  | (42)         |
| 86       | 18Cr-8Ni            | Nuts         | A194      | 8A          | S30400  | ...                      | ...                  | (42)         |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C<br>(6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |     |     |     |     |     |     |     |
|----------|-----------------------|----------------------------|--------------------------|--------------------|---------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|
|          |                       |                            |                          |                    | Min. Temp. to 40                                        | 65  | 100 | 125 | 150 | 175 | 200 | 225 |
| 61       | -198                  | 689                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 62       | -198                  | 793                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 63       | -198                  | 793                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 64       | -198                  | 793                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 65       | -198                  | 793                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 66       | -198                  | 793                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 67       | -198                  | 793                        | 552                      | 538                | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 68       | -29                   | 793                        | 586                      | 371                | 147                                                     | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 69       | -29                   | 758                        | 586                      | 482                | 147                                                     | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 70       | -198                  | 896                        | 586                      | 538                | 147                                                     | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 71       | -198                  | 896                        | 586                      | 538                | 147                                                     | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 72       | -198                  | 758                        | 655                      | 538                | 152                                                     | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 73       | -198                  | 758                        | 655                      | 538                | 152                                                     | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 74       | -198                  | 862                        | 689                      | 538                | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 75       | -198                  | 862                        | 689                      | 538                | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 76       | -198                  | 862                        | 689                      | 538                | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 77       | -198                  | 862                        | 689                      | 538                | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 78       | -198                  | 862                        | 689                      | 538                | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 79       | -198                  | 862                        | 689                      | 538                | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 80       | -29                   | 1000                       | 724                      | 343                | 181                                                     | 181 | 181 | 181 | 181 | 181 | 181 | 181 |
| 81       | -29                   | ...                        | ...                      | 40                 | ...                                                     | ... | ... | ... | ... | ... | ... | ... |
| 82       | -29                   | ...                        | ...                      | 40                 | ...                                                     | ... | ... | ... | ... | ... | ... | ... |
| 83       | -198                  | ...                        | ...                      | 40                 | ...                                                     | ... | ... | ... | ... | ... | ... | ... |
| 84       | -198                  | ...                        | ...                      | 40                 | ...                                                     | ... | ... | ... | ... | ... | ... | ... |
| 85       | -254                  | ...                        | ...                      | 40                 | ...                                                     | ... | ... | ... | ... | ... | ... | ... |
| 86       | -254                  | ...                        | ...                      | 40                 | ...                                                     | ... | ... | ... | ... | ... | ... | ... |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |     |     |     |     |     |     |     |     |     |     |     |
|----------|---------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|          | 250                                                     | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 |
| 61       | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 62       | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 63       | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 64       | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 65       | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 66       | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 67       | 138                                                     | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| 68       | 147                                                     | 147 | 147 | 147 | 147 | 147 | ... | ... | ... | ... | ... | ... |
| 69       | 147                                                     | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 141 | 133 | ... |
| 70       | 147                                                     | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 71       | 147                                                     | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 |
| 72       | 152                                                     | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 73       | 152                                                     | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 | 152 |
| 74       | 172                                                     | 171 | 170 | 170 | 169 | 169 | 169 | 169 | 169 | 168 | 167 | 166 |
| 75       | 172                                                     | 171 | 170 | 170 | 169 | 169 | 169 | 169 | 169 | 168 | 167 | 166 |
| 76       | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 168 |
| 77       | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 168 |
| 78       | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 79       | 172                                                     | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| 80       | 181                                                     | 181 | 181 | 181 | 181 | ... | ... | ... | ... | ... | ... | ... |
| 81       | ...                                                     | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 82       | ...                                                     | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 83       | ...                                                     | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 84       | ...                                                     | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 85       | ...                                                     | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 86       | ...                                                     | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, MPa, at Metal Temperature, °C [Note (1)] |     |     |     |     |     |     |     |     |     |     |     |     |
|---------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Line No.                                                | 550 | 575 | 600 | 625 | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 61                                                      | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 62                                                      | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 63                                                      | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 64                                                      | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 65                                                      | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 66                                                      | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 67                                                      | 138 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 68                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 69                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 70                                                      | 147 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 71                                                      | 147 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 72                                                      | 152 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 73                                                      | 152 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 74                                                      | 164 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 75                                                      | 164 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 76                                                      | 162 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 77                                                      | 162 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 78                                                      | 172 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 79                                                      | 172 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 80                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 81                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 82                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 83                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 84                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 85                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 86                                                      | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form | Spec. No. | Type/Grade | UNS No. | Class/Condition/<br>Temper | Size Range,<br>Dia., mm | Notes     |
|----------|---------------------|--------------|-----------|------------|---------|----------------------------|-------------------------|-----------|
| 87       | 18Cr-10Ni-Cb        | Nuts         | A194      | 8CA        | S34700  | ...                        | ...                     | (42)      |
| 88       | Naval brass         | Bolts        | B21       | ...        | C46400  | O60                        | ...                     | (8f)      |
| 89       | Naval brass         | Bolts        | B21       | ...        | C48200  | O60                        | ...                     | (8f)      |
| 90       | Naval brass         | Bolts        | B21       | ...        | C48500  | O60                        | ...                     | (8f)      |
| 91       | Cu                  | Bolts        | B187      | ...        | C10200  | O60                        | ...                     | (8f)      |
| 92       | Cu                  | Bolts        | B187      | ...        | C11000  | O60                        | ...                     | (8f)      |
| 93       | Cu                  | Bolts        | B187      | ...        | C12000  | O60                        | ...                     | (8f)      |
| 94       | Cu                  | Bolts        | B187      | ...        | C12200  | O60                        | ...                     | (8f)      |
| 95       | Cu-Si               | Bolts        | B98       | ...        | C65100  | O60                        | ...                     | (8f) (52) |
| 96       | Cu-Si               | Bolts        | B98       | ...        | C65500  | O60                        | ...                     | (8f) (52) |
| 97       | Cu-Si               | Bolts        | B98       | ...        | C66100  | O60                        | ...                     | (8f) (52) |
| 98       | Cu-Si               | Bolts        | B98       | ...        | C65500  | H01                        | ...                     | (8f)      |
| 99       | Cu-Si               | Bolts        | B98       | ...        | C66100  | H01                        | ...                     | (8f)      |
| 100      | Cu-Si               | Bolts        | B98       | ...        | C65500  | H02                        | ≤50                     | ...       |
| 101      | Cu-Si               | Bolts        | B98       | ...        | C66100  | H02                        | ≤50                     | ...       |
| 102      | Cu-Si               | Bolts        | B98       | ...        | C65100  | H06                        | >25, ≤38                | ...       |
| 103      | Cu-Si               | Bolts        | B98       | ...        | C65100  | H06                        | >13, ≤25                | ...       |
| 104      | Cu-Si               | Bolts        | B98       | ...        | C65100  | H06                        | ≤13                     | ...       |
| 105      | Al-Si-bronze        | Bolts        | B150      | ...        | C64200  | HR50                       | >25, ≤50                | ...       |
| 106      | Al-Si-bronze        | Bolts        | B150      | ...        | C64200  | HR50                       | >13, ≤25                | ...       |
| 107      | Al-Si-bronze        | Bolts        | B150      | ...        | C64200  | HR50                       | ≤13                     | ...       |
| 108      | Al-bronze           | Bolts        | B150      | ...        | C61400  | HR50                       | >25, ≤50                | ...       |
| 109      | Al-bronze           | Bolts        | B150      | ...        | C61400  | HR50                       | >13, ≤25                | ...       |
| 110      | Al-bronze           | Bolts        | B150      | ...        | C61400  | HR50                       | ≤13                     | ...       |
| 111      | Al-bronze           | Bolts        | B150      | ...        | C63000  | HR50                       | >50, ≤75                | ...       |
| 112      | Al-bronze           | Bolts        | B150      | ...        | C63000  | M20                        | >75, ≤100               | ...       |
| 113      | Al-bronze           | Bolts        | B150      | ...        | C63000  | HR50                       | >25, ≤50                | ...       |
| 114      | Al-bronze           | Bolts        | B150      | ...        | C63000  | HR50                       | ≥13, ≤25                | ...       |
| 115      | Low C-Ni            | Bolts        | B160      | ...        | N02201  | Hot fin./<br>ann.          | ...                     | (8f)      |
| 116      | Ni                  | Bolts        | B160      | ...        | N02200  | Hot fin.                   | ...                     | (8f)      |
| 117      | Ni                  | Bolts        | B160      | ...        | N02200  | Annealed                   | ...                     | (8f)      |
| 118      | Ni                  | Bolts        | B160      | ...        | N02200  | Cold drawn                 | ...                     | ...       |
| 119      | Ni-Cu               | Bolts        | B164      | ...        | N04400  | C.D./str. rel.             | ...                     | (54)      |
| 120      | Ni-Cu               | Bolts        | B164      | ...        | N04405  | Cold drawn                 | ...                     | (54)      |
| 121      | Ni-Cu               | Bolts        | B164      | ...        | N04400  | Cold drawn                 | ...                     | (54)      |
| 122      | Ni-Cu               | Bolts        | B164      | ...        | N04400  | Annealed                   | ...                     | (8f)      |
| 123      | Ni-Cu               | Bolts        | B164      | ...        | N04405  | Annealed                   | ...                     | (8f)      |
| 124      | Ni-Cu               | Rod          | B164      | ...        | N04405  | Hot fin.                   | ≤75                     | ...       |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C<br>(6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |      |      |
|----------|-----------------------|----------------------------|--------------------------|--------------------|---------------------------------------------------------|------|------|------|------|------|------|------|
|          |                       |                            |                          |                    | Min. Temp. to 40                                        | 65   | 100  | 125  | 150  | 175  | 200  | 225  |
| 87       | -254                  | ...                        | ...                      | 40                 | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 88       | -198                  | 345                        | 138                      | 149                | 86.2                                                    | 86.2 | 86.2 | 86.2 | 86.2 | ...  | ...  | ...  |
| 89       | -198                  | 345                        | 138                      | 149                | 86.2                                                    | 86.2 | 86.2 | 86.2 | 86.2 | ...  | ...  | ...  |
| 90       | -198                  | 345                        | 138                      | 149                | 86.2                                                    | 86.2 | 86.2 | 86.2 | 86.2 | ...  | ...  | ...  |
| 91       | -198                  | 207                        | 69                       | 149                | 46.0                                                    | 38.8 | 37.2 | 36.5 | 34.2 | ...  | ...  | ...  |
| 92       | -198                  | 207                        | 69                       | 149                | 46.0                                                    | 38.8 | 37.2 | 36.5 | 34.2 | ...  | ...  | ...  |
| 93       | -198                  | 207                        | 69                       | 149                | 46.0                                                    | 38.8 | 37.2 | 36.5 | 34.2 | ...  | ...  | ...  |
| 94       | -198                  | 207                        | 69                       | 149                | 46.0                                                    | 38.8 | 37.2 | 36.5 | 34.2 | ...  | ...  | ...  |
| 95       | -198                  | 276                        | 83                       | 149                | 55.2                                                    | 55.2 | 55.2 | 54.0 | 48.3 | ...  | ...  | ...  |
| 96       | -198                  | 359                        | 103                      | 149                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.8 | ...  | ...  | ...  |
| 97       | -198                  | 359                        | 103                      | 149                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.8 | ...  | ...  | ...  |
| 98       | -198                  | 379                        | 165                      | 149                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.8 | ...  | ...  | ...  |
| 99       | -198                  | 379                        | 165                      | 149                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.8 | ...  | ...  | ...  |
| 100      | -198                  | 483                        | 262                      | 149                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.8 | ...  | ...  | ...  |
| 101      | -198                  | 483                        | 262                      | 149                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.8 | ...  | ...  | ...  |
| 102      | -198                  | 517                        | 276                      | 149                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.9 | ...  | ...  | ...  |
| 103      | -198                  | 517                        | 310                      | 149                | 77.6                                                    | 77.6 | 77.6 | 77.6 | 77.6 | ...  | ...  | ...  |
| 104      | -198                  | 586                        | 379                      | 149                | 94.8                                                    | 94.8 | 94.8 | 94.8 | 94.8 | ...  | ...  | ...  |
| 105      | -198                  | 552                        | 290                      | 316                | 115                                                     | 100  | 95.2 | 93.6 | 92.1 | 89.1 | 76.9 | 57.7 |
| 106      | -198                  | 586                        | 290                      | 316                | 115                                                     | 100  | 95.2 | 93.6 | 92.1 | 89.1 | 76.9 | 57.7 |
| 107      | -198                  | 621                        | 290                      | 316                | 115                                                     | 100  | 95.2 | 93.6 | 92.1 | 89.1 | 76.9 | 57.7 |
| 108      | -198                  | 483                        | 221                      | 260                | 121                                                     | 121  | 121  | 121  | 121  | 121  | 119  | 115  |
| 109      | -198                  | 517                        | 241                      | 260                | 121                                                     | 121  | 121  | 121  | 121  | 121  | 119  | 115  |
| 110      | -198                  | 552                        | 276                      | 260                | 124                                                     | 124  | 124  | 124  | 124  | 124  | 122  | 118  |
| 111      | -198                  | 586                        | 293                      | 371                | 147                                                     | 147  | 147  | 146  | 145  | 144  | 143  | 140  |
| 112      | -198                  | 586                        | 293                      | 371                | 138                                                     | 137  | 134  | 133  | 132  | 131  | 130  | 128  |
| 113      | -198                  | 621                        | 310                      | 371                | 155                                                     | 155  | 155  | 155  | 155  | 155  | 155  | 153  |
| 114      | -198                  | 689                        | 345                      | 371                | 155                                                     | 155  | 155  | 155  | 155  | 155  | 155  | 153  |
| 115      | -198                  | 345                        | 69                       | 649                | 46.0                                                    | 44.8 | 44.0 | 43.6 | 43.3 | 43.1 | 43.0 | 43.0 |
| 116      | -198                  | 414                        | 103                      | 316                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 117      | -198                  | 379                        | 103                      | 316                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 118      | -198                  | 448                        | 276                      | 316                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 |
| 119      | -198                  | 579                        | 345                      | 316                | 115                                                     | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 120      | -198                  | 586                        | 345                      | 260                | 115                                                     | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 121      | -198                  | 586                        | 379                      | 260                | 115                                                     | 106  | 99.7 | 96.2 | 94.8 | 94.8 | 94.8 | 94.8 |
| 122      | -198                  | 483                        | 172                      | 482                | 115                                                     | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 123      | -198                  | 483                        | 172                      | 482                | 115                                                     | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 124      | -198                  | 517                        | 241                      | 482                | 115                                                     | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |      |      |      |      |      |      |
|----------|---------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|          | 250                                                     | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  |
| 87       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 88       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 89       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 90       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 91       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 92       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 93       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 94       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 95       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 96       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 97       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 98       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 99       | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 100      | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 101      | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 102      | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 103      | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 104      | ...                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 105      | 40.9                                                    | 24.1 | 14.5 | 10.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 106      | 40.9                                                    | 24.1 | 14.5 | 10.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 107      | 40.9                                                    | 24.1 | 14.5 | 10.3 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 108      | 111                                                     | 108  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 109      | 111                                                     | 109  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 110      | 115                                                     | 112  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 111      | 136                                                     | 126  | 97.2 | 73.9 | 54.4 | 39.3 | ...  | ...  | ...  | ...  | ...  | ...  |
| 112      | 124                                                     | 117  | 97.2 | 73.9 | 54.4 | 39.3 | ...  | ...  | ...  | ...  | ...  | ...  |
| 113      | 148                                                     | 126  | 97.2 | 73.9 | 54.4 | 39.3 | ...  | ...  | ...  | ...  | ...  | ...  |
| 114      | 148                                                     | 126  | 97.2 | 73.9 | 54.4 | 39.3 | ...  | ...  | ...  | ...  | ...  | ...  |
| 115      | 43.0                                                    | 43.0 | 43.0 | 43.0 | 42.9 | 42.7 | 42.2 | 41.6 | 40.7 | 33.1 | 27.4 | 22.8 |
| 116      | 68.9                                                    | 68.9 | 68.9 | 68.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 117      | 68.9                                                    | 68.9 | 68.9 | 68.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 118      | 68.9                                                    | 68.9 | 68.9 | 68.9 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 119      | 90.4                                                    | 90.4 | 90.4 | 90.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 120      | 90.4                                                    | 90.4 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 121      | 94.8                                                    | 94.8 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 122      | 90.4                                                    | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ...  |
| 123      | 90.4                                                    | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ...  |
| 124      | 90.4                                                    | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ...  |



**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |     |     |     |     |     |     |     |     |
|---------------------------------------------------------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Line No.                                                | 550  | 575  | 600  | 625  | 650 | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 87                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 88                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 89                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 90                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 91                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 92                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 93                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 94                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 95                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 96                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 97                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 98                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 99                                                      | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 100                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 101                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 102                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 103                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 104                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 105                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 106                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 107                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 108                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 109                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 110                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 111                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 112                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 113                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 114                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 115                                                     | 18.7 | 15.6 | 12.9 | 10.0 | 8.2 | ... | ... | ... | ... | ... | ... | ... |
| 116                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 117                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 118                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 119                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 120                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 121                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 122                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 123                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |
| 124                                                     | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... | ... |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Nominal Composition | Product Form   | Spec. No. | Type/Grade | UNS No. | Class/Condition/Temper | Size Range, Dia., mm | Notes             |
|----------|---------------------|----------------|-----------|------------|---------|------------------------|----------------------|-------------------|
| 125      | Ni-Cu               | Hex            | B164      | ...        | N04400  | Hot fin.               | ≥54, ≤100            | (8f)              |
| 126      | Ni-Cu               | All except hex | B164      | ...        | N04400  | Hot fin.               | >54                  | ...               |
| 127      | Ni-Cr-Fe            | Rod            | B166      | ...        | N06600  | Cold drawn             | ≤75                  | (41)<br>(54)      |
| 128      | Ni-Cr-Fe            | Rod            | B166      | ...        | N06600  | Hot fin.               | ≤75                  | ...               |
| 129      | Ni-Cr-Fe            | Bolts          | B166      | ...        | N06600  | Annealed               | ...                  | ...               |
| 130      | Ni-Cr-Fe            | Rod            | B166      | ...        | N06600  | Hot fin.               | >75                  | ...               |
| 131      | Ni-Mo               | Bolts          | B335      | ...        | N10001  | Annealed               | ...                  | ...               |
| 132      | Ni-Mo-Cr            | Bolts          | B574      | ...        | N10276  | Sol. ann.              | ...                  | ...               |
| 133      | Aluminum alloy      | Bolts          | B211      | 6061       | A96061  | T6, T651 wld.          | ≥3, ≤200             | (8f) (43)<br>(63) |
| 134      | Aluminum alloy      | Bolts          | B211      | 6061       | A96061  | T6, T651               | ≥3, ≤200             | (43)<br>(63)      |
| 135      | Aluminum alloy      | Bolts          | B211      | 2024       | A92024  | T4                     | >165, ≤200           | (43)<br>(63)      |
| 136      | Aluminum alloy      | Bolts          | B211      | 2024       | A92024  | T4                     | >114, ≤165           | (43)<br>(63)      |
| 137      | Aluminum alloy      | Bolts          | B211      | 2024       | A92024  | T4                     | >13, ≤114            | (43)<br>(63)      |
| 138      | Aluminum alloy      | Bolts          | B211      | 2024       | A92024  | T4                     | ≥3, <13              | (43)<br>(63)      |
| 139      | Aluminum alloy      | Bolts          | B211      | 2014       | A92014  | T6, T651               | ≥3, ≤200             | (43)<br>(63)      |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Line No. | Min. Temp., °C<br>(6) | Min. Tensile Strength, MPa | Min. Yield Strength, MPa | Max. Use Temp., °C | Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |      |      |
|----------|-----------------------|----------------------------|--------------------------|--------------------|---------------------------------------------------------|------|------|------|------|------|------|------|
|          |                       |                            |                          |                    | Min. Temp. to 40                                        | 65   | 100  | 125  | 150  | 175  | 200  | 225  |
| 125      | -198                  | 517                        | 207                      | 482                | 115                                                     | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 126      | -198                  | 552                        | 276                      | 482                | 115                                                     | 106  | 99.7 | 96.2 | 93.6 | 91.9 | 90.9 | 90.4 |
| 127      | -198                  | 724                        | 552                      | 260                | 138                                                     | 138  | 138  | 138  | 138  | 138  | 138  | 138  |
| 128      | -198                  | 621                        | 276                      | 649                | 115                                                     | 112  | 109  | 107  | 105  | 103  | 101  | 99.0 |
| 129      | -198                  | 552                        | 241                      | 649                | 115                                                     | 112  | 109  | 107  | 105  | 103  | 101  | 99.0 |
| 130      | -198                  | 586                        | 241                      | 649                | 115                                                     | 112  | 109  | 107  | 105  | 103  | 101  | 99.0 |
| 131      | -198                  | 689                        | 317                      | 427                | 172                                                     | 172  | 172  | 172  | 172  | 171  | 170  | 169  |
| 132      | -198                  | 689                        | 283                      | 538                | 172                                                     | 172  | 170  | 164  | 158  | 153  | 148  | 143  |
| 133      | -269                  | 165                        | ...                      | 204                | 33.1                                                    | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 26.4 | 16.1 |
| 134      | -269                  | 290                        | 241                      | 204                | 57.9                                                    | 57.9 | 57.9 | 57.9 | 57.9 | 47.3 | 34.9 | 21.1 |
| 135      | -269                  | 400                        | 262                      | 204                | 65.5                                                    | 65.5 | 65.5 | 65.5 | 65.5 | 43.1 | 29.3 | 29.3 |
| 136      | -269                  | 427                        | 276                      | 204                | 68.9                                                    | 68.9 | 68.9 | 68.9 | 68.9 | 46.1 | 31.3 | 31.3 |
| 137      | -269                  | 427                        | 290                      | 204                | 72.4                                                    | 72.4 | 72.4 | 72.4 | 70.2 | 46.2 | 31.2 | 31.2 |
| 138      | -269                  | 427                        | 310                      | 204                | 77.6                                                    | 77.6 | 77.6 | 77.6 | 70.2 | 46.2 | 31.2 | 31.2 |
| 139      | -269                  | 448                        | 379                      | 204                | 89.6                                                    | 89.6 | 89.6 | 89.6 | 84.2 | 46.9 | 26.2 | 20.2 |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |      |      |      |      |      |      |      |
|---------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Line No.                                                | 250  | 275  | 300  | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  |
| 125                                                     | 90.4 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ...  |
| 126                                                     | 90.4 | 90.4 | 90.4 | 90.4 | 90.4 | 89.8 | 89.0 | 88.0 | 87.0 | 86.4 | 75.6 | ...  |
| 127                                                     | 138  | 138  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 128                                                     | 97.3 | 95.6 | 94.0 | 92.6 | 91.2 | 89.9 | 88.7 | 87.7 | 86.7 | 85.8 | 75.6 | 58.4 |
| 129                                                     | 97.3 | 95.6 | 94.0 | 92.6 | 91.2 | 89.9 | 88.7 | 87.7 | 86.7 | 85.8 | 75.6 | 58.4 |
| 130                                                     | 97.3 | 95.6 | 94.0 | 92.6 | 91.2 | 89.9 | 88.7 | 87.7 | 86.7 | 85.8 | 75.6 | 58.4 |
| 131                                                     | 168  | 166  | 164  | 162  | 160  | 158  | 157  | 156  | 155  | ...  | ...  | ...  |
| 132                                                     | 139  | 135  | 131  | 128  | 125  | 122  | 120  | 118  | 117  | 115  | 115  | 114  |
| 133                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 134                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 135                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 136                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 137                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 138                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 139                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

| Design Stress, MPa, at Metal Temperature, °C [Note (1)] |      |      |      |      |      |     |     |     |     |     |     |     |
|---------------------------------------------------------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|
| Line No.                                                | 550  | 575  | 600  | 625  | 650  | 675 | 700 | 725 | 750 | 775 | 800 | 825 |
| 125                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 126                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 127                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 128                                                     | 39.7 | 27.0 | 19.2 | 15.0 | 13.7 | ... | ... | ... | ... | ... | ... | ... |
| 129                                                     | 39.7 | 27.0 | 19.2 | 15.0 | 13.7 | ... | ... | ... | ... | ... | ... | ... |
| 130                                                     | 39.7 | 27.0 | 19.2 | 15.0 | 13.7 | ... | ... | ... | ... | ... | ... | ... |
| 131                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 132                                                     | 114  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 133                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 134                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 135                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 136                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 137                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 138                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |
| 139                                                     | ...  | ...  | ...  | ...  | ...  | ... | ... | ... | ... | ... | ... | ... |

## **APPENDIX B**

# **STRESS TABLES AND ALLOWABLE PRESSURE TABLES FOR NONMETALS**

The data and Notes in [Appendix B](#) are requirements of this Code.

## Specification Index for Appendix B

(20)

| Spec. No.    | Title <a href="#">[Note (1)]</a>                                                                  |
|--------------|---------------------------------------------------------------------------------------------------|
| <b>ASTM</b>  |                                                                                                   |
| C361         | Reinforced Concrete Low-Head Pressure Pipe                                                        |
| C582         | Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment |
| C599         | Process Glass Pipe and Fittings                                                                   |
| D1785        | PVC Plastic Pipe, Schedules 40, 80, and 120                                                       |
| D2239        | PE Plastic Pipe (SDR-PR) Based on Controlled Inside Diameter                                      |
| D2241        | PVC Plastic Pressure-Rated Pipe (SDR Series)                                                      |
| D2513        | Thermoplastic Gas Pressure Pipe, Tubing and Fittings                                              |
| D2517        | Reinforced Epoxy Resin Gas Pressure Pipe and Fittings                                             |
| D2662        | PB Plastic Pipe (SDR-PR)                                                                          |
| D2666        | PB Plastic Tubing                                                                                 |
| D2672        | Joints for IPS PVC Pipe Using Solvent Cement                                                      |
| D2737        | PE Plastic Tubing                                                                                 |
| D2846        | CPVC Plastic Hot- and Cold-Water Distribution Systems                                             |
| D2996        | Filament-Wound Fiberglass RTR Pipe <a href="#">[Note (2)]</a>                                     |
| D2997        | Centrifugally Cast RTR Pipe <a href="#">[Note (2)]</a>                                            |
| D3000        | PB Plastic Pipe (SDR-PR) Based on Outside Diameter                                                |
| D3035        | PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter                                      |
| D3517        | Fiberglass RTR Pressure Pipe <a href="#">[Note (2)]</a>                                           |
| D3754        | Fiberglass RTR Sewer and Industrial Pressure Pipe <a href="#">[Note (2)]</a>                      |
| F441         | CPVC Plastic Pipe, Schedules 40 and 80                                                            |
| F442         | CPVC Plastic Pipe (SDR-PR)                                                                        |
| F2389        | Pressure-Rated Polypropylene (PP) Piping Systems                                                  |
| F2788/F2788M | Metric and Inch-sized Crosslinked Polyethylene (PEX) Pipe                                         |
| <b>AWWA</b>  |                                                                                                   |
| C300         | Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids               |
| C301         | Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids              |
| C302         | Reinforced Concrete Pressure Pipe, Noncylinder Type                                               |
| C950         | Fiberglass Pressure Pipe                                                                          |

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in [Appendix E](#).

## NOTES:

(1) For names of plastics identified only by abbreviation, see [para. A326.4](#).

(2) The term *fiberglass RTR* takes the place of the ASTM designation "*fiberglass*" (*glass-fiber-reinforced thermosetting resin*).

(20) **Table B-1 Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe**

| ASTM<br>Spec. No. | Pipe Designation    | Material<br>Designation | Cell<br>Class | Recommended<br>Temperature Limits, °F<br>[Notes (1), (2)] |         | Hydrostatic Design Stress, ksi, at |       |       |       |
|-------------------|---------------------|-------------------------|---------------|-----------------------------------------------------------|---------|------------------------------------|-------|-------|-------|
|                   |                     |                         |               | Minimum                                                   | Maximum | 73°F                               | 100°F | 180°F | 200°F |
|                   |                     |                         |               |                                                           |         | [Note (3)]                         |       |       |       |
| ...               | PR                  | ABS                     | 43232         | -40                                                       | 176     | ...                                | ...   | ...   | ...   |
| D2846             | SDR11               | CPVC4120                | 23447         | ...                                                       | 180     | 2.0                                | ...   | 0.5   | ...   |
| F441              | Sch. 40             | CPVC4120                | 23447         | 73                                                        | 200     | 2.0                                | ...   | 0.5   | ...   |
| F441              | Sch. 80             | CPVC4120                | 23447         | 73                                                        | 200     | 2.0                                | ...   | 0.5   | ...   |
| F442              | SDR-PR              | CPVC4120                | 23447         | 73                                                        | 200     | 2.0                                | 1.64  | 0.5   | ...   |
| D2239             | SDR-PR              | PE1404                  | ...           | 73                                                        | ...     | 0.40                               | ...   | ...   | ...   |
| D2737             | SDR7.3, SDR9, SDR11 | PE2305                  | ...           | 73                                                        | ...     | 0.50                               | ...   | ...   | ...   |
| D2737             | SDR7.3, SDR9, SDR11 | PE2306                  | ...           | 73                                                        | ...     | 0.63                               | ...   | ...   | ...   |
| D2737             | SDR7.3, SDR9, SDR11 | PE2406                  | ...           | 73                                                        | ...     | 0.63                               | ...   | ...   | ...   |
| D2737             | SDR7.3, SDR9, SDR11 | PE3306                  | ...           | 73                                                        | ...     | 0.63                               | ...   | ...   | ...   |
| D2737             | SDR7.3, SDR9, SDR11 | PE3406                  | ...           | 73                                                        | ...     | 0.63                               | ...   | ...   | ...   |
| D2737             | SDR7.3, SDR9, SDR11 | PE3408                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| D3035             | DR-PR               | PE1404                  | ...           | 73                                                        | ...     | 0.40                               | ...   | ...   | ...   |
| D3035             | DR-PR               | PE2708                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| D3035             | DR-PR               | PE3608                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| D3035             | DR-PR               | PE4608                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| D3035             | DR-PR               | PE4710                  | ...           | 73                                                        | ...     | 1.00                               | ...   | ...   | ...   |
| F714              | SDR-PR              | PE2708                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| F714              | SDR-PR              | PE3608                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| F714              | SDR-PR              | PE3708                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| F714              | SDR-PR              | PE3710                  | ...           | 73                                                        | ...     | 1.00                               | ...   | ...   | ...   |
| F714              | SDR-PR              | PE4608                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| F714              | SDR-PR              | PE4708                  | ...           | 73                                                        | ...     | 0.80                               | ...   | ...   | ...   |
| F714              | SDR-PR              | PE4710                  | ...           | 73                                                        | ...     | 1.00                               | ...   | ...   | ...   |
| F2788/<br>F2788M  | SDR/DR-PR           | PEX0006                 | ...           | -58                                                       | 230     | 0.63                               | ...   | 0.40  | 0.31  |
| F2788/<br>F2788M  | SDR/DR-PR           | PEX0008                 | ...           | -58                                                       | 230     | 0.80                               | ...   | 0.40  | 0.31  |
| F2389             | SDR6, SDR7.3, SDR11 | PP                      | ...           | 0                                                         | 210     | 0.63                               | 0.50  | 0.20  | ...   |
| D1785             | Sch. 40, 80, 120    | PVC1120                 | 12454         | 73                                                        | ...     | 2.00                               | ...   | ...   | ...   |
| D1785             | Sch. 40, 80, 120    | PVC1220                 | 12454         | 73                                                        | ...     | 2.00                               | ...   | ...   | ...   |
| D1785             | Sch. 40, 80, 120    | PVC2120                 | 14333         | 73                                                        | ...     | 2.00                               | ...   | ...   | ...   |
| D1785             | Sch. 40, 80, 120    | PVC2116                 | 14333         | 73                                                        | ...     | 1.60                               | ...   | ...   | ...   |
| D1785             | Sch. 40, 80, 120    | PVC2112                 | 14333         | 73                                                        | ...     | 1.25                               | ...   | ...   | ...   |
| D1785             | Sch. 40, 80, 120    | PVC2110                 | 14333         | 73                                                        | ...     | 1.00                               | ...   | ...   | ...   |
| D2241             | PR (SDR series)     | PVC1120                 | 12454         | 73                                                        | ...     | 2.00                               | ...   | ...   | ...   |
| D2241             | PR (SDR series)     | PVC1220                 | 12454         | 73                                                        | ...     | 2.00                               | ...   | ...   | ...   |
| D2241             | PR (SDR series)     | PVC2120                 | 14333         | 73                                                        | ...     | 2.00                               | ...   | ...   | ...   |
| D2241             | PR (SDR series)     | PVC2116                 | 14333         | 73                                                        | ...     | 1.60                               | ...   | ...   | ...   |
| D2241             | PR (SDR series)     | PVC2112                 | 14333         | 73                                                        | ...     | 1.25                               | ...   | ...   | ...   |



**Table B-1 Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (Cont'd)**

| ASTM<br>Spec. No. | Pipe Designation | Material<br>Designation | Cell<br>Class | Recommended<br>Temperature Limits, °F<br>[Notes (1), (2)] |         | Hydrostatic Design Stress, ksi, at |       |       |       |
|-------------------|------------------|-------------------------|---------------|-----------------------------------------------------------|---------|------------------------------------|-------|-------|-------|
|                   |                  |                         |               | Minimum                                                   | Maximum | 73°F<br>[Note (3)]                 | 100°F | 180°F | 200°F |
| D2241             | PR (SDR series)  | PVC2110                 | 14333         | 73                                                        | ...     | 1.00                               | ...   | ...   | ...   |

## NOTES:

- (1) These recommended limits are for low pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic. The upper temperature limits are reduced at higher pressures, depending on the combination of fluid and expected service life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.
- (2) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.
- (3) Use these hydrostatic design stress (HDS) values at all lower temperatures.

**Table B-1M Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (SI Units)**

(20)

| ASTM Spec. No.   | Pipe Designation    | Material Designation | Cell Class | Recommended Temperature Limits, °C<br>[Notes (1), (2)] |         | Hydrostatic Design Stress, MPa, at |      |      |      |
|------------------|---------------------|----------------------|------------|--------------------------------------------------------|---------|------------------------------------|------|------|------|
|                  |                     |                      |            | Minimum                                                | Maximum | 23°C<br>[Note (3)]                 | 38°C | 82°C | 93°C |
| ...              | PR                  | ABS                  | 43232      | -40                                                    | 80      | ...                                | ...  | ...  | ...  |
| D2846            | SDR11               | CPVC4120             | 23447      | ...                                                    | 82      | 13.8                               | ...  | 3.45 | ...  |
| F441             | Sch. 40             | CPVC4120             | 23447      | 23                                                     | 93.3    | 13.8                               | ...  | 3.45 | ...  |
| F441             | Sch. 80             | CPVC4120             | 23447      | 23                                                     | 93.3    | 13.8                               | ...  | 3.45 | ...  |
| F442             | SDR-PR              | CPVC4120             | 23447      | 23                                                     | 93.3    | 13.8                               | 11.3 | 3.45 | ...  |
| D2239            | SIDR-PR             | PE1404               | ...        | 23                                                     | ...     | 2.76                               | ...  | ...  | ...  |
| D2737            | SDR7.3, SDR9, SDR11 | PE2305               | ...        | 23                                                     | ...     | 3.45                               | ...  | ...  | ...  |
| D2737            | SDR7.3, SDR9, SDR11 | PE2306               | ...        | 23                                                     | ...     | 4.34                               | ...  | ...  | ...  |
| D2737            | SDR7.3, SDR9, SDR11 | PE2406               | ...        | 23                                                     | ...     | 4.34                               | ...  | ...  | ...  |
| D2737            | SDR7.3, SDR9, SDR11 | PE3306               | ...        | 23                                                     | ...     | 4.34                               | ...  | ...  | ...  |
| D2737            | SDR7.3, SDR9, SDR11 | PE3406               | ...        | 23                                                     | ...     | 4.34                               | ...  | ...  | ...  |
| D2737            | SDR7.3, SDR9, SDR11 | PE3408               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| D3035            | DR-PR               | PE1404               | ...        | 23                                                     | ...     | 2.76                               | ...  | ...  | ...  |
| D3035            | DR-PR               | PE2708               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| D3035            | DR-PR               | PE3608               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| D3035            | DR-PR               | PE4608               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| D3035            | DR-PR               | PE4710               | ...        | 23                                                     | ...     | 6.89                               | ...  | ...  | ...  |
| F714             | SDR-PR              | PE2708               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| F714             | SDR-PR              | PE3608               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| F714             | SDR-PR              | PE3708               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| F714             | SDR-PR              | PE3710               | ...        | 23                                                     | ...     | 6.89                               | ...  | ...  | ...  |
| F714             | SDR-PR              | PE4608               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| F714             | SDR-PR              | PE4708               | ...        | 23                                                     | ...     | 5.51                               | ...  | ...  | ...  |
| F714             | SDR-PR              | PE4710               | ...        | 23                                                     | ...     | 6.89                               | ...  | ...  | ...  |
| F2788/<br>F2788M | SDR/DR-PR           | PEX0006              | ...        | -50                                                    | 110     | 4.34                               | ...  | 2.76 | 2.17 |
| F2788/<br>F2788M | SDR/DR-PR           | PEX0008              | ...        | -50                                                    | 110     | 5.51                               | ...  | 2.76 | 2.17 |
| F2389            | SDR6, SDR7.3, SDR11 | PP                   | ...        | -18                                                    | 99      | 4.34                               | 3.45 | 1.38 | ...  |
| D1785            | Sch. 40, 80, 120    | PVC1120              | 12454      | 23                                                     | ...     | 13.8                               | ...  | ...  | ...  |
| D1785            | Sch. 40, 80, 120    | PVC1220              | 12454      | 23                                                     | ...     | 13.8                               | ...  | ...  | ...  |
| D1785            | Sch. 40, 80, 120    | PVC2120              | 14333      | 23                                                     | ...     | 13.8                               | ...  | ...  | ...  |
| D1785            | Sch. 40, 80, 120    | PVC2116              | 14333      | 23                                                     | ...     | 11.0                               | ...  | ...  | ...  |
| D1785            | Sch. 40, 80, 120    | PVC2112              | 14333      | 23                                                     | ...     | 8.6                                | ...  | ...  | ...  |
| D1785            | Sch. 40, 80, 120    | PVC2110              | 14333      | 23                                                     | ...     | 6.9                                | ...  | ...  | ...  |
| D2241            | PR (SDR series)     | PVC1120              | 12454      | 23                                                     | ...     | 13.8                               | ...  | ...  | ...  |
| D2241            | PR (SDR series)     | PVC1220              | 12454      | 23                                                     | ...     | 13.8                               | ...  | ...  | ...  |
| D2241            | PR (SDR series)     | PVC2120              | 14333      | 23                                                     | ...     | 13.8                               | ...  | ...  | ...  |

**Table B-1M Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (SI Units) (Cont'd)**

| ASTM Spec. No. | Pipe Designation | Material Designation | Cell Class | Recommended Temperature Limits, °C<br>[Notes (1), (2)] |         | Hydrostatic Design Stress, MPa, at |      |      |      |
|----------------|------------------|----------------------|------------|--------------------------------------------------------|---------|------------------------------------|------|------|------|
|                |                  |                      |            | Minimum                                                | Maximum | 23°C<br>[Note (3)]                 | 38°C | 82°C | 93°C |
| D2241          | PR (SDR series)  | PVC2116              | 14333      | 23                                                     | ...     | 11.0                               | ...  | ...  | ...  |
| D2241          | PR (SDR series)  | PVC2112              | 14333      | 23                                                     | ...     | 8.6                                | ...  | ...  | ...  |
| D2241          | PR (SDR series)  | PVC2110              | 14333      | 23                                                     | ...     | 6.9                                | ...  | ...  | ...  |

## NOTES:

- (1) These recommended limits are for low pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic. The upper temperature limits are reduced at higher pressures, depending on the combination of fluid and expected service life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.
- (2) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.
- (3) Use these hydrostatic design stress (HDS) values at all lower temperatures.

**Table B-2 Listed Specifications for Laminated Reinforced Thermosetting Resin Pipe**

| Spec. No. |
|-----------|
| ASTM C582 |

GENERAL NOTE: The intent of listing in this Table is to include all the types, grades, classes, and hydrostatic design bases in the listed specifications.

**Table B-3 Listed Specifications for Filament Wound and Centrifugally Cast Reinforced Thermosetting Resin and Reinforced Plastic Mortar Pipe**

| Spec. Nos. (ASTM Except as Noted) |       |           |
|-----------------------------------|-------|-----------|
| D2517                             | D2997 | D3754     |
| D2996                             | D3517 | AWWA C950 |

GENERAL NOTE: The intent of listing in this Table is to include all the types, grades, classes, and hydrostatic design bases in the listed specifications.

**Table B-4 Allowable Pressures and Recommended Temperature Limits for Concrete Pipe**

| Spec. No. | Material            | Class             | Allowable Gage Pressure |     | Recommended Temperature Limits [Note (1)] |     |         |     |
|-----------|---------------------|-------------------|-------------------------|-----|-------------------------------------------|-----|---------|-----|
|           |                     |                   |                         |     | Minimum                                   |     | Maximum |     |
|           |                     |                   | kPa                     | psi | °C                                        | °F  | °C      | °F  |
| ASTM C361 | Reinforced concrete | 25                | 69                      | 10  | ...                                       | ... | ...     | ... |
|           |                     | 50                | 138                     | 20  | ...                                       | ... | ...     | ... |
|           |                     | 75                | 205                     | 30  | ...                                       | ... | ...     | ... |
|           |                     | 100               | 275                     | 40  | ...                                       | ... | ...     | ... |
|           |                     | 125               | 345                     | 50  | ...                                       | ... | ...     | ... |
| AWWA C300 | Reinforced concrete | ...               | 1 795                   | 260 | ...                                       | ... | ...     | ... |
| AWWA C301 | Reinforced concrete | Lined cylinder    | 1 725                   | 250 | ...                                       | ... | ...     | ... |
|           |                     | Embedded cylinder | 2 415                   | 350 | ...                                       | ... | ...     | ... |
| AWWA C302 | Reinforced concrete | ...               | 310                     | 45  | ...                                       | ... | ...     | ... |

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

**Table B-5 Allowable Pressures and Recommended Temperature Limits for Borosilicate Glass Pipe**

| ASTM Spec. No. | Material           | Size Range |                               | Allowable Gage Pressure |     | Recommended Temperature Limits [Note (1)] |     |         |     |
|----------------|--------------------|------------|-------------------------------|-------------------------|-----|-------------------------------------------|-----|---------|-----|
|                |                    |            |                               |                         |     | Minimum                                   |     | Maximum |     |
|                |                    | DN         | NPS                           | kPa                     | psi | °C                                        | °F  | °C      | °F  |
| C599           | Borosilicate glass | 8–15       | $\frac{1}{4}$ – $\frac{1}{2}$ | 690                     | 100 | ...                                       | ... | 232     | 450 |
|                |                    | 20         | $\frac{3}{4}$                 | 515                     | 75  | ...                                       | ... | 232     | 450 |
|                |                    | 25–80      | 1–3                           | 345                     | 50  | ...                                       | ... | 232     | 450 |
|                |                    | 100        | 4                             | 240                     | 35  | ...                                       | ... | 232     | 450 |
|                |                    | 150        | 6                             | 138                     | 20  | ...                                       | ... | 232     | 450 |

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

**Table B-6 Allowable Pressures and Recommended Temperature Limits for PEX-AL-PEX and PE-AL-PE Pipe**

| ASTM Spec. No. | Material                                     | Size Range  |                                | Allowable Gage Pressure |     | Maximum Temperature Limits [Note (1)] |      |
|----------------|----------------------------------------------|-------------|--------------------------------|-------------------------|-----|---------------------------------------|------|
|                |                                              |             |                                |                         |     |                                       |      |
|                |                                              | mm          | in.                            | kPa                     | psi | °C                                    | °F   |
| F1281          | PEX-AL-PEX                                   | 9.12–60.75  | $\frac{3}{8}$ – $2\frac{1}{2}$ | 1 379                   | 200 | 23                                    | 73.4 |
|                |                                              |             |                                | 1 103                   | 160 | 60                                    | 140  |
|                |                                              |             |                                | 862                     | 125 | 82.2                                  | 180  |
| F1282          | PE-AL-PE                                     | 9.12–60.75  | $\frac{3}{8}$ – $2\frac{1}{2}$ | 1 379                   | 200 | 23                                    | 73.4 |
|                |                                              |             |                                | 1 103                   | 160 | 60                                    | 140  |
|                |                                              |             |                                | 862                     | 100 | 82.2                                  | 180  |
| F1974          | Metal insert fittings for PEX-AL-PEX systems | 12.16–25.32 | $\frac{1}{2}$ –1               | 862                     | 125 | 82                                    | 180  |
|                |                                              |             |                                | 1 103                   | 160 | 60                                    | 140  |
|                |                                              |             |                                | 862                     | 125 | 82                                    | 180  |

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

## **APPENDIX C**

# **PHYSICAL PROPERTIES OF PIPING MATERIALS**

Begins on the next page.

Table C-1 Thermal Expansion Data

$A = \text{Mean Coefficient of Thermal Expansion, } 10^{-6} \text{ in./in./}^{\circ}\text{F}$   
 $B = \text{Linear Thermal Expansion, in./100 ft}$

in Going From 70°F to Indicated Temperature [Note (1)]

| Material                                                                             | Coefficient | Temperature Range 70°F to |      |      |     |     |     |     |     |     |      |      |      |       |       |       |       |       |
|--------------------------------------------------------------------------------------|-------------|---------------------------|------|------|-----|-----|-----|-----|-----|-----|------|------|------|-------|-------|-------|-------|-------|
|                                                                                      |             | -325                      | -150 | -50  | 70  | 200 | 300 | 400 | 500 | 600 | 700  | 800  | 900  | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
| Group 1 carbon and low alloy steels [Note (2)]                                       | <i>A</i>    | 5.5                       | 5.9  | 6.2  | 6.4 | 6.7 | 6.9 | 7.1 | 7.3 | 7.4 | 7.6  | 7.8  | 7.9  | 8.1   | 8.2   | 8.3   | 8.4   | 8.4   |
|                                                                                      | <i>B</i>    | -2.6                      | -1.6 | -0.9 | 0   | 1.0 | 1.9 | 2.8 | 3.7 | 4.7 | 5.7  | 6.8  | 7.9  | 9.0   | 10.1  | 11.3  | 12.4  | 14.7  |
| Group 2 low alloy steels [Note (3)]                                                  | <i>A</i>    | 6.0                       | 6.5  | 6.7  | 7.0 | 7.3 | 7.4 | 7.6 | 7.7 | 7.8 | 7.9  | 8.0  | 8.1  | 8.2   | 8.3   | 8.4   | 8.4   | 8.5   |
|                                                                                      | <i>B</i>    | -2.9                      | -1.7 | -1.0 | 0   | 1.1 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0  | 7.0  | 8.1  | 9.2   | 10.3  | 11.4  | 12.5  | 13.5  |
| 5Cr-1Mo steels                                                                       | <i>A</i>    | 5.6                       | 6.0  | 6.2  | 6.4 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.2  | 7.3  | 7.4  | 7.5   | 7.6   | 7.6   | 7.7   | 7.8   |
|                                                                                      | <i>B</i>    | -2.7                      | -1.6 | -0.9 | 0   | 1.0 | 1.9 | 2.8 | 3.7 | 4.6 | 5.5  | 6.4  | 7.4  | 8.4   | 9.3   | 10.3  | 11.4  | 12.4  |
| 9Cr-1Mo steels                                                                       | <i>A</i>    | 5.0                       | 5.4  | 5.6  | 5.8 | 6.0 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6  | 6.7  | 6.8  | 6.9   | 7.0   | 7.1   | 7.2   | 7.2   |
|                                                                                      | <i>B</i>    | -2.4                      | -1.4 | -0.8 | 0   | 0.9 | 1.7 | 2.5 | 3.3 | 4.1 | 5.0  | 5.9  | 6.8  | 7.7   | 8.7   | 9.7   | 10.6  | 11.6  |
| Straight chromium stainless steels                                                   |             |                           |      |      |     |     |     |     |     |     |      |      |      |       |       |       |       |       |
|                                                                                      |             |                           |      |      |     |     |     |     |     |     |      |      |      |       |       |       |       |       |
| 12Cr to 13Cr steels                                                                  | <i>A</i>    | 5.1                       | 5.5  | 5.7  | 5.9 | 6.2 | 6.3 | 6.4 | 6.5 | 6.5 | 6.6  | 6.7  | 6.7  | 6.8   | 6.8   | 6.9   | 6.9   | 7.0   |
|                                                                                      | <i>B</i>    | -2.4                      | -1.5 | -0.8 | 0   | 1.0 | 1.7 | 2.5 | 3.3 | 4.2 | 5.0  | 5.8  | 6.7  | 7.6   | 8.5   | 9.4   | 10.2  | 11.1  |
| 15Cr to 17Cr steels                                                                  | <i>A</i>    | 4.5                       | 4.9  | 5.1  | 5.3 | 5.5 | 5.7 | 5.8 | 5.9 | 6.0 | 6.1  | 6.2  | 6.2  | 6.3   | 6.4   | 6.4   | 6.5   | 6.5   |
|                                                                                      | <i>B</i>    | -2.1                      | -1.3 | -0.7 | 0   | 0.9 | 1.6 | 2.3 | 3.0 | 3.8 | 4.6  | 5.4  | 6.2  | 7.0   | 7.9   | 8.7   | 9.5   | 10.4  |
| 27Cr steels                                                                          | <i>A</i>    | 4.3                       | 4.7  | 4.9  | 5.0 | 5.2 | 5.2 | 5.3 | 5.4 | 5.4 | 5.5  | 5.6  | 5.7  | 5.7   | 5.8   | 5.9   | 5.9   | 6.0   |
|                                                                                      | <i>B</i>    | -2.0                      | -1.2 | -0.7 | 0   | 0.8 | 1.4 | 2.1 | 2.8 | 3.5 | 4.2  | 4.9  | 5.6  | 6.4   | 7.2   | 8.0   | 8.7   | 9.6   |
| Austenitic stainless steels (304, 305, 316, 317, 321, 347, 348, 19-9DL, XM-15, etc.) | <i>A</i>    | 7.5                       | 8.0  | 8.2  | 8.5 | 8.9 | 9.2 | 9.5 | 9.7 | 9.9 | 10.0 | 10.1 | 10.2 | 10.3  | 10.4  | 10.6  | 10.7  | 10.8  |
|                                                                                      | <i>B</i>    | -3.6                      | -2.1 | -1.2 | 0   | 1.4 | 2.5 | 3.8 | 5.0 | 6.3 | 7.5  | 8.8  | 10.2 | 11.5  | 12.9  | 14.3  | 15.8  | 17.2  |
| Other austenitic stainless steels (309, 310, 315, XM-19, etc.)                       | <i>A</i>    | 7.1                       | 7.6  | 7.8  | 8.2 | 8.5 | 8.7 | 8.9 | 9.1 | 9.2 | 9.3  | 9.4  | 9.5  | 9.6   | 9.7   | 9.8   | 9.9   | 10.1  |
|                                                                                      | <i>B</i>    | -3.4                      | -2.0 | -1.1 | 0   | 1.3 | 2.4 | 3.5 | 4.7 | 5.8 | 7.0  | 8.2  | 9.5  | 10.7  | 12.0  | 13.3  | 14.7  | 16.1  |
| Gray iron                                                                            | <i>A</i>    | ...                       | ...  | ...  | ... | 5.8 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7  | 6.8  | 7.0  | 7.2   | ...   | ...   | ...   | ...   |
|                                                                                      | <i>B</i>    | ...                       | ...  | ...  | 0   | 0.9 | 1.6 | 2.4 | 3.2 | 4.1 | 5.0  | 6.0  | 7.0  | 8.0   | ...   | ...   | ...   | ...   |
| Ductile cast iron                                                                    | <i>A</i>    | ...                       | 4.9  | 5.3  | 5.7 | 6.0 | 6.3 | 6.6 | 6.8 | 7.0 | 7.1  | 7.3  | 7.4  | 7.5   | ...   | ...   | ...   | ...   |
|                                                                                      | <i>B</i>    | ...                       | -1.3 | -0.8 | 0   | 0.9 | 1.7 | 2.6 | 3.5 | 4.5 | 5.4  | 6.4  | 7.3  | 8.4   | ...   | ...   | ...   | ...   |

Table C-1 Thermal Expansion Data (Cont'd)

$A = \text{Mean Coefficient of Thermal Expansion, } 10^{-6} \text{ in./in./}^{\circ}\text{F}$   
 $B = \text{Linear Thermal Expansion, in./100 ft}$

in Going From 70°F to Indicated Temperature [Note (1)]

| Material                        | Coefficient | Temperature Range 70°F to |      |      |     |      |      |      |      |      |      |      |      |       |       |       |       |       |
|---------------------------------|-------------|---------------------------|------|------|-----|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
|                                 |             | -325                      | -150 | -50  | 70  | 200  | 300  | 400  | 500  | 600  | 700  | 800  | 900  | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
| Monel (67Ni-30Cu) N04400        | <i>A</i>    | 5.8                       | 6.8  | 7.2  | 7.7 | 8.1  | 8.3  | 8.5  | 8.7  | 8.8  | 8.9  | 8.9  | 9.0  | 9.1   | 9.1   | 9.2   | 9.2   | 9.3   |
|                                 | <i>B</i>    | -2.7                      | -1.8 | -1.0 | 0   | 1.3  | 2.3  | 3.4  | 4.5  | 5.6  | 6.7  | 7.8  | 9.0  | 10.1  | 11.3  | 12.4  | 13.6  | 14.8  |
| Nickel alloys N02200 and N02201 | <i>A</i>    | 5.3                       | 6.0  | 6.3  | 6.6 | 7.2  | 7.5  | 7.7  | 7.9  | 8.0  | 8.2  | 8.3  | 8.4  | 8.5   | 8.6   | 8.7   | 8.8   | 8.9   |
|                                 | <i>B</i>    | -2.7                      | -1.7 | -1.0 | 0   | 1.1  | 2.1  | 3.1  | 4.1  | 5.1  | 6.2  | 7.3  | 8.4  | 9.5   | 10.7  | 11.8  | 13.0  | 14.2  |
| Nickel alloy N06022             | <i>A</i>    | ...                       | ...  | ...  | 6.9 | 6.9  | 6.9  | 6.9  | 7.0  | 7.0  | 7.2  | 7.3  | 7.5  | 7.7   | 7.9   | 8.1   | 8.3   | 8.5   |
|                                 | <i>B</i>    | ...                       | ...  | ...  | 0   | 1.1  | 1.9  | 2.7  | 3.6  | 4.5  | 5.4  | 6.4  | 7.5  | 8.6   | 9.8   | 11.0  | 12.2  | 13.6  |
| Nickel alloy N06600             | <i>A</i>    | 5.5                       | 6.1  | 6.4  | 6.8 | 7.1  | 7.3  | 7.5  | 7.6  | 7.8  | 7.9  | 8.0  | 8.2  | 8.3   | 8.4   | 8.6   | 8.7   | 8.9   |
|                                 | <i>B</i>    | -2.6                      | -1.6 | -0.9 | 0   | 1.1  | 2.0  | 3.0  | 3.9  | 5.0  | 6.0  | 7.0  | 8.1  | 9.3   | 10.4  | 11.6  | 12.9  | 14.2  |
| Nickel alloy N06625             | <i>A</i>    | ...                       | ...  | ...  | 6.7 | 7.1  | 7.2  | 7.3  | 7.4  | 7.4  | 7.5  | 7.6  | 7.7  | 7.9   | 8.0   | 8.2   | 8.4   | 8.5   |
|                                 | <i>B</i>    | ...                       | ...  | ...  | 0   | 1.1  | 2.0  | 2.9  | 3.8  | 4.7  | 5.6  | 6.6  | 7.7  | 8.8   | 9.9   | 11.1  | 12.3  | 13.6  |
| Nickel alloys N08800 and N08810 | <i>A</i>    | 5.9                       | 6.9  | 7.4  | 7.9 | 8.4  | 8.6  | 8.8  | 8.9  | 9.0  | 9.1  | 9.2  | 9.3  | 9.4   | 9.5   | 9.6   | 9.7   | 9.8   |
|                                 | <i>B</i>    | -2.8                      | -1.7 | -1.1 | 0   | 1.3  | 2.4  | 3.5  | 4.6  | 5.7  | 6.9  | 8.1  | 9.3  | 10.5  | 11.8  | 13.0  | 14.4  | 15.7  |
| Nickel alloy N08825             | <i>A</i>    | ...                       | ...  | 7.2  | 7.5 | 7.7  | 7.9  | 8.0  | 8.1  | 8.2  | 8.3  | 8.4  | 8.5  | 8.6   | ...   | ...   | ...   | ...   |
|                                 | <i>B</i>    | ...                       | ...  | -1.0 | 0   | 1.2  | 2.2  | 3.2  | 4.2  | 5.2  | 6.3  | 7.4  | 8.5  | 9.6   | ...   | ...   | ...   | ...   |
| Nickel alloy N10276             | <i>A</i>    | ...                       | ...  | ...  | 6.0 | 6.3  | 6.5  | 6.7  | 6.9  | 7.1  | 7.2  | 7.4  | 7.5  | 7.6   | 7.7   | 7.8   | 7.9   | 8.0   |
|                                 | <i>B</i>    | ...                       | ...  | ...  | 0   | 1.0  | 1.8  | 2.7  | 3.6  | 4.5  | 5.5  | 6.4  | 7.5  | 8.5   | 9.5   | 10.6  | 11.7  | 12.8  |
| Copper alloys C1XXXX series     | <i>A</i>    | 7.7                       | 8.7  | 9.0  | 9.3 | 9.6  | 9.7  | 9.8  | 9.9  | 10.0 | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   |
|                                 | <i>B</i>    | -3.7                      | -2.3 | -1.3 | 0   | 1.5  | 2.7  | 3.9  | 5.1  | 6.4  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   |
| Bronze alloys                   | <i>A</i>    | 8.4                       | 8.8  | 9.2  | 9.6 | 10.0 | 10.1 | 10.2 | 10.3 | 10.4 | 10.5 | 10.6 | 10.7 | 10.8  | 10.9  | 11.0  | ...   | ...   |
|                                 | <i>B</i>    | -4.0                      | -2.3 | -1.3 | 0   | 1.6  | 2.8  | 4.0  | 5.3  | 6.6  | 8.0  | 9.3  | 10.7 | 12.1  | 13.5  | 14.9  | ...   | ...   |
| Brass alloys                    | <i>A</i>    | 8.2                       | 8.5  | 9.0  | 9.3 | 9.8  | 10.0 | 10.2 | 10.5 | 10.7 | 10.9 | 11.2 | 11.4 | 11.6  | 11.9  | 12.1  | ...   | ...   |
|                                 | <i>B</i>    | -3.9                      | -2.2 | -1.3 | 0   | 1.5  | 2.8  | 4.1  | 5.4  | 6.8  | 8.2  | 9.8  | 11.4 | 13.0  | 14.7  | 16.4  | ...   | ...   |
| Copper-nickel (70Cu-30Ni)       | <i>A</i>    | 6.7                       | 7.4  | 7.8  | 8.1 | 8.5  | 8.7  | 8.9  | 9.1  | 9.2  | 9.2  | ...  | ...  | ...   | ...   | ...   | ...   | ...   |
|                                 | <i>B</i>    | -3.2                      | -2.0 | -1.1 | 0   | 1.3  | 2.4  | 3.5  | 4.7  | 5.8  | 7.0  | ...  | ...  | ...   | ...   | ...   | ...   | ...   |

