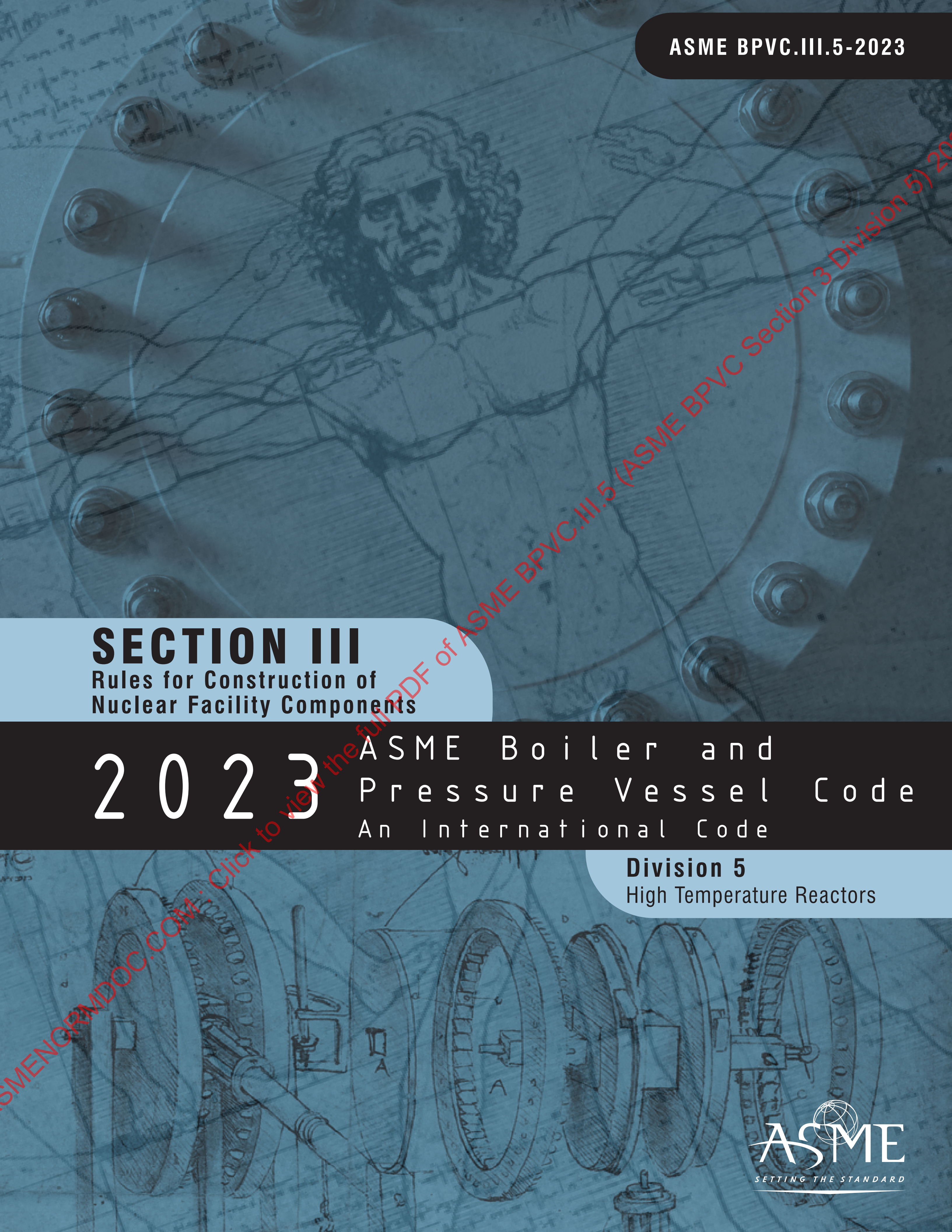

ASME BPVC.III.5-2023

SECTION III

Rules for Construction of Nuclear Facility Components

2023 ASME Boiler and Pressure Vessel Code

An International Code

Division 5

High Temperature Reactors

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AN INTERNATIONAL CODE

2023 ASME Boiler & Pressure Vessel Code

2023 Edition

July 1, 2023

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 5

High Temperature Reactors

ASME Boiler and Pressure Vessel Committee
on Construction of Nuclear Facility Components

The American Society of
Mechanical Engineers

Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2023

This international code or standard was developed under procedures accredited as meeting the criteria for American National Standards and it is an American National Standard. The standards committee that approved the code or standard was balanced to ensure that individuals from competent and concerned interests had an opportunity to participate. The proposed code or standard was made available for public review and comment, which provided an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

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The endnotes and preamble in this document (if any) are part of this American National Standard.

ASME Collective Membership Mark

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The American Society of Mechanical Engineers
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FOREWORD[*]

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)
(b) Committee on Materials (II)
(c) Committee on Construction of Nuclear Facility Components (III)
(d) Committee on Heating Boilers (IV)
(e) Committee on Nondestructive Examination (V)
(f) Committee on Pressure Vessels (VIII)
(g) Committee on Welding, Brazing, and Fusing (IX)
(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
(i) Committee on Nuclear Inservice Inspection (XI)
(j) Committee on Transport Tanks (XII)
(k) Committee on Overpressure Protection (XIII)
(l) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating to pressure integrity, which govern the construction[**] of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity and, for nuclear items other than pressure-retaining components, structural integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of components addressed by the Code. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code

[*] The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

[**] *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in this Section, the singular shall be interpreted as the plural, and vice versa, and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

The words "shall," "should," and "may" are used in this Standard as follows:

– *Shall* is used to denote a requirement.
– *Should* is used to denote a recommendation.
– *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the ASME Single Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the ASME Single Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code." An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the ASME Single Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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(23)

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CORRESPONDENCE WITH THE COMMITTEE (23)

General

ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at https://go.asme.org/CSCommittees.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive e-mail notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number(s) to which the proposed case applies

(4) the edition(s) of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements. Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Interpretation Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic e-mail confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

ORGANIZATION OF SECTION III

(23)

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, Division 4, and Division 5. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, by the letter "W" for Division 3, by the letter "F" for Division 4, and by the letter "H" for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, 4, and 5.

- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NCD — Class 2 and Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
- Division 2 — Code for Concrete Containments
  - Subsection CC — Concrete Containments
- Division 3 — Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
  - Subsection WA — General Requirements for Division 3
  - Subsection WB — Class TC Transportation Containments
  - Subsection WC — Class SC Storage Containments
  - Subsection WD — Class ISS Internal Support Structures
- Division 4 — Fusion Energy Devices
  - Subsection FA — Fusion Energy Device Facilities
  - Subsection FB — Pressure Boundary Components
- Division 5 — High Temperature Reactors
  - Subsection HA — General Requirements
    - Subpart A — Metallic Materials
    - Subpart B — Graphite Materials
    - Subpart C — Composite Materials
  - Subsection HB — Class A Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HC — Class B Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HF — Class A and B Metallic Supports
    - Subpart A — Low Temperature Service
  - Subsection HG — Class SM Metallic Core Support Structures
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HH — Class SN Nonmetallic Core Components
    - Subpart A — Graphite Materials
    - Subpart B — Composite Materials

2 SUBSECTIONS

Subsections are divided into Articles, subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3 ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection, except NCA, in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping With Certification Mark, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4 SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5 SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6 PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7 SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8 SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

9 REFERENCES

References used within Section III generally fall into one of the following four categories:

(a) References to Other Portions of Section III. When a reference is made to another Article, subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to Article NB-3000 includes all material in Article NB-3000; reference to NB-3100 includes all material in subarticle NB-3100; reference to NB-3110 includes all paragraphs, NB-3111 through NB-3113.

(b) References to Other Sections. Other Sections referred to in Section III are the following:

(1) Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

(2) Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

(3) Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

(4) Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

(c) Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials (ASTM). At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E94 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by The American Society of Mechanical Engineers and approved by the American National Standards Institute.[*] When a product is to conform to such a standard, for example ASME B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NCA-7100-1, for example ASME B16.5-2003. Standards published by The American Society of Mechanical Engineers are available from ASME (https://www.asme.org/).

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-100, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NCA-7100-1, for example MSS SP-58-2009.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 NW 36 Street, No. 130, Miami, FL 33166. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-605. When documents so designated are referred to in Section III, for example API-605–1988, they are standards published by the American Petroleum Institute and are listed in Table NCA-7100-1.

(d) References to Appendices. Section III uses two types of appendices that are designated as either Section III Appendices or Subsection Appendices. Either of these appendices is further designated as either Mandatory or Nonmandatory for use. Mandatory Appendices are referred to in the Section III rules and contain requirements that must be followed in construction. Nonmandatory Appendices provide additional information or guidance when using Section III.

(1) Section III Appendices are contained in a separate book titled "Appendices." These appendices have the potential for multiple subsection applicability. Mandatory Appendices are designated by a Roman numeral followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as II-1500 or XIII-1210. Nonmandatory Appendices are designated by a capital letter followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as D-1200 or Y-1440.

(2) Subsection Appendices are specifically applicable to just one subsection and are contained within that subsection. Subsection-specific mandatory and nonmandatory appendices are numbered in the same manner as Section III Appendices, but with a subsection identifier (e.g., NF, NH, D2, etc.) preceding either the Roman numeral or the capital letter for a unique designation. For example, NF-II-1100 or NF-A-1200 would be part of a Subsection NF mandatory or nonmandatory appendix, respectively. For Subsection CC, D2-IV-1120 or D2-D-1330 would be part of a Subsection CC mandatory or nonmandatory appendix, respectively.

(3) It is the intent of this Section that the information provided in both Mandatory and Nonmandatory Appendices may be used to meet the rules of any Division or Subsection. In case of conflict between Appendix rules and Division/Subsection rules, the requirements contained in the Division/Subsection shall govern. Additional guidance on Appendix usage is provided in the front matter of Section III Appendices.

[*] The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(23)**, placed next to the affected area. In addition, gender pronouns have been eliminated throughout this Division.

Page	*Location*	*Change*
xxv	List of Sections	*(1)* Under Section III, Division 4 added *(2)* Title of Section XI and subtitle of Section XI, Division 2 revised *(3)* Information on interpretations and Code cases moved to "Correspondence With the Committee"
xxix	Personnel	Updated
li	Correspondence With the Committee	Added (replaces "Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees")
liii	Organization of Section III	In para. 1, Division 4 added
lx	Cross-Referencing in the ASME BPVC	Updated
4	HAA-3300	Added
5	Table HAA-7100-1	Revised
11	HAB-1110	Subparagraph (b) revised
38	Table HAB-7100-1	Edition year for ISO/IEC 17025 revised
42	HAB-9200	*(1)* Definition of *EDN* deleted *(2)* Definition of *fluence* revised
46	Article HBA-2000	Added
53	HBB-2600	Added
73	Table HBB-3225-2	Last entry and Note (2) revised
75	Table HBB-3225-4A	Added
76	Table HBB-3225-4B	Former Table HBB-3225-4 redesignated
103	Table HBB-I-14.1(a)	*(1)* For "$2^1/_4$Cr–1Mo," SA-234, entry under "Types, Grades, or Classes" revised *(2)* For 9Cr–1Mo–V, all entries under "Types, Grades, or Classes" revised *(3)* Notes (1) and (6)(c) revised
104	Table HBB-I-14.1(b)	For 9Cr–1Mo–V, entries under "Class" revised
144	Table HBB-I-14.10E-1	Revised in its entirety
151	Figure HBB-II-3000-1	Editorially revised
152	Figure HBB-II-3000-2	Editorially revised
153	Figure HBB-II-3000-3	Editorially revised
161	Figure HBB-II-3000-11	Editorially revised
163	Figure HBB-II-3000-13	Editorially revised
164	Figure HBB-II-3000-14	Editorially revised

Page	Location	Change
177	HBB-T-1410	*(1)* In HBB-T-1411, definition of $(n)_j$ revised *(2)* In HBB-T-1413, first paragraph and Step 2 revised *(3)* In HBB-T-1414, Step 4 revised
180	HBB-T-1420	In subpara. (a), paragraph added below equation
188	Figure HBB-T-1420-1E	*(1)* In Note (2), third equation, variables to the left of the equal sign corrected by errata to N_{2S} *(2)* In Note (2) nomenclature, N_{S2} corrected by errata to N_{2S}
205	Table HBB-T-1820-1	*(1)* In second column head, "Maximum" corrected by errata to "Minimum" *(2)* Under "Maximum Time," last entry revised
205	HBB-T-1831	In subpara. (c), nomenclature corrected by errata
226	HBB-T-1832	In subpara. (c), nomenclature corrected by errata
228	Table HBB-T-1832-3	Under D, second entry "-4.499×10^{-17}" corrected by errata to "-4.499×10^{17}"
236	Figure HBB-T-1832-6	Revised
263	HBB-T-1834	*(1)* In subpara. (c), equation for ε_3, p_1 corrected by errata to p_2 *(2)* In subpara. (c), equation for a, operators corrected by errata
277	HBB-T-1835	In subpara. (c), TT corrected by errata to T in definition of Q_0
278	Table HBB-T-1835-2	Under Y, nineth entry, "410" corrected by errata to "376"
279	Figure HBB-T-1835-1	Revised
280	Figure HBB-T-1835-2	Revised
281	Figure HBB-T-1835-3	Revised
282	Figure HBB-T-1835-4	Revised
283	Figure HBB-T-1835-5	Revised
284	Figure HBB-T-1835-6	Revised
285	Figure HBB-T-1835-7	Revised
286	Figure HBB-T-1835-8	Revised
287	Figure HBB-T-1835-9	Revised
288	Figure HBB-T-1835-10	Revised
289	Figure HBB-T-1835-11	Revised
299	Nonmandatory Appendix HBB-Z	Added
363	HGB-2121	In subpara. (a), cross-reference to Section II, Part D tables corrected by errata
367	HGB-3213	Endnote 40 revised
372	Table HGB-3217-1	Note (6) revised
389	Article HGB-I-1000	Subparagraph (d) revised
391	HGB-II-2121	In subpara. (a), cross-reference to Section II, Part D tables corrected by errata
401	HGB-II-3220	Revised

Page	Location	Change
402	HGB-II-3222.4	*(1)* Endnote 46 revised *(2)* Cross-references to Subsection NG replaced by cross-references to Section III Appendices
404	HGB-II-3224	Revised
404	HGB-II-3224.1	Subparagraphs (a)(1), (a)(2), (b)(1), (b)(2), (b)(3), and (d) revised
405	HGB-II-3228.3	Revised
405	HGB-II-3229	First paragraph revised
405	HGB-II-3231	Subparagraph (b) revised
431	HHA-2230	First paragraph revised
434	HHA-3130	Revised
435	HHA-3140	Revised
435	HHA-3141	*(1)* Revised *(2)* Figure HHA-3141-1 moved to Article HHA-B-3000 and redesignated *(3)* Figure HHA-3141-2 deleted
436	HHA-3142	HHA-3142.1 and HHA-3142.2 revised
439	HHA-3215.2	Last line revised
439	HHA-3217	Subparagraphs (g)(2) and (g)(3) revised
444	HHA-3237	Revised
448	HHA-4110	Revised
449	HHA-4231	Revised
450	HHA-4241	Revised
450	HHA-4243	First line revised
450	HHA-4250	First paragraph revised
452	HHA-5110	Revised
452	HHA-5210	Subparagraph (f) revised
453	HHA-5400	Revised
453	HHA-5500	First paragraph revised
457	Article HHA-II-2000	*(1)* First paragraph revised *(2)* Forms MDS-1 and MDS-2 and Table HHA-II-2000-1 revised
462	Article HHA-II-3000	Revised in its entirety
470	HHA-III-3200	Revised
478	Article HHA-B-3000	Revised in its entirety
485	HHB-2111	In second paragraph, last line revised
486	HHB-2130	*(1)* Subparagraph (b) revised *(2)* Subparagraphs (c) and (d) added
486	HHB-2131	Subparagraphs (b) and (c) revised
487	HHB-2220	Subparagraph (c) revised
491	HHB-3130	Definition of R_{tc} deleted

Page	Location	Change
491	HHB-3142.1	Revised
494	HHB-3215.2	Last line revised
494	HHB-3220	Third paragraph revised
494	HHB-3221	Revised
495	Figure HHB-3221-1	Revised
496	HHB-3226.1	Revised
496	HHB-3227	Title and first line revised
499	HHB-4310	First paragraph revised
500	HHB-4360	Revised
502	HHB-5310	Revised
504	HHB-6200	Revised
506	HHB-I-1111	Subparagraph (d) revised
508	Table HHB-I-1120-1	Items (13), (14), and (23) revised
512	Form MDS-3	On seventh page of form, entries below "Design Strength and Material Reliability Curve Values" revised
527	Form MDS-4	On seventh page of form, entries below "Design Strength and Material Reliability Curve Values" revised
542	Table HHB-II-2000-1	*(1)* Items (13), (14), and (23) revised *(2)* Item (27) deleted
545	HHB-II-3100	First sentence revised
545	HHB-II-3200	Third paragraph revised
546	HHB-II-3400	In eq. (4), "$= -m \cdot \ln(x) + m \cdot \ln(S_c)$" corrected by errata to "$= m \cdot \ln(x) - m \cdot \ln(S_c)$"
548	HHB-II-3600	In subpara. (a), first sentence revised
561	HHB-B-1200	Definition of *ceramic matrix composite (CMC)* revised
576	HHB-C-1100	Third sentence revised
579	HHB-C-1320	Fifth paragraph revised
587	Nonmandatory Appendix HBB-D	Added
594	Nonmandatory Appendix HHB-E	Added

(23)

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

SUBSECTION HA
GENERAL REQUIREMENTS

SUBPART A
METALLIC MATERIALS

ARTICLE HAA-1000
INTRODUCTION

HAA-1100 GENERAL

HAA-1110 SCOPE

The rules of this Subsection HA, Subpart A constitute the general requirements associated with metallic components used in the construction of high temperature reactor systems and their supporting systems.

(a) The rules of Subsection HA, Subpart A are contained in Divisions 1 and 2, Subsection NCA, except for those paragraphs or subparagraphs (with numbered headers) replaced by corresponding numbered HAA paragraphs or subparagraphs in this Subpart or new numbered HAA paragraphs or subparagraphs added to this Subpart.

(b) Division 1 rules may use different terminology than Division 5 (e.g., Class 1 and Class 2 versus Class A and Class B, etc.) but the application and use of these rules is identical for Division 5 construction.

(c) Division 1, Class 1 requirements are applicable to Division 5 construction but shall be referred to as Division 5, Class A.

(d) Division 1, Class CS requirements are applicable to Division 5 construction but shall be referred to as Division 5, Class SM.

(e) Division 1, Class 2 requirements are applicable to Division 5 construction but shall be referred to as Division 5, Class B.

(f) Division 1, Class 3 and Class MC requirements are not applicable to Division 5 construction.

(g) References to Appendices are to the Section III Appendices, unless otherwise identified.

HAA-1120 DEFINITIONS

Definitions of key terms used in this Division for metallic components are included in Article HAA-9000. The definitions in Article HAA-9000 shall prevail should a conflict exist with definitions found in Division 1 or in other documents referenced in this Division. Unless defined in Article HAA-9000, the definitions of Divisions 1 and 2, Article NCA-9000 shall apply.

HAA-1130 LIMITS OF THESE RULES

(a) The rules of this Division for metallic materials provide requirements for new construction and include consideration of mechanical and thermal stresses due to cyclic operation and high temperature creep. They do not cover deterioration that may occur in service as a result of radiation effects, corrosion, erosion, thermal embrittlement, or instability of the material. These effects shall be taken into account with a view to realizing the design or the specified life of the components and supports. The changes in properties of materials subjected to neutron radiation may be checked periodically by means of material surveillance programs.

(b) The rules are not intended to be applicable to valve operators, controllers, position indicators, pump impellers, pump drivers, or other accessories and devices, unless they are pressure-retaining parts or act as core support structures or supports. If such items are in a support load path, the provisions of HFA-1100 apply.

(c) The rules of this Division do not apply to instruments, or permanently sealed fluid-filled tubing systems furnished with instruments, but do apply to instrument, control, and sampling piping when specified in Design Specifications.

(d) Excluding Subsections HF and HH and this Subsection HA, the Subsections of Division 5 consist of two subparts. Subpart A addresses the rules for low temperature service and Subpart B addresses the rules for elevated temperature service. Table HAA-1130-1 establishes the maximum temperature limits for the material under consideration at which the low temperature service rules shall be used. Elevated temperature service rules shall be used for temperatures above those listed in Table HAA-1130-1 (but limited to temperatures established in the applicable rules) for the material under consideration.

Table HAA-1130-1
Values of T_{max} for Various Classes of Permitted Materials

Materials	T_{max}, °F (°C)
Carbon steel	700 (370)
Low alloy steel	700 (370)
Martensitic stainless steel	700 (370)
Austenitic stainless steel	800 (425)
Nickel–chromium–iron	800 (425)
Nickel–copper	800 (425)

ARTICLE HAA-2000
CLASSIFICATION OF COMPONENTS AND SUPPORTS

HAA-2100

HAA-2120 PURPOSE OF CLASSIFYING ITEMS OF A NUCLEAR POWER PLANT

Construction rules are specified for items that are designated Class A, Class B, and Class SM. These Code classes are intended to be applied to the classification of items in high temperature reactor systems and their supporting systems.

Within these systems, this Division recognizes the different levels of importance associated with the function of each item as related to the safe operation of the nuclear power plant. The Code classes allow a choice of rules that provide assurance of structural integrity and quality commensurate with the relative importance assigned to the individual items of the nuclear power plant.

HAA-2130 CLASSIFICATIONS AND RULES OF DIVISION 5

HAA-2131 Code Classes and Rules of Division 5

(a) Division 5 provides rules for the construction of items in the following Code Classes:

(1) Class A — items constructed in accordance with the rules of Subsection HB.

(2) Class B — items constructed in accordance with the rules of Subsection HC.

(3) Class SM — metallic core support structures constructed in accordance with the rules of Subsection HG.

(b) Division 5 also provides rules for

(1) supports for Class A and Class B items, constructed in accordance with the rules of Subsection HF

(2) internal structures constructed in accordance with the rules of Subsection HG.

HAA-2133 Multiple Code Class Components

(a) Compartments in components consisting of multiple compartments such as heat exchangers may be assigned different Code classes, provided any interactions between compartments produced by operating conditions are taken into account and these conditions are specified in the Design Specifications.

(b) Supports for multiple Code class components shall be constructed in accordance with the rules of Subsection HF for the more restrictive Code class.

HAA-2134 Optional Use of Code Classes

(a) As an alternative to the rules of Subsection HC, a component designated as Class B may use the rules of Subsection HB for construction, but all of the applicable requirements of Subsection HB (i.e., all applicable Articles) shall be used.

(b) When (a) above is used, requirements from Subsection HC shall not be used, with the exception that the component remain designated and stamped as a Class B component.

(c) When (a) and (b) above are used, the Design Specification and Data Report Form shall identify the use of this paragraph.

ARTICLE HAA-3000 RESPONSIBILITIES AND DUTIES

HAA-3100

HAA-3120 CERTIFICATION

HAA-3121 Types of Certificates

Table HAA-8110-1 lists the types of certificates issued by the Society and indicates the responsibilities assumed by each Certificate Holder. Further details of these responsibilities are contained in this Article.

HAA-3200

HAA-3250 PROVISION OF DESIGN SPECIFICATIONS

HAA-3252 Contents of Design Specifications

(a) The Design Specifications shall contain sufficient detail to provide a complete basis for Division 5 construction. Such requirements shall not result in construction that fails to conform with the rules of this Division. All Design Specifications shall include (1) through (8).

(1) the functions and boundaries of the items covered [NCA-3211.19(c)]

(2) the design requirements (HAA-2100 and NCA-2140), including all required overpressure protection requirements (NCA-3211.21)

(3) the environmental conditions, including radiation (see Section III Appendices, Nonmandatory Appendix W for further insights and guidance)

(4) the Code classification of the items covered (Article HAA-2000)

(5) material requirements, including impact test requirements

(6) additional fracture mechanics data for base metal, weld metal, and heat-affected zone required to use Section III Appendices, Nonmandatory Appendix G, Figure G-2210-1 in accordance with Section III Appendices, Nonmandatory Appendix G, G-2110(b), when the methods of Section III Appendices, Nonmandatory Appendix G are used to provide protection against nonductile fracture for materials that have specified minimum yield strengths greater than 50.0 ksi (345 MPa) but not exceeding 90.0 ksi (620 MPa) at room temperature; where these materials of higher yield strengths are to be used in conditions where radiation may affect the material properties, the effect of radiation on the K_{Ic} curve shall be determined for the material prior to its use in construction

(7) when functionality of a component is a requirement, the Design Specification shall make reference to other appropriate documents that specify those operating requirements

(8) the effective Code Edition and Code Cases to be used for construction

Section III Appendices, Nonmandatory Appendix KK provides additional guidance on what a Division 5 Design Specification should contain as well as additional insights.

(b) The Design Specification shall identify those components and/or parts that require a preservice examination and shall include the following:

(1) examination

(-a) Edition of Section XI to be used

(-b) category and method

(-c) qualifications of personnel, procedures, and equipment

(2) welds

(-a) surface conditioning requirements

(-b) identification/marking system to be used

HAA-3300 (23)

HAA-3310

HAA-3311

HAA-3311.3 Exclusions. Material falling within the exclusions of HBA-2610 or HBB-2610 and NCD/NF/NG-2610 or material that is allowed by this Section to be furnished with a Certificate of Compliance is exempted from the requirements of NCA-3300, except

(a) Certified Material Test Reports or Certificates of Compliance shall meet the requirements of NCA-1225.1

(b) for Class A construction only, material identification and marking shall meet the requirements of NCA-4256.3

ARTICLE HAA-7000 REFERENCE STANDARDS

HAA-7100 GENERAL REQUIREMENTS

The standards and specifications referenced in the text of this Division associated with metallic components are listed in Table HAA-7100-1, unless they are already listed in Divisions 1 and 2, Table NCA-7100-2. The standards and specifications associated with nonmetallic components are addressed in their respective Subparts of this Subsection HA. Where reference is made within Division 5 to requirements that are part of the ASME Boiler and Pressure Vessel Code, they are not included in this Table.

(23)

Table HAA-7100-1
Standards and Specifications Referenced in Division 5 Associated With Metallic Components

Standard ID	Published Title	Division 5 Referenced Edition
American Society for Testing and Materials (ASTM)		
ASTM E112	Standard Test Methods for Determining Average Grain Size	1996 (R2004)
ASTM E1049	Standard Practices for Cycle Counting in Fatigue Analysis	1985 (R2017)
American Petroleum Institute (API) and American Society of Mechanical Engineers (ASME)		
API 579–1/ASME FFS-1	Fitness-For-Service (FFS)	2021

ARTICLE HAA-8000 NAMEPLATES, STAMPING WITH THE CERTIFICATION MARK, AND REPORTS

HAA-8100 AUTHORIZATION TO PERFORM CODE ACTIVITIES

HAA-8110 GENERAL

The rules for certificates, nameplates, the Certification Mark, and Data Reports for metallic components, metallic supports, and metallic core support structures under Division 5 shall be the same as those established for Division 1 metallic components, metallic supports, and metallic core support structures. The only change shall be the use of Division 5 terminology rather than Division 1 (e.g., Class A and Class B rather than Class 1 and Class 2) terminology and the specification of the Division 5 Subpart used.

Authorization to use the official Certification Mark or to certify work by other means provided in this Subsection HA, Subpart A (see Table HAA-8110-1) will be granted by the Society for a 3-yr period pursuant to the provisions set forth in this Article. Authorization to certify Owner's Data Report Forms, N-3 (see Section III Appendices, Mandatory Appendix V), will be granted pursuant to the provisions set forth in this Article.

HAA-8200 NAMEPLATES AND STAMPING WITH CERTIFICATION MARK

HAA-8210 GENERAL REQUIREMENTS

HAA-8211 HAA-8211 Nameplates

Each item and installation to which a Certification Mark is applied shall have a nameplate except as otherwise permitted by this subarticle. Marking shall include the following:

(a) the applicable official Certification Mark as shown in Table HAA-8110-1

(b) class of construction and Designator

(c) the statement "Certified by"

(d) Certificate Holder's name

(e) Certificate Holder's serial number and, if applicable, National Board number and/or Canadian registration number

(f) for line valves, the ANSI pressure class rating

HAA-8300 CERTIFICATION MARK

HAA-8310 GENERAL REQUIREMENTS

(a) The Certification Mark shall be applied by the Certificate Holder only with authorization of the Inspector. In any case, the Certification Mark shall not be applied until completion of the required examination and testing.

(b) Table HAA-8110-1 provides Certification Mark requirements as related to type of certificates, scope of work, and class of construction. The class of construction shall be indicated by the applicable letters A, B, or SM stamped below and outside the official Certification Mark.

(c) The completed Code Data Report Form indicates that the Inspector has inspected the item and authorized the application of the Certification Mark. The sequence for stamping and the completion of the Code Data Report shall be determined by agreement between the Authorized Nuclear Inspector and the Certificate Holder.

HAA-8400 DATA REPORTS

HAA-8410 GENERAL REQUIREMENTS

The appropriate Data Report,[1] as specified in Table HAA-8110-1, shall be filled out by the Certificate Holder or Owner and shall be signed by the Certificate Holder or Owner and the Inspector for each item to be marked with a Certification Mark (except as provided for elsewhere in this Article).

Table HAA-8110-1
Certificates and Certification Mark Issued by the Society for Construction of High Temperature Reactor Metallic Components

Type of Organization	Scope	Division 5			Data Report Form	Notes
		Class A	Class B	Class SM		
N Certificate Holder	Vessel	ASME N A	ASME N B	None	N-1/N-1A	(9)
	Pump	ASME N A	ASME N B	None	NPV-1	(1)
	Line valve	ASME N A	ASME N B	None	NPV-1	(1), (6)
	Storage tank	None	ASME N B	None	N-6	...
	Piping systems	ASME N A	ASME N B	None	N-5	(1)
	Core support structures	None	None	ASME N SM	NCS-1	(2)
	Appurtenance (Design only)	None	None	None	N-2A	(12)
NV Certificate Holder	Pressure and vacuum relief valves	ASME NV A	ASME NV B	None	NV-1	(1), (11)

Table HAA-8110-1
Certificates and Certification Mark Issued by the Society for Construction of High Temperature Reactor Metallic Components (Cont'd)

Type of Organization	Scope	Division 5			Data Report Form	Notes
		Class A	Class B	Class SM		
NPT Certificate Holder	Tubular products welded with filler metal	NPT A	NPT B	None	NM-1	(1), (7)
	Part	NPT A	NPT B	None	N-2	(1), (4), (8), (9)
	Appurtenance	NPT A	NPT B	None	N-2A	(1), (4), (8), (9), (12)
	Piping subassembly	NPT A	NPT B	None	NPP-1	(1), (3), (9), (10)
NA Certificate Holder	All items	NA A	NA B	NA SM	N-5	(1), (9)
Quality System Certificate Holder	Material	None	None	None	None	(7), (9)
NS Certificate Holder	Supports	None	None	None	None	(5)
Owners	Owner	None	None	None	N-3	...

NOTES:
(1) Items shall be stamped Class A, B, or SM in accordance with the classification stated in the Design Specification.
(2) A Data Report shall be filled out on Form NCS-1 (Section III Appendices, Mandatory Appendix V) by the Certificate Holder assuming overall responsibility. If this Certificate Holder also performs the fabrication, the Form NCS-1 shall be completed by this Certificate Holder and shall be certified by the Inspector for the core support structure to be stamped with the Certification Mark with N Designator and no N-2 Form is required. When a Certificate Holder is responsible for fabrication only, the Form N-2 (for a part) or N-2A (for an appurtenance) (Section III Appendices, Mandatory Appendix V) shall be completed by that Certificate Holder and certified by the Inspector for core support structures, appurtenances, or parts that are to be stamped with the Certification Mark with NPT Designator.

Table HAA-8110-1
Certificates and Certification Mark Issued by the Society for Construction of High Temperature Reactor Metallic Components (Cont'd)

NOTES (CONT'D):

(3) Data Report Form NPP-1 (Section III Appendices, Mandatory Appendix V) shall be forwarded in duplicate to the N Certificate Holder taking overall responsibility for the piping system and the NA Certificate Holder installing the piping system.

(4) Data Report Form N-2 for parts or N-2A for appurtenances shall be forwarded in duplicate to the Certificate Holder of the finished component or support.

(5) Welded supports shall be documented on an NS-1 Certificate of Conformance and nonwelded supports shall be documented on a manufacturer's Certificate of Compliance. The certificate documentation shall be forwarded in duplicate to the Certificate Holder who performs the installation. A single Certificate of Conformance may be used for ten supports when each is of the same design and each is identified on the NS-1 Certificate of Conformance by serial number.