**Table C-1 Thermal Expansion Data (Cont'd)**

$A = \text{Mean Coefficient of Thermal Expansion, } 10^{-6} \text{ in./in./}^{\circ}\text{F}$   
 $B = \text{Linear Thermal Expansion, in./100 ft}$ 
} in Going From 70°F to Indicated Temperature [Note (1)]

| Material                                    | Coefficient | Temperature Range 70°F to |      |      |      |      |      |      |      |      |     |     |     |       |       |       |       |       |
|---------------------------------------------|-------------|---------------------------|------|------|------|------|------|------|------|------|-----|-----|-----|-------|-------|-------|-------|-------|
|                                             |             | -325                      | -150 | -50  | 70   | 200  | 300  | 400  | 500  | 600  | 700 | 800 | 900 | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
| Aluminum alloys                             | A           | 9.9                       | 10.9 | 11.6 | 12.1 | 13.0 | 13.3 | 13.6 | 13.9 | 14.2 | ... | ... | ... | ...   | ...   | ...   | ...   | ...   |
|                                             | B           | -4.7                      | -2.9 | -1.7 | 0    | 2.0  | 3.7  | 5.4  | 7.2  | 9.0  | ... | ... | ... | ...   | ...   | ...   | ...   | ...   |
| Titanium alloys (Grades 1, 2, 3, 7, and 12) | A           | ...                       | ...  | 4.5  | 4.6  | 4.7  | 4.8  | 4.8  | 4.9  | 4.9  | 5.0 | 5.1 | ... | ...   | ...   | ...   | ...   | ...   |
|                                             | B           | ...                       | ...  | -0.6 | 0    | 0.7  | 1.3  | 1.9  | 2.5  | 3.1  | 3.8 | 4.5 | ... | ...   | ...   | ...   | ...   | ...   |

NOTES:

(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

(2) Group 1 alloys (by nominal composition):

|                                                      |                                                           |
|------------------------------------------------------|-----------------------------------------------------------|
| Carbon steels (C, C-Si, C-Mn, and C-Mn-Si)           | 3Cr-1Mo                                                   |
| C- $\frac{1}{2}$ Mo                                  | $\frac{1}{2}$ Ni- $\frac{1}{2}$ Mo-V                      |
| $\frac{1}{2}$ Cr- $\frac{1}{5}$ Mo-V                 | $\frac{1}{2}$ Ni- $\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-V    |
| $\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-Si                | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Mo-Cr-V                   |
| $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo                   | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Mo- $\frac{1}{3}$ Cr-V    |
| $\frac{1}{2}$ Cr- $\frac{1}{2}$ Ni- $\frac{1}{4}$ Mo | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Cu-Mo                     |
| $\frac{3}{4}$ Cr- $\frac{1}{2}$ Ni-Cu                | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V    |
| $\frac{3}{4}$ Cr- $\frac{3}{4}$ Ni-Cu-Al             | $\frac{3}{4}$ Ni-1Mo- $\frac{3}{4}$ Cr                    |
| 1Cr- $\frac{1}{5}$ Mo                                | 1Ni- $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo                   |
| 1Cr- $\frac{1}{5}$ Mo-Si                             | 1 $\frac{1}{4}$ Ni-1Cr- $\frac{1}{2}$ Mo                  |
| 1Cr- $\frac{1}{2}$ Mo                                | 1 $\frac{3}{4}$ Ni- $\frac{3}{4}$ Cr- $\frac{1}{4}$ Mo    |
| 1Cr- $\frac{1}{2}$ Mo-V                              | 2Ni- $\frac{3}{4}$ Cr- $\frac{1}{4}$ Mo                   |
| 1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo                 | 2Ni- $\frac{3}{4}$ Cr- $\frac{1}{3}$ Mo                   |
| 1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo-Si              | 2 $\frac{1}{2}$ Ni                                        |
| 1 $\frac{3}{4}$ Cr- $\frac{1}{2}$ Mo-Cu              | 3 $\frac{1}{2}$ Ni                                        |
| 2Cr- $\frac{1}{2}$ Mo                                | 3 $\frac{1}{2}$ Ni-1 $\frac{3}{4}$ Cr- $\frac{1}{2}$ Mo-V |
| 2 $\frac{1}{4}$ Cr-1Mo                               |                                                           |

(3) Group 2 alloys (by nominal composition):

|                      |                                        |
|----------------------|----------------------------------------|
| Mn-V                 | Mn- $\frac{1}{2}$ Mo- $\frac{1}{4}$ Ni |
| Mn- $\frac{1}{4}$ Mo | Mn- $\frac{1}{2}$ Mo- $\frac{1}{2}$ Ni |
| Mn- $\frac{1}{2}$ Mo | Mn- $\frac{1}{2}$ Mo- $\frac{3}{4}$ Ni |



TABLE STARTS ON NEXT PAGE

Table C-1M Thermal Expansion Data (SI Units)

|                                                                                      |             | $A = \text{Mean Coefficient of Thermal Expansion, } 10^{-6} \text{ mm/mm/}^{\circ}\text{C}$<br>$B = \text{Linear Thermal Expansion, mm/m}$ |      |      |      |      |      |      |      |      |      |      |      |      |      |
|--------------------------------------------------------------------------------------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                                                                                      |             | $\left. \begin{array}{l} \\ \end{array} \right\} \text{ in Going From } 20^{\circ}\text{C to Indicated Temperature Note [(1)]}$            |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Material                                                                             | Coefficient | Temperature Range 20°C to                                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |      |      |
|                                                                                      |             | -200                                                                                                                                       | -100 | -50  | 20   | 50   | 75   | 100  | 125  | 150  | 175  | 200  | 225  | 250  | 275  |
| Group 1 carbon and low alloy steels [Note (2)]                                       | A           | 9.9                                                                                                                                        | 10.7 | 11.1 | 11.5 | 11.8 | 11.9 | 12.1 | 12.3 | 12.4 | 12.6 | 12.7 | 12.9 | 13.0 | 13.2 |
|                                                                                      | B           | -2.2                                                                                                                                       | -1.3 | -0.8 | 0    | 0.4  | 0.7  | 1.0  | 1.3  | 1.6  | 2.0  | 2.3  | 2.6  | 3.0  | 3.4  |
| Group 2 low alloy steels [Note (3)]                                                  | A           | 10.8                                                                                                                                       | 11.7 | 12.0 | 12.6 | 12.8 | 13.0 | 13.1 | 13.2 | 13.4 | 13.5 | 13.6 | 13.7 | 13.8 | 13.9 |
|                                                                                      | B           | -2.4                                                                                                                                       | -1.4 | -0.8 | 0    | 0.4  | 0.7  | 1.0  | 1.4  | 1.7  | 2.1  | 2.4  | 2.8  | 3.2  | 3.6  |
| 5Cr-1Mo steels                                                                       | A           | 10.1                                                                                                                                       | 10.8 | 11.2 | 11.5 | 11.8 | 12.0 | 12.1 | 12.3 | 12.4 | 12.5 | 12.6 | 12.6 | 12.7 | 12.8 |
|                                                                                      | B           | -2.2                                                                                                                                       | -1.3 | -0.8 | 0    | 0.4  | 0.7  | 1.0  | 1.3  | 1.6  | 1.9  | 2.3  | 2.6  | 2.9  | 3.3  |
| 9Cr-1Mo steels                                                                       | A           | 9.0                                                                                                                                        | 9.8  | 10.1 | 10.5 | 10.6 | 10.7 | 10.9 | 11.0 | 11.1 | 11.2 | 11.3 | 11.4 | 11.5 | 11.6 |
|                                                                                      | B           | -2.0                                                                                                                                       | -1.2 | -0.7 | 0    | 0.3  | 0.6  | 0.9  | 1.2  | 1.4  | 1.7  | 2.0  | 2.3  | 2.6  | 3.0  |
| Straight chromium stainless steels                                                   |             |                                                                                                                                            |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 12Cr to 13Cr steels                                                                  | A           | 9.1                                                                                                                                        | 9.9  | 10.2 | 10.6 | 10.9 | 11.0 | 11.1 | 11.3 | 11.4 | 11.4 | 11.5 | 11.6 | 11.6 | 11.7 |
|                                                                                      | B           | -2.0                                                                                                                                       | -1.2 | -0.7 | 0    | 0.3  | 0.6  | 0.9  | 1.2  | 1.5  | 1.8  | 2.1  | 2.4  | 2.7  | 3.0  |
| 15Cr to 17Cr steels                                                                  | A           | 8.1                                                                                                                                        | 8.8  | 9.1  | 9.6  | 9.7  | 9.9  | 10.0 | 10.1 | 10.2 | 10.3 | 10.4 | 10.5 | 10.6 | 10.7 |
|                                                                                      | B           | -1.8                                                                                                                                       | -1.1 | -0.6 | 0    | 0.3  | 0.5  | 0.8  | 1.1  | 1.3  | 1.6  | 1.9  | 2.2  | 2.4  | 2.7  |
| 27Cr steels                                                                          | A           | 7.7                                                                                                                                        | 8.5  | 8.7  | 9.0  | 9.2  | 9.2  | 9.3  | 9.4  | 9.4  | 9.5  | 9.5  | 9.6  | 9.6  | 9.7  |
|                                                                                      | B           | -1.7                                                                                                                                       | -1.0 | -0.6 | 0    | 0.3  | 0.5  | 0.7  | 1.0  | 1.2  | 1.5  | 1.7  | 2.0  | 2.2  | 2.5  |
| Austenitic stainless steels (304, 305, 316, 317, 321, 347, 348, 19-9DL, XM-15, etc.) | A           | 13.5                                                                                                                                       | 14.3 | 14.7 | 15.3 | 15.6 | 15.9 | 16.2 | 16.4 | 16.6 | 16.8 | 17.0 | 17.2 | 17.4 | 17.5 |
|                                                                                      | B           | -3.0                                                                                                                                       | -1.7 | -1.0 | 0    | 0.5  | 0.9  | 1.3  | 1.7  | 2.2  | 2.6  | 3.1  | 3.5  | 4.0  | 4.5  |
| Other austenitic stainless steels (309, 310, 315, XM-19, etc.)                       | A           | 12.8                                                                                                                                       | 13.6 | 14.1 | 14.7 | 15.0 | 15.2 | 15.4 | 15.6 | 15.7 | 15.9 | 16.0 | 16.1 | 16.3 | 16.4 |
|                                                                                      | B           | -2.8                                                                                                                                       | -1.6 | -1.0 | 0    | 0.4  | 0.8  | 1.2  | 1.6  | 2.0  | 2.5  | 2.9  | 3.3  | 3.7  | 4.2  |
| Gray iron                                                                            | A           | ...                                                                                                                                        | ...  | ...  | 9.8  | 10.1 | 10.2 | 10.4 | 10.5 | 10.7 | 10.8 | 11.0 | 11.1 | 11.2 | 11.4 |
|                                                                                      | B           | ...                                                                                                                                        | ...  | ...  | 0    | 0.3  | 0.6  | 0.8  | 1.1  | 1.4  | 1.7  | 2.0  | 2.3  | 2.6  | 2.9  |
| Ductile cast iron                                                                    | A           | ...                                                                                                                                        | 8.8  | 9.5  | 10.3 | 10.5 | 10.7 | 10.9 | 11.1 | 11.3 | 11.6 | 11.8 | 12.0 | 12.2 | 12.4 |
|                                                                                      | B           | ...                                                                                                                                        | -1.1 | -0.7 | 0    | 0.3  | 0.6  | 0.9  | 1.2  | 1.5  | 1.8  | 2.1  | 2.5  | 2.8  | 3.1  |
| Monel (67Ni-30Cu) N04400                                                             | A           | 10.4                                                                                                                                       | 12.2 | 13.0 | 13.8 | 14.1 | 14.4 | 14.6 | 14.8 | 15.0 | 15.1 | 15.3 | 15.4 | 15.5 | 15.6 |
|                                                                                      | B           | -2.3                                                                                                                                       | -1.5 | -0.9 | 0    | 0.4  | 0.8  | 1.2  | 1.6  | 1.9  | 2.3  | 2.8  | 3.2  | 3.6  | 4.0  |
| Nickel alloys N02200 and N02201                                                      | A           | 9.6                                                                                                                                        | 10.8 | 11.4 | 11.9 | 12.4 | 12.7 | 13.0 | 13.3 | 13.5 | 13.7 | 13.9 | 14.0 | 14.2 | 14.3 |
|                                                                                      | B           | -2.2                                                                                                                                       | -1.4 | -0.8 | 0    | 0.4  | 0.7  | 1.0  | 1.4  | 1.8  | 2.1  | 2.5  | 2.9  | 3.3  | 3.6  |
| Nickel alloy N06022                                                                  | A           | ...                                                                                                                                        | ...  | ...  | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.4 | 12.5 | 12.5 | 12.6 |
|                                                                                      | B           | ...                                                                                                                                        | ...  | ...  | 0    | 0.4  | 0.7  | 1.0  | 1.3  | 1.6  | 1.9  | 2.2  | 2.6  | 2.9  | 3.2  |
| Nickel alloy N06600                                                                  | A           | 9.9                                                                                                                                        | 10.8 | 11.5 | 12.3 | 12.5 | 12.7 | 12.8 | 13.0 | 13.2 | 13.3 | 13.5 | 13.6 | 13.7 | 13.8 |
|                                                                                      | B           | -2.2                                                                                                                                       | -1.3 | -0.8 | 0    | 0.4  | 0.7  | 1.0  | 1.4  | 1.7  | 2.1  | 2.4  | 2.8  | 3.2  | 3.5  |
| Nickel alloy N06625                                                                  | A           | ...                                                                                                                                        | ...  | ...  | 12.0 | 12.4 | 12.6 | 12.8 | 12.9 | 13.0 | 13.1 | 13.2 | 13.2 | 13.2 | 13.3 |
|                                                                                      | B           | ...                                                                                                                                        | ...  | ...  | 0    | 0.4  | 0.7  | 1.0  | 1.4  | 1.7  | 2.0  | 2.4  | 2.7  | 3.0  | 3.4  |

**Table C-1M Thermal Expansion Data (SI Units)**

$A = \text{Mean Coefficient of Thermal Expansion, } 10^{-6} \text{ mm/mm/}^{\circ}\text{C}$   
 $B = \text{Linear Thermal Expansion, mm/m}$

} in Going From 20°C to Indicated Temperature Note [(1)]

| Temperature Range 20°C to |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 300                       | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  |
| 13.3                      | 13.4 | 13.6 | 13.7 | 13.8 | 14.0 | 14.1 | 14.2 | 14.4 | 14.5 | 14.6 | 14.7 | 14.8 | 14.9 | 15.0 | 15.1 | 15.1 | 15.2 | 15.3 | 15.3 | 15.4 |
| 3.7                       | 4.1  | 4.5  | 4.9  | 5.3  | 5.7  | 6.1  | 6.5  | 6.9  | 7.3  | 7.7  | 8.2  | 8.6  | 9.0  | 9.4  | 9.9  | 10.3 | 10.7 | 11.1 | 11.6 | 12.0 |
| 14.0                      | 14.1 | 14.2 | 14.3 | 14.4 | 14.5 | 14.6 | 14.6 | 14.7 | 14.8 | 14.8 | 14.9 | 15.0 | 15.0 | 15.1 | 15.1 | 15.2 | 15.2 | 15.3 | 15.3 | 15.3 |
| 3.9                       | 4.3  | 4.7  | 5.1  | 5.5  | 5.9  | 6.3  | 6.7  | 7.1  | 7.5  | 7.9  | 8.3  | 8.7  | 9.1  | 9.5  | 9.9  | 10.3 | 10.7 | 11.1 | 11.1 | 11.5 |
| 12.8                      | 12.9 | 13.0 | 13.0 | 13.1 | 13.2 | 13.2 | 13.3 | 13.4 | 13.4 | 13.5 | 13.6 | 13.6 | 13.7 | 13.7 | 13.8 | 13.9 | 13.9 | 14.0 | 14.0 | 14.1 |
| 3.6                       | 3.9  | 4.3  | 4.6  | 5.0  | 5.3  | 5.7  | 6.1  | 6.4  | 6.8  | 7.2  | 7.5  | 7.9  | 8.3  | 8.7  | 9.0  | 9.4  | 9.8  | 10.2 | 10.6 | 11.0 |
| 11.7                      | 11.8 | 11.9 | 11.9 | 12.0 | 12.1 | 12.2 | 12.3 | 12.3 | 12.4 | 12.5 | 12.6 | 12.7 | 12.7 | 12.8 | 12.9 | 13.0 | 13.1 | 13.3 | 13.4 | 13.6 |
| 3.3                       | 3.6  | 3.9  | 4.2  | 4.6  | 4.9  | 5.2  | 5.6  | 5.9  | 6.3  | 6.6  | 7.0  | 7.3  | 7.7  | 8.1  | 8.5  | 8.9  | 9.3  | 9.7  | 10.1 | 10.6 |
| 11.7                      | 11.8 | 11.8 | 11.9 | 11.9 | 12.0 | 12.0 | 12.1 | 12.1 | 12.2 | 12.2 | 12.3 | 12.3 | 12.4 | 12.4 | 12.5 | 12.5 | 12.5 | 12.5 | 12.6 | 12.6 |
| 3.3                       | 3.6  | 3.9  | 4.2  | 4.5  | 4.9  | 5.2  | 5.5  | 5.8  | 6.2  | 6.5  | 6.8  | 7.2  | 7.5  | 7.8  | 8.2  | 8.5  | 8.8  | 9.2  | 9.5  | 9.8  |
| 10.8                      | 10.8 | 10.9 | 11.0 | 11.0 | 11.1 | 11.2 | 11.2 | 11.3 | 11.3 | 11.4 | 11.4 | 11.5 | 11.5 | 11.5 | 11.6 | 11.6 | 11.7 | 11.7 | 11.8 | 11.9 |
| 3.0                       | 3.3  | 3.6  | 3.9  | 4.2  | 4.5  | 4.8  | 5.1  | 5.4  | 5.7  | 6.0  | 6.3  | 6.6  | 7.0  | 7.3  | 7.6  | 7.9  | 8.2  | 8.6  | 8.9  | 9.3  |
| 9.7                       | 9.8  | 9.9  | 9.9  | 10.0 | 10.0 | 10.1 | 10.2 | 10.2 | 10.3 | 10.4 | 10.4 | 10.5 | 10.5 | 10.6 | 10.6 | 10.7 | 10.7 | 10.8 | 10.8 | 10.9 |
| 2.7                       | 3.0  | 3.3  | 3.5  | 3.8  | 4.1  | 4.3  | 4.6  | 4.9  | 5.2  | 5.5  | 5.8  | 6.1  | 6.4  | 6.7  | 7.0  | 7.2  | 7.6  | 7.9  | 8.2  | 8.5  |
| 17.7                      | 17.8 | 17.9 | 18.0 | 18.1 | 18.2 | 18.3 | 18.4 | 18.4 | 18.5 | 18.6 | 18.7 | 18.8 | 18.9 | 19.0 | 19.1 | 19.2 | 19.3 | 19.4 | 19.4 | 19.4 |
| 4.9                       | 5.4  | 5.9  | 6.4  | 6.9  | 7.4  | 7.9  | 8.3  | 8.9  | 9.4  | 9.9  | 10.4 | 10.9 | 11.4 | 12.0 | 12.5 | 13.1 | 13.6 | 14.1 | 14.7 | 15.2 |
| 16.5                      | 16.6 | 16.6 | 16.7 | 16.8 | 16.9 | 17.0 | 17.1 | 17.2 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 | 17.7 | 17.8 | 17.9 | 18.0 | 18.1 | 18.2 | 18.3 |
| 4.6                       | 5.0  | 5.5  | 5.9  | 6.4  | 6.8  | 7.3  | 7.8  | 8.2  | 8.7  | 9.2  | 9.7  | 10.2 | 10.6 | 11.1 | 11.7 | 12.2 | 12.7 | 13.2 | 13.7 | 14.3 |
| 11.5                      | 11.7 | 11.8 | 12.0 | 12.1 | 12.3 | 12.4 | 12.6 | 12.7 | 12.9 | 13.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 3.2                       | 3.6  | 3.9  | 4.2  | 4.6  | 5.0  | 5.3  | 5.7  | 6.1  | 6.5  | 6.9  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 12.5                      | 12.6 | 12.8 | 12.9 | 13.0 | 13.1 | 13.2 | 13.2 | 13.3 | 13.4 | 13.5 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 3.5                       | 3.9  | 4.2  | 4.6  | 4.9  | 5.3  | 5.7  | 6.0  | 6.4  | 6.8  | 7.2  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 15.7                      | 15.8 | 15.9 | 16.0 | 16.0 | 16.1 | 16.1 | 16.2 | 16.2 | 16.3 | 16.3 | 16.4 | 16.4 | 16.5 | 16.5 | 16.5 | 16.6 | 16.6 | 16.7 | 16.7 | 16.8 |
| 4.4                       | 4.8  | 5.2  | 5.7  | 6.1  | 6.5  | 6.9  | 7.4  | 7.8  | 8.2  | 8.6  | 9.1  | 9.5  | 10.0 | 10.4 | 10.8 | 11.3 | 11.7 | 12.2 | 12.6 | 13.1 |
| 14.4                      | 14.5 | 14.6 | 14.7 | 14.8 | 14.9 | 15.0 | 15.1 | 15.2 | 15.3 | 15.4 | 15.5 | 15.6 | 15.6 | 15.7 | 15.8 | 15.9 | 15.9 | 16.0 | 16.1 | 16.2 |
| 4.0                       | 4.4  | 4.8  | 5.2  | 5.6  | 6.0  | 6.5  | 6.9  | 7.3  | 7.7  | 8.2  | 8.6  | 9.0  | 9.5  | 9.9  | 10.3 | 10.8 | 11.2 | 11.7 | 12.2 | 12.6 |
| 12.6                      | 12.7 | 12.8 | 12.9 | 13.0 | 13.2 | 13.3 | 13.5 | 13.6 | 13.8 | 13.9 | 14.1 | 14.3 | 14.4 | 14.6 | 14.8 | 14.9 | 15.1 | 15.2 | 15.4 | 15.6 |
| 3.5                       | 3.9  | 4.2  | 4.6  | 5.0  | 5.3  | 5.7  | 6.1  | 6.5  | 7.0  | 7.4  | 7.8  | 8.3  | 8.7  | 9.2  | 9.7  | 10.1 | 10.6 | 11.1 | 11.6 | 12.1 |
| 14.0                      | 14.1 | 14.2 | 14.3 | 14.4 | 14.5 | 14.6 | 14.7 | 14.8 | 14.9 | 15.0 | 15.1 | 15.2 | 15.3 | 15.4 | 15.6 | 15.7 | 15.8 | 15.9 | 16.1 | 16.2 |
| 3.9                       | 4.3  | 4.7  | 5.1  | 5.5  | 5.9  | 6.3  | 6.7  | 7.1  | 7.5  | 7.9  | 8.4  | 8.8  | 9.3  | 9.7  | 10.2 | 10.7 | 11.1 | 11.6 | 12.1 | 12.6 |
| 13.3                      | 13.3 | 13.4 | 13.5 | 13.5 | 13.6 | 13.7 | 13.8 | 14.0 | 14.1 | 14.2 | 14.3 | 14.5 | 14.6 | 14.8 | 14.9 | 15.0 | 15.1 | 15.3 | 15.4 | 15.6 |
| 3.7                       | 4.1  | 4.4  | 4.8  | 5.1  | 5.5  | 5.9  | 6.3  | 6.7  | 7.1  | 7.5  | 8.0  | 8.4  | 8.8  | 9.3  | 9.8  | 10.2 | 10.7 | 11.2 | 11.6 | 12.1 |

**Table C-1M Thermal Expansion Data (SI Units) (Cont'd)**

|                                             |             | $\left. \begin{array}{l} A = \text{Mean Coefficient of Thermal Expansion, } 10^{-6} \text{ mm/mm/}^{\circ}\text{C} \\ B = \text{Linear Thermal Expansion, mm/m} \end{array} \right\} \text{ in Going From } 20^{\circ}\text{C to Indicated Temperature Note [(1)]}$ |      |      |      |      |      |      |      |      |      |      |      |      |      |
|---------------------------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                                             |             | Temperature Range 20°C to                                                                                                                                                                                                                                           |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Material                                    | Coefficient | -200                                                                                                                                                                                                                                                                | -100 | -50  | 20   | 50   | 75   | 100  | 125  | 150  | 175  | 200  | 225  | 250  | 275  |
| Nickel alloys N08800 and N08810             | A           | 10.6                                                                                                                                                                                                                                                                | 12.5 | 13.3 | 14.2 | 14.6 | 14.9 | 15.1 | 15.3 | 15.5 | 15.6 | 15.8 | 15.9 | 16.0 | 16.1 |
|                                             | B           | -2.3                                                                                                                                                                                                                                                                | -1.5 | -0.9 | 0    | 0.4  | 0.8  | 1.2  | 1.6  | 2.0  | 2.4  | 2.8  | 3.3  | 3.7  | 4.1  |
| Nickel alloy N08825                         | A           | ...                                                                                                                                                                                                                                                                 | ...  | 12.9 | 13.5 | 13.6 | 13.7 | 13.9 | 14.0 | 14.2 | 14.3 | 14.4 | 14.4 | 14.5 | 14.6 |
|                                             | B           | ...                                                                                                                                                                                                                                                                 | ...  | -0.9 | 0    | 0.4  | 0.8  | 1.1  | 1.5  | 1.8  | 2.2  | 2.6  | 3.0  | 3.3  | 3.7  |
| Nickel alloy N10276                         | A           | ...                                                                                                                                                                                                                                                                 | ...  | ...  | 10.8 | 11.0 | 11.2 | 11.4 | 11.6 | 11.7 | 11.9 | 12.0 | 12.2 | 12.4 | 12.5 |
|                                             | B           | ...                                                                                                                                                                                                                                                                 | ...  | ...  | 0    | 0.3  | 0.6  | 0.9  | 1.2  | 1.5  | 1.8  | 2.2  | 2.5  | 2.8  | 3.2  |
| Copper alloys C1XXXX series                 | A           | 13.9                                                                                                                                                                                                                                                                | 15.7 | 16.2 | 16.7 | 17.0 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 | 17.7 | 17.8 | 17.8 | 17.9 |
|                                             | B           | -3.1                                                                                                                                                                                                                                                                | -1.9 | -1.1 | 0    | 0.5  | 0.9  | 1.4  | 1.8  | 2.3  | 2.7  | 3.2  | 3.6  | 4.1  | 4.6  |
| Bronze alloys                               | A           | 15.1                                                                                                                                                                                                                                                                | 15.8 | 16.4 | 17.2 | 17.6 | 17.9 | 18.0 | 18.2 | 18.2 | 18.3 | 18.4 | 18.5 | 18.5 | 18.6 |
|                                             | B           | -3.3                                                                                                                                                                                                                                                                | -1.9 | -1.1 | 0    | 0.5  | 1.0  | 1.4  | 1.9  | 2.4  | 2.8  | 3.3  | 3.8  | 4.3  | 4.7  |
| Brass alloys                                | A           | 14.7                                                                                                                                                                                                                                                                | 15.4 | 16.0 | 16.7 | 17.1 | 17.4 | 17.6 | 17.8 | 18.0 | 18.2 | 18.4 | 18.6 | 18.8 | 19.0 |
|                                             | B           | -3.2                                                                                                                                                                                                                                                                | -1.9 | -1.1 | 0    | 0.5  | 1.0  | 1.4  | 1.9  | 2.3  | 2.8  | 3.3  | 3.8  | 4.3  | 4.8  |
| Copper-nickel (70Cu-30Ni)                   | A           | 11.9                                                                                                                                                                                                                                                                | 13.4 | 14.0 | 14.5 | 14.9 | 15.2 | 15.3 | 15.5 | 15.7 | 15.8 | 16.0 | 16.1 | 16.3 | 16.4 |
|                                             | B           | -2.6                                                                                                                                                                                                                                                                | -1.6 | -1.0 | 0    | 0.4  | 0.8  | 1.2  | 1.6  | 2.0  | 2.5  | 2.9  | 3.3  | 3.7  | 4.2  |
| Aluminum alloys                             | A           | 18.0                                                                                                                                                                                                                                                                | 19.7 | 20.8 | 21.7 | 22.6 | 23.1 | 23.4 | 23.7 | 23.9 | 24.2 | 24.4 | 24.7 | 25.0 | 25.2 |
|                                             | B           | -4.0                                                                                                                                                                                                                                                                | -2.4 | -1.5 | 0    | 0.7  | 1.3  | 1.9  | 2.5  | 3.1  | 3.7  | 4.4  | 5.1  | 5.7  | 6.4  |
| Titanium alloys (Grades 1, 2, 3, 7, and 12) | A           | ...                                                                                                                                                                                                                                                                 | ...  | 8.2  | 8.3  | 8.4  | 8.5  | 8.5  | 8.6  | 8.6  | 8.6  | 8.7  | 8.7  | 8.7  | 8.8  |
|                                             | B           | ...                                                                                                                                                                                                                                                                 | ...  | -0.6 | 0    | 0.3  | 0.5  | 0.7  | 0.9  | 1.1  | 1.3  | 1.6  | 1.8  | 2.0  | 2.2  |

**Table C-1M Thermal Expansion Data (SI Units) (Cont'd)**

$A = \text{Mean Coefficient of Thermal Expansion, } 10^{-6} \text{ mm/mm/}^{\circ}\text{C}$   
 $B = \text{Linear Thermal Expansion, mm/m}$

} in Going From 20°C to Indicated Temperature Note [(1)]

| Temperature Range 20°C to |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 300                       | 325  | 350  | 375  | 400  | 425  | 450  | 475  | 500  | 525  | 550  | 575  | 600  | 625  | 650  | 675  | 700  | 725  | 750  | 775  | 800  |
| 16.2                      | 16.3 | 16.4 | 16.5 | 16.5 | 16.6 | 16.7 | 16.8 | 16.8 | 16.9 | 17.0 | 17.1 | 17.2 | 17.2 | 17.3 | 17.4 | 17.5 | 17.6 | 17.7 | 17.8 | 17.9 |
| 4.5                       | 5.0  | 5.4  | 5.8  | 6.3  | 6.7  | 7.2  | 7.6  | 8.1  | 8.5  | 9.0  | 9.5  | 9.9  | 10.4 | 10.9 | 11.4 | 11.9 | 12.4 | 12.9 | 13.4 | 14.0 |
| 14.7                      | 14.8 | 14.9 | 15.0 | 15.1 | 15.1 | 15.2 | 15.3 | 15.4 | 15.5 | 15.6 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 4.1                       | 4.5  | 4.9  | 5.3  | 5.7  | 6.1  | 6.5  | 7.0  | 7.4  | 7.8  | 8.3  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 12.6                      | 12.8 | 12.9 | 13.0 | 13.1 | 13.2 | 13.3 | 13.4 | 13.5 | 13.6 | 13.7 | 13.8 | 13.9 | 14.0 | 14.1 | 14.2 | 14.3 | 14.3 | 14.4 | 14.5 | 14.6 |
| 3.5                       | 3.9  | 4.3  | 4.6  | 5.0  | 5.4  | 5.7  | 6.1  | 6.5  | 6.9  | 7.3  | 7.7  | 8.1  | 8.5  | 8.9  | 9.3  | 9.7  | 10.1 | 10.5 | 10.9 | 11.4 |
| 18.0                      | 18.0 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 5.0                       | 5.5  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 18.7                      | 18.8 | 18.9 | 19.0 | 19.0 | 19.1 | 19.2 | 19.3 | 19.4 | 19.4 | 19.5 | 19.6 | 19.7 | 19.7 | 19.8 | ...  | ...  | ...  | ...  | ...  | ...  |
| 5.2                       | 5.7  | 6.2  | 6.7  | 7.2  | 7.7  | 8.3  | 8.8  | 9.3  | 9.8  | 10.3 | 10.9 | 11.4 | 11.9 | 12.5 | ...  | ...  | ...  | ...  | ...  | ...  |
| 19.2                      | 19.3 | 19.5 | 19.6 | 19.8 | 20.1 | 20.3 | 20.5 | 20.7 | 20.8 | 21.0 | 21.2 | 21.4 | 21.6 | 21.8 | ...  | ...  | ...  | ...  | ...  | ...  |
| 5.4                       | 5.9  | 6.4  | 7.0  | 7.5  | 8.2  | 8.7  | 9.3  | 9.9  | 10.5 | 11.1 | 11.8 | 12.4 | 13.1 | 13.7 | ...  | ...  | ...  | ...  | ...  | ...  |
| 16.5                      | 16.5 | 16.6 | 16.6 | 16.7 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 4.6                       | 5.0  | 5.5  | 5.9  | 6.3  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 25.5                      | 25.6 | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 7.1                       | 7.8  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 8.8                       | 8.8  | 8.9  | 8.9  | 9.0  | 9.2  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 2.5                       | 2.7  | 2.9  | 3.2  | 3.4  | 3.7  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  | ...  |

**Table C-1M Thermal Expansion Data (SI Units) (Cont'd)**

## NOTES:

(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

(2) Group 1 alloys (by nominal composition):

|                                                      |                                                           |
|------------------------------------------------------|-----------------------------------------------------------|
| Carbon steels (C, C-Si, C-Mn, and C-Mn-Si)           | 3Cr-1Mo                                                   |
| C- $\frac{1}{2}$ Mo                                  | $\frac{1}{2}$ Ni- $\frac{1}{2}$ Mo-V                      |
| $\frac{1}{2}$ Cr- $\frac{1}{5}$ Mo-V                 | $\frac{1}{2}$ Ni- $\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-V    |
| $\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-Si                | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Mo-Cr-V                   |
| $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo                   | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Mo- $\frac{1}{3}$ Cr-V    |
| $\frac{1}{2}$ Cr- $\frac{1}{2}$ Ni- $\frac{1}{4}$ Mo | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Cu-Mo                     |
| $\frac{3}{4}$ Cr- $\frac{1}{2}$ Ni-Cu                | $\frac{3}{4}$ Ni- $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V    |
| $\frac{3}{4}$ Cr- $\frac{3}{4}$ Ni-Cu-Al             | $\frac{3}{4}$ Ni-1Mo- $\frac{3}{4}$ Cr                    |
| 1Cr- $\frac{1}{5}$ Mo                                | 1Ni- $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo                   |
| 1Cr- $\frac{1}{5}$ Mo-Si                             | 1 $\frac{1}{4}$ Ni-1Cr- $\frac{1}{2}$ Mo                  |
| 1Cr- $\frac{1}{2}$ Mo                                | 1 $\frac{3}{4}$ Ni- $\frac{3}{4}$ Cr- $\frac{1}{4}$ Mo    |
| 1Cr- $\frac{1}{2}$ Mo-V                              | 2Ni- $\frac{3}{4}$ Cr- $\frac{1}{4}$ Mo                   |
| 1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo                 | 2Ni- $\frac{3}{4}$ Cr- $\frac{1}{3}$ Mo                   |
| 1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo-Si              | 2 $\frac{1}{2}$ Ni                                        |
| 1 $\frac{3}{4}$ Cr- $\frac{1}{2}$ Mo-Cu              | 3 $\frac{1}{2}$ Ni                                        |
| 2Cr- $\frac{1}{2}$ Mo                                | 3 $\frac{1}{2}$ Ni-1 $\frac{3}{4}$ Cr- $\frac{1}{2}$ Mo-V |
| 2 $\frac{1}{4}$ Cr-1Mo                               |                                                           |

(3) Group 2 alloys (by nominal composition):

|                      |                                        |
|----------------------|----------------------------------------|
| Mn-V                 | Mn- $\frac{1}{2}$ Mo- $\frac{1}{4}$ Ni |
| Mn- $\frac{1}{4}$ Mo | Mn- $\frac{1}{2}$ Mo- $\frac{1}{2}$ Ni |
| Mn- $\frac{1}{2}$ Mo | Mn- $\frac{1}{2}$ Mo- $\frac{3}{4}$ Ni |

**Table C-5 Thermal Expansion Coefficients, Nonmetals**

| Material Description             | Mean Coefficients (Divide Table Values by 10 <sup>6</sup> ) |            |           |            |
|----------------------------------|-------------------------------------------------------------|------------|-----------|------------|
|                                  | in./in., °F                                                 | Range, °F  | mm/mm, °C | Range, °C  |
| <b>Thermoplastics</b>            |                                                             |            |           |            |
| Acetal AP2012                    | 2                                                           | ...        | 3.6       | ...        |
| Acrylonitrile-butadiene-styrene  |                                                             |            |           |            |
| ABS 1208                         | 60                                                          | ...        | 108       | ...        |
| ABS 1210                         | 55                                                          | 45–55      | 99        | 7–13       |
| ABS 1316                         | 40                                                          | ...        | 72        | ...        |
| ABS 2112                         | 40                                                          | ...        | 72        | ...        |
| Cellulose acetate butyrate       |                                                             |            |           |            |
| CAB MH08                         | 80                                                          | ...        | 144       | ...        |
| CAB S004                         | 95                                                          | ...        | 171       | ...        |
| Chlorinated poly(vinyl chloride) |                                                             |            |           |            |
| CPVC 4120                        | 35                                                          | ...        | 63        | ...        |
| Polybutylene PB 2110             | 72                                                          | ...        | 130       | ...        |
| Polyether, chlorinated           | 45                                                          | ...        | 81        | ...        |
| Polyethylene                     |                                                             |            |           |            |
| PE2606                           | 100                                                         | 46–100     | 180       | 8–38       |
| PE2706                           | 100                                                         | 46–100     | 180       | 8–38       |
| PE3608                           | 90                                                          | 46–100     | 162       | 8–38       |
| PE3708                           | 90                                                          | 46–100     | 162       | 8–38       |
| PE3710                           | 90                                                          | 46–100     | 162       | 8–38       |
| PE4708                           | 80                                                          | 46–100     | 144       | 8–38       |
| PE4710                           | 80                                                          | 46–100     | 144       | 8–38       |
| Cross-linked polyethylene        |                                                             |            |           |            |
| PEX0006                          | 78                                                          | –58 to 212 | 140       | –50 to 100 |
| PEX0008                          | 78                                                          | –58 to 212 | 140       | –50 to 100 |
| Polyphenylene POP 2125           | 30                                                          | ...        | 54        | ...        |
| Polypropylene                    |                                                             |            |           |            |
| PP1110                           | 48                                                          | 33–67      | 86        | 1–19       |
| PP1208                           | 43                                                          | ...        | 77        | ...        |
| PP2105                           | 40                                                          | ...        | 72        | ...        |
| PP0210B44002                     | 80                                                          | ...        | 144       | ...        |
| PP0210G07G11030                  | 19                                                          | ...        | 35        | ...        |
| Poly(vinyl chloride)             |                                                             |            |           |            |
| PVC1120                          | 30                                                          | 23–37      | 54        | –5 to 3    |
| PVC1220                          | 35                                                          | 34–40      | 63        | 1–4        |
| PVC2110                          | 50                                                          | ...        | 90        | ...        |
| PVC2112                          | 45                                                          | ...        | 81        | ...        |
| PVC2116                          | 40                                                          | 37–45      | 72        | 3–7        |

**Table C-5 Thermal Expansion Coefficients, Nonmetals (Cont'd)**

| Material Description                                                      | Mean Coefficients (Divide Table Values by 10 <sup>6</sup> ) |           |           |           |
|---------------------------------------------------------------------------|-------------------------------------------------------------|-----------|-----------|-----------|
|                                                                           | in./in., °F                                                 | Range, °F | mm/mm, °C | Range, °C |
| PVC2120                                                                   | 30                                                          | ...       | 54        | ...       |
| Poly(vinylidene fluoride)                                                 | 79                                                          | ...       | 142       | ...       |
| Poly(vinylidene chloride)                                                 | 100                                                         | ...       | 180       | ...       |
| Poly(tetrafluoroethylene)                                                 | 55                                                          | 73–140    | 99        | 23–60     |
| Poly(fluorinated ethylene propylene)                                      | 46–58                                                       | 73–140    | 83–104    | 23–60     |
| Poly(perfluoroalkoxy alkane)                                              | 67                                                          | 70–212    | 121       | 21–100    |
| Poly(perfluoroalkoxy alkane)                                              | 94                                                          | 212–300   | 169       | 100–149   |
| Poly(perfluoroalkoxy alkane)                                              | 111                                                         | 300–408   | 200       | 149–209   |
| <b>Reinforced Thermosetting Resins<br/>and Reinforced Plastic Mortars</b> |                                                             |           |           |           |
| Glass-epoxy, centrifugally cast                                           | 9–13                                                        | ...       | 16–23.5   | ...       |
| Glass-polyester, centrifugally cast                                       | 9–15                                                        | ...       | 16–27     | ...       |
| Glass-polyester, filament-wound                                           | 9–11                                                        | ...       | 16–20     | ...       |
| Glass-polyester, hand lay-up                                              | 12–15                                                       | ...       | 21.5–27   | ...       |
| Glass-epoxy, filament-wound                                               | 9–13                                                        | ...       | 16–23.5   | ...       |
| <b>Other Nonmetallic Materials</b>                                        |                                                             |           |           |           |
| Borosilicate glass                                                        | 1.8                                                         | ...       | 3.25      | ...       |

## GENERAL NOTES:

- (a) For Code references to this Appendix, see [para. A319.3.1](#). These data are for use in the absence of more-applicable data. It is the designer's responsibility to verify that materials are suitable for the intended service at the temperatures shown.
- (b) Individual compounds may vary from the values shown. Consult manufacturer for specific values for products.



Table C-6 Moduli of Elasticity for Metals

| Material                                              | <i>E</i> = Modulus of Elasticity, psi (Multiply Tabulated Values by 10 <sup>6</sup> ) [Note (1)] |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
|-------------------------------------------------------|--------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|
|                                                       | Temperature, °F                                                                                  |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
|                                                       | −425                                                                                             | −325 | −200 | −100 | 70   | 200  | 300  | 400  | 500  | 600  | 700  | 800  | 900  | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 | 1,500 |
| Carbon steels with carbon content 0.30% or less       | 31.9                                                                                             | 31.4 | 30.8 | 30.3 | 29.4 | 28.8 | 28.3 | 27.4 | 27.3 | 26.5 | 25.5 | 24.2 | 22.5 | 20.4  | 18.0  | ...   | ...   | ...   | ...   |
| Carbon steels with carbon content above 0.30%         | 31.7                                                                                             | 31.2 | 30.6 | 30.1 | 29.2 | 28.6 | 28.1 | 27.7 | 27.1 | 26.4 | 25.3 | 24.0 | 22.3 | 20.2  | 17.9  | 15.4  | ...   | ...   | ...   |
| Carbon-molybdenum steels                              | 31.7                                                                                             | 31.1 | 30.5 | 30.0 | 29.0 | 28.5 | 28.0 | 27.6 | 27.0 | 26.3 | 25.3 | 23.9 | 22.2 | 20.1  | 17.8  | 15.3  | ...   | ...   | ...   |
| Nickel steels, Ni 2% to 9%                            | 30.1                                                                                             | 29.6 | 29.0 | 28.6 | 27.8 | 27.1 | 26.7 | 26.2 | 25.7 | 25.1 | 24.6 | 23.9 | 23.2 | 22.4  | 21.5  | 20.4  | 19.2  | 17.7  | ...   |
| Chromium steels:                                      |                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
| ½Cr through 2Cr                                       | 32.1                                                                                             | 31.6 | 30.9 | 30.5 | 29.6 | 29.0 | 28.5 | 28.0 | 27.4 | 26.9 | 26.2 | 25.6 | 24.8 | 23.9  | 23.0  | 21.8  | 20.5  | 18.9  | ...   |
| 2¼Cr through 3Cr                                      | 33.1                                                                                             | 32.6 | 31.9 | 31.4 | 30.6 | 29.9 | 29.4 | 28.8 | 28.3 | 27.7 | 27.0 | 26.3 | 25.6 | 24.7  | 23.7  | 22.5  | 21.1  | 19.4  | ...   |
| 5Cr through 9Cr                                       | 33.4                                                                                             | 33.0 | 32.4 | 31.9 | 31.0 | 30.3 | 29.7 | 29.2 | 28.6 | 28.1 | 27.5 | 26.9 | 26.2 | 25.4  | 24.4  | 23.3  | 22.0  | 20.5  | ...   |
| Austenitic stainless steels:                          |                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
| Type 304, 18Cr–8Ni                                    | 30.8                                                                                             | 30.3 | 29.7 | 29.2 | 28.3 | 27.5 | 27.0 | 26.4 | 25.9 | 25.3 | 24.8 | 24.1 | 23.5 | 22.8  | 22.0  | 21.2  | 20.3  | 19.2  | 18.1  |
| Type 310, 25Cr–20Ni                                   | 30.8                                                                                             | 30.3 | 29.7 | 29.2 | 28.3 | 27.5 | 27.0 | 26.4 | 25.9 | 25.3 | 24.8 | 24.1 | 23.5 | 22.8  | 22.0  | 21.2  | 20.3  | 19.2  | 18.1  |
| Type 316, 16Cr–12Ni–2Mo                               | 30.8                                                                                             | 30.3 | 29.7 | 29.2 | 28.3 | 27.5 | 27.0 | 26.4 | 25.9 | 25.3 | 24.8 | 24.1 | 23.5 | 22.8  | 22.0  | 21.2  | 20.3  | 19.2  | 18.1  |
| Type 321, 18Cr–10Ni–Ti                                | 30.8                                                                                             | 30.3 | 29.7 | 29.2 | 28.3 | 27.5 | 27.0 | 26.4 | 25.9 | 25.3 | 24.8 | 24.1 | 23.5 | 22.8  | 22.0  | 21.2  | 20.3  | 19.2  | 18.1  |
| Type 347, 18Cr–10Ni–Cb                                | 30.8                                                                                             | 30.3 | 29.7 | 29.2 | 28.3 | 27.5 | 27.0 | 26.4 | 25.9 | 25.3 | 24.8 | 24.1 | 23.5 | 22.8  | 22.0  | 21.2  | 20.3  | 19.2  | 18.1  |
| Type 309, 23Cr–12Ni                                   | 30.8                                                                                             | 30.3 | 29.7 | 29.2 | 28.3 | 27.5 | 27.0 | 26.4 | 25.9 | 25.3 | 24.8 | 24.1 | 23.5 | 22.8  | 22.0  | 21.2  | 20.3  | 19.2  | 18.1  |
| Straight chromium stainless steels (12Cr, 17Cr, 27Cr) | 31.8                                                                                             | 31.2 | 30.7 | 30.2 | 29.2 | 28.4 | 27.9 | 27.3 | 26.8 | 26.2 | 25.5 | 24.5 | 23.2 | 21.5  | 19.2  | 16.5  | ...   | ...   | ...   |
| Gray iron                                             | ...                                                                                              | ...  | ...  | ...  | 13.4 | 13.2 | 12.9 | 12.6 | 12.2 | 11.7 | 11.0 | 10.2 | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| <b>Nickel Alloys</b>                                  |                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
| N02200                                                | 32.7                                                                                             | 32.2 | 31.4 | 30.9 | 30.0 | 29.4 | 28.9 | 28.5 | 28.1 | 27.6 | 27.2 | 26.7 | 26.2 | 25.7  | 25.1  | 24.5  | 23.8  | 23.1  | 22.4  |
| N02201                                                | 32.7                                                                                             | 32.2 | 31.4 | 30.9 | 30.0 | 29.4 | 28.9 | 28.5 | 28.1 | 27.6 | 27.2 | 26.7 | 26.2 | 25.7  | 25.1  | 24.5  | 23.8  | 23.1  | 22.4  |
| N04400                                                | 28.3                                                                                             | 27.8 | 27.2 | 26.8 | 26.0 | 25.5 | 25.1 | 24.7 | 24.3 | 23.9 | 23.6 | 23.1 | 22.7 | 22.2  | 21.7  | 21.2  | 20.6  | 20.0  | 19.4  |
| N06002                                                | 31.1                                                                                             | 30.5 | 29.9 | 29.3 | 28.5 | 27.9 | 27.5 | 27.1 | 26.7 | 26.2 | 25.8 | 25.4 | 24.9 | 24.3  | 23.8  | 23.2  | 22.5  | 21.9  | 21.2  |

Temperature, °F

| Material                     | -425 | -325 | -200 | -100 | 70   | 200  | 300  | 400  | 500  | 600  | 700  | 800  | 900  | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 | 1,500 |
|------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|
| Nickel Alloys (Cont'd)       |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
| N06007                       | 30.3 | 29.8 | 29.1 | 28.6 | 27.8 | 27.2 | 26.8 | 26.4 | 26.0 | 25.6 | 25.2 | 24.7 | 24.3 | 23.8  | 23.2  | 22.6  | 22.0  | 21.4  | 20.7  |
| N06022                       | ...  | 32.1 | 31.3 | 30.8 | 29.9 | 29.3 | 28.8 | 28.4 | 28.0 | 27.5 | 27.1 | 26.6 | 26.1 | 25.6  | 25.0  | 24.4  | 23.7  | 23.0  | 22.3  |
| N06030                       | ...  | 31.5 | 30.7 | 30.2 | 29.3 | 28.7 | 28.2 | 27.8 | 27.4 | 27.0 | 26.5 | 26.1 | 25.6 | 25.1  | 24.5  | 23.9  | 23.2  | 22.5  | 21.9  |
| N06035                       | 29.2 | 29.1 | 29.0 | 28.8 | 28.5 | 28.1 | 27.8 | 27.5 | 27.1 | 26.7 | 26.3 | 25.8 | 25.5 | 24.8  | 24.1  | 23.6  | ...   | ...   | ...   |
| N06059                       | ...  | 32.7 | 31.9 | 31.3 | 30.5 | 29.9 | 29.4 | 29.0 | 28.5 | 28.1 | 27.6 | 27.1 | 26.6 | 26.0  | 25.4  | 24.8  | 24.1  | 23.4  | 22.8  |
| N06230                       | ...  | 32.8 | 32.0 | 31.5 | 30.6 | 29.9 | 29.5 | 29.0 | 28.6 | 28.2 | 27.7 | 27.2 | 26.7 | 26.1  | 25.5  | 24.9  | 24.2  | 23.6  | 22.8  |
| N06455                       | 32.5 | 32.0 | 31.2 | 30.7 | 29.8 | 29.2 | 28.7 | 28.3 | 27.9 | 27.4 | 27.0 | 26.5 | 26.0 | 25.5  | 24.9  | 24.3  | 23.6  | 22.9  | 22.2  |
| N06600                       | 33.8 | 33.3 | 32.5 | 31.9 | 31.0 | 30.3 | 29.9 | 29.4 | 29.0 | 28.6 | 28.1 | 27.6 | 27.1 | 26.5  | 25.9  | 25.3  | 23.7  | 23.0  | 22.3  |
| N06617                       | ...  | ...  | ...  | ...  | 29.2 | 28.4 | 28.0 | 27.7 | 27.4 | 27.0 | 26.5 | 26.0 | 25.5 | 24.9  | 24.3  | 23.8  | 23.2  | 22.5  | 21.8  |
| N06625                       | 32.7 | 32.2 | 31.4 | 30.9 | 30.0 | 29.4 | 28.9 | 28.5 | 28.1 | 27.6 | 27.2 | 26.7 | 26.2 | 25.7  | 25.1  | 24.5  | 23.7  | 23.0  | 22.3  |
| N08020                       | ...  | 30.0 | 29.3 | 28.8 | 28.0 | 27.4 | 27.0 | 26.6 | 26.2 | 25.8 | 25.4 | 24.9 | 24.4 | 23.9  | 23.4  | 22.8  | 22.2  | 21.6  | 20.9  |
| N08031                       | ...  | 30.7 | 30.1 | 29.5 | 28.7 | 28.1 | 27.7 | 27.2 | 26.8 | 26.4 | 26.0 | 25.5 | 25.0 | 24.5  | 24.0  | 23.4  | 22.8  | 22.1  | 21.4  |
| N08320                       | ...  | ...  | ...  | 28.6 | 27.8 | 27.1 | 26.7 | 26.4 | 26.0 | 25.7 | 25.3 | 24.7 | 24.2 | 23.6  | 23.2  | 22.7  | ...   | ...   | ...   |
| N08800                       | 31.1 | 30.5 | 29.9 | 29.3 | 28.5 | 27.9 | 27.5 | 27.1 | 26.7 | 26.2 | 25.8 | 25.4 | 24.9 | 24.4  | 23.8  | 23.2  | 22.6  | 21.9  | 21.2  |
| N08810                       | 31.1 | 30.5 | 29.9 | 29.3 | 28.5 | 27.9 | 27.5 | 27.1 | 26.7 | 26.2 | 25.8 | 25.4 | 24.9 | 24.4  | 23.8  | 23.2  | 22.6  | 21.9  | 21.2  |
| N08825                       | ...  | 30.0 | 29.3 | 28.8 | 28.0 | 27.4 | 27.0 | 26.6 | 26.2 | 25.8 | 25.4 | 24.9 | 24.4 | 23.9  | 23.4  | 22.8  | 22.2  | 21.6  | 20.9  |
|                              |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
| N10001                       | 33.9 | 33.4 | 32.6 | 32.0 | 31.1 | 30.4 | 30.0 | 29.5 | 29.1 | 28.7 | 28.2 | 27.7 | 27.2 | 26.6  | 26.0  | 25.3  | 22.6  | 21.9  | 21.2  |
| N10276                       | 32.5 | 32.0 | 31.2 | 30.7 | 29.8 | 29.2 | 28.7 | 28.3 | 27.9 | 27.4 | 27.0 | 26.5 | 26.0 | 25.5  | 24.9  | 24.3  | 23.6  | 22.9  | 22.2  |
| N10665                       | 34.2 | 33.7 | 32.9 | 32.3 | 31.4 | 30.7 | 30.2 | 29.8 | 29.3 | 28.9 | 28.4 | 27.9 | 27.4 | 26.8  | 26.2  | 25.6  | 24.9  | 24.2  | 23.4  |
| N10675                       | ...  | 33.7 | 32.9 | 32.3 | 31.4 | 30.7 | 30.2 | 29.8 | 29.3 | 28.9 | 28.4 | 27.9 | 27.4 | 26.8  | 26.2  | 25.6  | 24.9  | 24.2  | 23.4  |
| Aluminum and Aluminum Alloys |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
| A24430                       | 11.4 | 11.1 | 10.8 | 10.5 | 10.0 | 9.6  | 9.2  | 8.7  | 8.1  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| A91060                       | 11.4 | 11.1 | 10.8 | 10.5 | 10.0 | 9.6  | 9.2  | 8.7  | 8.1  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| A91100                       | 11.4 | 11.1 | 10.8 | 10.5 | 10.0 | 9.6  | 9.2  | 8.7  | 8.1  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| A93003                       | 11.4 | 11.1 | 10.8 | 10.5 | 10.0 | 9.6  | 9.2  | 8.7  | 8.1  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| A93004                       | 11.4 | 11.1 | 10.8 | 10.5 | 10.0 | 9.6  | 9.2  | 8.7  | 8.1  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| A96061                       | 11.4 | 11.1 | 10.8 | 10.5 | 10.0 | 9.6  | 9.2  | 8.7  | 8.1  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| A96063                       | 11.4 | 11.1 | 10.8 | 10.5 | 10.0 | 9.6  | 9.2  | 8.7  | 8.1  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
|                              |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
| A95052                       | 11.6 | 11.3 | 11.0 | 10.7 | 10.2 | 9.7  | 9.4  | 8.9  | 8.3  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |
| A95154                       | 11.6 | 11.3 | 11.0 | 10.7 | 10.2 | 9.7  | 9.4  | 8.9  | 8.3  | ...  | ...  | ...  | ...  | ...   | ...   | ...   | ...   | ...   | ...   |