(6) A single Data Report may be used for each group of 25 line valves and pumps of the same size and design with inlet piping connection of 4-in. nominal pipe size and smaller if each part is identified on the Data Report by an individual serial number.

(7) Material (NCA-1220) shall be documented by a Certified Material Test Report or a Certificate of Compliance in accordance with Articles NB/NF/NG-2000, or the Class 2 Requirements of Article NCD-2000, as applicable, for low-temperature service and HBB/HCB/HGB-2000 for elevated-temperature service.

(8) A multiple number of parts or appurtenances for a single nuclear power plant may be included on the applicable Data Report (i.e., N-2 or N-2A) provided that the parts or appurtenances are of the same class, size, and design and that the parts or appurtenances are manufactured for the same N Certificate Holder and authorized by the Inspector for stamping on the same day. Each part or appurtenance must be identified on the Data Report by an individual serial number.

(9) Miscellaneous items as described in NCA-1270 shall be stamped with the Certification Mark and listed on the appropriate Data Report Form when constructed as an "N" or "NPT" item or installed under an "NA" Certificate. An appropriate Certified Material Test Report or Certificate of Compliance is required in lieu of Data Reports and stamping for items furnished as material.

(10) A single Data Report may be used for each group of 25 braided flexible hose of the same nominal pipe size and design, provided each hose is identified on the Data Report by an individual serial number.

(11) The Data Report and nameplate, or marking information, shall be in conformance with NCA-8220 and HBA/NCD-7800 for low-temperature service or HBB/NCD-7800 for elevated-temperature service.

(12) An N Certificate Holder who designs an appurtenance that is fabricated by an NPT Certificate Holder is responsible for completing the design certification and design responsibility certification on the N-2A DataReport. The NPT Certificate Holder who fabricates the appurtenance is responsible for completing the fabrication certification on the N-2A Data Report. When an NPT Certificate Holder designs and fabricates an appurtenance, the NPT Certificate Holder is responsible for completing the fabrication certification, the design certification, and the design responsibility certification on the N-2A Data Report.

ARTICLE HAA-9000
GLOSSARY

HAA-9100 INTRODUCTION

This Article defines selected terms used in this Division for metallic pressure boundary components and metallic core support structures. The definitions in this Glossary shall prevail should a conflict exist with definitions found elsewhere in Division 1 or other documents referenced in this Division. Unless defined below, the definitions of Divisions 1 and 2, Article NCA-9000 shall apply.

HAA-9200 DEFINITIONS

elevated temperature service: service where the component(s) or core support structure(s), during normal, upset, emergency, or faulted operating conditions, experience temperatures in excess of those established in Table HAA-1130-1 for the material under consideration.

functionality: the ability of a Division 5 component to perform its specified function, including mechanical motion if appropriate, when subjected to its intended prescribed service, considering all Design and Service Loadings.

low temperature service: service where the component(s), support(s), or core support structure(s), during normal, upset, emergency, or faulted operating conditions do not experience temperatures that exceed those established in Table HAA-1130-1 for the material under consideration.

negligible creep: an amount of creep resulting from elevated temperature service of such minimal value as to be easily recognized as not resulting in the loss of functionality of the component over the design lifetime and that the specific determination of the magnitude of creep would not be necessary since the limits established by Division 5 for creep would not be exceeded.

zone of elevated temperature service: a portion of a component, subassembly, or piping subassembly (e.g., a vessel nozzle) that experiences elevated temperature service. A zone of elevated temperature service can also include an entire component, subassembly, or piping subassembly if applicable.

SUBPART B
GRAPHITE AND COMPOSITE MATERIALS

ARTICLE HAB-1000
INTRODUCTION

HAB-1100 GENERAL

(23) HAB-1110 SCOPE

The rules of this Subpart and Subsection HH constitute requirements for the design, construction, examination, and testing of Core Components and Core Assemblies used within the reactor pressure vessels of nuclear power plants.

(a) This Subpart contains General Requirement Articles HAB-1000 through HAB-9000.

(b) Subsection HH contains Technical Rules for Design and Construction of Nonmetallic Core Components and Core Assemblies. Subpart A, Graphite Materials, contains Articles HHA-1000 through HHA-5000, including Mandatory Appendix HHA-I, Mandatory Appendix HHA-II, Mandatory Appendix HHA-III, and Nonmandatory Appendix HHA-A. Subpart B, Composite Materials, contains Articles HHB-1000 through HHB-6000 and HHB-8000, including Mandatory Appendices HHB-I, HHB-II, and HHB-III and Nonmandatory Appendices HHB-A, HHB-B, HHB-C, HBB-D, and HHB-E.

HAB-1120 DEFINITIONS

Definitions of key terms used in this Subpart and Subsection HH are included in Article HAB-9000. Unless defined in Article HAB-9000, the definitions in Article NCA-9000 shall apply.

HAB-1130 LIMITS OF THESE RULES

The rules of this Subpart and Subsection HH provide requirements for new construction and include consideration of mechanical and thermal stresses due to cyclic operation. They include consideration of deterioration that may occur in service as a result of environmental considerations.

HAB-1140 USE OF CODE EDITIONS AND CASES

(a) See (1) and (2) below.

(1) Under the rules of this Division, the Owner or its designee shall establish the Code Edition to be included in the Design Specifications. All items of a nuclear power plant may be constructed to a single Code Edition, or each item may be constructed to individually specified Code Editions.

(2) In no case shall the Code Edition dates established in the Design Specifications be earlier than

(-a) 3 yr prior to the date that the nuclear power plant construction permit application is docketed; or

(-b) the latest Edition endorsed by the regulatory authority having jurisdiction at the plant site at the time the construction permit application is docketed; or

(-c) the Edition endorsed for a design certified or licensed by the regulatory authority.

(b) Except as permitted in (e) below for materials, Code Editions later than those established by (a) above may be used by mutual consent of the Owner or its designee, GC Certificate Holder, and the Designer. Specific provisions within an Edition later than those established in the Design Specifications may be used, provided that all related requirements are met.

(c) Code Cases are permissible and may be used beginning with the date of approval by the ASME Council. Only Code Cases that are specifically identified as being applicable to this Subpart; Subsection HH, Subpart A; or Subsection HH, Subpart B may be used.

(d) Code Cases may be used by mutual consent of the Owner or its designee, the GC Certificate Holder, and the Designer on or after the date permitted by (c) above.

(e) Materials produced and certified in accordance with Code Editions other than the one specified for construction of an item may be used, provided all of the following requirements are satisfied:

(1) The material (HAB-1220) meets the applicable requirements of a material specification permitted by HHA-2111 or HHB-2111.

(2) The material meets all the requirements of Article HHA-2000 or Article HHB-2000.

(3) The material was produced under the provisions of a Quality System Program that had been accepted by the Society or qualified by a party other than the Society

(HAB-3820), in accordance with the requirements of the latest Section III Edition issued at the time the material was produced.

(f) Code Editions [including the use of specific provisions of Editions permitted by (b) and (e) above] and Cases used shall be reviewed by the Owner or its designee for acceptability to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

(g) Except as otherwise permitted by this Code and stipulated in the Scope of a certificate, the latest Code Edition shall become mandatory for Quality System Program (HAB-3800 and HAB-4500) and Quality Assurance (Article HAB-4000) requirements 6 months after the date of issuance.

HAB-1150 UNITS OF MEASUREMENT

U.S. Customary units, SI, or any local customary units may be used to demonstrate compliance with all requirements of this edition (e.g., materials, design, manufacture, examination, inspection, testing, and certification).

In general, it is expected that a single system of units shall be used for all aspects of design except where unfeasible or impractical. When Core Components are manufactured at different locations where local customary units are different from those used for the general design, the local units may be used for the design and documentation of that Core Component. Similarly, for proprietary Core Components or those uniquely associated with a system of units different from that used for the general design, the alternate units may be used for the design and documentation of that Core Component.

For any single equation, all variables shall be expressed in a single system of units. When separate equations are provided for U.S. Customary and SI units, those equations must be executed using variables in the units associated with the specific equation. Data expressed in other units shall be converted to U.S. Customary or SI units for use in these equations. The result obtained from execution of these equations may be converted to other units.

Production, measurement and test equipment, drawings, and other fabrication documents may be in U.S. Customary, SI, or local customary units in accordance with the fabricator's practice. When values shown in calculations and analysis, fabrication documents, or measurement and test equipment are in different units, any conversions necessary for verification of Code compliance and to ensure that dimensional consistency is maintained shall be in accordance with the following:

(a) Conversion factors shall be accurate to at least four significant figures.

(b) The results of conversions of units shall be expressed to a minimum of three significant figures.

Conversion of units, using the precision specified above, shall be performed to ensure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in Section III, Appendices, Nonmandatory Appendix AA, Guidance for the Use of U.S. Customary and SI Units in the ASME Boiler and Pressure Vessel Code. Whenever local customary units are used, the manufacturer shall provide the source of the conversion factors that shall be subject to verification and acceptance by the Inspector.

Material that has been manufactured and certified to either the U.S. Customary or SI material specification may be used regardless of the unit system used in design.

All entries on a Data Report shall be in units consistent with the fabrication drawings for the Core Component using U.S. Customary, SI, or local customary units. It is acceptable to show alternate units parenthetically. Users of this Code are cautioned that the receiving Jurisdiction should be contacted to ensure the units are acceptable.

HAB-1200 GENERAL REQUIREMENTS FOR ITEMS AND INSTALLATION

HAB-1210 CORE ASSEMBLY

The Core Assembly shall require a Design Specification (HAB-3250), Design Report (HAB-3350), and other design documents specified in Article HAB-3000. Data Reports shall be as required in Article HAB-8000.

HAB-1220 MATERIALS

Materials shall be manufactured to the requirements of Article HHA-2000 or Article HHB-2000.

HAB-1280 INSTALLATION

HAB-1281 Activities and Requirements

The requirements pertaining to installation governing materials, machining, examination, testing, inspection, and reporting shall be in accordance with the applicable rules in Subsection HH, and certification shall be as required in Article HAB-8000.

HAB-1283 Services

Services such as handling, rigging, setting, temporary bolting, and temporary aligning may be performed by organizations that are not GC Certificate Holders as provided for in HAB-3125.

ARTICLE HAB-2000 CLASSIFICATION OF CORE COMPONENTS

HAB-2100 GENERAL REQUIREMENTS

HAB-2110 SCOPE

Rules for the design and construction of Core Components and Core Assemblies are provided in Subsection HH.

HAB-2130 CODE CLASSES AND RULES OF DIVISION 5

HAB-2131 Code Classes and Design Rules for Core Components

Division 5 provides rules for the construction of items in the following Code Classes:

(a) Items constructed in accordance with the rules of Subsection HH are assigned to Code Class SN in accordance with the rules of Division 5.

(b) Core Components shall be assigned to Structural Reliability Classes in the Design Specification (HHA-3111 or HHB-3111).

HAB-2140 DESIGN BASIS

HAB-2141 Consideration of Plant and System Operating and Test Conditions[2]

(a) Core Components of a nuclear power system (HAB-1110) may be subjected to plant and system operating and test conditions that are required to be considered in the design of the Core Components in order to satisfy applicable systems safety criteria. The significance of plant and system operating and test conditions upon design may vary from item to item within a system for a specific operating or test condition experienced by the plant or system. The temperatures, pressures, and mechanical loads to which Core Components are subjected in consequence of plant or system operating and test conditions are referred to in this Subpart and Subsection HH as Core Component Design or Service Loadings.

(b) The definition of plant and system operating and test conditions and the determination of their significance to the design and functionality of Core Components of a nuclear power system are beyond the scope of this Subpart and Subsection HH. Appropriate guidance for the selection of plant or system operating and test conditions, which may be determined to be of significance in the selection of Core Component Design and Service Loadings, the combinations thereof, and the corresponding acceptable limits, may be derived from systems safety criteria documents for specific types of nuclear power systems and may be found in the requirements of regulatory and enforcement authorities having jurisdiction at the site.

HAB-2142 Establishment of Design, Service, and Test Loadings and Limits

In the Design Specification, the Owner or its designee shall identify the loadings and combinations of loadings and establish the appropriate Design, Service, and Test Limits for each Core Component.

(a) Loadings. The Design and Service Loadings shall be identified considering all plant or system operating and test conditions anticipated or postulated to occur during the intended service life of the Core Assembly. There are no Test Loading requirements established for Core Assemblies or Core Components.

(b) Limits. The selection of Design and Service Limits for each Core Component shall be established in accordance with HAB-2142.4. The rules of this Subpart and Subsection HH do not ensure functionality of the Core Assembly. The selection of limits for Design and Service Loadings to ensure functionality is beyond the scope of this Subpart and Subsection HH, Subpart A and Subpart B. When assurance of functionality is required, it is the responsibility of the Owner to define the appropriate limiting parameters by referring to documents that specify the requirements for functionality.

HAB-2142.1 Design Loadings. Design Loadings for Core Components and Core Assemblies shall be as defined in Subsection HH.

HAB-2142.2 Service Loadings. When the Design Specification or Subsection HH, Subpart A or Subpart B requires computations to demonstrate compliance with specified Service Limits, the Design Specification shall provide information from which Service Loadings can be identified (pressure, temperature, mechanical loads, cycles, or transients). The Design Specification shall designate the appropriate Service Limit (HAB-2142.4) to be associated with each Service Loading or combination of Service Loadings.

HAB-2142.4 Design and Service Limits.

(a) Design Limits. The limits for Design Loadings shall meet the requirements of Subsection HH.

(b) Service Limits. The Design Specification may designate Service Limits as defined in (1) through (4) below.

(1) Level A Service Limits. Level A Service Limits are those sets of limits that must be satisfied for all Level A Service Loadings identified in the Design Specifications to which the Core Component may be subjected in the performance of its specified service function.

(2) Level B Service Limits. Level B Service Limits are those sets of limits that must be satisfied for all Level B Service Loadings identified in the Design Specifications for which these Service Limits are designated. The Core Component must withstand these loadings without damage requiring repair.

(3) Level C Service Limits. Level C Service Limits are those sets of limits that must be satisfied for all Level C Service Loadings identified in the Design Specifications for which these Service Limits are designated. These sets of limits permit large deformations in areas of structural discontinuity that may necessitate the removal of the Core Component from service for inspection or repair of damage to the Core Component. Therefore, the selection of this limit shall be reviewed by the Owner for compatibility with established system safety criteria (HAB-2141).

(4) Level D Service Limits. Level D Service Limits are those sets of limits that must be satisfied for all Level D Service Loadings identified in the Design Specifications for which these Service Limits are designated. These sets of limits permit gross general deformations with some consequential loss of dimensional stability and damage requiring repair, which may require removal of the Core Component from service. Therefore, the selection of this limit shall be reviewed by the Owner for compatibility with established system safety criteria (HAB-2141).

(c) Alternative Service Limits. Core Components may be alternatively designed using more restrictive Service Limits than specified in the Design Specification. For example, Level B Service Limits may be used where Level C Service Limits have been specified.

HAB-2143 Acceptance Criteria

(a) Core Components shall comply with the design rules established for the Design and Service Loadings identified in Subsection HH, Subpart A or Subpart B.

(b) It is the responsibility of the Owner to define acceptance criteria for the Service Level Loading for which acceptance criteria are not contained in this Subpart and Subsection HH, Subpart A or Subpart B.

(c) Design documentation shall be completed in accordance with the requirements of this Subpart and Subsection HH, Subpart A or Subpart B applicable to the Core Component.

ARTICLE HAB-3000
RESPONSIBILITIES AND DUTIES

HAB-3100 GENERAL

HAB-3110 RESPONSIBILITIES VERSUS LEGAL LIABILITIES

The various parties involved in the design and construction of Core Components and Core Assemblies have specific responsibilities for complying with these requirements. The responsibilities set forth herein relate only to Code compliance and are not to be construed as involving contractual or legal liabilities.

HAB-3120 CERTIFICATION

HAB-3121 Types of Certificates

Table HAB-8100-1 lists the types of certificates issued by the Society associated with Core Components and Core Assemblies and indicates the responsibilities assumed by each Certificate Holder. Further details of these responsibilities are contained in this Article.

HAB-3125 Subcontracted Services

(a) Services may be subcontracted that are both within and beyond the scope of this Subpart and Subsection HH. There are no requirements for the subcontracting of services beyond the scope of this Subpart and Subsection HH. Services covered by this Subpart and Subsection HH may be either of a type for which the Society issues certificates or of the type for which the Society does not issue certificates. Subcontracts for activities for which certificates are required shall be made only to Certificate Holders. A Certificate Holder may subcontract to another organization the surveying and auditing of its subcontractors and Material Organizations but must retain the responsibility for these activities and for the qualification of these subcontractors and Material Organizations.

(b) It is the right of the Designer to subcontract stress analysis or the complete design of all or a portion of a Core Assembly or the material testing for the generation of the Material Data Sheets. However, the Designer is responsible for the design of the Core Assembly and for the Design Output Documents.

(c) The Quality Assurance Manual shall describe the manner in which the Certificate Holder controls and accepts the responsibility for the subcontracted activities.

HAB-3126 Subcontracted Calibration Services

As an alternative to survey and audit of subcontracted calibration services, a GC Certificate Holder, a Material Organization, or an approved supplier may accept accreditation by accrediting bodies recognized by the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA), provided that the requirements of (a) through (d) are met.

(a) A documented review of the supplier's accreditation shall be performed and shall include verification that the

(1) accreditation is to ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories, from an accredited body recognized by the ILAC MRA

(2) published scope of accreditation for the calibration laboratory covers the needed measurement parameters, ranges, and uncertainties

(b) The procurement documents shall specify

(1) that the service must be provided in accordance with the accredited ISO/IEC 17025 program and scope of accreditation

(2) that the calibration certificate/report shall include identification of the laboratory equipment/standards used

(3) that the calibration certificate/report shall include as-found calibration data when calibrated items are found to be out-of-tolerance

(4) that the service supplier shall not subcontract the service to any other supplier

(5) that the GC Certificate Holder, Material Organization, or approved supplier must be notified of any condition that adversely impacts the laboratory's ability to maintain the scope of accreditation

(6) additional technical and quality requirements, as necessary, based on a review of the procured scope of services, including, but not limited to, tolerances, accuracies, ranges, and industry standards

(c) At receipt inspection, the GC Certificate Holder, Material Organization, or approved supplier shall be responsible for validating that the supplier's documentation certifies

(1) that the subcontracted calibration was performed in accordance with the supplier's ISO/IEC 17025 program and scope of accreditation

(2) conformance to the procurement document's requirements

(d) This activity shall be documented in the Material Organization's Quality System Manual, GC Certificate Holder's Quality Assurance Program, or approved supplier's quality program.

HAB-3127 Subcontracted Testing Services

As an alternative to survey and audit of suppliers of subcontracted services, a GC Certificate Holder, a Material Organization, or an approved supplier may accept accreditation by accrediting bodies recognized by the ILAC MRA, provided the requirements of (a) through (d) are met.

(a) A documented review of the supplier's accreditation shall be performed and shall include verification that the

(1) accreditation is to ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories, from an accredited body recognized by the ILAC MRA

(2) published scope of accreditation for the testing laboratory covers the needed testing services, including test methodology and tolerances/uncertainties

(b) The procurement documents shall specify

(1) that the service must be provided in accordance with the accredited ISO/IEC 17025 program and scope of accreditation

(2) that the service supplier shall not subcontract the service to any other supplier

(3) that the GC Certificate Holder, Material Organization, or approved supplier must be notified of any condition that adversely impacts the laboratory's ability to maintain the scope of accreditation

(4) additional technical and quality requirements, as necessary, based on a review of the procured scope of services, including, but not limited to, tolerances, accuracies, ranges, and industry standards

(c) At receipt inspection, the GC Certificate Holder, Material Organization, or approved supplier shall be responsible for validating that the supplier's documentation certifies

(1) that the subcontracted testing was performed in accordance with the supplier's ISO/IEC 17025 program and scope of accreditation

(2) conformance to the procurement document's requirements

(d) This activity shall be documented in the GC Certificate Holder's Quality Assurance Program, Material Organization's Quality System Program Manual, or approved supplier's quality program.

HAB-3200 OWNER'S RESPONSIBILITIES

HAB-3220 CATEGORIES OF THE OWNER'S RESPONSIBILITIES

The responsibilities of the Owner include the requirements of (a) through (r) below.

(a) obtaining an Owner's Certificate (HAB-3230)

(b) documenting a Quality Assurance Program (HAB-8140)

(c) obtaining a written agreement with an Authorized Inspection Agency (HAB-3230 and HAB-8130)

(d) certifying and filing Owner's Data Report (HAB-3280)

(e) establishing the Code Editions and Code Cases to be used in Design Specifications, and determining that they are acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site (HAB-1140)

(f) verifying through a review of the required documentation that the Code Editions and Code Cases used for completed Core Components and materials satisfy HAB-1140 and are acceptable to the regulatory and enforcement authorities

(g) classifying Core Components (HHA-3111 or HHB-3111)

(h) designating the Designer, Material Manufacturer, Core Component manufacturer, and Installer for design and construction and verifying through a review of the required documentation that the Designer has fulfilled its responsibilities for design and construction

(i) providing adequate structures, foundations, and auxiliary systems for the items covered by HAB-3240

(j) providing and correlating Design Specifications, including establishment of Core Component and Core Assembly boundaries (HAB-3252)

(k) certifying Design Specifications (HAB-3255)

(l) reviewing Design Reports (HAB-3260)

(m) reviewing and approving the Construction Specification, Design Drawings, and Construction Report (Table HAB-3255-1)

(n) making available to the Inspector the documents specified by this Subpart and Subsection HH and those requested by the Inspector to ensure compliance with Code requirements (HAB-5242)

(o) providing for the design and arrangement of Core Components to permit accessibility in accordance with Section XI

(p) designating the preservice inspection requirements

(q) designating records to be maintained and providing for their maintenance (HAB-3290)

(r) performing other duties as defined throughout this Subpart and Subsection HH

The activities necessary to provide compliance with responsibilities assigned to the Owner by (e) through (r) above may be performed on the Owner's behalf by a designee; however, the responsibility for compliance remains with the Owner.

HAB-3230 OWNER'S CERTIFICATE

The Owner, after receipt of notification from the regulatory authority that an application for a construction permit or combined license for a specific plant has been docketed, shall obtain an Owner's certificate from the Society for unit(s) docketed concurrently for each site prior to beginning field installation. The information to be supplied by the Owner when making applications is given in forms issued by the Society. A written agreement with an Authorized Inspection Agency (HAB-8130) is required prior to application.

HAB-3240 PROVISION OF ADEQUATE SUPPORTING STRUCTURES

It is the responsibility of the Owner to ensure that intervening elements, foundations, and building structures adequate to support the items covered by this Subpart and Subsection HH are provided and to ensure that jurisdictional boundary interfaces for Code items are defined and compatible. Loads imposed upon structures outside the scope of this Subpart and Subsection HH by items covered by this Subpart and Subsection HH shall be defined in the Design Specification.

HAB-3250 PROVISION OF DESIGN SPECIFICATIONS

HAB-3251 Provision and Correlation

It is the responsibility of the Owner to provide, or cause to be provided, Design Specifications for Core Components and Core Assemblies. The Owner, either directly or through its designee, shall be responsible for the proper correlation of all Design Specifications. The applicable data from Construction Specification and Design Drawings shall be provided in sufficient documented detail to form the basis for Core Component machining or finishing and installation in accordance with this Subpart and Subsection HH.

HAB-3252 Contents of Design Specifications[3]

(a) The Design Specifications shall contain sufficient detail to provide a complete basis for design in accordance with this Subpart and Subsection HH. Such requirements shall not result in a Core Assembly that fails to conform to the rules of this Subpart and Subsection HH. All Design Specifications shall include (1) through (11) below.

(1) the functions and boundaries of the items covered (HAB-3254)

(2) the design requirements for the Core Components and Core Assembly

(3) the environmental conditions, including radiation

(4) the Design class of the Core Components covered (HAB-2130)

(5) material requirements

(6) when functionality of a component is a requirement, the Design Specification shall make reference to other appropriate documents that specify the functional requirements

(7) the effective Code Edition and Code Cases to be used for design and construction

(8) design life

(9) corrosion effects

(10) construction surveillance required by the Designer

(11) loads from internal structures

(b) The Design Specification shall identify those components that require a preservice examination and shall include the following:

(1) Edition of Section XI to be used

(2) category and method

(3) qualifications of personnel, procedures, and equipment

HAB-3254 Boundaries of Jurisdiction

In order to define the boundaries of components with respect to adjacent components, intervening elements, and other structures, the Design Specifications shall include

(a) the locations of each such boundary

(b) the forces, moments, strains, or displacements that are imposed at each such boundary

(c) the structural characteristics of the attached components or structures, whether or not they are within this Subpart's and Subsection HH, Subpart A's and Subpart B's jurisdiction when such components or structures provide constraints to the movement of components.

HAB-3255 Certification of the Design Specifications

The Design Specifications shall be certified to be correct and complete and to be in compliance with the requirements of HAB-3250 by one or more Certifying Engineers on behalf of the Owner or its designee. The Certifying Engineers shall be competent in the applicable field of design and related nuclear power plant requirements and qualified by the Owner or its designee in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII. These Certifying Engineers are not required to be independent of the organization preparing the Design Specifications. Document distribution for design and construction is shown in Table HAB-3255-1.

HAB-3256 Filing of Design Specifications

The Design Specifications in their entirety shall become a principal document governing design and construction of items. A copy of the Design Specification(s) shall be made available to the Inspector at the manufacturing site before construction begins, and a copy shall be filed at the location of the installation and made available to the enforcement authorities having jurisdiction over the plant installation before the Core Assembly is placed into service. Document distribution for construction is shown in Table HAB-3255-1.

HAB-3260 REVIEW OF DESIGN REPORT

(a) The Design Report that the Designer provides shall be reviewed by the Owner or its designee to determine that all the Design and Service Loadings as stated in the Design Specification have been evaluated, and that the acceptance criteria explicitly provided for in this Subpart and Subsection HH, or additional acceptance criteria permitted by this Subpart and Subsection HH, when established in the Design Specification, associated with the specified Design and Service Loadings, have been considered. The responsibility for the method of analysis and the accuracy of the Design Report remains with the Designer.

(b) Documentation shall be provided by the Owner or its designee to indicate that the review required by (a) above has been conducted. Prior to the certification of the component, a copy of this documentation shall be attached to the copy of the Design Report that is made available to the Inspector. A copy of this documentation shall be included with the Design Report, which is filed at the location of the installation in accordance with HAB-4134.17 and made available to the regulatory and enforcement authorities having jurisdiction at the site of the nuclear power plant installation. Document distribution for design and construction is shown in Table HAB-3255-1.

HAB-3280 OWNER'S DATA REPORT AND FILING

The Owner or its designee shall prepare the Form N-3 (Section III Appendices, Mandatory Appendix V).

HAB-3290 OWNER'S RESPONSIBILITY FOR RECORDS

The Owner shall be responsible for designating the records to be maintained (HAB-4134.17). The Owner shall also be responsible for continued maintenance of the records required by this Subpart, Subsection HH, and Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, at the power plant site, the GC Certificate Holder's facility, or other locations determined by the Owner. The Owner shall advise the enforcement authority in writing regarding the location of the records.

HAB-3300 RESPONSIBILITIES OF A DESIGNER

HAB-3320 CATEGORIES OF THE DESIGNER'S RESPONSIBILITY

The Designer has the following categories of responsibility:

(a) obtain a G Certificate (HAB-3330)

(b) prepare the structural design of the components and assemblies in conformance with this Subpart and Subsection HH, Subpart A or Subpart B and the Design Specification (HAB-3250)

(c) prepare the Design Drawings and Construction Specification (HAB-3340)

(d) prepare and submit the Design Report (HAB-3352)

(e) conduct surveillance of construction to the extent designated by the Owner in the Design Specification (HAB-3220)

(f) review construction documents (HAB-3450) as specified in the Construction Specification

(g) establish and maintain a Quality Assurance Program (HAB-3460)

(h) modify Design Drawings and the Construction Specification (HAB-3370)

(i) certify the Construction Report (HAB-3380)

(j) distribute documents as shown in Table HAB-3255-1

(k) generate the Material Data Sheets (HAB-3353)

HAB-3330 OBTAINING A CERTIFICATE

A G Certificate (HAB-8100) shall be obtained for the design of any Core Components intended to be in compliance with the requirements of this Subpart and Subsection HH, Subpart A or Subpart B.

HAB-3340 DESIGN DRAWINGS AND CONSTRUCTION SPECIFICATION

HAB-3341 Design Drawings

The Design Drawings shall contain all details necessary to construct the item in accordance with the requirements of the Design Specification, the Construction Specification, and this Subpart and Subsection HH, Subpart A or Subpart B.

HAB-3342 Construction Specification

The Construction Specification shall contain the following:

(a) material specifications

(b) material shipping, handling, and storage requirements

(c) inspection requirements

(d) appropriate Code references

(e) requirements for personnel or equipment qualification

(f) material or Core Component examination and testing requirements

(g) acceptance testing requirements

(h) requirements for shop and field drawings

(i) identification of Core Components

(j) construction surveillance to be performed by the Designer as required by the Design Specification

(k) construction documents that require review by the Designer and those that require both review and approval by the Designer will include the requirements of Table HAB-3255-1 as a minimum

HAB-3350 REQUIREMENTS FOR DESIGN OUTPUT DOCUMENTS

HAB-3351 General

The drawings used for construction shall comply with the Design Specifications and the rules of this Subpart and Subsection HH, Subpart A or Subpart B and shall be in agreement with the other Design Output Documents.

HAB-3352 Design Report[4]

(a) The Designer shall prepare a Design Report in sufficient detail to show that the applicable stress or Probability of Failure limits are satisfied when the component is subject to the loading conditions specified in the Design Specification, this Subpart, and Subsection HH, Subpart A or Subpart B. The Design Report prepared by the Designer shall contain calculations and sketches substantiating that the design is in accordance with the Design Specification, this Subpart, and Subsection HH, Subpart A or Subpart B.

(b) The drawings used for construction shall be in agreement with the Design Report before it is certified and shall be identified and described in the Design Report. It is the responsibility of the Designer to furnish a Design Report for the Core Assembly. The Design Report shall be certified by a Certifying Engineer.

HAB-3353 Material Data Sheet[5]

The Designer shall complete the required testing and generate the Material Data Sheets as described in HHA-2200 or HHB-2200. The Designer shall certify the Material Data Sheets.

HAB-3354 Modification of Documents and Reconciliation With Design Report

Any modification of any document used for construction, from the corresponding document used for design analysis, shall be reconciled with the Design Report by the person or organization responsible for the design. A revision or addenda to the Design Report shall be prepared and (if required by HAB-3352) certified to indicate the basis on which this has been accomplished. All such revised documentation shall be filed with the completed Design Report.

HAB-3355 Submittal of Design Report for Owner Review

The Designer shall submit to the Owner or its designee a copy of the completed Design Report for all components for review and documentation of review to the extent required by HAB-3260.

HAB-3356 Availability of Design Report

The Designer shall provide the GC Certificate Holder with a copy of the completed Design Report and the drawings used for construction. These documents are to be available to the Inspector.

HAB-3360 CERTIFICATION OF THE CONSTRUCTION SPECIFICATION, DESIGN DRAWINGS, AND DESIGN REPORT

(a) The Construction Specification, Design Drawings, and Design Report shall be reviewed and certified to be correct and in accordance with the Design Specification, this Subpart, and Subsection HH, Subpart A or Subpart B by one or more Certifying Engineers competent in the field of design of Core Components and Core Assemblies and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII. These Certifying Engineers are not required to be independent of the organization designing the component. Distribution of Construction Specification, Design Drawings, and the Design Report is shown in Table HAB-3255-1.

(b) For the Designer to certify the Construction Specification and Design Drawings, it is necessary that the Design Specification has been certified. For the GC Certificate Holder or Material Organization to do work in accordance with Construction Specifications and Design Drawings, it is necessary that these documents have been certified.

HAB-3370 REVISION OF DESIGN DRAWINGS AND CONSTRUCTION SPECIFICATION

Design Documents issued for use in construction shall be revised to reflect any change in the design. Changes to Design Output Documents shall be reviewed and certified in accordance with HAB-3350.

HAB-3380 CERTIFICATION OF CONSTRUCTION REPORT

The Construction Report shall be evaluated by the Designer, who shall certify that the Construction Report conforms to the requirements of this Subpart and Subsection HH, Subpart A or Subpart B and the Design Specification. The Designer shall also provide any supplemental analysis needed to substantiate this evaluation. Prior to certification, the Designer shall review the file of as-built, design, shop, and field drawings to establish that the list in the Construction Report provided by the GC Certificate Holder corresponds to the as-built, design, shop, and field drawings that will be maintained as a file by the Owner. Distribution of the Construction Report is shown in Table HAB-3255-1.