Table C-6 Moduli of Elasticity for Metals (Cont'd)

| Material                                     | <i>E</i> = Modulus of Elasticity, psi (Multiply Tabulated Values by 10 <sup>6</sup> ) [Note (1)] |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
|----------------------------------------------|--------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|-----|-------|-------|-------|-------|-------|-------|
|                                              | Temperature, °F                                                                                  |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
|                                              | -425                                                                                             | -325 | -200 | -100 | 70   | 200  | 300  | 400  | 500  | 600  | 700  | 800  | 900 | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 | 1,500 |
| <b>Aluminum and Aluminum Alloys (Cont'd)</b> |                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
| A95454                                       | 11.6                                                                                             | 11.3 | 11.0 | 10.7 | 10.2 | 9.7  | 9.4  | 8.9  | 8.3  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| A95652                                       | 11.6                                                                                             | 11.3 | 11.0 | 10.7 | 10.2 | 9.7  | 9.4  | 8.9  | 8.3  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| A03560                                       | 11.7                                                                                             | 11.4 | 11.1 | 10.8 | 10.3 | 9.8  | 9.5  | 9.0  | 8.3  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| A95083                                       | 11.7                                                                                             | 11.4 | 11.1 | 10.8 | 10.3 | 9.8  | 9.5  | 9.0  | 8.3  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| A95086                                       | 11.7                                                                                             | 11.4 | 11.1 | 10.8 | 10.3 | 9.8  | 9.5  | 9.0  | 8.3  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| A95456                                       | 11.7                                                                                             | 11.4 | 11.1 | 10.8 | 10.3 | 9.8  | 9.5  | 9.0  | 8.3  | ...  | ...  | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| <b>Copper and Copper Alloys</b>              |                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
| C83600                                       | ...                                                                                              | 14.8 | 14.6 | 14.4 | 14.0 | 13.7 | 13.4 | 13.2 | 12.9 | 12.5 | 12.0 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C92200                                       | ...                                                                                              | 14.8 | 14.6 | 14.4 | 14.0 | 13.7 | 13.4 | 13.2 | 12.9 | 12.5 | 12.0 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C46400                                       | ...                                                                                              | 15.9 | 15.6 | 15.4 | 15.0 | 14.6 | 14.4 | 14.1 | 13.8 | 13.4 | 12.8 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C65500                                       | ...                                                                                              | 15.9 | 15.6 | 15.4 | 15.0 | 14.6 | 14.4 | 14.1 | 13.8 | 13.4 | 12.8 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C95200                                       | ...                                                                                              | 15.9 | 15.6 | 15.4 | 15.0 | 14.6 | 14.4 | 14.1 | 13.8 | 13.4 | 12.8 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C95400                                       | ...                                                                                              | 15.9 | 15.6 | 15.4 | 15.0 | 14.6 | 14.4 | 14.1 | 13.8 | 13.4 | 12.8 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C10200                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C11000                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C12000                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C12200                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C12500                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C14200                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C23000                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C61400                                       | ...                                                                                              | 18.0 | 17.7 | 17.5 | 17.0 | 16.6 | 16.3 | 16.0 | 15.6 | 15.1 | 14.5 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C70600                                       | ...                                                                                              | 19.0 | 18.7 | 18.5 | 18.0 | 17.6 | 17.3 | 16.9 | 16.5 | 16.0 | 15.4 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C97600                                       | ...                                                                                              | 20.1 | 19.8 | 19.6 | 19.0 | 18.5 | 18.2 | 17.9 | 17.5 | 16.9 | 16.2 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C71000                                       | ...                                                                                              | 21.2 | 20.8 | 20.6 | 20.0 | 19.5 | 19.2 | 18.8 | 18.4 | 17.8 | 17.1 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| C71500                                       | ...                                                                                              | 23.3 | 22.9 | 22.6 | 22.0 | 21.5 | 21.1 | 20.7 | 20.2 | 19.6 | 18.8 | ...  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| <b>Unalloyed Titanium</b>                    |                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
| Grades 1, 2, 3,<br>7, and 12                 | ...                                                                                              | ...  | ...  | ...  | 15.5 | 15.0 | 14.6 | 14.0 | 13.3 | 12.6 | 11.9 | 11.2 | ... | ...   | ...   | ...   | ...   | ...   | ...   |

**Table C-6 Moduli of Elasticity for Metals (Cont'd)**

| Material         | <i>E</i> = Modulus of Elasticity, psi (Multiply Tabulated Values by 10 <sup>6</sup> ) [Note (1)] |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
|------------------|--------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|-----|-------|-------|-------|-------|-------|-------|
|                  | Temperature, °F                                                                                  |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
|                  | −425                                                                                             | −325 | −200 | −100 | 70   | 200  | 300  | 400  | 500  | 600  | 700  | 800  | 900 | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 | 1,500 |
| Zirconium Alloys |                                                                                                  |      |      |      |      |      |      |      |      |      |      |      |     |       |       |       |       |       |       |
| R60702           | ...                                                                                              | ...  | ...  | ...  | 14.4 | 13.5 | 12.6 | 11.7 | 10.9 | 10.1 | 9.3  | 8.2  | ... | ...   | ...   | ...   | ...   | ...   | ...   |
| R60705           | ...                                                                                              | ...  | ...  | ...  | 13.7 | 13.1 | 12.7 | 12.2 | 11.7 | 11.3 | 10.8 | 10.4 | ... | ...   | ...   | ...   | ...   | ...   | ...   |

NOTE: (1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

**Table C-6M Moduli of Elasticity for Metals (SI Units)**

| Material                                              | <i>E</i> = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10 <sup>3</sup> ) [Note (1)] |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------------------------------------------------------|--------------------------------------------------------------------------------------------------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                                                       | Temperature, °C                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|                                                       | −255                                                                                             | −200 | −125 | −75 | 25  | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 |
| Carbon steels with carbon content 0.30% or less       | 220                                                                                              | 216  | 212  | 209 | 202 | 198 | 195 | 192 | 189 | 185 | 179 | 171 | 162 | 151 | 137 | 122 | 107 | ... | ... | ... | ... |
| Carbon steels with carbon content above 0.30%         | 218                                                                                              | 215  | 211  | 207 | 201 | 197 | 194 | 191 | 188 | 183 | 178 | 170 | 161 | 149 | 136 | 121 | 106 | ... | ... | ... | ... |
| Carbon-molybdenum steels                              | 218                                                                                              | 214  | 210  | 207 | 200 | 196 | 193 | 190 | 187 | 183 | 177 | 170 | 160 | 149 | 135 | 121 | 106 | ... | ... | ... | ... |
| Nickel steels, Ni 2% to 9%                            | 207                                                                                              | 204  | 200  | 197 | 191 | 187 | 184 | 181 | 178 | 174 | 171 | 167 | 163 | 158 | 153 | 147 | 141 | 133 | ... | ... | ... |
| Chromium steels:                                      |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| ½Cr through 2Cr                                       | 221                                                                                              | 218  | 213  | 210 | 204 | 200 | 197 | 193 | 190 | 186 | 183 | 179 | 174 | 169 | 164 | 157 | 150 | 142 | ... | ... | ... |
| 2¼Cr through 3Cr                                      | 228                                                                                              | 225  | 220  | 217 | 210 | 206 | 202 | 199 | 196 | 192 | 188 | 184 | 180 | 175 | 169 | 162 | 155 | 146 | ... | ... | ... |
| 5Cr through 9Cr                                       | 230                                                                                              | 228  | 223  | 220 | 213 | 208 | 205 | 201 | 198 | 195 | 191 | 187 | 183 | 179 | 174 | 168 | 161 | 153 | ... | ... | ... |
| Austenitic stainless steels:                          |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Type 304, 18Cr–8Ni                                    | 212                                                                                              | 209  | 204  | 201 | 195 | 189 | 186 | 183 | 179 | 176 | 172 | 169 | 165 | 160 | 156 | 151 | 146 | 140 | 134 | 127 | ... |
| Type 310, 25Cr–20Ni                                   | 212                                                                                              | 209  | 204  | 201 | 195 | 189 | 186 | 183 | 179 | 176 | 172 | 169 | 165 | 160 | 156 | 151 | 146 | 140 | 134 | 127 | ... |
| Type 316, 16Cr–12Ni–2Mo                               | 212                                                                                              | 209  | 204  | 201 | 195 | 189 | 186 | 183 | 179 | 176 | 172 | 169 | 165 | 160 | 156 | 151 | 146 | 140 | 134 | 127 | ... |
| Type 321, 18Cr–10Ni–Ti                                | 212                                                                                              | 209  | 204  | 201 | 195 | 189 | 186 | 183 | 179 | 176 | 172 | 169 | 165 | 160 | 156 | 151 | 146 | 140 | 134 | 127 | ... |
| Type 347, 18Cr–10Ni–Cb                                | 212                                                                                              | 209  | 204  | 201 | 195 | 189 | 186 | 183 | 179 | 176 | 172 | 169 | 165 | 160 | 156 | 151 | 146 | 140 | 134 | 127 | ... |
| Type 309, 23Cr–12Ni                                   | 212                                                                                              | 209  | 204  | 201 | 195 | 189 | 186 | 183 | 179 | 176 | 172 | 169 | 165 | 160 | 156 | 151 | 146 | 140 | 134 | 127 | ... |
| Straight chromium stainless steels (12Cr, 17Cr, 27Cr) | 219                                                                                              | 215  | 212  | 208 | 201 | 195 | 192 | 189 | 186 | 182 | 178 | 173 | 166 | 157 | 145 | 131 | ... | ... | ... | ... | ... |
| Gray iron                                             | ...                                                                                              | ...  | ...  | ... | 92  | 91  | 89  | 87  | 85  | 82  | 78  | 73  | 67  | ... | ... | ... | ... | ... | ... | ... | ... |
| <b>Nickel Alloys</b>                                  |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| N02200                                                | 225                                                                                              | 222  | 216  | 213 | 207 | 202 | 199 | 197 | 194 | 191 | 189 | 186 | 183 | 180 | 176 | 172 | 169 | 164 | 160 | 156 | ... |
| N02201                                                | 225                                                                                              | 222  | 216  | 213 | 207 | 202 | 199 | 197 | 194 | 191 | 189 | 186 | 183 | 180 | 176 | 172 | 169 | 164 | 160 | 156 | ... |
| N04400                                                | 195                                                                                              | 192  | 188  | 185 | 179 | 175 | 173 | 171 | 168 | 166 | 163 | 161 | 158 | 155 | 152 | 149 | 146 | 142 | 139 | 135 | ... |
| N06002                                                | 214                                                                                              | 211  | 206  | 202 | 196 | 192 | 189 | 187 | 184 | 182 | 179 | 176 | 173 | 170 | 167 | 163 | 160 | 156 | 152 | 148 | ... |
| N06007                                                | 209                                                                                              | 205  | 200  | 197 | 191 | 187 | 185 | 182 | 180 | 177 | 175 | 172 | 169 | 166 | 163 | 160 | 156 | 152 | 148 | 144 | ... |

**Table C-6M Moduli of Elasticity for Metals (SI Units) (Cont'd)**

|                              |  | <i>E</i> = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10 <sup>3</sup> ) [Note (1)] |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|------------------------------|--|--------------------------------------------------------------------------------------------------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                              |  | Temperature, °C                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Material                     |  | -255                                                                                             | -200 | -125 | -75 | 25  | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 |
| Nickel Alloys (Cont'd)       |  |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| N06022                       |  | ...                                                                                              | 221  | 216  | 212 | 206 | 201 | 199 | 196 | 193 | 191 | 188 | 185 | 182 | 179 | 175 | 172 | 168 | 164 | 160 | 155 | 151 |
| N06030                       |  | ...                                                                                              | 217  | 212  | 208 | 202 | 197 | 195 | 192 | 189 | 187 | 184 | 181 | 178 | 175 | 172 | 168 | 165 | 161 | 156 | 152 | 148 |
| N06035                       |  | 201                                                                                              | 201  | 200  | 199 | 196 | 194 | 192 | 190 | 187 | 185 | 182 | 179 | 176 | 173 | 170 | 166 | 162 | ... | ... | ... | ... |
| N06059                       |  | ...                                                                                              | 225  | 220  | 216 | 210 | 205 | 203 | 200 | 197 | 194 | 192 | 189 | 185 | 182 | 178 | 175 | 171 | 167 | 162 | 158 | 154 |
| N06230                       |  | ...                                                                                              | 226  | 221  | 217 | 211 | 206 | 203 | 200 | 198 | 195 | 192 | 189 | 186 | 183 | 179 | 176 | 172 | 168 | 163 | 159 | 154 |
| N06455                       |  | 224                                                                                              | 220  | 215  | 212 | 205 | 201 | 198 | 195 | 193 | 190 | 187 | 184 | 181 | 178 | 175 | 171 | 167 | 163 | 159 | 155 | ... |
| N06600                       |  | 233                                                                                              | 229  | 224  | 220 | 213 | 209 | 206 | 203 | 201 | 198 | 195 | 192 | 189 | 186 | 182 | 178 | 174 | 170 | 165 | 161 | ... |
| N06617                       |  | ...                                                                                              | ...  | ...  | ... | 201 | 196 | 193 | 191 | 189 | 187 | 184 | 181 | 178 | 174 | 171 | 167 | 164 | 160 | 156 | 152 | 146 |
| N06625                       |  | 225                                                                                              | 222  | 216  | 213 | 207 | 202 | 199 | 197 | 194 | 191 | 189 | 186 | 183 | 180 | 176 | 172 | 169 | 164 | 160 | 156 | ... |
|                              |  |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| N08020                       |  | ...                                                                                              | 207  | 202  | 199 | 193 | 189 | 186 | 184 | 181 | 179 | 176 | 173 | 170 | 167 | 164 | 161 | 157 | 153 | 150 | ... | ... |
| N08031                       |  | ...                                                                                              | 212  | 207  | 204 | 198 | 193 | 191 | 188 | 185 | 183 | 180 | 178 | 175 | 172 | 168 | 165 | 161 | 157 | 153 | 149 | 145 |
| N08320                       |  | ...                                                                                              | ...  | ...  | 198 | 192 | 187 | 185 | 182 | 180 | 177 | 175 | 172 | 169 | 167 | 163 | 159 | 156 | 152 | 149 | 144 | ... |
| N08800                       |  | 214                                                                                              | 211  | 206  | 202 | 196 | 192 | 189 | 187 | 184 | 182 | 179 | 176 | 173 | 170 | 167 | 164 | 160 | 156 | 152 | 148 | ... |
| N08810                       |  | 214                                                                                              | 211  | 206  | 202 | 196 | 192 | 189 | 187 | 184 | 182 | 179 | 176 | 173 | 170 | 167 | 164 | 160 | 156 | 152 | 148 | ... |
| N08825                       |  | ...                                                                                              | 207  | 202  | 199 | 193 | 189 | 186 | 184 | 181 | 179 | 176 | 173 | 170 | 167 | 164 | 161 | 157 | 153 | 150 | ... | ... |
|                              |  |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| N10001                       |  | 233                                                                                              | 230  | 224  | 221 | 214 | 209 | 206 | 204 | 201 | 198 | 196 | 193 | 189 | 186 | 182 | 178 | 174 | 170 | 166 | 161 | ... |
| N10276                       |  | 224                                                                                              | 220  | 215  | 212 | 205 | 201 | 198 | 195 | 193 | 190 | 187 | 184 | 181 | 178 | 175 | 171 | 167 | 163 | 159 | 155 | ... |
| N10665                       |  | 235                                                                                              | 232  | 227  | 223 | 216 | 211 | 208 | 206 | 203 | 200 | 197 | 194 | 191 | 188 | 184 | 180 | 176 | 172 | 168 | 163 | ... |
| N10675                       |  | ...                                                                                              | 232  | 227  | 223 | 216 | 211 | 208 | 206 | 203 | 200 | 197 | 194 | 191 | 188 | 184 | 180 | 176 | 172 | 168 | ... | ... |
| Aluminum and Aluminum Alloys |  |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| A24430                       |  | 78                                                                                               | 77   | 74   | 72  | 69  | 66  | 63  | 60  | 57  | 52  | 46  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A91060                       |  | 78                                                                                               | 77   | 74   | 72  | 69  | 66  | 63  | 60  | 57  | 52  | 46  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A91100                       |  | 78                                                                                               | 77   | 74   | 72  | 69  | 66  | 63  | 60  | 57  | 52  | 46  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A93003                       |  | 78                                                                                               | 77   | 74   | 72  | 69  | 66  | 63  | 60  | 57  | 52  | 46  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A93004                       |  | 78                                                                                               | 77   | 74   | 72  | 69  | 66  | 63  | 60  | 57  | 52  | 46  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A96061                       |  | 78                                                                                               | 77   | 74   | 72  | 69  | 66  | 63  | 60  | 57  | 52  | 46  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A96063                       |  | 78                                                                                               | 77   | 74   | 72  | 69  | 66  | 63  | 60  | 57  | 52  | 46  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
|                              |  |                                                                                                  |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| A95052                       |  | 80                                                                                               | 78   | 76   | 74  | 70  | 67  | 65  | 62  | 58  | 53  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A95154                       |  | 80                                                                                               | 78   | 76   | 74  | 70  | 67  | 65  | 62  | 58  | 53  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Table C-6M Moduli of Elasticity for Metals (SI Units) (Cont'd)

| E = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10 <sup>3</sup> ) [Note (1)] |                 |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------------------------------------------------------------------------------------------|-----------------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Material                                                                                  | Temperature, °C |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|                                                                                           | -255            | -200 | -125 | -75 | 25  | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 |
| Aluminum and Aluminum Alloys (Cont'd)                                                     |                 |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| A95454                                                                                    | 80              | 78   | 76   | 74  | 70  | 67  | 65  | 62  | 58  | 53  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A95652                                                                                    | 80              | 78   | 76   | 74  | 70  | 67  | 65  | 62  | 58  | 53  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A03560                                                                                    | 80              | 79   | 76   | 75  | 71  | 68  | 65  | 62  | 58  | 54  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A95083                                                                                    | 80              | 79   | 76   | 75  | 71  | 68  | 65  | 62  | 58  | 54  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A95086                                                                                    | 80              | 79   | 76   | 75  | 71  | 68  | 65  | 62  | 58  | 54  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| A95456                                                                                    | 80              | 79   | 76   | 75  | 71  | 68  | 65  | 62  | 58  | 54  | 47  | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Copper and Copper Alloys                                                                  |                 |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| C83600                                                                                    | ...             | 102  | 101  | 99  | 96  | 94  | 93  | 91  | 89  | 87  | 84  | 81  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C92200                                                                                    | ...             | 102  | 101  | 99  | 96  | 94  | 93  | 91  | 89  | 87  | 84  | 81  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C46400                                                                                    | ...             | 110  | 108  | 106 | 103 | 101 | 99  | 97  | 96  | 93  | 90  | 86  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C65500                                                                                    | ...             | 110  | 108  | 106 | 103 | 101 | 99  | 97  | 96  | 93  | 90  | 86  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C95200                                                                                    | ...             | 110  | 108  | 106 | 103 | 101 | 99  | 97  | 96  | 93  | 90  | 86  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C95400                                                                                    | ...             | 110  | 108  | 106 | 103 | 101 | 99  | 97  | 96  | 93  | 90  | 86  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C10200                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C11000                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C12000                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C12200                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C12500                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C14200                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C23000                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C61400                                                                                    | ...             | 124  | 122  | 121 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98  | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C70600                                                                                    | ...             | 131  | 129  | 127 | 124 | 121 | 119 | 117 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C97600                                                                                    | ...             | 139  | 137  | 135 | 131 | 128 | 126 | 123 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C71000                                                                                    | ...             | 146  | 144  | 142 | 138 | 134 | 132 | 130 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C71500                                                                                    | ...             | 161  | 158  | 156 | 152 | 148 | 145 | 143 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Unalloyed Titanium                                                                        |                 |      |      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Grades 1, 2, 3, 7, and 12                                                                 | ...             | ...  | ...  | ... | 107 | 103 | 101 | 97  | 93  | 88  | 84  | 80  | 75  | 71  | ... | ... | ... | ... | ... | ... | ... |

Table C-6M Moduli of Elasticity for Metals (SI Units) (Cont'd)

| Material         | <i>E</i> = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10 <sup>3</sup> ) <a href="#">[Note (1)]</a> |      |      |     |    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |
|------------------|------------------------------------------------------------------------------------------------------------------|------|------|-----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|
|                  | Temperature, °C                                                                                                  |      |      |     |    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |
|                  | −255                                                                                                             | −200 | −125 | −75 | 25 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 |  |
| Zirconium Alloys |                                                                                                                  |      |      |     |    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |
| R60702           | ...                                                                                                              | ...  | ...  | ... | 99 | 92  | 87  | 81  | 76  | 71  | 66  | 60  | ... | ... | ... | ... | ... | ... | ... | ... | ... |  |
| R60705           | ...                                                                                                              | ...  | ...  | ... | 94 | 90  | 87  | 84  | 82  | 79  | 76  | 73  | ... | ... | ... | ... | ... | ... | ... | ... | ... |  |

NOTE: (1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.



**Table C-8 Modulus of Elasticity, Nonmetals**

| <b>Material Description</b>                     | <b><i>E</i>, ksi (73.4°F)</b> | <b><i>E</i>, MPa (23°C)</b> |
|-------------------------------------------------|-------------------------------|-----------------------------|
| <b>Thermoplastics [Note (1)]</b>                |                               |                             |
| Acetal                                          | 410                           | 2 830                       |
| ABS, Type 1210                                  | 250                           | 1 725                       |
| ABS, Type 1316                                  | 340                           | 2 345                       |
| CAB                                             | 120                           | 825                         |
| PVC, Type 1120                                  | 420                           | 2 895                       |
| PVC, Type 1220                                  | 410                           | 2 825                       |
| PVC, Type 2110                                  | 340                           | 2 345                       |
| PVC, Type 2116                                  | 380                           | 2 620                       |
| Chlorinated PVC                                 | 420                           | 2 895                       |
| Chlorinated polyether                           | 160                           | 1 105                       |
| PE2606                                          | 100                           | 690                         |
| PE2706                                          | 100                           | 690                         |
| PE3608                                          | 125                           | 860                         |
| PE3708                                          | 125                           | 860                         |
| PE3710                                          | 125                           | 860                         |
| PE4708                                          | 130                           | 895                         |
| PE4710                                          | 130                           | 895                         |
| PEX0006                                         | 71                            | 440                         |
| PEX0008                                         | 88                            | 490                         |
| Polypropylene                                   | 120                           | 825                         |
| Poly(vinylidene chloride)                       | 100                           | 690                         |
| Poly(vinylidene fluoride)                       | 194                           | 1 340                       |
| Poly(tetrafluoroethylene)                       | 57                            | 395                         |
| Poly(fluorinated ethylene propylene)            | 67                            | 460                         |
| Poly(perfluoroalkoxy alkane)                    | 100                           | 690                         |
| <b>Thermosetting Resins, Axially Reinforced</b> |                               |                             |
| Epoxy-glass, centrifugally cast                 | 1,200–1,900                   | 8 275–13 100                |
| Epoxy-glass, filament-wound                     | 1,100–2,000                   | 7 585–13 790                |
| Polyester-glass, centrifugally cast             | 1,200–1,900                   | 8 275–13 100                |
| Polyester-glass, hand lay-up                    | 800–1,000                     | 5 515–6 895                 |
| <b>Other</b>                                    |                               |                             |
| Borosilicate glass                              | 9,800                         | 67 570                      |

GENERAL NOTE: For Code references to this Appendix, see [para. A319.3.2](#). These data are for use in the absence of more-applicable data. It is the designer's responsibility to verify that materials are suitable for the intended service at the temperatures shown.

NOTE: (1) The modulus of elasticity data shown for thermoplastics are based on short-term tests. The manufacturer should be consulted to obtain values for use under long-term loading.

## **APPENDIX D**

# **FLEXIBILITY AND STRESS INTENSIFICATION FACTORS**

(20)

DELETED (see ASME B31J)

## APPENDIX E

### REFERENCE STANDARDS

(20)

Standards incorporated in this Code by reference, and the names and addresses of the sponsoring organizations, are shown in this Appendix. It is not practical to refer to a specific edition of each standard throughout the Code text; instead, the specific edition reference dates are shown here. Specific edition reference dates are not provided for ASME codes and standards. For ASME codes and standards, the latest published edition in effect at the time this Code is specified is the specific edition referenced by this Code unless otherwise specified in the engineering design. Subsequent issues and revisions of these referenced standards and any new standards incorporated in the Code by reference will be listed (after review and acceptance by the Code Committee) in revisions of this [Appendix E](#).

A component ordinarily is not marked to indicate the edition date of the standard to which it is manufactured. It is therefore possible that an item taken from inventory was produced in accordance with a superseded edition, or an edition not yet approved by the Code (because it is of later date than that listed and is in use). If compliance with a specific edition is a requirement of the intended service, it usually will be necessary to state the specific requirement in the purchase specification and to maintain identification of the component until it is put in service.

| ASTM Specifications               | ASTM Specifications (Cont'd) | ASTM Specifications (Cont'd) |
|-----------------------------------|------------------------------|------------------------------|
| A20-96a                           | A263-94a                     | A381/A381M-18                |
| A36/A36M-19                       | A264-94a                     | A387/A387M-06a               |
| A47/A47M-99 (R2018) <sup>e1</sup> | A265-94a                     | A395/A395M-99 (R2018)        |
| A48/A48M-03 (R2016)               | A268/A268M-05                | A403/A403M-16                |
|                                   | A269-08                      | A409/A409M-15                |
| A53/A53M-07                       | A270/A270M-15                | A420/A420M-07                |
|                                   | A276/A276M-16a               | A426/A426M-08                |
| A105/A105M-09                     | A278/A278M-01 (R2015)        | A437/A437M-10a               |
| A106/A106M-08                     | A283/A283M-18                |                              |
| A126-04                           |                              | A451/A451M-06                |
| A134/A134M-18                     | A285/A285M-17                | A453/A453M-12                |
| A135/A135M-06                     | A299/A299M-04                | A479/A479M-17                |
| A139/A139M-04                     |                              | A487/A487M-93 (R2007)        |
|                                   | A302/A302M-03 (R2007)        | A494/A494M-17a               |
| A179-90a (R2005)                  | A307-07b                     |                              |
| A181/A181M-06                     | A312/A312M-17                | A508/A508M-18                |
| A182/A182M-17                     | A320/A320M-10                | A515/A515M-03 (R2007)        |
| A193/A193M-10a                    | A333/A333M-05                | A516/A516M-06                |
| A194/A194M-17a                    | A334/A334M-04a               | A524-96 (R2005)              |
| A197/A197M-00 (R2015)             | A335/A335M-06                | A536-84 (R2014)              |
|                                   | A350/A350M-07                | A537/A537M-08                |
| A203/A203M-17                     |                              |                              |
| A204/A204M-03 (R2007)             | A351/A351M-16                | A553/A553M-06                |
| A210/A210M-19                     | A352/A352M-06                | A563-07a                     |
| A213-09b                          | A353/A353M-04                | A571/A571M-01 (R2015)        |
| A216/A216M-08                     | A354-17 <sup>e1</sup>        | A587-96 (R2005)              |
| A217/A217M-08                     | A358/A358M-15                |                              |
| A234/A234M-07                     | A369/A369M-06                | A645/A645M-05                |
| A240/A240M-16a                    | A370-11                      | A671/A671M-16                |
| A249/A249M-16a                    | A376/A376M-17                | A672-08                      |

| ASTM Specifications (Cont'd)  | ASTM Specifications (Cont'd) | ASTM Specifications (Cont'd) |
|-------------------------------|------------------------------|------------------------------|
| A675/A675M-03 (R2009)         | B169/B169M-05                | B523/B523M-18                |
| A691-98 (R2007)               | B171/B171M-09                | B550/B550M-07 (R2019)        |
| A694/A694M-16                 | B187/B187M-06                |                              |
| A696-90a (R2012)              |                              | B551/B551M-12 (R2017)        |
|                               | B209-07                      | B564-15                      |
| A707/A707M-14                 | B210/B210M-19                | B572-06 (R2016)              |
| A723/A723M-18a                | B211/B211M-19                | B574-10                      |
| A789/A789M-17a                | B221-08                      | B575-10                      |
| A790/A790M-17                 | B241/B241M-16                | B581-02 (R2008)              |
|                               | B247-02a                     | B582-07                      |
| A813/A813M-09                 |                              | B584-08a                     |
| A814/A814M-08                 | B265-15                      |                              |
| A815/A815M-10a                | B280-08                      | B619-10 <sup>ε1</sup>        |
| A860/A860M-14                 | B283/B283M-14a               | B620-03 (R2008)              |
|                               |                              | B621-02 (R2006)              |
| A928/A928M-11                 | B333-03 (R2008)              | B622-10                      |
| A992/A992M-11 (R2015)         | B335-03 (R2008)              | B625-05                      |
| A995/A995M-13                 | B336-04b                     | B626-17a                     |
|                               | B338-17                      | B649-17                      |
| A1010/A1010M-01 (R2009)       | B348-13                      |                              |
| A1011/A1011M-18a              |                              | B658/B658M-11 (R2016)        |
| A1053/A1053M-11               | B361-08                      | B668-05                      |
|                               | B363-14                      | B675-02 (R2018)              |
| B21/B21M-06                   | B366/B366M-16                | B688-18                      |
| B26/B26M-09                   | B367-13                      | B690-18                      |
| B32-08                        | B371/B371M-08                |                              |
| B42-02 <sup>ε1</sup>          | B381-13                      | B704-03 (R2014)              |
| B43-98 (R2004)                |                              | B705-05 (R2014)              |
|                               | B407-08a (R2014)             | B709-04                      |
| B61-08                        | B408-06 (R2016)              | B725-05                      |
| B62-09                        | B409-06 (R2016)              | B729-05                      |
| B68-02/B68M-99 (R2005)        | B423-05                      | B804-02 (R2007)              |
| B75-02/B75M-99 (R2005)        | B424-05                      | B813-10                      |
| B88-03/B88M-05                | B425-99 (R2005)              | B828-02                      |
| B96/B96M-11                   | B435-06                      | B861-14                      |
| B98/B98M-08                   | B443-00 (R2005)              | B862-14                      |
|                               | B444-06                      |                              |
| B127-05                       | B446-03 (R2008)              | C14-07                       |
| B148-97 (R2009)               |                              | C301-04                      |
| B150/B150M-08                 | B462-18                      | C361-08                      |
|                               | B463-04                      |                              |
| B152/B152M-06a <sup>ε1</sup>  | B464-05                      | C582-09                      |
| B160-05 (R2009)               | B466/B466M-07                | C599-91 (R1995)              |
| B161-05 <sup>ε1</sup>         | B467-88 (R2003)              |                              |
| B162-99 (R2005) <sup>ε1</sup> | B474/B474M-15                | D1527-99 (R2005)             |
| B163-11 <sup>ε2</sup>         | B491/B491M-06                | D1600-08                     |
| B164-03 (R2008)               | B493/B493M-14 (R2019)        | D1694-95 (R2000)             |
| B165-05                       |                              | D1785-15                     |
| B166-19                       | B514-05 (R2014)              |                              |
| B167-11 (R2016)               | B515-95 (R2014)              | D2235-04                     |
| B168-11                       | B517-05 (R2014)              | D2239-12                     |

| ASTM Specifications (Cont'd)   | ASTM Specifications (Cont'd)             | ASME Standards (Use Latest Edition)      |
|--------------------------------|------------------------------------------|------------------------------------------|
| D2241-15                       | E272-19                                  | A13.1                                    |
| D2282-99 <sup>ε1</sup>         | E280-15 (R2019) <sup>ε1</sup>            | B1.1                                     |
| D2321-08                       | E310-15                                  | B1.20.1                                  |
| D2464-06                       | E446-15                                  | B1.20.3                                  |
| D2466-06                       | E709-15                                  | B1.20.7                                  |
| D2467-06                       |                                          |                                          |
| D2468-96a                      | F336-02 (R2009)                          | B16.1                                    |
|                                | F437-09                                  | B16.3                                    |
| D2513-09                       | F438-09                                  | B16.4                                    |
| D2517-06                       | F439-09                                  | B16.5                                    |
| D2564-04 <sup>ε1</sup>         | F441/F441M-15                            | B16.9                                    |
| D2609-02 (R2008)               | F442/F442M-13                            | B16.10                                   |
| D2657-07                       | F493-04                                  | B16.11                                   |
| D2662-96a                      | F714-13                                  | B16.14                                   |
| D2666-96a                      |                                          | B16.15                                   |
| D2672-96a (R2003)              | F1055-98 (R2006)                         | B16.18                                   |
| D2683-04                       | F1281-03 <sup>ε1</sup>                   | B16.20                                   |
| D2737-03                       | F1282-03 <sup>ε1</sup>                   |                                          |
|                                | F1290-98a (R2004)                        | B16.21                                   |
| D2837-08                       | F1412-09                                 | B16.22                                   |
| D2846/D2846M-19                | F1476-07 (R2013)                         | B16.24                                   |
| D2855-96 (R2002)               | F1498-08                                 | B16.25                                   |
| D2992-06                       | F1545-15a                                | B16.26                                   |
| D2996-01 (R2007) <sup>ε1</sup> | F1548-01 (R2018)                         | B16.34                                   |
| D2997-01 (R2007) <sup>ε1</sup> | F1673-04                                 | B16.36                                   |
| D3000-95a                      | F1970-05                                 | B16.39                                   |
|                                | F1974-04                                 | B16.42                                   |
| D3035-15                       | F2389-17a                                | B16.47                                   |
| D3139-98 (R2005)               | F2788/F2788M-18                          | B16.48                                   |
| D3261-03                       | F3125/F3125M-15a                         | B16.50                                   |
|                                | <b>AISC Publication</b>                  | B18.2.1                                  |
| D3517-06                       |                                          | B18.2.2                                  |
| D3754-06                       | 325-05 (Steel Construction Manual, 2006) | B31P                                     |
| D3839-08                       |                                          | B18.31.2                                 |
| D3840-01 (R2005)               | <b>ASCE Standard</b>                     |                                          |
|                                |                                          |                                          |
| D4024-05                       | ASCE/SEI 7-16                            | B36.10M                                  |
| D4161-01 (R2005)               |                                          | B36.19M                                  |
|                                | <b>ASME Codes (Use Latest Edition)</b>   |                                          |
| D5421-05                       |                                          | B46.1                                    |
| D5685-05                       | ASME Boiler and Pressure Vessel Code     | BPE                                      |
| D6041-97 (R2002)               | Section I                                | PCC-1                                    |
|                                | Section II, Part C                       | PCC-2                                    |
|                                | Section II, Part D                       | PTC 19.3 TW                              |
| E29-13                         | Section III, Division 1, Subsection NH   | <b>API Specifications</b>                |
| E94/E94M-17                    | Section V                                |                                          |
| E112-13                        | Section VIII, Division 1                 | 5B, 2008                                 |
| E114-15                        | Section VIII, Division 2                 | 5L, 2009                                 |
| E155-15                        | Section VIII, Division 3                 | 6D, 2014 with Errata 1–9 and Addenda 1–2 |
| E165/E165M-18                  | Section IX                               | 15LE, 2008                               |
| E186-15                        |                                          | 15LR, 2001                               |
| E213-14 <sup>ε1</sup>          |                                          |                                          |

| <b>API Standards</b>                              | <b>AWWA Standards (Cont'd)</b>      | <b>MSS Standard Practices (Cont'd)</b> |
|---------------------------------------------------|-------------------------------------|----------------------------------------|
| 526, 2017 with Errata 1                           | C300-16                             | SP-75-2014                             |
| 570, 2016 with Errata 1 and Addenda 1-2           | C301-14                             | SP-78-2011                             |
| 594, 2017                                         | C302-16                             | SP-79-2018                             |
| 599, 2013                                         | C500-09                             | SP-80-2013                             |
| 600, 2015                                         |                                     | SP-81-2017                             |
|                                                   | C606-15                             | SP-83-2018                             |
| 602, 2015 with Errata 1                           | C900-16                             | SP-85-2011                             |
| 603, 2013                                         | C950-2013 with Errata               | SP-88-2015                             |
| 608, 2012                                         | <b>CEN Technical Report</b>         | SP-93-2014                             |
| 609, 2016 with Errata                             |                                     | SP-95-2018                             |
|                                                   | CEN/TR 14549:2004                   | SP-97-2019                             |
| <b>API Recommended Practice</b>                   |                                     |                                        |
| RP 941, 8 <sup>th</sup> Ed., 2016 with Errata 1-2 | <b>CGA Publication</b>              | SP-105-2016a                           |
|                                                   |                                     | SP-106-2019                            |
|                                                   | G-4.1-2009                          | SP-119-2010                            |
|                                                   |                                     | SP-122-2017                            |
| <b>ASQ Standards</b>                              | <b>CSA Publication</b>              | <b>NACE Standards and Publications</b> |
| 9001: 2015                                        |                                     |                                        |
| Q9000-2: 1997                                     |                                     | MR0103-2012                            |
| Q9000-3: 1997                                     | Z245.1-2014                         | MR0175/ISO 15156-2:2009/Cir.2:2014     |
|                                                   |                                     | MR0175/ISO 15156-3:2009/Cir.4:2014     |
| <b>AWS Standards</b>                              | <b>EJMA Publication</b>             | SP0170-2012                            |
| A3.0M/A3.0:2020                                   |                                     | SP0472-2010                            |
| A5.4/A5.4M:2012                                   | EJMA Standards, Tenth Edition, 2015 |                                        |
| A5.8M/A5.8:2019                                   |                                     | <b>NFPA Specifications</b>             |
| A5.9/A5.9M:2017 (ISO 14343:2009 MOD)              | <b>ISO Standard</b>                 |                                        |
| A5.11/A5.11M:2018                                 | ISO 15649:2001                      | 54/Z223.1-2018                         |
| A5.14/A5.14M:2018                                 |                                     | 1963-2014                              |
| A5.22/A5.22M:2012                                 | <b>MSS Standard Practices</b>       |                                        |
| A5.31M/A5.31:2012                                 |                                     | <b>PFI Standards</b>                   |
| B4.0:2016                                         | SP-6-2017                           | ES-7-2013                              |
| B4.0M:2000 (R2010)                                | SP-9-2018                           | ES-24-2013                             |
| D10.10/D10.10M:1999 (R2009)                       | SP-25-2018                          | ES-48-2015                             |
| QC1:2016-AMD1                                     | SP-42-2013                          |                                        |
|                                                   | SP-43-2013                          | <b>PPI Technical Report</b>            |
| <b>AWWA Standards</b>                             | SP-44-2016 (2017 Reissue)           |                                        |
|                                                   | SP-45-2003 (R2008)                  | TR-21-2001                             |
| C110/A21.10-12                                    | SP-51-2012                          |                                        |
| C111/A21.11-17                                    | SP-53-2012                          | <b>SAE Standards</b>                   |
| C115/A21.15-11                                    | SP-55-2011                          |                                        |
| C150/A21.50-14                                    | SP-58-2018                          | J513-1999 (R2019)                      |
| C151/A21.51-17                                    | SP-65-2012                          | J514-2012                              |
| C200-17                                           | SP-70-2011                          | J518-1-2013                            |
| C207-18                                           | SP-71-2018                          | J518-2-2017                            |
| C208-17                                           | SP-72-2010a                         |                                        |

GENERAL NOTE: The issue date shown immediately following the hyphen after the number of the standard (e.g., C207-18 and SP-6-2017) is the effective date of the issue (edition) of the standard. Any additional number shown following the issue date and prefixed by the letter "R" is the latest date of reaffirmation [e.g., B408-06 (R2016)].

Specifications and standards of the following organizations appear in [Appendix E](#):

|      |                                                                                                                                                                                                                                |      |                                                                                                                                                                                                                                |      |                                                                                                                                                                                          |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AISC | American Institute of Steel Construction<br>130 East Randolph Street<br>Suite 2000<br>Chicago, Illinois 60601<br>(312) 670-2400<br><a href="http://www.aisc.org">www.aisc.org</a>                                              | AWWA | American Water Works Association<br>6666 West Quincy Avenue<br>Denver, Colorado 80235<br>(800) 926-7337<br><a href="http://www.awwa.org">www.awwa.org</a>                                                                      |      | Vienna, Virginia 22180<br>(703) 281-6613<br><a href="http://www.msshq.org">www.msshq.org</a>                                                                                             |
| API  | American Petroleum Institute<br>Publications and Distribution Section<br>1220 L Street, NW<br>Washington, DC 20005-4070<br>(202) 682-8375<br><a href="http://www.api.org">www.api.org</a>                                      | CEN  | European Committee for Standardization<br>Avenue Marnix 17, B-1000<br>Brussels, Belgium<br>+32 2 550 08 11<br><a href="http://www.cen.eu">www.cen.eu</a>                                                                       | NACE | NACE International<br>15835 Park Ten Place<br>Houston, Texas 77084-4906<br>(281) 228-6200<br><a href="http://www.nace.org">www.nace.org</a>                                              |
| ASCE | American Society of Civil Engineers<br>1801 Alexander Bell Drive<br>Reston, Virginia 20191<br>(800) 548-2723<br><a href="http://www.asce.org">www.asce.org</a>                                                                 | CGA  | Compressed Gas Association, Inc.<br>14501 George Carter Way,<br>Suite 103<br>Chantilly, Virginia 20151<br>(703) 788-2700<br><a href="http://www.cganet.com">www.cganet.com</a>                                                 | NFPA | National Fire Protection Association<br>1 Batterymarch Park<br>Quincy, Massachusetts 02169-7471<br>(617) 770-3000 or<br>(800) 344-3555<br><a href="http://www.nfpa.org">www.nfpa.org</a> |
| ASME | The American Society of Mechanical Engineers<br>Two Park Avenue<br>New York, New York 10016-5990<br>(800) 843-2763<br><a href="http://www.asme.org">www.asme.org</a>                                                           | CSA  | Canadian Standards Association<br>178 Rexdale Boulevard<br>Toronto, Ontario<br>M9W 1R3, Canada<br>(416) 747-4044 or<br>(800) 463-6727<br><a href="http://www.csagroup.org">www.csagroup.org</a>                                | PFI  | Pipe Fabrication Institute<br>511 Avenue of the Americas<br>New York, New York 10011<br>(514) 634-3434<br><a href="http://www.pfi-institute.org">www.pfi-institute.org</a>               |
| ASQ  | American Society for Quality<br>P.O. Box 3005<br>Milwaukee, Wisconsin 53201<br>(800) 248-1946<br><a href="http://www.asq.org">www.asq.org</a>                                                                                  | EJMA | Expansion Joint Manufacturers Association, Inc.<br>25 North Broadway<br>Tarrytown, New York 10591<br>(914) 332-0040<br><a href="http://www.ejma.org">www.ejma.org</a>                                                          | PPI  | Plastics Pipe Institute<br>105 Decker Court, Suite 825<br>Irving, Texas 75062<br>(469) 499-1044<br><a href="http://www.plasticpipe.org">www.plasticpipe.org</a>                          |
| ASTM | American Society for Testing and Materials (ASTM International)<br>100 Barr Harbor Drive<br>P.O. Box C700<br>West Conshohocken,<br>Pennsylvania 19428-2959<br>(610) 832-9585<br><a href="http://www.astm.org">www.astm.org</a> | ISO  | International Organization for Standardization<br>Central Secretariat<br>Chemin de Blandonnet 8<br>Case Postale 401<br>1214 Vernier, Geneva<br>Switzerland<br>+41 22 749 01 11<br><a href="http://www.iso.org">www.iso.org</a> | SAE  | SAE International<br>400 Commonwealth Drive<br>Warrendale, Pennsylvania 15096<br>(724) 776-4841 or<br>(877) 606-7323<br><a href="http://www.sae.org">www.sae.org</a>                     |
| AWS  | American Welding Society<br>8669 NW 36 Street, No. 130<br>Miami, Florida 33166<br>(800) 443-9353<br><a href="http://www.aws.org">www.aws.org</a>                                                                               | MSS  | Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.<br>127 Park Street, NE                                                                                                                          | SEMI | Semiconductor Equipment and Materials International<br>3081 Zanker Road<br>San Jose, California 95134<br>(408) 943-6900<br><a href="http://www.semi.org">www.semi.org</a>                |

GENERAL NOTE TO LIST OF ORGANIZATIONS: Some of the organizations listed above publish standards that have been approved as American National Standards. Copies of these standards may also be obtained from:

|      |                                                                                                                                                              |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ANSI | American National Standards Institute<br>25 West 43rd Street<br>New York, New York 10036<br>(212) 642-4900<br><a href="http://www.ansi.org">www.ansi.org</a> |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|



## APPENDIX F

### GUIDANCE AND PRECAUTIONARY CONSIDERATIONS

#### F300 GENERAL

This Appendix provides guidance and precautionary considerations relating to particular fluid services and piping applications. These are not Code requirements but should be taken into account as applicable in the engineering design. Further information on these subjects can be found in the literature.

#### F300.1 Piping That Has Been Placed in Service

Examples of industry standards that address piping that has been placed in service are ASME PCC-2, Repair of Pressure Equipment and Piping, and API 570, Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems.

- (20) **F300.1.5 Rounding.** The following are examples of rounding in accordance with [para. 300.1.5](#):

(a) If the requirement were 6 mm maximum, a measured value of 6.2 mm would be acceptable because the measured value would first be rounded to 6 mm before comparing it to the requirement.

(b) If the requirement were 6.0 mm maximum, a measured value of 6.2 mm would not meet the requirement.

(c) The basic allowable stress at temperature from [Appendix A](#) is 19.0 ksi. A calculated stress due to sustained loads of 19,049 psi would be acceptable because the calculated value would first be rounded to 19.0 ksi before comparing it to the requirement.

#### F301 DESIGN CONDITIONS

Selection of pressures, temperatures, forces, and other conditions that may apply to the design of piping can be influenced by unusual requirements that should be considered when applicable. These include but are not limited to the following.

#### F301.4 Ambient Effects

Where fluids can be trapped (e.g., in double seated valves) and subjected to heating and consequent expansion, means of pressure relief should be considered to avoid excessive pressure buildup.

#### F301.5 Dynamic Effects

##### F301.5.1 Impact

(a) Impact caused by unsteady fluid flow is possible when condensation occurs inside piping normally handling a gas such as steam. Means should be considered to provide drainage of condensate from low areas to avoid damage from hydraulic shock or liquid slugging that may result from the presence of the condensate.

(b) Geysering is an effect that can occur in piping handling fluids at or near their boiling temperatures under conditions when rapid evolution of vapor within the piping causes rapid expulsion of liquid. In such cases, a pressure surge can be generated that may be destructive to the piping. Geysering usually is associated with vertical pipelines but may occur in inclined lines under certain conditions.

#### F301.7 Thermal Expansion and Contraction Effects

*bowing during cooldown* : an effect that can occur, usually in horizontal piping, on introduction of a fluid at or near its boiling temperature and at a flow rate that allows stratified two-phase flow, causing large circumferential temperature gradients and possibly unacceptable stresses at anchors, supports, guides, and within pipe walls. (Two-phase flow can also generate excessive pressure oscillations and surges that may damage the piping.)

#### F301.10 Cyclic Effects

**F301.10.1 Pressure Cycling.** The rules in [para. K304.8](#) may be considered where fatigue due to pressure cycling is a concern.

**F301.10.2 Fatigue at Mixing Points.** Consideration (20) should be given to the potential for fatigue on surfaces exposed to cyclic thermal gradients and pressure variations resulting from chemically thermic reactions or physical mixing of widely differing temperature streams.

**F301.10.3 Severe Cyclic Conditions.** Designating piping as being under severe cyclic conditions should be considered when piping is subjected to both a high stress range and many cycles. The phrase *many cycles* can be taken as when the stress range factor,  $f$ , is less than the maximum,  $f_m$ . The phrase *high stress range* is normally taken as when the calculated stress range

approaches the allowable stress range. Examples include piping associated with batch chemical reactors that cycle more frequently than once a day and piping that has a reasonable likelihood of vibrating.

Frequently, failures occur at small branch connections attached to main piping runs that do not have a high stress range. When experience shows that these small branch connections might be vulnerable to fatigue failure, consideration should be given to designating such piping as being under severe cyclic conditions. See the following references for guidance on the design of small branch connections to avoid fatigue failure:

(a) Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework, published by Energy Institute

(b) Design Guideline for Small Diameter Branch Connections, published jointly by Gas Machinery Research Council, Pipeline Research Council International, and Southwest Research Institute

More-conservative approaches to designating piping as being under severe cyclic conditions should be taken when the fluid handled is toxic, flammable, or damaging to human tissue; when failure of the piping would be costly; and also when examination of the piping during operation or normal outages is impracticable.

## (20) F302 DESIGN CRITERIA

### F302.2 Pressure–Temperature Design Criteria

**F302.2.4 Allowances for Pressure and Temperature Variations.** Consideration should be given to the occasional variations in pressure and temperature resulting from the mixing of fluids during which an exothermic reaction occurs.

## F304 PRESSURE DESIGN

### F304.7 Pressure Design of Other Metallic Components

**F304.7.4 Expansion Joints.** The following are specific considerations to be evaluated by the designer when specifying expansion joint requirements, in addition to the guidelines given in EJMA Standards:

(a) susceptibility to stress corrosion cracking of the materials of construction, considering specific alloy content, method of manufacture, and final heat treated condition.

(b) consideration of not only the properties of the flowing medium but also the environment external to the expansion joint and the possibility of condensation or ice formation due to the operation of the bellows at a reduced temperature.

(c) consideration of specifying a minimum bellows or ply thickness. The designer is cautioned that requiring excessive bellows thickness may reduce the fatigue life of the expansion joint and increase end reactions.

(d) accessibility of the expansion joint for maintenance and inspection.

(e) need for leak tightness criteria for mechanical seals on slip type joints.

(f) specification of installation procedures and shipping or preset bars so that the expansion joint will not be extended, compressed, or offset to compensate for improper alignment of piping, other than the intentional offset specified by the piping designer.

(g) need to request data from the expansion joint manufacturer, including

(1) effective thrust area

(2) lateral, axial, and rotational stiffness (spring constant)

(3) calculated design cycle life under specified design conditions

(4) friction force in hinges, tie rods, etc.

(5) installed length and weight

(6) requirements for additional support or restraint in the piping

(7) expansion joint elements that are designed to be uninsulated during operation

(8) certification of pressure containing and/or restraining materials of construction

(9) maximum test pressure

(10) design calculations

## F307 VALVES

(a) Extended bonnet valves are recommended where necessary to establish a temperature differential between the valve stem packing and the fluid in the piping, to avoid packing leakage and external icing or other heat flux problems. The valve should be positioned to provide this temperature differential. Consideration should be given to possible packing shrinkage in low temperature fluid service.

(b) The effect of external loads on valve operability and leak tightness should be considered.

## F308 FLANGES AND GASKETS

### F308.2 Specific Flanges

**Slip-On Flanges.** The need for venting the space between the welds in double-welded slip-on flanges should be considered for fluid services (including vacuum) that require leak testing of the inner fillet weld, or when fluid handled can diffuse into the enclosed space, resulting in possible failure.

### F308.4 Gaskets

Materials should be selected such that they are suitable for all of the expected service conditions. The following are some specific considerations:

(a) Gasket materials not subject to cold flow should be considered for use with raised-face flanges for fluid services at elevated pressures with temperatures significantly above or below ambient.

(b) Use of full-face gaskets with flat-faced flanges should be considered when using gasket materials subject to cold flow for low pressure and vacuum services at moderate temperatures. When such gasket materials are used in other fluid services, the use of tongue-and-groove or other gasket-confining flange facings should be considered.

(c) The effect of flange facing finish should be considered in gasket material selection.

### F309 BOLTING

#### F309.1 General

The use of controlled bolting procedures should be considered in high, low, and cycling temperature services, and under conditions involving vibration or fatigue, to reduce

(a) the potential for joint leakage due to differential thermal expansion

(b) the possibility of stress relaxation and loss of bolt tension

### F312 FLANGED JOINTS

#### F312.1 General

Three distinct elements of a flanged joint must act together to provide a leak-free joint — the flanges, the gasket, and the bolting. Factors that affect performance include the following:

(a) *Selection and Design*

(1) consideration of service conditions (including external loads, bending moments, and application of thermal insulation)

(2) flange rating, type, material, facing, and facing finish (see [para. F308.2](#))

(3) gasket type, material, thickness, and design (see [para. F308.4](#))

(4) bolt material, strength (cold and at temperature), and specifications for tightening of bolts (see [para. F309.1](#))

(5) design for access to the joint

(b) *Installation*. See [para. 335.2.5](#).

(1) condition of flange mating surfaces

(2) joint alignment and gasket placement before bolt-up

(3) implementation of specified bolting procedures

### F321 PIPING SUPPORT

#### F321.4 Wear of Piping at Support Points

The use of pads or other means of pipe attachment at support points should be considered for piping systems subject to wear and pipe wall metal loss from relative movement between the pipe and its supports (e.g., from wave action on offshore production applications).

### F322 DESIGN CONSIDERATIONS FOR SPECIFIC SYSTEMS

#### F322.6 Pressure Relief Piping

*Stop Valves in Pressure Relief Piping.* If stop valves are located in pressure relief piping in accordance with [para. 322.6.1\(a\)](#), and if any of these stop valves are to be closed while the equipment is in operation, an authorized person should be present. The authorized person should remain in attendance at a location where the operating pressure can be observed and should have access to means for relieving the system pressure in the event of overpressure. Before leaving the station, the authorized person should lock or seal the stop valves in the open position.

### F323 MATERIALS

(20)

(a) Selection of materials to resist deterioration in service is not within the scope of this Code. However, suitable materials should be specified or selected for use in piping and associated facilities not covered by this Code but that affect the safety of the piping. Consideration should be given to allowances made for temperature and pressure effects of process reactions, for properties of reaction or decomposition products, and for hazards from instability of contained fluids. Consideration should be given to the use of cladding, lining, or other protective materials to reduce the effects of corrosion, erosion, and abrasion.

(b) Information on material performance can be found in ASME BPVC, Section II, Part D, Nonmandatory Appendix A.

#### F323.1 General Considerations

The following are some general considerations that should be evaluated when selecting and applying materials in piping (see also [para. FA323.4](#)):

(a) the possibility of exposure of the piping to fire and the melting point, degradation temperature, loss of strength at elevated temperature, and combustibility of the piping material under such exposure

(b) the susceptibility to brittle failure or failure from thermal shock of the piping material when exposed to fire or to fire-fighting measures, and possible hazards from fragmentation of the material in the event of failure

(c) the ability of thermal insulation to protect piping against failure under fire exposure (e.g., its stability, fire resistance, and ability to remain in place during a fire)

(d) the susceptibility of the piping material to crevice corrosion under backing rings, in threaded joints, in socket welded joints, and in other stagnant, confined areas

(e) the possibility of adverse electrolytic effects if the metal is subject to contact with a dissimilar metal

(f) the compatibility of lubricants or sealants used on threads with the fluid service

(g) the compatibility of packing, seals, and O-rings with the fluid service

(h) the compatibility of materials, such as cements, solvents, solders, and brazing materials, with the fluid service

(i) the chilling effect of sudden loss of pressure on highly volatile fluids as a factor in determining the lowest expected service temperature

(j) the possibility of pipe support failure resulting from exposure to low temperatures (which may embrittle the supports) or high temperatures (which may weaken them)

(k) the compatibility of materials, including sealants, gaskets, lubricants, and insulation, used in strong oxidizer fluid service (e.g., oxygen or fluorine)

(l) the possibility of adverse effects from microbiologically influenced corrosion (MIC) or its remediation

### F323.2 Temperature Limitations

**F323.2.2 Lower Temperature Limits.** Regarding materials considered for use at a lower exemption temperature without impact testing using [para. 323.2.2\(h\)](#) or [323.2.2\(i\)](#), the simplified rules of [para. 323.2.2](#) should not be used for piping systems that are anticipated to experience shock loading or thermal bowing, or if they contain welds between dissimilar materials, especially welds between austenitic and ferritic materials. More rigorous means of testing or analysis should be used for such piping systems. For example, the additional stress due to circumferential shear near a dissimilar weld due to differential thermal contraction and its effect on the combined stress should be determined.

The modulus of elasticity for the condition under consideration should be used when evaluating the reactions.

Cold springing or misalignment can result in significant stresses in the ambient condition. The designer is responsible for ensuring that such stresses are accounted for before any credit is taken for reduction in minimum design temperature without impact testing.

### F323.4 Specific Material Considerations — Metals

The following are some specific considerations that should be evaluated when applying certain metals in piping:

(a) *Cast Irons — Gray, Malleable, and High Silicon (14.5%).* Their lack of ductility and their sensitivity to thermal and mechanical shock.