HAB-3400 RESPONSIBILITIES OF A GC CERTIFICATE HOLDER

HAB-3420 CATEGORIES OF THE GC CERTIFICATE HOLDER'S RESPONSIBILITIES

The GC Certificate Holder is responsible for

(a) obtaining a GC Certificate (HAB-3430).

(b) constructing the components and assembling the components in accordance with the Design Drawings and Construction Specification(s) and in accordance with this Subpart and Subsection HH, Subpart A or Subpart B.

(c) qualifying Material Organizations (HAB-3842).

(d) establishing and maintaining a Quality Assurance Program (HAB-3460).

(e) documenting a Quality Assurance Program (HAB-3462).

(f) filing the Quality Assurance Manual (HAB-3463).

(g) preparing construction procedures (HAB-3451).

(h) preparing shop and field drawings (HAB-3452).

(i) preparing the Construction Report (HAB-3454).

(j) obtaining agreement with an Authorized Inspection Agency (HAB-8130).

(k) completing Data Reports (HAB-3455).

(l) distributing documents as shown in Table HAB-3255-1.

(m) conducting mechanical testing of Core Components (HHA-4200 or HHB-4200).

(n) making available to the Inspector the documents specified by this Subpart and Subsection HH and those requested by the Inspector to ensure compliance with Code requirements.

(o) reviewing Certified Material Test Reports for materials (HAB-1220) used by it.

(p) preparing, accumulating, controlling, and protecting required records while in its custody (HAB-4134.17).

(q) documenting review and approval of material used by it as permitted by HAB-1140(e).

(r) subcontracting (HAB-3125) for materials manufacture, design, component machining, installation, examination, testing, and inspection. The GC Certificate Holder shall retain overall responsibility, including certification.

HAB-3430 OBTAINING A CERTIFICATE

A GC Certificate (HAB-8100) shall be obtained for the construction of any Core Components or Core Assemblies intended to be in compliance with the requirements of this Subpart and Subsection HH.

HAB-3440 COMPLIANCE WITH THIS SUBPART AND SUBSECTION HH

The GC Certificate Holder has the responsibility for the construction of the Core Components or Core Assemblies, in accordance with the Design Drawings and Construction Specification and in accordance with this Subpart and Subsection HH.

HAB-3450 CONSTRUCTION DOCUMENTS

HAB-3451 Construction Procedures

Construction procedures shall provide sufficient detailed information about the methods of construction to enable those reviewing the procedures to determine whether the requirements of the Design Specification, the Construction Specification, and the Design Drawings will be satisfied. Construction procedures shall include test procedures to be performed by the GC Certificate Holder that are needed to establish conformance with the requirements of the documents listed in this Article. Distribution of procedures is shown in Table HAB-3255-1.

HAB-3452 Shop and Field Drawings

The GC Certificate Holder shall provide shop and field drawings. Distribution of shop and field drawings is shown in Table HAB-3255-1.

HAB-3453 Material Documentation

The GC Certificate Holder shall collect CMTRs to verify that materials comply with the requirements of this Subpart, Subsection HH, and the Construction Specification.

HAB-3454 Contents of the Construction Report

The GC Certificate Holder shall provide a Construction Report. The report shall include the following:

(a) a summary of construction progress showing key dates of major construction activities

(b) a complete and detailed record of all Core Component and Core Assembly acceptance testing

(c) a summary of quality control records for Core Components

(d) a list of as-built, design, field, and shop drawings showing the latest revision used for construction and date

(e) a summary of deviations (nonconformances) giving a brief description of the nature of the deviations (nonconformances) and the corrective actions and the date when the corrective actions were taken

(f) records of where each component is installed in the Core Assembly

(g) distribution and approvals as shown in Table HAB-3255-1

HAB-3455 Data Report

The GC Certificate Holder shall certify compliance with this Subpart and Subsection HH by signing the appropriate Data Report (Article HAB-8000) that all details of materials, construction, and workmanship of the component or assembly conform to this Subpart, Subsection HH, and the Construction Specification. Distribution of the Data Reports is shown in Table HAB-3255-1.

HAB-3460 RESPONSIBILITY FOR QUALITY ASSURANCE

HAB-3461 Scope of Responsibilities for Quality Assurance

(a) The GC Certificate Holder shall be responsible for surveying, qualifying, and auditing suppliers of subcontracted services (HAB-3125), including nondestructive examination contractors and Material Organizations. Material Organizations holding a Quality Systems Certificate (Materials) and GC Certificate Holders whose scope includes supply or manufacture and supply of material need not be surveyed or audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate Certificate need not be surveyed nor audited for work within the scope of the subcontractor's certificate.

(b) A GC Certificate Holder may qualify vendors of subcontracted services (HAB-3125) other than those requiring a Certificate of Authorization, such as a Material Organization, for another GC Certificate Holder doing work for that GC Certificate Holder. The qualification documentation shall be supplied to the other GC Certificate Holder prior to their use of the subcontracted service or Material Organization.

HAB-3462 Documentation of Quality Assurance Program

The GC Certificate Holder shall be responsible for documenting its Quality Assurance Program (HAB-4134).

HAB-3463 Filing of Quality Assurance Manual

The GC Certificate Holder shall file with the Authorized Inspection Agency (HAB-5121) copies of the Quality Assurance Manual. The GC Certificate Holder shall keep a copy on file available to the Inspector (HAB-5123).

HAB-3800 MATERIAL ORGANIZATIONS

The requirements of HAB-3800 provide for various entities known as GC Certificate Holders, Material Organizations known as Material Manufacturers, Core Component manufacturers, Installers (HAB-3820), and approved suppliers (HAB-4555.3). These entities are involved in performance of operations, processes, and services related to the procurement, manufacture, and supply of material, machining or finishing of components, and installation of Core Components into Core Assemblies as defined in the glossary (HAB-9200).

HAB-3820 CERTIFICATION OR QUALIFICATION OF MATERIAL ORGANIZATIONS

(a) A Material Organization shall be certified by obtaining a Quality Systems Certificate issued by the Society verifying the adequacy of the Material Organization's Quality System Program (HAB-4500).

(b) Alternatively, the GC Certificate Holder (HAB-3461) may qualify Material Organizations not certified by the Society by evaluation of the organization's Quality System Program in accordance with the requirements of HAB-3842.

(c) A GC Certificate Holder may furnish material, machine Core Components, or perform installation when stated in the scope of its certificate. In this case, a Quality Systems Certificate is not required, nor is the user of the material, Core Components, or installation services required to survey, qualify, or audit such a GC Certificate Holder.

HAB-3830 RESPONSIBILITIES OF MATERIAL ORGANIZATIONS

The Material Organization shall be responsible for establishing, documenting, implementing, and maintaining a Quality System Program in accordance with the requirements of HAB-4550, and as applicable to its scope of activities:

(a) material manufacture (Material Manufacturers)

(b) Core Component machining or finishing (Core Component manufacturers)

(c) installation (Installers)

(d) establishing and maintaining measures for the traceability of material and Core Components while under its control (HAB-4556)

(e) controlling quality during construction, including control of testing, examination, and treatment of material and Core Components (HAB-4557, HAB-4558)

(f) approving and controlling operations performed by suppliers of subcontracted services (HAB-4555)

(g) preparing Certified Material Test Reports (HAB-3860)

(h) shipment of material and parts (HAB-4557.3)

HAB-3840 EVALUATION OF THE PROGRAM

HAB-3841 Evaluation by the Society

(a) The Society, when requested by the applicant on forms issued by the Society, will arrange for a survey of the Material Organization's Quality System Program for the scope of activities at the locations listed on the application. The Program will be evaluated on the basis of its compliance with the applicable material requirements of this Subpart and Subsection HH, Subpart A or Subpart B and the requirements of this subarticle. The Quality Systems Certificate, which is issued for a 3-yr period, will describe and specify the scope and limits of work and locations for which the certified Material Organization is qualified and will be subject to a planned audit program by the Society. Not later than 6 months prior to the expiration of the Certificate, the certified Material Organization shall apply for a renewal evaluation and for issuance of a new Certificate.

(b) The applicant shall supply all information required by forms provided by the Society.

(c) The applicant's Quality System Program shall be accepted by the Society prior to the issuance of a Certificate.

(d) A controlled copy of the certified Material Organization's Quality System Manual shall be filed with the Society. The Manual shall be the Society's guide for surveying and auditing the certified Material Organization's continued compliance with the accepted Quality System Program.

(e) The certified Material Organization shall make available for on-site review by the Society any procedures, process sheets, or drawings as are necessary to understand the Program. Detailed technical procedures will not be approved by the Society. The certified Material Organization shall keep a controlled copy of the Manual on file and in a place and manner readily available to the Society's audit team.

(f) The certified Material Organization shall obtain the Society's review and acceptance of proposed revisions to the Quality System Manual prior to implementation.

(g) When the applicant requests that the scope of the Quality Systems Certificate include shipment of material and Core Components from qualified Material Organizations to parties other than the applicant, the control of this activity shall be included in the Manual and will be reviewed by the Society.

(h) When the applicant requests that the scope of the Quality Systems Certificate include approval and control of suppliers (HAB-4555.3), this activity shall be included in the Manual and will be reviewed by the Society.

HAB-3842 Evaluation by Parties Other Than the Society

HAB-3842.1 Qualification of Material Organizations.

(a) The qualification of Material Organizations by parties other than the Society shall be limited to the manufacture of material, or machining or finishing of Core Components and the installation of Core Assemblies, or subcontracted services to the GC Certificate Holder performing the evaluation, or their designee.

(b) When a Material Organization has been qualified by a GC Certificate Holder, it is not necessary for another party to requalify that organization for materials or services that are to be furnished to the party that performed the evaluation.

HAB-3842.2 Evaluation of the Qualified Material Organization's Program by GC Certificate Holders. Evaluation of a Material Organization's Quality System Program by a GC Certificate Holder, as provided by HAB-3820(b), shall be performed in accordance with the requirements of (a) through (g) below.

(a) The Quality System Program shall be surveyed, accepted, and audited by the party performing the evaluation on the basis of its compliance with the applicable requirements of this Subpart and Subsection HH, Subpart A or Subpart B, and the requirements of HAB-4550.

(b) The Quality System Manual (HAB-4553.1) shall be the party's guide for surveying and auditing the qualified Material Organization's continued compliance with the accepted Quality System Program.

(c) The qualified Material Organization shall make available for on-site review by the party performing the evaluation any procedures, process sheets, or drawings as are necessary to understand the Program. The qualified Material Organization shall keep a controlled copy of the Manual on file and in a place and manner readily available to the party performing the audit.

(d) The qualified Material Organization shall notify the qualifying GC Certificate Holder accepting its Program of proposed revisions to its Quality System Manual. The party accepting the Program shall evaluate and accept such revisions prior to the implementation of the revisions on purchased materials or services.

(e) When the qualified Material Organization's scope of activities includes approval and control of suppliers (HAB-4555.3), this activity shall be included in the Quality System Manual, and shall be reviewed by the party accepting the Program. During surveys or audits of qualified Material Organizations, the party performing the evaluation shall review objective evidence that the qualified Material Organization's control of suppliers is adequate to ensure compliance with the applicable requirements of this Subpart and Subsection HH, Subpart A or Subpart B.

(f) When the qualified Material Organization's scope of activities includes shipment of material to parties other than the party performing the qualification, control of this activity shall be included in the Quality System Manual and shall be reviewed by the party accepting the Program. During surveys or audits of qualified Material Organizations, the party performing the evaluation shall review objective evidence that the qualified Material Organization's control of shipments is adequate to ensure compliance with the applicable material requirements of this Subpart and Subsection HH, Subpart A or Subpart B.

(g) Audits by parties performing evaluations of qualified Material Organizations shall meet the following requirements:

(1) The party performing the evaluation shall include audit frequency in their Manual.

(2) Audit frequencies shall be commensurate with the schedule of production or procurement, but shall be conducted at least once annually during the interval in which materials are controlled or services are performed by the Material Organization being evaluated.

(3) Audits shall meet the requirements of HAB-4559.1(a) through HAB-4559.1(e).

HAB-3860 CERTIFICATION REQUIREMENTS

HAB-3861 Certification Requirements for Material Organizations

(a) The Material Organization whose scope of activities includes material manufacture [HAB-3830(a)] shall provide a Certified Material Test Report (HAB-3862) for the material.

(1) The certification affirms that the contents of the report are correct and accurate and that all test results and operations performed by the Material Organization or its subcontractors are in compliance with the material specification and the specific applicable material requirements of this Subpart and Subsection HH.

(2) Chemical analyses, tests, examinations, and heat treatments required by the material specification that were not performed shall be listed on the Certified Material Test Report as applicable, or may be listed on an identified attachment.

(b) The Material Organization shall transmit all certifications required by HAB-3862.1(b), received from other Material Organizations or approved suppliers in accordance with (a) above, to the purchaser at the time of shipment.

(c) The GC Certificate Holder shall complete all operations not completed by the Material Organization and shall provide a Certified Material Test Report for all operations performed by it or its approved suppliers. The GC Certificate Holder shall certify that the contents of the report are correct and accurate and that all test results and operations performed by the GC Certificate Holder or its approved suppliers are in compliance with the requirements of the material specification, this Subpart, and Subsection HH. Alternatively, the GC Certificate Holder shall provide a Certified Material Test Report for the operations it performed and at least one Certified Material Test Report from each of its approved suppliers for the operations they performed.

HAB-3862 Certification of Material

HAB-3862.1 Material Certification.

(a) The Certified Material Test Report shall include the results of all required chemical analyses, tests, and examinations.

(b) When required chemical analyses, heat treatment, tests, or examinations are subcontracted, the approved supplier's certification for the operations performed shall be furnished as an identified attachment to the Certified Material Test Report. When operations other than chemical analysis, heat treatment, tests, or examination that require maintenance of traceability are subcontracted, these operations and the approved suppliers performing them shall be listed on the Certified Material Test Report, or the approved suppliers certification for the operation may be furnished as an attachment to the Certified Material Test Report.

(c) When specific times or temperatures (or temperature ranges) of heat treatments are required by material specifications, they shall be reported. When specific times and temperatures (or temperature ranges) are not required by the material specification, a statement of the type of heat-treated condition shall be reported.

(d) Reporting of actual dimensions and visual examination results is neither required nor prohibited by this paragraph.

(e) Material identification shall be described in the Certified Material Test Report.

(f) Notarization of the Certified Material Test Report is not required.

HAB-3862.2 Quality System Program Statement.

(a) When the Material Organization holds a Quality Systems Certificate, the Material Organization's Quality Systems Certificate number and expiration date shall be shown on the Certified Material Test Report or on a certification included with the documentation that accompanies the material.

(b) When the Material Organization has been qualified by a party other than the Society, the revision and date of the applicable written Quality System Program shall be shown on the Certified Material Test Report or on a certification included with the documentation that accompanies the material.

(c) The inclusion of the Quality Systems Certificate number and expiration date or reference to revision and date of the applicable written Quality System Program shall be considered the Material Organization's certification that all activities have been performed in accordance with the applicable requirements of this subarticle.

Table HAB-3255-1
Document Distribution for Design and Construction of Core Components and Assemblies

Document	Prepared by	Reviewed by	Certified by	Approved by	Provided to [Note (1)]	Available on Request
Design Specification (HAB-3250)	O	O	O	...	G, GC, I, J	...
Construction Specification (HAB-3340)	G	O	G	O	O, GC, MO	I, J
Design Drawings (HAB-3340)	G	O	G	O	O, GC, MO	I, J
Design Report (HAB-3352)	G	O	G	O	O, GC	I, J
Material Data Sheets (HAB-3353)	G	O	G	...	O	J
Construction procedures (HAB-3451)	GC, MO	G	...	G	G, O	I, J
Certified Material Test Reports	MO, GC	G	MO, GC	...	GC, O	I, J
Shop and field drawings (HAB-3452)	GC, MO	G	...	G	GC	I
Construction Report (HAB-3454)	GC	G,O	G	O	G, O, J	I, J
Data Report Form G-1 (HAB-8410)	GC, G	I	GC, I	...	O, I	J
Data Report Forms G-2 and G-4 (HAB-8410)	GC, MO	I	GC, MO, I	...	GC, I	J
Data Report Form N-3 (HAB-8420)	O	I	O, I	J	...	...

Legend:

G = G Certificate Holder (Designer)
GC = GC Certificate Holder
I = Inspector
J = Enforcement authority
MO = Material Organizations (Material Manufacturer, Core Component manufacturer, or Installer)
O = Owner or its designee

NOTE:

(1) Information is provided to the indicated participants when required to satisfy their designated responsibilities under this Subpart and Subsection HH. Other information is provided only by specific arrangement with the Owner. Participants are required to furnish only such information as is necessary to permit the recipient to perform its duties in conformance with this Subpart and Subsection HH. Other information may be furnished at the discretion of the responsible parties.

ARTICLE HAB-4000 QUALITY ASSURANCE REQUIREMENTS

HAB-4100 REQUIREMENTS

HAB-4110 SCOPE AND APPLICABILITY

(a) This Article sets forth the requirements for planning, managing, and conducting Quality Assurance Programs for controlling the quality of activities performed under this Subpart and Subsection HH, and the rules governing the evaluation of such Programs prior to the issuance of certificates for the design and construction of the Core Assembly. The Quality Assurance requirements for Material Organizations for material manufacture, Core Component manufacture, and installation are provided in HAB-3800. GC Certificate Holders are advised to consult other regulations for Quality Assurance requirements governing activities beyond the scope of this Division.

(b) As identified, modified, and supplemented in HAB-4120 and HAB-4134, GC Certificate Holders shall comply with the requirements of ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Applications, Part I and when specifically stated, Part II.[6]

HAB-4120 DEFINITIONS

(a) The definitions in Article HAB-9000 shall apply.

(b) The definitions in Article NCA-9000 shall apply, unless defined in Article HAB-9000.

(c) The terms and definitions of ASME NQA-1 shall apply, unless defined in Article HAB-9000 or Article NCA-9000.

(d) For the following terms, which are defined in both ASME NQA-1 and Article HAB-9000 or Article NCA-9000, the definitions in Article NCA-9000 or Article HAB-9000 shall apply, as determined by (b):

(1) item
(2) Owner
(3) quality assurance
(4) repair
(5) rework
(6) service
(7) use-as-is
(8) nonconformance

HAB-4130 ESTABLISHMENT AND IMPLEMENTATION

HAB-4131 Material Organizations

The requirements of HAB-3800 and HAB-4500 apply.

HAB-4133 Owner's Quality Assurance Program

HAB-4133.1 The Owner shall maintain a Quality Assurance Program. For this purpose, the Owner may use a Quality Assurance Program accepted by the regulatory authority.

HAB-4133.2 The Owner shall maintain either a Quality Manual or a procedure accepted by the Inspector that describes how the Owner will meet their Code responsibilities (see HAB-3200), including control of their designee(s).

HAB-4133.3 Owners performing activities that require a GC Certificate shall include the requirements of HAB-3800 or HAB-4100, as applicable, in their Quality Assurance Program and obtain the appropriate Certificate(s).

HAB-4133.4 The Owner shall assure that organizations performing activities requiring a GC Certificate have a Quality Assurance Program meeting the requirements of HAB-3800 or HAB-4100, as applicable.

HAB-4134 GC Certificate Holders

HAB-4134.1 Organization. The provisions of ASME NQA-1, Requirement 1 shall apply.

HAB-4134.2 Quality Assurance Program.

(a) The provisions of ASME NQA-1, Requirement 2 shall apply and the system used to meet these requirements shall be described in the Quality Assurance Manual. The Quality Assurance Manual shall also include a statement of policy and authority indicating management support. The specific responsibilities of the quality assurance organization of the GC Certificate Holder shall also include the review of written procedures and monitoring of the activities concerned with the Quality Assurance Program as covered in this Article.

(b) In lieu of Requirement 2, para. 301, the qualification of nondestructive examination personnel shall be as required by HHA-5220 or HHB-5220.

(c) The controls used in the Quality Assurance Program shall be documented in the Quality Assurance Manual. The Quality Assurance Manual may be hard copy or electronic, provided the controls are described to assure approved revisions are made available for use by the GC Certificate Holder personnel. The Program need not be in the same format or sequential arrangement as the requirements in this Article, as long as all applicable requirements of this Article have been covered. A copy,

including all changes that are made, shall be made available to the Inspector. The GC Certificate Holder shall make available to the Inspector such drawings and process sheets as are necessary to make the Quality Assurance Program understandable.

(d) The GC Certificate Holder shall be responsible for advising its Authorized Inspection Agency of any changes that are proposed to be made to the Quality Assurance Manual, and shall have acceptance of the Authorized Inspection Agency's Inspector Supervisor before putting such changes into effect. The GC Certificate Holder shall be responsible for promptly notifying the Inspector of such accepted changes, including evidence of acceptance by the Authorized Inspection Agency, and for simultaneously reconciling copies of the Quality Assurance Manual.

HAB-4134.3 Design Control.

(a) The provisions of ASME NQA-1, Requirement 3 shall apply.

(b) Measures shall be established to ensure that applicable requirements of the Design Specifications and of this Subpart and Subsection HH for items are correctly translated into specifications, drawings, procedures, and instructions.

(c) Design documents shall be verified for adequacy and compliance with the Design Specification, this Subpart, and Subsection HH.

(d) Computer programs used for design analysis shall meet the requirements of ASME NQA-1, Part II, Subpart 2.7.

(e) Paragraph 601, "Configuration Management of Operating Facilities," is not applicable.

HAB-4134.4 Procurement Document Control. The provisions of ASME NQA-1, Requirement 4 shall apply, except that

(a) procurement documents shall require suppliers to provide a Quality Assurance Program consistent with the applicable requirements of this Subpart and Subsection HH

(b) this requirement does not apply to Authorized Inspection Agency services

HAB-4134.5 Instructions, Procedures, and Drawings. The provisions of ASME NQA-1, Requirement 5 shall apply.

HAB-4134.6 Document Control. The requirements of HAB-3125 shall be used for subcontracted services. The provisions of ASME NQA-1, Requirement 6 shall apply. If electronic controls are used, the Certificate Holder shall describe the review, approval, and control process to assure correct documents are being used at the location where the activity is performed.

HAB-4134.7 Control of Purchased Items and Services. The requirements of HAB-3125 shall be used for subcontracted services. The provisions of ASME NQA-1, Requirement 7 shall apply, except that

(a) the requirement does not apply to Authorized Inspection Agency services.

(b) in para. 300, "Bid Evaluation," the decision to perform bid evaluation for materials to confirm conformance to procurement documents shall remain the responsibility of the GC Certificate Holder.

(c) in para. 503, "Certificate of Conformance," changes, waivers, or deviations are not acceptable unless they meet the requirements of this Subpart and Subsection HH.

(d) in para. 503(c), "Certificate of Conformance," the resolution of nonconformances shall be in conformance with the requirements of this Subpart and Subsection HH.

(e) other than as provided in HAB-4134.3, the use of ASME NQA-1, Requirement 7, para. 700, Commercial Grade Items and Services, is not permitted.

(f) documentary evidence that items conform to the requirements of this Section shall be available at the construction or installation site before use or installation. Requirements for documentary evidence are satisfied for material when the applicable rules of HAB-3860 for material certification are met. For stamped items, the requirements are satisfied by a Data Report.

(g) the requirements of HAB-3126 and HAB-3127 may be used.

HAB-4134.8 Identification and Control of Items.

(a) The provisions of ASME NQA-1, Requirement 8 shall apply.

(b) All characteristics required to be reported by the material specifications, this Subpart, and Subsection HH shall appear on checklists, and each such characteristic shall be examined by accepted procedures as required and the results recorded. Characteristics included on Certified Material Test Reports need not be duplicated in the checklists. Checklists shall provide for a record that the Certified Material Test Reports have been received, reviewed, and found acceptable. When the results of the examination or test procedure conducted by the GC Certificate Holder are necessary to show compliance with material specification or other requirements, the checklists shall show the required range of values. The checklists shall include spaces for inclusion of document number and revision to which examination or tests were made; a signature, initials, or stamp; the date of the examination performed by the GC Certificate Holder's representative; the signature, initials, or stamp of an Inspector; and the date on which those activities were witnessed.

HAB-4134.9 Control of Processes.

(a) The provisions of ASME NQA-1, Requirement 9 shall apply, except that requirements for welding and brazing are not applicable to Core Components or Core Assemblies.

(b) The GC Certificate Holder shall prepare instructions, procedures, drawings, checklists, travelers, or other appropriate documents, including the document numbers

and revisions to which the process conforms, with space provided for reporting results of completion of specific operations at checkpoints of manufacture or installation. The documents shall include space for a signature, initials, or stamp; the date that the activity was performed by the GC Certificate Holder's representative; the signature, initials, or stamp of an Inspector; and the date on which those activities were witnessed.

HAB-4134.10 Inspection.

(a) The provisions of ASME NQA-1, Requirement 10 shall apply, except for para. 700, "Inspections During Operations."

(b) The GC Certificate Holder shall prepare process sheets, travelers, or checklists, including the document numbers and revision to which the examination or test is to be performed, with space provided for recording results of examinations and tests. The documents shall include space for a signature, initials, or stamp; the date that the activity was performed by the GC Certificate Holder's representative; the signature, initials, or stamp of an Inspector; and the date on which those activities were witnessed. The examination checklist for construction of items shall be filled in and completed by the GC Certificate Holder.

(c) Mandatory hold points at which witnessing is required by the GC Certificate Holder's representative or the Inspector shall be indicated in the controlling documents (HAB-4134.9). Work shall not proceed beyond mandatory hold points without the consent of the GC Certificate Holder's representative or the Inspector, as appropriate.

HAB-4134.11 Test Control. The provisions of ASME NQA-1, Requirement 11 shall apply.

HAB-4134.12 Control of Measuring and Test Equipment.

(a) The provisions of ASME NQA-1, Requirement 12 shall apply.

(b) The GC Certificate Holder may perform periodic checks on equipment to determine that calibration is maintained. When periodic checking is used, discrepancies need only be resolved to the prior check, provided the discrepancy is discovered by the periodic check. The methods and frequency of periodic checking, when used, shall be included in the GC Certificate Holder's Quality Assurance Program.

HAB-4134.13 Handling, Storage, and Shipping. The provisions of ASME NQA-1, Requirement 13 shall apply.

HAB-4134.14 Inspection and Test Status. The provisions of ASME NQA-1, Requirement 14 shall apply for inspections and tests, but not for operating status.

HAB-4134.15 Control of Nonconforming Items. The provisions of ASME NQA-1, Requirement 15 shall apply, except that the definition of "repair" given in Article NCA-9000 shall apply in lieu of the definitions of "repair" and "rework" given in ASME NQA-1.

HAB-4134.16 Corrective Action.

(a) The provisions of ASME NQA-1, Requirement 16 shall apply.

(b) The requirements shall also extend to the performance of the subcontractor's corrective action measures.

HAB-4134.17 Quality Assurance Records.

(a) General. The provisions of ASME NQA-1, Requirement 17 shall apply except that the requirements for para. 400, "Classification"; para. 500, "Receipt Control of Records"; and para. 600, "Storage," are not applicable. Such records shall be classified and maintained as required by this Subpart and Subsection HH.

(b) Records Index. The records shall be indexed. The records and the indices thereto shall be accessible to the Owner, Owner's designee, and Inspector.

(c) Lifetime Records. The records listed in Table HAB-4134.17-1 shall be classified as lifetime records. The GC Certificate Holder shall be responsible for the retention and maintenance of these records while they are under its control. The Owner shall be responsible for retention and maintenance of those records that are transferred to it.

(d) Nonpermanent Records. The records listed in Table HAB-4134.17-2 shall be classified as nonpermanent records. The GC Certificate Holder shall be responsible for their retention for the period specified in Table HAB-4134.17-2. In no case need nonpermanent records be retained for longer than 10 yr after completion of the applicable Code Data Report.

HAB-4134.18 Audits.

(a) The provisions of ASME NQA-1, Requirement 18 shall apply.

(b) Results of audits shall be made available to the Inspector for Core Components.

(c) The audit frequency shall be specified in the GC Certificate Holder's Quality Assurance Manual. The GC Certificate Holder's audit frequency shall be commensurate with its schedule of activities and shall be such that each ongoing Code activity is audited at least once annually.

Table HAB-4134.17-1
Lifetime Quality Assurance Records

List Number	Record
1	Index to lifetime records (HAB-4134.17)
2	Code Data Reports (HAB-8400)
3	Design Specification (HAB-3250)
4	Design Output Documents (HAB-3350)
5	Construction Specification (HAB-3340)
6	As-built drawings (HAB-3454)
7	Heat treatment records [Note (1)]
8	Final Nondestructive Examination Records (as required)
9	Certified Material Test Reports (CMTR) and documentation providing traceability to location used, if required
10	Construction Report (HAB-3454)

GENERAL NOTE: Nonconformance reports that affect those records listed shall be incorporated into the record or be retained with the record.

NOTE:
(1) Heat treatment records may be a summary supplied as part of the CMTR.

Table HAB-4134.17-2
Nonpermanent Quality Assurance Records

List Number	Record	Retention Period
1	QA Program Manual	3 yr after superseded or invalidated
2	Design procurement and QA procedures (HAB-4134.5)	3 yr after superseded or invalidated
3	Installation and NDE procedures	10 yr after superseded or invalidated
4	Personnel qualification records	3 yr after superseded or invalidated
5	Purchase orders	10 yr after superseded or invalidated
6	Audit and survey reports (HAB-4134.18)	3 yr after completion of report
7	Calibration records (HAB-4134.12)	Until recalibrated
8	Process sheets, travelers, or checklists (HAB-4134.10)	10 yr after completion
9	Certifying Engineer qualification records (Section III Appendices, Mandatory Appendix XXIII)	3 yr after superseded or invalidated

GENERAL NOTE: Nonconformance reports, which affect those records listed and are not incorporated into the record, shall be retained for the retention period applicable to the record the nonconformance report affects.

HAB-4500 GRAPHITE AND COMPOSITE MATERIAL ORGANIZATION QUALITY SYSTEM PROGRAM REQUIREMENTS

HAB-4550 QUALITY SYSTEM PROGRAM REQUIREMENTS

HAB-4551 Responsibility and Organization

HAB-4551.1 General.

(a) The Material Organization shall establish a Quality System Program for the control of quality during manufacture or during other work it proposes to perform, and for the traceability of material under its control. The Program shall be planned, documented, implemented, and maintained in accordance with the requirements of HAB-4500.

(b) The establishment of the Program shall include consideration of the technical aspects and provide for planning and accomplishment of activities affecting quality. The Program shall provide for any special controls, processes, test equipment, tools, and skills to attain the required quality and for verification of quality.

HAB-4551.2 Scope and Applicability.

(a) The Quality System Manual shall define the specific activities included in the scope of the work the Material Organization proposes to perform, including any combination of

(1) material manufacture

(2) Core Component machining

(3) installation

(4) testing, examination, repair, or treatments required by the material specification or the specific applicable material requirements of this Subpart and Subsection HH, and certification of the results of such tests, examinations, or treatments

(5) receipt, identification, verification, handling, storage, and shipment of material

(6) approval and control of subcontracted services (HAB-4555.3)

(b) The Program shall include measures to comply with all requirements of this subarticle, to the extent necessary to ensure compliance with the requirements of this Subpart and Subsection HH.

HAB-4551.3 Organization.

(a) The organizational structure for executing the Program may take various forms, provided the persons and organizations assigned the quality system functions have the required authority and organizational freedom.

(b) Persons or organizations responsible for defining and measuring the overall effectiveness of the Program shall

(1) be designated

(2) be sufficiently independent from the pressures of production

(3) have direct access to responsible management at a level where appropriate action can be initiated

(4) report regularly on the effectiveness of the Program

(c) The organizational structure, functional responsibilities, levels of authority, and lines of communication for activities affecting quality shall be documented. Persons or organizations responsible for ensuring that an appropriate Quality System Program has been established and verifying that activities affecting quality have been correctly performed shall have sufficient authority, access to work areas, and organizational freedom to

(1) identify quality problems

(2) initiate, recommend, or provide solutions to quality problems through designated channels

(3) verify implementation of solutions

(4) ensure that further processing, delivery, or use is controlled until proper disposition of a nonconformance, deficiency, or unsatisfactory condition has occurred

(d) Individuals or groups assigned the responsibility of checking, auditing, or otherwise verifying that production and quality control activities have been correctly performed shall be independent of the individual or group directly responsible for performing the specific activity. Such persons shall not report directly to the supervisor with immediate responsibility for the work being verified.

(e) Management shall regularly review the status and adequacy of the Quality System Program.

HAB-4552 Personnel

HAB-4552.1 Indoctrination, Training, and Qualification of Personnel.

(a) Measures shall be established to ensure that all personnel performing or managing activities affecting quality are indoctrinated and trained. The assignment of personnel shall be at the discretion of the organization's management. Indoctrination and training measures shall reflect the following requirements:

(1) Personnel to be indoctrinated or trained shall be identified.

(2) The extent of indoctrination and training shall be commensurate with the scope, complexity, and nature of the activity as well as the education, experience, and proficiency of the person.

(3) Personnel shall be indoctrinated in the general criteria, applicable codes, standards, company procedures, Quality System Program requirements, job responsibilities, and authority as they relate to a particular function.

(4) Training shall be provided, as needed, to achieve initial proficiency, maintain proficiency, and adapt to changes in technology, methods, and job responsibilities.

(b) All nondestructive examination personnel shall be qualified on the basis of education, experience, training, and examination in accordance with the requirements of HHA-5220 or HHB-5220.

(c) Personnel who lead audits shall be qualified on the basis of education, experience, training, audit participation, and examination in accordance with the organization's Quality System Program.

HAB-4552.2 Personnel Records.

(a) Records shall be maintained of the implementation of indoctrination and training of personnel. Records of indoctrination and training may take the form of attendance sheets, training logs, or personnel training records.

(b) Qualification records of all nondestructive examination personnel shall be documented and maintained.

(c) Qualification records of personnel who lead audits shall be documented and maintained and shall include education, experience, audit training and examination, and audit participation used as the basis of qualification.

HAB-4553 Program Documentation

HAB-4553.1 Quality System Manual.

(a) The Quality System Program shall be described and summarized in a Quality System Manual that shall be a major basis for demonstration of compliance with the rules of this Division.

(b) The Program documented in the Manual shall be implemented by written procedures that are maintained either separately or in the Quality System Manual.

(c) Detailed technical procedures and processes, such as those for nondestructive examination, are not considered part of the Manual; however, the controls of such procedures and processes shall be covered by the Manual.

(d) The Quality System Manual may be hard copy or electronic, provided the controls are described to ensure approved revisions are made available for use by the Material Organization personnel.

HAB-4553.2 Procedures, Instructions, and Drawings.

(a) Activities affecting quality shall be prescribed by and performed in accordance with documented instructions, procedures, or drawings of a type appropriate to the circumstances.

(b) These documents shall include or reference appropriate acceptance criteria for determining that the prescribed activities have been satisfactorily completed.

HAB-4553.3 Document Control. The preparation, issue, and change of documents, including electronic documents, that specify quality requirements or prescribe activities affecting quality, such as Quality System Program Manuals, purchase specifications, instructions, procedures, and drawings shall be controlled to ensure that the correct documents are being used at the location where the activity is performed. Such documents, including changes thereto, shall be reviewed for adequacy and approved for release by authorized personnel.

HAB-4553.4 Quality Assurance Records. Records that furnish documentary evidence of quality shall be specified, prepared, controlled, and maintained. Records shall be legible, identifiable, and retrievable. Records shall be protected against damage, deterioration, or loss. Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

HAB-4553.5 Records of Examinations and Tests. All characteristics required to be reported by the material specification, this Subpart, and Subsection HH shall be verified and the results recorded. Records shall be traceable to the document and revision to which an inspection, examination, or test was performed.

HAB-4555 Control of Purchased Materials and Services

HAB-4555.1 General.

(a) Measures shall be established to ensure that all purchased material and subcontracted services conform to the requirements of this Subpart and Subsection HH.

(b) These measures shall be designed to prevent the use of incorrect or defective material or materials that have not received the required examinations or tests.

HAB-4555.2 Sources of Material and Services.

(a) Material shall be furnished by a Material Organization [HAB-3820(a) or HAB-3820(b)] or by a GC Certificate Holder [HAB-3820(c)].

(b) Core Component machining or finishing shall be performed by a Material Organization [HAB-3820(a) or HAB-3820(b)] or by a GC Certificate Holder [HAB-3820(c)].

(c) Installation shall be performed by a Material Organization [HAB-3820(a) or HAB-3820(b)] or by a GC Certificate Holder [HAB-3820(c)].

(d) Services including performance and certification of operations, processes, the results of tests, examinations, or treatments required by the material specification or by this Subpart and Subsection HH shall be furnished by a Material Organization, by an approved supplier, or by a GC Certificate Holder.

HAB-4555.3 Approval and Control of Suppliers of Subcontracted Services.

(a) The Material Organization or GC Certificate Holder shall be responsible for the approval and control of activities performed by suppliers of subcontracted services. Such control shall provide for source evaluation and selection, evaluation of objective evidence of quality, audit, and examination of items and services upon delivery, in accordance with requirements documented in the Material Organization's or GC Certificate Holder's Program.

(b) The Material Organization or GC Certificate Holder shall be responsible for establishing and verifying that the supplier's controls applicable to the activities performed are adequate by either

(1) performing a survey of the supplier's quality system and performing triennial audits covering applicable elements of the approved supplier's established quality system that are consistent with the requirements of this

subarticle, supplemented by annual evaluations of the approved supplier's quality system, including a review of the history of conditions adverse to quality, nonconformances, and corrective actions, or

(2) having the supplier perform the activities in accordance with controls established by the Material Organization's or GC Certificate Holder's Program

(c) As an alternative to the survey and audit of subcontracted calibration services, a Material Organization, approved supplier, or GC Certificate Holder may accept accreditation by accrediting bodies recognized by the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA), provided that the following requirements are met:

(1) A documented review of the calibration supplier's accreditation shall be performed and shall include verification that

(-a) the accreditation is to ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories, from an accredited body recognized by the ILAC MRA

(-b) the published scope of accreditation for the calibration laboratory covers the needed measurement parameters, ranges, and uncertainties

(2) The procurement documents shall specify

(-a) that the service must be provided in accordance with the accredited ISO/IEC 17025 program and scope of accreditation

(-b) that the calibration certificate/report shall include identification of the laboratory equipment/standards used

(-c) that the calibration certificate/report shall include as-found calibration data when calibrated items are found to be out-of-tolerance

(-d) that the service supplier shall not subcontract the service to any other supplier

(-e) that the Material Organization, approved supplier, or GC Certificate Holder must be notified of any condition that adversely impacts the laboratory's ability to maintain the scope of accreditation

(-f) additional technical and quality requirements, as necessary, based on a review of the procured scope of services, including, but not limited to, tolerances, accuracies, ranges, and industry standards

(3) At receipt inspection, the Material Organization, approved supplier, or GC Certificate Holder shall be responsible for validating that the supplier's documentation certifies

(-a) that the subcontracted calibration was performed in accordance with the supplier's ISO/IEC 17025 program and scope of accreditation

(-b) conformance to the procurement document's requirements

(4) This activity shall be documented in the Material Organization's Quality System Program Manual, approved supplier's quality program, or GC Certificate Holder's Quality Assurance Program Manual.

(d) As an alternative to survey and audit of subcontracted testing services, a Material Organization, approved supplier, or GC Certificate Holder may accept accreditation by accrediting bodies recognized by the ILAC MRA, provided the following requirements are met:

(1) A documented review of the supplier's accreditation shall be performed and shall include verification that the

(-a) accreditation is to ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories, from an accredited body recognized by the ILAC MRA

(-b) published scope of accreditation for the testing laboratory covers the needed testing services, including test methodology and tolerances/uncertainties

(2) The procurement documents shall specify

(-a) that the service must be provided in accordance with the accredited ISO/IEC 17025 program and scope of accreditation

(-b) that the service supplier shall not subcontract the service to any other supplier

(-c) that the Material Organization, approved supplier, or GC Certificate Holder must be notified of any condition that adversely impacts the laboratory's ability to maintain the scope of accreditation

(-d) additional technical and quality requirements, as necessary, based on a review of the procured scope of services, including, but not limited to, tolerances, accuracies, ranges, and industry standards

(3) At receipt inspection, the Material Organization, approved supplier, or GC Certificate Holder shall be responsible for validating that the testing supplier's documentation certifies

(-a) that the subcontracted testing was performed in accordance with the supplier's ISO/IEC 17025 program and scope of accreditation

(-b) conformance to the procurement document's requirements

(4) This activity shall be documented in the Material Organization's Quality System Program Manual, approved supplier's quality program, or GC Certificate Holder's Quality Assurance Program Manual.

(e) The Material Organization or GC Certificate Holder shall be responsible for ensuring that all material and activities conform to all applicable requirements of this Subpart and Subsection HH.

HAB-4555.4 Procurement Document Control.

(a) Procurement documents shall include requirements necessary to ensure compliance with the requirements of this Subpart and Subsection HH.

(b) Procurement documents shall require material or subcontracted services to be furnished in accordance with the applicable requirements of this subarticle.

(c) Procurement documents shall require approved suppliers to reference the accepted quality system or controls established by the Material Organization or GC Certificate Holder on documentation that accompanies the services furnished.

(d) Procurement documents that specify quality requirements or prescribe activities affecting quality shall be reviewed for adequacy and approved for release by authorized personnel.

HAB-4556 Identification, Marking, and Material Control

HAB-4556.1 General.

(a) Control shall be established to ensure that only correct and accepted material is used. Identification shall be maintained on these materials or on documents traceable to these materials, or in a manner that ensures the identification is established and maintained.

(b) Measures shall be established for controlling and identifying material, including that which is partially processed, throughout the manufacturing process; during the performance of tests, examinations, and treatments; and during receipt, storage, handling, and shipment.

(c) Identification marking shall be transferred to all pieces when material is divided.

HAB-4556.2 Marking Method. Materials shall be marked by any method acceptable to the purchaser that will not result in harmful contamination or sharp discontinuities and will identify these materials in accordance with the material specification.

HAB-4556.3 Identification of Completed Material.

(a) The identification of completed material by the Material Manufacturer shall consist of marking each billet with an identification number, traceable to the forming lot number, the charge number, the grade of the material, and any additional marking required by this Subpart and Subsection HH to facilitate traceability of the material to reports of the results of all tests and examinations performed.

(b) The identification of machined Core Components by the Core Component Manufacturer shall consist of marking each Core Component with an identification number, traceable to the material identification number, and any additional marking required by this Subpart and Subsection HH to facilitate traceability of the material to reports of the results of all tests and examinations performed.

(c) A marking symbol or code may be used that identifies the material, provided such code or symbol is explained in the Certified Material Test Report (HAB-3862.1).

(d) All requirements of the material specification shall be met except where specifically exempted or superseded by a provision of this Subpart and Subsection HH. When special requirements or provisions of this Subpart and Subsection HH conflict with the requirements of the material specification, the material specification and grade number shall be followed with an asterisk (*) to indicate that the material specification has been revised as shown on the material certification.

(e) Except as required by the specification, keys and dowels, or other products where the largest space available for marking is less than 1 in. (25 mm) in any one direction need not be individually marked, provided they are packed in packages or containers that shall be clearly identified by legible marking to ensure positive identification of the material. The markings on the containers shall identify the material with the Certified Material Test Report (HAB-3862.1), as applicable.

HAB-4557 Process Control

HAB-4557.1 General. Processes affecting quality of materials or services shall be controlled. Special processes that control or verify quality shall be performed by qualified personnel using qualified procedures in accordance with specific requirements as applicable.

HAB-4557.2 Manufacturing Process Control. Operations shall be performed under a controlled system, such as process sheets, shop procedures, checklists, travelers, or equivalent procedures. Measures shall be established to ensure that processes are controlled in accordance with the material specification and the rules of this Subpart and Subsection HH.

HAB-4557.3 Handling, Storage, Shipping, and Preservation. Instructions shall be established for handling, storage, shipping, and preservation of material to prevent damage or deterioration.

HAB-4558 Control of Examinations, Tests, and Nonconforming Material

HAB-4558.1 Inspection, Examination, and Test Control.

(a) Inspections, examinations, and tests shall be established to ensure conformance with the requirements of the material specification, this Subpart, and Subsection HH.

(b) Inspections or examinations required to verify conformance of material or an activity to specified requirements shall be planned. Characteristics to be inspected or examined, and inspection or examination methods to be employed, shall be specified. Inspection or examination results shall be documented.

(c) Tests required to verify conformance to specified requirements shall be planned. Characteristics to be tested and test methods to be employed shall be specified. Test results shall be documented, and their conformance with acceptance criteria shall be evaluated.

HAB-4558.2 Control of Measuring and Test Equipment.

(a) Procedures shall be in effect to ensure that tools, gages, instruments, and other measuring and testing devices used to verify compliance with the material specification, this Subpart, and Subsection HH are calibrated

and properly adjusted at specific periods or use intervals to maintain accuracy within necessary limits. Periodic checks on equipment may be performed to determine that calibration is maintained.

(b) Calibration shall be against certified equipment having known valid relationships and documented traceability to nationally recognized standards, where such standards exist. If no known nationally recognized standards exist, the basis for calibration shall be documented.

(c) Control measures shall include provisions for measuring and test equipment identification and for determining calibration status by equipment marking or on records traceable to the equipment.

HAB-4558.3 Discrepancies in Measuring or Testing Equipment.

(a) When discrepancies in excess of tolerances for measuring or testing equipment are found at calibration, appropriate corrective action shall be taken, and material measured or tested since the previous calibration shall be reviewed to determine that all applicable requirements have been met.

(b) When periodic checks on equipment are performed to determine that calibration is maintained, potential material discrepancies need only be resolved to the previous check, provided

(1) the methods used and frequency of periodic checking are described in calibration procedures

(2) the calibration discrepancy was found by periodic check

HAB-4558.4 Inspection and Test Status. Measures shall be established so that the status and results of any required inspections, examinations, or tests can be determined at any time. Status shall be maintained through indicators such as physical location and tags, marking, shop travelers, stamps, inspection records, or other suitable means. The authority for application and removal of such indicators shall be specified.

HAB-4558.5 Control of Nonconforming Material.

(a) Adequate control measures shall be established to prevent the use of material that does not conform to the requirements of the material specification, this Subpart, and Subsection HH.

(b) Material with nonconformances shall be identified, segregated when practical, and reviewed for acceptance or rejection in accordance with documented procedures. The responsibility and authority for the disposition of nonconformances in these materials shall be defined.

(c) Measures that control further processing of nonconforming or defective material pending a decision on its disposition shall be established and maintained. These control measures shall extend to notification of other affected organizations, as appropriate.

HAB-4559 Audits and Corrective Action

HAB-4559.1 Audits.

(a) Audits shall be performed in accordance with written procedures or checklists by personnel not having direct responsibility in the areas being audited.

(b) Audit results shall be documented by auditing personnel for review by management having responsibility in the area being audited.

(c) Procedures shall include provisions for documentation of corrective action taken in response to deficiencies. Follow-up action, including re-audit of deficient areas, where indicated, shall be taken to verify implementation of such corrective actions.

(d) In addition to audits of Material Organizations and suppliers, a comprehensive system of planned internal audits shall be performed at least annually to ensure compliance with all aspects of the Quality System Program and to determine the effectiveness of the Program.

(e) Internal audits shall be performed in accordance with the requirements of (a) through (d) above.

HAB-4559.2 Corrective Action.

(a) Measures shall be established to ensure that conditions adverse to quality, such as failures, malfunctions, deviations, defective material and equipment, nonconformances, and quality system deficiencies, are promptly identified and reported to appropriate levels of management. The measures shall also ensure that the cause of conditions adverse to established quality levels are determined and corrected.

(b) The identification of significant or recurring conditions adverse to quality, the cause of the condition, and the corrective action taken shall be documented and reported to appropriate levels of management.

(c) These requirements shall also extend to the performance of the approved supplier's corrective action measures.

ARTICLE HAB-5000
AUTHORIZED INSPECTION

HAB-5100 INTRODUCTION

HAB-5110 APPLICABILITY

(a) This Article provides the requirements for the inspection of items constructed in accordance with this Subpart and Subsection HH by the Authorized Inspection Agency.

(b) When preservice examinations are required by this Subpart and Subsection HH, inspection of the preservice examinations by the Authorized Inspection Agency shall be in accordance with applicable paragraphs of Section XI.

HAB-5120 PERFORMANCE OF INSPECTION

HAB-5121 Authorized Inspection Agency

(a) An Authorized Inspection Agency is one designated by, or is one acceptable to, the appropriate Enforcement Authority. The Authorized Inspection Agency shall be accredited by the Society in accordance with the provisions set forth in ASME QAI-1, Qualification for Authorized Inspection.

(b) The Authorized Inspection Agency shall notify the Society when it enters into an agreement with an Owner or a GC Certificate Holder, or whenever an existing agreement is terminated. The Authorized Inspection Agency shall also notify the Enforcement Authority whenever an agreement with an Owner is written or an Owner's agreement is terminated.

HAB-5122 Authorized Nuclear Inspector Supervisor

The Authorized Inspection Agency shall employ Inspector Supervisors qualified in accordance with ASME QAI-1, Qualification for Authorized Inspection, to supervise Inspectors performing inspections required by this Subpart and Subsection HH.

HAB-5123 Authorized Nuclear Inspector

The Authorized Inspection Agency shall also employ an Inspector qualified in accordance with ASME QAI-1, Qualification for Authorized Inspection, to perform inspections required by this Subpart and Subsection HH. The inspections required by this Subpart and Subsection HH shall be performed by an Inspector. The Inspector shall not be in the employ of a GC Certificate Holder.

HAB-5125 Duties of Inspector Supervisors

The responsibilities of the Inspector Supervisor include the requirements of (a) through (h).

(a) Supervisors, in conjunction with Inspectors employed by the same Authorized Inspection Agency (HAB-5121), shall participate in the Society's review of the applicant's Quality Assurance Program (HAB-8160). In those cases where the Supervisor performs the functions of the Inspector, the Supervisor may represent both during the review of the Program.

(b) A Supervisor designated by the Authorized Inspection Agency shall review and accept any proposed modifications to Quality Assurance Manuals before they are put into effect.

(c) The Supervisor shall audit the Inspector's performance at least twice per year at locations where the Certificate Holder is actively engaged in work according to this Subpart and Subsection HH.

(d) The Supervisor shall be available as needed for consultation and support of the local inspection staff.

(e) The Supervisor shall maintain supervisory control over one or more Inspectors and shall perform all the functions and maintain the records required of the Supervisor in ASME QAI-1.

(f) The portion of a GC Certificate Holder's Quality Assurance Program that involves supply or manufacture and supply of materials [HAB-3820(c)] shall be audited by the Supervisor at least once each year.

(g) The Owner's Quality Assurance Program shall be audited annually by the Supervisor. The Supervisor shall report the results to the Society for review and determination as to whether the Owner's Certificate shall be renewed.

(h) At least once each year, the Supervisor shall audit the GC Certificate Holder's or Owner's (or the Owner's designee's) Certifying Engineer qualification activities to verify that the procedures are being followed and that records exist to support the qualification activities.

HAB-5130 ACCESS FOR INSPECTION AGENCY PERSONNEL[7]

HAB-5131 Access to the GC Certificate Holder's Facilities

(a) The GC Certificate Holder shall arrange for the Authorized Inspection Agency personnel to have free access at all times to those locations where Code activities, including those concerned with supply or manufacture of materials, are being performed on an item, when so requested. The GC Certificate Holder shall keep the Inspector informed of the progress of the work and shall notify the Inspector reasonably in advance when the item will be ready for any required tests or inspections.

(b) The GC Certificate Holder shall provide personnel to accompany the Inspector Supervisor during the Supervisor's required audits.

HAB-5132 Access to the Owner's Facilities

The Owner shall arrange for the Authorized Inspection Agency personnel to have free access to the Owner's facilities as required to perform duties under the Owner's agreement with the Authorized Inspection Agency (HAB-5121).

HAB-5200 DUTIES OF INSPECTORS

HAB-5210 GENERAL INSPECTION DUTIES

(a) The Inspector who performs the detailed inspections in compliance with this Subpart and Subsection HH shall witness or otherwise verify all examinations and make all inspections required by this Subpart and Subsection HH. The Inspector shall also make any other inspections and witness or verify (including making measurements) any other examinations and additional investigations that, in the Inspector's judgment, are necessary to ascertain whether the item being inspected has been constructed in compliance with the rules of this Subpart and Subsection HH. This shall include verification that the items being inspected have been constructed in accordance with the approved Design Drawings and Construction Specifications.

(b) The duties of the Inspector shall not be interpreted by virtue of these rules to extend to any construction requirements beyond those of this Subpart and Subsection HH that may be set forth in the Design Specification (HAB-3250) or on Design Drawings and Construction Specifications (HAB-3340). However, such requirements shall not result in construction that fails to conform with the requirements of this Subpart and Subsection HH (HAB-3252 and HAB-3450).

HAB-5220 CATEGORIES OF DUTIES FOR INSPECTORS

The duties of the Inspector shall include, but not necessarily be limited to, those given in (a) through (k) as follows:

(a) verifying the scope of work to be performed [HAB-5230(a)]

(b) monitoring the GC Certificate Holder's Quality Assurance Program including subcontracted activities (HAB-5240)

(c) reviewing the GC Certificate Holder's qualification records (HAB-5250)

(d) verifying materials (HAB-5260)

(e) witnessing or verifying in-process construction activities, examinations, and tests (HAB-5270)

(f) reviewing and signing Data Reports and Construction Reports (HAB-5290)

(g) reviewing drawings and inspecting in accordance with them

(h) monitoring the Code activities of the Owner

(i) assuring that Design Reports that are required by HAB-3352 are available

(j) performing all other duties specifically required in ASME QAI-1, Qualification for Authorized Inspection, as applicable

(k) verifying all preservice examinations have been completed to the Section XI edition specified [HAB-3252(b)]

HAB-5230 SCOPE OF WORK, DESIGN SPECIFICATIONS, AND DESIGN REPORTS

(a) The Inspector shall verify that the scope stated in the Certificate includes the work to be performed.

(b) The Inspector shall verify that the Design Specification, Design Drawings, Construction Specifications, Construction Reports, and Design Reports, when required, are on file and that they have been properly certified in accordance with HAB-3255, HAB-3360, and HAB-3380.

(c) The Inspector shall not be held responsible for the scope or adequacy of the Design Specifications, for the completeness or accuracy of the Design Report or calculations, for the information reported in the Construction Report, but shall verify that the certified document has been certified by a Certifying Engineer. The Owner or its designee, Designer, or Certificate Holder, on whose behalf the document has been certified, shall provide objective evidence that the Certifying Engineer has been qualified by the Owner or its designee, Designer, or Certificate Holder, in accordance with the requirements of this Subpart and Subsection HH.

HAB-5240 QUALITY ASSURANCE PROGRAMS

HAB-5241 Stipulation of Inspections Prior to Issuance of Process Sheets or Controls

Prior to the issuance of process sheets or controls required by HAB-4134.9, the GC Certificate Holder shall review them and the applicable drawings with the Inspector, who shall then stipulate the inspections intended to be performed in order to fulfill the requirements of HAB-5210.

HAB-5242 Monitoring of Quality Assurance Programs

(a) The Inspector shall monitor the performance of the GC Certificate Holder for conformity to the requirements of their Quality Assurance Program accepted by the Society. The Inspector shall verify that all changes to the Quality Assurance Manual have been accepted by the Authorized Inspection Agency before they are put into effect.

(b) The Inspector shall monitor the Owner's progress in compiling supporting data needed to complete the ASME Data Report Form N-3 (see Section III Appendices, Mandatory Appendix V).

HAB-5243 Process Control Checklist

The Inspector shall indicate concurrence on the GC Certificate Holder's process sheets or checklist that compliance has been attained at each stipulated point (HAB-5241).

HAB-5250 QUALIFICATION RECORDS

HAB-5251 Review of Qualification Records

The Inspector shall review the qualification records of the GC Certificate Holder.

HAB-5255 Examination Procedures

Inspectors shall assure themselves that the examination and testing procedures required by this Subpart and Subsection HH have been qualified. When there is a specific reason to question whether the examination or testing procedure requirements are being met, the Inspector may require requalification of the procedure.

HAB-5256 Nondestructive Examination Personnel

The Inspector has the duty to verify the qualification and certification of nondestructive examination (NDE) personnel employed by the Certificate Holder and has the duty to monitor the NDE activities and require requalification of any personnel when there is reason to question the performance of that person. In addition, the Inspector shall monitor the Certificate Holder's Quality Assurance Program as it relates to the NDE activities of Material Organizations and NDE subcontractors that the Certificate Holder qualified.

HAB-5260 MATERIALS AND CORE COMPONENTS

HAB-5261 Inspection of Materials for Compliance

Inspectors shall assure themselves that all materials used comply with all applicable requirements of this Subpart and Subsection HH. The GC Certificate Holder shall make available to the Inspector certified reports of the results of all tests performed in accordance with (a) and (b) as follows:

(a) the material specifications

(b) the requirements in Article HHA-2000 or Article HHB-2000, including certified reports of the results of all required tests and examinations performed.

HAB-5262 Dimensional Check

Inspectors shall assure themselves that the item is being constructed within the tolerances required by the Design Specification, Design Drawings, Construction Specifications, this Subpart, and Subsection HH.

HAB-5270 EXAMINATIONS AND TESTS

The Inspector shall witness examinations and tests, when feasible. Alternatively, the Inspector shall check the examination and test records to determine the acceptability of the items involved.

HAB-5290 DATA REPORTS AND CONSTRUCTION REPORTS

(a) The appropriate Data Reports prepared by the GC Certificate Holder shall be reviewed and signed by the Inspector only after they have been certified by a responsible representative of the GC Certificate Holder and after the Inspector is satisfied that all requirements of this Subpart and Subsection HH have been met and that each Data Report certified is a correct record. Certification by the Designer of the G-1 Data Report is also required prior to verification by the Inspector.

(b) The Inspector shall review and separately verify that the information contained in the Construction Report is valid and corresponds to the requirements of this Subpart and Subsection HH and that the Designer's review and certification of the Construction Report have taken account of all requirements of this Subpart and Subsection HH.

HAB-5300 RESPONSIBILITIES OF THE AUTHORIZED INSPECTION AGENCY

The responsibilities of the Authorized Inspection Agency shall include, but not necessarily be limited to, those given in (a) through (h) as follows:

(a) Maintain a staff of Inspectors (HAB-5123) and Inspector Supervisors (HAB-5122).

(b) Make agreements with GC Certificate Holders and Owners for inspection service (HAB-5121 and HAB-8130). Notify the Society whenever such agreements are terminated (HAB-5121).

(c) Provide for participation in the Society's review of the applicant's Quality Assurance Program (HAB-5125).

(d) Provide for the review and acceptance of any proposed modifications to Quality Assurance Manuals before they are put into effect (HAB-5125).

(e) Review and accept the GC Certificate Holder's method of marking material and Core Components.

(f) Review and accept the GC Certificate Holder's provisions of positive identification and traceability of items.

(g) Determine by agreement with the GC Certificate Holder the sequence for completion of the Data Reports.

(h) Perform all other duties specifically required in ASME QAI-1, Qualifications for Authorized Inspection, as applicable.

ARTICLE HAB-7000
REFERENCE STANDARDS

HAB-7100 GENERAL REQUIREMENTS

The standards and specifications referenced in the text of this Subpart and Subsection HH are listed in Table HAB-7100-1. When editions other than the referenced editions are used, the differences shall be reviewed to ensure that all technical requirements of the Code are satisfied. References to requirements of the ASME Boiler and Pressure Vessel Code are not included in this table.

(23)

Table HAB-7100-1
Standards and Specifications Referenced in This Subpart and Subsection HH

Standard ID	Published Title	Referenced Edition
	The American Society of Mechanical Engineers (ASME)	
ASME NQA-1	Quality Assurance Requirements for Nuclear Facility Applications	2015
ASME QAI-1	Qualifications for Authorized Inspection	Latest
	American Society for Testing and Materials (ASTM International)	
ASTM C625	Standard Practice for Reporting Irradiation Results on Graphite	2005
ASTM C781	Standard Practice for Testing Graphite and Boronated Graphite Materials for High-Temperature Gas-Cooled Nuclear Reactor Components	2008
ASTM C1783	Standard Guide for Development of Specifications for Fiber Reinforced Carbon–Carbon Composite Structures for Nuclear Applications	2015
ASTM C1793	Standard Guide for Development of Specifications for Fiber Reinforced Silicon Carbide–Silicon Carbide Composite Structures for Nuclear Applications	2015
ASTM C1835	Standard Classification for Fiber Reinforced Silicon Carbide–Silicon Carbide (SiC–SiC) Composite Structures	2016
ASTM C1836	Standard Classification for Fiber Reinforced Carbon–Carbon Composite Structures	2016
ASTM D7219	Standard Specification for Isotropic and Near-isotropic Nuclear Graphites	2008
ASTM D7301	Standard Specification for Nuclear Graphite Suitable for Components Subjected to Low Neutron Irradiation Dose	2008
	International Organization for Standardization (ISO)	
ISO/IEC 17025	General requirements for the competence of testing and calibration laboratories	2017

ARTICLE HAB-8000 CERTIFICATES AND DATA REPORTS

HAB-8100 AUTHORIZATION TO PERFORM CODE ACTIVITIES

HAB-8110 GENERAL

Authorization to certify work provided in this Subpart and Subsection HH (see Table HAB-8100-1) will be granted by the Society for a 3-yr period pursuant to the provisions set forth in this Article.

HAB-8120 SCOPE OF CERTIFICATES

(a) The certificate (HAB-3120) will identify the shop or field facility covered and state the scope of activities for which authorization is granted. The Society may, at its discretion, limit or extend the scope of an authorization to any types or classes of items or to a specific location.

(b) A Certificate of Authorization will be issued by the Society to an organization for certifying a data report form.

(c) The Society may, at any time, make regulations concerning the issuance and use of Certificates as it deems appropriate, and all regulations shall become binding upon the holders of a valid certificate.

HAB-8130 INSPECTION AGREEMENT REQUIRED

GC Certificate Holders and Owners shall possess an agreement with an Authorized Inspection Agency[8] to provide inspection and audit services. The agreement with the Authorized Inspection Agency shall be made prior to application for a survey or, in the case of the Owner, an interview. GC Certificate Holders and Owners shall notify the Society whenever their agreements with an Authorized Inspection Agency are canceled or changed to another Authorized Inspection Agency.

HAB-8140 QUALITY ASSURANCE PROGRAM REQUIREMENTS

It is a requirement that the Owner and Certificate Holder have a Quality Assurance Program (Article HAB-4000) that has been evaluated and accepted by the Society.

HAB-8150 APPLICATION FOR CERTIFICATION

An Organization desiring a Certificate shall apply to the Society upon forms issued by the Society describing the scope of Code activities to be performed.

HAB-8153 Code Activities Prior to Obtaining a GC Certificate

Code activities performed prior to issuance of a GC Certificate shall be subject to the acceptance of the Inspector.

HAB-8160 EVALUATION

HAB-8161 Evaluation for a Certificate

(a) Applicants for a new or renewed certificate for design or construction of Core Components or Core Assemblies require a survey of their shop or field facilities. The purpose of the survey is to evaluate the applicant's Quality Assurance Manual and the implementation of the Quality Assurance Program.

(b) The extent of the survey will be determined by the Society based on a review of the applicant's intended scope of Code activities described in the application. The acceptance by the Society of the Quality Assurance Program shall not be interpreted to mean endorsement of technical capability to perform design work such as system design or stress analysis, where the scope of the certificate includes such activities. Such capability is implied for the specific component involved by the certification of Design Reports (HAB-3360) by a Certifying Engineer on behalf of the Certificate Holder.

HAB-8162 Evaluation for an Owner's Certificate

(a) The Owner, after receipt of notification from the regulatory authority that an application for a construction permit or combined license for a specific plant has been docketed, shall obtain an Owner's Certificate (HAB-3230) from the Society for unit(s) docketed concurrently for each nuclear power plant site prior to field installation. In lieu of a survey, the Owner will be interviewed by the Society to verify the Owner's understanding of Code responsibilities (HAB-3220) and to obtain the Owner's agreement to meet the requirements.

(b) The Owner's Certificate (HAB-3230) shall be applicable to nuclear power plant unit(s) docketed concurrently for each site.

HAB-8170 ISSUANCE

Each GC Certificate Holder or G Certificate Holder shall have agreed that each Certificate is at all times the property of the Society, that it will be used according to the rules and regulations of this Subpart and Subsection HH, and that the Certificate will be promptly returned to the Society upon demand, or when the GC Certificate

Holder or G Certificate Holder discontinues the scope of Code activities covered by its Certificate. The holder shall not permit any other party to use its Certificate. The Society reserves the absolute right to cancel or refuse to renew such authorization, returning fees paid for the prorated unexpired term.

HAB-8180 RENEWAL

HAB-8181 Certificates of Authorization, Certificates of Authorization (Corporate), and Quality Assurance Program Certificate Holders

(a) Not later than 6 months prior to the date of expiration of any Certificate, the GC Certificate Holder or G Certificate Holder shall apply for a renewal of such authorization and the issuance of a new Certificate.

(b) A Certificate issued for a specific field site, or a Certificate that has been extended to a specific field site activity, is valid for the duration of the contract at the specified site or 3 yr, whichever occurs first.