(b) *Carbon Steel, and Low and Intermediate Alloy Steels*

(1) the possibility of embrittlement when handling alkaline or strong caustic fluids

(2) the possible conversion of carbides to graphite during long time exposure to temperatures above 427°C (800°F) of carbon steels, plain nickel steel, carbon-manganese steel, manganese-vanadium steel, and carbon-silicon steel

(3) the possible conversion of carbides to graphite during long time exposure to temperatures above 468°C (875°F) of carbon-molybdenum steel, manganese-molybdenum-vanadium steel, and chromium-vanadium steel

(4) the advantages of silicon-killed carbon steel (0.1% silicon minimum) for temperatures above 482°C (900°F)

(5) the possibility of damage due to hydrogen exposure at elevated temperature (see API RP 941); hydrogen damage (blistering) may occur at lower temperatures under exposure to aqueous acid solutions<sup>1</sup>

(6) the possibility of stress corrosion cracking when exposed to cyanides, acids, acid salts, or wet hydrogen sulfide; a maximum hardness limit is usually specified (see NACE MR0175/ISO 15156-2 or MR0103 and SP0472)<sup>1</sup>

(7) the possibility of sulfidation in the presence of hydrogen sulfide at elevated temperatures

(c) *High Alloy (Stainless) Steels*

(1) the possibility of stress corrosion cracking of austenitic stainless steels exposed to media such as chlorides and other halides either internally or externally; the latter can result from improper selection or application of thermal insulation, or from use of marking inks, paints, labels, tapes, adhesives, and other accessory materials containing chlorides or other halides (see NACE MR0175/ISO 15156-3)<sup>1</sup>

<sup>1</sup> Titles of referenced documents are

API RP 941, Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants

NACE MR0103, Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments

NACE MR0175/ISO 15156-2, Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons

NACE MR0175/ISO 15156-3, Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys

NACE SP0472, Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments

NACE SP0170, Protection of Austenitic Stainless Steels and Other Austenitic Alloys from Polythionic Acid Stress Corrosion Cracking During a Shutdown of Refinery Equipment

(2) the susceptibility to intergranular corrosion of austenitic stainless steels sensitized by exposure to temperatures between 427°C and 871°C (800°F and 1,600°F); as an example, stress corrosion cracking of sensitized metal at room temperature by polythionic acid (reaction of oxidizable sulfur compound, water, and air); stabilized or low carbon grades may provide improved resistance (see NACE SP0170)<sup>1</sup>

(3) the susceptibility to intercrystalline attack of austenitic stainless steels on contact with liquid metals (including aluminum, antimony, bismuth, cadmium, gallium, lead, magnesium, tin, and zinc) or their compounds

(4) the brittleness of ferritic and martensitic stainless steels at room temperature after service at temperature above 371°C (700°F)

*(d) Nickel and Nickel Base Alloys*

(1) the susceptibility to grain boundary attack of nickel and nickel base alloys not containing chromium when exposed to small quantities of sulfur at temperatures above 316°C (600°F)

(2) the susceptibility to grain boundary attack of nickel base alloys containing chromium at temperatures above 593°C (1,100°F) under reducing conditions and above 760°C (1,400°F) under oxidizing conditions

(3) the possibility of stress corrosion cracking of nickel-copper Alloy 400 in hydrofluoric acid vapor in the presence of air, if the alloy is highly stressed (including residual stresses from forming or welding)

*(e) Aluminum and Aluminum Alloys*

(1) the compatibility with aluminum of thread compounds used in aluminum threaded joints to prevent seizing and galling

(2) the possibility of corrosion from concrete, mortar, lime, plaster, or other alkaline materials used in buildings or structures

(3) the susceptibility of Alloy Nos. 5083, 5086, 5154, and 5456 to exfoliation or intergranular attack; and the upper temperature limit of 66°C (150°F) shown in [Appendix A](#) to avoid such deterioration

*(f) Copper and Copper Alloys*

(1) the possibility of dezincification of brass alloys

(2) the susceptibility to stress-corrosion cracking of copper-based alloys exposed to fluids such as ammonia or ammonium compounds

(3) the possibility of unstable acetylide formation when exposed to acetylene

*(g) Titanium and Titanium Alloys.* The possibility of deterioration of titanium and its alloys above 316°C (600°F).

*(h) Zirconium and Zirconium Alloys.* The possibility of deterioration of zirconium and zirconium alloys above 316°C (600°F).

*(i) Tantalum.* Above 299°C (570°F), the possibility of reactivity of tantalum with all gases except the inert gases. Below 299°C, the possibility of embrittlement of tantalum

by nascent (monatomic) hydrogen (but not molecular hydrogen). Nascent hydrogen is produced by galvanic action, or as a product of corrosion by certain chemicals.

*(j) Metals With Enhanced Properties.* The possible loss of strength, in a material whose properties have been enhanced by heat treatment, during long-continued exposure to temperatures above its tempering temperature.

*(k)* The desirability of specifying some degree of production impact testing, in addition to the weld procedure qualification tests, when using materials with limited low temperature service experience below the minimum temperature stated in [Table A-1](#) or [Table A-1M](#).

## F331 HEAT TREATMENT

### F331.1 Heat Treatment Considerations

(20)

Heat treatment temperatures listed in [Table 331.1.1](#) for some materials may be higher than the minimum tempering temperatures specified in the ASTM specifications for the base material. For higher-strength normalized and tempered materials, there is consequently a possibility of reducing tensile properties of the base material, particularly if long holding times at the higher temperatures are used.

## F335 ASSEMBLY AND ERECTION

### F335.9 Cleaning of Piping

The following are some general considerations that may be evaluated in determining the need for cleaning of piping:

*(a)* requirements of the service, including possible contaminants and corrosion products during fabrication, assembly, storage, erection, and testing.

*(b)* for low temperature service, removal of moisture, oil, grease, and other contaminants to prevent sticking of valves or blockage of piping and small cavities.

*(c)* for strong oxidizer fluid service (e.g., oxygen or fluorine), special cleaning and inspection. Reference may be made to the Compressed Gas Association's Pamphlet G-4.1 Cleaning Equipment for Oxygen Service.

*(d)* purging, flushing, or blowing down unwanted dirt, debris, and residual fluid from the inside of a piping system should be performed with caution and control. It is left to the discretion, knowledge, and responsibility of the owner or designer as to the degree of caution and control necessary for a safe work environment. The fluid selected for the purpose of purging, flushing, or blowing down shall preferably be inert. However, for cases in which the use of a flammable or toxic fluid is unavoidable, e.g., when displacing residual testing or flushing fluid with the service fluid, the implementation of additional precautionary considerations may be necessary. Those precautionary considerations should include

(1) the discharge of liquids to a safe collection point



(2) the discharge of flammable liquids away from ignition sources and personnel

(3) venting of gases to a safe outdoor location

(4) venting of flammable gases away from ignition sources and personnel

(5) further protection of personnel via controlled access of the work area, including perimeter warning signs for personnel not involved in the purging process

(6) for precautionary requirements and recommendations regarding the displacement of flushing and testing fluids using a flammable gas, refer to ANSI Z223.1/NFPA 54, National Fuel Gas Code

### F335.10 Identification of Piping

Consideration should be given to identifying the contents of piping, with special consideration given to piping conveying flammable, hazardous, or fire-quenching fluids. Reference may be made to ASME A13.1, Scheme for the Identification of Piping Systems.

## F345 TESTING

**F345.2.3 Special Provisions for Testing.** When piping subassemblies are tested separately, consideration should be given to performing an additional leak test of the assembled piping system prior to initial operation. The test fluid should be nonhazardous to the process and the people performing the examination. Examination for leaks should be at all joints that have not been previously examined for leaks, or that have been reassembled after being examined for leaks. Examples include flanges where isolation blanks were removed after the leak test and joints where instrumentation or other components were removed for the leak test.

### F345.4 Hydrostatic Leak Test

**F345.4.1 Test Fluid.** Consideration should be given to susceptibility to microbiologically influenced corrosion (MIC). This condition is especially prevalent in no-flow, high-moisture environments. Internal MIC may also depend on the characteristics of the treated or untreated test fluid.

Internal MIC may be lessened or possibly eliminated by properly draining and drying systems and/or by proper selection of test fluid.

### F345.5 Pneumatic Leak Test

**F345.5.1 Precautions.** Consideration should be given to the risk associated with the release of stored energy and to the establishment of the minimum safe distance between personnel and the equipment being tested. Equations and considerations are available in ASME PCC-2, Repair of Pressure Equipment and Piping, Article 5.1.

## FA323 MATERIALS

### FA323.4 Material Considerations — Nonmetals

The following are some considerations to be evaluated when applying nonmetals in piping. See also [paras. F323 and F323.1](#).

(a) *Static Charges.* Because of the possibility of producing hazardous electrostatic charges in nonmetallic piping and metallic piping lined with nonmetals, consideration should be given to grounding such systems conveying nonconductive fluids.

(b) *Compressed Gases.* If nonmetallic piping is used above ground for compressed air or other compressed gases, special precautions should be observed. In determining the needed safeguarding for such services, the energetics and the specific failure mechanism need to be evaluated. Encasement of the plastic piping in shatter-resistant material may be considered.

(c) *Brittle Piping.* If borosilicate glass or other brittle piping material is used, take into account its lack of ductility and its sensitivity to thermal and mechanical shock.

## FA328 BONDING OF PLASTICS

(20)

### FA328.2 Bonding Qualifications

**FA328.2.1 Qualification Requirements.** Nonmetallic piping joined using a solvent-cement joining method should follow the manufacturer's recommended cure time. Solvent cement manufacturers specify these cure times by taking into account pipe material, solvent cement type, pipe size, temperature, and humidity.

## FK300 GENERAL STATEMENTS

The rules in [Chapter IX](#) provide an alternative to those in [Chapters I](#) through [VI](#). They include special considerations for thick-walled piping components such as the theory of failure and the approaches to fatigue and thermal stresses, generally resulting in lower design factors with respect to burst strength than the base Code. [Chapter IX](#) rules may allow thinner piping components than the base Code, resulting in lower piping weight, balanced against increased requirements for material testing, fatigue analysis, fabrication, and examination. Although High Pressure Fluid Service is often considered to be service exceeding that allowed by the ASME B16.5, Class 2500 pressure-temperature rating for a particular material group, there are no pressure limitations for the application of these rules. The decision by an owner to specify High Pressure Fluid Service is based on the economic, technical, and other issues pertaining to the piping.

### **FU315 HYGIENIC CLAMP JOINTS**

To lower the probability of leaks in piping that is subject to transient temperature and pressure fluctuations, consider the use of a two-bolt clamp to increase clamping

force in lieu of a hinged clamp for those processes that require

- (a)* passivation
- (b)* clean-in-place (CIP)
- (c)* steam- (or sterilize-) in-place (SIP)

## APPENDIX G

# SAFEGUARDING

### G300 SCOPE

(a) Safeguarding is the provision of protective measures to minimize the risk of accidental damage to the piping or to minimize the harmful consequences of possible piping failure.

(b) In most instances, the safeguarding inherent in the facility (the piping, the plant layout, and its operating practices) is sufficient without need for additional safeguarding. In some instances, however, engineered safeguards must be provided.

(c) [Appendix G](#) outlines some considerations pertaining to the selection and utilization of safeguarding. Where safeguarding is required by the Code, it is necessary to consider only the safeguarding that will be suitable and effective for the purposes and functions stated in the Code or evident from the designer's analysis of the application.

#### G300.1 General Considerations

In evaluating a piping installation design to determine what safeguarding may exist or is necessary, the following should be reviewed:

(a) the hazardous properties of the fluid, considered under the most severe combination of temperature, pressure, and composition in the range of expected operating conditions.

(b) the quantity of fluid that could be released by piping failure, considered in relation to the environment, recognizing the possible hazards ranging from large releases of otherwise innocuous fluids to small leakages of toxic fluids.

(c) expected conditions in the environment, evaluated for their possible effect on the hazards caused by a possible piping failure. This includes consideration of ambient or surface temperature extremes, degree of ventilation, proximity of fired equipment, etc.

(d) the probable extent of operating, maintenance, and other personnel exposure, as well as reasonably probable sources of damage to the piping from direct or indirect causes.

(e) the probable need for grounding of static charges to prevent ignition of flammable vapors.

(f) the safety inherent in the piping by virtue of materials of construction, methods of joining, and history of service reliability.

#### G300.2 Safeguarding by Plant Layout and Operation

Representative features of plant layout and operation that may be evaluated and selectively utilized as safeguarding include

(a) plant layout features, such as open-air process equipment structures; spacing and isolation of hazardous areas; slope and drainage; buffer areas between plant operations and populated communities; or control over plant access

(b) protective installations, such as fire protection systems; barricades or shields; ventilation to remove corrosive or flammable vapors; instruments for remote monitoring and control; containment and/or recovery facilities; or facilities (e.g., incinerators) for emergency disposal of hazardous materials

(c) operating practices, such as restricted access to processing areas; work permit system for hazardous work; or special training for operating, maintenance, and emergency crews

(d) means for safe discharge of fluids released during pressure relief device operation, blowdown, cleanout, etc.

(e) procedures for startup, shutdown, and management of operating conditions, such as gradual pressurization or depressurization, and gradual warmup or cooldown, to minimize the possibility of piping failure, e.g., brittle fracture

#### G300.3 Engineered Safeguards

Engineered safeguards that may be evaluated and selectively applied to provide added safeguarding include

(a) means to protect piping against possible failures, such as

(1) thermal insulation, shields, or process controls to protect from excessively high or low temperature and thermal shock

(2) armor, guards, barricades, or other protection from mechanical abuse

(3) damping or stabilization of process or fluid flow dynamics to eliminate or to minimize or protect against destructive loads (e.g., severe vibration pulsations, cyclic operating conditions)

(b) means to protect people and property against harmful consequences of possible piping failure, such as confining and safely disposing of escaped fluid by



shields for flanged joints, valve bonnets, gages, or sight glasses; or for the entire piping system if of frangible material; limiting the quantity or rate of fluid escaping by automatic shutoff or excess flow valves, additional block

valves, flow-limiting orifices, or automatic shutdown of pressure source; limiting the quantity of fluid in process at any time, where feasible

## APPENDIX H

### SAMPLE CALCULATIONS FOR BRANCH REINFORCEMENT

#### H300 INTRODUCTION (SI UNITS)

The following examples are intended to illustrate the application of the rules and definitions in [para. 304.3.3](#) for welded branch connections.

#### (20) H301 EXAMPLE 1

A DN 200 (NPS 8) run (header) in an oil piping system has a DN 100 (NPS 4) branch at right angles (see [Figure H301](#)). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 2068 kPa at 200°C. The fillet welds at the crotch are minimum size in accordance with [para. 328.5.4](#). A corrosion allowance of 2.5 mm is specified. Is additional reinforcement necessary?

#### Solution

From [Appendix A, Table A-1M](#),  $S = 110$  MPa for API 5L Grade A; from [Table A-1B](#),  $E = 1.0$  for API 5L seamless;  $W = 1.0$ .

$$T_h = (8.18)(0.875) = 7.16 \text{ mm}$$

$$T_b = (6.02)(0.875) = 5.27 \text{ mm}$$

$$\begin{aligned} L_4 &= (2.5)(7.16 - 2.5) = 11.65 \text{ mm} \\ &\text{or } (2.5)(5.27 - 2.5) = 6.93 \text{ mm,} \\ &\text{whichever is less} \\ &= 6.93 \text{ mm} \end{aligned}$$

$$d_1 = [114.3 - (2)(5.27 - 2.5)]/(\sin 90) \text{ deg} = 108.8 \text{ mm}$$

$$\begin{aligned} d_2 &= (5.27 - 2.5) + (7.16 - 2.5) + 109/2 \\ &= 61.9 \text{ mm} \end{aligned}$$

Use  $d_1$  or  $d_2$ , whichever is greater.

$$d_1 = 108.8 \text{ mm}$$

$$t_h = \frac{(2068)(219.1)}{(2)(110,000)(1.0)(1.00) + (2)(0.4)(2068)} = 2.04 \text{ mm}$$

$$t_b = \frac{(2068)(114.3)}{(2)(110,000)(1.0)(1.00) + (2)(0.4)(2068)} = 1.07 \text{ mm}$$

$$\begin{aligned} t_c &= (0.7)(6.02) = 4.21 \text{ mm, or 6 mm, whichever is less} \\ &= 4.21 \text{ mm} \end{aligned}$$

Minimum leg dimension of fillet weld

$$4.21/0.707 = 6.0 \text{ mm}$$

Thus, the required area

$$A_1 = (2.04)(108.8)(2 - \sin 90 \text{ deg}) = 222 \text{ mm}^2$$

The reinforcement area in run wall

$$A_2 = (108.8)(7.16 - 2.04 - 2.5) = 285 \text{ mm}^2$$

in branch wall

$$A_3 = (2)(6.93)[(5.27 - 1.07) - 2.5] = 24 \text{ mm}^2$$

in branch welds

$$A_4 = (2)\left(\frac{1}{2}\right)(6.0)^2 = 36 \text{ mm}^2$$

The total reinforcement area = 345 mm<sup>2</sup>. This is more than the 222 mm<sup>2</sup> so that no additional reinforcement is required to sustain the internal pressure.

#### H302 EXAMPLE 2

(20)

There is a DN 200 (NPS 8) branch at right angles to a DN 300 (NPS 12) header ([Figure H301](#)). Both run and branch are of aluminum alloy Schedule 80 ASTM B241 6061-T6 seamless pipe. The connection is reinforced by a ring 350 mm O.D. (measured along the run) cut from a piece of DN 300 (NPS 12) Schedule 80 ASTM B241 6063-T6 seamless pipe and opened slightly to fit over the run pipe. Allowable stresses for welded construction apply in accordance with [Appendix A, Note \(33\)](#). The fillet welds have the minimum dimensions permitted in [para. 328.5.4](#). A zero corrosion allowance is specified. What is the maximum permissible design pressure if the design temperature is -195°C?

**Solution**

From [Appendix A, Table A-1M](#),  $S = 55.2$  MPa for Grade 6061-T6 (welded) pipe and  $S = 39.3$  MPa for Grade 6063-T6 (welded) pad, both at  $-195^\circ\text{C}$ . From [Table A-1B](#),  $E = 1.0$  for ASTM B241;  $W = 1.0$ .

Leg dimensions of welds to the branch

$$t_c = \text{lesser of } 0.7\bar{T}_b \text{ or } 6 \text{ mm} \\ = 6 \text{ mm}$$

$$\frac{12.7}{0.707} \text{ or } \frac{6}{0.707} = 8.5 \text{ mm}$$

and to the reinforcing pad

$$\frac{0.5\bar{T}_r}{0.707} = \frac{(0.5)(17.48)}{0.707} = 12.36 \text{ mm}$$

$$T_h = (17.48)(0.875) = 15.3 \text{ mm}$$

$$T_b = (12.7)(0.875) = 11.1 \text{ mm}$$

$$T_r = (17.48)(0.875) = 15.3 \text{ mm}$$

$$L_4 = (2.5)(15.3 - 0.0) = 38.25 \text{ mm}$$

[This is smaller than  $(2.5)(11.1 - 0) + 15.3 = 43.05$  mm]

$$d_1 = 219.1 - (2)(11.1 - 0) = 197 \text{ mm}$$

$$d_2 = d_1 \text{ because this is greater than } T_b + T_c + d_1/2$$

$$t_h = \frac{323.8P}{(2)(55\,200)(1.0)(1.0) + (2)(0.4)P}$$

$$t_b = \frac{219.1P}{(2)(55\,200)(1.0)(1.0) + (2)(0.4)P}$$

Using the symbol

$$q = \frac{P}{110,400 + 0.8P}$$

we can briefly write

$$t_h = 323.8q \text{ and } t_b = 219.1q$$

The required area

$$A_1 = 197t_h = 63\,789q$$

The reinforcement area in the run wall

$$A_2 = (197)(15.3 - 323.8q - 0) \\ = 3\,014 - 63\,789q$$

in branch wall

$$A_3 = (2)(38.25)(11.1 - 219.1q - 0) \\ = 849 - 16\,761q$$

in reinforcing ring

$$A_4 = (15.3)(350 - 219.1)(39\,300/55\,200) = 1\,426 \text{ mm}^2$$

in fillet welds

$$A_4 = (2)\left(\frac{1}{2}\right)(8.5)^2 + (2)\left(\frac{1}{2}\right)(12.36)^2 = 225 \text{ mm}^2$$

The total reinforcement area =  $5\,514 - 80\,550q$ .

At the maximum permissible normal operating pressure, the required area and the reinforcement area are equal; thus

$$63\,789q = 5\,514 - 80\,550q \\ 144\,339q = 5\,514 \\ q = 0.0382$$

But also

$$q = \frac{P}{110\,400 + 0.8P}$$

Thus

$$P = (0.0382)(110\,400 + 0.8P) = 4\,217 + 0.03P \\ 0.97P = 4\,217 \\ P = 4\,347 \text{ kPa}$$

**H303 EXAMPLE 3**

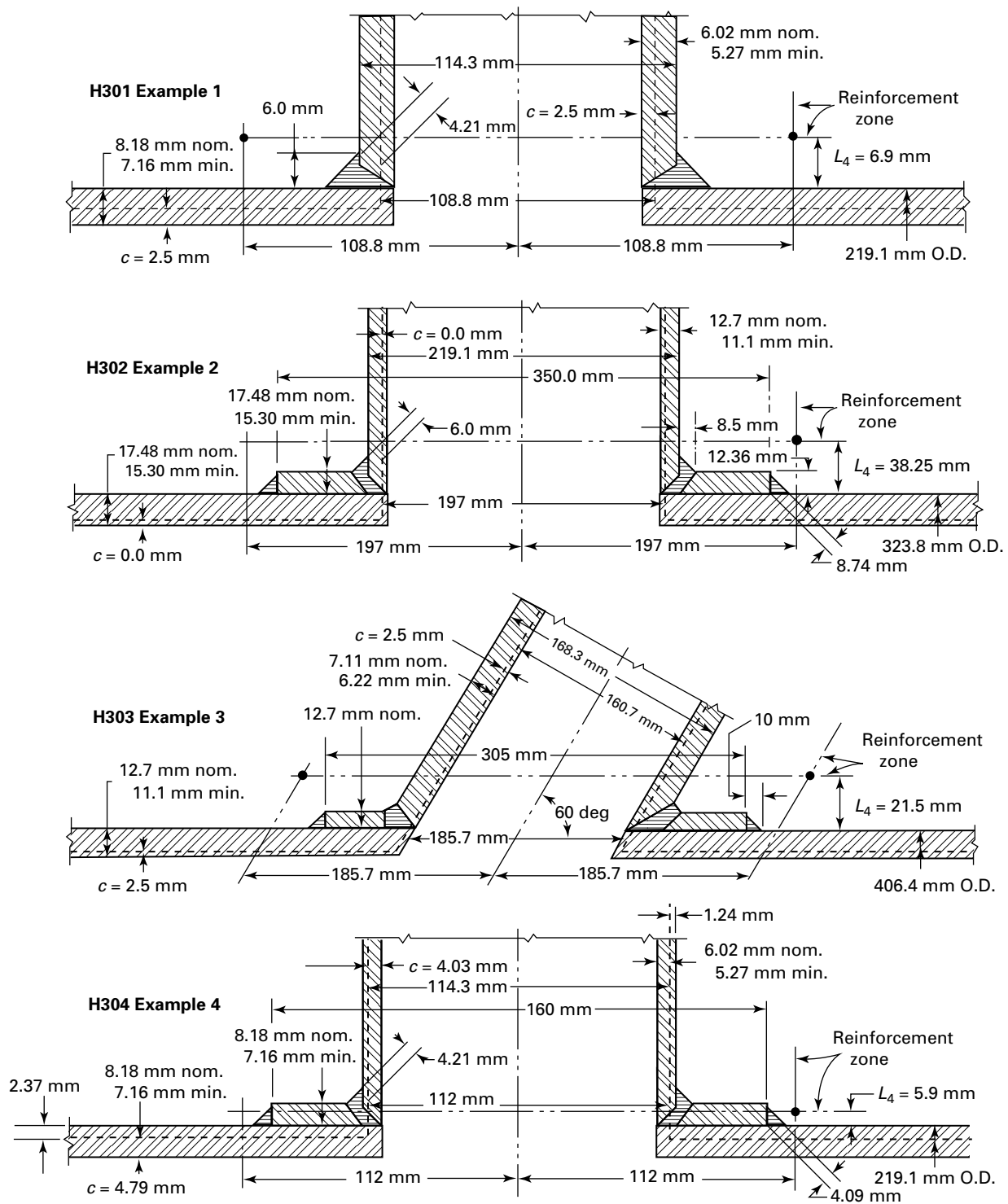
(20)

A DN 150 (NPS 6) Schedule 40 branch has its axis at a 60 deg angle to the axis of a DN 400 (NPS 16) Schedule 40 run (header) in an oil piping system ([Figure H301](#)). Both pipes are API 5L Grade A seamless. The connection is reinforced with a ring 305 mm O.D. (measured along the run) made from 12.7 mm ASTM A285 Grade C plate. All fillet welds are equivalent to 45 deg fillet welds with 10 mm legs. Corrosion allowance = 2.5 mm. The design pressure is 3 450 kPa at  $370^\circ\text{C}$ . Is the design adequate for the internal pressure?

**Solution**

From [Appendix A, Table A-1M](#),  $S = 99.3$  MPa for API 5L Grade A and ASTM A285 Grade C; from [Table A-1B](#),  $E = 1.0$  for API 5L seamless pipe;  $W = 1.0$ .

$$T_h = (12.7)(0.875) = 11.1 \text{ mm}$$

Figure H301 Illustrations for SI Units Examples in [Appendix H](#)

$$T_b = (7.11)(0.875) = 6.22 \text{ mm}$$

$$T_r = 12.7 \text{ mm}$$

$$\begin{aligned} L_4 &= \text{lesser of } (2.5)(6.22 - 2.5) + 12.7 = 22 \text{ mm} \\ &\quad \text{or } (2.5)(11.1 - 2.5) = 21.5 \text{ mm} \\ &= 21.5 \text{ mm} \end{aligned}$$

$$t_h = \frac{(3450)(406.4)}{(2)(99300)(1.0)(1.0) + (2)(0.4)(3450)} = 6.96 \text{ mm}$$

$$t_b = \frac{(3450)(168.3)}{(2)(99300)(1.0)(1.0) + (2)(0.4)(3450)} = 2.88 \text{ mm}$$

$$d_1 = d_2 = \frac{168.3 - (2)(6.22 - 2.5)}{\sin 60 \text{ deg}} = \frac{160.9}{0.866} = 185.7 \text{ mm}$$

The required area

$$A_1 = (6.96)(185.7)(2 - 0.866) = 1466 \text{ mm}^2$$

The reinforcement in the run wall

$$A_2 = (185.7)(11.1 - 6.96 - 2.5) = 305 \text{ mm}^2$$

in branch wall

$$A_3 = (2) \left( \frac{21.5}{0.866} \right) (6.22 - 2.88 - 2.5) = 41.7 \text{ mm}^2$$

in ring

$$A_4 = (12.7) \left( 305 - \frac{168.3}{0.866} \right) = 1405 \text{ mm}^2$$

in fillet welds

$$A_4 = (4) \left( \frac{1}{2} \right) (10)^2 = 200 \text{ mm}^2$$

The total reinforcement is

$$200 + 1405 + 41.7 + 305 = 1952 \text{ mm}^2$$

This total is greater than the  $1466 \text{ mm}^2$ , so that no additional reinforcement is required.

#### (20) H304 EXAMPLE 4

A DN 200 (NPS 8) run (header) in an oil piping system has a DN 100 (NPS 4) branch at right angles (Figure H301). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 2400 kPa at 205°C. It is assumed that the piping system is to remain in service until all metal

thickness, in both branch and run, in excess of that required by eq. (3a) of para. 304.1.2 has corroded away so that area  $A_2$  as defined in para. 304.3.3(c)(1) is zero. What reinforcement is required for this connection?

#### Solution

From Appendix A, Table A-1M,  $S = 110 \text{ MPa}$  for API 5L Grade A; from Table A-1B,  $E = 1.0$  for API 5L seamless;  $W = 1.0$ .

$$t_h = \frac{(2400)(219.1)}{(2)(110000)(1.0)(1.0) + (2)(0.4)(2400)} = 2.37 \text{ mm}$$

$$t_b = \frac{(2400)(114.3)}{(2)(110000)(1.0)(1.0) + (2)(0.4)(2400)} = 1.24 \text{ mm}$$

$$d_1 = 114.3 - (2)(1.24) = 112 \text{ mm}$$

Required reinforcement area

$$A_1 = (2.37)(112) = 265 \text{ mm}^2$$

Try fillet welds only

$$L_4 = (2.5)(2.37) = 5.9 \text{ mm}$$

$$\text{or } (2.5)(1.24) = 3.1 \text{ mm}$$

Use 3.1 mm.

Due to limitation in the height at the reinforcement zone, no practical fillet weld size will supply enough reinforcement area; therefore, the connection must be further reinforced. Try a 160 mm O.D. reinforcing ring (measured along the run). Assume the ring to be cut from a piece of DN 200 (NPS 8) Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds.

Minimum ring thickness

$$T_r = (8.18)(0.875) = 7.16 \text{ mm}$$

$$\text{New } L_4 = (2.5)(1.24) + 7.16 = 10.3 \text{ mm}$$

$$\text{or } (2.5)(2.37) = 5.9 \text{ mm}$$

Use 5.9 mm.

Reinforcement area in the ring (considering only the thickness within  $L_4$ )

$$X_1 = (5.9)(160 - 114.3) = 270 \text{ mm}^2$$

$$\text{Leg dimension of weld} = \frac{(0.5)(8.18)}{0.707} = 5.8 \text{ mm}$$

Reinforcement area in fillet welds

$$X_2 = (2)\left(\frac{1}{2}\right)(5.8)^2 = 34 \text{ mm}^2$$

Total reinforcement area

$$A_4 = X_1 + X_2 = 304 \text{ mm}^2$$

This total reinforcement area is greater than the required area; therefore, a reinforcing ring 160 mm O.D., cut from a piece of DN 200 (NPS 8) Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds would provide adequate reinforcement for this connection.

### H305 EXAMPLE 5 (Not Illustrated)

A DN 40 (NPS 1½) Class 3000 forged steel socket welding coupling has been welded at right angles to a DN 200 (NPS 8) Schedule 40 run (header) in oil service, using a weld conforming to Figure 328.5.4D, illustration (a). The run is ASTM A53 Grade B seamless pipe. The design pressure is 2760 kPa and the design temperature is 230°C. The corrosion allowance is 2.5 mm. Is additional reinforcement required?

#### Solution

No. According to para. 304.3.2(b), the design is adequate to sustain the internal pressure and no calculations are necessary. It is presumed, of course, that calculations have shown the run pipe to be satisfactory for the service conditions according to eqs. (2) and (3).

### H310 INTRODUCTION (U.S. CUSTOMARY UNITS)

The following examples are intended to illustrate the application of the rules and definitions in para. 304.3.3 for welded branch connections.

#### H311 EXAMPLE 1

An NPS 8 run (header) in an oil piping system has an NPS 4 branch at right angles (see Figure H311). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 300 psig at 400°F. The fillet welds at the crotch are minimum size in accordance with para. 328.5.4. A corrosion allowance of 0.10 in. is specified. Is additional reinforcement necessary?

#### Solution

From Appendix A,  $S = 16.0$  ksi for API 5L Grade A (Table A-1);  $E = 1.0$  for API 5L seamless (Table A-1B);  $W = 1.0$ .

$$T_h = (0.322)(0.875) = 0.282 \text{ in.}$$

$$T_b = (0.237)(0.875) = 0.207 \text{ in.}$$

$$\begin{aligned} L_4 &= (2.5)(0.282 - 0.1) = 0.455 \text{ in.} \\ &\text{or } (2.5)(0.207 - 0.1) + 0 = 0.268 \text{ in.,} \\ &\text{whichever is less} \\ &= 0.268 \text{ in.} \end{aligned}$$

$$d_1 = [4.5 - (2)(0.207 - 0.1)]/\sin 90 \text{ deg} = 4.286 \text{ in.}$$

$$\begin{aligned} d_2 &= (0.207 - 0.1) + (0.282 - 0.1) + 4.286/2 \\ &= 2.432 \text{ in.} \end{aligned}$$

Use  $d_1$  or  $d_2$ , whichever is greater.

$$d_1 = 4.286 \text{ in.}$$

$$t_h = \frac{(300)(8.625)}{(2)(16,000)(1.0)(1.0) + (2)(0.4)(300)} = 0.080 \text{ in.}$$

$$t_b = \frac{(300)(4.500)}{(2)(16,000)(1.0)(1.0) + (2)(0.4)(300)} = 0.042 \text{ in.}$$

$$\begin{aligned} t_c &= (0.7)(0.237) = 0.166 \text{ in., or } 0.25, \text{ whichever is less} \\ &= 0.166 \text{ in.} \end{aligned}$$

Minimum leg dimension of fillet weld

$$0.166/0.707 = 0.235 \text{ in.}$$

Thus, the required area

$$A_1 = (0.080)(4.286)(2 - \sin 90 \text{ deg}) = 0.343 \text{ sq in.}$$

The reinforcement area in run wall

$$A_2 = (4.286)(0.282 - 0.08 - 0.10) = 0.437 \text{ sq in.}$$

in branch wall

$$A_3 = (2)(0.268)[(0.207 - 0.042) - 0.10] = 0.035 \text{ sq in.}$$

in branch welds

$$A_4 = (2)\left(\frac{1}{2}\right)(0.235)^2 = 0.055 \text{ sq in.}$$

The total reinforcement area = 0.527 sq in. This is more than 0.343 sq in. so that no additional reinforcement is required to sustain the internal pressure.

### H312 EXAMPLE 2

There is an NPS 8 branch at right angles to an NPS 12 header (Figure H311). Both run and branch are of aluminum alloy Schedule 80 ASTM B241 6061-T6

seamless pipe. The connection is reinforced by a ring 14 in. O.D. (measured along the run) cut from a piece of NPS 12 Schedule 80 ASTM B241 6063-T6 seamless pipe and opened slightly to fit over the run pipe. Allowable stresses for welded construction apply in accordance with [Appendix A, Note \(33\)](#). The fillet welds have the minimum dimensions permitted in [para. 328.5.4](#). A zero corrosion allowance is specified. What is the maximum permissible design pressure if the design temperature is  $-320^{\circ}\text{F}$ ?

### Solution

From [Appendix A, Table A-1](#),  $S = 8.0$  ksi for Grade 6061-T6 (welded) pipe and  $S = 5.7$  ksi for Grade 6063-T6 (welded) pad, both at  $-320^{\circ}\text{F}$ . From [Table A-1B](#),  $E = 1.0$  for ASTM B241;  $W = 1.0$ .

Leg dimensions of welds

$$\frac{t_c}{0.707} = \frac{0.250}{0.707} = 0.354 \text{ in.}$$

$$\frac{(0.5)(0.687)}{0.707} = 0.486 \text{ in.}$$

$$T_h = (0.687)(0.875) = 0.601 \text{ in.}$$

$$T_b = (0.500)(0.875) = 0.438 \text{ in.}$$

$$T_r = (0.687)(0.875) = 0.601 \text{ in.}$$

$$L_4 = (2.5)(0.601 - 0.00) = 1.503 \text{ in.}$$

[This is smaller than  $(2.5)(0.438 - 0.00) + 0.601 = 1.696$  in.]

$$d_2 = d_1 = 8.625 - (2)(0.438 - 0.00) = 7.749 \text{ in.}$$

$$t_h = \frac{12.75P}{(2)(8,000)(1.0)(1.0) + (2)(0.4)(P)}$$

$$t_b = \frac{8.625P}{(2)(8,000)(1.0)(1.0) + (2)(0.4)(P)}$$

Using the symbol

$$q = \frac{P}{16,000 + 0.8P}$$

we can briefly write

$$t_h = 12.75q \text{ and } t_b = 8.625q$$

The required area

$$A_1 = 7.749t_h = 98.80q$$

The reinforcement area in run wall

$$A_2 = (7.749)(0.601 - 12.75q - 0.00)$$

$$= 4.657 - 98.80q$$

in branch wall

$$A_3 = (2)(1.503)(0.438 - 8.625q - 0.00)$$

$$= 1.317 - 25.93q$$

in ring

$$A_4 = (0.601)(14 - 8.625)(5,700/8,000) = 2.302$$

in fillet welds

$$A_4 = (2)\left(\frac{1}{2}\right)(0.354)^2 + (2)\left(\frac{1}{2}\right)(0.486)^2 = 0.362$$

The total reinforcement area =  $8.638 - 124.73q$ .

At the maximum permissible normal operating pressure, the required area and the reinforcement area are equal; thus

$$98.80q = 8.638 - 124.73q$$

$$223.53q = 8.638$$

$$q = 0.0386$$

But also

$$q = \frac{P}{16,000 + 0.8P}$$

Thus

$$P = (0.0386)(16,000 + 0.8P) = 618.3 + 0.0309P$$

$$0.961P = 618.3$$

$$P = 643.1 \text{ psig}$$

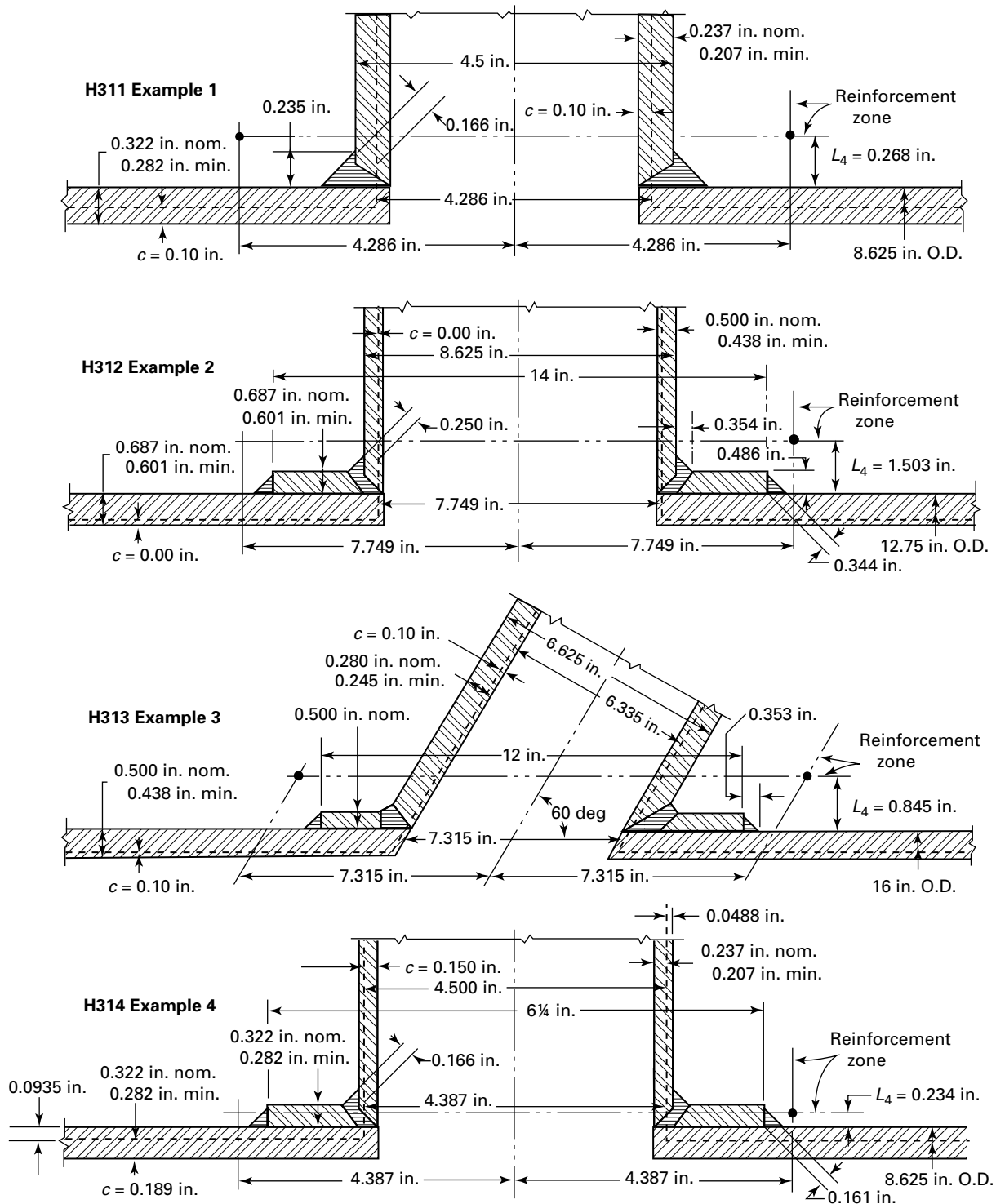
which is the maximum permissible design pressure.

### H313 EXAMPLE 3

An NPS 6 Schedule 40 branch has its axis at a 60 deg angle to the axis of an NPS 16 Schedule 40 run (header) in an oil piping system ([Figure H311](#)). Both pipes are API 5L Grade A seamless. The connection is reinforced with a ring 12 in. O.D. (measured along the run) made from  $\frac{1}{2}$  in. ASTM A285 Grade C plate. All fillet welds are equivalent to 45 deg fillet welds with  $\frac{3}{8}$  in. legs. Corrosion allowance = 0.10 in. The design pressure is 500 psig at  $700^{\circ}\text{F}$ . Is the design adequate for the internal pressure?

### Solution

From [Appendix A](#),  $S = 14.4$  ksi for API 5L Grade A and ASTM A285 Grade C ([Table A-1](#));  $E = 1.0$  for API 5L seamless pipe ([Table A-1B](#));  $W = 1.0$ .

Figure H311 Illustrations for U.S. Customary Units Examples in [Appendix H](#)



$$T_h = (0.500)(0.875) = 0.438 \text{ in.}$$

$$T_b = (0.280)(0.875) = 0.245 \text{ in.}$$

$$T_r = 0.500 \text{ in.}$$

$$L_4 = (2.5)(0.245 - 0.10) + 0.500 = 0.8625$$

This is greater than  $2.5(0.438 - 0.10) = 0.845 \text{ in.}$

$$t_h = \frac{(500)(16)}{(2)(14,400)(1.0)(1.0) + (2)(0.4)(500)} = 0.274 \text{ in.}$$

$$t_b = \frac{(500)(6.625)}{(2)(14,400)(1.0)(1.0) + (2)(0.4)(500)} = 0.113 \text{ in.}$$

$$d_2 = d_1 = \frac{6.625 - (2)(0.245 - 0.10)}{\sin 60 \text{ deg}} = \frac{6.335}{0.866} = 7.315 \text{ in.}$$

The required area

$$A_1 = (0.274)(7.315)(2 - 0.866) = 2.27 \text{ sq in.}$$

The reinforcement in the run wall

$$A_2 = (7.315)(0.438 - 0.274 - 0.10) = 0.468 \text{ sq in.}$$

in branch wall

$$A_3 = (2) \left( \frac{0.845}{0.866} \right) (0.245 - 0.113 - 0.10) = 0.062 \text{ sq in.}$$

in ring

$$A_4 = (0.500) \left( 12 - \frac{6.625}{0.866} \right) = 2.175 \text{ sq in.}$$

in fillet welds

$$A_4 = (4) \left( \frac{1}{2} \right) \left( \frac{3}{8} \right)^2 = 0.281 \text{ sq in.}$$

The total reinforcement = 2.986 sq in. This total is greater than 2.27 sq in., so that no additional reinforcement is required.

### H314 EXAMPLE 4

An NPS 8 run (header) in an oil piping system has an NPS 4 branch at right angles (Figure H311). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 350 psig at 400°F. It is assumed that the piping system is to remain in service until all metal thickness, in both branch and run, in excess of that required by eq. (3a) of para. 304.1.2 has corroded away so that area  $A_2$  as

defined in para. 304.3.3(c)(1) is zero. What reinforcement is required for this connection?

### Solution

From Appendix A,  $S = 16.0 \text{ ksi}$  for API 5L Grade A (Table A-1);  $E = 1.0$  for API 5L seamless (Table A-1B);  $W = 1.0$ .

$$t_h = \frac{(350)(8.625)}{(2)(16,000)(1.0)(1.0) + (2)(0.4)(350)} = 0.0935 \text{ in.}$$

$$t_b = \frac{(350)(4.500)}{(2)(16,000)(1.0)(1.0) + (2)(0.4)(350)} = 0.0488 \text{ in.}$$

$$d_1 = 4.500 - (2)(0.0488) = 4.402 \text{ in.}$$

Required reinforcement area

$$A_1 = (0.0935)(4.402) = 0.412 \text{ sq in.}$$

Try fillet welds only

$$L_4 = (2.5)(0.0935) = 0.234 \text{ in.}$$

or  $(2.5)(0.0488) = 0.122 \text{ in.}$

Use 0.122 in.

Due to limitation in the height at the reinforcement zone, no practical fillet weld size will supply enough reinforcement area; therefore, the connection must be further reinforced. Try a  $6\frac{1}{4} \text{ in.}$  O.D. reinforcing ring (measured along the run). Assume the ring to be cut from a piece of NPS 8 Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds.

Minimum ring thickness

$$T_r = (0.322)(0.875) = 0.282 \text{ in.}$$

$$\text{New } L_4 = (2.5)(0.0488) + 0.282 = 0.404 \text{ in.}$$

$$\text{or } (2.5)(0.0935) = 0.234 \text{ in.}$$

Use 0.234 in.

Reinforcement area in the ring (considering only the thickness within  $L_4$ )

$$X_1 = (0.234)(6.25 - 4.5) = 0.410 \text{ sq in.}$$

$$\text{Leg dimension of weld} = \frac{(0.5)(0.322)}{0.707} = 0.228 \text{ in.}$$

Reinforcement area in fillet welds

$$X_2 = (2)\left(\frac{1}{2}\right)(0.228)^2 = 0.052 \text{ sq in.}$$

Total reinforcement area

$$A_4 = X_1 + X_2 = 0.462 \text{ sq in.}$$

This total reinforcement area is greater than the required area; therefore, a reinforcing ring  $6\frac{1}{4}$  in. O.D., cut from a piece of NPS 8 Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds would provide adequate reinforcement for this connection.

### H315 EXAMPLE 5 (Not Illustrated)

An NPS  $1\frac{1}{2}$  Class 3000 forged steel socket welding coupling has been welded at right angles to an NPS 8 Schedule 40 run (header) in oil service, using a weld

conforming to [Figure 328.5.4D](#), illustration (a). The run is ASTM A53 Grade B seamless pipe. The design pressure is 400 psi and the design temperature is 450°F. The corrosion allowance is 0.10 in. Is additional reinforcement required?

### Solution

No. According to [para. 304.3.2\(b\)](#), the design is adequate to sustain the internal pressure and no calculations are necessary. It is presumed, of course, that calculations have shown the run pipe to be satisfactory for the service conditions according to [eqs. \(2\) and \(3\)](#).

## **APPENDIX J**

## **NOMENCLATURE**

(20)

| Symbol | Definition                                                                             | Units [Note (1)] |                  | Reference            |                                  |                    |
|--------|----------------------------------------------------------------------------------------|------------------|------------------|----------------------|----------------------------------|--------------------|
|        |                                                                                        | SI               | U.S. Customary   | Paragraph            | Table/Fig./App.                  | Equation           |
| $A$    | Factor for determining minimum value of $R_1$                                          | ...              | ...              | 304.2.3              | ...                              | (5)                |
| $A_1$  | Area required for branch reinforcement                                                 | mm <sup>2</sup>  | in. <sup>2</sup> | 304.3.3<br>304.3.4   | 304.3.3<br>304.3.4<br>App. H     | (6) (6a) (9) (9a)  |
| $A_2$  | Area available for branch reinforcement in run pipe                                    | mm <sup>2</sup>  | in. <sup>2</sup> | 304.3.3<br>304.3.4   | 304.3.3<br>304.3.4<br>App. H     | (6a) (7) (9a) (10) |
| $A_3$  | Area available for branch reinforcement in branch pipe                                 | mm <sup>2</sup>  | in. <sup>2</sup> | 304.3.3<br>304.3.4   | 304.3.3<br>304.3.4<br>App. H     | (6a) (8) (9a) (11) |
| $A_4$  | Area available for branch reinforcement in pad or connection                           | mm <sup>2</sup>  | in. <sup>2</sup> | 304.3.3<br>304.3.4   | 304.3.3<br>304.3.4<br>App. H     | (6a) (9a) (12)     |
| $A_f$  | Conveyed fluid cross-sectional area considering nominal pipe thickness less allowances | mm <sup>2</sup>  | in. <sup>2</sup> | 320.2                | ...                              | (23d)              |
| $A_p$  | Pipe cross-sectional area considering nominal pipe thickness less allowances           | mm <sup>2</sup>  | in. <sup>2</sup> | 320.2                | ...                              | (23d)              |
| $A_p$  | Cross-sectional area of pipe                                                           | mm <sup>2</sup>  | in. <sup>2</sup> | 319.4.4              | ...                              | (17)               |
| $a$    | Rupture life exponent                                                                  | ...              | ...              | V303.1.4<br>V304     | ...                              | (V3)               |
| $C$    | Cold spring factor                                                                     | ...              | ...              | 319.5.1              | ...                              | (21)               |
| $C$    | Material constant used in computing Larson-Miller parameter                            | ...              | ...              | V303.1.3<br>V303.1.4 | ...                              | (V2) (V3)          |
| $C_1$  | Estimated self-spring or relaxation factor                                             | ...              | ...              | 319.5.1              | ...                              | (22)               |
| $C_x$  | Size of fillet weld, socket welds other than flanges                                   | mm               | in.              | ...                  | 328.5.2C                         | ...                |
| $CF$   | Welded joint fatigue curve coefficient                                                 | ...              | ...              | W302.2               | W302.1-1<br>W302.1-2<br>W302.1-3 | (W1) (W9)          |

| Symbol | Definition                                                                                  | Units [Note (1)] |                | Reference                                                                                                                                                                                                     |                                                           |                                                                                                        |
|--------|---------------------------------------------------------------------------------------------|------------------|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
|        |                                                                                             | SI               | U.S. Customary | Paragraph                                                                                                                                                                                                     | Table/Fig./App.                                           | Equation                                                                                               |
| $c$    | Sum of mechanical allowances (thread or groove depth) plus corrosion and erosion allowances | mm               | in.            | 302.4<br>304.1.1<br>304.1.2<br>304.2.3<br>304.3.3<br>304.3.4<br>304.4.1<br>304.5.2<br>304.5.3<br>A304.1.1<br>K302.3.5<br>K302.4<br>K304.1.1<br>K304.5.2<br>K304.5.3<br>K304.8.3<br>S301.2<br>V303.1.1<br>V304 | 304.3.3<br>304.3.4<br>328.5.5<br>H301                     | (2) (3b) (4a)<br>(4b) (4c)<br>(7) (8)<br>(10) (11)<br>(12) (13)<br>(14) (15)<br>(25) (33)<br>(36) (37) |
| $c_i$  | Sum of internal allowances                                                                  | mm               | in.            | K304.1.1<br>K304.1.2                                                                                                                                                                                          | ...                                                       | (34b) (35a)<br>(35b)                                                                                   |
| $c_o$  | Sum of external allowances                                                                  | mm               | in.            | K304.1.1<br>K304.1.2                                                                                                                                                                                          | ...                                                       | (34a) (35a)<br>(35b)                                                                                   |
| $D$    | Outside diameter of pipe as listed in tables of standards and specifications or as measured | mm               | in.            | 304.1.1<br>304.1.2<br>304.1.3<br>304.2.1<br>304.2.3<br>319.4.1<br>A304.1.1<br>A304.1.2<br>A328.2.5<br>K304.1.1<br>K304.1.2<br>K304.1.3<br>K304.8.3<br>S301.2<br>V304                                          | 304.1.1<br>304.2.3<br>341.3.2<br>K305.1.2<br>App. A Notes | (3a) (3c) (3d)<br>(3e) (5)<br>(16) (26a)<br>(26b) (26c)<br>(27) (34a)<br>(35a) (37)                    |
| $D_b$  | Outside diameter of branch pipe                                                             | mm               | in.            | 304.3.1<br>304.3.3<br>304.3.4                                                                                                                                                                                 | 304.3.3<br>304.3.4                                        | ...                                                                                                    |
| $D_h$  | Outside diameter of header pipe                                                             | mm               | in.            | 304.3.1<br>304.3.3<br>304.3.4                                                                                                                                                                                 | 304.3.3<br>304.3.4                                        | ...                                                                                                    |
| $D_x$  | Distance from node to node (for stress analysis)                                            | m                | ft             | ...                                                                                                                                                                                                           | S301.3.2<br>S303.3                                        | ...                                                                                                    |
| $D_y$  | Distance from node to node (for stress analysis)                                            | m                | ft             | ...                                                                                                                                                                                                           | S301.3.2<br>S303.3                                        | ...                                                                                                    |
| $D_z$  | Distance from node to node (for stress analysis)                                            | m                | ft             | ...                                                                                                                                                                                                           | S301.3.2<br>S303.3                                        | ...                                                                                                    |

| Symbol | Definition                                                                                   | Units [Note (1)] |                | Reference                                                                                                                                         |                              |                                          |
|--------|----------------------------------------------------------------------------------------------|------------------|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|------------------------------------------|
|        |                                                                                              | SI               | U.S. Customary | Paragraph                                                                                                                                         | Table/Fig./App.              | Equation                                 |
| $d$    | Inside diameter of pipe (note differences in definition between paras. 304.1.1 and K304.1.1) | mm               | in.            | 304.1.1<br>304.1.2<br>K304.1.1<br>K304.1.2                                                                                                        | K305.1.2                     | (3b) (34b)<br>(35b)                      |
| $d$    | Pipe inside diameter considering nominal pipe thickness less allowances                      | mm               | in.            | 320.2                                                                                                                                             | ...                          | (23d)                                    |
| $d_1$  | Effective length removed from pipe at branch                                                 | mm               | in.            | 304.3.3                                                                                                                                           | 304.3.3<br>App. H            | (6) (7)                                  |
| $d_2$  | Half-width of reinforcement zone                                                             | mm               | in.            | 304.3.3<br>304.3.4                                                                                                                                | 304.3.3<br>304.3.4<br>App. H | (7) (10)                                 |
| $d_b$  | Inside diameter of branch pipe                                                               | mm               | in.            | ...                                                                                                                                               | 304.3.4                      | ...                                      |
| $d_g$  | Inside or pitch diameter of gasket                                                           | mm               | in.            | 304.5.3                                                                                                                                           | 304.5.3<br>U304.5.3          | (15)                                     |
| $d_h$  | Inside diameter of header pipe                                                               | mm               | in.            | ...                                                                                                                                               | 304.3.4                      | ...                                      |
| $d_t$  | Fatigue damage due to thermal stress with constant amplitude                                 | ...              | ...            | W302.1<br>W305.1                                                                                                                                  | ...                          | (W2) (W5)                                |
| $d_w$  | Fatigue damage due to wave stress with variable amplitude                                    | ...              | ...            | ...                                                                                                                                               | ...                          | (W5) (W8)                                |
| $d_x$  | Design inside diameter of extruded outlet                                                    | mm               | in.            | 304.3.4                                                                                                                                           | 304.3.4                      | (9) (10)                                 |
| $E$    | Quality factor                                                                               | ...              | ...            | 302.3.1<br>304.1.1<br>304.1.2<br>304.2.3<br>304.3.3<br>304.4.1<br>304.5.1<br>304.5.2<br>304.5.3<br>K304.5.3<br>S301.1<br>S301.2<br>S303.1<br>V304 | Appendix A Notes<br>App. H   | (3a) (3b) (3c)<br>(4a) (4b)<br>(4c) (15) |
| $E$    | Modulus of elasticity (at specified condition)                                               | MPa              | ksi            | A319.3.2<br>W302.1<br>X302.2.3                                                                                                                    | App. C                       | (X1)                                     |
| $E_a$  | Reference modulus of elasticity at 21°C (70°F)                                               | MPa              | ksi            | 319.3.2<br>319.4.1<br>319.4.4<br>319.5.1                                                                                                          | ...                          | (21) (22)                                |

| Symbol    | Definition                                                                  | Units [Note (1)] |                | Reference                                                                                                                                        |                                                                        |                |
|-----------|-----------------------------------------------------------------------------|------------------|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|----------------|
|           |                                                                             | SI               | U.S. Customary | Paragraph                                                                                                                                        | Table/Fig./App.                                                        | Equation       |
| $E_c$     | Casting quality factor                                                      | ...              | ...            | 302.3.1<br>302.3.3<br>302.3.5<br>302.3.6<br>305.2.3<br>306.1.4<br>V303.1.1                                                                       | 302.3.3C<br>Table A-1A                                                 | ...            |
| $E_{CSA}$ | Modulus of elasticity of carbon steel at ambient temperature of 21°C (70°F) | MPa              | ksi            | W302.1                                                                                                                                           | ...                                                                    | ...            |
| $E_j$     | Joint quality factor                                                        | ...              | ...            | 302.3.1<br>302.3.4<br>302.3.5<br>305.2.3<br>306.1.4<br>321.1.3<br>341.4.1<br>341.5.1<br>K302.3.4<br>K305.1.1<br>K306.1.1<br>V303.1.1<br>X302.2.2 | 302.3.4<br>App. A Notes<br>Table A-1B                                  | ...            |
| $E_m$     | Modulus of elasticity at maximum or minimum temperature                     | MPa              | ksi            | 319.3.2<br>319.5<br>319.5.1                                                                                                                      | ...                                                                    | (21) (22)      |
| $E_t$     | Modulus of elasticity at test temperature                                   | MPa              | ksi            | X302.2.3                                                                                                                                         | ...                                                                    | (X1)           |
| $F$       | Service (design) factor                                                     | ...              | ...            | A302.3.2<br>A304.1.1<br>A304.1.2                                                                                                                 | ...                                                                    | (26c)          |
| $F_a$     | Axial force range between any two conditions being evaluated                | N                | lbf            | 319.4.4                                                                                                                                          | ...                                                                    | (17)           |
| $F_a$     | Sustained longitudinal force                                                | N                | lb             | 320.2                                                                                                                                            | ...                                                                    | (23d)          |
| $F_{avg}$ | Multiplier applied to the average stress for rupture in 100 000 h           | ...              | ...            | 302.3.2                                                                                                                                          | ...                                                                    | ...            |
| $F_x$     | Force along the x-axis                                                      | N                | lb             | ...                                                                                                                                              | S301.5.2<br>S302.5.1<br>S302.6.3.1<br>S303.7.1<br>S303.7.2<br>S303.7.3 | ...            |
| $F_y$     | Force along the y-axis                                                      | N                | lb             | ...                                                                                                                                              | S301.5.2<br>S302.5.1<br>S302.6.3.1                                     | ...            |
| $f$       | Stress range factor                                                         | ...              | ...            | 302.3.5<br>S301.1<br>S301.7<br>S303.1                                                                                                            | 302.3.5                                                                | (1a) (1b) (1c) |

| Symbol    | Definition                                                                                                       | Units [Note (1)] |                | Reference                              |                          |                   |
|-----------|------------------------------------------------------------------------------------------------------------------|------------------|----------------|----------------------------------------|--------------------------|-------------------|
|           |                                                                                                                  | SI               | U.S. Customary | Paragraph                              | Table/Fig./App.          | Equation          |
| $f_E$     | Environment correction factor                                                                                    | ...              | ...            | W302.1                                 | W302.1-3<br>W302.1-4     | (W1) (W9)         |
| $f_I$     | Fatigue improvement factor                                                                                       | ...              | ...            | W302.1<br>W302.2                       | W302.1-3                 | (W1) (W9)         |
| $f_{M,k}$ | Fatigue factor for stress ratio                                                                                  | ...              | ...            | W302.1                                 | ...                      | (W1) (W9)         |
| $f_m$     | Maximum value of stress range factor                                                                             | ...              | ...            | 302.3.5                                | ...                      | (1c)              |
| $f_t$     | Temperature correction factor                                                                                    | ...              | ...            | W302.1                                 | ...                      | (W1) (W9)         |
| $g$       | Root gap for welding                                                                                             | mm               | in.            | K328.4.3                               | 328.4.4<br>K328.5.4      | ...               |
| $h$       | Nominal thread depth                                                                                             | mm               | in.            | K304.1.1                               | 304.1.1                  | ...               |
| $h$       | Weibull stress range shape distribution parameter                                                                | ...              | ...            | W302.2<br>W302.3                       | W301-1                   | (W3) (W4)<br>(W8) |
| $h_F$     | Through-wall dimension (height) of a flaw drawn normal to the inside pressure-retaining surface of the component | mm               | in.            | R307                                   | R307<br>R308.1<br>R308.2 | ...               |
| $h_x$     | Height of extruded outlet                                                                                        | mm               | in.            | 304.3.4                                | 304.3.4                  | ...               |
| $I_a$     | Sustained longitudinal index                                                                                     | ...              | ...            | 320.1<br>320.2<br>323.2.2              | ...                      | (23d)             |
| $I_i$     | Sustained in-plane moment index                                                                                  | ...              | ...            | 320.1<br>320.2<br>323.2.2              | ...                      | (23b)             |
| $I_o$     | Sustained out-plane moment index                                                                                 | ...              | ...            | 320.1<br>320.2<br>323.2.2              | ...                      | (23b)             |
| $I_t$     | Sustained torsional moment index                                                                                 | ...              | ...            | 320.1<br>320.2<br>323.2.2              | ...                      | (23c)             |
| $i$       | Stress intensification factor                                                                                    | ...              | ...            | 319.3.6                                | ...                      | ...               |
| $i$       | Service condition                                                                                                | ...              | ...            | V303.1.1<br>V303.1.4<br>V303.2<br>V304 | ...                      | ...               |
| $i_a$     | Axial force stress intensification factor                                                                        | ...              | ...            | 319.4.4                                | ...                      | (17)              |
| $i_i$     | In-plane stress intensification factor                                                                           | ...              | ...            | 319.4.4<br>320.2<br>S301.7             | ...                      | (18) (23b)        |
| $i_o$     | Out-plane stress intensification factor                                                                          | ...              | ...            | 319.4.4<br>320.2                       | ...                      | (18) (23b)        |



| Symbol | Definition                                                                                                    | Units [Note (1)] |                | Reference                      |                                  |           |
|--------|---------------------------------------------------------------------------------------------------------------|------------------|----------------|--------------------------------|----------------------------------|-----------|
|        |                                                                                                               | SI               | U.S. Customary | Paragraph                      | Table/Fig./App.                  | Equation  |
| $i_t$  | Torsional stress intensification factor                                                                       | ...              | ...            | 319.4.4                        | ...                              | (17)      |
| $K$    | Factor determined by ratio of branch diameter to run diameter                                                 | ...              | ...            | 304.3.4                        | 304.3.4                          | (9)       |
| $K_1$  | Constant in empirical flexibility equation                                                                    | ...              | ...            | 319.4.1                        | ...                              | (16)      |
| $k$    | Flexibility factor                                                                                            | ...              | ...            | 319.3.6                        | ...                              | ...       |
| $k$    | Fatigue strength thickness exponent                                                                           | ...              | ...            | W302.2                         | W302.1-1<br>W302.1-2<br>W302.1-3 | (W1) (W9) |
| $L$    | Developed length of piping between anchors (the running centerline length between stiffened sections of pipe) | m                | ft             | 304.1.3<br>319.4.1<br>K304.2.4 | ...                              | (16)      |
| $L_4$  | Height of reinforcement zone outside run pipe                                                                 | mm               | in.            | 304.3.3                        | 304.3.3<br>App. H                | (8)       |
| $L_5$  | Height of reinforcement zone for extruded outlet                                                              | mm               | in.            | 304.3.4                        | 304.3.4                          | (11)      |
| $L_d$  | Piping cycle design life                                                                                      | ...              | ...            | W302.2                         | ...                              | (W7)      |
| $L_w$  | Design storm period of occurrence                                                                             | ...              | ...            | W302.2                         | ...                              | (W6)      |
| $LMP$  | Larson-Miller parameter, used to estimate design life                                                         | ...              | ...            | V303.1.3<br>V303.1.4<br>V304   | ...                              | (V2) (V3) |
| $l_F$  | Length of a flaw drawn parallel to the inside pressure-retaining surface of the component                     | mm               | in.            | R307                           | R307<br>R308.1<br>R308.2         | ...       |
| $M$    | Length of full thickness pipe adjacent to miter bend                                                          | mm               | in.            | 304.2.3                        | 304.2.3                          | ...       |
| $M_i$  | In-plane moment range between any two conditions being evaluated                                              | N-mm             | in.-lbf        | 319.4.4                        | 319.4.4A<br>319.4.4B             | (18)      |
| $M_i$  | In-plane bending moment for the sustained condition being evaluated                                           | N-mm             | in.-lbf        | 320.2                          | ...                              | (23b)     |
| $M_o$  | Out-plane moment range between any two conditions being evaluated                                             | N-mm             | in.-lbf        | 319.4.4                        | 319.4.4A<br>319.4.4B             | (18)      |
| $M_o$  | Out-plane bending moment for the sustained condition being evaluated                                          | N-mm             | in.-lbf        | 320.2                          | ...                              | (23b)     |
| $M_t$  | Sustained torsional moment                                                                                    | N-mm             | in.-lbf        | 320.2                          | ...                              | (23c)     |
| $M_t$  | Torsional moment range between any two conditions being evaluated                                             | N-mm             | in.-lbf        | 319.4.4                        | 319.4.4A<br>319.4.4B             | ...       |

| Symbol   | Definition                                                                              | Units [Note (1)] |                | Reference                                                                                                                                                                                  |                                            |                                                                                                |
|----------|-----------------------------------------------------------------------------------------|------------------|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|------------------------------------------------------------------------------------------------|
|          |                                                                                         | SI               | U.S. Customary | Paragraph                                                                                                                                                                                  | Table/Fig./App.                            | Equation                                                                                       |
| $M_y$    | Moment along the y-axis                                                                 | N-m              | ft-lb          | ...                                                                                                                                                                                        | S303.7.1<br>S303.7.2<br>S303.7.3           | ...                                                                                            |
| $M_z$    | Moment along the z-axis                                                                 | N-m              | ft-lb          | ...                                                                                                                                                                                        | S301.5.2                                   | ...                                                                                            |
| $m$      | Misfit of branch pipe                                                                   | mm               | in.            | 328.4.3<br>K328.4.3                                                                                                                                                                        | 328.4.4<br>K328.5.4                        | ...                                                                                            |
| $m$      | Welded joint fatigue curve exponent                                                     | ...              | ...            | W302.2                                                                                                                                                                                     | W301-1<br>W302.1-1<br>W302.1-2<br>W302.1-3 | (W1) (W8)<br>(W9)                                                                              |
| $N$      | Equivalent number of full displacement cycles                                           | ...              | ...            | 300.2<br>302.3.5<br>K304.8.1                                                                                                                                                               | 302.3.5                                    | (1c) (1d)                                                                                      |
| $N_d$    | Design number of pipe stress cycles                                                     | ...              | ...            | ...                                                                                                                                                                                        | ...                                        | (W7) (W8)                                                                                      |
| $N_E$    | Number of cycles of maximum computed displacement stress range                          | ...              | ...            | 302.3.5                                                                                                                                                                                    | ...                                        | (1d)                                                                                           |
| $N_i$    | Number of cycles associated with displacement stress range, $S_i$ ( $i = 1, 2, \dots$ ) | ...              | ...            | 302.3.5                                                                                                                                                                                    | ...                                        | (1d)                                                                                           |
| $N_i$    | Number of cycles for loading condition $i$                                              | ...              | ...            | W302.1                                                                                                                                                                                     | ...                                        | (W2)                                                                                           |
| $N_{ti}$ | Allowable number of cycles for loading condition $i$                                    | ...              | ...            | W302.1                                                                                                                                                                                     | W302.1-3                                   | (W1) (W2)                                                                                      |
| $N_w$    | Design storm wave height associated cycles                                              | ...              | ...            | W302.2                                                                                                                                                                                     | ...                                        | (W4) (W6)<br>(W8)                                                                              |
| $n$      | Slope of log time to rupture versus log stress plot at 100 000 h                        | ...              | ...            | 302.3.2                                                                                                                                                                                    | ...                                        | ...                                                                                            |
| $P$      | Internal design gage pressure                                                           | kPa              | psi            | 304.1.1<br>304.1.2<br>304.2.1<br>304.4.1<br>304.5.1<br>304.5.2<br>304.5.3<br>345.4.2<br>A304.1.1<br>A304.1.2<br>A304.5.1<br>H302<br>K304.1.2<br>K304.7.2<br>K304.8.3<br>K345.4.2<br>S301.2 | ...                                        | (3a) (3b) (3c)<br>(15) (24)<br>(26a) (26b)<br>(26c) (34a)<br>(34b) (35a)<br>(35b) (37)<br>(38) |
| $P_{a2}$ | See ASME BPVC, Section VIII, Division 1, UG-28                                          | ...              | ...            | 304.1.3                                                                                                                                                                                    | ...                                        | ...                                                                                            |

| Symbol     | Definition                                                                                                                                          | Units [Note (1)] |                 | Reference                                   |                                            |                        |
|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------|---------------------------------------------|--------------------------------------------|------------------------|
|            |                                                                                                                                                     | SI               | U.S. Customary  | Paragraph                                   | Table/Fig./App.                            | Equation               |
| $P_i$      | Gage pressure during service condition $i$                                                                                                          | kPa              | psi             | V303.1.1<br>V303.2                          | ...                                        | (V1)                   |
| $P_j$      | Piping internal gage pressure for the condition being considered; the as-installed and operating conditions are subscripted as $j = 1, 2, 3, \dots$ | kPa              | psi             | 320.2<br>S300.1<br>S301<br>S302<br>S303     | S301.1<br>S301.3.1<br>S302.1<br>S302.6.2.1 | (23d)                  |
| $P_m$      | Maximum allowable internal pressure for miter bends                                                                                                 | kPa              | psi             | 304.2.3                                     | ...                                        | (4a) (4b) (4c)         |
| $P_{\max}$ | Maximum allowable gage pressure for continuous operation of component at maximum design temperature                                                 | kPa              | psi             | V303.1.1<br>V304                            | ...                                        | (V1)                   |
| $P_S$      | Limiting design pressure based on column instability, for convoluted U-shaped bellows                                                               | kPa              | psi             | X302.2.3                                    | ...                                        | (X1)                   |
| $P_T$      | Minimum test gage pressure                                                                                                                          | kPa              | psi             | 345.4.2<br>A382.2.5<br>K345.4.2<br>X302.2.3 | ...                                        | (24) (27) (38)<br>(X1) |
| $q$        | Temporary symbol for $D/t$                                                                                                                          | ...              | ...             | H302                                        | ...                                        | ...                    |
| $q$        | Weibull stress range scale distribution factor                                                                                                      | MPa              | ksi             | ...                                         | ...                                        | (W3) (W4)              |
| $R$        | Range of reaction forces or moments in flexibility analysis                                                                                         | N or N-mm        | lbf or in.-lbf  | 319.5.1                                     | ...                                        | (21)                   |
| $R_1$      | Effective radius of miter bend                                                                                                                      | mm               | in.             | 304.2.3                                     | 304.2.3                                    | (4b) (5)               |
| $R_1$      | Bend radius of welding elbow or pipe bend                                                                                                           | mm               | in.             | 304.2.1                                     | 304.2.1                                    | (3d) (3e)              |
| $R_a$      | Estimated instantaneous reaction force or moment at installation temperature                                                                        | N or N-mm        | lbf or in.-lbf  | 319.5.1                                     | ...                                        | ...                    |
| $R_a$      | Roughness average                                                                                                                                   | $\mu\text{m}$    | $\mu\text{in.}$ | K302.3.3                                    | 302.3.3C<br>341.3.2<br>K341.3.2            | ...                    |
| $R_m$      | Estimated instantaneous maximum reaction force or moment at maximum or minimum metal temperature                                                    | N or N-mm        | lbf or in.-lbf  | 319.5.1                                     | ...                                        | (21)                   |
| $R_T$      | Ratio of the average temperature-dependent trend curve value of tensile strength to the room temperature tensile strength                           | ...              | ...             | 302.3.2<br>K302.3.2                         | ...                                        | (31d)                  |
| $R_Y$      | Ratio of the average temperature-dependent trend curve value of yield strength to the room temperature yield strength                               | ...              | ...             | 302.3.2<br>K302.3.2                         | ...                                        | (31c)                  |
| $r$        | Corner radius of lap joint stub end                                                                                                                 | mm               | in.             | 308.2.1                                     | ...                                        | ...                    |
| $r_2$      | Mean radius of pipe using nominal wall thickness, $\bar{T}$                                                                                         | mm               | in.             | 304.2.3<br>319.4.4                          | 304.2.3                                    | (4a) (4b) (4c)         |

| Symbol | Definition                                                                                                                    | Units [Note (1)] |                | Reference                                                                                                                                                                                 |                                            |                                                   |
|--------|-------------------------------------------------------------------------------------------------------------------------------|------------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|---------------------------------------------------|
|        |                                                                                                                               | SI               | U.S. Customary | Paragraph                                                                                                                                                                                 | Table/Fig./App.                            | Equation                                          |
| $r_i$  | Ratio of lesser computed displacement stress range, $S_{\nu}$ , to maximum computed stress range, $S_E$ ( $i = 1, 2, \dots$ ) | ...              | ...            | 302.3.5                                                                                                                                                                                   | ...                                        | (1d)                                              |
| $r_x$  | External contour radius of extruded outlet                                                                                    | mm               | in.            | 304.3.4                                                                                                                                                                                   | 304.3.4                                    | (12)                                              |
| $S$    | Basic allowable stress for metals                                                                                             | MPa              | ksi            | 300.2<br>302.3.1<br>302.3.5<br>304.1.1<br>304.1.2<br>304.1.3<br>304.2.1<br>304.2.3<br>304.3.3<br>304.4.1<br>304.5.1<br>304.5.2<br>304.5.3<br>304.7.2<br>345.4.2<br>H300<br>S301.2<br>V304 | A-1<br>A-1M                                | (3a) (3b) (3c)<br>(4a) (4b)<br>(4c) (15)<br>(24)  |
| $S$    | Bolt design stress                                                                                                            | MPa              | ksi            | 300.2<br>302.3.1                                                                                                                                                                          | A-2                                        | ...                                               |
| $S$    | Design stress for nonmetals                                                                                                   | ...              | ...            | A302.3.1<br>A304.1.1<br>A304.1.2<br>A304.5.2<br>A345.4.2                                                                                                                                  | B-1                                        | (26a) (26b)<br>(26c)                              |
| $S$    | Allowable stress for metals                                                                                                   | MPa              | ksi            | K302.3.2<br>K304.1.2<br>K304.5.3<br>K304.7.2<br>K345.4.2                                                                                                                                  | K-1                                        | (31a) (31b)<br>(34a) (34b)<br>(35a) (35b)<br>(38) |
| $S$    | Stress intensity                                                                                                              | MPa              | ksi            | K304.8.3                                                                                                                                                                                  | ...                                        | (37)                                              |
| $S_A$  | Allowable displacement stress range                                                                                           | MPa              | ksi            | 300.2<br>302.3.5<br>319.2.3<br>319.3.4<br>319.4.1<br>319.4.4<br>K302.3.5<br>S301.7<br>S303.8                                                                                              | S301.7<br>S303.7.1<br>S303.7.2<br>S303.7.3 | (1a) (1b) (16)<br>(32)                            |
| $S_a$  | Bolt design stress at atmospheric temperature                                                                                 | MPa              | ksi            | 304.5.1<br>A304.5.1                                                                                                                                                                       | ...                                        | ...                                               |
| $S_a$  | Axial stress range due to displacement strains                                                                                | MPa              | ksi            | 319.4.4                                                                                                                                                                                   | ...                                        | (17)                                              |
| $S_a$  | Stress due to sustained longitudinal force                                                                                    | MPa              | ksi            | 320.2                                                                                                                                                                                     | ...                                        | (23a) (23d)                                       |

| Symbol         | Definition                                                                                                     | Units [Note (1)] |                | Reference                                                                         |                                            |                        |
|----------------|----------------------------------------------------------------------------------------------------------------|------------------|----------------|-----------------------------------------------------------------------------------|--------------------------------------------|------------------------|
|                |                                                                                                                | SI               | U.S. Customary | Paragraph                                                                         | Table/Fig./App.                            | Equation               |
| $S_{aw}$       | Allowable maximum probable stress range during $N_w$ wave cycles                                               | MPa              | ksi            | W302.2<br>W305.3.2                                                                | ...                                        | (W4) (W8)              |
| $S_b$          | Bolt design stress at design temperature                                                                       | MPa              | ksi            | 304.5.1<br>A304.5.1                                                               | ...                                        | ...                    |
| $S_b$          | Bending stress range due to displacement strains                                                               | MPa              | ksi            | 319.4.4                                                                           | ...                                        | (17) (18)              |
| $S_b$          | Stress due to sustained bending moments                                                                        | MPa              | ksi            | 320.2                                                                             | ...                                        | (23a) (23b)            |
| $S_c$          | Basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis      | MPa              | ksi            | 302.3.5<br>K302.3.5<br>S301.7                                                     | ...                                        | (1a) (1b) (32)         |
| $S_d$          | Allowable stress from Table A-1 or Table A-1M for the material at design temperature                           | MPa              | ksi            | V303.1.1<br>V304                                                                  | ...                                        | (V1)                   |
| $S_E$          | Computed displacement stress range                                                                             | MPa              | ksi            | 300.2<br>302.3.5<br>319.2.3<br>319.4.4<br>319.5.1<br>K302.3.5<br>S301.7<br>S303.7 | S301.7<br>S303.7.1<br>S303.7.2<br>S303.7.3 | (17) (22)              |
| $S_{Ei}$       | Computed displacement stress range for condition $i$ corresponding to cycles $N_i$                             | MPa              | ksi            | W302.1                                                                            | W302.1-1<br>W302.1-2                       | (W1)                   |
| $S_{Ei, \max}$ | Computed maximum displacement stress for condition $i$ corresponding to stress range $S_{Ei}$ and cycles $N_i$ | MPa              | ksi            | W302.1                                                                            | ...                                        | ...                    |
| $S_{Ei, \min}$ | Computed minimum displacement stress for condition $i$ corresponding to stress range $S_{Ei}$ and cycles $N_i$ | MPa              | ksi            | W302.1                                                                            | ...                                        | ...                    |
| $S_{EW}$       | Computed maximum stress range due to wave motion                                                               | MPa              | ksi            | W302.2<br>W305.1                                                                  | ...                                        | (W3)                   |
| $S_F$          | Separation distance between the outer extent of a flaw and the nearest surface                                 | mm               | in.            | R307                                                                              | R307                                       | ...                    |
| $S_f$          | Allowable stress for flange material or pipe                                                                   | MPa              | ksi            | 304.5.1<br>A304.5.1                                                               | ...                                        | ...                    |
| $S_H$          | Mean long-term hydrostatic strength (LTHS)                                                                     | kPa              | psi            | A328.2.5                                                                          | ...                                        | (27)                   |
| $S_h$          | Basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis      | MPa              | ksi            | 302.3.5<br>319.5.1<br>K302.3.5<br>S301.6<br>S301.7                                | S301.6<br>S302.6.3.1                       | (1a) (1b) (22)<br>(32) |

| Symbol   | Definition                                                                          | Units [Note (1)] |                   | Reference                                                                                                                                                    |                                  |             |
|----------|-------------------------------------------------------------------------------------|------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|-------------|
|          |                                                                                     | SI               | U.S.<br>Customary | Paragraph                                                                                                                                                    | Table/Fig./App.                  | Equation    |
| $S_i$    | A computed displacement stress range smaller than $S_E$ ( $i = 1, 2, \dots$ )       | MPa              | ksi               | 302.3.5                                                                                                                                                      | ...                              | (1d)        |
| $S_i$    | Equivalent stress during service condition, $i$ (the higher of $S_{pi}$ and $S_L$ ) | MPa              | ksi               | V303.1.1<br>V303.1.2<br>V304                                                                                                                                 | ...                              | ...         |
| $S_L$    | Stress due to sustained loads                                                       | MPa              | ksi               | 302.3.5<br>302.3.6<br>320.1<br>320.2<br>K302.3.5<br>K302.3.6<br>S301.3<br>S301.6<br>S301.7<br>S302.6.1<br>S302.6.3<br>S303.6<br>V303.1.1<br>V303.1.4<br>V304 | S301.6<br>S302.6.3.1<br>S303.7.3 | (1b) (23a)  |
| $S_{pi}$ | Equivalent stress for pressure during service condition, $i$                        | MPa              | ksi               | V303.1.1<br>V304                                                                                                                                             | ...                              | (V1)        |
| $S_S$    | Mean short-term burst stress                                                        | kPa              | psi               | A328.2.5                                                                                                                                                     | ...                              | (27)        |
| $S_T$    | Specified minimum tensile strength at room temperature                              | MPa              | ksi               | 302.3.2<br>K302.3.2                                                                                                                                          | ...                              | (31d)       |
| $S_T$    | Allowable stress at test temperature                                                | MPa              | ksi               | 345.4.2<br>A345.4.2<br>K345.4.2                                                                                                                              | ...                              | (24) (38)   |
| $S_t$    | Torsional stress range due to displacement strains                                  | MPa              | ksi               | 319.4.4                                                                                                                                                      | ...                              | (17)        |
| $S_t$    | Stress due to sustained torsional moment                                            | MPa              | ksi               | 320.2                                                                                                                                                        | ...                              | (23a) (23c) |
| $S_{ut}$ | Tensile strength at temperature                                                     | MPa              | ksi               | K302.3.2                                                                                                                                                     | ...                              | (31b) (31d) |
| $S_Y$    | Specified minimum yield strength at room temperature                                | MPa              | ksi               | 302.3.2<br>K302.3.2<br>K328.2.1                                                                                                                              | ...                              | (31c)       |
| $S_y$    | Yield strength (ASME BPVC)                                                          | MPa              | ksi               | 302.2.4                                                                                                                                                      | ...                              | ...         |
| $S_{yi}$ | Yield strength of the component under consideration for condition $i$               | MPa              | ksi               | W302.1                                                                                                                                                       | ...                              | ...         |
| $S_{yT}$ | Yield strength at test temperature                                                  | MPa              | ksi               | X302.2.3                                                                                                                                                     | ...                              | ...         |

| Symbol   | Definition                                                                                                                                   | Units [Note (1)] |                | Reference                                                                                         |                                            |                                       |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------|----------------|---------------------------------------------------------------------------------------------------|--------------------------------------------|---------------------------------------|
|          |                                                                                                                                              | SI               | U.S. Customary | Paragraph                                                                                         | Table/Fig./App.                            | Equation                              |
| $S_{yt}$ | Yield strength at temperature                                                                                                                | MPa              | ksi            | K302.3.1<br>K302.3.2<br>K304.7.2<br>K304.8.3<br>K345.2.1                                          | ...                                        | (31a) (31b)<br>(31c)                  |
| $S_{yt}$ | Yield strength at bellows design temperature                                                                                                 | MPa              | ksi            | X302.2.3                                                                                          | ...                                        | ...                                   |
| $T$      | Pipe wall thickness (measured or minimum in accordance with purchase specification)                                                          | mm               | in.            | 304.1.1<br>304.2.3<br>306.4.2<br>A304.1.1<br>K304.1.1<br>K304.1.2<br>K304.8.3<br>S301.2<br>S301.7 | 302.3.3D<br>304.2.3<br>323.3.1<br>K323.3.1 | (4a) (4b) (4c)<br>(35a) (35b)<br>(37) |
| $T_1$    | Maximum temperature (for stress analysis)                                                                                                    | °C               | °F             | S301.7<br>S302.5                                                                                  | S301.3.1                                   | ...                                   |
| $T_2$    | Minimum temperature (for stress analysis)                                                                                                    | °C               | °F             | S301.7<br>S302.5                                                                                  | S301.3.1                                   | ...                                   |
| $T_2$    | Minimum thickness of fabricated lap                                                                                                          | mm               | in.            | ...                                                                                               | 328.5.5                                    | ...                                   |
| $T_b$    | Branch pipe wall thickness (measured or minimum in accordance with purchase specification)                                                   | mm               | in.            | 304.3.3<br>304.3.4                                                                                | 304.3.3<br>304.3.4<br>App. H               | (8) (11) (12)                         |
| $T_{cr}$ | Critical temperature                                                                                                                         | °C               | °F             | 300.2                                                                                             | 302.3.5                                    | ...                                   |
| $T_E$    | Effective temperature for service condition, $i$ (temperature corresponding to $S_i$ , Table A-1 and Table A-1M)                             | °C               | °F             | V303.1.2<br>V303.1.3<br>V304                                                                      | ...                                        | (V2)                                  |
| $T_E$    | Effective component thickness at weld joint                                                                                                  | mm               | in.            | W302.1                                                                                            | W302.1-1<br>W302.1-2                       | (W1) (W9)                             |
| $T_h$    | Header pipe wall thickness (measured or minimum in accordance with purchase specification)                                                   | mm               | in.            | 304.3.1<br>304.3.3<br>304.3.4                                                                     | 304.3.3<br>304.3.4<br>App. H               | (7) (10)                              |
| $T_i$    | Temperature of the component for the coincident operating pressure-temperature condition, $i$ , under consideration                          | °C               | °F             | V303.1.4<br>V303.2                                                                                | 302.3.5                                    | (V3)                                  |
| $T_j$    | Pipe metal temperature for the condition being considered; the as-installed and operating conditions are subscripted as $j = 1, 2, 3, \dots$ | °C               | °F             | S300.1<br>S301<br>S302<br>S303                                                                    | S301.1<br>S301.3.1<br>S302.1               | ...                                   |
| $T_r$    | Minimum thickness of reinforcing ring or saddle made from pipe (nominal thickness if made from plate)                                        | mm               | in.            | 304.3.3<br>H304<br>H312<br>H314                                                                   | 304.3.3                                    | ...                                   |

| Symbol      | Definition                                                                                                                       | Units [Note (1)] |                   | Reference                                                                                                                                                               |                                                          |                                                                                             |
|-------------|----------------------------------------------------------------------------------------------------------------------------------|------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------------------------|
|             |                                                                                                                                  | SI               | U.S.<br>Customary | Paragraph                                                                                                                                                               | Table/Fig./App.                                          | Equation                                                                                    |
| $T_s$       | Effective branch wall thickness                                                                                                  | mm               | in.               | 319.4.4                                                                                                                                                                 | ...                                                      | ...                                                                                         |
| $T_x$       | Corroded finished thickness of extruded outlet                                                                                   | mm               | in.               | 304.3.4                                                                                                                                                                 | 304.3.4                                                  | (12)                                                                                        |
| $\bar{T}$   | Nominal wall thickness of pipe                                                                                                   | mm               | in.               | A328.2.5<br>S301.2<br>V304                                                                                                                                              | 323.2.2A<br>328.5.2B<br>328.5.2C<br>328.5.5<br>K302.3.3D | (27)                                                                                        |
| $\bar{T}$   | Component nominal thickness at welded joint                                                                                      | mm               | in.               | W302.1                                                                                                                                                                  | ...                                                      | ...                                                                                         |
| $\bar{T}_b$ | Nominal branch pipe wall thickness                                                                                               | mm               | in.               | 319.4.4<br>328.5.4<br>331.1.3                                                                                                                                           | 304.3.3<br>328.5.4D<br>328.5.4F<br>App. H                | ...                                                                                         |
| $\bar{T}_h$ | Nominal header pipe wall thickness                                                                                               | mm               | in.               | 319.4.4<br>328.5.4<br>331.1.3                                                                                                                                           | 304.3.3<br>328.5.4D                                      | ...                                                                                         |
| $\bar{T}_m$ | Nominal thickness of branch weld for integrally reinforced branch connection fittings [see para. 328.5.4(c) for further details] | mm               | in.               | 328.5.4(c)<br>331.1.3                                                                                                                                                   | 328.5.4F                                                 | ...                                                                                         |
| $\bar{T}_r$ | Nominal thickness of reinforcing ring or saddle                                                                                  | mm               | in.               | 328.5.4<br>331.1.3<br>H302                                                                                                                                              | 328.5.4D                                                 | ...                                                                                         |
| $\bar{T}_w$ | Nominal wall thickness, thinner of components joined by butt weld                                                                | mm               | in.               | 344.6.2<br>R304<br>R307<br>R308                                                                                                                                         | 341.3.2<br>K341.3.2<br>R307<br>R308.1<br>R308.2          | ...                                                                                         |
| $t$         | Pressure design thickness                                                                                                        | mm               | in.               | 304.1.1<br>304.1.2<br>304.1.3<br>304.2.1<br>304.3.3<br>304.4.1<br>304.5.2<br>A304.1.1<br>A304.1.2<br>A304.1.3<br>K304.1.1<br>K304.1.2<br>K304.1.3<br>K304.5.2<br>S301.2 | 304.1.1<br>App. A Notes                                  | (2) (3a) (3b)<br>(3c) (13)<br>(14) (25)<br>(26a) (26b)<br>(26c) (33)<br>(34a) (34b)<br>(36) |
| $t_b$       | Pressure design thickness of branch                                                                                              | mm               | in.               | 304.3.3<br>304.3.4                                                                                                                                                      | 304.3.3<br>304.3.4<br>App. H                             | (8) (11)                                                                                    |



| Symbol     | Definition                                                                                    | Units [Note (1)] |                  | Reference                                                                                                                                        |                                                       |                                          |
|------------|-----------------------------------------------------------------------------------------------|------------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|------------------------------------------|
|            |                                                                                               | SI               | U.S. Customary   | Paragraph                                                                                                                                        | Table/Fig./App.                                       | Equation                                 |
| $t_c$      | Throat thickness of cover fillet weld                                                         | mm               | in.              | 328.5.4<br>331.1.3                                                                                                                               | 328.5.4D<br>328.5.4F<br>App. H                        | ...                                      |
| $t_h$      | Pressure design thickness of header                                                           | mm               | in.              | 304.3.3<br>304.3.4                                                                                                                               | 304.3.3<br>304.3.4<br>App. H                          | (6) (7) (9)<br>(10)                      |
| $t_i$      | Total duration of service condition, $i$ , at pressure, $P_i$ , and temperature, $T_i$        | h                | hr               | V303.2<br>V304                                                                                                                                   | ...                                                   | (V4)                                     |
| $t_m$      | Minimum required thickness, including mechanical, corrosion, and erosion allowances           | mm               | in.              | 304.1.1<br>304.2.1<br>304.4.1<br>304.5.2<br>304.5.3<br>328.4.2<br>A304.1.1<br>A304.2.1<br>K304.1.1<br>K304.2.1<br>K304.5.2<br>K328.4.2<br>S301.2 | 304.5.3<br>328.3.2<br>328.4.3<br>K341.3.2<br>U304.5.3 | (2) (13) (14)<br>(15) (25)<br>(33) (36)  |
| $t_{\min}$ | For branch, the smaller of $\bar{T}_b$ or $\bar{T}_r$                                         | mm               | in.              | 328.5.4                                                                                                                                          | 328.5.4D                                              | ...                                      |
| $t_{ri}$   | Rupture life of a component subjected to repeated service conditions, $i$ , and stress, $S_i$ | h                | hr               | V303.1.4<br>V303.2<br>V304                                                                                                                       | ...                                                   | (V3) (V4)                                |
| $U$        | Straight line distance between anchors                                                        | m                | ft               | 319.4.1                                                                                                                                          | ...                                                   | (16)                                     |
| $u$        | Creep-rupture usage factor, summed up from individual usage factors, $t_i/t_{ri}$             | ...              | ...              | V303.2<br>V303.3<br>V304                                                                                                                         | ...                                                   | (V4)                                     |
| $V_a$      | Average zero-crossing frequency                                                               | Hz               | Hz               | W302.2<br>W302.3                                                                                                                                 | ...                                                   | (W6) (W7)                                |
| $W$        | Weld joint strength reduction factor                                                          | ...              | ..               | 302.2.2<br>302.3.5<br>304.1.1<br>304.1.2<br>304.2.1<br>304.2.3<br>304.3.3<br>304.4.1<br>304.5.1<br>304.5.2<br>304.5.3<br>V303.1.1<br>V304        | 302.3.5<br>App. H                                     | (3a) (3b) (3c)<br>(4a) (4b)<br>(4c) (15) |
| $X_1$      | Ring reinforcement area                                                                       | mm <sup>2</sup>  | in. <sup>2</sup> | H304                                                                                                                                             | ...                                                   | ...                                      |
| $X_2$      | Fillet weld reinforcement area                                                                | mm <sup>2</sup>  | in. <sup>2</sup> | H304                                                                                                                                             | ...                                                   | ...                                      |

| Symbol    | Definition                                                                                                                | Units [Note (1)] |                   | Reference                               |                        |                |
|-----------|---------------------------------------------------------------------------------------------------------------------------|------------------|-------------------|-----------------------------------------|------------------------|----------------|
|           |                                                                                                                           | SI               | U.S.<br>Customary | Paragraph                               | Table/Fig./App.        | Equation       |
| $x_{min}$ | Size of fillet weld to slip-on or socket welding flange                                                                   | mm               | in.               | ...                                     | 328.5.2B               | ...            |
| Y         | Coefficient for effective stressed diameter                                                                               | ...              | ...               | 304.1.1<br>304.1.2<br>S301.2<br>V304    | 304.1.1                | (3a) (3b) (3c) |
| Y+        | Single acting support — a pipe support that provides support to the piping system in only the vertically upward direction | ...              | ...               | S300.1<br>S302<br>S302.1<br>S302.6.2    | S302.5.1<br>S302.6.3.1 | ...            |
| y         | Resultant of total displacement                                                                                           | mm               | in.               | 319.4.1                                 | ...                    | (16)           |
| Z         | Section modulus of pipe                                                                                                   | mm <sup>3</sup>  | in. <sup>3</sup>  | 319.4.4                                 | ...                    | (18)           |
| Z         | Sustained section modulus of pipe                                                                                         | mm <sup>3</sup>  | in. <sup>3</sup>  | 320.2                                   | ...                    | (21b) (23c)    |
| $\alpha$  | Angle of change in direction at miter joint                                                                               | deg              | deg               | 304.2.3<br>306.3.2<br>306.3.3<br>M306.3 | 304.2.3                | ...            |
| $\beta$   | Smaller angle between axes of branch and run                                                                              | deg              | deg               | 304.3.1<br>304.3.3                      | 304.3.3                | (6) (8)        |
| $\Gamma$  | Gamma function                                                                                                            | ...              | ...               | ...                                     | W301-1                 | (W8)           |
| $\gamma$  | Span of the pipe bend                                                                                                     | deg              | deg               | 304.2.1                                 | 304.2.1                | ...            |
| $\theta$  | Angle of miter cut                                                                                                        | deg              | deg               | 304.2.3                                 | 304.2.3                | (4a) (4c) (5)  |
| $\sigma$  | Standard deviation                                                                                                        | ...              | ...               | ...                                     | W302.1-1<br>W302.1-2   | ...            |

GENERAL NOTE: For Code reference to this Appendix, see [para. 300.3](#).

NOTE: (1) Note that the use of these units is not required by the Code. They represent sets of consistent units (except where otherwise stated) that may be used in computations, if stress values in ksi and MPa are multiplied by 1,000 for use in equations that also involve pressure in psi and kPa values.

## **APPENDIX K**

### **ALLOWABLE STRESSES FOR HIGH PRESSURE PIPING**

(20)

See next page.

Specification Index for **Appendix K**

| Spec. No.   | Title                                                                                                                                                                                                                                    |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ASTM</b> |                                                                                                                                                                                                                                          |
| A53         | Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless                                                                                                                                                                      |
| A105        | Carbon Steel Forgings for Piping Applications                                                                                                                                                                                            |
| A106        | Seamless Carbon Steel Pipe for High-Temperature Service                                                                                                                                                                                  |
| A182        | Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service                                                                                                              |
| A210        | Seamless Medium-Carbon Steel Boiler and Superheater Tubes                                                                                                                                                                                |
| A234        | Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service                                                                                                                                        |
| A312        | Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes                                                                                                                                                               |
| A333        | Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications with Required Notch Toughness                                                                                                                          |
| A334        | Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service                                                                                                                                                             |
| A335        | Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service                                                                                                                                                                          |
| A350        | Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components                                                                                                                                             |
| A358        | Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications                                                                                                             |
| A403        | Wrought Austenitic Stainless Steel Piping Fittings                                                                                                                                                                                       |
| A420        | Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service                                                                                                                                                      |
| A508        | Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels                                                                                                                                                |
| A694        | Carbon and Alloy Steel Forgings for Pipe Flanges, Fittings, Valves, and Parts for High-Pressure Transmission Service                                                                                                                     |
| A723        | Alloy Steel Forgings for High-Strength Pressure Component Application                                                                                                                                                                    |
| A789        | Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service                                                                                                                                                       |
| A790        | Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe                                                                                                                                                                             |
| A815        | Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings                                                                                                                                                   |
| A928        | Ferritic/Austenitic (Duplex) Stainless Steel Pipe Electric Fusion Welded with Addition of Filler Metal                                                                                                                                   |
| B164        | Nickel-Copper Alloy Rod, Bar and Wire                                                                                                                                                                                                    |
| B165        | Nickel-Copper Alloy (UNS N04400) Seamless Pipe and Tube                                                                                                                                                                                  |
| B166        | Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Rod, Bar, and Wire      |
| B167        | Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Seamless Pipe and Tube  |
| B338        | Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers                                                                                                                                                 |
| B363        | Seamless and Welded Unalloyed Titanium and Titanium Alloy Welding Fittings                                                                                                                                                               |
| B366        | Factory-Made Wrought Nickel and Nickel Alloy Fittings                                                                                                                                                                                    |
| B381        | Titanium and Titanium Alloy Forgings                                                                                                                                                                                                     |
| B564        | Nickel Alloy Forgings                                                                                                                                                                                                                    |
| B574        | Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Molybdenum-Chromium-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Rod |
| B622        | Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube                                                                                                                                                                                    |
| B861        | Titanium and Titanium Alloy Seamless Pipe                                                                                                                                                                                                |
| <b>API</b>  |                                                                                                                                                                                                                                          |
| 5L          | Line Pipe                                                                                                                                                                                                                                |

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in [Appendix E](#).

# NOTES FOR TABLE K-1

(20)

## GENERAL NOTES:

- (a) The allowable stress values and P-Number assignments in [Table K-1](#), together with the referenced Notes, are requirements of [Chapter IX](#).
- (b) [Notes \(1\) through \(4\)](#) are referenced in column headings. [Notes \(5\) through \(20\)](#) are referenced in the Notes column for specific materials.
- (c) At this time, SI units equivalents have not been provided in [Table K-1](#). To convert stress values in [Table K-1](#) to MPa at a given temperature in °C, determine the equivalent temperature in °F and interpolate to calculate the stress value in ksi at the given temperature. Multiply by 6.895 to determine allowable stress in MPa at the given temperature.
- (d) The following abbreviations are used in the Condition and Size or Thickness Range columns: ann., annealed; A.W., as worked; C.W., cold worked; H.W., hot worked; hex., hexagons; O.D., outside diameter; rd., rounds; rec., rectangles; rel., relieved; sq., squares; and str., stress.
- (e) Samples representative of all piping components, as well as their fabrication welds, shall be impact tested in accordance with [para. K323.3](#).
- (f) A product analysis of the material shall be performed. See [para. K323.1.5](#).
- (g) Material defects may be repaired by welding only in accordance with [para. K323.1.6](#).
- (h) The following abbreviations are used in the Product Form column: ftgs., fittings; smls., seamless; and wld., welded.

## NOTES:

- (1) See the ASME BPVC, Section IX, QW-200.3 for a description of P-Number groupings. P-Numbers are indicated by number or by a number followed by a letter (e.g., 8, 5B, and 11A).
- (2) The stress values in [Table K-1](#) are allowable stresses in tension in accordance with [para. K302.3.1\(a\)](#). Stress values in shear and bearing are stated in [para. K302.3.1\(b\)](#); those in compression in [para. K302.3.1\(c\)](#).
- (3) The lower temperature limit for listed materials shall be in accordance with [para. K323.2.2](#).
- (4) The upper temperature limit for listed materials shall be in accordance with [para. K323.2.1](#).
- (5) Pipe and tubing shall be examined for longitudinal defects in accordance with [Table K305.1.2](#).
- (6) DELETED.
- (7) Galvanized pipe furnished to this specification is not permitted for pressure containing service. See [para. K323.4.2\(b\)](#).
- (8) If this grade is cold expanded, the most severely deformed portion of a representative sample shall be impact tested in accordance with [para. K323.3](#).
- (9) DELETED.
- (10) DELETED.
- (11) No welding is permitted on this material.
- (12) DELETED.
- (13) Welds shall be of a design that permits fully interpretable radiographic examination; joint quality factor,  $E_j$ , shall be 1.00 in accordance with [para. K302.3.4](#).
- (14) Pipe furnished to this specification shall be supplied in the solution heat treated condition.
- (15) This unstabilized grade of stainless steel increasingly tends to precipitate intergranular carbides as the carbon content increases above 0.03%. See also [para. F323.4\(c\)\(2\)](#).
- (16) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 448 MPa (65 ksi).
- (17) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 483 MPa (70 ksi).
- (18) Stress values shown are for the lowest strength base material permitted by the specification to be used in the manufacture of this grade of fitting. If a higher strength base material is used, the higher stress values for that material may be used in design.
- (19) Stress values shown are applicable for both product specification levels (PSL 1 and PSL 2) and any delivery condition and service condition allowed for the applicable pipe strength level in API 5L.
- (20) This steel may develop embrittlement in service above 260°C (500°F).

(20)

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX****Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated**

| Nominal Composition                     | Product Form | Spec. No. | Type or Grade | UNS No. | P-No. (1) | Notes        | Specified Min. Strength, ksi |       |
|-----------------------------------------|--------------|-----------|---------------|---------|-----------|--------------|------------------------------|-------|
|                                         |              |           |               |         |           |              | Tensile                      | Yield |
| Carbon steel                            | Smls. pipe   | A53       | B             | K03005  | 1         | (5) (7)      | 60                           | 35    |
| Carbon steel                            | Smls. pipe   | A106      | B             | K03006  | 1         | (5)          | 60                           | 35    |
| Carbon steel                            | Smls. pipe   | A333      | 6             | K03006  | 1         | (5)          | 60                           | 35    |
| Carbon steel                            | Smls. tube   | A334      | 6             | K03006  | 1         | (5)          | 60                           | 35    |
| Carbon steel                            | Smls. pipe   | API 5L    | B             | ...     | 1         | (5) (8)      | 60                           | 35    |
| Carbon steel                            | Smls. tube   | A210      | A-1           | K02707  | 1         | (5)          | 60                           | 37    |
| Carbon steel                            | Smls. pipe   | A106      | C             | K03501  | 1         | (5)          | 70                           | 40    |
| Carbon steel                            | Smls. tube   | A210      | C             | K03501  | 1         | (5)          | 70                           | 40    |
| Carbon steel                            | Smls. pipe   | API 5L    | X42           | ...     | 1         | (5) (8) (19) | 60.2                         | 42.1  |
| Carbon steel                            | Smls. pipe   | API 5L    | X46           | ...     | 1         | (5) (8) (19) | 63.1                         | 46.4  |
| Carbon steel                            | Smls. pipe   | API 5L    | X52           | ...     | 1         | (5) (8) (19) | 66.7                         | 52.2  |
| Carbon steel                            | Smls. pipe   | API 5L    | X56           | ...     | 1         | (5) (8) (19) | 71.1                         | 56.6  |
| Carbon steel                            | Smls. pipe   | API 5L    | X60           | ...     | 1         | (5) (8) (19) | 75.4                         | 60.2  |
| Carbon steel                            | Smls. pipe   | API 5L    | X65           | ...     | 1         | (5) (8) (19) | 77.6                         | 65.3  |
| Carbon steel                            | Smls. pipe   | API 5L    | X70           | ...     | 1         | (5) (8) (19) | 82.7                         | 70.3  |
| Carbon steel                            | Smls. pipe   | API 5L    | X80           | ...     | 1         | (5) (8) (19) | 90.6                         | 80.5  |
| Carbon steel                            | Smls. ftgs.  | A234      | WPB           | K03006  | 1         | ...          | 60                           | 35    |
| Carbon steel                            | Smls. ftgs.  | A420      | WPL6          | K03006  | 1         | ...          | 60                           | 35    |
| Carbon steel                            | Forgings     | A105      | ...           | K03504  | 1         | ...          | 70                           | 36    |
| Carbon steel                            | Forgings     | A350      | LF2           | K03011  | 1         | ...          | 70                           | 36    |
| Carbon steel                            | Smls. ftgs.  | A234      | WPC           | K03501  | 1         | ...          | 70                           | 40    |
| Carbon steel                            | Forgings     | A694      | F42           | K03014  | 1         | ...          | 60                           | 42    |
| Carbon steel                            | Forgings     | A694      | F46           | K03014  | 1         | ...          | 60                           | 46    |
| Carbon steel                            | Forgings     | A694      | F48           | K03014  | 1         | ...          | 62                           | 48    |
| Carbon steel                            | Forgings     | A694      | F50           | K03014  | 1         | ...          | 64                           | 50    |
| Carbon steel                            | Forgings     | A694      | F52           | K03014  | 1         | ...          | 66                           | 52    |
| Carbon steel                            | Forgings     | A694      | F56           | K03014  | 1         | ...          | 68                           | 56    |
| Carbon steel                            | Forgings     | A694      | F60           | K03014  | 1         | ...          | 75                           | 60    |
| Carbon steel                            | Forgings     | A694      | F65           | K03014  | 1         | ...          | 77                           | 65    |
| Carbon steel                            | Forgings     | A694      | F70           | K03014  | 1         | ...          | 82                           | 70    |
| C- $\frac{1}{2}$ Mo                     | Smls. pipe   | A335      | P1            | K11522  | 3         | (5)          | 55                           | 30    |
| 1Cr- $\frac{1}{2}$ Mo                   | Smls. pipe   | A335      | P12           | K11562  | 4         | (5)          | 60                           | 32    |
| 1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo-Si | Smls. pipe   | A335      | P11           | K11597  | 4         | (5)          | 60                           | 30    |
| 2 $\frac{1}{4}$ Cr-1Mo                  | Smls. pipe   | A335      | P22           | K21590  | 5A        | (5)          | 60                           | 30    |
| 5Cr- $\frac{1}{2}$ Mo                   | Smls. pipe   | A335      | P5            | K41545  | 5B        | (5)          | 60                           | 30    |
| 3 $\frac{1}{2}$ Ni                      | Smls. pipe   | A333      | 3             | K31918  | 9B        | (5)          | 65                           | 35    |
| 3 $\frac{1}{2}$ Ni                      | Smls. tube   | A334      | 3             | K31918  | 9B        | (5)          | 65                           | 35    |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX**Numbers in Parentheses Refer to Notes for [Appendix K](#) Table; Specifications Are ASTM Unless Otherwise Indicated

| Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F,<br>Not Exceeding [Notes (2)-(4)] |      |      |      |      |      |      |      |                  |              |
|---------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------------------|--------------|
| Min.<br>Temp.<br>to 100                                                                                             | 200  | 300  | 400  | 500  | 600  | 650  | 700  | Type<br>or Grade | Spec.<br>No. |
| 28.0                                                                                                                | 25.7 | 24.8 | 23.9 | 22.8 | 21.4 | 20.7 | 19.4 | B                | A53          |
| 28.0                                                                                                                | 25.7 | 24.8 | 23.9 | 22.8 | 21.4 | 20.7 | 20.1 | B                | A106         |
| 28.0                                                                                                                | 25.7 | 24.8 | 23.9 | 22.8 | 21.4 | 20.7 | 20.1 | 6                | A333         |
| 28.0                                                                                                                | 25.7 | 24.8 | 23.9 | 22.8 | 21.4 | 20.7 | 20.1 | 6                | A334         |
| 28.0                                                                                                                | 25.7 | 24.8 | 23.9 | 22.8 | 21.4 | 20.7 | 20.1 | B                | API 5L       |
| 29.6                                                                                                                | 27.1 | 26.2 | 25.3 | 24.2 | 22.7 | 21.9 | 21.2 | A-1              | A210         |
| 32.0                                                                                                                | 29.3 | 28.3 | 27.4 | 26.1 | 24.6 | 23.7 | 22.9 | C                | A106         |
| 32.0                                                                                                                | 29.3 | 28.3 | 27.4 | 26.1 | 24.6 | 23.7 | 22.9 | C                | A210         |
| 33.7                                                                                                                | 30.1 | 27.4 | 25.2 | 23.8 | 22.7 | 22.2 | 21.8 | X42              | API 5L       |
| 36.5                                                                                                                | 33.2 | 30.2 | 27.8 | 26.2 | 25.0 | 24.6 | 24.1 | X46              | API 5L       |
| 39.6                                                                                                                | 37.4 | 34.0 | 31.3 | 29.4 | 28.2 | 27.6 | 27.0 | X52              | API 5L       |
| 42.6                                                                                                                | 40.5 | 36.8 | 33.9 | 31.9 | 30.6 | 29.9 | 29.3 | X56              | API 5L       |
| 45.2                                                                                                                | 43.0 | 39.1 | 36.1 | 33.9 | 32.5 | 31.8 | 31.2 | X60              | API 5L       |
| 47.6                                                                                                                | 45.3 | 42.5 | 39.1 | 36.8 | 35.2 | 34.6 | 33.8 | X65              | API 5L       |
| 51.0                                                                                                                | 48.5 | 45.8 | 42.2 | ...  | ...  | ...  | ...  | X70              | API 5L       |
| 57.0                                                                                                                | 54.2 | 52.0 | 48.2 | ...  | ...  | ...  | ...  | X80              | API 5L       |
| 28.0                                                                                                                | 25.7 | 24.8 | 23.9 | 22.8 | 21.4 | 20.7 | 20.1 | WPB              | A234         |
| 28.0                                                                                                                | 25.7 | 24.8 | 23.9 | 22.8 | 21.4 | 20.7 | 20.1 | WPL6             | A420         |
| 28.8                                                                                                                | 26.4 | 25.4 | 24.6 | 23.4 | 22.1 | 21.4 | 20.6 | ...              | A105         |
| 28.8                                                                                                                | 26.4 | 25.4 | 24.6 | 23.4 | 22.1 | 21.4 | 20.6 | LF2              | A350         |
| 32.0                                                                                                                | 29.3 | 28.3 | 27.4 | 26.1 | 24.6 | 23.7 | 22.9 | WPC              | A234         |
| 33.6                                                                                                                | 29.7 | 27.2 | 25.3 | 23.8 | ...  | ...  | ...  | F42              | A694         |
| 35.3                                                                                                                | 32.5 | 29.8 | 27.7 | 26.0 | ...  | ...  | ...  | F46              | A694         |
| 36.7                                                                                                                | 33.9 | 31.0 | 28.9 | 27.1 | ...  | ...  | ...  | F48              | A694         |
| 38.0                                                                                                                | 35.3 | 32.3 | 30.1 | 28.2 | ...  | ...  | ...  | F50              | A694         |
| 39.3                                                                                                                | 36.7 | 33.7 | 31.3 | 29.4 | ...  | ...  | ...  | F52              | A694         |
| 41.3                                                                                                                | 39.1 | 36.2 | 33.7 | 31.7 | ...  | ...  | ...  | F56              | A694         |
| 45.0                                                                                                                | 42.4 | 38.8 | 36.1 | 33.9 | ...  | ...  | ...  | F60              | A694         |
| 47.3                                                                                                                | 44.8 | 42.1 | 39.1 | 36.7 | ...  | ...  | ...  | F65              | A694         |
| 50.7                                                                                                                | 47.9 | 45.3 | 42.2 | ...  | ...  | ...  | ...  | F70              | A694         |
| 24.0                                                                                                                | 22.6 | 21.7 | 20.9 | 20.2 | 19.6 | 19.3 | 18.9 | P1               | A335         |
| 25.6                                                                                                                | 23.1 | 21.8 | 20.8 | 20.1 | 19.5 | 19.2 | 19.0 | P12              | A335         |
| 24.0                                                                                                                | 22.2 | 21.0 | 20.2 | 19.5 | 18.8 | 18.5 | 18.1 | P11              | A335         |
| 24.0                                                                                                                | 22.4 | 21.8 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 | P22              | A335         |
| 24.0                                                                                                                | 21.7 | 20.9 | 20.6 | 20.5 | 20.2 | 19.9 | 19.6 | P5               | A335         |
| 28.0                                                                                                                | 25.7 | 24.7 | 23.9 | 22.7 | 21.0 | 20.0 | 18.9 | 3                | A333         |
| 28.0                                                                                                                | 25.7 | 24.7 | 23.9 | 22.7 | 21.0 | 20.0 | 18.9 | 3                | A334         |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition                                       | Product Form | Spec. No. | Type or Grade | UNS No. | P-No. (1) | Notes | Specified Min. Strength, ksi |       |
|-----------------------------------------------------------|--------------|-----------|---------------|---------|-----------|-------|------------------------------|-------|
|                                                           |              |           |               |         |           |       | Tensile                      | Yield |
| 9Ni                                                       | Smls. pipe   | A333      | 8             | K81340  | 11A       | (5)   | 100                          | 75    |
| 9Ni                                                       | Smls. tube   | A334      | 8             | K81340  | 11A       | (5)   | 100                          | 75    |
| C- $\frac{1}{2}$ Mo                                       | Forgings     | A182      | F1            | K12822  | 3         | ...   | 70                           | 40    |
| 1Cr- $\frac{1}{2}$ Mo                                     | Forgings     | A182      | F12, Cl. 2    | K11564  | 4         | ...   | 70                           | 40    |
| 1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo-Si                   | Forgings     | A182      | F11, Cl. 2    | K11572  | 4         | ...   | 70                           | 40    |
| 2 $\frac{1}{4}$ Cr-1Mo                                    | Forgings     | A182      | F22, Cl. 3    | K21590  | 5A        | ...   | 75                           | 45    |
| 5Cr- $\frac{1}{2}$ Mo                                     | Forgings     | A182      | F5            | K41545  | 5B        | ...   | 70                           | 40    |
| 2Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-V                | Forgings     | A723      | 1, Cl. 1      | K23550  | ...       | (11)  | 115                          | 100   |
| 2Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-V                | Forgings     | A723      | 1, Cl. 2      | K23550  | ...       | (11)  | 135                          | 120   |
| 2Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-V                | Forgings     | A723      | 1, Cl. 3      | K23550  | ...       | (11)  | 155                          | 140   |
| 2 $\frac{3}{4}$ Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V | Forgings     | A723      | 2, Cl. 1      | K23550  | ...       | (11)  | 115                          | 100   |
| 2 $\frac{3}{4}$ Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V | Forgings     | A723      | 2, Cl. 2      | K23550  | ...       | (11)  | 135                          | 120   |
| 2 $\frac{3}{4}$ Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V | Forgings     | A723      | 2, Cl. 3      | K23550  | ...       | (11)  | 155                          | 140   |
| 3 $\frac{1}{2}$ Ni                                        | Smls ftgs.   | A420      | WPL3          | K31918  | 9B        | ...   | 65                           | 35    |
| 3 $\frac{1}{2}$ Ni                                        | Forgings     | A350      | LF3           | K32025  | 9B        | ...   | 70                           | 37.5  |
| 3 $\frac{1}{2}$ Ni-1 $\frac{3}{4}$ Cr- $\frac{1}{2}$ Mo-V | Forgings     | A508      | 4N, Cl. 2     | K22375  | 11B       | ...   | 115                          | 100   |
| 4Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V                | Forgings     | A723      | 3, Cl. 1      | K23550  | ...       | (11)  | 115                          | 100   |
| 4Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V                | Forgings     | A723      | 3, Cl. 2      | K23550  | ...       | (11)  | 135                          | 120   |
| 4Ni-1 $\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-V                | Forgings     | A723      | 3, Cl. 3      | K23550  | ...       | (11)  | 155                          | 140   |
| 9Ni                                                       | Smls. ftgs.  | A420      | WPL8          | K81340  | 11A       | ...   | 100                          | 75    |