HAB-8182 Owner's Certificate

(a) Annually, the Authorized Nuclear Inspector Supervisor shall audit the Owner's Quality Assurance Program and report the results to the Society for review and determination as to whether the certificate shall remain valid.

(b) Triennially, the Authorized Nuclear Inspector Supervisor shall audit the Owner's Quality Assurance Program and report the results to the Society for review and determination as to whether the Owner's Certificate shall be renewed.

(c) The Owner's Certificate expires when all N-3 Data Reports for the units listed on the Certificate have been completed. Triennially, the Society shall review the status of construction and determine whether the Owner's Certificate shall be renewed.

HAB-8200 NAMEPLATES

The Core Assembly shall not be issued with a nameplate. The G-1 Data Report shall take the place of the nameplate. The G-1 Data Report shall be traceable to the serial number of the vessel in which the Core Assembly is installed.

HAB-8400 DATA REPORTS

HAB-8410 GENERAL REQUIREMENTS

The appropriate Data Report,[9] as specified in Table HAB-8100-1, shall be filled out by the G Certificate Holder, GC Certificate Holder, Material Organization, or Owner and shall be signed by the G Certificate Holder, GC Certificate Holder, Material Organization, or Owner and the Inspector for each item.

HAB-8411 Compiling Data Report Records

Data Reports (G-1, G-2, and G-4), which are the basis for approval of the final G-1 Data Report, may be compiled in any one of the following methods:

(a) by attaching each Data Report for items that make up that Core Assembly to its respective Data Report Form G-1, or

(b) by assigning each Data Report for items that make up the Core Assembly a unique identifying number and listing the numbers on Data Report Form G-1, or

(c) by attaching a drawing that uniquely identifies each item that makes up the Core Assembly to its respective Data Report Form G-1.

HAB-8412 Availability of Data Reports

All Data Reports and referenced supporting material shall be available to the Inspector and enforcement authority having jurisdiction at the location of the nuclear power plant site.

HAB-8420 OWNER'S DATA REPORT

The Owner who has obtained an Owner's Certificate shall be responsible for completing one or more of Form N-3 (see Section III Appendices, Mandatory Appendix V). The Owner shall certify, by signing the form, that each GC Certificate Holder, G Certificate Holder, or Material Organization was the holder of the appropriate Certificate and that components and installation comply with the applicable requirements of this Section. Review of the completed Owner's Data Report Form N-3 (see Section III Appendices, Mandatory Appendix V), including attached Data Reports for all components and installation as required to verify Code Compliance, shall be the authority of the Inspector to sign the Owner's Data Report.

Table HAB-8100-1
Certificates Issued by the Society for Construction of Nuclear Core Components and Core Assemblies

Type	Scope	Data Report Form	Notes
G Certificate Holder	Design	G-1	(1)
GC Certificate Holder	Construction	G-1	(1)
	Material manufacture	None	(2)
	Core Component machining	G-2	(3)
	Installation	G-4	(4)
Quality Systems Certificate Holder	Material manufacture	None	(2)
	Core Component machining	G-2	(3)
	Installation	G-4	(4)
Owner	Owner	N-3	...

NOTES:
(1) The G-1 Data Report shall be traceable to the serial number for the vessel in which it is installed.
(2) Material (HAB-1220) shall be documented by a Certified Material Test Report in accordance with Article HHA-2000 or Article HHB-2000.
(3) Data Report Form G-2 for Core Components shall be forwarded in duplicate to the GC Certificate Holder of the finished Core Assembly.
(4) Data Report Form G-4 for installation shall be forwarded in duplicate to the GC Certificate Holder of the finished Core Assembly.

ARTICLE HAB-9000 GLOSSARY

HAB-9100 INTRODUCTION

This Article defines selected terms used in this Subpart and Subsection HH. The definitions in this Glossary shall prevail should a conflict exist with definitions found elsewhere in this Subpart and Subsection HH or other documents referenced in this Subpart and Subsection HH. Unless defined below, the definitions of Article NCA-9000 shall apply.

(23) HAB-9200 DEFINITIONS

advanced ceramic: a highly engineered, high-performance, predominately nonmetallic, inorganic, ceramic material having specific functional attributes.

approved supplier: a supplier that has been evaluated and approved by a Material Organization or GC Certificate Holder in accordance with the requirements of HAB-4550.

billet: an extruded, molded, or isomolded graphite artefact with dimensions sufficient to meet the Designer's requirements for Core Components.

carbon–carbon (C–C): a specific type of ceramic composite comprising carbon-based fibers in a carbon matrix.

ceramic: refractory, inorganic, and nonmetallic material made from compounds of a metal and a nonmetal displaying ionic and covalent primary atomic bonding and arranged in either crystalline or partly crystalline microstructure.

Ceramic Composite Material: as used in this Subpart, a ceramic matrix composite material, either a carbon–carbon or a silicon-carbide/silicon-carbide material system.

ceramic matrix composite (CMC): a material consisting of two or more materials (insoluble in one another) in which the major continuous component (matrix component) is a ceramic, while the secondary component(s) (reinforcing component) may be ceramic, glass-ceramic, metal, or organic in nature. These components are combined on a macroscale to form a useful engineering material possessing certain properties or behaviors not possessed by the individual constituents.

Certificate: a Certificate of Authorization, Quality Systems Certificate (Materials), or Owner's Certificate issued by the Society.

Composite Core Component: a single finished Ceramic Composite Material item complying with the requirements of this Subpart and Subsection HH, Subpart B.

construction: all operations required to build the Core Assembly (manufacture materials, machine Core Components, and install) in accordance with Design Drawings and the Construction Specification.

construction procedure: a written description of installation methods the Installer uses to ensure conformance with the requirements of the Construction Specification, Design Drawings, this Subpart, and Subsection HH, Subpart A or Subpart B.

construction report: a report prepared by the GC Certificate Holder that summarizes activities performed to construct the component in accordance with the Construction Specification, Design Drawings, and the requirements of this Subpart and Subsection HH, Subpart A or Subpart B.

continuous-fiber-reinforced ceramic matrix composite (CFCC): a ceramic matrix composite in which the reinforcing phase(s) consist of continuous filaments, fibers, yarn, braid, or knitted or woven fabrics.

Core Assembly: the assembly of Core Components that comprise the reactor core, excluding fuel elements.

Core Component: a single machined graphite or ceramic composite item complying with the requirements of this Subpart and Subsection HH, Subpart A or Subpart B.

Core Component manufacturer: the party that machines the Core Components from the graphite or ceramic composite material.

damage dose: measure of the interaction of a specific fluence with the material based on the flux, flux spectrum, and the time that the material was subjected to irradiation.

Designer: the organization responsible for preparation of Design Output Documents.

dpa: displacements per atom, damage dose unit.

fluence: fast neutron fluence, at designer defined energy for fast neutron based on reactor energy spectrum.

fuel block: in a prismatic reactor, the graphite block into which the fuel compacts (fuel elements) are inserted.

fuel elements: fuel compacts in a prismatic reactor or fuel spheres in a pebble bed reactor.

G Certificate Holder: the organization assuming responsibility for Code compliance with respect to design of Core Components or Core Assemblies.

GC Certificate Holder: the organization assuming responsibility for Code compliance with respect to material, manufacture, installation, examination, testing, inspection, and certification of Core Components or Core Assemblies in accordance with the Design Drawings and Construction Specification.

generated data: material data generated in accordance with the requirements of the material and purchase specification.

graphite: as used in this Subpart and Subsection HH, Subpart A, the carbonaceous material (e.g., petroleum coke and coal tar pitch) that is formed and heated to 4,550°F (2 500°C) or greater and has a predominantly hexagonal crystalline structure.

Graphite Core Component: a single machined graphite item complying with the requirements of this Subpart and Subsection HH, Subpart A.

graphite grade: the designation given to a graphite material by a manufacturer such that it is always reproduced from the same raw materials, to the same specifications, using the same process.

graphitizing charge: the billets of the same graphite grade in the same graphitizing furnace run.

Inspector: an employee of an Authorized Inspection Agency who has qualifications for and has been properly qualified for Core Components and Core Assemblies in accordance with HAB-5123.

Inspector Supervisor: an employee of an Authorized Inspection Agency who has been assigned by that agency to oversee and direct the work of one or more Inspectors and who has qualifications for and has been properly qualified for Core Components and Core Assemblies in accordance with HAB-5122.

installation: those actions required to construct the Core Assembly from the Core Components.

Installer: the party installing the Core Components.

irradiated: subjected to irradiation to a sufficiently large damage dose to alter the properties of the material.

irradiation temperature: the temperature at which a Core Component or Core Assembly operates while under irradiation.

item: a product manufactured or installed under a Certificate of Authorization (HAB-3120), or material (HAB-1220).

Material Manufacturer: the party that manufactures the graphite or ceramic composite material.

Material Organization: an organization certified by holding a Quality Systems Certificate issued by the Society, or qualified by a Certified Material Organization or GC Certificate Holder, in accordance with the requirements of HAB-3800.

monitor: observe or check compliance with this Subpart and Subsection HH, and the Owner's, G Certificate Holder's, or GC Certificate Holder's Quality Assurance Program. This activity is not necessarily documented or required to be continuous.

nonirradiated: not subjected to irradiation or subjected to irradiation at a sufficiently low damage dose as to not alter the properties of the material.

oxidized: subject to gasification and weight loss with a deleterious effect on material properties.

Quality Systems Certificate: a Certificate issued by the Society that permits an organization to perform specified Material Organization activities in accordance with Code requirements.

service: an activity performed by a subcontractor such as designing, machining, installation, repair, and nondestructive examination.

shop and field drawings: drawings provided by the Core Component manufacturer or Installer that describe construction details, physical dimensions, arrangements, and any significant engineering features needed to establish conformance to the Design Drawings, Construction Specification, this Subpart, and Subsection HH, Subpart A or Subpart B.

silicon-carbide/silicon-carbide (SiC–SiC): a specific type of ceramic composite comprising silicon-carbide-based fibers in a silicon-carbide matrix.

slow crack growth (SCG): subcritical crack growth (extension) that may result from, but is not restricted to, such mechanisms as environmentally assisted stress corrosion or diffusive crack growth.

stress-temperature-time states: a material's structural changes arising from combinations of stress, temperature, and time.

structural reliability class: the class allocated to a Core Component by the Designer that defines the component's desired reliability.

witness coupons: composite bars, panels, or tubes of the same composition and architecture, coprocessed in the same lot/batch and with the same nominal thickness as the composite component. Witness coupons are prepared and used when test coupons/sections cannot be effectively or economically cut from a composite component.

SUBSECTION HB
CLASS A METALLIC PRESSURE BOUNDARY COMPONENTS

SUBPART A
LOW TEMPERATURE SERVICE

ARTICLE HBA-1000
INTRODUCTION

HBA-1100 GENERAL

HBA-1110 SCOPE

The rules of this Subsection HB, Subpart A constitute the requirements associated with Class A metallic components used in the construction of high temperature reactor systems and their supporting systems when subjected to low temperature service.

(a) Subsection HB, Subpart A provides rules for the material, design, fabrication, examination, installation, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of metallic pressure boundary components that are intended to conform to the requirements for Class A construction for service when Service Loading temperatures do not exceed the appropriate temperature limits established in Table HAA-1130-1 for the material under consideration.

(b) The rules of Subsection HB, Subpart A are contained in Division 1, Subsection NB, except for those paragraphs or subparagraphs (with numbered headers) replaced by corresponding numbered HBA paragraphs or subparagraphs in this subpart or new numbered HBA paragraphs or subparagraphs added to this Subpart.

(c) Division 1 rules may use different terminology than Division 5 (e.g., Class 1 versus Class A, etc.), but the application of these rules is identical for Division 5 use.

(d) The rules of this Subpart cover the requirements for strength and pressure integrity of items, the failure of which would violate the pressure-retaining boundary. The rules cover initial construction requirements, but do not cover deterioration that may occur in service as a result of corrosion, radiation effects, or instability of materials.

(e) This Subpart does not contain rules to cover all details of construction of Class A vessels and components. Where complete details are not provided in this Subpart, it is intended that the N Certificate Holder, subject to the approval of the Owner or its designee and acceptance by the Inspector, shall provide details of construction that will be consistent with those provided by the rules of this Subpart.

(23)

ARTICLE HBA-2000 MATERIALS

HBA-2600 METALLIC MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

HBA-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b), Material Organizations shall have a Quality System Program that meets the requirements of Division 1, NCA-3300.

(b) The requirements of Division 1, NCA-1225 and Division 1, NCA-4256 shall be met as required by Division 1, NB-2130 and Division 1, NB-2150, respectively. The other requirements of Division 1, NCA-3300 and Division 1, NCA-4200 need not be used by Material Organizations for small products, as defined in (c) below; for material used in items commensurate with their contribution to safety or risk, as defined in (d) below; for brazing material; and for material that is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (see Division 1, NCA-4100) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (5) below.

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges NPS 2 (DN 50) and less

(2) bolting material, including studs, nuts, and bolts of 1-in. (25-mm) nominal diameter and less

(3) bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less

(4) material for pumps and valves with inlet pipe connections of NPS 2 (DN 50) and less

(5) material exempted by Division 1, NB-2121(c)

(d) For the purpose of this paragraph, items commensurate with their contribution to safety or risk are defined as given in (1) and (2) below.

(1) The Owner or the Owner's designee has established that the exemption is consistent with the safety or risk significance of the item. The determination of the safety or risk significance of the item to design and operations is beyond the scope of this Section. Appropriate guidance for the safety or risk significance of the item shall be derived from system criteria documents for specific types of nuclear power systems and may be found in the requirements of regulatory and enforcement authorities having jurisdiction at the site.

(2) The Owner or the Owner's designee has permitted the exemption in the Design Specification and shall specify to which items this exemption applies.

ARTICLE HBA-7000
OVERPRESSURE PROTECTION

HBA-7800 MARKING, STAMPING WITH CERTIFICATION MARK, AND DATA REPORTS

HBA-7810 PRESSURE RELIEF VALVES

HBA-7811 Marking and Stamping With Certification Mark

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data herein in such a way that the marking will not be obliterated in service. The data shall be in characters not less than $^{3}/_{32}$ in. (2.5 mm) high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Certification Mark shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

(a) the name, or an acceptable abbreviation, of the Certificate Holder

(b) Certificate Holder's design or type number

(c) size ________NPS (DN) of the valve inlet

(d) set pressure ________psi (kPa)

(e) certified capacity and overpressure in percent or psi (kPa):

(1) lb/hr (kg/h) of saturated steam for valves certified on steam

(2) scfm (standard cubic feet per minute) at 60°F (15°C) and 14.7 psia (101 kPa) of air for valves certified on air or gas, or

(3) gal/min of water at 70°F (20°C) for valves certified on water

(f) applicable official Certification Mark, as shown in Table HAA-8110-1

In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and NB-3593.2.

ARTICLE HBA-8000
NAMEPLATES, STAMPING WITH THE CERTIFICATION MARK, AND REPORTS

HBA-8100 REQUIREMENTS

The applicable requirements given in Article HAA-8000 shall apply to Class A metallic pressure boundary components.

SUBPART B
ELEVATED TEMPERATURE SERVICE

ARTICLE HBB-1000
INTRODUCTION

HBB-1100 GENERAL

HBB-1110 SCOPE

The rules of this Subsection HB, Subpart B constitute the requirements associated with Class A metallic components used in the construction of high temperature reactor systems and their supporting systems when subjected to elevated temperature service.

(a) Subsection HB, Subpart B provides rules for the material, design, fabrication, examination, installation, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of metallic pressure boundary components or portions of those components, including parts and appurtenances, that are intended to conform to the requirements for Class A construction for service when Service Loading temperatures exceed the appropriate temperature limits established in Table HAA-1130-1 for the material under consideration. These zones of elevated temperature service shall have their finalized geometry descriptions and temperature profile details finalized in the Design Report prior to any fabrication and examination efforts.

(b) References to Appendices are to the Section III Appendices, unless otherwise identified as a Subsection HB, Subpart B Appendix, or other subsection-specific Appendix.

(c) The rules of this Subpart are applicable to Class A components independent of the type of contained fluid — water, steam, sodium, helium, or any other process fluid.

(d) The stress limits and design rules of Division 1, Subsection NB are applicable only to service conditions where creep and relaxation effects are negligible. Consequently, the rules of Division 1, Subsection NB only guard against the time-independent failure modes — ductile rupture, gross distortion (buckling and incremental collapse), and fatigue. Therefore, those portions of the component, part, or appurtenance that are at all times experiencing temperatures within the range covered by Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 may be designed in compliance with the rules of Article HBB-3000, or alternatively, in compliance with the rules of Division 1, Article NB-3000. In addition, the rules of Subsection HB, Subpart B extend specific rules of Division 1, Article NB-3000 to elevated temperature service, provided the designer can demonstrate that the combined effects of temperature, stress level, and duration of loading do not introduce significant creep effects.

(e) At temperatures and loading conditions where creep effects are significant, the design analysis shall also consider the time-dependent material properties and structural behavior by guarding against the four modes of failure shown below:

(1) ductile rupture from short-term loadings

(2) creep rupture from long-term loadings

(3) creep–fatigue failure

(4) gross distortion due to incremental collapse and ratcheting

(f) Brief guidelines are also provided in Subsection HB, Subpart B for the three modes of failure shown below:

(1) loss of function due to excessive deformation

(2) buckling due to short-term loadings

(3) creep buckling due to long-term loadings

(g) Design procedures and materials data not contained in Subsection HB, Subpart B may be required to ensure the integrity or the continued functioning of the structural part during the specified service life. For example, the rules do not provide methods to evaluate deterioration that may occur in service as a result of corrosion, mass transfer phenomena, radiation effects, or other material instabilities. Nor do the rules ensure continued functional performance of deformation-sensitive structures such as valves and pumps.

(h) Mandatory Appendix HBB-II of this Subpart addresses limited elevated temperature service for components fabricated from SA-533 Type B, Class 1 plates; SA-508 Grade 3, Class 1 forgings; and their weldments.

HBB-1120 TEMPERATURE AND SERVICE LIFE LIMITS

The rules of Subsection HB, Subpart B shall not be used for structural parts that will be subjected either to metal temperatures or to times greater than those values associated with the S_{mt} data for the specified material (see Mandatory Appendix HBB-I-14).

HBB-1130 ORGANIZATION OF SUBSECTION HB, SUBPART B

In general, the numbering of rules in Subsection HB, Subpart B follows the numbering system used in Division 1, Subsection NB. References to Appendices are to the Section III Appendices unless otherwise identified as Subsection HBB Appendices.

ARTICLE HBB-2000
MATERIAL

HBB-2100

HBB-2120 PRESSURE-RETAINING MATERIALS

HBB-2121 Permitted Material Specifications

(a) All materials shall comply with the rules of Division 1, Article NB-2000, except for those paragraphs replaced by correspondingly numbered paragraphs of Subsection HB, Subpart B.

(b) In complying with (a) above, the base and weld material specifications of Tables HBB-I-14.1(a) and HBB-I-14.1(b), Tables HBB-I-14.10A-1 through HBB-I-14.10E-1, and Table HBB-I-14.11 and the allowable stress intensities in Tables HBB-I-14.3A through HBB-I-14.3E, and Figures HBB-I-14.13A through HBB-I-14.3C shall be considered extensions of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(c) Pressure-retaining material and material welded thereto, except for temporary or nonstructural attachments as per Division 1, NB-4435 and in (h) below, and except for hard surfacing metals and cladding which is 10% or less of the thickness of the base material, shall conform to the requirements of one of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, including all applicable footnotes in the table, and to all of the special requirements of this Article which apply to the product form in which the material is used.

(d) The requirements of this Article do not apply to items not associated with the pressure-retaining function of a component such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies.

(e) Material made to specifications other than those specified in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 may be used for safety valve disks and nozzles, when the nozzles are internally contained by the external body structure, and for valve disks in line valves whose inlet connections are NPS 2 (DN 50) and less.

(f) Material for instrument line fittings, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, provided that the fittings are in conformance with the requirements of Division 1, NB-3671.4 and the material is determined to be adequate for the service conditions by the piping system designer.

(g) Welding material used in the manufacture of items shall comply with Table HBB-I-14.1(b) and the SFA specifications in Section II, Part C, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to material used as backing rings or backing strips in welded joints.

(h) Attachments welded to a pressure boundary (including the weld metal used to make the attachment) expecting elevated temperature service need not comply with the limits on upper values of service temperatures and times, as stated in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, provided the rules listed below are met.

(1) The design of the welded attachment complies with the rules in HBB-3354.

(2) The attachment material and weld are of similar alloy composition to the pressure boundary material.[10]

HBB-2123 Design Stress Intensity Values

Design stress intensity values for material are listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, as extended in coverage by the rules of HBB-2121(b). With the exception of attachment material covered by HBB-2121(h), no material shall be used at metal and design temperatures above those for which values are given.

HBB-2160 DETERIORATION OF MATERIAL IN SERVICE

(a) Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3211.19), with specific attention being given to the effects of service conditions upon the properties of the material.

(b) Special consideration shall be given to the influence of elements such as copper and phosphorus on the effects of irradiation on the properties of material (including welding material) in the core belt line region of the reactor vessel. Any special requirement shall be specified in the Design Specifications [NCA-3211.19(b) and Division 1, NB-3124]. When so specified, the check analysis shall be made in accordance with the base metal specification and in accordance with Division 1, NB-2420 for the welding material.

(c) The combination of fabrication induced cold working and subsequent elevated temperature service may affect time-dependent material properties.

(d) Long-time, elevated temperature, service may result in the reduction of the subsequent yield and ultimate tensile strengths.

(1) For 304 and 316 austenitic stainless steels and Alloy 800H, the tensile strength and yield strength reduction factors, of Table HBB-3225-2, are selected to correspond to the maximum wall-averaged temperature achieved during any Level A, B, or C Service Loading.

(2) For 2¹/₄Cr-1Mo and 9Cr-1Mo-V, the tensile strength and yield strength reduction factors are based on the specific cumulative time history of the wall-averaged temperature. The procedure to define this effect is as follows:

(-a) Partition the entire time history of the wall-averaged temperature of all Level A, B, and C Service Loadings into, n, discreet temperature intervals.

(-b) The temperature of each interval, i, is defined to coincide with the maximum of the interval, and is represented as T_i (°F). The total service time (hours) specified for that temperature interval is represented as t_i.

(-c) The hours, t_i, within each temperature interval, i, are converted to equivalent hours, $(t_{equiv})_i$, corresponding to the temperature of the highest temperature interval, T_{max}. The equivalent hours, $(t_{equiv})_i$, at temperature T_i, are defined as:

$$\log_{10}\left(t_{\text{equiv}}\right)_i = \left[10 + \log_{10}\left(t_i\right)\right]\left(T_i + 460_i\right)/\left(T_{\max} + 460\right) - 10$$

(-d) Define the total equivalent hours, t_{equiv}, as:

$$t_{\text{equiv}} = \sum_{i=1}^{n}\left(t_{\text{equiv}}\right)_i$$

(-e) From Table HBB-3225-2, obtain the strength reduction factors corresponding to t_{equiv} hours of service at a temperature of T_{max}.

(3) When the yield and ultimate tensile strengths are reduced by the elevated temperature service, it is necessary to appropriately reduce the values of S_{mt} and S_m. To reflect the effects of long-time elevated temperature service, the S_{mt} values of Tables HBB-I-14.3A through HBB-I-14.3E shall be redefined as the lower of (-a) through (-f) below, and the values of S_m shall be defined as the lower of (-b) through (-f) below:

(-a) the S_{mt} value in Tables HBB-I-14.3A through HBB-I-14.3E;

(-b) the product of one-third of the specified minimum tensile strength at room temperature (Table HBB-3225-1) and the tensile strength reduction factor (Table HBB-3225-2);

(-c) the product of one-third of the tensile strength at temperature (Table HBB-3225-1) and the tensile strength reduction factor (Table HBB-3225-2);

(-d) the product of two-thirds of the specified minimum yield strength at room temperature (Table HBB-I-14.5) and the yield strength reduction factor (Table HBB-3225-2);

(-e) for 2¹/₄Cr-1Mo and 9Cr-1Mo-V, the product of two-thirds of the yield strength at temperature (Table HBB-I-14.5) and the yield strength reduction factor (Table HBB-3225-2);

(-f) for 304 and 316 austenitic stainless steels and Alloy 800H, the product of 90% of the yield strength at temperature (Table HBB-I-14.5) and the yield strength reduction factor (Table HBB-3225-2).

(4) The yield and tensile strength reduction factors (see Table HBB-3225-2) are based on the ratio of the average strength after exposure to elevated temperature to the tabulated yield strength (see Table HBB-I-14.5) or tabulated tensile strength (see Table HBB-3225-1) as applicable. There is no credit for strength increase so the maximum factor is 1.0.

HBB-2400

HBB-2430

HBB-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, nor A-No. 8 weld filler metal to be used for weld metal cladding.

HBB-2433.1 Method. Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of Division 1, NB-2432 in conjunction with Figure NB-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS A4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with Division 1, NB-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

HBB-2433.2 Acceptance Standards. For design temperatures up to and including 800°F (425°C), the minimum acceptable delta ferrite shall be 5 FN (Ferrite Number). For design temperatures exceeding 800°F (425°C), the delta ferrite shall be limited to the range 3 FN to 10 FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of Division 1, NB-2130 or NB-4120.

HBB-2500

HBB-2530

HBB-2539 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of Division 1, NB-2539.1 through NB-2539.7 are met. The weld material used to make weld repairs shall meet the requirements of Table HBB-I-14.1(b) and Division 1, NB-2400. Additional requirements may be listed in the Design Specifications, as per Division 1, NB-2160, to assure that the repair weld is adequate for the service conditions. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

(23) HBB-2600

HBB-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program that meets the requirements of Division 1, NCA-3300.

(b) The requirements of Division 1, NCA-1225 and Division 1, NCA-4256 shall be met as required by Division 1, NB-2130 and Division 1, NB-2150, respectively. The other requirements of Division 1, NCA-3300 and Division 1, NCA-4200 need not be used by Material Organizations for small products, as defined in (c) below: for material used in items commensurate with their contribution to safety or risk, as defined in (d) below; for brazing material; and for material that is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (see Division 1, NCA-4100) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as follows:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges NPS 2 (DN 50) and less

(2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less

(3) bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less

(4) material for pumps and valves with inlet pipe connections of NPS 2 (DN 50) and less

(5) material exempted by Division 1, NB-2121(c)

(d) For the purpose of this paragraph, items commensurate with their contribution to safety or risk are defined as given in (1) and (2) below.

(1) The Owner or the Owner's designee has established that the exemption is consistent with the safety or risk significance of the item. The determination of the safety or risk significance of the item to design and operations is beyond the scope of this Section. Appropriate guidance for the safety or risk significance of the item shall be derived from system criteria documents for specific types of nuclear power systems and may be found in the requirements of regulatory and enforcement authorities having jurisdiction at the site.

(2) The Owner or the Owner's designee has permitted the exemption in the Design Specification and shall specify to which items this exemption applies.

HBB-2800 FATIGUE ACCEPTANCE TEST

(a) For 304 and 316 austenitic stainless steel components intended for service where conditions for Levels A, B, and C do not satisfy the limits of HBB-T-1324(a) and HBB-T-1324(b), a uniaxial fatigue acceptance test of each lot of material shall be performed.

(b) The fatigue test shall be performed in air at 1,100°F (595°C) at an axial strain range of 1.0% with a 1-hr hold period at the maximum positive strain point in each cycle. Test-specimen location and orientation shall be in accordance with the general guidance of SA-370, paras. 6.1.1 and 6.1.2 and the applicable product specifications. Testing shall be conducted in accordance with ASTM Standard E 606. The test shall exceed 200 cycles without fracture or a 20% drop in the load range.

(c) Failure to meet this requirement shall be cause for rejection of the lot for use in Class A elevated temperature components.

(d) The definition of "lot" shall be obtained from the material specification. Where more than one definition is provided by the specification, the definition used to establish the tensile properties shall govern. Either the Material Organization or N-Type Certificate Holder may perform the lot qualification test.

(e) Retesting is permitted. Two additional specimens shall be tested and both specimens must pass the cyclic life requirement. Further retests are not permitted.

ARTICLE HBB-3000
DESIGN

HBB-3100 GENERAL REQUIREMENTS FOR DESIGN

HBB-3110 SCOPE, ACCEPTABILITY, AND LOADINGS

HBB-3111 Scope

(a) Article HBB-3000 is a self-contained set of design rules for metal structures serving as component pressure-retaining boundaries under temperatures that may at times exceed those for which design stress-intensity values S_m are given in Section II, Part D, Subpart 1.

(b) The design rules of Division 1, Article NB-3000 shall apply only where specifically called out by the rules of Subsection HB, Subpart B.

HBB-3111.1 Acceptability. An acceptable design of a Class A Component for elevated temperature service is one that

(a) is capable of meeting the functional requirements as specified in the Design Specifications (NCA-3211.19); and

(b) satisfies the requirements for a design by analysis, either in HBB-3200 or in the Design Rules for components, while under the loadings described in HBB-3111.2 and the Design Specifications; and

(c) satisfies the general design rules of HBB-3130 and the applicable design rules for components that apply to a vessel (HBB-3300), pump (HBB-3400), valve (HBB-3500), or piping (HBB-3600). The Design Specifications shall state which subarticle applies to the given component.

(d) As an alternative to (b) and (c) above, the rules of Division 1, Article NB-3000 may be applied to those portions of the component that never experience temperatures that exceed the temperature limit in the applicability column for which design stress-intensity values are given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

HBB-3111.2 Loadings. The loadings that shall be taken into account in designing a component include, but are not limited to, the following:

(a) internal and external pressure;

(b) weight of the component and its normal contents under service or test loadings, including additional pressure due to static and dynamic head of liquids;

(c) superimposed loads such as from other components, operating equipment, insulation, corrosion-resistant or erosion-resistant linings and piping;

(d) wind loads, snow loads, vibrations, and earthquake loads where specified;

(e) reactions of supporting lugs, rings, saddles, or other types of supports;

(f) temperature effects;

(g) impact forces caused by either external or internal events.

HBB-3112 Design Parameters

(a) The design parameters are the pressures, temperatures, and mechanical load forces applicable to the design of nuclear power plant components. The simplest set of design parameters would consist of the temperature, pressure, and load forces that exist at some given time.

(b) To design a zone of a component for service at elevated temperature, two types of design parameter data are needed in the Design Specifications (NCA-3211.19): first, an expected loading history which consists of how each design parameter varies as a function of time; and second, a list of events that occur under each loading category defined in HBB-3113.

(c) The design parameter data stipulated in (1) and (2) below shall be specified in the Design Specifications (NCA-3211.19) for each component:

(1) the loading event history to be used in the structural analysis;

(2) the design parameters from which the designer will determine the most severe loading for each loading category defined in HBB-3113. (If fluid conditions are specified, the designer eventually must convert the data to metal temperatures and surface pressures.)

(d) It is permissible for the designer to establish the zone boundaries inside the component. However, the zone boundaries and applicable design parameters shall be fully described in the Design Report.

HBB-3112.1 Specified Pressure.

(a) The specified internal and external pressure histories shall describe pressure values not less than the maximum pressure differences between the inside and outside of the pressure boundary in a given zone of the component, or between any two chambers of a combination unit.

(b) The specified pressure histories shall be used in the computations made to show compliance with the limits of HBB-3200.

(c) All pressures referred to in this Article are to be taken as the value above atmospheric pressure unless otherwise stated.

HBB-3112.2 Specified Temperature. The specified temperature history for the loading category shall enable the designer to describe a temperature value not less than the maximum local wall averaged temperature that will exist in the structural metal in a given zone of the component. And for the particular analyses of Service Loadings (HBB-3113.2), the designer shall determine the history of the maximum local metal temperature in a given zone and shall use these metal temperature histories in the computations to show compliance with the limits of HBB-3200.

(a) All temperatures referred to in this Article are the metal temperatures expressed in degrees Fahrenheit (°F) or degrees Celsius (°C).

(b) Where a component is heated by trace heating, induction coils, jacketing, or by internal heat generation, the designer shall consider the effect of such heating in the establishment of the design temperature histories.

(c) Elevated temperature mechanical properties are extremely sensitive to temperature. The Design Specifications shall specify any inaccuracies in temperature measurement and prediction that are to be considered in the design analyses made to show compliance with the limits of HBB-3200.

HBB-3112.3 Specified Mechanical Load Forces. The specified load forces for a given loading category (HBB-3113) shall define all expected mechanical loadings that must be considered in design analysis computations made to show compliance with the limits of HBB-3200.

HBB-3113 Loading Categories

Loading categories used in this Subsection consist of Design Loading, Service Loadings (Levels A, B, C, and D), and Test Loadings.