**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**Numbers in Parentheses Refer to Notes for [Appendix K](#) Table; Specifications Are ASTM Unless Otherwise Indicated

| Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F,<br>Not Exceeding [Notes (2)-(4)] |      |      |      |      |      |      |      |                  |              |
|---------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------------------|--------------|
| Min.<br>Temp.<br>to 100                                                                                             | 200  | 300  | 400  | 500  | 600  | 650  | 700  | Type<br>or Grade | Spec.<br>No. |
| 58.3                                                                                                                | 57.3 | 53.6 | ...  | ...  | ...  | ...  | ...  | 8                | A333         |
| 58.3                                                                                                                | 57.3 | 53.6 | ...  | ...  | ...  | ...  | ...  | 8                | A334         |
| 32.0                                                                                                                | 30.1 | 28.9 | 27.8 | 27.0 | 26.2 | 25.7 | 25.2 | F1               | A182         |
| 32.0                                                                                                                | 29.0 | 27.2 | 26.0 | 25.1 | 24.4 | 24.1 | 23.7 | F12, Cl. 2       | A182         |
| 32.0                                                                                                                | 29.5 | 28.1 | 27.0 | 26.0 | 25.1 | 24.6 | 24.2 | F11, Cl. 2       | A182         |
| 36.0                                                                                                                | 33.0 | 31.5 | 30.5 | 29.8 | 29.2 | 28.9 | 28.5 | F22, Cl. 3       | A182         |
| 32.0                                                                                                                | 29.0 | 27.8 | 27.5 | 27.3 | 26.9 | 26.6 | 26.1 | F5               | A182         |
| 71.7                                                                                                                | 70.3 | 69.5 | 69.0 | 68.5 | 68.0 | 66.9 | 65.5 | 1, Cl. 1         | A723         |
| 85.0                                                                                                                | 83.4 | 82.4 | 81.8 | 81.3 | 80.6 | 79.4 | 77.6 | 1, Cl. 2         | A723         |
| 98.3                                                                                                                | 96.5 | 95.3 | 94.6 | 94.0 | 93.2 | 91.8 | 89.8 | 1, Cl. 3         | A723         |
| 71.7                                                                                                                | 70.3 | 69.5 | 69.0 | 68.5 | 68.0 | 66.9 | 65.5 | 2, Cl. 1         | A723         |
| 85.0                                                                                                                | 83.4 | 82.4 | 81.8 | 81.3 | 80.6 | 79.4 | 77.6 | 2, Cl. 2         | A723         |
| 98.3                                                                                                                | 96.5 | 95.3 | 94.6 | 94.0 | 93.2 | 91.8 | 89.8 | 2, Cl. 3         | A723         |
| 28.0                                                                                                                | 25.7 | 24.7 | 23.9 | 22.7 | 21.0 | 20.0 | ...  | WPL3             | A420         |
| 30.0                                                                                                                | 27.4 | 26.6 | 25.6 | 24.3 | 22.6 | 21.4 | ...  | LF3              | A350         |
| 71.7                                                                                                                | 69.7 | 68.7 | 67.7 | 66.9 | 65.9 | 65.1 | ...  | 4N, Cl. 2        | A508         |
| 71.7                                                                                                                | 70.3 | 69.5 | 69.0 | 68.5 | 68.0 | 66.9 | 65.5 | 3, Cl. 1         | A723         |
| 85.0                                                                                                                | 83.4 | 82.4 | 81.8 | 81.3 | 80.6 | 79.4 | 77.6 | 3, Cl. 2         | A723         |
| 98.3                                                                                                                | 96.5 | 95.3 | 94.6 | 94.0 | 93.2 | 91.8 | 89.8 | 3, Cl. 3         | A723         |
| 58.3                                                                                                                | 57.3 | 53.6 | ...  | ...  | ...  | ...  | ...  | WPL8             | A420         |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Product Form      | Spec. No. | Type or Grade       | UNS No. | Thick-ness Range, in. | P-No. (1) | Notes              | Specified Min. Strength, ksi |       |
|---------------------|-------------------|-----------|---------------------|---------|-----------------------|-----------|--------------------|------------------------------|-------|
|                     |                   |           |                     |         |                       |           |                    | Tensile                      | Yield |
| 16Cr-12Ni-2Mo       | Smls. & wld. pipe | A312      | TP316L              | S31603  | ...                   | 8         | (5) (13)           | 70                           | 25    |
| 16Cr-12Ni-2Mo       | Wld. pipe         | A358      | 316L, Cl. 1 & 3     | S31603  | ...                   | 8         | (5) (13) (14)      | 70                           | 25    |
| 16Cr-12Ni-2Mo-N     | Smls. & wld. pipe | A312      | TP316LN             | S31653  | ...                   | 8         | (5) (13)           | 75                           | 30    |
| 16Cr-12Ni-2Mo-N     | Wld. pipe         | A358      | 316LN, Cl. 1 & 3    | S31653  | ...                   | 8         | (5) (13) (14)      | 75                           | 30    |
| 18Cr-8Ni            | Smls. & wld. pipe | A312      | TP304L              | S30403  | ...                   | 8         | (5) (13)           | 70                           | 25    |
| 18Cr-8Ni            | Wld. pipe         | A358      | 304L, Cl. 1 & 3     | S30403  | ...                   | 8         | (5) (13) (14)      | 70                           | 25    |
| 18Cr-8Ni-N          | Smls. & wld. pipe | A312      | TP304LN             | S30453  | ...                   | 8         | (5) (13)           | 75                           | 30    |
| 18Cr-8Ni-N          | Wld. pipe         | A358      | 304LN, Cl. 1 & 3    | S30453  | ...                   | 8         | (5) (13) (14)      | 75                           | 30    |
| 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321               | S32100  | $>\frac{3}{8}$        | 8         | (5)                | 70                           | 25    |
| 18Cr-10Ni-Ti        | Smls. pipe        | A312      | TP321               | S32100  | $\leq\frac{3}{8}$     | 8         | (5)                | 75                           | 30    |
| 18Cr-10Ni-Ti        | Wld. pipe         | A312      | TP321               | S32100  | ...                   | 8         | (5) (13)           | 75                           | 30    |
| 18Cr-10Ni-Ti        | Wld. pipe         | A358      | 321, Cl. 1 & 3      | S32100  | ...                   | 8         | (5) (13) (14)      | 75                           | 30    |
| 18Cr-8Ni            | Smls. & wld. pipe | A312      | TP304               | S30400  | ...                   | 8         | (5) (13) (15)      | 75                           | 30    |
| 18Cr-8Ni            | Wld. pipe         | A358      | 304, Cl. 1 & 3      | S30400  | ...                   | 8         | (5) (13) (14) (15) | 75                           | 30    |
| 16Cr-12Ni-2Mo       | Smls. & wld. pipe | A312      | TP316               | S31600  | ...                   | 8         | (5) (13) (15)      | 75                           | 30    |
| 16Cr-12Ni-2Mo       | Wld. pipe         | A358      | 316, Cl. 1 & 3      | S31600  | ...                   | 8         | (5) (13) (14) (15) | 75                           | 30    |
| 18Cr-13Ni-3Mo       | Smls. & wld. pipe | A312      | TP317               | S31700  | ...                   | 8         | (5) (13) (15)      | 75                           | 30    |
| 18Cr-10Ni-Cb        | Smls. & wld. pipe | A312      | TP347               | S34700  | ...                   | 8         | (5) (13)           | 75                           | 30    |
| 18Cr-10Ni-Cb        | Wld. pipe         | A358      | 347, Cl. 1 & 3      | S34700  | ...                   | 8         | (5) (13) (14)      | 75                           | 30    |
| 18Cr-8Ni-N          | Smls. & wld. pipe | A312      | TP304N              | S30451  | ...                   | 8         | (5) (13) (15)      | 80                           | 35    |
| 18Cr-8Ni-N          | Wld. pipe         | A358      | 304N, Cl. 1 & 3     | S30451  | ...                   | 8         | (5) (13) (14) (15) | 80                           | 35    |
| 16Cr-12Ni-2Mo-N     | Smls. & wld. pipe | A312      | TP316N              | S31651  | ...                   | 8         | (5) (13) (15)      | 80                           | 35    |
| 16Cr-12Ni-2Mo-N     | Wld. pipe         | A358      | 316N, Cl. 1 & 3     | S31651  | ...                   | 8         | (5) (13) (14) (15) | 80                           | 35    |
| 22Cr-5Ni-3Mo-N      | Smls. & wld. tube | A789      | ...                 | S31803  | ...                   | 10H       | (5) (13) (20)      | 90                           | 65    |
| 22Cr-5Ni-3Mo-N      | Smls. & wld. pipe | A790      | ...                 | S31803  | ...                   | 10H       | (5) (13) (20)      | 90                           | 65    |
| 22Cr-5Ni-3Mo-N      | Smls. & wld. pipe | A790      | 2205                | S32205  | ...                   | 10H       | (5) (13) (20)      | 95                           | 65    |
| 22Cr-5Ni-3Mo-N      | Wld. pipe         | A928      | Cl. 1, 3, & 4       | S31803  | ...                   | 10H       | (5) (13) (20)      | 90                           | 65    |
| 22Cr-5Ni-3Mo-N      | Wld. pipe         | A928      | 2205, Cl. 1, 3, & 4 | S32205  | ...                   | 10H       | (5) (13) (20)      | 95                           | 65    |
| 22Cr-5Ni-3Mo-N      | Smls. & wld. tube | A789      | ...                 | S32205  | ...                   | 10H       | (5) (13) (20)      | 95                           | 70    |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F,<br>Not Exceeding [Notes (2)-(4)] |      |      |      |      |      |      |      |                     |              |
|---------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|---------------------|--------------|
| Min.<br>Temp.<br>to 100                                                                                             | 200  | 300  | 400  | 500  | 600  | 650  | 700  | Type<br>or Grade    | Spec.<br>No. |
| 20.0                                                                                                                | 17.0 | 15.2 | 14.0 | 13.1 | 12.5 | 12.2 | 12.0 | TP316L              | A312         |
| 20.0                                                                                                                | 17.0 | 15.2 | 14.0 | 13.1 | 12.5 | 12.2 | 12.0 | 316L, Cl. 1 & 3     | A358         |
| 24.0                                                                                                                | 20.4 | 18.3 | 16.8 | 15.6 | 14.6 | 14.2 | 13.8 | TP316LN             | A312         |
| 24.0                                                                                                                | 20.4 | 18.3 | 16.8 | 15.6 | 14.6 | 14.2 | 13.8 | 316LN, Cl. 1 & 3    | A358         |
| 20.0                                                                                                                | 17.1 | 15.4 | 14.0 | 13.1 | 12.4 | 12.2 | 12.0 | TP304L              | A312         |
| 20.0                                                                                                                | 17.1 | 15.4 | 14.0 | 13.1 | 12.4 | 12.2 | 12.0 | 304L, Cl. 1 & 3     | A358         |
| 24.0                                                                                                                | 20.0 | 17.9 | 16.6 | 15.5 | 14.7 | 14.4 | 14.1 | TP304LN             | A312         |
| 24.0                                                                                                                | 20.0 | 17.9 | 16.6 | 15.5 | 14.7 | 14.4 | 14.1 | 304LN, Cl. 1 & 3    | A358         |
| 20.0                                                                                                                | 18.0 | 16.6 | 15.4 | 14.3 | 13.5 | 13.2 | 13.0 | TP321               | A312         |
| 24.0                                                                                                                | 21.6 | 19.8 | 18.4 | 17.2 | 16.2 | 15.8 | 15.5 | TP321               | A312         |
| 24.0                                                                                                                | 21.6 | 19.8 | 18.4 | 17.2 | 16.2 | 15.8 | 15.5 | TP321               | A312         |
| 24.0                                                                                                                | 21.6 | 19.8 | 18.4 | 17.2 | 16.2 | 15.8 | 15.5 | 321, Cl. 1 & 3      | A358         |
| 24.0                                                                                                                | 20.0 | 17.9 | 16.6 | 15.5 | 14.7 | 14.4 | 14.1 | TP304               | A312         |
| 24.0                                                                                                                | 20.0 | 17.9 | 16.6 | 15.5 | 14.7 | 14.4 | 14.1 | 304, Cl. 1 & 3      | A358         |
| 24.0                                                                                                                | 20.7 | 18.7 | 17.1 | 16.0 | 15.1 | 14.8 | 14.6 | TP316               | A312         |
| 24.0                                                                                                                | 20.7 | 18.7 | 17.1 | 16.0 | 15.1 | 14.8 | 14.6 | 316, Cl. 1 & 3      | A358         |
| 24.0                                                                                                                | 20.7 | 18.7 | 17.1 | 16.0 | 15.1 | 14.8 | 14.6 | TP317               | A312         |
| 24.0                                                                                                                | 22.1 | 20.6 | 19.2 | 18.1 | 17.2 | 16.9 | 16.6 | TP347               | A312         |
| 24.0                                                                                                                | 22.1 | 20.6 | 19.2 | 18.1 | 17.2 | 16.9 | 16.6 | 347, Cl. 1 & 3      | A358         |
| 28.0                                                                                                                | 22.9 | 20.0 | 18.1 | 16.8 | 15.9 | 15.6 | 15.3 | TP304N              | A312         |
| 28.0                                                                                                                | 22.9 | 20.0 | 18.1 | 16.8 | 15.9 | 15.6 | 15.3 | 304N, Cl. 1 & 3     | A358         |
| 28.0                                                                                                                | 24.8 | 22.8 | 21.1 | 19.8 | 18.7 | 18.2 | 17.8 | TP316N              | A312         |
| 28.0                                                                                                                | 24.8 | 22.8 | 21.1 | 19.8 | 18.7 | 18.2 | 17.8 | 316N, Cl. 1 & 3     | A358         |
| 51.7                                                                                                                | 46.2 | 43.0 | 41.0 | 39.7 | ...  | ...  | ...  | ...                 | A789         |
| 51.7                                                                                                                | 46.2 | 43.0 | 41.0 | 39.7 | ...  | ...  | ...  | ...                 | A790         |
| 52.0                                                                                                                | 46.2 | 43.0 | 41.0 | 39.7 | ...  | ...  | ...  | 2205                | A790         |
| 51.7                                                                                                                | 46.2 | 43.0 | 41.0 | 39.7 | ...  | ...  | ...  | Cl. 1, 3, & 4       | A928         |
| 52.0                                                                                                                | 46.2 | 43.0 | 41.0 | 39.7 | ...  | ...  | ...  | 2205, Cl. 1, 3, & 4 | A928         |
| 55.0                                                                                                                | 49.8 | 46.3 | 44.2 | 42.7 | ...  | ...  | ...  | ...                 | A789         |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Product Form       | Spec. No. | Type or Grade              | UNS No. | Thick-ness Range, in. | P-No. (1) | Notes         | Specified Min. Strength, ksi |       |
|---------------------|--------------------|-----------|----------------------------|---------|-----------------------|-----------|---------------|------------------------------|-------|
|                     |                    |           |                            |         |                       |           |               | Tensile                      | Yield |
| 25Cr-7Ni-4Mo-N      | Smls. & wld. tube  | A789      | ...                        | S32750  | ...                   | 10H       | (5) (13) (20) | 116                          | 80    |
| 25Cr-7Ni-4Mo-N      | Smls. & wld. pipe  | A790      | 2507                       | S32750  | ...                   | 10H       | (5) (13) (20) | 116                          | 80    |
| 25Cr-7Ni-4Mo-N      | Wld. pipe          | A928      | 2507, Cl. 1, 3, & 4        | S32750  | ...                   | 10H       | (5) (13) (20) | 116                          | 80    |
| 16Cr-12Ni-2Mo       | Forgings           | A182      | F316L                      | S31603  | ...                   | 8         | (16)          | 70                           | 25    |
| 16Cr-12Ni-2Mo       | Smls. & wld. ftgs. | A403      | WP316L, Cl. S & WX         | S31603  | ...                   | 8         | (13)          | 70                           | 25    |
| 16Cr-12Ni-2Mo-N     | Forgings           | A182      | F316LN                     | S31653  | ...                   | 8         | (17)          | 75                           | 30    |
| 16Cr-12Ni-2Mo-N     | Smls. & wld. ftgs. | A403      | WP316LN, Cl. S & WX        | S31653  | ...                   | 8         | (13)          | 75                           | 30    |
| 18Cr-8Ni            | Forgings           | A182      | F304L                      | S30403  | ...                   | 8         | (16)          | 70                           | 25    |
| 18Cr-8Ni            | Smls. & wld. ftgs. | A403      | WP304L, Cl. S & WX         | S30403  | ...                   | 8         | (13)          | 70                           | 25    |
| 18Cr-8Ni-N          | Forgings           | A182      | F304LN                     | S30453  | ...                   | 8         | (17)          | 75                           | 30    |
| 18Cr-8Ni-N          | Smls. & wld. ftgs. | A403      | WP304LN, Cl. S & WX        | S30453  | ...                   | 8         | (13)          | 75                           | 30    |
| 18Cr-10Ni-Ti        | Forgings           | A182      | F321                       | S32100  | ...                   | 8         | (17)          | 75                           | 30    |
| 18Cr-10Ni-Ti        | Smls. & wld. ftgs. | A403      | WP321, Cl. S & WX          | S32100  | ...                   | 8         | (13)          | 75                           | 30    |
| 18Cr-8Ni            | Forgings           | A182      | F304                       | S30400  | ...                   | 8         | (15) (17)     | 75                           | 30    |
| 18Cr-8Ni            | Smls. & wld. ftgs. | A403      | WP304, Cl. S & WX          | S30400  | ...                   | 8         | (13) (15)     | 75                           | 30    |
| 16Cr-12Ni-2Mo       | Forgings           | A182      | F316                       | S31600  | ...                   | 8         | (15) (17)     | 75                           | 30    |
| 16Cr-12Ni-2Mo       | Smls. & wld. ftgs. | A403      | WP316, Cl. S & WX          | S31600  | ...                   | 8         | (13) (15)     | 75                           | 30    |
| 18Cr-13Ni-3Mo       | Smls. & wld. ftgs. | A403      | WP317, Cl. S & WX          | S31700  | ...                   | 8         | (13) (15)     | 75                           | 30    |
| 18Cr-10Ni-Cb        | Forgings           | A182      | F347                       | S34700  | ...                   | 8         | (17)          | 75                           | 30    |
| 18Cr-10Ni-Cb        | Smls. & wld. ftgs. | A403      | WP347, Cl. S & WX          | S34700  | ...                   | 8         | (13)          | 75                           | 30    |
| 18Cr-8Ni-N          | Forgings           | A182      | F304N                      | S30451  | ...                   | 8         | (15)          | 80                           | 35    |
| 18Cr-8Ni-N          | Smls. & wld. ftgs. | A403      | WP304N, Cl. S & WX         | S30451  | ...                   | 8         | (13) (15)     | 80                           | 35    |
| 16Cr-12Ni-2Mo-N     | Forgings           | A182      | F316N                      | S31651  | ...                   | 8         | (15)          | 80                           | 35    |
| 16Cr-12Ni-2Mo-N     | Smls. & wld. ftgs. | A403      | WP316N, Cl. S & WX         | S31651  | ...                   | 8         | (13) (15)     | 80                           | 35    |
| 22Cr-5Ni-3Mo-N      | Forgings           | A182      | F51                        | S31803  | ...                   | 10H       | (20)          | 90                           | 65    |
| 22Cr-5Ni-3Mo-N      | Smls. & wld. ftgs. | A815      | WPS31803, Cl. WP-S & WP-WX | S31803  | ...                   | 10H       | (13) (20)     | 90                           | 65    |
| 22Cr-5Ni-3Mo-N      | Forgings           | A182      | F60                        | S32205  | ...                   | 10H       | (20)          | 95                           | 65    |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)****Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated**

| <b>Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F,<br/>Not Exceeding [Notes (2)-(4)]</b> |            |            |            |            |            |            |            |                               |                      |
|-----------------------------------------------------------------------------------------------------------------------------|------------|------------|------------|------------|------------|------------|------------|-------------------------------|----------------------|
| <b>Min.<br/>Temp.<br/>to 100</b>                                                                                            | <b>200</b> | <b>300</b> | <b>400</b> | <b>500</b> | <b>600</b> | <b>650</b> | <b>700</b> | <b>Type<br/>or Grade</b>      | <b>Spec.<br/>No.</b> |
| 64.0                                                                                                                        | 56.4       | 51.8       | 48.6       | 46.6       | ...        | ...        | ...        | ...                           | A789                 |
| 64.0                                                                                                                        | 56.4       | 51.8       | 48.6       | 46.6       | ...        | ...        | ...        | 2507                          | A790                 |
| 64.0                                                                                                                        | 56.4       | 51.8       | 48.6       | 46.6       | ...        | ...        | ...        | 2507, Cl. 1, 3, & 4           | A928                 |
| 20.0                                                                                                                        | 17.0       | 15.2       | 14.0       | 13.1       | 12.5       | 12.2       | 12.0       | F316L                         | A182                 |
| 20.0                                                                                                                        | 17.0       | 15.2       | 14.0       | 13.1       | 12.5       | 12.2       | 12.0       | WP316L, Cl. S & WX            | A403                 |
| 24.0                                                                                                                        | 20.4       | 18.3       | 16.8       | 15.6       | 14.6       | 14.2       | 13.8       | F316LN                        | A182                 |
| 24.0                                                                                                                        | 20.4       | 18.3       | 16.8       | 15.6       | 14.6       | 14.2       | 13.8       | WP316LN, Cl. S & WX           | A403                 |
| 20.0                                                                                                                        | 17.1       | 15.4       | 14.0       | 13.1       | 12.4       | 12.2       | 12.0       | F304L                         | A182                 |
| 20.0                                                                                                                        | 17.1       | 15.4       | 14.0       | 13.1       | 12.4       | 12.2       | 12.0       | WP304L, Cl. S & WX            | A403                 |
| 24.0                                                                                                                        | 20.0       | 17.9       | 16.6       | 15.5       | 14.7       | 14.4       | 14.1       | F304LN                        | A182                 |
| 24.0                                                                                                                        | 20.0       | 17.9       | 16.6       | 15.5       | 14.7       | 14.4       | 14.1       | WP304LN, Cl. S & WX           | A403                 |
| 24.0                                                                                                                        | 21.6       | 19.8       | 18.4       | 17.2       | 16.2       | 15.8       | 15.5       | F321                          | A182                 |
| 24.0                                                                                                                        | 21.6       | 19.8       | 18.4       | 17.2       | 16.2       | 15.8       | 15.5       | WP321, Cl. S & WX             | A403                 |
| 24.0                                                                                                                        | 20.0       | 17.9       | 16.6       | 15.5       | 14.7       | 14.4       | 14.1       | F304                          | A182                 |
| 24.0                                                                                                                        | 20.0       | 17.9       | 16.6       | 15.5       | 14.7       | 14.4       | 14.1       | WP304, Cl. S & WX             | A403                 |
| 24.0                                                                                                                        | 20.7       | 18.7       | 17.1       | 16.0       | 15.1       | 14.8       | 14.6       | F316                          | A182                 |
| 24.0                                                                                                                        | 20.7       | 18.7       | 17.1       | 16.0       | 15.1       | 14.8       | 14.6       | WP316, Cl. S & WX             | A403                 |
| 24.0                                                                                                                        | 20.7       | 18.7       | 17.1       | 16.0       | 15.1       | 14.8       | 14.6       | WP317, Cl. S & WX             | A403                 |
| 24.0                                                                                                                        | 22.1       | 20.6       | 19.2       | 18.1       | 17.2       | 16.9       | 16.6       | F347                          | A182                 |
| 24.0                                                                                                                        | 22.1       | 20.6       | 19.2       | 18.1       | 17.2       | 16.9       | 16.6       | WP347, Cl. S & WX             | A403                 |
| 28.0                                                                                                                        | 22.9       | 20.0       | 18.1       | 16.8       | 15.9       | 15.6       | 15.3       | F304N                         | A182                 |
| 28.0                                                                                                                        | 22.9       | 20.0       | 18.1       | 16.8       | 15.9       | 15.6       | 15.3       | WP304N, Cl. S & WX            | A403                 |
| 28.0                                                                                                                        | 24.8       | 22.8       | 21.1       | 19.8       | 18.7       | 18.2       | 17.8       | F316N                         | A182                 |
| 28.0                                                                                                                        | 24.8       | 22.8       | 21.1       | 19.8       | 18.7       | 18.2       | 17.8       | WP316N, Cl. S & WX            | A403                 |
| 51.7                                                                                                                        | 46.2       | 43.0       | 41.0       | 39.7       | ...        | ...        | ...        | F51                           | A182                 |
| 51.7                                                                                                                        | 46.2       | 43.0       | 41.0       | 39.7       | ...        | ...        | ...        | WPS31803, Cl. WP-S &<br>WP-WX | A815                 |
| 52.0                                                                                                                        | 46.2       | 43.0       | 41.0       | 39.7       | ...        | ...        | ...        | F60                           | A182                 |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition | Product<br>Form    | Spec.<br>No. | Type<br>or Grade              | UNS<br>No. | Thick-<br>ness<br>Range,<br>in. | P-No.<br>(1) | Notes     | Specified Min.<br>Strength, ksi |       |
|------------------------|--------------------|--------------|-------------------------------|------------|---------------------------------|--------------|-----------|---------------------------------|-------|
|                        |                    |              |                               |            |                                 |              |           | Tensile                         | Yield |
| 22Cr-5Ni-3Mo-N         | Smls. & wld. ftgs. | A815         | WPS32205, Cl.<br>WP-S & WP-WX | S32205     | ...                             | 10H          | (13) (20) | 95                              | 65    |
| 25Cr-7Ni-4Mo-N         | Forgings           | A182         | F53                           | S32750     | ...                             | 10H          | (20)      | 116                             | 80    |
| 25Cr-7Ni-4Mo-N         | Smls. & wld. ftgs. | A815         | WPS32750,<br>Cl. S & WX       | S32750     | ...                             | 10H          | (13) (20) | 116                             | 80    |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F,<br>Not Exceeding [Notes (2)–(4)] |      |      |      |      |     |     |     |                               |              |
|---------------------------------------------------------------------------------------------------------------------|------|------|------|------|-----|-----|-----|-------------------------------|--------------|
| Min.<br>Temp.<br>to 100                                                                                             | 200  | 300  | 400  | 500  | 600 | 650 | 700 | Type<br>or Grade              | Spec.<br>No. |
| 52.0                                                                                                                | 46.2 | 43.0 | 41.0 | 39.7 | ... | ... | ... | WPS32205, Cl.<br>WP-S & WP-WX | A815         |
| 64.0                                                                                                                | 56.4 | 51.8 | 48.6 | 46.6 | ... | ... | ... | F53                           | A182         |
| 64.0                                                                                                                | 56.4 | 51.8 | 48.6 | 46.6 | ... | ... | ... | WPS32750, Cl. S<br>& WX       | A815         |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Nominal Composition | Product Form       | Spec. No. | P-No. (1) | UNS Number | Condition             | Size or Thickness Range, in.  | Notes     | Specified Min. Strength, ksi |       |
|---------------------|--------------------|-----------|-----------|------------|-----------------------|-------------------------------|-----------|------------------------------|-------|
|                     |                    |           |           |            |                       |                               |           | Tensile                      | Yield |
| 67Ni-30Cu           | Smls. pipe & tube  | B165      | 42        | N04400     | Annealed              | >5 O.D.                       | (5)       | 70                           | 25    |
| 72Ni-15Cu-8Fe       | Smls. pipe & tube  | B167      | 43        | N06600     | H.W.                  | >5 O.D.                       | (5)       | 75                           | 25    |
| 72Ni-15Cu-8Fe       | Smls. pipe & tube  | B167      | 43        | N06600     | H.W. ann.             | >5 O.D.                       | (5)       | 75                           | 25    |
| 67Ni-30Cu           | Smls. pipe & tube  | B165      | 42        | N04400     | Annealed              | ≤5 O.D.                       | (5)       | 70                           | 28    |
| 72Ni-15Cu-8Fe       | Smls. pipe & tube  | B167      | 43        | N06600     | H.W.                  | ≤5 O.D.                       | (5)       | 80                           | 30    |
| 72Ni-15Cu-8Fe       | Smls. pipe & tube  | B167      | 43        | N06600     | H.W. ann.             | ≤5 O.D.                       | (5)       | 80                           | 30    |
| 72Ni-15Cu-8Fe       | Smls. pipe & tube  | B167      | 43        | N06600     | C.W. ann.             | >5 O.D.                       | (5)       | 80                           | 30    |
| 72Ni-15Cu-8Fe       | Smls. pipe & tube  | B167      | 43        | N06600     | C.W. ann.             | ≤5 O.D.                       | (5)       | 80                           | 35    |
| 54Ni-16Mo-15Cr      | Smls. pipe & tube  | B622      | 43        | N10276     | ...                   | All                           | (5)       | 100                          | 41    |
| 67Ni-30Cu           | Smls. pipe & tube  | B165      | 42        | N04400     | Str. rel.             | All                           | (5)       | 85                           | 55    |
| 67Ni-30Cu           | Smls. & wld. ftgs. | B366      | 42        | N04400     | ...                   | All                           | (13) (18) | 70                           | 25    |
| 67Ni-30Cu           | Forgings           | B564      | 42        | N04400     | Annealed              | All                           | ...       | 70                           | 25    |
| 72Ni-15Cu-8Fe       | Smls. & wld. ftgs. | B366      | 43        | N06600     | ...                   | All                           | (13) (18) | 75                           | 25    |
| 72Ni-15Cu-8Fe       | Forgings           | B564      | 43        | N06600     | Annealed              | All                           | ...       | 80                           | 35    |
| 54Ni-16Mo-15Cr      | Smls. & wld. ftgs. | B366      | 43        | N10276     | ...                   | All                           | (13)      | 100                          | 41    |
| 54Ni-16Mo-15Cr      | Forgings           | B564      | 43        | N10276     | Annealed              | All                           | ...       | 100                          | 41    |
| 67Ni-30Cu           | Rod and bar        | B164      | 42        | N04400     | Annealed              | All                           | ...       | 70                           | 25    |
| 72Ni-15Cu-8Fe       | Rod and bar        | B166      | 43        | N06600     | C.W. ann. & H.W. ann. | All                           | ...       | 80                           | 35    |
| 72Ni-15Cu-8Fe       | Rod and bar        | B166      | 43        | N06600     | H.W., A.W.            | Sq., rec. & hex.              | ...       | 85                           | 35    |
| 72Ni-15Cu-8Fe       | Rod and bar        | B166      | 43        | N06600     | H.W., A.W.            | >3 rd.                        | ...       | 85                           | 35    |
| 67Ni-30Cu           | Rod and bar        | B164      | 42        | N04400     | H.W.                  | Rod, sq. & rec. ≤12, hex. ≤2½ | ...       | 80                           | 40    |
| 72Ni-15Cu-8Fe       | Rod and bar        | B166      | 43        | N06600     | H.W., A.W.            | ½ to 3 rd.                    | ...       | 90                           | 40    |
| 54Ni-16Mo-15Cr      | Rod                | B574      | 43        | N10276     | ...                   | All                           | ...       | 100                          | 41    |
| 72Ni-15Cu-8Fe       | Rod and bar        | B166      | 43        | N06600     | H.W., A.W.            | ¼ to ½ rd.                    | ...       | 95                           | 45    |



**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]

| Min.<br>Temp. to<br>100 | 200  | 300  | 400  | 500  | 600  | 650  | 700  | UNS<br>Number | Spec.<br>No. |
|-------------------------|------|------|------|------|------|------|------|---------------|--------------|
| 20.0                    | 17.5 | 16.3 | 15.8 | 15.8 | 15.8 | 15.8 | 15.7 | N04400        | B165         |
| 20.0                    | 19.0 | 18.2 | 17.5 | 16.8 | 16.2 | 15.9 | 15.7 | N06600        | B167         |
| 20.0                    | 19.0 | 18.2 | 17.5 | 16.8 | 16.2 | 15.9 | 15.7 | N06600        | B167         |
| 22.4                    | 19.6 | 18.2 | 17.7 | 17.6 | 17.6 | 17.6 | 17.5 | N04400        | B165         |
| 24.0                    | 22.9 | 21.9 | 21.0 | 20.2 | 19.4 | 19.1 | 18.8 | N06600        | B167         |
| 24.0                    | 22.9 | 21.9 | 21.0 | 20.2 | 19.4 | 19.1 | 18.8 | N06600        | B167         |
| 24.0                    | 22.9 | 21.9 | 21.0 | 20.2 | 19.4 | 19.1 | 18.8 | N06600        | B167         |
| 28.0                    | 25.6 | 25.0 | 24.6 | 24.2 | 23.9 | 23.8 | 23.5 | N06600        | B167         |
| 32.8                    | 29.8 | 27.6 | 25.6 | 23.8 | 22.4 | 21.8 | 21.4 | N10276        | B622         |
| 44.0                    | 41.4 | 40.3 | 39.8 | 39.4 | ...  | ...  | ...  | N04400        | B165         |
| 20.0                    | 17.5 | 16.3 | 15.8 | 15.8 | 15.8 | 15.8 | 15.7 | N04400        | B366         |
| 20.0                    | 17.5 | 16.3 | 15.8 | 15.8 | 15.8 | 15.8 | 15.7 | N04400        | B564         |
| 20.0                    | 19.0 | 18.2 | 17.5 | 16.8 | 16.2 | 15.9 | 15.7 | N06600        | B366         |
| 28.0                    | 25.6 | 25.0 | 24.6 | 24.2 | 23.9 | 23.8 | 23.5 | N06600        | B564         |
| 32.8                    | 29.8 | 27.6 | 25.6 | 23.8 | 22.4 | 21.8 | 21.4 | N10276        | B366         |
| 32.8                    | 29.8 | 27.6 | 25.6 | 23.8 | 22.4 | 21.8 | 21.4 | N10276        | B564         |
| 20.0                    | 17.5 | 16.3 | 15.8 | 15.8 | 15.8 | 15.8 | 15.7 | N04400        | B164         |
| 28.0                    | 25.6 | 25.0 | 24.6 | 24.2 | 23.9 | 23.8 | 23.5 | N06600        | B166         |
| 28.0                    | 26.6 | 25.8 | 25.5 | 25.5 | 25.4 | 25.4 | 25.2 | N06600        | B166         |
| 28.0                    | 26.6 | 25.8 | 25.5 | 25.5 | 25.4 | 25.4 | 25.2 | N06600        | B166         |
| 32.0                    | 31.0 | 29.7 | 28.7 | 28.2 | 27.8 | 27.5 | 27.2 | N04400        | B164         |
| 32.0                    | 30.4 | 29.6 | 29.1 | 29.1 | 29.1 | 28.9 | 28.7 | N06600        | B166         |
| 32.8                    | 29.8 | 27.6 | 25.6 | 23.8 | 22.4 | 21.8 | 21.4 | N10276        | B574         |
| 36.0                    | 34.2 | 33.4 | 32.8 | 32.7 | 32.7 | 32.5 | 32.3 | N06600        | B166         |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Nominal<br>Composition | Product Form | Spec.<br>No. | Grade | UNS No. | P-No.<br>(1) | Notes | Specified Min.<br>Strength, ksi |       |
|------------------------|--------------|--------------|-------|---------|--------------|-------|---------------------------------|-------|
|                        |              |              |       |         |              |       | Tensile                         | Yield |
| Ti                     | Smls. pipe   | B861         | 2     | R50400  | 51           | (5)   | 50                              | 40    |
| Ti                     | Smls. tube   | B338         | 2     | R50400  | 51           | (5)   | 50                              | 40    |
| Ti-Pd                  | Smls. pipe   | B861         | 7     | R52400  | 51           | (5)   | 50                              | 40    |
| Ti-Pd                  | Smls. tube   | B338         | 7     | R52400  | 51           | (5)   | 50                              | 40    |
|                        |              |              |       |         |              |       |                                 |       |
| Ti                     | Smls. pipe   | B861         | 3     | R50550  | 52           | (5)   | 65                              | 55    |
| Ti                     | Smls. tube   | B338         | 3     | R50550  | 52           | (5)   | 65                              | 55    |
|                        |              |              |       |         |              |       |                                 |       |
| Ti                     | Smls. ftgs.  | B363         | WPT2  | R50400  | 51           | ...   | 50                              | 40    |
| Ti                     | Forgings     | B381         | F-2   | R50400  | 51           | ...   | 50                              | 40    |
| Ti-Pd                  | Forgings     | B381         | F-7   | R52400  | 51           | ...   | 50                              | 40    |
|                        |              |              |       |         |              |       |                                 |       |
| Ti                     | Smls. ftgs.  | B363         | WPT3  | R50550  | 52           | ...   | 65                              | 55    |
| Ti                     | Forgings     | B381         | F-3   | R50550  | 52           | ...   | 65                              | 55    |

**Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

| Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)-(4)] |      |      |      |      |      |     |     |       |              |
|------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|-----|-----|-------|--------------|
| Min.<br>Temp.<br>to 100                                                                                          | 200  | 300  | 400  | 500  | 600  | 650 | 700 | Grade | Spec.<br>No. |
| 30.0                                                                                                             | 25.0 | 20.5 | 15.7 | 11.8 | 9.1  | ... | ... | 2     | B861         |
| 30.0                                                                                                             | 25.0 | 20.5 | 15.7 | 11.8 | 9.1  | ... | ... | 2     | B338         |
| 30.0                                                                                                             | 25.0 | 20.5 | 15.7 | 11.8 | 9.1  | ... | ... | 7     | B861         |
| 30.0                                                                                                             | 25.0 | 20.5 | 15.7 | 11.8 | 9.1  | ... | ... | 7     | B338         |
| 40.0                                                                                                             | 33.1 | 26.8 | 21.6 | 17.4 | 13.7 | ... | ... | 3     | B861         |
| 40.0                                                                                                             | 33.1 | 26.8 | 21.6 | 17.4 | 13.7 | ... | ... | 3     | B338         |
| 30.0                                                                                                             | 25.0 | 20.5 | 15.7 | 11.8 | 9.1  | ... | ... | WPT2  | B363         |
| 30.0                                                                                                             | 25.0 | 20.5 | 15.7 | 11.8 | 9.1  | ... | ... | F-2   | B381         |
| 30.0                                                                                                             | 25.0 | 20.5 | 15.7 | 11.8 | 9.1  | ... | ... | F-7   | B381         |
| 40.0                                                                                                             | 33.1 | 26.8 | 21.6 | 17.4 | 13.7 | ... | ... | WPT3  | B363         |
| 40.0                                                                                                             | 33.1 | 26.8 | 21.6 | 17.4 | 13.7 | ... | ... | F-3   | B381         |

## APPENDIX L

### ALUMINUM ALLOY PIPE FLANGES

#### L300 GENERAL

This Appendix covers pressure–temperature ratings, materials, dimensions, and marking of forged aluminum alloy flanges, as an alternative to applying the rules in [paras. 304.5.1\(b\)](#) and [304.5.2\(b\)](#). DN 15 (NPS ½) through DN 600 (NPS 24) flanges may be welded neck, slip-on, socket welding, lapped, or blind in ratings of Classes 150, 300, and 600.

Requirements and recommendations regarding bolting and gaskets are included.

#### L301 PRESSURE–TEMPERATURE RATINGS

##### L301.1 Ratings Basis

Ratings are maximum allowable working gage pressures at the temperatures shown in [Tables L301.2M](#) and [L301.2U](#) for the applicable material and pressure Class. For intermediate temperatures, linear interpolation is permitted.

##### L301.2 Ratings of Flanged Joints

(a) In addition to the considerations in [para. F312.1](#), consideration must be given to the low modulus of elasticity of aluminum alloys. External moments should be limited, and controlled bolt tightening or other techniques may be necessary to achieve and maintain a leak-free joint.

(b) For ratings of slip-on and socket welding flanges made of Alloy 6061-T6, see [Tables L301.2M](#) and [L301.2U](#), [Note \(3\)](#).

##### L301.3 Temperature Considerations

Application of the ratings in this Appendix to flanged joints at both high and low temperatures shall take into consideration the risk of leakage due to forces and moments developed in the connected piping or equipment. The following provisions are intended to minimize these risks.

**L301.3.1 Flange Attachment.** Slip-on and socket welding flanges are not recommended for service below –50°F if flanges are subject to thermal cycling.

**L301.3.2 Differential Thermal Expansion and Conductivity.** Because aluminum alloys have thermal expansion coefficients approximately twice those for

steel, and thermal conductivity approximately three times that of steel, it may be necessary to provide for differential expansion and expansion rates between components of the flanged joint. Consideration shall be given to thermal transients (e.g., startup, shutdown, and upset) in addition to the operating temperature of the joint.

##### L301.4 Hydrostatic Test

A flange shall be capable of withstanding a hydrostatic test at 1.5 times its 100°F pressure rating.

#### L302 MARKING

Marking shall be in accordance with MSS SP-25, except as follows. Marking shall be stamped on the edge of each flange.

##### L302.1 Name

The manufacturer's name or trademark shall be applied.

##### L302.2 Material

The marking ASTM B247 shall be applied, followed by the applicable alloy and temper designations.

##### L302.3 Rating

The marking shall be the applicable rating Class — 150, 300, or 600.

##### L302.4 Designation

The marking B31.3L shall be applied.

##### L302.5 Size

The marking of NPS shall be applied. A reducing size shall be designated by its two nominal pipe sizes. See examples in [Note \(4\)](#) of [Table 6](#), ASME B16.5.

**Table L301.2M Pressure-Temperature Ratings (SI Units)**

| Material<br>ASTM B247<br>Alloy and<br>Temper | Class 150<br>Temperature [Note (1)] |      |      |      | Class 300<br>Temperature [Note (1)] |      |      |      | Class 600<br>Temperature [Note (1)] |      |      |      |
|----------------------------------------------|-------------------------------------|------|------|------|-------------------------------------|------|------|------|-------------------------------------|------|------|------|
|                                              | 38                                  | 66   | 93   | 121  | 38                                  | 66   | 93   | 121  | 38                                  | 66   | 93   | 121  |
| 3003-H112                                    | 275                                 | 275  | 240  | 240  | 725                                 | 690  | 655  | 655  | 1415                                | 1380 | 1345 | 1275 |
| 6061-T6<br>[Note (2)]                        | 1895                                | 1860 | 1825 | 1795 | 4965                                | 4895 | 4825 | 4655 | 9930                                | 9790 | 9655 | 9345 |
| 6061-T6<br>[Note (3)]                        | 1265                                | 1240 | 1215 | 1195 | 3310                                | 3265 | 3215 | 3105 | 6620                                | 6525 | 6435 | 6230 |

GENERAL NOTE: Pressures are in kPa; temperatures are in °C.

NOTES:

- (1) The minimum temperature is -269°C (-425°F). The maximum rating below 38°C (100°F) shall be the rating shown for 38°C.
- (2) Ratings apply to welding neck, lapped, and blind flanges.
- (3) Ratings apply to slip-on and socket welding flanges.

## L303 MATERIALS

### L303.1 Flange Material

Flanges shall be forgings conforming to ASTM B247. For specific alloys and tempers, see [Tables L301.2M](#) and [L301.2U](#). For precautions in use, see [para. 323.5](#) and [Appendix F, para. F323](#).

**L303.1.1 Repair Welding of Flanges.** Repair welding of flanges manufactured to this Appendix shall be restricted to any damaged areas of the weld bevel of welding neck flanges unless specifically approved by the Purchaser after consideration of the extent, location, and effect on temper and ductility. Repair welding of any area other than the weld bevel on 6061-T6 welding neck flanges shall restrict the pressure/temperature ratings to those specified for slip-on and socket welding flanges in [Tables L301.2M](#) and [L301.2U](#). Any repair welding shall be performed in accordance with [para. 328.6](#).

### L303.2 Bolting Materials

Bolting listed in [Table L303.2](#) and in ASME B16.5, Table 1B, may be used subject to the following limitations.

**L303.2.1 High Strength Bolting.** Bolting materials listed as high strength in ASME B16.5, Table 1B, may be used in any flanged joints. See [para. L305](#).

**L303.2.2 Intermediate Strength Bolting.** Bolting materials in [Table L303.2](#), and bolting listed as intermediate strength in ASME B16.5, Table 1B, may be used in any flanged joints. See [para. L305](#).

**L303.2.3 Low Strength Bolting.** Bolting materials listed as low strength in ASME B16.5, Table 1B, may be used in Classes 150 and 300 flanged joints. See [para. L305](#).

### L303.3 Gaskets

Gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group 1a may be used with any rating Class and bolting.

**L303.3.1 Gaskets for Low-Strength Bolting.** If bolting listed as low strength (see [para. L303.2.3](#)) is used, gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group 1a shall be used.

**Table L301.2U Pressure-Temperature Ratings (U.S. Customary Units)**

| Material ASTM B247<br>Alloy and Temper | Class 150<br>Temperature [Note (1)] |     |     |     | Class 300<br>Temperature [Note (1)] |     |     |     | Class 600<br>Temperature [Note (1)] |       |       |       |
|----------------------------------------|-------------------------------------|-----|-----|-----|-------------------------------------|-----|-----|-----|-------------------------------------|-------|-------|-------|
|                                        | 100                                 | 150 | 200 | 250 | 100                                 | 150 | 200 | 250 | 100                                 | 150   | 200   | 250   |
| 3003-H112                              | 40                                  | 40  | 35  | 35  | 105                                 | 100 | 95  | 95  | 205                                 | 200   | 195   | 185   |
| 6061-T6 [Note (2)]                     | 275                                 | 270 | 265 | 260 | 720                                 | 710 | 700 | 675 | 1 440                               | 1 420 | 1 400 | 1 355 |
| 6061-T6 [Note (3)]                     | 185                                 | 180 | 175 | 175 | 480                                 | 475 | 465 | 450 | 960                                 | 945   | 935   | 905   |

GENERAL NOTE: Pressures are in psig; temperatures are in °F.

NOTES:

- (1) The minimum temperature is -269°C (-425°F). The maximum rating below 38°C (100°F) shall be the rating shown for 38°C.
- (2) Ratings apply to welding neck, lapped, and blind flanges.
- (3) Ratings apply to slip-on and socket welding flanges.

**Table L303.2 Aluminum Bolting Materials**

| ASTM Specification | Alloy | Temper   |
|--------------------|-------|----------|
| B211               | 2014  | T6, T261 |
| B211               | 2024  | T4       |
| B211               | 6061  | T6, T261 |

GENERAL NOTE Repair welding of bolting material is prohibited.

**L303.3.2 Gaskets for Class 150 Flanged Joints.** It is recommended that only gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group Ia be used.

**L303.3.3 Gaskets for Class 300 and Higher Flanged Joints.** It is recommended that only gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group I be used. For gaskets in Group Ib, line flanges should be of the welding neck or lapped joint type; controlled-torque tightening practices should be used.

## **L304 DIMENSIONS AND FACINGS**

(a) Flanges shall meet the dimensional and tolerance requirements of ASME B16.5.

(b) Flange facing and facing finish shall be in accordance with ASME B16.5, except that small male and female facings (on ends of pipe) shall not be used.

## **L305 DESIGN CONSIDERATIONS**

The following design considerations are applicable to all flanged joints that incorporate a flange manufactured to this Appendix:

(a) The differential expansion within a flanged joint must be considered; also, see [para. F312](#).

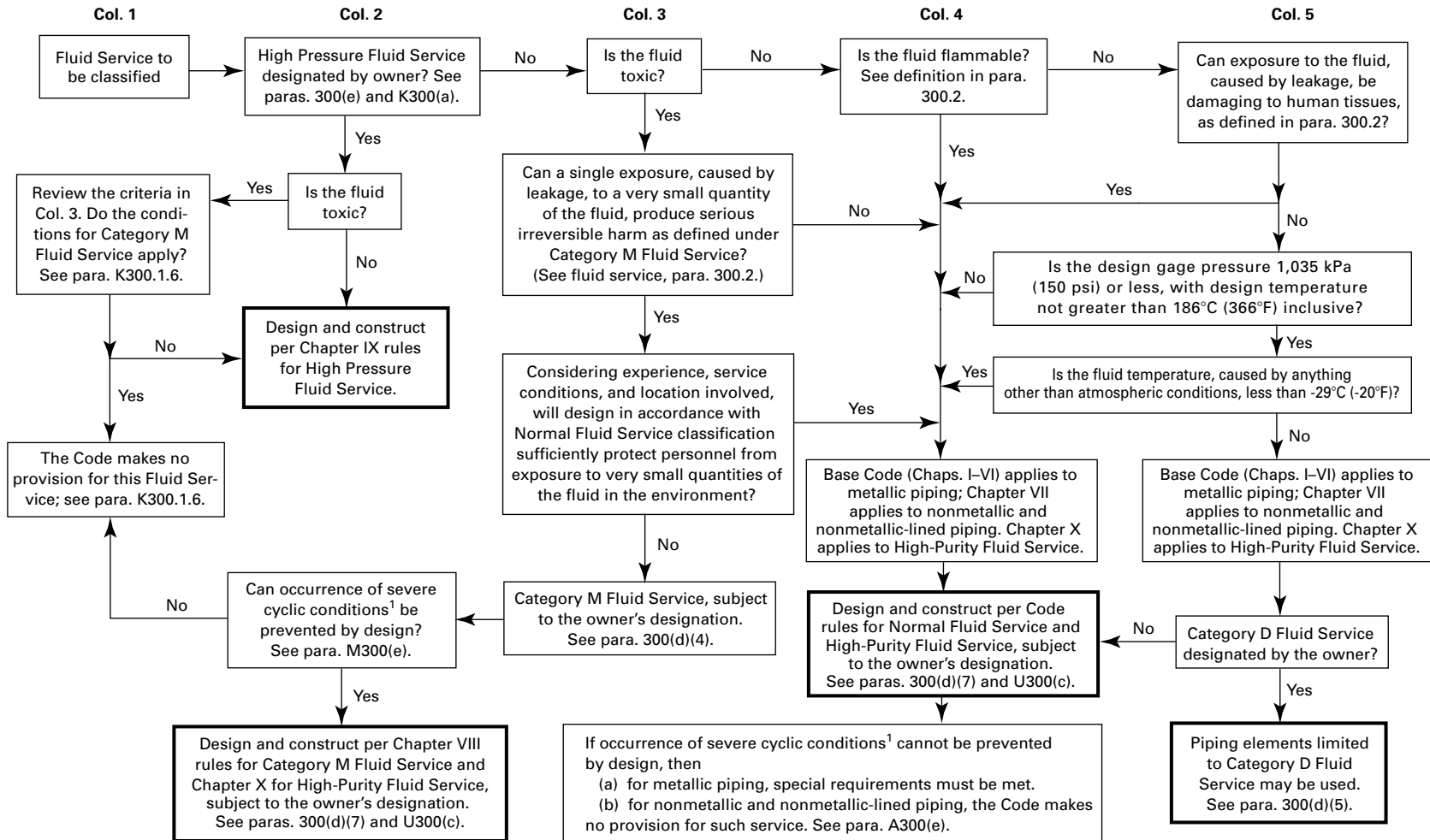
(b) Where a gasket other than those recommended in [para. L303.3](#) is specified, the designer shall verify by calculations the ability of the selected bolting to seat the selected gasket and maintain a sealed joint under the expected operating conditions without over-stressing the components.

## **APPENDIX M**

### **GUIDE TO CLASSIFYING FLUID SERVICES**

See [Figure M300](#).

Figure M300 Guide to Classifying Fluid Services



## GENERAL NOTES:

(a) See [paras. 300\(b\)\(1\)](#), [300\(d\)\(4\)](#) and [\(5\)](#), and [300\(e\)](#) for decisions the owner must make. Other decisions are the designer's responsibility; see [para. 300\(b\)\(2\)](#).

(b) The term "fluid service" is defined in [para. 300.2](#).

NOTE: (1) Severe cyclic conditions are defined in [para. 300.2](#). Requirements are found in [Chapter II, Parts 3 and 4](#), and in [paras. 323.4.2](#) and [341.4.3](#).



## APPENDIX N

### APPLICATION OF ASME B31.3 INTERNATIONALLY

#### N100 INTRODUCTION

The ASME B31.3 Process Piping Code is an internationally recognized code for pressure piping. ISO 15649, Petroleum and natural gas industries — Piping, incorporates ASME B31.3 by normative reference and contains provisions for agreed common international practice that are additional to B31.3. ISO 15649 was prepared by Technical Committee TC 67, Subcommittee SC 6, Working Group WG 5.

#### N200 COMPLIANCE WITH THE EUROPEAN PRESSURE EQUIPMENT DIRECTIVE (PED)

The European Pressure Equipment Directive 97/23/EC is mandatory throughout all Member States of the European Union (EU) and the rest of the European Economic Area, effective May 30, 2002. The PED contains essential safety requirements that must be satisfied before a manufacturer can declare conformity with the Directive and place its product on the market anywhere in the European Community.

Some articles of the PED and its essential safety requirements are either not satisfied or are not addressed by ASME B31.3, and aspects of ASME B31.3 differ from the PED and the essential safety requirements.

Examples of where essential safety requirements are not fully satisfied by ASME B31.3 are as follows:

- (a) decomposition of unstable fluids
- (b) draining and venting
- (c) short duration pressure surge
- (d) temperature monitoring devices
- (e) external fire
- (f) marking and labeling
- (g) operating instructions
- (h) route of underground piping
- (i) joint coefficients
- (j) listed materials

To assist industry in using ASME B31.3, the Engineering Equipment and Materials Users' Association (EEMUA) has cooperated with the European Petroleum Industry Association (Europia) to publish CEN/TR 14549 — Guide to the use of ISO 15649 and ANSI/ASME B31.3 for piping in Europe in compliance with the Pressure Equipment Directive.

The format of the guide is that of a set of additional and modified requirements to ISO 15649 and ASME B31.3 that are required by the PED. It also gives a more-detailed explanation of the principal aspects and processes that require attention in order to be in compliance with the PED, especially where different from industry practice that was current before May 2002.

The full text of the PED can be found at [http://ec.europa.eu/growth/sectors/pressure-gas/pressure-equipment/directive\\_en](http://ec.europa.eu/growth/sectors/pressure-gas/pressure-equipment/directive_en).

## APPENDIX Q

### QUALITY SYSTEM PROGRAM

[This Appendix is a Code requirement only when specified by the owner in accordance with [para. 300\(b\)\(1\)](#).]

Design, construction, inspection, examination, testing, manufacture, fabrication, and erection of piping in accordance with this Code shall be performed under a Quality System Program following the principles of an appropriate standard such as the ISO 9000 series.<sup>1</sup> The details describing the quality system shall be documented and shall be available upon request. A determination of the need for registration and/or certification of the quality system program shall be the responsibility of the owner.

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<sup>1</sup> The series is also available from the American National Standards Institute (ANSI) and the American Society for Quality (ASQ) as American National Standards that are identified by similar “9000” numbers, sometimes with the prefix “Q” replacing the prefix “ISO.” Each standard of the series is listed in [Appendix E](#).

## APPENDIX R

### USE OF ALTERNATIVE ULTRASONIC ACCEPTANCE CRITERIA

#### R300 GENERAL

(a) This Appendix provides alternative fracture-mechanics-based acceptance criteria for ultrasonic examination that may be used for Code piping in lieu of those described in [para. 344.6](#).

(b) The acceptance criteria within this Appendix are applicable to  $\bar{T}_w$  having a thickness equal to or greater than 25 mm (1.0 in.). The acceptance criteria stated in [para. 344.6.2](#) shall be used for all thicknesses less than 25 mm (1.0 in.).

#### (20) R301 SCOPE

(a) The examination shall be conducted using automated or semiautomated techniques utilizing computer-based data acquisition.

(b) The examination shall be performed in accordance with a written procedure approved by UT (ultrasonic testing) Level III personnel [see [para. R303\(a\)](#)] and conforming to the requirements of ASME BPVC, Section V, Article 4.

#### R302 EQUIPMENT

A mechanical guided scanner capable of maintaining a fixed and consistent search unit position relative to the weld centerline shall be used.

#### R303 PERSONNEL

(a) Personnel performing nondestructive examination to the requirements of this Appendix shall be qualified and certified in the ultrasonic testing method in accordance with a procedure as described in ASME BPVC, Section V, Article 1, T-120(e) or (f).

(b) Setup and scanning of welds shall be performed by personnel certified as UT Level II or III (or by Level I personnel under the direct supervision of Level II or Level III personnel).

(c) Interpretation and evaluation of data shall be performed by UT Level II or III personnel.

(d) Personnel demonstration requirements shall be as stated in ASME BPVC, Section V, Article 4, Mandatory Appendix VIII.

#### R304 EXAMINATION

(a) The initial straight beam scan for reflectors that could interfere with the angle beam examination shall be performed (1) manually, (2) as part of a previous manufacturing process, or (3) during the weld examination, provided detection of these reflectors is included in the demonstration as required in [para. R301\(c\)](#).

(b) The examination area shall include the volume of the weld, plus the lesser of 25 mm (1.0 in.) or  $\bar{T}_w$  of adjacent base metal on each side of the weld. Alternatively, the examination volume may be reduced to include the actual heat-affected zone (HAZ) plus 6 mm (0.25 in.) of base material beyond the heat-affected zone on each side of the weld, provided the extent of the weld HAZ is measured and documented.

#### R305 DATA RECORDING AND CAPTURE

Data shall be recorded in the unprocessed form as specified in ASME BPVC, Section V, Article 4, V-471.6. The data record shall include the complete examination area as specified in [para. R304\(b\)](#).

#### R306 DATA ANALYSIS

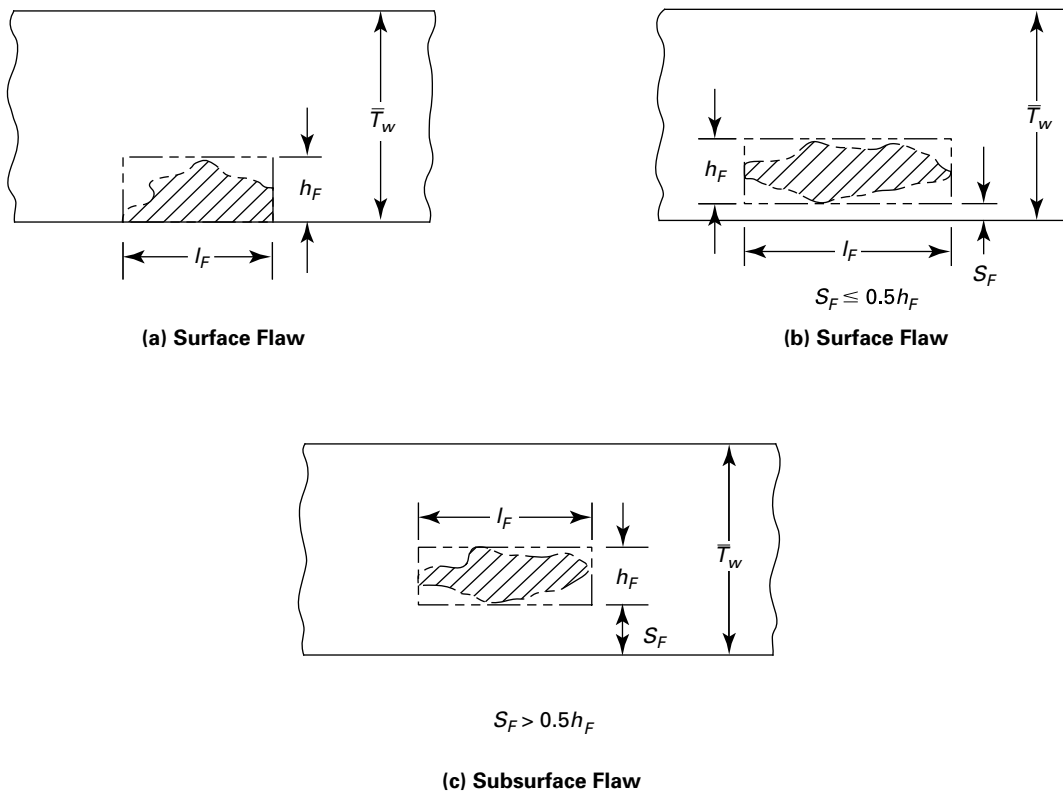
(a) Reflectors exceeding the limits of (1) or (2) shall be investigated to determine whether the indication originates from a flaw or is a geometric indication as described in (b).

(1) For amplitude-based techniques, the location, amplitude, and extent of all reflectors that produce a response greater than 20% of the reference level shall be evaluated.

(2) For non-amplitude-based techniques, the location and extent of all images that have an indicated length greater than 4.0 mm (0.16 in.) shall be investigated.

(b) Ultrasonic indications of geometric and metallurgical origin shall be classified as specified in ASME BPVC, Section V, Article 4, T-481. Alternatively, other techniques or nondestructive examination methods may be used to classify an indication as geometric (e.g., alternative beam angles, radiography). The method employed is for information only to classify the indication as geometric, and the Code requirements for examination techniques are only required to the extent that they are applicable.

Figure R307 Surface and Subsurface Flaws



### R307 FLAW EVALUATION

(a) *Dimensions.* The dimensions of the flaw(s) shall be determined by the rectangle that fully contains the area of the flaw(s). Refer to [Figure R307](#).

(1) The length,  $l_F$ , of the flaw shall be drawn parallel to the inside pressure-retaining surface of the component.

(2) The height,  $h_F$ , of the flaw shall be drawn normal to the inside pressure-retaining surface of the component.

(3) The flaw shall be characterized as a surface or subsurface flaw, as shown in [Figure R307](#).

(4) A subsurface flaw shall be considered as a surface flaw if the separation ( $S_F$  in [Figure R307](#)) of the flaw from the nearest surface of the component is equal to or less than half the through-wall dimension [ $h_F$  in [Figure R307](#), illustration (b)] of the subsurface flaw.

(b) *Multiple Flaws*

(1) Discontinuous flaws that are oriented primarily in parallel planes shall be considered to lie in a single plane if the distance between the adjacent planes is equal to or less than 13 mm (0.50 in.) or  $0.5\bar{T}_w$ , whichever is less.

(2) If the space between two flaws aligned along the axis of weld is less than the height of the flaw of greater height, the two flaws shall be considered a single flaw.

(3) If the space between two flaws aligned in the through-thickness dimension is less than the height of the flaw of greater height, the two flaws shall be considered a single flaw.

### R308 FLAW ACCEPTANCE CRITERIA

Flaws shall be evaluated using the applicable criteria of [Table R308.1](#) or [Table R308.2](#). Regardless of flaw height or aspect ratio, flaw length shall not exceed  $4\bar{T}_w$ .

**Table R308.1 Acceptance Criteria for Surface Flaws**

| Aspect Ratio, $h_F/l_F$ | Maximum<br>$h_F/\bar{T}_w$ for Nominal Weld Thickness |                                           |
|-------------------------|-------------------------------------------------------|-------------------------------------------|
|                         | 25 mm to 65 mm<br>(1.0 in. to 2.5 in.)                | 100 mm to 300 mm<br>(3.9 in. to 11.8 in.) |
|                         |                                                       |                                           |
| 0.00                    | 0.031                                                 | 0.019                                     |
| 0.05                    | 0.033                                                 | 0.020                                     |
| 0.10                    | 0.036                                                 | 0.022                                     |
| 0.15                    | 0.041                                                 | 0.025                                     |
| 0.20                    | 0.047                                                 | 0.028                                     |
| 0.25                    | 0.055                                                 | 0.033                                     |
| 0.30                    | 0.064                                                 | 0.038                                     |
| 0.35                    | 0.074                                                 | 0.044                                     |
| 0.40                    | 0.083                                                 | 0.050                                     |
| 0.45                    | 0.085                                                 | 0.051                                     |
| 0.50                    | 0.087                                                 | 0.052                                     |

## GENERAL NOTES:

- (a) Aspect ratio ( $h_F/l_F$ ) used may be determined by rounding the calculated  $h_F/l_F$  down to the nearest 0.05 increment value within the column, or by linear interpolation.
- (b) For intermediate thickness  $\bar{T}_w$  [thicknesses greater than 65 mm (2.5 in.) and less than 100 mm (3.9 in.)], linear interpolation is permitted to obtain  $h_F/\bar{T}_w$  values. Otherwise, the lower values shall be used.

**Table R308.2 Acceptance Criteria for Subsurface Flaws**

| Aspect Ratio, $h_F/l_F$ | Maximum<br>$h_F/\bar{T}_w$ for Nominal Weld Thickness |                                           |
|-------------------------|-------------------------------------------------------|-------------------------------------------|
|                         | 25 mm to 65 mm<br>(1.0 in. to 2.5 in.)                | 100 mm to 300 mm<br>(3.9 in. to 11.8 in.) |
|                         |                                                       |                                           |
| 0.00                    | 0.068                                                 | 0.040                                     |
| 0.10                    | 0.076                                                 | 0.044                                     |
| 0.20                    | 0.086                                                 | 0.050                                     |
| 0.30                    | 0.108                                                 | 0.058                                     |
| 0.40                    | 0.132                                                 | 0.066                                     |
| 0.50                    | 0.156                                                 | 0.080                                     |
| 0.60                    | 0.180                                                 | 0.094                                     |
| 0.70                    | 0.206                                                 | 0.108                                     |
| 0.80                    | 0.232                                                 | 0.122                                     |
| 0.90                    | 0.258                                                 | 0.138                                     |
| 1.00                    | 0.286                                                 | 0.152                                     |

## GENERAL NOTES:

- (a) Aspect ratio ( $h_F/l_F$ ) used may be determined by rounding the calculated  $h_F/l_F$  down to the nearest 0.10 increment value within the column, or by linear interpolation.
- (b) For intermediate thickness  $\bar{T}_w$  [thicknesses greater than 65 mm (2.5 in.) and less than 100 mm (3.9 in.)], linear interpolation is permitted to obtain  $h_F/\bar{T}_w$  values. Otherwise, the lower values shall be used.

## APPENDIX S

### PIPING SYSTEM STRESS ANALYSIS EXAMPLES

(20)

#### S300 INTRODUCTION

The examples in this Appendix are intended to illustrate the application of the rules and definitions in [Chapter II, Part 5](#), Flexibility and Support; and the stress limits of [para. 302.3.5](#). The loadings and conditions necessary to comply with the intent of the Code are presented.

##### S300.1 Definitions and Nomenclature

*global axes:* these are Cartesian X, Y, and Z axes. In this Appendix, vertically upward is taken to be the +Y direction with gravity acting in the -Y direction.

$P_j$ : piping internal pressure; see [para. 301.2](#); when more than one condition exists for the piping system, each is subscripted (e.g.,  $P_1$ ,  $P_2$ , ...).

$T_j$ : pipe maximum or minimum metal temperature; see [paras. 301.3](#) and [319.3.1\(a\)](#); when more than one condition exists for the piping system, each is subscripted (e.g.,  $T_1$ ,  $T_2$ , ...).

Y+: a “single acting support” that provides support in only the vertically upward direction and is considered to be “active” when the pipe exerts a downward force on the support. The pipe is free to move upward, i.e., the pipe “lifts off” the support; the support in the “lift-off” situation is considered to be “removed” from providing support, i.e., inactive, during the load condition considered.

#### S301 EXAMPLE 1: CODE-COMPLIANT PIPING SYSTEM

##### S301.1 Example Description

This example is intended to illustrate the design of an adequately supported and sufficiently flexible piping system. The piping system in [Figure S301.1](#) is fabricated from ASTM A106 Grade B seamless pipe (i.e.,  $E = 1.00$ ); the pipe is DN 400 (NPS 16) with a nominal wall thickness of 9.53 mm (0.375 in.), 127 mm (5 in.) thickness of calcium silicate insulation, and 1.59 mm (0.063 in.) corrosion allowance; the fluid has a specific gravity of 1.0. The equivalent number of full displacement cycles expected for the piping system is fewer than 7 000 [i.e.,  $f = 1.00$  in accordance with [para. 302.3.5\(d\)](#)].

The piping system is in normal fluid service. The reference modulus of elasticity used for the piping analysis is 202.3 GPa (29.4 Msi) from [Appendix C, Tables C-6](#) and

[C-6M](#) in accordance with [paras. 319.3.2](#) and [319.4.4](#), and Poisson’s ratio is 0.3 in accordance with [para. 319.3.3](#).

The piping internal pressures and temperatures expected during normal operation and the design conditions are listed in [Table S301.1](#); see [paras. 319.2.3\(b\)](#) and [319.3.1\(a\)](#). The design conditions are set sufficiently in excess of the operating conditions so as to provide additional margin on the allowable stress for pressure design as required by the owner.

##### S301.2 Design Conditions

The design conditions establish the pressure rating, flange ratings, component ratings, and minimum required pipe wall thickness in accordance with [para. 301.2.1](#). For example, ASME B16.5 requires a minimum of Class 300 for ASTM A105 flanges. Also, the minimum required pipe wall thickness,  $t_m$ , is determined from the design conditions by inserting [eq. \(3a\)](#) into [eq. \(2\)](#); terms are defined in [para. 304.1.1](#) and [Appendix J](#).

$$E = 1.0$$

$$P = \text{design pressure} \\ = 3800 \text{ kPa (550 psi)}$$

$$S = \text{allowable stress from Appendix A, Tables A-1 and A-1M} \\ = 127.4 \text{ MPa (18.4 ksi) at design temperature } 288^\circ\text{C (550}^\circ\text{F)}$$

$$W = 1.0 \text{ for carbon steel at any temperature in accordance with Table 302.3.5, Note (9)}$$

$$Y = 0.4 \text{ from Table 304.1.1}$$

Insert [eq. \(3a\)](#) into [eq. \(2\)](#).

**Figure S301.1 Simple Code-Compliant Model**

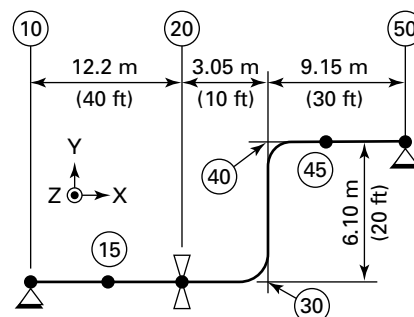


**Table S301.1 Pressure–Temperature Combinations**

| Conditions                                               | Pressure            | Temperature   |
|----------------------------------------------------------|---------------------|---------------|
| Design conditions                                        | 3 800 kPa (550 psi) | 288°C (550°F) |
| Operating ( $P_1, T_1$ )<br>maximum metal<br>temperature | 3 450 kPa (500 psi) | 260°C (500°F) |
| Minimum metal<br>temperature                             | 0 kPa (0 psi)       | –1°C (30°F)   |
| Ambient (as-installed)<br>temperature                    | 0 kPa (0 psi)       | –1°C (30°F)   |

$$t_m = t + c$$

$$t = \frac{\left(\frac{3800}{1000} \text{ MPa}\right)(406.4 \text{ mm})}{2\left[(127.4 \text{ MPa})(1.00)(1.00) + \left(\frac{3800}{1000} \text{ MPa}\right)(0.4)\right]}$$

$$c = 1.59 \text{ mm}$$

$$t_m = 5.99 \text{ mm} + 1.59 \text{ mm} = 7.58 \text{ mm} (0.299 \text{ in.})$$

In accordance with [para. 304.1.2\(a\)](#),  $t$  must be less than  $D/6$  for [eq. \(3a\)](#) to be appropriate without considering additional factors to compute the pressure design thickness,  $t$  [i.e.,  $t < D/6$ , or  $7.58 \text{ mm} < 406.4 \text{ mm}/6$ ]. Since  $7.58 \text{ mm} (0.299 \text{ in.}) < 67.7 \text{ mm} (2.67 \text{ in.})$ , [eq. \(3a\)](#) is applicable without special consideration of factors listed in [para. 304.1.2\(b\)](#).

Now select a pipe schedule of adequate thickness. Determine the specified minimum pipe wall thickness,  $T$ , from nominal pipe wall thickness,  $\bar{T}$ , considering a mill tolerance of 12.5%.

Select DN 400 (NPS 16) Schedule 30/STD nominal wall thickness from ASME B36.10M.

$$\bar{T} = 9.53 \text{ mm} (0.375 \text{ in.})$$

$$T = (9.53 \text{ mm})(1.00 - 0.125) = 8.34 \text{ mm} (0.328 \text{ in.})$$

Since  $T > t_m$  [i.e.,  $8.34 \text{ mm} (0.328 \text{ in.}) > 7.58 \text{ mm} (0.299 \text{ in.})$ ], the selection of the nominal pipe wall thickness,  $\bar{T}$ , for Schedule 30/STD pipe is acceptable. The long radius elbows specified for this piping system are in accordance with ASME B16.9 and are specified to be for use with Schedule 30/STD wall thickness pipe.

### S301.3 Computer Model Input

[Tables S301.3.1](#) and [S301.3.2](#) list the “node numbers,” lengths, etc., for each piping element displayed in [Figure S301.1](#). A bend radius of 1.5 times the nominal pipe diameter [i.e.,  $609.6 \text{ mm} (24 \text{ in.})$ ] and nominal wall thickness of  $9.53 \text{ mm} (0.375 \text{ in.})$  are used for the elbows in the computer model. Generic computer program options are as follows:

- (a) include pressure stiffening on elbows
- (b) exclude pressure thrust and Bourdon effects

(c) use nominal section properties for both the stiffnesses, forces, moments, and deflections calculation

(d) use “nominal less allowances” section properties for the stress due to sustained loads,  $S_L$ , calculation

(e) use nominal section properties for displacement stress range,  $S_E$ , calculation

### S301.4 Pressure Effects

For the operating, sustained, and displacement stress range load cases, the effect of pressure stiffening on the elbows is included to determine the end reactions in accordance with ASME B31J, Table 1-1, Note (4). The effects of pressure-induced elongation and Bourdon effects are not included, as both are deemed negligible for this particular example.

### S301.5 The Operating Load Case

The operating load case is used to determine the operating position of the piping and reaction loads for any attached equipment, anchors, supports, guides, or stops. The operating load case is based on the temperature range from the ambient (as-installed) temperature of  $-1^\circ\text{C} (30^\circ\text{F})$  to the maximum operating metal temperature of  $260^\circ\text{C} (500^\circ\text{F})$ , in accordance with [paras. 319.2.3\(b\)](#) and [319.3.1\(b\)](#). [Tables C-1](#) and [C-1M](#) values used for Row A and Row B expansion coefficients are listed below.

(a) Row A =  $13.1 \times 10^{-6} \text{ mm/mm/}^\circ\text{C}$  ( $7.30 \times 10^{-6} \text{ in./in./}^\circ\text{F}$ )

(b) Row B =  $3.43 \text{ mm/m}$  ( $4.00 \text{ in./100 ft}$ )

**Table S301.3.1 Generic Pipe Stress Model Input**

| Term                        | Value                                                   |
|-----------------------------|---------------------------------------------------------|
| Operating conditions:       |                                                         |
| internal pressure, $P_1$    | 3 450 kPa (500 psi)                                     |
| maximum metal temp., $T_1$  | 260°C (500°F)                                           |
| minimum metal temp., $T_2$  | –1°C (30°F)                                             |
| ambient (as-installed) temp | –1°C (30°F)                                             |
| Line size                   | DN 400 (NPS 16)                                         |
| Pipe                        | Schedule 30/STD, 9.53 mm (0.375 in.)                    |
| Mechanical allowance, $c$   | 1.59 mm (0.063 in.)                                     |
| Mill tolerance              | 12.5%                                                   |
| Elbows                      | Long radius                                             |
| Fluid specific gravity      | 1.0                                                     |
| Insulation thickness        | 127 mm (5 in.)                                          |
| Insulation density          | 176 kg/m <sup>3</sup> (11.0 lbf/ft <sup>3</sup> )       |
| Pipe material               | ASTM A106 Grade B                                       |
| Pipe density                | 7 833.4 kg/m <sup>3</sup> (0.283 lbf/in. <sup>3</sup> ) |

**Table S301.3.2 Element Connectivity, Type, and Lengths**

| From | To | $D_x$ ,<br>m (ft) | $D_y$ ,<br>m (ft) | Element Type                   |
|------|----|-------------------|-------------------|--------------------------------|
| 10   | 15 | 6.10 (20)         | ...               | 10 anchor<br>15 bisection node |
| 15   | 20 | 6.10 (20)         | ...               | 20 Y support                   |
| 20   | 30 | 3.05 (10)         | ...               | Three-node elbow [Note (1)]    |
| 30   | 40 | ...               | 6.10 (20)         | Three-node elbow [Note (1)]    |
| 40   | 45 | 3.05 (10)         | ...               | Informational node             |
| 45   | 50 | 6.10 (20)         | ...               | 50 anchor                      |

GENERAL NOTE: This piping system is planar, i.e.,  $D_z = 0$  m (ft) for each piping element.

NOTE: (1) The specified element lengths are measured to and/or from each elbow's tangent intersection point.

The operating load case in this example also includes the effects of internal pressure, pipe weight, insulation weight, and fluid weight on the piping system. Both pipe stiffness and displacement stress range are based on the nominal thickness of the pipe. Pipe deflections and internal reaction loads for the operating load case are listed in Table S301.5.1. Piping loads acting on the anchors and support structure are listed in Table S301.5.2.

## S301.6 The Sustained Load Case

Stresses due to the sustained loads, such as axial forces, internal pressure, and intensified bending moments in this example, are combined in accordance with para. 320 to determine  $S_L$ . The sustained load case excludes thermal effects and includes the effects of internal pressure [ $P_1 = 3450$  kPa (500 psi)], pipe weight, insulation weight, and fluid weight on the piping system.

Nominal section properties are used to generate the stiffness matrix and sustained loads for the computer model in accordance with para. 319.3.5. The nominal thickness, less allowances, is used to calculate the section properties for  $S_L$  in accordance with para. 320.

A summary of the sustained load case internal reaction forces, moments, and stress due to sustained loads,  $S_L$ , is provided in Table S301.6. Since this example model lies in only one plane, only the stress due to sustained bending moments due to the in-plane bending moment is not zero. The in-plane bending moment is intensified at each elbow by the sustained in-plane moment index for an unflanged elbow,  $I_i$ . Note that  $S_L$  for the nodes listed in Table S301.6 do not exceed the 130.8 MPa (19.0 ksi) sustained allowable stress,  $S_h$ , for A106 Grade B piping at the operating maximum metal temperature,  $T_1 = 260^\circ\text{C}$  ( $500^\circ\text{F}$ ), from Appendix A, Tables A-1 and A-1M. By limiting  $S_L$  to  $S_h$  in accordance with para. 302.3.5(c), the piping system is deemed adequately protected against collapse.

**Table S301.5.1 Operating Load Case Results: Internal Loads and Deflections**

| Node Number | Axial Force<br>(Structural Only),<br>N (lb) (Unsigned)<br>[Notes (1), (2)] | Bending Moment,<br>N-m (ft-lb)<br>(Unsigned)<br>[Note (1)] | Horizontal<br>Deflection,<br>mm (in.)<br>[Note (1)] | Vertical<br>Deflection,<br>mm (in.)<br>[Note (1)] |
|-------------|----------------------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------|
| 10          | 29 700 (6,670)                                                             | 22 100 (16,300)                                            | 0.00                                                | 0.00                                              |
| 15          | 29 700 (6,670)                                                             | 11 000 (8,110)                                             | 21 (0.8)                                            | -1 (-0.1)                                         |
| 20          | 29 700 (6,670)                                                             | 46 400 (34,200)                                            | 42 (1.6)                                            | 0.00                                              |
| 30 near     | 29 700 (6,670)                                                             | 64 700 (47,700)                                            | 50 (1.9)                                            | -3 (-0.1)                                         |
| 30 mid      | 50 700 (11,400)                                                            | 77 500 (57,100)                                            | 51 (2.0)                                            | -2 (-0.1)                                         |
| 30 far      | 40 200 (9,040)                                                             | 72 000 (53,100)                                            | 47 (1.8)                                            | 2 (0.1)                                           |
| 40 near     | 28 400 (6,380)                                                             | 72 600 (53,600)                                            | -26 (-1.0)                                          | 18 (0.7)                                          |
| 40 mid      | 40 100 (9,050)                                                             | 80 400 (59,400)                                            | -30 (-1.2)                                          | 21 (0.8)                                          |
| 40 far      | 29 700 (6,670)                                                             | 74 300 (54,900)                                            | -29 (-1.1)                                          | 23 (0.9)                                          |
| 45          | 29 700 (6,670)                                                             | 18 100 (13,400)                                            | -21 (-0.8)                                          | 16 (0.6)                                          |
| 50          | 29 700 (6,670)                                                             | 59 000 (43,600)                                            | 0.00                                                | 0.00                                              |

NOTES:

- (1) Forces, moments, and deflections are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
- (2) No operating axial pressure force is included in the axial forces listed above.



**Table S301.5.2 Operating Load Case Results: Reactions on Supports and Anchors**

| Node       | Global Axis Forces and Moments [Note (1)] |                                          |                                               |
|------------|-------------------------------------------|------------------------------------------|-----------------------------------------------|
|            | $F_x$ , N (lb)<br>(Signed)<br>[Note (2)]  | $F_y$ , N (lb)<br>(Signed)<br>[Note (2)] | $M_z$ , N·m (ft·lb)<br>(Signed)<br>[Note (2)] |
| 10 anchor  | -29 700 (-6,670)                          | -12 900 (-2,890)                         | -22 100 (-16,300)                             |
| 20 support | ...                                       | -65 300 (-14,700)                        | ...                                           |
| 50 anchor  | +29 700 (+6,670)                          | +5 300 (+1,180)                          | -59 000 (-43,600)                             |

## NOTES:

- (1) Reactions are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
- (2) Reaction forces and moments are those acting on the restraints and are signed based on their vectors acting along and about the selected coordinate system.

**Table S301.6 Sustained Forces, Moments, and Stresses [Allowable  $S_h = 130.8$  MPa (19.0 ksi)]**

| Node       | Axial Force,<br>(Structural Only),<br>N (lb) (Unsigned)<br>[Notes (1), (2)] | Bending Moment,<br>N·m (ft·lb)<br>(Unsigned)<br>[Note (1)] | Sustained Stress,<br>$S_L$ , MPa (ksi)<br>[Notes (1)–(3)] |
|------------|-----------------------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------|
| 10 anchor  | 3 270 (735)                                                                 | 17 300 (12,700)                                            | 59.0 (8.60)                                               |
| 20 support | 3 270 (735)                                                                 | 56 100 (41,400)                                            | 98.9 (14.4)                                               |
| 30 near    | 3 270 (735)                                                                 | 5 280 (3,900)                                              | 52.7 (7.50)                                               |
| 30 mid     | 17 200 (3,860)                                                              | 14 000 (10,300)                                            | 69.1 (9.90)                                               |
| 30 far     | 19 900 (4,480)                                                              | 16 300 (12,000)                                            | 73.3 (10.5)                                               |
| 40 near    | 8 000 (1,800)                                                               | 370 (270)                                                  | 42.0 (6.00)                                               |
| 40 mid     | 7 170 (1,610)                                                               | 250 (185)                                                  | 42.1 (6.00)                                               |
| 40 far     | 3 270 (735)                                                                 | 2 350 (1,720)                                              | 46.0 (6.70)                                               |
| 50 anchor  | 3 270 (735)                                                                 | 37 800 (27,900)                                            | 79.5 (11.6)                                               |

## NOTES:

- (1) Forces, moments, and stresses are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
- (2) Both the unsigned sustained axial forces (listed above) and the unsigned sustained axial pressure force, 413 000 N (92,800 lb), are summed to calculate the stresses due to sustained loads,  $S_L$ , in accordance with para. 320.
- (3) The sustained longitudinal indices,  $I_o$ , are defaulted to 1.0 for all piping components in the absence of more applicable data, in accordance with para. 320.2, and are applied to both the stresses due to sustained axial reactions and axial pressure force.

**Table S301.7 Displacement Stress Range**  
**[Allowable, Eq. (1a),  $S_A = 205.2$  MPa (29.75 ksi)]**

| Node Number | Axial Force Range, N (lb) (Unsigned) [Notes (1), (2)] | In-Plane Bending Moment Range, N·m (ft·lb) (Unsigned) [Notes (1)] | Displacement Stress Range, $S_E$ , From Eq. (17), MPa (ksi) [Notes (1), (2)] |
|-------------|-------------------------------------------------------|-------------------------------------------------------------------|------------------------------------------------------------------------------|
| 10          | 26 400 (5,940)                                        | 4 840 (3,570)                                                     | 6.43 (0.93)                                                                  |
| 20          | 26 400 (5,940)                                        | 9 740 (7,190)                                                     | 10.7 (1.55)                                                                  |
| 30 near     | 26 400 (5,940)                                        | 59 400 (43,800)                                                   | 137 (19.9)                                                                   |
| 30 mid      | 32 200 (7,200)                                        | 63 400 (46,800)                                                   | 147 (21.3)                                                                   |
| 30 far      | 20 400 (4,580)                                        | 55 700 (41,100)                                                   | 128 (18.6)                                                                   |
| 40 near     | 20 400 (4,580)                                        | 72 900 (53,900)                                                   | 168 (24.4)                                                                   |
| 40 mid      | 33 200 (7,420)                                        | 80 800 (59,600)                                                   | 187 (27.1)                                                                   |
| 40 far      | 26 400 (5,940)                                        | 76 700 (56,600)                                                   | 177 (25.7)                                                                   |
| 50          | 26 400 (5,940)                                        | 97 000 (71,500)                                                   | 86.4 (12.4)                                                                  |

## NOTES:

- (1) All ranges listed above are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
- (2) Axial force ranges do not have their sign retained, do not include axial pressure force ranges, and are included in the displacement stress range,  $S_E$ , in accordance with para. 319.4.4.

### S301.7 The Displacement Stress Range Load Case

The displacement stress range,  $S_E$ , in this example is based on the temperature range from the minimum metal (as-installed) temperature,  $-1^\circ\text{C}$  ( $30^\circ\text{F}$ ), to maximum metal temperature for the thermal cycles under analysis [ $T_1 = 260^\circ\text{C}$  ( $500^\circ\text{F}$ )], in accordance with paras. 319.2.3(b) and 319.3.1(a). The displacement stress range,  $S_E$ , for each element is calculated in accordance with eq. (17) and is listed in Table S301.7, along with the internal reaction loads. Nominal section properties are used to generate the stiffness matrix and displacement stress ranges in the piping in accordance with para. 319.3.5. Since this example model lies in only one plane, only the in-plane bending moment range is not zero. The in-plane moment range is intensified at each elbow in accordance with ASME B31J, Table 1-1 stress intensification factor,  $i_f$ , for an unflanged elbow.

For simplicity, the allowable displacement stress range,  $S_A$ , is calculated in accordance with eq. (1a). Though eq. (1a) is used in this example, it is also acceptable to calculate  $S_A$  in accordance with eq. (1b), which permits  $S_A$  to exceed the eq. (1a) value for each piping element, based on the magnitude of each element's  $S_L$ .

The following terms are as defined in para. 302.3.5(d) and Appendix J:

$$f = 1.00 \text{ for 7 000 equivalent full displacement cycles, from Figure 302.3.5 or eq. (1c)}$$

$$S_A = f(1.25S_c + 0.25S_h) \\ = (1.00)[(1.25)(138 \text{ MPa}) + (0.25)(130.8 \text{ MPa})]$$

$$= 205.2 \text{ MPa (29.75 ksi)}$$

$$S_c = \text{allowable stress from Appendix A, Tables A-1 and A-1M}$$

$$= 138 \text{ MPa (20.0 ksi) at ambient (as-installed) temperature}$$

$$S_h = \text{allowable stress from Appendix A, Tables A-1 and A-1M}$$

$$= 130.8 \text{ MPa (19.0 ksi) at } T_1$$

$$T_1 = \text{maximum metal temperature}$$

$$= 260^\circ\text{C (500}^\circ\text{F)}$$

Note that each piping element's displacement stress range based on minimum to maximum metal temperature for the thermal cycles under analysis,  $S_E$ , does not exceed the eq. (1a) allowable,  $S_A$ . By limiting  $S_E$  to  $S_A$ , the piping system is deemed adequate to accommodate up to 7 000 equivalent full displacement cycles.

Considering both the stress due to sustained loads and displacement stress range load cases, the piping system is compliant with the requirements of the Code; redesign of the piping system is not required unless the sustained or operating reaction loads at either anchor data point 10 or 50 exceed the allowable loads for the attached equipment nozzle or the support structure at node 20 is overloaded. The nozzle load and support structure analyses are beyond the scope of this Appendix and are not addressed.

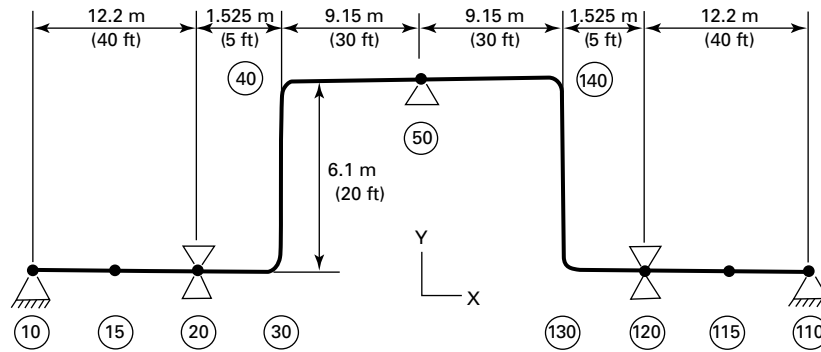
## S302 EXAMPLE 2: ANTICIPATED SUSTAINED CONDITIONS CONSIDERING PIPE LIFT-OFF

### S302.1 Example Description

This example is intended to illustrate the analysis of a piping system in which a portion of the piping lifts off at least one Y+ support in at least one operating condition. The emphasis of this example is to describe the effect this removal of support has on the determination of anticipated sustained conditions. The same principles utilized for this example would also apply for guides and stops (that are single directional or gap-type) that are not engaged during any anticipated operating condition.

The examples in this Appendix are intended for illustration purposes only and are not intended to portray the same as either adequate or even acceptable piping geometries and/or support scenarios. The piping system in Figure S302.1 is the same in material properties as in Example 1; see para. S301.1. Note that the distance from node 20 to the elbow node 30 and from nodes 120 to 130 in Example 2's model is 1.52 m (5 ft). Also, note that both the design and operating conditions are well below the creep regime; therefore, the piping system will not develop any permanent creep-related displacements, relaxation, or sag.

Figure S302.1 Lift-Off Model



### S302.2 Design Conditions

The design conditions are similar to those in the Example 1 model; see [para. S301.2](#) and [Table S302.2](#). Note that the nominal thickness remains unchanged from Example 1 even though the design temperature and corrosion allowance have increased; the corrosion allowance in this example model is 3.18 mm (0.125 in.).

### S302.3 Computer Model Input

[Table S302.3](#) lists the node numbers, lengths, etc., for each piping component that is displayed in [Figure S302.1](#). The computer-based options are the same as those for the Example 1 model; see [para. S301.3](#).

### S302.4 Pressure Effects

The pressure effect considerations are the same as those for Example 1; see [para. 301.4](#).

### S302.5 The Operating Load Case

The operating case evaluated and discussed in this example includes the effects of pipe weight, insulation weight, fluid weight, internal pressure [ $P_1 = 3040$  kPa (440 psi)], and temperature [ $T_1 = 288^\circ\text{C}$  (550°F)]. [Tables C-1](#) and [C-1M](#) values used for Row A and Row B expansion coefficients are listed below.

(a) Row A =  $13.2 \times 10^{-6}$  mm/mm/ $^\circ\text{C}$  ( $7.35 \times 10^{-6}$  in./in./ $^\circ\text{F}$ )

(b) Row B = 3.80 mm/m (4.5 in./100 ft)

An operating load case is evaluated to determine the operating position of the piping and determine the reaction loads for any attached equipment, anchors, supports, guides, or stops. In particular, each operating load case's support scenario is evaluated or assessed by the designer in order to determine whether any anticipated sustained conditions need to be evaluated with one or more Y+ supports removed. Further operating load case discussion can be found in [para. S301.5](#).

Piping loads acting on the anchors and support structure for the operating load case are listed in [Table S302.5](#). Note that only nodes 10 through 50 are listed in the following tables; this is for convenience since the model is symmetric; the reactions, deflections, and stresses for nodes 10 through 40 are the same as for nodes 110 through 140 except that some signs may be reversed.

### S302.6 Sustained Conditions

**S302.6.1 The Stress Due to Sustained Loads,  $S_L$ , Calculations.** The stress due to (long-term) sustained loads,  $S_L$ , is computed in accordance with [para. 320.2](#) for each sustained condition that is evaluated; see [para. S302.6.2](#).

**S302.6.2 Anticipated Sustained Conditions.** All anticipated sustained conditions utilizing all possible support scenarios should be considered. The designer has identified three anticipated sustained conditions for the piping system; each is listed in [Table S302.6.2](#), along with the support status of the node 50 Y+ support, as either assessed by analysis or determined by the designer. The designer has deemed the Sustained Condition 3 as both controlling the sustained design and requiring evaluation.

Table S302.2 Pressure-Temperature Combinations

| Conditions                                                  | Pressure               | Temperature   |
|-------------------------------------------------------------|------------------------|---------------|
| Design                                                      | 3 230 kPa<br>(465 psi) | 302°C (575°F) |
| Operating ( $P_1$ , $T_1$ )<br>maximum metal<br>temperature | 3 040 kPa<br>(440 psi) | 288°C (550°F) |
| Minimum metal<br>temperature                                | 0 kPa (0 psi)          | -1°C (30°F)   |
| Ambient (as-installed)<br>temperature                       | 0 kPa (0 psi)          | -1°C (30°F)   |

**Table S302.3 Generic Pipe Stress Model Input: Component Connectivity, Type, and Lengths**

| From | To  | $D_x$ , m (ft) | $D_y$ , m (ft) | Component Type              |
|------|-----|----------------|----------------|-----------------------------|
| 10   | 15  | 6.10 (20)      | ...            | 10 anchor                   |
|      |     |                |                | 15 informational node       |
| 15   | 20  | 6.10 (20)      | ...            | 20 Y support                |
| 20   | 30  | 1.52 (5)       | ...            | Three-node elbow [Note (1)] |
| 30   | 40  | ...            | 6.10 (20)      | Three-node elbow [Note (1)] |
| 40   | 45  | 3.05 (10)      | ...            | Informational node          |
| 45   | 50  | 6.10 (20)      | ...            | 50 Y+ support               |
| 110  | 115 | -6.10 (-20)    | ...            | 110 anchor                  |
| 115  | 120 | -6.10 (-20)    | ...            | 120 Y support               |
| 120  | 130 | -1.52 (-5)     | ...            | Three-node elbow [Note (1)] |
| 130  | 140 | ...            | 6.10 (20)      | Three-node elbow [Note (1)] |
| 140  | 145 | -3.05 (-10)    | ...            | Informational node          |
| 145  | 50  | -6.10 (-20)    | ...            | ...                         |

NOTE: (1) The specified component lengths are measured to and/or from each elbow's tangent intersection point.

**Table S302.5 Results for Operating Case: Reactions on Support and Anchors**

| Node       | Global Axis Forces and Moments [Note (1)] |                                          |                                               |
|------------|-------------------------------------------|------------------------------------------|-----------------------------------------------|
|            | $F_x$ , N (lb)<br>(Signed)<br>[Note (2)]  | $F_y$ , N (lb)<br>(Signed)<br>[Note (2)] | $M_z$ , N·m (ft·lb)<br>(Signed)<br>[Note (2)] |
| 10 anchor  | -24 400 (-5,500)                          | -20 200 (-4,500)                         | -51 700 (-38,100)                             |
| 20 support | ...                                       | -49 000 (-11,000)                        | ...                                           |
| 50 Y+      | ...                                       | 0 [Note (3)]                             | ...                                           |

NOTES:

- (1) Reactions are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
- (2) Reactions are signed based on their directions relative to the selected coordinate system's positive directions. Reactions  $F_x$  and  $M_z$  are positive in sign for anchor 110.
- (3) No support is provided at the node 50 Y+ restraint for the operating case. Sustained Condition 2's support load at node 50 Y+ is 26 300 N (5,900 lb); see Table S302.6.2 and para. S302.6.3.

**S302.6.3 Results for the Evaluated Sustained Condition.** Table S302.6.2's Sustained Conditions 1 and 2 reflect the ambient temperature support scenario. Sustained Condition 3 reflects the support scenario of the operating case. All three sustained conditions exclude thermal effects. Sustained Conditions 2 and 3 include the effects of internal pressure [ $P_1 = 3\,040$  kPa (440 psi)], pipe weight, insulation weight, and fluid weight on the piping system. A summary of the Sustained Condition 3 reactions and stresses due to sustained loads,  $S_L$ , appears in Table S302.6.3.

In the determination of  $S_L$ , the sustained longitudinal force index,  $I_o$ , is defaulted to 1.0 in the absence of more applicable data in accordance with para. 320. The in-plane bending moment is indexed at each elbow by the appropriate  $I_i$  calculated for this example

by multiplying 0.75 times  $i_i$  determined from ASME B31, Table 1-1. See para. S301.6 for additional information concerning the stress due to sustained loads determination.

### S302.7 Displacement Stress Range Load Cases

The displacement stress range load cases are not listed, since they are not the subject of this example.

### S302.8 Code Compliance — Satisfying the Intent of the Code

The Sustained Condition 3 results indicate that the piping system is not protected against collapse for the cycles under analysis when considering the operating case support scenario. Note the greatest Stresses due

**Table S302.6.2 Sustained Load Condition Listing**

| Sustained Condition                  | Node 50's Support Status<br>(Active/Inactive) |
|--------------------------------------|-----------------------------------------------|
| 1: Ambient (as-installed) [Note (1)] | Active                                        |
| 2: $P_1$ [Note (2)]                  | Active                                        |
| 3: $P_1$ [Note (3)]                  | Inactive                                      |

## NOTES:

- (1) Sustained Condition 1, the ambient condition, includes only pipe weight and insulation weight without fluid contents or internal pressure.
- (2) Sustained Condition 2 reflects the support scenario of the ambient condition, excludes thermal effects, and includes internal pressure, pipe weight, insulation weight, and fluid weight.
- (3) Sustained Condition 3 reflects the support scenario of the operating condition, excludes thermal effects, and includes internal pressure, pipe weight, insulation weight, and fluid weight.

to sustained loads,  $S_L$ , are at elbow nodes 40 and 140 and “Lift-Off” support location, node 50. Therefore, redesign of the piping system is required.

If the piping system is redesigned such that it is compliant with the intent of the Code, then the piping system would require no further attention unless the sustained, hydrostatic leak test, or operating reaction loads at either anchor data point 10 or 110 exceed the allowable loads for the attached equipment nozzle, or the support structure at either node 20 or 120 is overloaded. The nozzle loads and support structure analyses are beyond the scope of this Appendix and are not addressed. Although the occasional load cases are important to the design and analysis of a piping system, they are not discussed in this example.

**S303 EXAMPLE 3: MOMENT REVERSAL****S303.1 Example Description**

This example is intended to illustrate the flexibility analysis required for a piping system that is designed for more than one operating condition and also experiences a “reversal of moments” between any two of the anticipated operating conditions. The examples in this Appendix are intended for illustration purposes only and are not intended to portray the same as either adequate or even acceptable piping geometries and/or

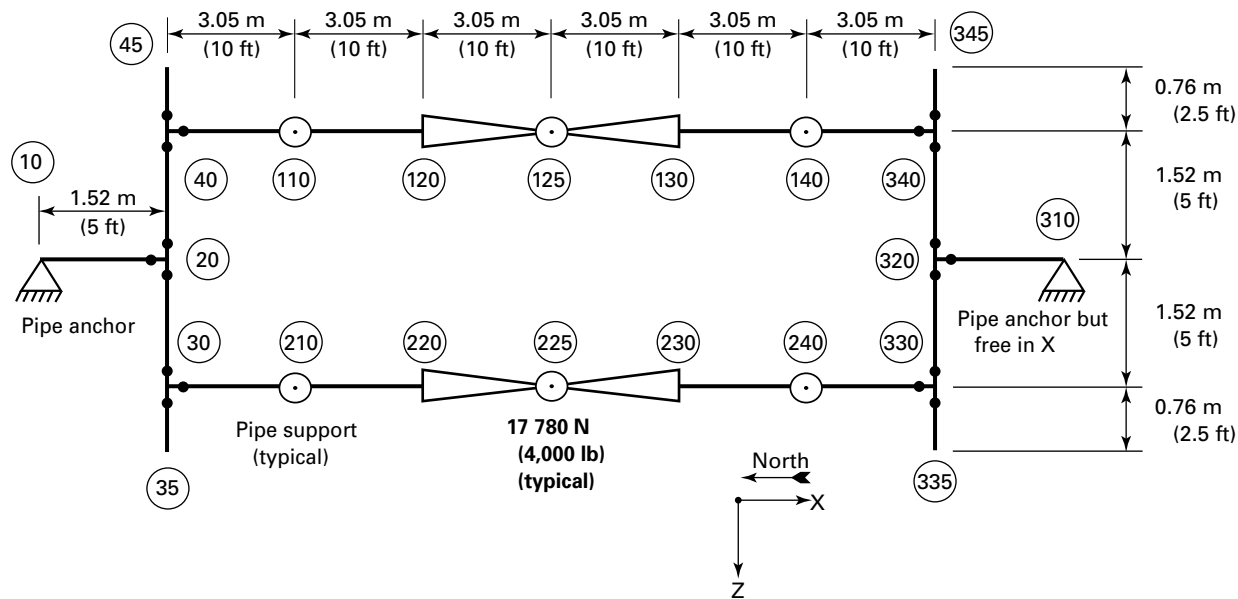
**Table S302.6.3 Sustained Forces, Moments, and Stresses for Sustained Condition 3 With Node 50's Y+ Support Inactive [Allowable  $S_n = 127$  MPa (18.4 ksi): Fails]**

| Node       | Axial Force,<br>(Structural Only),<br>N (lb) (Signed)<br>[Notes (1)–(3)] | Bending Moment,<br>N·m (ft·lb)<br>(Unsigned)<br>[Note (1)] | Sustained Stress,<br>$S_L$ , MPa (ksi)<br>[Notes (1)–(3)] |
|------------|--------------------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------|
| 10 anchor  | +9 000 (+2,000)                                                          | 25 400 (18,800)                                            | 77.5 (11.3)                                               |
| 20 support | +9 000 (+2,000)                                                          | 39 600 (29,200)                                            | 95.6 (13.9)                                               |
| 30 near    | +9 000 (+2,000)                                                          | 4 500 (3,300)                                              | 55.9 (8.14)                                               |
| 30 mid     | +32 000 (+7,200)                                                         | 9 700 (7,150)                                              | 67.1 (9.77)                                               |
| 30 far     | +35 000 (+7,850)                                                         | 12 200 (9,000)                                             | 73.2 (10.6)                                               |
| 40 near    | +23 100 (+5,200)                                                         | 31 400 (23,200)                                            | 124 (18.0)                                                |
| 40 mid     | +22 500 (+5,050)                                                         | 31 200 (23,000)                                            | 123 (17.9)                                                |
| 40 far     | +9 000 (+2,000)                                                          | 23 600 (17,500)                                            | 106 (15.3)                                                |
| 50 Y+      | –9 000 (–2,000)                                                          | 64 900 (47,800)                                            | 128 (18.6)                                                |

GENERAL NOTE: No support is provided at the node 50 Y+ restraint for Sustained Condition 3; see Table S302.6.2 and para. S302.6.3. The stress due to sustained loads,  $S_L$ , at node 50 Y+ when active is 76.3 MPa (11.0 ksi) for Sustained Condition 2.

## NOTES:

- (1) Forces, moments, and stresses are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units. The magnitude of loads and stresses for nodes 10 through 40 are the same for nodes 110 through 140, though the loads may differ in sign.
- (2) The sustained longitudinal force indices,  $I_{\omega}$ , are defaulted to 1.0 for all piping components in the absence of more applicable data in accordance with para. 320.2.
- (3) Both the sustained axial forces listed above and sustained axial pressure force, +370 000 N (+83,000 lb), are summed in accordance with para. 320 to calculate the stresses due to sustained loads,  $S_L$ .

**Figure S303.1 Moment Reversal Model**

support scenarios. Both the design and operating conditions are well below the creep regime.

The piping system in [Figure S303.1](#) consists of two headers and two branches, which are referred to as gas “meter runs.” Only one of the branches is in service (operating) at a given time; the out-of-service branch is purged and at ambient (as-installed) condition. The design specification calls for each of the meter run branches to alternate in and out of service five times every 2 weeks for the piping system’s planned 30-yr service life ( $N = 3,900$  equivalent full displacement cycles), i.e.,  $f = 1.15$  in accordance with [para. 302.3.5\(d\)](#). The piping system is fabricated from ASTM A53 Grade B pipe ( $E = 1.00$ ), both piping headers are DN 600 (NPS 24) and the branches are DN 500 (NPS 20), and both branch and header are 9.53 mm (0.375 in.) thick. For simplicity, each piping segment or component is 1.524 m (5 ft) in length.

The piping system is in normal fluid service. The fluid is gaseous, is considered to add no weight and to be neither a corrosive nor an erosive hazard, i.e., there is no corrosion allowance. The line is not insulated. The ambient (as-installed) temperature is 4°C (40°F). The reference modulus of elasticity used is 202.3 GPa (29.4 Msi) and Poisson’s ratio is 0.3. Consideration is given to the close proximity of the three tees in each header in accordance with the guidance in [para. 319.3.6](#), and the stress intensification factors from ASME B31J are considered to adequately represent the header tees for this piping system. The piping internal pressure and minimum to maximum metal temperature range expected during normal operation for each meter run and the design condi-

tions are listed in [Table S303.1](#). The design conditions are set sufficiently in excess of the operating conditions so as to provide additional margin on the allowable as required by the owner.

### S303.2 Design Conditions

The design conditions establish the pressure rating, flange ratings, components ratings, and minimum required pipe wall thickness. ASME B16.5 requires a minimum of Class 300 for ASTM A105 flanges. The minimum required wall thickness for both the branch and header is 4.4 mm (0.171 in.), considering a 12.5% mill tolerance; therefore, selection of the standard wall thickness of 9.5 mm (0.375 in.) is acceptable.

### S303.3 Computer Model Input

[Table S303.3](#) lists the node numbers, lengths, etc., for each piping component that is displayed in [Figure S303.1](#). Note that flanges and valve components are not explicitly included in the model listing in [Table S303.3](#). For simplicity, an entire branch (from tee centerline to tee centerline) is considered to be at the operating conditions listed in [Table S303.1](#), e.g., the East meter run branch from nodes 40 through 340 operates at 1 724 kPa (250 psi) and 121°C (250°F) for Operating Case 2. The computer-based options are the same as those for the Example 1 model, except that pressure stiffening is not included in the analyses for this example; see [para. S301.3](#).



**Table S303.1 Pressure–Temperature Combinations**

| Condition                             | Header(s)              |                  | West Branch            |                  | East Branch            |                  |
|---------------------------------------|------------------------|------------------|------------------------|------------------|------------------------|------------------|
|                                       | Pressure               | Temperature      | Pressure               | Temperature      | Pressure               | Temperature      |
| Design                                | 2 069 kPa<br>(300 psi) | 149°C<br>(300°F) | 2 069 kPa<br>(300 psi) | 149°C<br>(300°F) | 2 069 kPa<br>(300 psi) | 149°C<br>(300°F) |
| Operating Case 1<br>[Note (1)]        | 1 724 kPa<br>(250 psi) | 121°C<br>(250°F) | 1 724 kPa<br>(250 psi) | 121°C<br>(250°F) | 0 kPa<br>(0 psi)       | 4°C<br>(40°F)    |
| Operating Case 2<br>[Note (2)]        | 1 724 kPa<br>(250 psi) | 121°C<br>(250°F) | 0 kPa<br>(0 psi)       | 4°C<br>(40°F)    | 1 724 kPa<br>(250 psi) | 121°C<br>(250°F) |
| Ambient (as-installed)<br>temperature | ...                    | 4°C<br>(40°F)    | ...                    | 4°C<br>(40°F)    | ...                    | 4°C<br>(40°F)    |

GENERAL NOTE: For computer-based temperature and pressure data input, consider the West Branch temperature and pressure to be in effect from nodes 30 through 330 as listed in Table S303.3. Likewise, consider the East Branch temperature and pressure to be in effect from nodes 40 through 340 as listed in Table S303.3; see para. S303.3.

NOTES:

- (1) East Branch is at ambient (as-installed) conditions.  
 (2) West Branch is at ambient (as-installed) conditions.

### S303.4 Pressure Effects

Neither pressure stiffening nor Bourdon effects are included in the analyses.

### S303.5 Operating Load Case(s)

The operating load case is used to determine the operating position of the piping and reaction loads for any attached equipment, anchors, supports, guides, or stops. The owner has mandated in the design specification that the meter runs and piping be more than adequately supported. Therefore, the operating load case, while necessary to set the limits of the strain ranges, does not contribute to the emphasis of this example, and its output is not included. Tables C-1 and C-1M values used for Row A and Row B expansion coefficients are listed below.

(a) Row A =  $12.3 \times 10^{-6}$  mm/mm/°C ( $6.80 \times 10^{-6}$  in./in./°F)

(b) Row B = 1.34 mm/m (1.68 in./100 ft)

### S303.6 Sustained Load Case

Stresses due to the sustained loads, such as axial forces, internal pressure, and intensified bending moments in this example, are combined in accordance with para. 320 to determine  $S_L$ . For reasons similar to those expressed for the operating load case, the sustained load case output is not included.

### S303.7 Displacement Stress Range Load Cases

The displacement stress range,  $S_E$ , is computed in accordance with paras. 319.2.3(b) and 319.3.1(a), in which the strains evaluated for the ambient temperature (which is also the as-installed and minimum metal temperature condition for this particular example) are algebraically subtracted from the strains evaluated for Operating

Case 1 as listed in Table S303.1. Similarly, the displacement stress range,  $S_E$ , is computed from the algebraic strain difference evaluated from the ambient (as-installed) condition to Operating Case 2 as listed in Table S303.1. The individual displacement stress range,  $S_E$ , along with the internal reaction loads, is evaluated for each piping component in accordance with eq. (17), is listed in Table S303.7.1 (Operating Case 1), and has the same results as listed in Table S303.7.2 (Operating Case 2), with the exception that some signs differ (indicating the moment reversal range between the two conditions).

The algebraic strain difference between the two resultant case evaluations discussed above produces the greatest displacement stress range for the piping system in accordance with paras. 319.2.1(d), 319.2.3(b), and 319.3.1(a), i.e.,  $S_E$ , the “stress range corresponding to the total displacement strains.” The resulting reactions’ combination and  $S_E$  for each piping component are listed in Table S303.7.3.

The values in the tables listed in this paragraph consist of averaged and truncated results originally obtained from commercial pipe stress analysis vendors. In spite of the averaging and truncation processes, as well as the various methods in which each vendor has chosen to perform the modeling of branch connections, each vendor's results are within  $\pm 6\%$  of the values listed in Tables S303.7.1, S303.7.2, and S303.7.3.

### S303.8 Code Compliance — Satisfying the Intent of the Code

The piping system is compliant with the sustained load requirements of the Code. The displacement stress range from the ambient (as-installed) condition to each of the operating cases indicates the piping system is in

**Table S303.3 Generic Pipe Stress Model Input: Component Connectivity, Type, and Lengths**

| From | To  | $D_x$ , m (ft) | $D_z$ , m (ft) | Component Type                               |
|------|-----|----------------|----------------|----------------------------------------------|
| 10   | 20  | 1.52 (5)       | ...            | 10 anchor (DN 600 Header)                    |
|      |     |                |                | 20 welding tee                               |
| 20   | 30  | ...            | 1.52 (5)       | 30 welding tee                               |
| 30   | 35  | ...            | 0.76 (2.5)     | 35 simulated end cap                         |
| 20   | 40  | ...            | -1.52 (-5)     | 40 welding tee                               |
| 40   | 45  | ...            | -0.76 (-2.5)   | 45 end cap                                   |
| 40   | 110 | 3.05 (10)      | ...            | (East DN 500 Branch)                         |
|      |     |                |                | 110 Y support                                |
| 110  | 120 | 3.05 (10)      | ...            | 120 pipe segment                             |
| 120  | 125 | 3.05 (10)      | ...            | 8890 N (2,000 lb) meter                      |
|      |     |                |                | 125 Y support                                |
| 125  | 130 | 3.05 (10)      | ...            | 8890 N (2,000 lb) meter                      |
| 130  | 140 | 3.05 (10)      | ...            | 140 pipe segment                             |
| 140  | 340 | 3.05 (10)      | ...            | 340 welding tee                              |
| 30   | 210 | 3.05 (10)      | ...            | (West DN 500 Branch)                         |
|      |     |                |                | 210 Y support                                |
| 210  | 220 | 3.05 (10)      | ...            | 220 pipe segment                             |
| 220  | 225 | 3.05 (10)      | ...            | 8890 N (2,000 lb) meter                      |
|      |     |                |                | 225 Y support                                |
| 225  | 230 | 3.05 (10)      | ...            | 8890 N (2,000 lb) meter                      |
| 230  | 240 | 3.05 (10)      | ...            | 240 pipe segment                             |
| 240  | 330 | 3.05 (10)      | ...            | 330 welding tee                              |
| 310  | 320 | 3.05 (10)      | ...            | (DN 600 Header)                              |
|      |     |                |                | 310 anchor [free in the X (axial) direction] |
|      |     |                |                | 320 welding tee                              |
| 320  | 330 | ...            | 1.52 (5)       | 330 welding tee                              |
| 330  | 335 | ...            | 0.76 (2.5)     | 335 end cap                                  |
| 320  | 340 | ...            | -1.52 (-5)     | 340 welding tee                              |
| 340  | 345 | ...            | -0.76 (-2.5)   | 345 end cap                                  |

GENERAL NOTE: This piping system is planar, i.e.,  $D_y = 0$  m (0 ft) for each piping component.

compliance with the intent of the Code even when limited to the [eq. \(1a\)](#) allowable,  $S_A$ . But the “stress range corresponding to the total displacement strains,” which considers the algebraic strain difference between the two operating cases, indicates that the piping system is not protected against fatigue failure for the cycles under analysis even when considering the [eq. \(1b\)](#) allowable,  $S_A$ . Therefore, redesign of the piping system is required.