HBB-3113.1 Design Loadings. The specified design parameters for the Design Loadings category shall equal or exceed those of the most severe combination of coincident pressure, temperature, and load forces specified under events which cause Service Level A Loadings (HBB-3113.3) for the same zone of the component. These specified design parameters for Design Loadings shall be called Design Temperature, Design Pressure, and Design Mechanical Loads. These specified design parameters shall be used in computations to show compliance with the requirements on Design Limits in HBB-3222.1.

HBB-3113.2 Service Loadings. Each loading to which the component may be subjected shall be categorized in accordance with the following definitions and shall be described in the Design Specifications (NCA-3211.19) in such detail as will provide a complete basis for construction in accordance with these rules. The Service Loading categories shall be as defined in HBB-3113.3, HBB-3113.4, HBB-3113.5, and HBB-3113.6.

HBB-3113.3 Level A Service Loadings. Level A Service Loadings are any loadings arising from system start-up, operation in the design power range, hot standby, and system shut-down, and excepting only those loadings covered by Level B, C, and D Service Loadings or Test Loading.

HBB-3113.4 Level B Service Loadings. (From incidents of moderate frequency.) These are deviations from Level A Service Loadings that are anticipated to occur often enough that design should include a capability to withstand the loadings without operational impairment. The events which cause Level B Service Loadings include those transients which result from any single operator error or control malfunction, transients caused by a fault in a system component requiring its isolation from the system, and transients due to loss of load or power. These events include any abnormal incidents not resulting in a forced outage and also forced outages for which the corrective action does not include any repair of mechanical damage. The estimated duration of a Level B Service Loading shall be included in the Design Specifications.

HBB-3113.5 Level C Service Loadings. (From infrequent incidents.) These are deviations from Level A Service Loadings that require shutdown for correction of the loadings or repair of damage in the system. The conditions have a low probability of occurrence, but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events may not exceed 25. If more than 25 are expected, then some types of events must be evaluated by the more stringent requirements of the Level B Service Limits.

HBB-3113.6 Level D Service Loadings. (From limiting faults.) These are combinations of loadings associated with extremely low probability, postulated events whose consequences are such that the integrity and functionality of the nuclear energy system may be impaired to the extent that only considerations of public health and safety are involved.

HBB-3113.7 Test Loadings. These are pressure loadings that occur during hydrostatic tests, pneumatic tests, and leak tests. Other types of tests shall be classified under either Service Level A or B loading categories given in the above subparagraphs. If any elevated temperature tests are specified as Test Loadings for a component, then these loadings shall be considered as part of the Service Level B loadings for the component.

HBB-3114 Load Histogram

HBB-3114.1 Level A and B Service Events. The Design Specifications (NCA-3211.19) shall include an expected loading history or load histogram for all Service Loadings from Level A and B service events (including all Test Loadings). These load histograms shall give all expected mechanical load forces, pressure, and temperatures for the various zones of the component throughout its service life. These histograms are then used in meeting the analysis requirements of HBB-3200.

HBB-3114.2 Level C Service Events. The Design Specifications shall include a time history of the design parameters during each type of Level C Service event. However, these events need not be specified as to time of occurrence during the service life of the component. The design parameter data shall be used in meeting the analysis requirements of HBB-3200. Level C Service events may be assumed as occurring between operational cycles (HBB-3213.15) of Level A Service events unless otherwise specified in the Design Specifications (NCA-3211.19).

HBB-3120 SPECIAL CONSIDERATIONS

HBB-3121 Corrosion

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the component by a suitable increase in or addition to the thickness of the base metal over that determined by the design formulas. Material added or included for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for the various areas. It should be noted that the tests on which the design fatigue curves are based did not include tests in the presence of corrosive environments that might accelerate fatigue failure.

HBB-3122 Cladding

Cladding requirements are contained in HBB-3227.8.

HBB-3123 Welding

HBB-3123.1 Dissimilar Welds. In satisfying the requirements of this subarticle, caution should be exercised in design and construction involving dissimilar metals having different coefficients of thermal expansion in order to avoid difficulties in service.

HBB-3123.2 Fillet Welded Attachments. Fillet welded attachment requirements are contained in HBB-3356.2.

HBB-3124 Environmental Effects

Changes in material properties may occur due to environmental effects. In particular, fast neutron irradiation (>1 MeV) above a certain level may result in significant increase in the brittle fracture transition temperature and deterioration in the resistance to fracture at temperatures above the transition range (upper shelf energy). Therefore, nozzles or other structural discontinuities in ferritic vessels should preferably not be placed in regions of high neutron flux.

HBB-3125 Configuration

Accessibility to permit the examinations required by the edition and addenda of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

HBB-3130 GENERAL DESIGN RULES

HBB-3131 Scope

Design rules generally applicable to all components are provided in HBB-3130. The Design subarticle for the specific component provides rules applicable to that particular component. In case of conflict between HBB-3130 and the design rules for a particular component, the component design rules shall govern.

HBB-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NCA-7100-1 when the standard or specification is referenced in the specific design subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design subarticle for a specific component.

HBB-3133 Size Restrictions in Nozzle, Branch, Piping, and Other Connections

The size of certain design features is restricted on nozzle, branch, piping, and other connections. Table HBB-3133-1 provides assistance in understanding where the limits are imposed.

HBB-3134 Leak Tightness

Where a system leak tightness greater than that required or demonstrated by a hydrostatic test is required, the leak tightness requirements for each component shall be set forth in the applicable Design Specifications (NCA-3211.19).

HBB-3135 Attachments

Lugs, brackets, stiffeners, and other attachments may be welded, bolted, or studded to the outside or inside of a component. The effects of attachments in producing thermal stresses, stress concentrations, and restraints on pressure-retaining members shall be taken into account in the analysis for compliance with design criteria of HBB-3200. For example, the temperature patterns around an attachment may lead to higher thermal stresses simply due to the *cooling-fin effect* of the attachment.

**Table HBB-3133-1
Size Restrictions on Connections**

Division 1 (NB) or Division 5 (HBB) Reference Paragraph	Service Conditions	Item Description	Item	Nominal Sizes Allowed
NB-3352.4(d), NB-3337.3	Noncreep	Partial penetration nozzle welds & other Cat. D welds	Vessel	All
HBB-3352(e), HBB-3337.3	Creep	(As above)	Vessel	O.D. ≤ 1 in. (25 mm)
NB-3431, HBB-3337.3, NB-3352.4(d)	Noncreep	Partial penetration piping connection weld	Pump	O.D. ≤ 2 in. (50 mm)
HBB-3421.4, HBB-3337.3, HBB-3352(e)	Creep	(As above)	Pump	O.D. ≤ 2 in. (50 mm)
NB-3544.8	Noncreep	Socket weld ends	Valve	O.D. ≤ 2 in. (50 mm)
HBB-3544	Creep	(As above)	Valve	O.D. ≤ 2 in. (50 mm)
NB-3661.3	Noncreep	Partial penetration branch connection weld	Pipe	O.D. ≤ 2 in. (50 mm)
HBB-3660(a), HBB-3352(e), HBB-3337.3	Creep	(As above)	Pipe	O.D. ≤ 1 in. (25 mm)
NB-3643, NB-3661.2	Noncreep	Socket welds	Pipe	O.D. ≤ 2 in. (50 mm)
HBB-3660(b)	Creep	(As above)	Pipe	O.D. ≤ 1 in. (25 mm)
NB-3671.3	Noncreep	Seal-welded threaded joints	Pipe	All
HBB-3660(b)	Creep	(As above)	Pipe	O.D. ≤ 1 in. (25 mm)
NB-3671.6, NB-4511	Noncreep	Brazed joints	Tubesheet, tube & pipe	O.D. ≤ 1 in. (25 mm)
NB-4511, HBB-3671.6	Creep	(As above)	Tubesheet, tube & pipe	O.D. ≤ 1 in. (25 mm)
NB-3671.4	Noncreep	Flared, flareless & compression joints	Tube & pipe	O.D. ≤ 1 in. (25 mm)
HBB-3671.1	Creep	(As above)	Tube & pipe	None
NB-4730	Noncreep	Tube joints at electrical & mechanical penetration assemblies	Tube & pipe	O.D. ≤ 2 in. (50 mm)
NB-4730	Creep	(As above)	Tube & pipe	O.D. ≤ 2 in. (50 mm)
NB-3643.3, NB-3661.1, NB-3337.2, NB-3352.4(d)	Noncreep	Deposited weld metal as reinforcement for openings & branch connections	All	All
HBB-3331(b)	Creep	(As above)	All	O.D. ≤ 4 in. (100 mm)
NB-3352.4(c), NB-3661.1	Noncreep	Full penetration corner welds at nozzle, branch & piping connections	All	All
HBB-3352(d), HBB-3660(c)	Creep	(As above)	All	O.D. ≤ 4 in. (100 mm)

HBB-3136 Reinforcement for Openings

See HBB-3330 and HBB-3643 for the rules applicable to reinforcement of openings in the pressure boundaries of vessels and piping, respectively. For all other components, the rules of HBB-3330 shall apply unless otherwise specified in the Design Specifications.

HBB-3137 Design Considerations Related to Other Articles of the Code

HBB-3137.1 Design Considerations for Static Pressure Testing. Since every component and appurtenance must eventually undergo a static pressure test, the designer shall ensure that such a test can be performed. If the only available test fluid can leave harmful residues on surfaces, the design shall preferably be such as to leave surfaces accessible for cleaning following the static pressure test. Special access hatches as well as drain lines may be required.

HBB-3137.2 Design Considerations for Overpressure Protection of the System.

(a) Each component and the system into which it will be installed shall be protected against overpressure events as required by the rules on overpressure protection of Class A components and systems exposed to elevated temperature service.

(b) The Service Loadings listed in the Design Specifications include those overpressure events that the designer shall consider in the design of that particular component. However, the component designer shall also review the final design to determine if additional overpressure transients can arise from one of the following:

(1) failure of nonpressure boundary parts of the component;

(2) failure of external power sources to the component;

(3) functioning of the component in conjunction with specified plant and system service conditions (Levels A, B, C, and D).

The designer shall report to the Owner regarding all sources of overpressure transients that can arise from (1), (2), and (3) above.

HBB-3138 Elastic Follow-up

(a) When only a small portion of the structure undergoes inelastic strains while the major portion of the structural system behaves in an elastic manner, the calculations of load forces, stresses, and strains shall consider the behavior of the entire structural system. In these cases, certain areas may be subjected to strain concentrations, due to the elastic follow-up of the rest of the connected structure. These abnormally large strain concentrations may result when structural parts of different flexibility are in series and the flexible portions are highly stressed. Examples include:

(1) local reduction in size of a cross section or local use of a weaker material;

(2) in a piping system of uniform size, a configuration for which most of the system lies near the hypothetical straight line connecting the two anchors, (stiffeners, flanges, or other stiff members), and with only a small portion departing from this line. Then the small portion absorbs most of the expansion strain.

(b) If possible, the above conditions should be avoided in design. Where such conditions cannot be avoided, the analysis required in HBB-3250 will determine the acceptability of the design to guard against harmful consequences of elastic follow-up.

HBB-3139 Welding

HBB-3139.1 Abrupt Changes in Mechanical Properties at Weld and Compression Contact Junctions. In satisfying the requirements of Article HBB-3000, particular considerations shall be given to the design, analysis, and construction of welded and compression contact junctions between two materials that have different mechanical properties. Such properties at elevated temperatures include thermal expansion, creep rate, creep ductility, and fatigue life. Examples of such junctions are bimetallic welds, brazed joints, compression or shrink fits, bolted flanges, and other types of mechanical joints. When temperatures cycle between low temperatures and elevated temperatures, the inelastic strains can result in significant localized strain accumulation near an abrupt change in mechanical properties.

HBB-3139.2 Weld Design. All welds shall comply with the rules of Division 1, NB-3350. Exceptions to this requirement are allowed only if a specific callout is made in either HBB-3400, HBB-3500, or HBB-3600.

HBB-3200 DESIGN BY ANALYSIS

HBB-3210 DESIGN CRITERIA

HBB-3211 Requirements for Acceptability

For a Class A component intended for elevated temperature service, the requirements for the acceptability of a design based on analysis shall be as stipulated in (a) through (d).

(a) The design shall be such that the calculated or experimentally determined stresses, strains, and deformations will not exceed the limits described in this subarticle;

(b) The design details shall conform to the rules of HBB-3100 and to those given in subsequent subarticles applicable to the specific component;

(c) If the designer has demonstrated that the elevated temperature service parameters (time, stress level, and temperature) do not introduce significant creep effects,[11] then the experimental and analytical methods of Division 1, Subsection NB shall be applicable. The other restrictions on temperature maxima that appear in Section III Appendices, Mandatory Appendix XIII, XIII-3450(e) shall not apply provided the designer demonstrates the validity of values and methods for the higher temperatures.

(d) For portions of the component which do not experience elevated temperature service, the rules of Division 1, Article NB-3000 may be used to satisfy (a) and (b) above. Alternatively, properties and allowable stress values from Division 1, Subsection NB may be used in analyses to demonstrate compliance with the rules of HBB-3200.

HBB-3212 Basis for Determining Stress, Strain, and Deformation Quantities

(a) For elastic analysis allowed by Subsection HB, Subpart B, the maximum shear stress theory shall be used to determine stress intensities for multiaxial stress states (Section III Appendices, Mandatory Appendix XIII, XIII-1220).

(b) For inelastic analysis required by Subsection HB, Subpart B, appropriate multiaxial stress-strain relationships and associated flow rules shall be used to combine multiaxial stresses and strains.

(c) One of the materials of this Subsection, 9Cr-1Mo-V, has several unique characteristics that should be recognized and reflected in multiaxial stress-strain relationships. These include the following:

(1) There is not a clear distinction between time-independent elastic–plastic behavior and time-dependent creep behavior.

(2) Flow stresses are strongly strain-rate sensitive at elevated temperatures.

(3) The material exhibits cyclic softening over the entire elevated-temperature use range and significant flow softening at 1,000°F (540°C) and above.

HBB-3213 Terms Relating to Analysis

In Subsection HB, Subpart B, the stress and strain limits for design evaluation are related to the type of structural behavior under loading. The controlled quantities fall into two general categories:[12]

(a) Load-Controlled Quantities — These quantities are stress intensities that are computed on the basis of equilibrium with the applied forces and moments during plant operation. Included in this category are general primary membrane, local primary membrane, primary bending stresses, and secondary stresses with a large amount of elastic follow-up.

(b) Deformation-Controlled Quantities — These quantities are strains, cyclic strain ranges, or deformations that result from load deflection and/or strain compatibility.

Other terms used in Subsection HB, Subpart B relating to structural analysis are defined in the subparagraphs of HBB-3213.

HBB-3213.1 Stress Intensity.[13] Stress intensity is defined as twice the maximum shear stress, which is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

HBB-3213.2 Gross Structural Discontinuity. Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire wall thickness of the pressure-retaining member. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

HBB-3213.3 Local Structural Discontinuity. Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

HBB-3213.4 Normal Stress. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components, one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.

HBB-3213.5 Shear Stress. Shear stress is the component of stress tangent to the plane of reference.

HBB-3213.6 Membrane Stress. Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

HBB-3213.7 Bending Stress. Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear.

HBB-3213.8 Primary Stress. Primary stress is any normal stress or shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are:

(a) general membrane stress in a circular cylindrical shell or a spherical shell due to internal pressure or to distributed loads;

(b) bending stress in the central portion of a flat head due to pressure;

(c) stresses in piping due to net cross section forces (normal or shear) arising from thermal expansion of structural material.

Refer to Table HBB-3217-1 for examples of primary stress.

HBB-3213.9 Secondary Stress. Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are:

(a) general thermal stress [see HBB-3213.13(a)];

(b) bending stress at a gross structural discontinuity.

Refer to Table HBB-3217-1 for examples of secondary stress.

HBB-3213.10 Local Primary Membrane Stress. Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress.

A stressed region may be considered local if the distance over which the membrane stress intensity exceeds $1.1S_o$ does not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the minimum midsurface radius of curvature and t is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions that exceed $1.1S_o$ shall not be closer in the meridional direction than $2.5\sqrt{R_L t_L}$, where R_L is defined as $(R_1 + R_2)/2$ and t_L is defined as $(t_1 + t_2)/2$ (where t_1 and t_2 are the minimum thicknesses at each of the regions considered, and R_1 and R_2 are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds $1.1S_o$. Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds $1.1S_o$, shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds $1.1S_o$. An example of a local primary membrane stress is the membrane stress in a shell produced by external load and moment at a permanent support or at a nozzle connection.

HBB-3213.11 Peak Stress. Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [see HBB-3213.13(b)] including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture, and, at elevated temperatures, as a possible source of localized rupture or creep–fatigue failure. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stress are:

(a) the thermal stress in the austenitic steel cladding of a carbon steel part;

(b) certain thermal stresses that may cause fatigue but not distortion;

(c) the stress at a local structural discontinuity;

(d) surface stresses produced by thermal shock.

HBB-3213.13 Thermal Stress. Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. Thermal stresses that are not classified as peak stresses fit in this category. Refer to HBB-T-1331(d) for further guidance on classification. Examples of general thermal stress are:

(1) stress produced by an axial temperature distribution in a cylindrical shell;

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached;

(3) the equivalent linear stress[14] produced by the radial temperature distribution in a cylindrical shell.

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in Table HBB-3217-1. Examples of local thermal stress are:

(1) the stress in a small hot spot in a vessel wall;

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;

(3) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal.

HBB-3213.15 Service Cycle. Service cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of service conditions that may occur are further defined in HBB-3113.

HBB-3213.16 Strain Cycle. Strain cycle is a condition in which the strain goes from an initial value, through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. In cases where creep or ratcheting is present in the cycle, there will not be a return to the initial strain value. Instead the designer will have to examine the hysteresis loop for inelastic analysis and the stress history for elastic analysis to determine the end point of the cycle. See HBB-T-1413 for the method of combining cycles for fatigue analysis. A single service cycle may result in one or more strain cycles. Dynamic effects shall also be considered as strain cycles.

HBB-3213.17 Fatigue Strength Reduction Factor. Fatigue strength reduction factor is a stress intensification or a strain intensification factor that accounts for the effect of a local structural discontinuity (stress or strain concentration) on the fatigue strength. Factors currently exist only for cycles that do not involve significant creep effects.

HBB-3213.18 Free End Displacement. Free end displacement consists of the relative motions that would occur between a fixed attachment and connected piping if the two members were separated and permitted to move.

HBB-3213.20 Deformation. Deformation of a component part is an alteration of its shape or size.

HBB-3213.21 Inelasticity. Inelasticity is a general characteristic of material behavior in which the material does not return to its original shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

HBB-3213.22 Creep. Creep is the special case of inelasticity that relates to the stress-induced time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

HBB-3213.23 Plasticity. Plasticity is the special case of inelasticity in which the material undergoes time-independent nonrecoverable deformation. For 9Cr-1Mo-V, time-independent plasticity at higher temperatures occurs only in limiting cases where strain rates are high relative to creep rates.

HBB-3213.24 Plastic Analysis. Plastic analysis is that method that computes the structural behavior under given loads considering the plasticity characteristics of the materials, including strain hardening and the stress redistribution occurring in the structure. For 9Cr-1Mo-V, a plastic analysis must generally account for rate dependence and creep effects. A plastic analysis thus implies a full inelastic analysis.

HBB-3213.25 Plastic Analysis — Collapse Load. A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criteria for determination of the collapse load shall be used. A load-deflection or load-strain curve is plotted with load as the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load deflection or load strain curve makes with the ordinate is called θ. A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle $\phi = \tan^{-1} (2 \tan \theta)$ with the ordinate. The collapse load is the load at the intersection of the load-deflection or load-strain curve and the collapse limit line. If this method is used, particular care should be given to assuring that the strains or deflections that are used are indicative of the load carrying capacity of the structure.

HBB-3213.26 Plastic Instability Load. The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbounded plastic deformation can occur without an increase in load. At the plastic tensile instability load, the true stress in the material increases faster than strain hardening can accommodate.

HBB-3213.27 Limit Analysis. Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (nonstrain-hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods that are used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term *mechanism* is commonly used in lieu of *kinematically admissible velocity field*.

HBB-3213.28 Limit Analysis — Collapse Load. The methods of limit analysis are used to compute the maximum carrying load for a structure assumed to be made of ideally plastic material. If creep effects exist, then the influence of time-dependent deformations on the collapse load shall be considered.

HBB-3213.29 Calculated Collapse Load — Lower Bound. If, for a given load, any system of stresses can be found that everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis that permits calculations of a lower bound to the collapse load. If creep effects exist, then the influence of time-dependent deformations on the collapse load shall be considered.

HBB-3213.30 Plastic Hinge. A plastic hinge is an idealized concept used in Limit Analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells, a plastic hinge is formed where the generalized stresses lie on the yield surface.

HBB-3213.31 Strain Limiting Load. When a limit is placed upon a strain, the load associated with the strain limit is called the strain limiting load.

HBB-3213.32 Test Collapse Load. Test collapse load is the collapse load determined by tests according to the criteria given in Section III Appendices, Mandatory Appendix II, II-1430.

HBB-3213.33 Ratcheting. Ratcheting is a progressive cyclic inelastic deformation. Total inelastic strain per cycle may vary from cycle to cycle in the most general situation. Stable ratcheting occurs when the net inelastic strain from a given load cycle is constant for subsequent cycles.

(a) Progressive incremental inelastic deformation can occur in a component that is subjected to cyclic variations of mechanical secondary stress, thermal secondary stress, or both in the presence of a primary stress.

(b) Where creep effects are significant, creep ratcheting can occur, even in the absence of plastic yielding. At least two mechanisms are involved in creep ratcheting. First, creep can alter the residual stresses and thus affect the time-independent behavior. Secondly, the time-dependent deformation can be enhanced because of the nonlinear interaction of primary and secondary stresses. This latter effect is referred to as *enhanced creep*.

HBB-3213.34 Shakedown. Shakedown is the absence of significant progressive, cyclic, inelastic deformation, or ratcheting (HBB-3213.33). A structure shakes down if, after a few cycles of load application, the deformation stabilizes.

HBB-3213.35 Design Information on the Nameplate. Design Information on the Nameplate are the Design Temperature and the Design Pressure for the zone of the structure nearest the pressure relief device (or the top of the component if there are no pressure relief devices). The values for these parameters shall appear on the nameplate.

HBB-3213.36 Use-Fraction. Use-fraction is the material damage due to primary stresses expressed as a time ratio.

HBB-3213.37 Fatigue Damage. Fatigue damage is that part of the total material damage caused by cyclic deformation that is independent of time effects (e.g., stress holdtime, strain holdtime, frequency). The damage is expressed in terms of a cycle ratio.

HBB-3213.38 Creep Damage. Creep damage is that part of the total material damage caused by time exposure to steady and transient stresses at elevated temperatures, expressed as a time ratio. (Relaxation damage is a form of creep damage.)

HBB-3213.39 Creep–Fatigue Interaction. Creep–fatigue interaction is the effect of combined creep and fatigue on the total creep–fatigue damage accumulated at failure.

HBB-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each rule or limit of HBB-3220 and HBB-3230 is satisfied when the component is subjected to the loadings described in HBB-3111. This detailed analysis shall become a part of the Design Report (NCA-3550).

HBB-3214.1 Elastic Analysis. The analysis guidelines and methods in Division 1, Article NB-3000 apply (HBB-3211). As an aid to the evaluation of these elastic stresses, equations and methods for the solution of certain recurring problems have been placed in Section III Appendices, Nonmandatory Appendix A.

HBB-3214.2 Inelastic Analysis. When thermal and mechanical loadings are sufficiently severe to produce yielding and/or when thermal creep processes are active, inelastic design analysis may be required. The rules and limits of Nonmandatory Appendix HBB-T were established with the expectation that inelastic analyses would sometimes be required, and that such analyses would be sufficiently comprehensive to predict significant behavioral features. Generally, this requires analysis of combined time-independent elastic–plastic material behavior and time-dependent creep behavior capable of predicting stresses, strains, and deformations as functions of time for specific thermal-mechanical load histories.

The constitutive equations, which describe the inelastic behavior, should reflect the following features when they have a significant influence on structural response: the effects of plastic strain hardening including cyclic loading effects and the hardening or softening that can occur with high temperature exposure; primary creep and the effects of creep strain hardening as well as softening (due to reverse loadings); and the effects of prior creep on subsequent plasticity, and vice versa.

The basis for choosing the selected methods and relations used should be included in the Design Report.

Since the rules and limits incorporate design factors and margins to account for material property variations and uncertainties, it is generally appropriate to use average stress-strain and creep data in inelastic design analyses. The buckling and instability limits of Nonmandatory Appendix HBB-T are an exception; in HBB-T-1510(g) it is stated that the minimum expected stress-strain curve should be used.

For 9Cr-1Mo-V, decoupling of plastic and creep strains in the classical constitutive framework is generally a poor representation of the true material behavior. Unified constitutive equations, which do not distinguish between rate-dependent plasticity and time-dependent creep, represent the rate dependence and softening that occur, particularly at higher temperatures.

HBB-3214.3 Mechanical and Physical Properties. The values of some mechanical and physical properties needed for analysis are listed in Section II, Part D, Subpart 2, Tables TM and TE, and in Mandatory Appendix HBB-I-14 and Nonmandatory Appendix HBB-T. Properties covered include:

(a) isochronous stress-strain curves

(b) yield strength

(c) stress-to-rupture

(d) modulus of elasticity

(e) instantaneous and mean coefficients of thermal expansion

Other mechanical and physical property relations used in the analysis shall be described and justified in the Design Report.

HBB-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (HBB-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities that are subject to the specified limits. The steps in the procedure are stipulated in the following subparagraphs.

(a) At the point on the component that is being investigated, choose an orthogonal set of coordinates such as tangential, longitudinal, and radial, and designate them by the subscripts, t, l, and r. The stress components in these directions are then designated σ_t, σ_l, and σ_r for direct stresses and τ_{lt}, τ_{lr}, and τ_{rt} for shearing stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:

F = peak stress components as defined in HBB-3213.11. Tables HBB-3217-1 and HBB-3217-2 provide assistance in the determination of the category to which a stress should be assigned.

P_b = primary bending stress components at a surface as defined in HBB-3213.8

P_m, P_L = average primary stress components as defined in HBB-3213.8 and HBB-3213.10

Q = secondary stress components as defined in HBB-3213.9

It should be noted that each of the symbols for the above stress categories represents six scalar quantities corresponding to the six stress components, σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, and τ_{rt}. In the particular case of the six membrane stress components, each component shall be averaged across the thickness of the structural section.

(c) For each category, calculate the algebraic sum of the σ_t values that result from the different types of loadings and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the t, l, and r directions into principal stresses, σ_1, σ_2, and σ_3. (In many pressure component calculations, the t, l, and r directions may be so chosen that the shearing stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r.

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity, S, is the largest absolute value of S_{12}, S_{23}, and S_{31}.

HBB-3216 Derivation of Stress Differences and Strain Differences

The ability of the component to withstand the specified cyclic operation without creep–fatigue failure shall be determined as in HBB-3250. The evaluation shall demonstrate, by evaluating the stresses and strains at selected points of the components, that the combined creep-fatigue damage is everywhere within design limits. Only the stress and strain differences due to the operational cycles as specified in the Design Specifications need be considered.

HBB-3217 Classification of Stresses

Tables HBB-3217-1 and HBB-3217-2 provide assistance in the determination of the category to which a stress should be assigned. For portions of the component not exposed to elevated temperature service, the classification or category may be selected as in Division 1, Article NB-3000.

HBB-3220 DESIGN RULES AND LIMITS FOR LOAD-CONTROLLED STRESSES IN STRUCTURES OTHER THAN BOLTS

HBB-3221 General Requirements

(a) The rules for design against failure from load-controlled stresses are illustrated in Figure HBB-3221-1 and are explained in HBB-3220. The allowable stress intensity values used in HBB-3220 are listed in Section II, Part D, Subpart 1, Tables 2A and 2B and Tables HBB-I-14.1(a) through HBB-I-14.13C. Note that the strain, deformation, and fatigue limits of HBB-3250 require analyses beyond those required by the rules of HBB-3220.

(b) The stress intensity limits used in Figure HBB-3221-1 and throughout this Subsection are defined for base metal and at weldments as follows:

(1) Base Metal

S_m = the lowest stress intensity value at a given temperature among the time-independent strength quantities that are defined in Section II, Part D as criteria for determining S_m; in Subsection HB, Subpart B, the S_m values are extended to elevated temperatures by using the same criteria. As described in HBB-2160(d), it may be necessary to adjust the values of S_m to account for the effects of long-time service at elevated temperature.

S_{mt} = the allowable limit of general primary membrane stress intensity to be used as a reference for stress calculations for the actual service life and under the Level A and B Service Loadings; the allowable values are shown in Figures HBB-I-14.3A through HBB-I-14.3E and in Tables HBB-I-14.3A through HBB-I-14.3E. The S_{mt} values are the lower of two stress intensity values, S_m (time independent) and S_t (time dependent). As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

S_o = the maximum allowable value of general primary membrane stress intensity to be used as a reference for stress calculations under Design Loadings. The allowable values are given in Table HBB-I-14.2. [The values correspond to the S values given in Section II, Part D, Subpart 1, Table 1A, except for a few cases at lower temperatures where values of S_{mt} (defined below and given in Tables HBB-I-14.3A through HBB-I-14.3E) at

Table HBB-3217-1
Classification of Stress Intensity in Vessels for Some Typical Cases

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane	P_m
			Gradient through plate thickness	Q
		Axial thermal gradient	Membrane	Q [Note (1)]
			Bending	Q
	Junction with head or flange	Internal pressure	Membrane	P_L
			Bending	Q [Note (2)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section. Stress component perpendicular to cross section.	P_m
		External load or moment	Bending across full section. Stress component perpendicular to cross section.	P_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane	P_L
			Bending	Q
			Peak (fillet or corner)	F
	Any location	Temp. diff. between shell and head	Membrane	Q [Note (1)]
			Bending	Q
Dished head or conical head	Crown	Internal pressure	Membrane	P_m
			Bending	P_b
	Knuckle or junction to shell	Internal pressure	Membrane	P_L [Note (3)]
			Bending	Q
Flat head	Center region	Internal pressure	Membrane	P_m
			Bending	P_b
	Junction to shell	Internal pressure	Membrane	P_L
			Bending	Q [Note (2)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (Av. through cross section)	P_m
			Bending (Av. through width of lig., but gradient through plate)	P_b
			Peak	F
	Isolated or atypical ligament	Pressure	Membrane	Q
			Bending	F
			Peak	F

Table HBB-3217-1
Classification of Stress Intensity in Vessels for Some Typical Cases (Cont'd)

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Nozzle (HBB-3227.5)	Within the limits of reinforcement defined by HBB-3334	Pressure and external loads and moments including those attributable to restrained free end displacements of attached piping	General membrane	P_m
			Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	P_m
	Outside the limits of reinforcement defined by HBB-3334	Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane stresses	P_m
		Pressure and external loads and moments other than those attributable to restrained free end displacements of attached piping	Membrane	P_L
			Bending	P_b
		Pressure and all external loads and moments	Membrane	P_L
			Bending	Q
			Peak	F
	Nozzle wall	Gross structural discontinuities at nozzle to shell junction	Local membrane	P_L
			Bending	Q
			Peak	F
	Any	Differential expansion	Membrane	Q [Note (1)]
			Bending	Q
			Peak	F
Cladding	Any	Differential expansion	Membrane	F
			Bending	F
Any	Any	Radial temp. Distribution [Note (5)]	Equivalent Linear stress [Note (4)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:
(1) These classifications may be modified for purposes of certain criteria in Nonmandatory Appendix HBB-T.
(2) If the bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge bending is classified as P_b. Otherwise, it is classified as Q.
(3) Consideration must also be given to the possibility of wrinkling and exessive deformation in vessels with large diameter-to-thickness ratio.
(4) Consider possibility of thermal stress ratchet (see HBB-3250).
(5) Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

Table HBB-3217-2
Classification of Stress Intensity in Piping, Typical Cases

Piping Component	Locations	Origin of Stresses	Classification [Note (1)]	Discontinuities Considered	
				Gross	Local
Pipe or tube, elbows, and reducers. Intersections and branch connections except in the crotch regions	Any, except crotch regions of intersections	Internal pressure	P_m	No	No
			P_L and Q	Yes	No
			F	Yes	Yes
		Sustained mechanical loads including weight	P_b	No	No
			P_L and Q	Yes	No
			F	Yes	Yes
		Expansion	P_m, P_b, and Q [Note (1)], [Note (2)]	Yes	No
			F	Yes	Yes
		Axial thermal gradient	Q [Note (1)]	Yes	No
			F	Yes	Yes
Intersections, including tees and branch connections	In the crotch region	Internal pressure, sustained mechanical loads, and expansion	P_L and Q [Note (3)]	Yes	No
			F	Yes	Yes
		Axial thermal gradient	Q [Note (1)]	Yes	No
			F	Yes	Yes
Bolts and flanges	Any	Internal pressure, gasket compression, bolt load	P_m	No	No
			Q	Yes	No
			F	Yes	Yes
		Thermal gradient	Q [Note (1)]	Yes	No
			F	Yes	Yes
		Expansion	P_m, P_b, and Q [Note (1)], [Note (2)]	Yes	No
			F	Yes	Yes
Any	Any	Nonlinear radial thermal gradient	F	Yes	Yes
		Linear radial thermal gradient	Q [Note (1)]	Yes	No

NOTES:
(1) These classifications may be modified for purposes of certain criteria in Nonmandatory Appendix HBB-T.
(2) See HBB-3138 and HBB-3213.8.
(3) Analysis is not required when reinforced in accordance with HBB-3643.

300,000 hr exceed the S values. In those limited cases, S_o is equal to S_{mt} at 300,000 hr rather than S.]

S_t = a temperature and time-dependent stress intensity limit; the data considered in establishing these values are obtained from long-term, constant load, uniaxial tests. For each specific time, t, the S_t values shall be the lesser of:

(a) 100% of the average stress required to obtain a total (elastic, plastic, primary, and secondary creep) strain of 1%;

(b) 80% of the minimum stress to cause initiation of tertiary creep; and

(c) 67% of the minimum stress to cause rupture.

S_y = the yield strength of a material at a given temperature from Table HBB-I-14.5

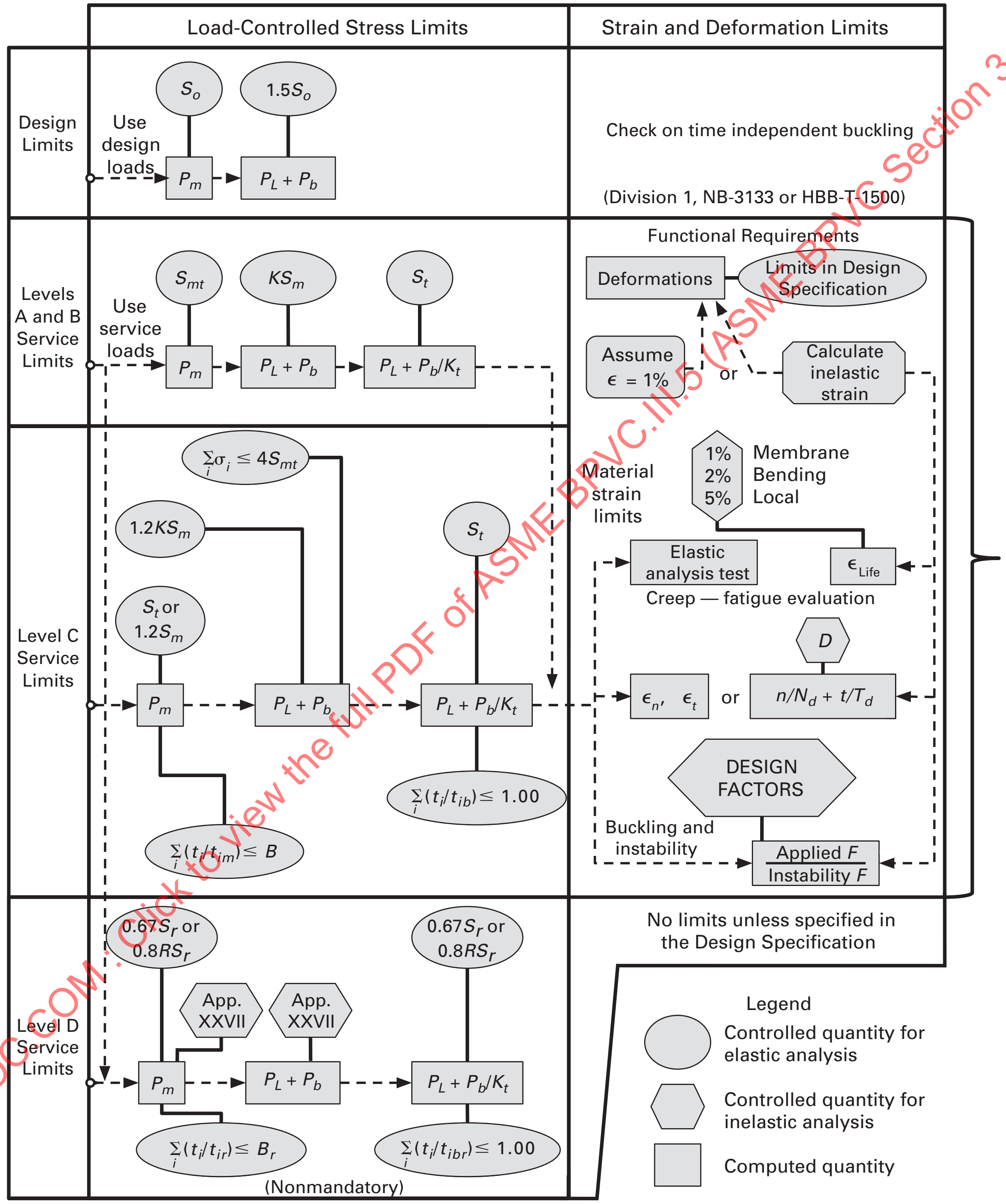
(2) Weldments

S_{mt} = the allowable limit of general primary membrane stress intensity, and shall be taken as the lower of the S_{mt} values from Tables HBB-I-14.3A through HBB-I-14.3E, or:

$$0.8\ S_r \times R$$

As described in HBB-2160(d), it may be necessary to adjust the values of S_m to account for the effects of long-time service at elevated temperature.

Figure HBB-3221-1
Flow Diagram for Elevated Temperature Analysis



S_t = temperature and time-dependent stress intensity limit at a weldment, and shall be taken as the lower of the tabulated S_t values from Tables HBB-I-14.4A through HBB-I-14.4E, or:

$$0.8\, S_r \times R$$

where

R = the appropriate ratio of the weld metal creep rupture strength to the base metal creep rupture strength from Tables HBB-I-14.10A-1 through HBB-I-14.10E-1. The lowest S_t value of the adjacent base metals shall be utilized for the weldment.

S_r = the expected minimum stress-to-rupture strength given in Tables HBB-I-14.6A through HBB-I-14.6F

HBB-3222 Design and Service Limits

HBB-3222.1 Design Limits. The stress calculations required for the analysis of Design Loadings (HBB-3113.1) shall be based on a linearly elastic material model. The calculated stress intensity values shall satisfy the limits of (a) and (b) below.

(a) The general primary membrane stress intensity, derived from P_m, shall not exceed S_o:[15]

$$P_m \leq S_o \tag{1}$$

(b) The combined primary membrane plus bending stress intensity, derived from P_L and P_b, shall not exceed $1.5 S_o$:

$$\left(P_L + P_b\right) \leq (1.5)\, S_o \tag{2}$$

Note that the local primary membrane stress, P_L, includes the general primary membrane stress, P_m. As in Division 1, Subsection NB, the left-hand side of eq. (2) does not represent a simple algebraic combination since P_L and P_b may each represent as many as six quantities [HBB-3215(b)].

(c) External pressure and other compression inducing loadings shall be investigated for adequate buckling strength, using the limits of Division 1, NB-3133 or other limits and time-independent factors permitted under HBB-3252.

HBB-3222.2 Level A Service Limits. The stress intensity limits for Level A Service Limits (HBB-3113.3) also apply to the stresses under both Level A and B Service Loadings. The limits for both are given in HBB-3223.

HBB-3223 Level A and B Service Limits

The stress calculations required for the analysis of Level A and B Service Loadings (HBB-3113.4) are based on a linearly elastic material model. The calculated stress-intensity values shall satisfy the conditions of (a) through (g) below.

(a) The general primary membrane stress intensity, derived from P_m for Level A and B Service Loadings, shall not exceed S_{mt}

$$P_m \leq S_{mt} \tag{3}$$

where S_{mt} is determined for the time, t, corresponding to the total duration of the particular loading during the entire service life, and for temperature, T, corresponding to the maximum wall averaged temperature that occurs during the particular loading event.

(b) When time, t, [in (a) above] is less than the total specified service life of the component, the cumulative effect of all the loadings shall be evaluated by the use-fraction sum in HBB-3224(b). In addition, it is permissible and often advantageous to subdivide a loading history into several load levels and into several temperatures at any given load level.

(c) The combined primary membrane plus bending stress intensities, derived from P_L and P_b for Level A and B Service Loadings, shall satisfy the following limits with:

$$P_L + P_b \leq K S_m \tag{4}$$

$$P_L + P_b / K_t \leq S_t \tag{5}$$

The factor K_t accounts for the reduction in extreme fiber bending stress due to the effect of creep. The factor is given by

$$K_t = \left(K + 1\right) / 2 \tag{6}$$

The factor, K, is the section factor for the cross section being considered. It is the ratio of the load set producing a fully plastic section to a load set producing initial yielding of the extreme fiber of the cross section. In evaluating the initial yield and fully plastic section capabilities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified service load set. Values of K for various sections are given in Section III Appendices, Nonmandatory Appendix A, Table A-9521(b)-1.

(d) In evaluating across-the-wall bending of shell type structures, K = 1.5 (for rectangular sections) shall be used. Thus, for across-the-wall shell bending, K_t = 1.25 in eq. (c)(6). Note that the classification of stresses of primary membrane or primary bending for use with these section factors shall be consistent with the specific rules for the component type (see HBB-3300 to HBB-3600).

(e) In eq. (c)(5), the S_t value is determined for the time, t, corresponding to the total duration of the combined stress intensity derived from P_L and P_b/K_t and the maximum wall averaged temperature, T, during the entire service life of the component.

(f) When t is less than the total service life of the component, the cumulative effect of all $[P_L + (P_b/K_t)]$ loadings shall be evaluated by the use-fraction sum of HBB-3224(d). It is permissible and often advantageous to separate a loading history into several load levels and into several temperatures at any given load level.

(g) Under all conditions where a bending loading occurs across a section, the propensity for buckling of that part of the section in compression shall be investigated under the requirements of HBB-3250.

HBB-3224 Level C Service Limits

The stress calculations required for Level C Service Loadings analysis are based on a linearly elastic material model. The calculated stress intensity values shall satisfy the conditions of (a) through (d) below.

(a) The general primary membrane stress intensity, derived from P_m for Level C Service Loadings, shall not exceed the smaller of $1.2S_m$ and $1.0S_t$

$$P_m \le \begin{cases} 1.2\ S_m \\ 1.0\ S_t \end{cases} \tag{7}$$

(b) In addition, the use-fraction sum associated with the general primary membrane stresses for all increments of primary loadings during Level A, B, and C Loadings shall satisfy the following requirements:

$$\sum_i \left(\frac{t_i}{t_{im}} \right) \le B \tag{8}$$

where

B = use-fraction factor and is equal to 1.0 [or less if so specified in the Design Specifications (NCA-3211.19)]

t_i = the total duration of a specific loading, P_{mi}, at elevated temperature, T, during the entire service life of the component. Note that $\sum_i (t_i)$ is that part of the component service life at elevated temperatures (i.e., temperatures above values governed by the rules of Division 1, Subsection NB as explained in HBB-3211).

t_{im} = maximum allowed time under the load stress intensity, S_i, as determined from a graph of S_t-vs-time (see Figures HBB-I-14.4A through HBB-I-14.4E.)

The use of Figures HBB-I-14.4A through HBB-I-14.4E for determining t_{im} for two loading conditions at two different temperatures is shown schematically in Figure HBB-3224-1. In Figure HBB-3224-1, P_{mi} (i = 1, 2, 3, etc.) represents the calculated membrane stress intensity for the loading condition and temperature in question; and T_i represents the maximum local wall averaged temperature during t_i. Note that it may be desirable to consider that a given stress intensity, P_{mi}, acts during several time periods, t_i, in order to take credit for the fact that the temperature varies with time.

(c) The combined primary membrane plus bending stress intensities, derived from P_L and P_b for Level C Service Loadings, shall satisfy the following limits, with $1.0 < K \le 1.5$:

$$P_L + P_b \le 1.2 K S_m \tag{9}$$

$$P_L + P_b / K_t \le S_t \tag{10}$$

where K_t is defined as in HBB-3223(c).

(d) In addition, the sum of the use-fractions associated with the primary membrane plus bending stresses for all increments of primary loadings during Level A, B, and C Service Loadings shall not exceed the value, 1.00:

$$\sum_i \left(\frac{t_i}{t_{ib}} \right) \le 1.00 \tag{11}$$

where

t_i = the total duration of the loading at temperature, T_i; and

t_{ib} = the time value determined by entering Figures HBB-I-14.4A through HBB-I-14.4E at a value of stress equal to $P_L + P_b/K_t$, as shown in Figure HBB-3224-2.

Figure HBB-3224-1 Use-Fractions for Membrane Stress

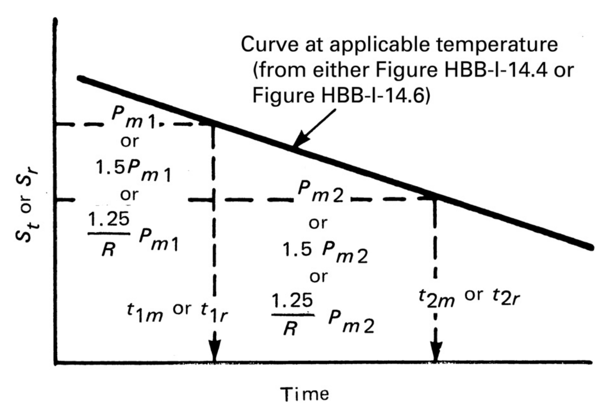
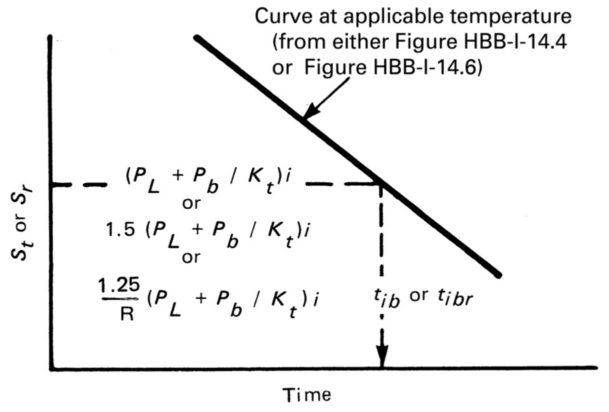


Figure HBB-3224-2
Use-Fractions for Membrane Plus Bending Stress



HBB-3225 Level D Service Limits

The rules of this paragraph may be used in the evaluation of components subjected to loads specified as Level D Service Loadings.

(a) The rules in HBB-3225 (and in Section III Appendices, Mandatory Appendix XXVII) shall be applied in all instances unless alternative or supplementary criteria, as required by public health and safety considerations for specific components or systems, are defined in, and made applicable by, the Owner's Design Specifications (NCA-3211.19). The type of analysis (elastic or inelastic) used by the system designer shall be indicated in the Design Specifications (see Section III Appendices, Mandatory Appendix XXVII, XXVII-2000).

(b) The general primary membrane stress intensity, derived from P_m for the Level D Service Loadings, shall not exceed the smaller of $0.67S_r$, $0.8RS_r$, and one of the Level D Service Limits in Section III Appendices, Mandatory Appendix XXVII:

$$P_m \le \begin{cases} \text{Limit in Mandatory Appendix XXVII for } P_m \\ 0.67\ S_r \\ 0.8\ RS_r \end{cases} \tag{12}$$

where

R = the appropriate ratio of the weld metal creep strength to the base metal strength from Tables HBB-I-14.10A-1 through HBB-I-14.10E-1

S_r = the expected minimum stress-to-rupture in time t taken from Figures HBB-I-14.6A through HBB-I-14.6F

(c) In addition, the use-fraction sum associated with the general primary membrane stresses that arise from all Service Loadings, shall satisfy the requirement:

$$\sum_i \left(\frac{t_i}{t_{ir}} \right) \le B_r$$

where

B_r = use-fraction factor and is equal to 1.0 (or less if so specified in the Design Specifications (NCA-3211.19)

t_i = the total duration of a specific loading, P_{mi}, at elevated temperature, T_i, during the entire service life of the component. Note that $\sum_i (t_i)$ is that part of the component service life at elevated temperatures (i.e., temperatures above values governed by the rules of Division 1, Subsection NB, as explained in HBB-3211).

t_{ir} = maximum allowed time under the load stress intensity $1.5P_{mi}$ for base metal or, for weldments, the higher of $1.5P_{mi}$ or $(1.25/R)P_{mi}$. The allowable time under load is determined from the graph of minimum stress-to-rupture versus time (see Figures HBB-I-14.6A through HBB-I-14.6F).

The use of Figures HBB-I-14.6A through HBB-I-14.6F for determining t_{ir} for two loading conditions at two different temperatures is shown schematically in Figure HBB-3224-1. In Figure HBB-3224-1, $1.5P_{mi}$ (i = 1, 2, 3, etc.) represents 1.5 times the calculated membrane stress intensity for the loading condition and temperature in question, and T_i represents the maximum local wall averaged temperature during t_i. Note that it may be desirable to consider that a given stress intensity acts during several time periods, t_i, in order to take credit for the variation of temperature with time.

(d) The combined primary membrane plus bending stress intensities, derived from P_L and P_b, shall satisfy the following limits, with $1.0 \le K \le 1.5$, and Level D Service Limits in Section III Appendices, Mandatory Appendix XXVII for $P_L + P_b$:

$$P_L + P_b / K_t \le \begin{cases} 0.67\ S_r \\ 0.8\ RS_r \end{cases} \tag{13}$$

where K_t is defined in HBB-3223(c).

(e) In addition, the sum of the use-fraction associated with the primary membrane plus bending stresses that arise from all Service Loadings, shall not exceed the value of 1.00:

$$\sum_i \left(\frac{t_i}{t_{ibr}} \right) \le 1.00$$

where

t_i = the total duration of loading at temperature, T_i

t_{ibr} = the time value determined by entering Figures HBB-I-14.6A through HBB-I-14.6F at a value of stress equal to $1.5(P_L + P_b/K_t)$ for base metal or higher of $1.5(P_L + P_b/K_t)$ and $1.25(P_L + P_b/K_t)/R$ for weldments as shown in Figure HBB-3224-2

(f) For the purpose of Section III Appendices, Mandatory Appendix XXVII calculations, the yield strength and tensile strength values shall be defined as follows:

(1) Yield strength values shall be the product of the value shown in Table HBB-I-14.5 and the strength reduction factor shown in Tables HBB-3225-2, HBB-3225-3A, and HBB-3225-3B.

(2) Tensile strength values shall be the product of the value shown in Table HBB-3225-1 and the strength reduction factor shown in Tables HBB-3225-2, HBB-3225-3A, HBB-3225-3B, and HBB-3225-4B, where the strength reduction factor is selected as a function of the accumulated time-temperature history to which the component has been exposed prior to the event under analysis. Where a component has been exposed to a varying temperature history, the reduction factor employed shall be determined by assuming that the component has operated at the maximum temperature throughout its prior operational life (exclusive of Level D Service Condition.)

HBB-3226 Pressure Testing Limitations

During any static pressure testing, the following limits shall not be exceeded in any structural part:

(a) The general primary membrane stress intensity shall not exceed 90% of the tabulated yield strength at temperature.

(b) The primary membrane plus bending stress intensity shall not exceed 135% of the tabulated yield stress at temperature.

(c) The external pressure shall not exceed 135% of the maximum pressure allowed by the design rules of HBB-3250.

HBB-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special operating conditions or configurations. Some of these deviations are more restrictive, and some are less restrictive, than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of HBB-3227 take precedence for the particular situations to which they apply.

HBB-3227.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of load categories other than Level D Service Loading, shall be considered.

The average bearing stress for Service Levels A, B, and C shall be limited to the lesser of:

(1) the tabulated yield strength at the Service Temperature; or

(2) the stress at 0.2% offset strain as obtained from the isochronous stress-strain curve for the temperature of service and for the time duration equal to the total service life the component is expected to spend at temperatures greater than those listed in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) For clad surfaces, the properties of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(c) When bearing loads are applied near free edges, such as at a protruding edge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to $0.6S_{mt}$ in the case of load-controlled stresses. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

HBB-3227.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear (for example, keys, shear rings, screw threads), experienced as a result of any loading categories other than Level D Service Loadings, shall be limited to $0.6S_{mt}$.

(b) The maximum primary shear stress, experienced as a result of any loading categories other than Level D Service Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_{mt}$.

HBB-3227.3 Progressive Distortion of Nonintegral Connections. Screwed on caps, screwed in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operational cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Such nonintegral connections shall not be used where service temperatures are expected to exceed those associated with allowable stress intensity values for the specific materials as shown in Section II, Part D, Subpart 1, Tables 2A and 2B.

Table HBB-3225-1
Tensile Strength Values, S_u

U.S. Customary Units, ksi

For Metal Temperature Not Exceeding, °F	See Section II, Part D, Subpart 1, Table U for Values up to 1,000°F				
	304 SS	316 SS	Ni-Fe-Cr UNS N08810	$2^1/_4$Cr-1Mo	9Cr-1Mo-1V
1,050	55.0	61.5	57.4	49.2	51.4
1,100	52.3	58.3	55.3	43.7	45.5
1,150	49.1	54.7	52.9	37.1	39.4
1,200	45.6	50.6	50.2	29.6	33.2
1,250	41.8	46.0	47.0	...	...
1,300	37.7	41.0	43.6	...	...
1,350	33.4	35.7	39.9	...	...
1,400	29.1	30.0	36.0	...	...
1,450	24.8	24.2	32.0	...	...
1,500	20.6	18.2	27.8	...	...
1,550	...	...	23.7	...	...
1,600	...	...	19.7	...	...
1,650	...	...	16.0	...	...

SI Units, MPa

For Metal Temperature Not Exceeding, °C	See Section II, Part D, Subpart 1, Table U for Values up to 538°C				
	304 SS	316 SS	Ni-Fe-Cr UNS N08810	$2^1/_4$Cr–1Mo	9Cr-1Mo-1V
550	388	435	402	358	379
575	373	417	391	327	341
600	355	396	378	290	303
625	335	373	362	248	265
650	314	347	345	202	228
675	289	318	326	...	...
700	264	288	305	...	...
725	238	255	282	...	...
750	211	221	258	...	...
775	185	185	233	...	...
800	159	149	208	...	...
825	...	...	182	...	...
850	...	...	157	...	...
875	...	...	132	...	...
900	...	...	109	...	...

GENERAL NOTES:

(a) The tabulated values of tensile strength and yield strength are those which the Committee believes are suitable for use in design calculations required by this Subsection. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value which may be as much as 10% above the tensile strength trend curve adjusted to the minimum specified room temperature tensile strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either *average* or *minimum* as these terms are applied to a statistical treatment of a homogeneous set of data.

(b) Neither the ASME Material Specifications nor the rules of this Subsection required elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means should be considered.

(23)

Table HBB-3225-2
Tensile and Yield Strength Reduction Factor Due to Long Time Prior Elevated Temperature Service

Material	Service Temp., °F (°C)	YS Reduction Factor	TS Reduction Factor
304 SS	≥ 900 (480)	1.00	0.80
316 SS	≥ 900 (480)	1.00	0.80
800H	≥ 1,350 (730)	0.90	0.90
$2^1/_4$Cr-1Mo	≥ 800 (425)	[Note (1)]	[Note (1)]
9Cr-1Mo-V	≥ 900 (480)	[Note (2)]	[Note (2)]

GENERAL NOTE: No reduction factor required for service below the indicated temperature.

NOTES:
(1) See Tables HBB-3225-3A and HBB-3225-3B are selected to correspond to the maximum wall-averaged temperature achieved during any Level A, B, or C Service Loading.
(2) See Tables HBB-3225-4A and HBB-3225-4B.

Table HBB-3225-3A
Yield Strength Reduction Factors for $2^1/_4$Cr-1Mo

U.S. Customary Units

Temp., °F	1E0	1E1	3E1	1E2	3E2	1E3	3E3	1E4	3E4	1E5	3E5
700	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.93	0.86
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.91	0.85	0.80
1,000	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.91	0.85	0.79	0.74
1,050	1.00	1.00	1.00	1.00	1.00	0.96	0.90	0.84	0.78	0.72	0.67
1,100	1.00	1.00	1.00	1.00	1.00	0.91	0.85	0.79	0.73	0.68	0.63
1,150	1.00	1.00	1.00	1.00	0.94	0.86	...	...	...	...	...
1,200	1.00	1.00	1.00	0.96	0.89	0.82	...	...	...	...	...

SI Units

Temp., °C	1E0	1E1	3E1	1E2	3E2	1E3	3E3	1E4	3E4	1E5	3E5
375	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
425	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93
475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95	0.88
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.94	0.89	0.82
525	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95	0.88	0.82	0.77
550	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.88	0.82	0.76	0.71
575	1.00	1.00	1.00	1.00	1.00	0.94	0.88	0.82	0.76	0.71	0.66
600	1.00	1.00	1.00	1.00	0.99	0.90	...	...	...	...	...
625	1.00	1.00	1.00	0.99	0.93	0.85	...	...	...	...	...
650	1.00	1.00	1.00	0.96	0.89	0.82	...	...	...	...	...

Table HBB-3225-3B
Tensile Strength Reduction Factors for $2\frac{1}{4}$Cr-1Mo

U.S. Customary Units

Temp.,°F	1E0	1E1	3E1	1E2	3E2	1E3	3E3	1E4	3E4	1E5	3E5
700	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.94
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.92	0.88
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.92	0.86	0.82
950	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.91	0.86	0.82	0.77
1,000	1.00	1.00	1.00	1.00	1.00	0.97	0.92	0.86	0.82	0.76	0.72
1,050	1.00	1.00	1.00	1.00	1.00	0.92	0.88	0.82	0.77	0.71	0.67
1,100	1.00	1.00	1.00	1.00	0.94	0.88	0.83	0.77	0.72	0.67	0.62
1,150	1.00	1.00	1.00	0.95	0.89	0.83	...	...	...	...	...
1,200	1.00	1.00	1.00	0.90	0.84	0.78	...	...	...	...	...

SI Units

Temp.,°C	1E0	1E1	3E1	1E2	3E2	1E3	3E3	1E4	3E4	1E5	3E5
375	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
425	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.89
475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.94	0.88	0.84
500	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.93	0.88	0.83	0.79
525	1.00	1.00	1.00	1.00	1.00	0.98	0.94	0.88	0.84	0.79	0.74
550	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.84	0.80	0.74	0.70
575	1.00	1.00	1.00	1.00	0.98	0.91	0.86	0.80	0.75	0.70	0.65
600	1.00	1.00	1.00	1.00	0.93	0.87	...	...	...	...	...
625	1.00	1.00	1.00	0.94	0.88	0.82	...	...	...	...	...
650	1.00	1.00	1.00	0.90	0.84	0.78	...	...	...	...	...

Table HBB-3225-4A
Yield Strength Reduction Factors for 9Cr-1Mo-V

(23)

U.S. Customary Units

Temp.,°F	Time, hr 1	10	3 × 10^1	10^2	3 × 10^2	10^3	3 × 10^3	10^4	3 × 10^4	10^5	3 × 10^5	5 × 10^5
700	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.94
1,050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.86
1,100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.88	0.79
1,150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.82	0.74
1,200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.76	0.69

SI Units

Temp.,°C	Time, h 1	10	3 × 10^1	10^2	3 × 10^2	10^3	3 × 10^3	10^4	3 × 10^4	10^5	3 × 10^5	5 × 10^5
375	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
425	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
525	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
550	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.90
575	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.83
600	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.86	0.77
625	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.81	0.74
650	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.76	0.69

GENERAL NOTE: The values in this table are extrapolated from shorter term test data using an engineering model. For longer design lives, the designer should consider further strength reductions to account for potential in-service material degradation, per HBB-2160(a). In addition, enhanced material surveillance programs and/or heightened in-service inspection per the rules of ASME Section XI may be warranted.

(23)

Table HBB-3225-4B
Tensile Strength Reduction Factors for 9Cr-1Mo-V

U.S. Customary Units

Temp., °F	Time, hr: 1	10	3×10^1	10^2	3×10^2	10^3	3×10^3	10^4	3×10^4	10^5	3×10^5	5×10^5
700	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.94
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.88	0.83
1,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.83	0.77
1,050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.81	0.75
1,100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.79	0.73
1,150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.88	0.76	0.71
1,200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.84	0.73	0.68

SI Units

Temp., °C	Time, h: 1	10	3×10^1	10^2	3×10^2	10^3	3×10^3	10^4	3×10^4	10^5	3×10^5	5×10^5
375	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
425	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.85
525	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.85	0.79
550	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.82	0.76
575	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.80	0.74
600	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.78	0.73
625	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.87	0.75	0.71
650	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.84	0.73	0.68

GENERAL NOTE: The values in this table are extrapolated from shorter term test data using an engineering model. For longer design lives, the designer should consider further strength reductions to account for potential in-service material degradation, per HBB-2160(a). In addition, enhanced material surveillance programs and/or heightened in-service inspection per the rules of ASME Section XI may be warranted.

HBB-3227.4 Triaxial Stresses. The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_{mt}.

HBB-3227.5 Nozzle Piping Transition. The P_m classification of stresses resulting from pressure, external loads, and moments is applicable for that length of nozzle which lies within the limits of reinforcement given by Division 1, NB-3334, whether or not nozzle reinforcement is provided. Beyond the limits of reinforcement, a P_m classification shall be applied to the general primary membrane stress intensity averaged across the section (not thickness) resulting from combined pressure and external mechanical loads; a P_L or $P_L + P_b$ classification shall be respectively applied to local primary membrane or local primary membrane plus bending stress intensities that result from design pressure and external mechanical loads; and a $P_L + P_b + Q$ classification shall be applied to primary plus secondary stress intensities resulting from all loads including external load or moment attributable to restrained free end displacement of the attached pipe.

HBB-3227.7 Requirements for Specially Designed Welded Seals.

(a) Welded seals, such as omega and canopy seals (Division 1, NB-4360), shall be designed to meet the pressure-induced general primary membrane stress intensity limits specified in Subsection HB, Subpart B for their materials of fabrication. Note that the general primary membrane stress intensity varies around the toroidal cross section.

(b) All other membrane and bending stress intensities developed in the welded seals may be considered as secondary stress intensities or peak stress intensities, as appropriate.

HBB-3227.8 Cladding. The rules of (a) through (d) below apply to the analysis of clad components constructed of material under this Subsection.

(a) Load-Controlled Stresses. No structural strength shall be attributed to the cladding in satisfying the load-controlled stress limits in HBB-3200.

(b) Design Dimensions. The dimensions stipulated in (1) and (2) below shall be used in the design of the component.

(1) For components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding.

(2) For components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

(c) Deformation-Controlled Quantities. No structural strength shall be attributed to the cladding in satisfying requirements on buckling instability. However, the cladding shall be considered in all other calculations related to satisfying limits on deformation-controlled quantities.

(d) Bearing Stresses. In satisfying (a), the presence of cladding shall be included.

HBB-3230 STRESS LIMITS FOR LOAD-CONTROLLED STRESSES ON BOLTS

HBB-3231 General Requirements

(a) Elevated temperature components that contain bolts not exposed to elevated temperature service may be designed using the materials, design methods, and design limits of Division 1, Subsection NB (Section III Appendices, Mandatory Appendix XIII, XIII-4000, and Nonmandatory Appendix E).

(b) Bolts which are to experience elevated temperature service shall comply with the requirements of HBB-3230.

HBB-3232 Design Limits for Bolts at Elevated Temperatures

(a) The number and cross-sectional area of bolts required to resist the design pressure may be determined in accordance with the procedures of Section III Appendices, Nonmandatory Appendix E, using the larger of the bolt loads given by the equations of Section III Appendices, Nonmandatory Appendix E as a design mechanical load. The reference allowable bolt design stress intensity values shall be the S_o values given in Table HBB-I-14.12 for bolting materials.

(b) When the seal is effected by a seal weld and no gasket is used, the gasket factor, m, and the minimum design seating stress, y, may be taken as zero.

(c) When gaskets are used for preservice testing only, the design shall be acceptable if the requirements of (a) above are satisfied using $m = y = 0$, and the requirements of HBB-3233 are satisfied using the appropriate m and y factors for the test gasket.

HBB-3233 Level A and B Service Limits for Bolts at Elevated Temperatures

HBB-3233.1 Average Stress. The maximum value of stress due to pressure loading, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed the S_{mt} stress values of Figures HBB-I-14.13A through HBB-I-14.13C. The rules of HBB-3232 shall apply except for the S_{mt} values replacing S_o values.