If the piping system is redesigned such that it is compliant with the intent of the Code, then the piping system would require no further attention unless the sustained, hydrostatic leak test, or operating reaction loads at either anchor data point 10 or 310, or meter runs 130 or 230, exceeded the allowable loads for the attached equipment, nozzles, or support structure. The meter loads, nozzle loads, and support structure analyses are beyond the scope of this example. Although the occasional load cases are important to the design and analysis of a piping system, they are not discussed in this example.



**Table S303.7.1 Operating Case 1: Displacement Stress Range [Eq. (1b) Allowable  $S_A = 364$  MPa (52.7 ksi): Passes]**

| Node       | Global Axis Forces and Moments [Note (1)]      |                                                 | Eq. (17), $S_E$ ,<br>MPa (ksi)<br>[Note (3)] |
|------------|------------------------------------------------|-------------------------------------------------|----------------------------------------------|
|            | $F_x$ , N (lb)<br>(Signed)<br>[Notes (2), (3)] | $M_y$ , N·m (ft·lb)<br>(Unsigned)<br>[Note (2)] |                                              |
| 10 anchor  | 0                                              | 180 000 (132,000)                               | 68.0 (9.9)                                   |
| 20 tee     | 0                                              | 180 000 (132,000)                               | 224 (32.4)                                   |
| 30 tee     | -94 000 (-21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 40 tee     | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 110 Y      | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 120 meter  | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 125 Y      | -94 000 (-21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 130 meter  | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 140 Y      | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 310 anchor | 0                                              | 180 000 (132,000)                               | 68.0 (9.9)                                   |
| 320 tee    | 0                                              | 180 000 (132,000)                               | 224 (32.4)                                   |
| 330 tee    | -94 000 (-21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 340 tee    | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 210 Y      | -94 000 (-21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 220 meter  | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 225 Y      | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 230 meter  | -94 000 (-21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 240 Y      | -94 000 (-21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |

GENERAL NOTE: The stress due to sustained load used in determining the eq. (1b) allowable displacement stress range,  $S_A$ , for nodes 20 and 320 is 28.4 MPa (4.12 ksi).

## NOTES:

- (1) Force ranges, moment ranges, and displacement stress ranges are averaged from commercial programs' results, are obtained by analyzing the piping system in both U.S. Customary and SI units, and are directly affected by the stiffness chosen for valves, flanges, other relatively stiff components, and branch connections.
- (2) Each force range and moment range is signed based on its direction relative to the selected coordinate system's positive direction.
- (3) In accordance with para. 319.4.4, no operating pressure force range is included in the force ranges and displacement stress ranges listed above.

**Table S303.7.2 Operating Case 2: Displacement Stress Range [Eq. (1b) Allowable  $S_A = 364$  MPa (52.7 ksi): Passes]**

| Node       | Global Axis Forces and Moments [Note (1)]      |                                                 | Eq. (17), $S_E$ ,<br>MPa (ksi)<br>[Note (3)] |
|------------|------------------------------------------------|-------------------------------------------------|----------------------------------------------|
|            | $F_x$ , N (lb)<br>(Signed)<br>[Notes (2), (3)] | $M_y$ , N·m (ft·lb)<br>(Unsigned)<br>[Note (2)] |                                              |
| 10 anchor  | 0                                              | 180 000 (132,000)                               | 68.0 (9.9)                                   |
| 20 tee     | 0                                              | 180 000 (132,000)                               | 224 (32.4)                                   |
| 30 tee     | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 40 tee     | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 110 Y      | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 120 meter  | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 125 Y      | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 130 meter  | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 140 Y      | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 310 anchor | 0                                              | 180 000 (132,000)                               | 68.0 (9.9)                                   |
| 320 tee    | 0                                              | 180 000 (132,000)                               | 224 (32.4)                                   |
| 330 tee    | +94 000 (+21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 340 tee    | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 110 (15.7)                                   |
| 210 Y      | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 220 meter  | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 225 Y      | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 230 meter  | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |
| 240 Y      | −94 000 (−21,000)                              | 52 800 (38,800)                                 | 35.2 (5.1)                                   |

GENERAL NOTE: The stress due to sustained load used in determining the eq. (1b) allowable displacement stress range,  $S_A$ , for nodes 20 and 320 is 28.4 MPa (4.12 ksi).

## NOTES:

- (1) Force ranges, moment ranges, and displacement stress ranges are averaged from commercial programs' results, are obtained by analyzing the piping system in both U.S. Customary and SI units, and are directly affected by the stiffness chosen for valves, flanges, other relatively stiff components, and branch connections.
- (2) Each force range and moment range is signed based on its direction relative to the selected coordinate system's positive direction.
- (3) In accordance with para. 319.4.4, no operating pressure force range is included in the force ranges and displacement stress ranges listed above.

**Table S303.7.3 Moment Reversal Load Combination Considering Operating Cases 1 and 2, Total Strain Based: Displacement Stress Range [Eq. (1b) Allowable  $S_A = 364$  MPa (52.7 ksi): Fails]**

| Global Axis Forces and Moments [Note (1)] |                                                  |                                               |                                                 |
|-------------------------------------------|--------------------------------------------------|-----------------------------------------------|-------------------------------------------------|
| Node                                      | $F_x$ , N (lb)<br>(Unsigned)<br>[Notes (2), (3)] | $M_y$ , N·m (ft-lb)<br>(Unsigned) [ Note (3)] | Eq. (17), $S_E$ , MPa (ksi)<br>[Notes (2), (3)] |
| 10 and 310 anchor                         | 0                                                | 361 000 (265,000)                             | 136 (19.7)                                      |
| 20 and 320 tee                            | 0                                                | 361 000 (265,000)                             | 448 (64.7)                                      |
| 30 and 330 tee                            | 188 000 (42,100)                                 | 106 000 (77,600)                              | 220 (31.4)                                      |
| 40 and 340 tee                            | 188 000 (42,100)                                 | 106 000 (77,600)                              | 220 (31.4)                                      |
| 110 and 210 Y                             | 188 000 (42,100)                                 | 106 000 (77,600)                              | 70.4 (10.2)                                     |
| 120 and 220 meter                         | 188 000 (42,100)                                 | 106 000 (77,600)                              | 70.4 (10.2)                                     |
| 125 and 225 Y                             | 188 000 (42,100)                                 | 106 000 (77,600)                              | 70.4 (10.2)                                     |
| 130 and 230 meter                         | 188 000 (42,100)                                 | 106 000 (77,600)                              | 70.4 (10.2)                                     |
| 140 and 240 Y                             | 188 000 (42,100)                                 | 106 000 (77,600)                              | 70.4 (10.2)                                     |

GENERAL NOTE: The stress due to sustained load used in determining the eq. (1b) allowable displacement stress range,  $S_A$ , for nodes 20 and 320 is 28.4 MPa (4.12 ksi).

NOTES:

- (1) Force ranges, moment ranges, and displacement stress ranges are averaged from commercial programs' results, are obtained by analyzing the piping system in both U.S. Customary and SI units, and are directly affected by the stiffness chosen for valves, flanges, other relatively stiff components, and branch connections.
- (2) In accordance with para. 319.4.4, no operating pressure force range is included in the force ranges and displacement stress ranges listed above.
- (3) Signs are not listed for  $F_x$  and  $M_y$ , listed above since signs are irrelevant following the load combination summation; see paras. 319.2.3(b), 319.3.1(a), 319.4.4, and 302.3.5(d) in determining the greatest displacement stress range,  $S_E$ .

## APPENDIX V

# ALLOWABLE VARIATIONS IN ELEVATED TEMPERATURE SERVICE

### V300 APPLICATION

(a) This Appendix covers application of the Linear Life Fraction Rule, which provides a method for evaluating variations at elevated temperatures above design conditions where material creep properties [see [para. V302\(c\)](#)] control the allowable stress at the temperature of the variation. This Appendix is a Code requirement only when specified by the owner in accordance with the last sentence of [para. 302.2.4\(f\)\(1\)](#).

(b) Life Fraction analysis addresses only the gross strength of piping components; it does not consider local stress effects. It is the designer's responsibility to provide construction details suitable for elevated temperature design.

#### V300.1 Definitions

*duration* :

- (a) the extent of any service condition, hours
- (b) the cumulative extent of all repetitions of a given service condition during service life, hours

*excursion* : any condition under which pressure, temperature, or both exceed the design conditions.

*operating condition* : any condition of pressure and temperature under which the design conditions are not exceeded.

*service condition*: any operating condition or excursion.

*service life*: the life assigned to a piping system for design purposes, hours.

#### V301 DESIGN BASIS

Life Fraction analysis shall be performed in accordance with one of the following design basis options selected by the owner:

- (a) All service conditions in the creep range and their durations are included.
- (b) To simplify the analysis, less severe service conditions need not be individually evaluated if their durations are included with the duration of a more severe service condition.

### V302 CRITERIA

(a) All of the criteria in [para. 302.2.4](#) shall be met.

(b) Only carbon steels, low and intermediate alloy steels, austenitic stainless steels, and high nickel alloys are included.

(c) Service conditions are considered only in the calculation of the usage factors in accordance with [para. V303](#) when the allowable stress at the temperature of those conditions in [Table A-1](#) or [Table A-1M](#) is based on the creep criteria stated in [para. 302.3.2](#).

(d) Creep-fatigue interaction effects shall be considered when the number of cycles exceeds 100.

### V303 PROCEDURE

The cumulative effect of all service conditions during the service life of the piping is determined by the Linear Life Fraction Rule in accordance with the following procedure.

#### V303.1 Calculations for Each Service Condition *i*

The following steps shall be repeated for each service condition considered.

##### V303.1.1 Equivalent Stress for Pressure

(a) Using [eq. \(V1\)](#), compute a pressure-based equivalent stress,  $S_{pi}$

$$S_{pi} = S_d P_i / P_{\max} \quad (V1)$$

where

$P_i$  = gage pressure, kPa (psig), during service condition *i*

$P_{\max}$  = maximum allowable gage pressure, kPa (psig), for continuous operation of pipe or component at design temperature, considering allowances, *c*, and mill tolerance, but without considering weld joint strength reduction factor, *W*; weld joint quality factors, *E<sub>j</sub>*; or casting quality factor, *E<sub>c</sub>*

$S_d$  = allowable stress, MPa (ksi), at design temperature, °C (°F)

$S_{pi}$  = pressure-based equivalent stress, MPa (ksi)

(b) Compute the maximum stress due to sustained loads,  $S_L$ , during service condition  $i$ , in accordance with para. 302.3.5(c).

(c) The equivalent stress,  $S_i$ , for use in para. V303.1.2 is the greater of the values calculated in (a) and (b), divided by their respective weld joint strength reduction factor,  $W$ , in accordance with para. 302.3.5(e).

**V303.1.2 Effective Temperature.** From Table A-1 or Table A-1M, find the temperature corresponding to a basic allowable stress equal to the equivalent stress,  $S_i$ , using linear interpolation if necessary. This temperature,  $T_E$ , is the effective temperature for service condition  $i$ .

**V303.1.3 Larson–Miller Parameter.** Compute the LMP for the basic design life for service condition  $i$ , using eq. (V2)  
(SI Units)

$$LMP = (C + 5)(T_E + 273) \quad (V2)$$

(U.S. Customary Units)

$$LMP = (C + 5)(T_E + 460) \quad (V2)$$

where

$C$  = Larson–Miller constant  
 = 30 for 9Cr–1Mo–V  
 = 20 for carbon, low, and intermediate alloy steels, except 9Cr–1Mo–V  
 = 15 for austenitic stainless steel and high nickel alloys

$T_E$  = effective temperature, °C (°F); see para. V303.1.2

**V303.1.4 Rupture Life.** Compute the rupture life,  $t_{ri}$ , h, using eq. (V3)

$$t_{ri} = 10^a \quad (V3)$$

where

(SI Units)

$$a = \frac{LMP}{T_i + 273} - C$$

(U.S. Customary Units)

$$a = \frac{LMP}{T_i + 460} - C$$

and

$T_i$  = temperature, °C (°F), of the component for the coincident operating pressure–temperature condition  $i$  under consideration

$t_{ri}$  = allowable rupture life, h, associated with a given service condition  $i$  and stress,  $S_i$

$LMP$  and  $C$  are as defined in para. V303.1.3.

## V303.2 Determine Creep–Rupture Usage Factor

The usage factor,  $u$ , is the summation of individual usage factors,  $t_i/t_{ri}$ , for all service conditions considered in para. V303.1. See eq. (V4).

$$u = \sum (t_i/t_{ri}) \quad (V4)$$

where

$i$  = as a subscript, 1 for the prevalent operating condition;  $i = 2, 3$ , etc., for each of the other service conditions considered

$t_i$  = total duration, h, associated with any service condition,  $i$ , at pressure,  $P_i$ , and temperature,  $T_i$

$t_{ri}$  = as defined in para. V303.1.4

## V303.3 Evaluation

The calculated value of  $u$  indicates the nominal amount of creep–rupture life expended during the service life of the piping system. If  $u \leq 1.0$ , the usage factor is acceptable including excursions. If  $u > 1.0$ , the designer shall either increase the design conditions (selecting piping system components of a higher allowable working pressure if necessary) or reduce the number and/or severity of excursions until the usage factor is acceptable.

## V304 EXAMPLE

(20)

The following example illustrates the application of the procedure in para. V303:

Pipe material: ASTM A691, Gr. 2 $\frac{1}{4}$ CR Cl. 32 pipe

Pipe size: NPS 30 (30 in. O.D.)

Nominal pipe wall thickness: 0.85 in.

Corrosion allowance: 0.0625 in.

Mill tolerance: 0.01 in.

Design pressure: 250 psig

Design temperature: 1,025°F

Allowable stress at 1,025°F: 6.85 ksi

Allowable stress at 1,050°F: 5.7 ksi

Total service life: 175,200 hr

Three service conditions are considered.

(a) Normal operation is 157,200 hr at design conditions of 250 psig, 1,025°F.

(b) Excursion 1 condition is up to 16,000 hr at excursion condition of 250 psig, 1,050°F. [This is a 20% reduction in allowable stress (6.85 ksi to 5.7 ksi), and, with the owner's approval, it complies with the criteria of para. 302.2.4. As a simplification, and in accordance with para. V301(b), this 16,000-hr total includes less severe excursions.]

(c) Excursion 2 condition is up to 2,000 hr at excursion condition of 330 psig, 1,025°F. [This is a 32% variation above the design pressure, and, with the owner's approval, it complies with the criteria of para. 302.2.4. As a simplification, and in accordance with para. V301(b), this 2,000-hr total includes less severe excursions.]

Compute pressure-based equivalent stress,  $S_{pi}$ , from eq. (V1).

From Table A-1,  $S_d = 6.85$  ksi at 1,025°F

$$P_{\max} = \frac{2(\bar{T} - c - \text{mill tol.}) \times SEW}{D - 2(\bar{T} - c - \text{mill tol.}) \times Y}$$

Letting  $S = S_d$  and, in accordance with the definition of  $P_{\max}$  in para. V303.1.1,  $E = 1$  and  $W = 1$ , and for all the service temperatures  $Y = 0.7$ ,

$$P_{\max} = 368 \text{ psi}$$

$$S_{p1} = 6.85(250/368) = 4.65 \text{ ksi}$$

$$S_{p2} = 6.85(250/368) = 4.65 \text{ ksi}$$

$$S_{p3} = 6.85(330/368) = 6.14 \text{ ksi}$$

NOTE: In eq. (V1), design pressure could be used in this example for  $P_{\max}$ , as this will always be conservative. Here the actual  $P_{\max}$  of the piping system is used.

The stress due to sustained loads,  $S_L$ , for each condition  $i$ , calculated in accordance with para. 320.2, is

$$S_{L1} = 3.0 \text{ ksi}$$

$$S_{L2} = 3.0 \text{ ksi}$$

$$S_{L3} = 3.7 \text{ ksi}$$

For pipe with a longitudinal weld ( $E = 1$ ),  $W$  is 0.8, 0.77, and 1.0 for  $S_{p1}$ ,  $S_{p2}$ , and  $S_{p3}$ , respectively. Note that condition 3 is short term, so  $W = 1$ . Also note that with the owner's approval, and in accordance with para. 302.3.5(f)(2),  $W$  may be larger than the  $W$  factors listed in Table 302.3.5. The designer chooses not to apply  $W$  for girth welds, so  $W$  is 1.00 for  $S_{L1}$ ,  $S_{L2}$ , and  $S_{L3}$ . The equivalent stress,  $S_i$ , is the greater of  $S_{pi}/W$  and  $S_{Li}/W$ . Therefore,  $S_i$  is as follows:

$$\begin{aligned} S_1 &= \text{MAX} (S_{p1}/W, S_{L1}/W) \\ &= \text{MAX} (4.65/0.8, 3.0/1.0) \\ &= \text{MAX} (5.81, 3.00) = 5.81 \text{ ksi} \end{aligned}$$

$$\begin{aligned} S_2 &= \text{MAX} (S_{p2}/W, S_{L2}/W) \\ &= \text{MAX} (4.65/0.77, 3.0/1.0) \\ &= \text{MAX} (6.04, 3.00) = 6.04 \text{ ksi} \end{aligned}$$

$$\begin{aligned} S_3 &= \text{MAX} (S_{p3}/W, S_{L3}/W) \\ &= \text{MAX} (6.14/1.0, 3.7/1.0) \\ &= \text{MAX} (6.14, 3.70) = 6.14 \text{ ksi} \end{aligned}$$

From Table A-1, find the temperature,  $T_E$ , corresponding to each  $S_i$ .

$$T_{E1} = 1,048^\circ\text{F}$$

$$T_{E2} = 1,043^\circ\text{F}$$

$$T_{E3} = 1,040^\circ\text{F}$$

Compute the LMP for each condition  $i$  using eq. (V2).

$$LMP = (20 + 5)(1,048 + 460) = 37,700$$

$$LMP = (20 + 5)(1,043 + 460) = 37,575$$

$$LMP = (20 + 5)(1,040 + 460) = 37,500$$

Compute the rupture life,  $t_{ri}$ , using eq. (V3).

$$a = 37,700/(1,025 + 460) - 20 = 5.39$$

$$t_{r1} = 10^{5.39} = 245,471 \text{ hr}$$

$$a = 37,575/(1,050 + 460) - 20 = 4.88$$

$$t_{r2} = 10^{4.88} = 75,858 \text{ hr}$$

$$a = 37,500/(1,025 + 460) - 20 = 5.25$$

$$t_{r3} = 10^{5.25} = 177,828 \text{ hr}$$

Compute the usage factor,  $u$ , the summation of  $t_i/t_{ri}$ , for all service conditions using eq. (V4).

$$t_1/t_{r1} = 157,200/245,471 = 0.640$$

$$t_2/t_{r2} = 16,000/75,858 = 0.211$$

$$t_3/t_{r3} = 2,000/177,828 = 0.011$$

$$u = 0.640 + 0.211 + 0.011 = 0.862 < 1.0$$

Therefore, the excursion is acceptable.

## APPENDIX W

### HIGH-CYCLE FATIGUE ASSESSMENT OF PIPING SYSTEMS

#### W300 APPLICATION

This Appendix addresses the fatigue evaluation of Code piping subjected to cyclic loadings when the total number of significant stress cycles due to all causes exceeds 100,000. The Appendix may be used subject to the owner's approval. When it is used, the details shall be documented in the engineering design.

A significant stress cycle is defined as a cycle with a computed stress range, in accordance with [para. 319](#), greater than 20.7 MPa (3.0 ksi) for ferritic steels and austenitic stainless steels. For other materials, or corrosive environments, all cycles shall be considered significant, unless otherwise documented in the engineering design. The allowable displacement stress range requirements of [para. 302](#), using the computed stress range in accordance with [para. 319](#), provide an acceptable method of evaluating piping systems for fatigue when the number of significant stress cycles is less than or equal to 100,000. The piping cyclic loadings may be due to thermal expansion, anchor motion, vibration, inertial loads, wave motion or other sources.

Fatigue due to pressure cycling is not addressed in this Appendix, but it shall be considered in the engineering design. The methods in [Chapter IX](#) or ASME BPVC, Section VIII, Division 2 may be applied to address pressure cycling.

The design, fabrication, examination, and testing requirements of this Appendix are in addition to the requirements of [Chapters I](#) through [VI](#).

#### W301 NOMENCLATURE

$CF$  = welded joint fatigue curve coefficient, SI (U.S. Customary) units  
 $d_t$  = fatigue damage due to thermal stress with constant amplitude  
 $d_w$  = fatigue damage due to wave stress with variable amplitude  
 $E$  = modulus of elasticity at operating temperature  
 $e$  = base of natural logarithm  
 $E_{CSA}$  = modulus of elasticity of carbon steel at ambient temperature or 21°C (70°F)  
 $f_E$  = environmental correction factor (see [Table W302.1-4](#))  
 $f_I$  = fatigue improvement factor from ASME BPVC, Section VIII, Division 2

$f_{M,k}$  = fatigue factor for stress ratio  
 $f_t$  = temperature correction factor  
 $h$  = Weibull stress range shape distribution parameter  
 $k$  = fatigue strength thickness exponent (see [Tables W302.1-1](#) through [W302.1-3](#))  
 $L_d$  = piping cyclic design life, yr  
 $L_w$  = design storm period of occurrence, yr  
 $m$  = welded joint fatigue curve exponent  
 $N_d$  = design number of pipe stress cycles  
 $N_i$  = number of cycles for loading condition  $i$   
 $N_{ti}$  = allowable number of cycles for loading condition  $i$   
 $N_w$  = design storm wave height associated cycles  
 $q$  = Weibull stress range scale distribution parameter that can be expressed in terms of stress range  
 $S_{aw}$  = allowable maximum probable stress range during  $N_w$  wave cycles, MPa (ksi)  
 $S_{Ei}$  = computed displacement stress range for condition  $i$  corresponding to cycles  $N_i$ , MPa (ksi)  
 $S_{Ei, \max}$  = computed maximum displacement stress for condition  $i$  corresponding to stress range  $S_{Ei}$  and cycles  $N_i$ , MPa (ksi)  
 $S_{Ei, \min}$  = computed minimum displacement stress for condition  $i$  corresponding to stress range  $S_{Ei}$  and cycles  $N_i$ , MPa (ksi)  
 $S_{EW}$  = computed maximum stress range due to wave motion, MPa (ksi)  
 $S_{yi}$  = yield strength of the component under consideration for condition  $i$   
 $T_E$  = effective component thickness at weld joint, mm (in.)  
 $\bar{T}$  = component nominal thickness at weld joint, mm (in.)  
 $V_o$  = average zero-crossing frequency, Hz  
 $\Gamma(1 + m/h)$  = gamma function of argument  $1 + m/h$  [see [Table W301-1](#) and [eq. \(W8\)](#)]  
 $\sigma$  = standard deviation;  $-2\sigma$  is a 95% prediction interval and  $-3\sigma$  is a 99% prediction interval on a statistical basis

**Table W301-1 Gamma Function Evaluation**

| $1 + m/h$ | $\Gamma(1 + m/h)$ | $1 + m/h$ | $\Gamma(1 + m/h)$ |
|-----------|-------------------|-----------|-------------------|
| 3.00      | 2.00              | 5.00      | 24.00             |
| 3.05      | 2.10              | 5.05      | 25.88             |
| 3.10      | 2.20              | 5.10      | 27.93             |
| 3.15      | 2.31              | 5.15      | 30.16             |
| 3.20      | 2.42              | 5.20      | 32.58             |
| 3.25      | 2.55              | 5.25      | 35.21             |
| 3.30      | 2.68              | 5.30      | 38.08             |
| 3.35      | 2.83              | 5.35      | 41.20             |
| 3.40      | 2.98              | 5.40      | 44.60             |
| 3.45      | 3.15              | 5.45      | 48.30             |
| 3.50      | 3.32              | 5.50      | 52.34             |
| 3.55      | 3.51              | 5.55      | 56.75             |
| 3.60      | 3.72              | 5.60      | 61.55             |
| 3.65      | 3.94              | 5.65      | 66.80             |
| 3.70      | 4.17              | 5.70      | 72.53             |
| 3.75      | 4.42              | 5.75      | 78.78             |
| 3.80      | 4.69              | 5.80      | 85.62             |
| 3.85      | 4.99              | 5.85      | 93.10             |
| 3.90      | 5.30              | 5.90      | 101.27            |
| 3.95      | 5.64              | 5.95      | 110.21            |
| 4.00      | 6.00              | 6.00      | 120.00            |
| 4.05      | 6.39              | 6.05      | 130.72            |
| 4.10      | 6.81              | 6.10      | 142.45            |
| 4.15      | 7.27              | 6.15      | 155.31            |
| 4.20      | 7.76              | 6.20      | 169.41            |
| 4.25      | 8.29              | 6.25      | 184.86            |
| 4.30      | 8.86              | 6.30      | 201.81            |
| 4.35      | 9.47              | 6.35      | 220.41            |
| 4.40      | 10.14             | 6.40      | 240.83            |
| 4.45      | 10.85             | 6.45      | 263.26            |
| 4.50      | 11.63             | 6.50      | 287.89            |
| 4.55      | 12.47             | 6.55      | 314.95            |
| 4.60      | 13.38             | 6.60      | 344.70            |
| 4.65      | 14.37             | 6.65      | 377.42            |
| 4.70      | 15.43             | 6.70      | 413.41            |
| 4.75      | 16.59             | 6.75      | 453.01            |
| 4.80      | 17.84             | 6.80      | 496.61            |
| 4.85      | 19.20             | 6.85      | 544.61            |
| 4.90      | 20.67             | 6.90      | 597.49            |
| 4.95      | 22.27             | 6.95      | 655.77            |

GENERAL NOTE: This Table shows the evaluation of the gamma function,  $\Gamma$ , for values between 3 and 6.95, e.g.,  $\Gamma(3) = 2$ . Gamma function for values of  $(1 + m/h)$  not listed here may be computed directly from the mathematical definition of the gamma function or computed from the following approximation:

$$\Gamma(1 + m/h) \cong \sqrt{2\pi(m/h)} [(m/h)/e]^{m/h}$$

## W302 DESIGN FOR FATIGUE

The fatigue design procedure in this Appendix addresses two types of cyclic loading — fatigue loading where the loading spectrum may be reduced to a series of stress range–cycle pairs, and fatigue loading where the loading spectrum may be represented by a two-parameter Weibull distribution. Fatigue damage is the summation based on the linear damage rule. The fatigue design analysis method in this Appendix is based on the following general requirements:

(a) In the absence of more directly applicable data, the stress intensification factors shown in [Appendix D](#) for elbows, bends, and ASME B16.9 tees may be used. The stress intensification factors for other components are the responsibility of the designer and their validity shall be documented in the engineering design.

(b) Integral construction is recommended. Fabricated components such as branch connections and miter elbows are not recommended.

(c) The maximum stress range from all sources of loadings shall not exceed the displacement stress range requirements of [para. 302.3.5](#) with  $f = 1.0$ .

(d) Inertial forces due to wave loading shall be considered as occasional loads and shall satisfy the requirements of [para. 302.3.6](#).

### W302.1 Fatigue Damage Due to Cyclic Stress Range From Other Than Wave Motion

The maximum stress range,  $S_E$ , shall be computed in accordance with [para. 319](#) and meet the allowable displacement stress range requirements of [para. 302.3.5](#) with  $f = 1.0$ . The stress range–cycle pairs ( $S_{Ei}$ ,  $N_i$ ) shall be established from a stress–cycle histogram by the Rain-flow method of ASME BPVC, Section VIII, Division 2, Annex 5-B. Fatigue damage shall be computed as follows:

Allowable fatigue cycles for load case  $i$

$$N_{fi} = \frac{f_I}{f_E} \left( \frac{CF \cdot f_{M,k} \cdot f_t}{S_{Ei} \cdot T_E^k} \right)^m \quad (W1)$$

where

$f_I = 1.0$  unless otherwise documented in the engineering design

$f_{M,k} = 1.0$  unless  $(S_{Ei, \max} + S_{Ei, \min}) > S_{yi}$ , in which case  $f_{M,k} = (1 - S_{Ei, \min} / S_{Ei, \max})^{0.2778}$

$f_t =$  temperature correction factor  
 $= E/E_{CSA}$

$T_E = 16$  mm (0.625 in.) for  $\bar{T} \leq 16$  mm (0.625 in.)  
 $= \bar{T}$  for 16 mm (0.625 in.)  $< \bar{T} < 150$  mm (6 in.)  
 $= 150$  mm (6 in.) for  $\bar{T} \geq 150$  mm (6 in.)

Fatigue damage due to displacement loadings



**Table W302.1-1 Fatigue Material Coefficients ( $-3\sigma$ )**

| Material                                        | CF       |                      | <i>m</i> | <i>k</i> |
|-------------------------------------------------|----------|----------------------|----------|----------|
|                                                 | SI Units | U.S. Customary Units |          |          |
| Ferritic steels and austenitic stainless steels | 14 137   | 999.1                | 3.13     | 0.222    |
| Aluminum                                        | 2 303    | 162.8                | 3.61     | 0.222    |

GENERAL NOTES:

(a) SI units include  $S_{Ei}$  (MPa) and  $T_E$  (mm) in eq. (W1).(b) U.S. Customary units include  $S_{Ei}$  (ksi) and  $T_E$  (in.) in eq. (W1).

$$d_t := \sum \frac{N_i}{N_{ti}} \quad (\text{W2})$$

where  $d_t$  must be less than 1.0. When computing fatigue damage in accordance with eq. (W2), cycles associated with a stress range less than 20.7 MPa (3 ksi) need not be considered.

The fatigue material coefficients used in eq. (W1) shall be in accordance with Table W302.1-1. Alternatively, when specified in the engineering design and approved by the owner, the fatigue material coefficients may be in accordance with Table W302.1-2. The maximum temperature limits for Table W302.1-1 and Table W302.1-2 are 371°C (700°F) for ferritic steels, 427°C (800°F) for austenitic stainless steels, and 204°C (400°F) for aluminum. The fatigue material coefficients for temperatures in excess of these limits or for materials not listed in Table W302.1-1 or Table W302.1-2 shall be specified and the basis documented in the engineering design.

When the number of cycles,  $N_{ti}$ , exceeds  $10^7$ , and with approval of the owner, the fatigue material coefficients in Table W302.1-3 may be used instead of the coefficients in Table W302.1-1 or Table W302.1-2 when applying eq. (W1). Alternatively, when specified in the engineering design and approved by the owner, optional fatigue material coefficients may be developed for  $N_{ti} > 10^6$ .

**Table W302.1-2 Fatigue Material Coefficients ( $-2\sigma$ )**

| Material                                        | CF       |                      | <i>m</i> | <i>k</i> |
|-------------------------------------------------|----------|----------------------|----------|----------|
|                                                 | SI Units | U.S. Customary Units |          |          |
| Ferritic steels and austenitic stainless steels | 16 942   | 1,198                | 3.13     | 0.222    |
| Aluminum                                        | 2 828    | 199.9                | 3.61     | 0.222    |

GENERAL NOTES:

(a) SI units include  $S_{Ei}$  (MPa) and  $T_E$  (mm) in eq. (W1).(b) U.S. Customary units include  $S_{Ei}$  (ksi) and  $T_E$  (in.) in eq. (W1).

The environmental fatigue factor,  $f_E$ , is typically a function of the fluid environment, loading frequency, temperature, and material variables, e.g., grain size and chemical composition. In the absence of more directly applicable data, the values of  $f_E$  provided in Table W302.1-4 may be used for the effect of the environment on the fatigue life of carbon steel piping at temperatures less than or equal to 93°C (200°F). The values of  $f_E$  for other materials, temperatures, or environments may be assumed to be 4.0 if more-specific data is not available. Alternative environmental fatigue factors may be used when justified based on applicable data, and shall be specified and the basis documented in the engineering design.

### W302.2 Fatigue Damage Due to Cyclic Stress Range From Wave Motion

This paragraph addresses variable amplitude random loadings where the long-term stress range distribution may be represented by a two-parameter Weibull distribution. The specific requirements are written for wave loadings for applications such as floating offshore platforms; however, the method may be applied to other applications where the Weibull distribution applies. In this Appendix, a “sea state” is defined as the general condition of the free surface on a large body of water with respect to wind waves and swell at a certain location and time. A sea state is characterized by statistics, including the wave height and period, and represented here by parameters  $h$  and  $V_o$ .

When designing for wave motion, the design sea state shall be specified by the owner. The sea state shall be characterized by a two-parameter wave-scatter diagram of significant wave height and zero upcrossing period. The stress range is assumed proportional to wave height, and the Weibull stress range shape distribution parameter and average zero crossing frequency are determined from the data.

The long-term stress range distribution may be represented by a two-parameter Weibull distribution as follows:

**Table W302.1-3 Optional Fatigue Material Coefficients When  $N_{ti} > 10^7$** 

| Material                                        | CF                        | <i>m</i> | <i>k</i> |
|-------------------------------------------------|---------------------------|----------|----------|
| Ferritic steels and austenitic stainless steels | $CFa[(f_E/f_i)10^7]^{ax}$ | 5.0      | 0.222    |

GENERAL NOTES:

(a)  $CFa$  is  $CF$  from Table W302.1-1 or Table W302.1-2 in SI or U.S. Customary units.(b)  $ax = (1/m_2 - 1/m_1)$ , where $m_1$  = value of  $m$  from Table W302.1-1 or Table W302.1-2 $m_2$  = value of  $m$  from Table W302.1-3(For ferritic and austenitic stainless steels,  $ax = -0.1195$ .)

(20) **Table W302.1-4 Environmental Fatigue Factors for Carbon Steel Piping,  $T \leq 93^\circ\text{C}$  (200°F)**

| Environment                       | $f_E$ |
|-----------------------------------|-------|
| Air                               | 1.0   |
| Seawater with cathodic protection | 2.51  |
| Seawater with free corrosion      | 3.0   |

$$F = e^{-(S_{EW}/q)^h} \quad (\text{W3})$$

$$q = \frac{S_{aw}}{[\ln(N_w)]^{1/h}} \quad (\text{W4})$$

where

$F$  = probability for exceeding the stress range,  $S_{EW}$

The design fatigue curve is represented by a single equation of the form given by eq. (W1).

Allowable fatigue damage for variable wave loadings

$$d_w = 1 - d_t \quad (\text{W5})$$

Design storm wave height associated cycles

$$N_w = 3.156 \times 10^7 \times V_o \times L_w \quad (\text{W6})$$

Design number of pipe stress cycles

$$N_d = 3.156 \times 10^7 \times V_o \times L_d \quad (\text{W7})$$

The maximum probable stress range shall be determined from the maximum probable wave height based on a two-parameter Weibull model. The maximum probable wave height (or maximum probable stress range) will be exceeded, on average, once every  $N_w$  design wave cycles.

Allowable maximum probable stress range during  $N_w$  wave cycles

$$S_{aw} = \left( \frac{d_w a}{N_d} \right)^{1/m} \times \frac{[\ln(N_w)]^{1/h}}{\left[ \Gamma \left( 1 + \frac{m}{h} \right) \right]^{1/m}} \quad (\text{W8})$$

where

$$a = \left( \frac{f_I}{f_E} \right) \times \left( \frac{CF \cdot f_M \cdot k \cdot f_t}{T_E^k} \right)^m \quad (\text{W9})$$

$f_I = 1.0$  unless otherwise documented in the engineering design

The fatigue material coefficients,  $CF$ ,  $m$ , and  $k$ , shall be in accordance with Table W302.1-1, unless the alternative analysis methods of para. W302.3 are applied.

The computed maximum stress range,  $S_{EW}$ , is assumed to be proportional to the maximum probable wave height (trough to peak). The stress range shall be computed in

accordance with para. 319 from the imposed displacements created by the maximum probable wave height and shall not exceed the allowable maximum probable stress range,  $S_{aw}$ .

This Appendix does not prescribe specific values for  $h$ ,  $V_o$ ,  $L_w$ , or  $L_d$ . These design parameters shall be specified by the owner or regulatory authority, as applicable. The values for  $h$  and  $V_o$  are determined by statistical data based on the specific sea state. The design life of the piping,  $L_d$ , and the design maximum probable wave height based on the design storm period of occurrence,  $L_w$ , shall be based on the intended life of the piping and acceptable risk.

In the absence of more-applicable data for the specific sea state, the following typical values may be used:

- (a)  $h = 1.0$
- (b)  $V_o = 0.159$  Hz
- (c)  $L_d = 20$  yr
- (d)  $L_w = 100$  yr

### W302.3 Alternative Analysis Methods

The fatigue analysis method presented in para. W302.1 is based on a design fatigue curve with a single linear slope on a log-log stress-cycles plot, except when the optional coefficients of Table W302.1-3 are applied for a bilinear fatigue curve. The fatigue analysis method presented in para. W302.2 is based on a two-parameter Weibull model for a design fatigue curve with a single linear slope on a log-log stress-cycles plot and a single sea state, represented by parameters  $h$  and  $V_o$ . With the owner's approval, the designer may apply more-applicable data or more rigorous analysis methods for fatigue of piping, e.g., a bilinear fatigue curve with a change in slope of the fatigue curve at cycles  $>10^7$  or an endurance limit.

The fatigue analysis method of ASME BPVC, Section VIII, Division 2 may be used for piping as an alternative to the method of this Appendix.

## W305 FLUID SERVICE REQUIREMENTS

### W305.1 General

The requirements in Chapters I through VI apply in addition to the requirements of this Appendix. When the fatigue damage,  $d_b$ , computed in accordance with para. W302.1 exceeds 0.5 or when  $S_{EW}$ , computed in accordance with para. W302.2, exceeds  $0.8S_{aw}$ , the requirements for severe cyclic conditions in Chapters I through VI shall apply. For special applications, e.g., offshore piping, the owner may elect to require the supplemental requirements of para. W305.3.

### W305.3 Optional Supplemental Requirements

When these supplemental requirements are specified, the requirements for para. W305.1 also apply.

**W305.3.1 Examination.** The following additional examination is required:

All longitudinal welds shall be fully radiographed in accordance with [para. 344.5](#) with acceptance criteria in accordance with [Table 341.3.2](#) for Normal Fluid Service.

The extent of examination of circumferential groove welds shall be as follows:

(a) At least 10% of the welds shall be randomly examined using the liquid penetrant method ([para. 344.4](#)) or, for magnetic materials, the magnetic particle method ([para. 344.3](#)) with acceptance criteria in accordance with [para. 341.3.2](#).

(b) When the requirements for severe cyclic conditions do not apply, a minimum of 10% of the welds shall be fully radiographed in accordance with [para. 344.5](#) with accep-

tance criteria in accordance with [Table 341.3.2](#) for Normal Fluid Service.

Piping specified as critical by the owner shall be subjected to 100% radiography and 100% liquid penetrant or magnetic particle examination using the methods and acceptance criteria described above.

**W305.3.2 Leak Testing.** Leak testing of the system shall be in accordance with the requirements of [para. 345](#), except that the test duration for hydrostatic testing shall be a minimum of 30 min after the test pressure has been adequately stabilized.

# APPENDIX X

## METALLIC BELLOWS EXPANSION JOINTS

(Design requirements of Appendix X are dependent on and compatible with EJMA standards.)

### X300 GENERAL

The intent of this Appendix is to set forth design, manufacturing, and installation requirements and considerations for bellows type expansion joints, supplemented by the EJMA standards. It is intended that applicable provisions and requirements of [Chapters I](#) through [VI](#) of this Code shall be met, except as modified herein. This Appendix does not specify design details. The detailed design of all elements of the expansion joint is the responsibility of the manufacturer. This Appendix is not applicable to expansion joints in piping designed in accordance with [Chapter IX](#).

### X301 PIPING DESIGNER RESPONSIBILITIES

The piping designer shall specify the design conditions and requirements necessary for the detailed design and manufacture of the expansion joint in accordance with [para. X301.1](#) and the piping layout, anchors, restraints, guides, and supports required by [para. X301.2](#).

#### X301.1 Expansion Joint Design Conditions

The piping designer shall specify all necessary design conditions including the following.

**X301.1.1 Static Design Conditions.** The design conditions shall include any possible variations of pressure or temperature, or both, above operating levels. Use of a design metal temperature other than the fluid temperature for any component of the expansion joint shall be verified by computation, using accepted heat transfer procedures, or by test or measurement on similarly designed equipment in service under equivalent operating conditions.

**X301.1.2 Cyclic Design Conditions.** These conditions shall include coincident pressure, temperature, imposed end displacements and thermal expansion of the expansion joint itself, for cycles during operation. Cycles due to transient conditions (startup, shutdown, and abnormal operation) shall be stated separately. (See EJMA standards, 4.12.1.5 on fatigue life expectancy, for guidance in defining cycles.)

**X301.1.3 Other Loads.** Other loads, including dynamic effects (e.g., wind, thermal shock, vibration, seismic forces, and hydraulic surge); and static loads, e.g., weight (insulation, snow, ice, etc.), shall be stated.

**X301.1.4 Fluid Properties.** Properties of the flowing medium pertinent to design requirements, including the owner-designated fluid service category, flow velocity and direction, for internal liners, etc., shall be specified.

**X301.1.5 Other Design Conditions.** Other conditions that may affect the design of the expansion joint, such as use of shrouds, external or internal insulation, limit stops, other constraints, and connections in the body (e.g., drains or bleeds) shall be stated.

#### X301.2 Piping Design Requirements

**X301.2.1 General.** Piping layout, anchorage, restraints, guiding, and support shall be designed to avoid imposing motions and forces on the expansion joint other than those for which it is intended. For example, a bellows expansion joint is not normally designed to absorb torsion. Pipe guides, restraints, and anchorage shall conform to the EJMA standards. Anchors and guides shall be provided to withstand expansion joint thrust forces when not self-restrained by tie rods, hinge bars, pins, etc. (See [para. X302.1](#).) Column buckling of the piping (e.g., due to internal fluid pressure) shall also be considered.

##### X301.2.2 Design of Anchors

(a) *Main Anchors.* Main anchors shall be designed to withstand the forces and moments listed in [\(b\)](#), and pressure thrust, defined as the product of the effective thrust area of the bellows and the maximum pressure to which the joint will be subjected in operation. Consideration shall be given to the increase of pressure thrust loads on anchors due to unrestrained expansion joints during leak testing if supplemental restraints are not used during the test (see [para. 345.3.3](#)). For convoluted, omega, or disk type joints, the effective thrust area recommended by the manufacturer shall be used. If this information is unavailable, the area shall be based on the mean diameter of the bellows.

(b) *Intermediate Anchors.* Anchors shall be capable of withstanding the following forces and moments:

(1) those required to compress, extend, offset, or rotate the joint by an amount equal to the calculated linear or angular displacement

(2) static friction of the pipe in moving on its supports between extreme extended and contracted positions (with calculated movement based on the length of pipe between anchor and expansion joint)

- (3) operating and transient dynamic forces caused by the flowing medium
- (4) other piping forces and moments

## **X302 EXPANSION JOINT MANUFACTURER RESPONSIBILITIES**

The expansion joint manufacturer shall provide the detailed design and fabrication of all elements of the expansion joint in accordance with the requirements of the Code and the engineering design. This includes

- (a) all piping within the end connections of the assembly supplied by the manufacturer, including pipe, flanges, fittings, connections, bellows, and supports or restraints of piping
- (b) specifying the need for supports or restraints external to the assembly as required, and of the data for their design
- (c) determining design conditions for all components supplied with the expansion joint that are not in contact with the flowing medium

### **X302.1 Expansion Joint Design**

The design of bellows-type expansion joints shall be based on recognized and accepted analysis methods and design conditions stated in [para. X301.1](#). These joints shall be designed so that permanent deformation of the expansion joint and pressure-restraint hardware will not occur during leak testing. Convolute-type bellows shall be designed in accordance with the EJMA standards, except as otherwise required or permitted herein. Design of other types of bellows shall be qualified as required by [para. 304.7.2](#).

**X302.1.1 Factors of Safety.** The factor of safety on squirm pressure shall be not less than 2.25. The factor of safety on ultimate rupture pressure shall be not less than 3.0.

**X302.1.2 Design Stress Limits.** For convolute type bellows, stresses shall be calculated either by the formulas shown in the EJMA standards or by other methods acceptable to the owner.

(a) The circumferential and meridional membrane stress in the bellows, the tangent end, and reinforcing ring members (including tensile stress in fasteners) due to design pressure shall not exceed the allowable stress values given in [Table A-1](#) or [Table A-1M](#).

(b) Meridional membrane and bending stresses at design pressure shall be of a magnitude that will not result in permanent deformation of the convolutions at test pressure. Correlation with previous test data may be used to satisfy this requirement.

For an unreinforced bellows, annealed after forming, the meridional membrane plus bending stress in the bellows shall not exceed 1.5 times the allowable stress given in [Table A-1](#) or [Table A-1M](#).

(c) Stresses shall be calculated in restraints (tie rods, hinge bars, pins, etc.) in self-restrained expansion joints and in the attachments of the restraining devices to the pipe or flanges. Direct tension, compression, bearing, and shear stresses shall not exceed the allowable stress limits stated in [para. 302.3.1](#). The summation of general bending stress plus tension or compression stress shall not exceed the stress values listed in [Appendix A, Table A-1](#) or [A-1M](#), and [Table A-2](#) or [A-2M](#), times the shape factor of the cross section. The shape factor is the ratio of the plastic moment to the yield moment (e.g., 1.5 for a rectangular section). For attachment of restraints to piping, see [para. 321.3](#). Local stresses may be evaluated using the criteria of ASME BPVC, Section VIII, Division 2, Part 5. Compression members shall be evaluated for buckling in accordance with the AISC Manual of Steel Construction, Allowable Stress Design. For self-restrained expansion joints, the restraints shall be designed to withstand the full design pressure thrust. Additional considerations may be required where time-dependent stresses prevail.

(d) Pressure design of pipe sections, fittings, and flanges shall meet the requirements of [paras. 303](#) and [304](#).

(e) When the operating metal temperature of the bellows element is in the creep range,<sup>1</sup> the design shall be given special consideration and, in addition to meeting the requirements of this Appendix, shall be qualified as required by [para. 304.7.2](#).

### **X302.1.3 Fatigue Analysis**

(a) A fatigue analysis<sup>1</sup> that takes into account all design cyclic conditions shall be performed and the calculated design cycle life shall be reported. The method of analysis for convolute U-shaped bellows shall be in accordance with EJMA standards.

(b) Material design fatigue curves for bellows with seams welded using an autogeneous method are provided in the EJMA standards. The curves are for use only in conjunction with the EJMA stress equations.

(c) Fatigue testing in accordance with Appendix F of the EJMA standards is required to develop fatigue curves for bellows of materials other than those provided for use in conjunction with the EJMA stress equations.

(d) When applying the fatigue curves from the EJMA standards, a fatigue correction factor,  $f_c = 75\%$ , shall be used.

(e) An alternate fatigue correction factor,  $f_c$ , may be used with the permission of the owner.

### **X302.1.4 Limitations**

(a) Expansion joint bellows shall not be constructed from lap welded pipe or lap welded tubing.

<sup>1</sup> Consideration shall be given to the detrimental effects of creep-fatigue interaction when the operating metal temperature of the bellows element will be in the creep range. Creep-fatigue interaction may become significant at temperatures above 425°C (800°F) for austenitic stainless steels.



(b) All pressure containing or pressure thrust restraining materials shall conform to the requirements of Chapter III and Appendix A.

### X302.2 Expansion Joint Manufacture

Expansion joints shall be produced in accordance with the manufacturer's specification, which shall include at least the following requirements.

#### X302.2.1 Fabrication

(a) All welds shall be made by qualified welders or welding operators using welding procedures qualified as required by para. 328.2.

(b) The longitudinal seam weld in the bellows element shall be a full penetration butt weld. Prior to forming, the thickness of the weld shall be not less than 1.00 nor more than 1.10 times the thickness of the bellows material.

(c) A full fillet weld may be used as a primary weld to attach a bellows element to an adjoining piping component.

(d) When bellows are attached directly to an adjoining piping component by welding and the piping component is P-Nos. 4, 5A, 5B, or 5C base metal, the attachment weld shall be heat treated in accordance with para. 331.1, except that the exemptions from heat treatment given in para. 331 shall not be permitted. The holding time shall be based on the thickness of the piping component at the bellows attachment weld location. Examination of the attachment welds shall be performed after heat treatment. This heat treatment may affect bellows pressure capacity, mechanical properties, and corrosion resistance. If the required heat treatment is determined to be detrimental to the bellows' performance, the bellows shall not be attached directly to the piping component. In that case, the piping component side of the weld joint shall be buttered in accordance with ASME BPVC, Section IX, QW-283 with appropriate filler metal, heat treated in accordance with Table 331.1.1, and then welded to the bellows.

**X302.2.2 Examination.** The following are minimum quality control requirements:

(a) Required examinations shall be in accordance with paras. 341 and 344.

(b) The longitudinal seam weld in the bellows tube shall be 100% examined prior to forming, either by radiography or, for material thickness  $\leq 2.4$  mm ( $\frac{3}{32}$  in.) welded in a single pass, by liquid penetrant examination of both inside and outside surfaces. For the purposes of this Appendix, either examination is acceptable for design with a factor  $E_f$  of 1.00 when used within the stated thickness limits.

(c) After forming, a liquid penetrant examination shall be conducted on all accessible surfaces of the weld, inside and outside. Welds attaching the bellows to the piping, etc., shall be 100% liquid penetrant examined.

(d) Acceptance criteria for radiography shall be in accordance with Table 341.3.2. Acceptance criteria for liquid penetrant examination shall be that cracks, undercutting, and incomplete penetration are not permitted.

#### X302.2.3 Leak Test

(a) Each expansion joint shall receive a hydrostatic, pneumatic, or combination hydrostatic-pneumatic shop pressure test by the manufacturer in accordance with para. 345, except that the test pressure shall be the lesser of that calculated by eq. (24) (para. 345.4.2) or eq. (X1), but not less than 1.5 times the design pressure.  $S_T/S$  in eq. (24) shall be based on the bellows material. When the bellows' design temperature is equal to or greater than  $T_{cr}$  as defined in Table 302.3.5, General Note (b),  $S_T/S$  in eq. (24) shall be replaced by  $S_{yT}/S_{yb}$ , where  $S_{yT}$  is the yield strength at the test temperature and  $S_{yb}$  is the yield strength at the bellows' design temperature. Yield strength values shall be determined in accordance with para. 302.3.2, with the bellows material treated as an unlisted material. The test pressure shall be maintained for not less than 10 min.

$$P_T = 1.5P_S E_t / E \quad (X1)$$

where

$E$  = modulus of elasticity at design temperature

$E_t$  = modulus of elasticity at test temperature

$P_S$  = limiting design pressure based on column instability (for convoluted U-shaped bellows, see 4.13.1 and 4.13.2 of the EJMA standards)

$P_T$  = minimum test gage pressure

(b) Expansion joints designed to resist the pressure thrust shall not be provided with any additional axial restraint during the leak test. Moment restraint simulating piping rigidity may be applied if necessary.

(c) In addition to examination for leaks and general structural integrity during the pressure test, the expansion joint shall be examined before, during, and after the test to confirm that no unacceptable squirm has occurred. Squirm shall be considered to have occurred if under the internal test pressure an initially symmetrical bellows deforms, resulting in lack of parallelism or uneven spacing of convolutions. Such deformation shall be considered unacceptable when the maximum ratio of bellows pitch under pressure to the pitch before applying pressure exceeds 1.15 for unreinforced bellows or 1.20 for reinforced bellows. Examination for leakage and deformation shall be performed at a pressure not less than two-thirds of the test pressure, after full test pressure has been applied.

(d) Examination for squirm shall be performed at full test pressure. For safety purposes, this may be accomplished by remote viewing (e.g., by optical magnification or video recording) of the changes in convolution spacing with respect to a temporarily mounted dimensional

reference. Examination for leakage shall be performed at a pressure not less than two-thirds of test pressure, after application of full test pressure. For a pneumatic test, the precautions of [para. 345.5.1](#) shall be observed.

## APPENDIX Z

### PREPARATION OF TECHNICAL INQUIRIES

#### Z300 INTRODUCTION

The ASME B31 Committee, Code for Pressure Piping, will consider written requests for interpretations and revisions of the Code rules, and develop new rules if dictated by technological development. The Committee's activities in this regard are limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. As a matter of published policy, ASME does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity, and, accordingly, inquiries requesting such consideration will be returned. Moreover, ASME does not act as a consultant on specific engineering problems or on the general application or understanding of the Code rules. If, based on the inquiry information submitted, it is the opinion of the Committee that the inquirer should seek professional assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

An inquiry that does not provide the information needed for the Committee's full understanding will be returned.

The Introduction states that "it is the owner's responsibility to select the Code Section" for a piping installation. An inquiry requesting a Code Section recommendation from the Committee will be returned.

#### Z301 PREVIOUS INTERPRETATIONS

Previously issued interpretations are available at <http://go.asme.org/interpretations>. The user is encouraged to use this feature to review previously published interpretations for additional understanding of the Code prior to submitting an inquiry. While this approach is timelier than submitting new inquiries, it should be used with caution because published interpretations are usually not updated based on subsequent Code revisions.

#### Z302 REQUIREMENTS

Inquiries shall be limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. Inquiries shall meet the following requirements:

(a) *Scope.* Involve a single rule or closely related rules in the scope of the Code. An inquiry letter concerning unrelated subjects will be returned.

(b) *Background.* State the purpose of the inquiry, which may be either to obtain an interpretation of Code rules, or to propose consideration of a revision to the present rules. Provide concisely the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Edition, Addenda, paragraphs, figures, and tables. If sketches are provided, they shall be limited to the scope of the inquiry.

(c) *Inquiry Structure*

(1) *Proposed Question(s).* The inquiry shall be stated in a condensed and precise question format, omitting superfluous background information, and, where appropriate, composed in such a way that "yes" or "no" (perhaps with provisos) would be an acceptable reply. The inquiry statement should be technically and editorially correct.

(2) *Proposed Reply(ies).* Provide a proposed reply stating what it is believed that the Code requires.

If in the inquirer's opinion, a revision to the Code is needed, recommended wording shall be provided in addition to information justifying the change.

#### Z303 SUBMITTAL

Inquiries should be submitted through the online Interpretation Submittal Form. The form is accessible at <http://go.asme.org/InterpretationRequest>.

Inquiries submitted by e-mail or by hard copy in type-written or legible handwritten form will be considered. The e-mail and hard-copy submittals shall include the name and mailing address of the inquirer, and be sent to the following addresses, as applicable:

Secretary  
ASME B31 Committee  
Two Park Avenue  
New York, NY 10016-5990  
E-mail: [MohamedR@asme.org](mailto:MohamedR@asme.org)



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## NOTES FOR INDEX

### GENERAL NOTES:

- (a) Reference is not made to a paragraph that merely states that a previous paragraph applies.  
 (b) To locate references with letter prefix, refer to the table below.

| <b>Prefix</b> | <b>Location</b> | <b>Prefix</b> | <b>Location</b>    | <b>Prefix</b> | <b>Location</b> |
|---------------|-----------------|---------------|--------------------|---------------|-----------------|
| A*            | Chapter VII     | FU            | App. F             | U             | Chapter X       |
| B             | App. B          | G             | App. G             | UM            | Chapter X       |
| C             | App. C          | K             | Chapter IX, App. K | V             | App. V          |
| D             | App. D          | M             | Chapter VIII       | X             | App. X          |
| F             | App. F          | MA            | Chapter VIII       |               |                 |
| FA            | App. F          | N             | App. N             |               |                 |

\* For [Tables A-1, A-1M, A-1A, A-1B, A-2, and A-2M](#), see [Appendix A](#).

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# ASME CODE FOR PRESSURE PIPING, B31

|                   |                                                                                                                                                       |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| B31.1-2020        | Power Piping                                                                                                                                          |
| B31.3-2020        | Process Piping                                                                                                                                        |
| B31.3-2010        | Tuberías de Proceso                                                                                                                                   |
| B31.4-2019        | Pipeline Transportation Systems for Liquids and Slurries                                                                                              |
| B31.5-2019        | Refrigeration Piping and Heat Transfer Components                                                                                                     |
| B31.8-2020        | Gas Transmission and Distribution Piping Systems                                                                                                      |
| B31.8S-2020       | Managing System Integrity of Gas Pipelines                                                                                                            |
| B31.8S-2010       | Gestión de Integridad de Sistemas de Gasoductos                                                                                                       |
| B31.9-2020        | Building Services Piping                                                                                                                              |
| B31.12-2019       | Hydrogen Piping and Pipelines                                                                                                                         |
| B31E-2008         | Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems                                                                           |
| B31G-2012         | Manual for Determining the Remaining Strength of Corroded Pipelines: Supplement to ASME B31 Code for Pressure Piping                                  |
| B31G-2012         | Manual para la determinación de la resistencia remanente de tuberías corroídas                                                                        |
| B31J-2017         | Stress Intensification Factors ( <i>i</i> -Factors), Flexibility Factors ( <i>k</i> -Factors), and Their Determination for Metallic Piping Components |
| B31J-2008 (R2013) | Método de prueba estándar para determinar factores de intensificación de esfuerzo (Factores <i>i</i> ) para componentes de tuberías metálicas         |
| B31P-2017         | Standard Heat Treatments for Fabrication Processes                                                                                                    |
| B31Q-2021         | Pipeline Personnel Qualification                                                                                                                      |
| B31Q-2010         | Calificación del personal de líneas de tuberías                                                                                                       |
| B31T-2018         | Standard Toughness Requirements for Piping                                                                                                            |

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