HBB-3233.2 Maximum Stress in the Cross Section. The maximum values for service stresses (averaged across the bolt cross section and neglecting stress concentrations), such as those produced by a combination of preload, pressure, and thermal expansion, shall not exceed two times the S_{mt} values of Figures HBB-I-14.13A through HBB-I-14.13C unless the design lifetime is divided into two or more loading periods and the possibility of creep rupture due to membrane stresses is guarded against by satisfying the use-fraction rule described in HBB-3224(b), with the use-fraction factor, B, set equal to 0.5.[16] Stress intensity, rather than maximum stress, shall be limited to this value when bolts are tightened by devices which result in residual torsion stresses. Residual torsion stresses are minimized by devices such as heaters and stretchers.

HBB-3233.3 Maximum Stress in the Bolt Periphery. The maximum value of service stress at the periphery of the bolt cross section (resulting from tension-plus-bending and neglecting stress concentrations) shall not exceed the lesser of three times the S_{mt} values in Figures HBB-I-14.13A through HBB-I-14.13C or $K_t S_t$ unless the design lifetime is divided into two or more loading periods and the possibility of creep rupture due to bending stresses is guarded against by satisfying the use-fraction rule described in HBB-3224(d), but with the use-fraction set at 0.67 instead of 1.0.[16] Stress intensity, rather than maximum stress, shall be limited to this value when bolts are tightened by devices that result in residual torsion stresses. Residual torsion stresses are minimized by devices such as heaters and stretchers.

HBB-3233.4 Nonductile Fracture. The rules of HBB-3241 shall apply to bolts.

HBB-3234 Level C Service Limits

The limits of HBB-3233 shall apply to primary loads in bolts.

HBB-3235 Level D Service Limits

The rules of HBB-3225 shall apply to primary loads in bolts.

HBB-3240 SPECIAL REQUIREMENTS FOR ELEVATED TEMPERATURE COMPONENTS

HBB-3241 Nonductile Fracture

(a) A portion of the Design Report (NCA-3211.40) shall justify the ability of the component to withstand the expected service conditions without undergoing nonductile fracture. Even though components are not expected to fail by nonductile fracture while at elevated temperatures, the stress relaxation occurring under elevated temperature conditions will often lead to high residual stresses during the portion of the operational cycle with lowest temperatures. For loading times, stresses, and temperatures where creep effects are not significant (HBB-3211), an acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G for ferritic materials. When Section III Appendices, Nonmandatory Appendix G is not applicable, the fracture analysis shall consider the anticipated stress level and flaw size, and compare these conditions with the fracture toughness of the material in the flaw region and at the appropriate temperature.

(b) The above justification requirements do not apply to Type 304 SS, Type 316 SS, or Alloy 800H, unless the fabrication effects substantially alter the fracture characteristics of these materials in such a manner that nonductile fracture becomes a plausible failure mode. The Design Specifications shall state when and how environmental effects shall be considered for nonductile fracture behavior in these materials.

HBB-3250 LIMITS ON DEFORMATION-CONTROLLED QUANTITIES

HBB-3251 General Requirements

The strains and deformation resulting from the specified operating conditions shall be evaluated. This evaluation shall include the effects of ratcheting, the interaction of creep and fatigue, and the possibility of buckling and structural instability. The N Certificate Holder shall document, as a portion of the Design Report (NCA-3211.40), what effects and conditions were considered in the final analysis procedures, the evaluation criteria, and the conclusions of the evaluation.

HBB-3252 Criteria

It is the responsibility of the Owner to define the acceptability criteria to be applied as buckling, strain, deformation, and fatigue limits in the Design Specifications (NCA-3211.19). The acceptability criteria and material properties contained in Nonmandatory Appendix HBB-T may be used. However, alternative criteria may be applied by the Certificate Holder subject to approval by the Owner. The Owner's approval shall be indicated by incorporating the alternative criteria into the Design Specifications.

HBB-3300 VESSEL DESIGNS

HBB-3310 GENERAL REQUIREMENTS

HBB-3311 Acceptability

(a) The requirements for acceptability of Class A vessel design are stated in HBB-3111.1.

(b) In cases of conflict between this subarticle and the rules of HBB-3100 and HBB-3200, the requirements of HBB-3300 shall govern.

HBB-3330 OPENINGS AND REINFORCEMENT

HBB-3331 General Requirements for Openings

(a) For vessels or parts thereof that meet the requirements of HBB-3330, the analysis limits of HBB-3220 related to load-controlled stresses need not be demonstrated in the vicinity of the openings. However, the deformation-controlled limits (HBB-3250) shall be satisfied in the vicinity of any opening exposed to conditions where creep effects are significant [HBB-3211(c)].

(b) Openings (for nozzle, branch, and piping connections) using deposited weld metal as reinforcement, as shown in Division 1, Figure NB-4244(c)-1, shall be limited to nominal diameters of 4 in. (100 mm) or less.

(c) If it is shown by analysis that all of the requirements of HBB-3200 have been met for the structural material near an opening, then the rules of HBB-3332 through HBB-3339 are waived.

HBB-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

The rules of Division 1, NB-3332 shall apply except that

(a) the $1.1S_m$ limit, which defines a locally stressed area, shall be replaced by $1.1S_{mt}$. The S_{mt} value shall correspond to the time equal to the service life of the vessel.

(b) t_r is the thickness which meets the requirements for primary membrane and primary membrane plus bending under Level A and B Service Loadings.

HBB-3333 Reinforcement Required for Openings in Flat Heads

The requirements of Division 1, NB-3333 shall apply, with the t_r defined as in HBB-3332.

HBB-3334 Limits of Reinforcement

The requirements of Division 1, NB-3334 shall apply.

HBB-3335 Metal Available for Reinforcement

The requirements of Division 1, NB-3335 shall apply except that subparagraph (a) is replaced by:

(a) metal forming a part of the vessel wall that is in excess of t_r (as defined in HBB-3332) and is exclusive of corrosion allowance;

HBB-3336 Strength of Reinforcing Material

(a) Material used for nozzle wall reinforcement shall be made of the same alloy type as that of the vessel wall, and the strength properties shall be assumed equivalent to those of the vessel wall material.

(b) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

HBB-3337 Attachment of Nozzles and Other Connections

HBB-3337.1 General Requirements. Nozzles and other Category D connections (HBB-3351) shall be attached to the shell or head of the vessel by one of the methods provided in HBB-3352.

HBB-3337.2 Full Penetration Welded Nozzles. Full penetration nozzle welds, as shown in Division 1, Figures NB-4244(a)-1, NB-4244(b)-1, NB-4244(c)-1, and NB-4244(e)-1, may be used (except as otherwise provided in HBB-3337.3) for the purpose of achieving continuity of metal and facilitating the required radiographic examination. When all or part of the required reinforcement is attributable to the nozzle, the nozzle shall be attached by full penetration welds through either the vessel or the nozzle thickness, or both.

HBB-3337.3 Partial Penetration Welded Nozzles.

(a) Partial penetration welds, as shown in Division 1, Figures NB-4244(d)-1 and NB-4244(d)-2, are allowed only for attachments on which there are essentially no piping reactions. Examples of such attachments include control rod housings, pressurized heater attachments, and openings for instrumentation.

(b) Earthquake loadings normally need not be considered in determining whether piping reactions are substantial. However, such loadings shall be considered if significant creep effects can occur at the nozzle.

(c) For such attachments, all reinforcement shall be integral with the portion of the vessel penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the attachment.

(d) Nozzles attached by partial penetration welds shall have an interference fit or a maximum diametral clearance between the nozzle and the vessel penetration of

(1) 0.010 in. (0.25 mm) for $d \leq 1$ in. (25 mm)

(2) 0.020 in. (0.50 mm) for 1 in. (25 mm) $< d \leq 4$ in. (100 mm)

(3) 0.030 in. (0.75 mm) for $d > 4$ in. (100 mm)

where d is the outside diameter of the nozzle.

(e) The ratio of nominal nozzle diameter to that of the main vessel shall be 0.1 or less.

(f) If significant creep effects occur in the vicinity of the nozzle, the use of partial penetration welds shall be restricted to nozzles with nominal diameters of 1 in. (25 mm) or less.

HBB-3338 Evaluation of Strain and Creep–Fatigue Limits in Openings

HBB-3338.1 General. For the purpose of determining deformation-controlled stresses for the evaluation of strain and creep-fatigue limits in openings, two applicable methods are listed below.

(a) Analytical Method. This method uses suitable analytical techniques such as finite element computer analyses, which provide detailed stress distributions around openings.

(b) Stress Index Method. This uses various equations covering a range of variation of applicable dimensional ratios and configurations (HBB-3338.2). This method covers only single, isolated openings. Stress indices may also be determined by analytical methods.

HBB-3338.2 Stress Index Method. The stress indices and rules provided in Division 1, NB-3338 may be used to determine stress components due to pressure in satisfying strain and creep–fatigue limits using elastic and simplified inelastic analyses (HBB-T-1320, HBB-T-1330, and HBB-T-1430).

HBB-3339 Alternative Rules for Nozzle Design

Subject to the limitations stipulated in Division 1, NB-3339.1, the requirements of Division 1, NB-3339 constitute an acceptable alternative to the rules of HBB-3332 through HBB-3336 and HBB-3338, provided t_r is as defined in HBB-3332(b) and HBB-3333.

HBB-3339.1 Stress Indices. The stress indices and rules provided in Division 1, NB-3339.7 may be used to determine stress components due to pressure in satisfying strain and creep–fatigue limits using elastic and simplified inelastic analyses (HBB-T-1320, HBB-T-1330, HBB-T-1430).

HBB-3350 DESIGN OF WELDED CONSTRUCTION

HBB-3351 Welded Joint Category

The term *Category*, as used herein, defines the location of a joint in a vessel, but not the type of joint. The categories established by this paragraph are for use in specifying special requirements regarding joint type and degree of examination for certain welded pressure joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements will apply to joints of a given category only when specifically so stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure HBB-3351-1 illustrates typical joint locations included in each category.

HBB-3351.1 Category A. Category A comprises longitudinal welded joints within the main shell, communicating chambers,[17] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[18] of a flat sided vessel; and circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.[17]

HBB-3351.2 Category B. Category B comprises circumferential welded joints within the main shell, communicating chambers,[17] nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.[17]

HBB-3351.3 Category C. Category C comprises welded joints connecting flanges, Van Stone laps, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers[17] any welded joint connecting one side plate[18] to another side plate of a flat sided vessel.

HBB-3351.4 Category D. Category D comprises welded joints connecting communicating chambers[17] or nozzles to main shells, to spheres, to transitions in diameter, to heads or to flat sided vessels, and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

HBB-3352 Permissible Types of Welded Joints

(a) The permissible types of welded joints and their dimensional requirements are described in the rules for fabrication of Class A components for elevated temperature service.

(b) The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle, α, not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure HBB-3352-1 shows typical butt welds for each category joint.

(c) When Category B joints with opposing lips to form an integral backing strip or joints with backing strips not later removed are used, the suitability for cyclic operation shall be analyzed using a fatigue strength reduction factor of not less than 2 under conditions where creep effects are insignificant [HBB-3211(c)]. For conditions where creep effects are significant, see HBB-3353(b).

(d) The corners of the end of each nozzle neck extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half the thickness, t_n, of the nozzle neck, or $^3/_4$ in. (19 mm), whichever is smaller. The d is the outside diameter of the nozzle.

(e) Where partial penetration welds are used, a fatigue strength reduction factor of not less than 4 shall be used for any related fatigue and analysis under conditions where creep effects are insignificant [HBB-3211(c)]. For conditions where creep effects are significant, see HBB-3353(b).

(f) Oblique full penetration nozzles are permitted provided (1), (2), and (3) below are satisfied.

(1) The opening shall be completely reinforced, with the reinforcement located in the shell or head of the vessel.

(2) The nozzle shall be subjected to essentially no pipe reactions and no thermal stresses greater than in the vessel itself.

(3) The nozzle wall and the weld shall develop the full strength of the nozzle.

Figure HBB-3351-1
Welded Joint Locations Typical of Categories A, B, C, and D

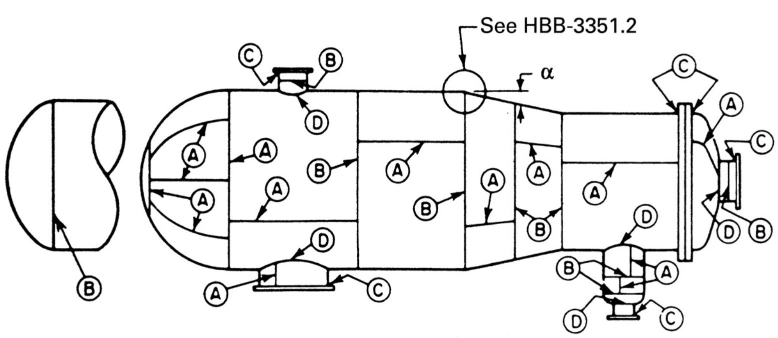
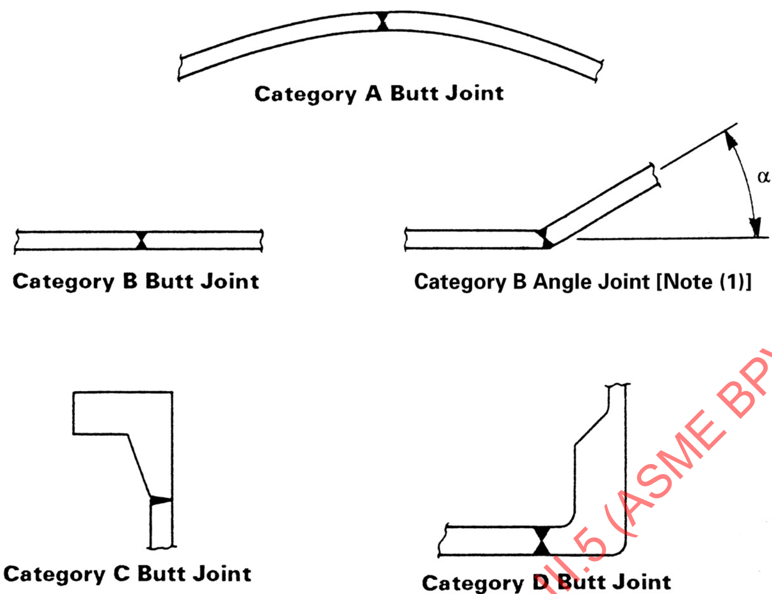


Figure HBB-3352-1
Typical Butt Joints



NOTE:
(1) When α does not exceed 30 deg, joint meets requirements for butt joints.

(g) Non-full penetration welds, which are permitted by HBB-3354 and HBB-3356 at attachment welds, shall have a surface geometry free from weld irregularities and abrupt changes in contour. When the designer determines that contour control is required in order that the criteria of this Subsection be satisfied, the necessary dimensions and tolerances shall be indicated on the fabrication drawings.

(h) Full penetration corner welds [as shown in Division 1, Figures NB-4243-1 and NB-4244(b)-1, and defined as Category C and D vessel welds, or, as similar welds for piping, pumps, and valves] shall be limited to nominal diameters of 4 in. (100 mm) or less.

HBB-3353 Design of Welded Construction at Elevated Temperatures

(a) Because of the potential for limited ductility of weld metal at elevated temperatures and the potential for high strain concentrations (both metallurgical and geometric) in the heat-affected zones of weldments, the analysis requirements of this paragraph shall be satisfied for the design and location of all pressure-retaining and other primary structural welds subjected to metal temperatures where creep effects are significant (HBB-3211). The potential for reduced ductility often precludes locating welds in regions of high loading.

(b) For meeting the analysis requirements of HBB-3251 at elevated temperature weld regions, the assumed weld surface should model the most severe strain concentrations expected in the actual weld placed in service. This geometry may be prescribed on a drawing or may be recorded by prior observation. Prior observations of weld surface geometry can be visual; remote visual (e.g., using a borescope device or making a surface replica); or ultrasonic, based on a weld mockup test in which the same weld procedures are used on the same nominal pipe diameter and wall thickness, or based on a radiographic technique that is suitable for inspection of internal surfaces.

HBB-3354 Structural Attachment Welds

(a) Welds for structural attachments shall meet the requirements of Division 1, NB-4430, NB-4240, and the rules of HBB-3352(g).

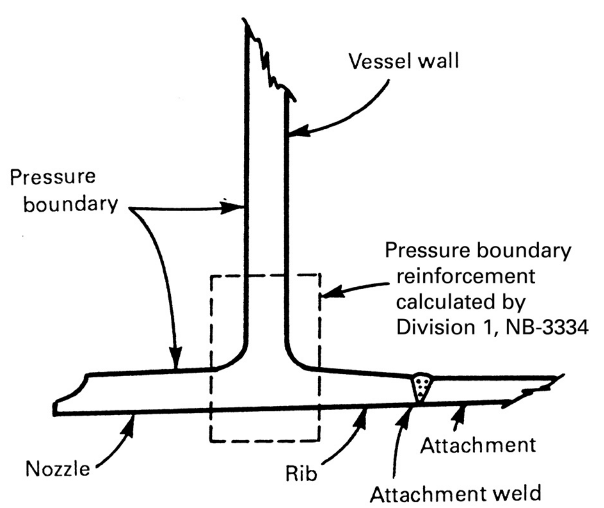
(b) Those attachments using the exemption of HBB-2121(h) shall also comply with the design rules listed below.

(1) The attachment weld shall be located on a rib outside the limits of reinforcement as defined by Division 1, NB-3334 (see example in Figure HBB-3354-1). The rib may be fabricated by forging, machining, or weld metal buildup.

(2) The attachment weld shall comply with the rules for Class A pressure boundary welds.

(3) Loads on the pressure boundary from all permanent attachments shall be considered in the analysis in the Design Report.

Figure HBB-3354-1
Permissible Attachment Weld Location



HBB-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration.

HBB-3356 Fillet Welds

HBB-3356.1 At Pressure Loaded Joints. Fillet welds are not permitted for pressure-retaining joints [see HBB-3337.3 and HBB-3352(g)].

HBB-3356.2 At Structural Attachment Joints.

(a) Fillet welds conforming to Division 1, Figure NB-4427-1 may be used for structural attachments to components, except as restricted and limited by the rules of Division 1, NB-4433.

(b) Analysis limits for stress limits, strain limits, and damage limits shall be one-half of the allowable values under HBB-3200 rules for the weaker of the two base materials being joined.

(c) Evaluation for fatigue shall use a fatigue strength reduction factor of four, and shall include consideration of temperature differences between the component and the attachment and of expansion (or contraction) of the component as a result of internal (or external) pressure.

HBB-3357 Thermal Treatment

All pressure vessels and pressure vessel parts shall be given the appropriate postweld heat treatment prescribed in Division 1, NB-4620.

HBB-3360 SPECIAL VESSEL REQUIREMENTS

HBB-3361 Category A or B Joints Between Sections of Unequal Thickness

In general, a tapered transition section as shown in Figure HBB-3361-1, which is a type of gross structural discontinuity (HBB-3213.2), shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper. An ellipsoidal or hemispherical head that has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder provided the remaining thickness is at least as great as that required for a shell of the same diameter. The adequacy of the transition shall be evaluated by stress analysis. See HBB-3200 for stress intensity limitations and other rules. The requirements of this paragraph do not apply to flange hubs.

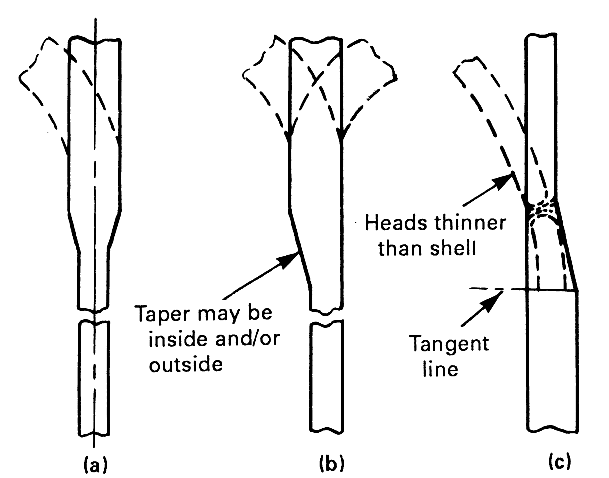
HBB-3362 Bolted Flange Connections

It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ASME B16.5, Steel Pipe Flanges and Flanged Fittings.

HBB-3363 Access Openings

Access openings, where provided, shall preferably consist of handhole or manhole openings having removable covers. These covers may be located on either the inside or outside of the shell or head openings and may be attached by studs or bolts in combination with gaskets and/or welded membrane seals or strength welds. Plugs using pipe threads are not permitted.

Figure HBB-3361-1
Category A and B Joints Between Sections of Unequal Thickness



GENERAL NOTE: Length of taper may include the width of the weld.

HBB-3364 Supports

All vessels shall be so supported and the supporting members shall be arranged and attached to the vessel wall in such a way as to provide for the maximum imposed loadings. The stresses produced in the vessel by such loadings and by steady state and transient thermal conditions shall be subjected to the stress limits of Subsection HB, Subpart B (NCA-3211.18 and Division 1, Subsection NF).

HBB-3400 DESIGN OF CLASS A PUMPS

HBB-3410 GENERAL REQUIREMENTS

HBB-3410.1 Scope. The rules of this subarticle constitute requirements for the design of Class A pumps.

(a) The scope of these rules covers the strength and pressure integrity of the structural parts of pumps whose failure would violate the pressure boundary.

(b) Such parts include

(1) pump casing

(2) pump inlets and outlets

(3) pump cover

(4) clamping ring

(5) seal housings

(6) related bolting

(7) pump internal heat exchanger piping

(8) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint, except as noted below

(9) piping identified with the pump and external to or forming a part of the pressure-retaining boundary and supplied with the pump

(10) mounting feet or pedestal supports when integrally attached to the pump pressure-retaining boundary and supplied with the pump

(c) The requirements of this subarticle do not apply to the pump shaft, nonstructural internals, or the seal package. Compliance with the requirements of this subarticle does not guarantee proper functioning of the component.

HBB-3410.2 Definitions.

(a) A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

(b) An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

(c) Seal housing is defined as that portion of the pump cover or casing that forms the primary pressure boundary.

(d) The figures accompanying the pump types are intended to be typical examples to aid in the determination of a pump type and are not to be considered as limiting. Bearing locations and inlet and outlet orientations are optional.

(e) The seal gland plate is to be considered a part of the seal housing and therefore is subject to Code requirements. The seal chamber pressure shall be specified in the Design Specification.

(f) Figures HBB-3410.2-1 and HBB-3410.2-2 show typical single and double volute casings, respectively.

HBB-3411 Acceptability of Large Pumps

(a) The requirements for the design of a Class A pump having an inlet connection greater than NPS 4 (DN 100) are stated in HBB-3111.1.

(b) In cases of conflict between this subarticle and the rules of HBB-3100 and HBB-3200, the requirements of HBB-3400 shall govern.

HBB-3412 Acceptability of Small Pumps

(a) The requirements for the design of a Class A pump having an inlet connection NPS 4 (DN 100) or smaller are stated in HBB-3111.1.

(b) In cases of conflict between this subarticle and the rules of HBB-3100 and HBB-3200, the requirements of HBB-3400 shall govern.

HBB-3413 Alternative Design Rules

For any size Class A pump, an experimental stress analysis may be used to determine elastic stresses and strains used with HBB-3200 limits and/or Nonmandatory Appendix HBB-T limits provided (a) and (b) below are satisfied.

(a) The experimental stress analysis is in accordance with the procedures of Section III Appendices, Mandatory Appendix II.

(b) The HBB-3421 design requirements are met.

Figure HBB-3410.2-1
Typical Single Volute Casing

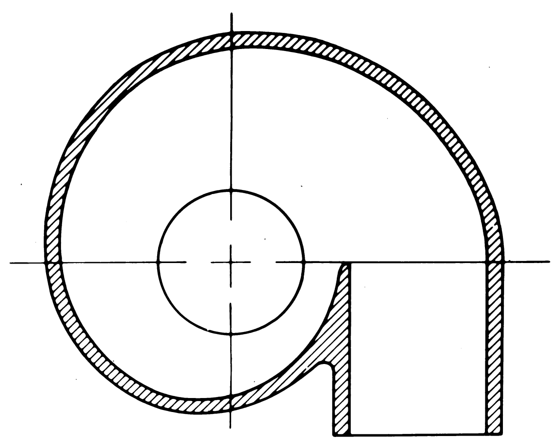
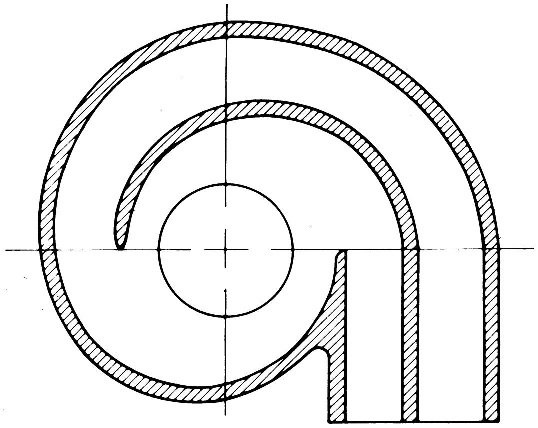


Figure HBB-3410.2-2
Typical Double Volute Casing



HBB-3420 DESIGN CONSIDERATIONS

HBB-3421 Design Requirements

HBB-3421.1 Loadings. Loadings, design and service conditions, special considerations, and general design rules are described in HBB-3100.

HBB-3421.2 Piping Under External Pressure. Piping located within the pressure-retaining boundary of the pump shall be designed in accordance with HBB-3250.

HBB-3421.3 Piping Under Internal Pressure. Piping identified with the pump and external to or forming a part of the pressure-retaining boundary, such as auxiliary water connections, shall be designed in accordance with HBB-3600.

HBB-3421.4 Piping Connections Using Partial Penetration Welds. Partial penetration welds are permitted for piping connections NPS 2 (DN 50) and smaller when used in accordance with the rules of HBB-3337.3 and HBB-3352.

HBB-3421.5 Bolting — Radially Split Configurations. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in HBB-3230.

HBB-3421.7 Supports. Pump supports shall be designed in accordance with the requirements of Division 1, Subsection NF if negligible creep effects are present during the cycle. Otherwise, the supports shall comply with HBB-3200.

HBB-3421.8 Axially Oriented Inlets and Outlets.

(a) An axially oriented pump casing inlet or outlet shall be considered an opening in a vessel and will require reinforcement. It shall be treated as required in HBB-3331 through HBB-3336.

(b) To avoid stress concentrations, the outside radius r_2, Division 1, Figure NB-3441.3-2, shall not be less than one-half the thickness of the inlets and outlets as reinforced.

HBB-3421.9 Radially Oriented Inlets and Outlets. Reinforcement of radially oriented inlets and outlets is required. HBB-3330 and HBB-3421.11 shall apply.

HBB-3421.10 Tangential Inlets and Outlets. Reinforcement of tangential inlets and outlets is required. HBB-3330 and HBB-3421.11 shall apply.

HBB-3421.11 Stress Analysis, Nozzle Loads, and Reinforcement.

(a) Stress Analysis. The analysis methods in Division 1, NB-3400 shall apply only to elastic analysis. In particular, stress equations may be used in satisfying the limits on load-controlled stresses, and they may be applied to analysis under HBB-3250 when creep effects are insignificant [HBB-3211(c)].

(b) Nozzle Loads. The forces and moments produced by the connected piping on the pump inlet and outlet shall be furnished to the pump supplier by the user in accordance with NCA-3211.19(c).

(c) Reinforcement. The distance ℓ in Figure HBB-3421.11-1 is the limit of reinforcement. The value of ℓ shall be determined from the relationship:

$$\ell = 0.5\sqrt{r_m t_m}$$

where

r_i = inlet or outlet inside radius
= $d_i/2$
r_m = $r_i + 0.5t_m$
t_m = mean inlet or outlet wall thickness taken between section x–x and a parallel section y–y tangent to crotch radius

HBB-3421.12 Earthquake Design Analysis. When earthquake loadings are specified in the Design Specification (NCA-3211.19), the designer shall assess the ability of the pump to withstand such loadings while maintaining the integrity of the pressure-retaining materials. For example, the assessment should include inertia effects from moving parts and piping reactions.

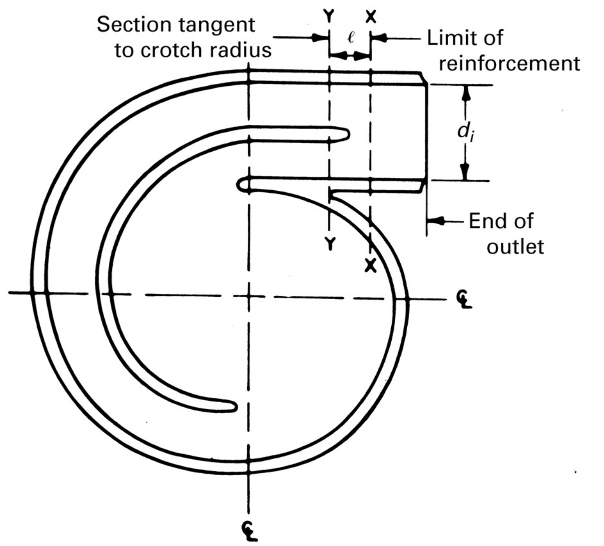
HBB-3421.13 Attachments. Attachments are permitted when designed in accordance with HBB-3135 and Division 1, NB-4430.

HBB-3421.14 Appurtenances. Appurtenances as defined in NCA-1260 are permitted provided the requirements for documentation are fulfilled as described in NCA-1260.

HBB-3421.15 Pump Covers. Pump covers shall be designed in accordance with HBB-3200.

HBB-3421.17 Cladding. The design of clad pressure-retaining parts shall be in accordance with HBB-3227.8.

Figure HBB-3421.11-1
Minimum Tangential Inlet and Outlet Wall Thickness



HBB-3421.19 Cutwater Tip Stresses. It is recognized that localized high stresses can occur at the cutwater tip of volute casings (Division 1, Figure NB-3441.3-2). Adequacy of the design in this area shall be demonstrated as follows:

(a) an evaluation of load-controlled stresses showing that sufficient area is available in the volute casing to meet the stress limit of HBB-3220; and

(b) an evaluation of the localized stress at the cutwater tip by:

(1) an investigation through experimental analysis in accordance with Section III Appendices, Mandatory Appendix II; or by

(2) a detailed stress analysis; or by

(3) a combination of the above.

(c) Where experimental and/or detailed stress analysis is used, stress and strain intensity at this point shall meet the requirements of HBB-3250.

HBB-3430 PUMP TYPES

Design requirements for specific pump types are listed in Division 1, NB-3430.

HBB-3500 DESIGN OF CLASS A VALVES

HBB-3510 DESIGN REQUIREMENTS

HBB-3511 Acceptability

(a) The requirements for acceptability of a Class A valve design are stated in HBB-3111.1.

(b) Compliance with the requirements of this subarticle does not guarantee proper functioning of the component.

(c) In cases of conflict between this subarticle and the rules of HBB-3100 and HBB-3200, the requirements of HBB-3500 shall govern.

HBB-3512 Stress Analysis

The analysis methods in Division 1, NB-3500 shall apply only to elastic analysis. In particular, the stress indices and stress equations may be used in satisfying the limits on load-controlled stresses, or they may be applied to analyses under HBB-3250 when creep effects are insignificant [HBB-3211(c)].

HBB-3520

HBB-3524 Earthquake Design Analysis

(a) When earthquake loadings are specified in the Design Specifications (NCA-3211.19), the designer shall assess the ability of the valve to withstand such loadings while maintaining the integrity of the pressure boundary materials. For example, the assessment should include inertia effects from moving parts and piping reactions.

(b) Where valves are provided with operators having extended structures and the Design Specifications state that these structures are essential to maintaining pressure integrity, an analysis may be based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses.

HBB-3526 Level C Service Limits

(a) If valve function is not required during any Level C Service Loadings included in the Design Specifications, the rules used in evaluating these conditions shall be those of HBB-3510.

(b) If valve function must be assured during Level C Service Loadings, this requirement shall be included in the Design Specifications and the specified emergency conditions for the plant shall be considered as the Level A Service Loadings for the valve.

HBB-3540

HBB-3544 Body Shape Rules

The rules of Division 1, NB-3544 provide a convenient guide for design of valve bodies for elevated temperature service. However, specific rules may be bypassed when justified by analysis.

HBB-3546 Other Valve Parts

(a) For valve stems, stem retaining structures, and other significantly stressed valve parts whose failure can lead to gross violation of the pressure-retaining boundary, the primary stresses shall not exceed the stress intensity limit, S_o. For materials not covered in Tables HBB-I-14.1(a), HBB-I-14.1(b), and HBB-I-14.2 but allowed under the rules of Division 1, NB-2121(c), the S_o values are those given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) Valve designs requiring solenoid plunger type or electromagnetic indicator type core tubes may substitute HBB-3600 rules to govern the requirements for the extension.

HBB-3550 CYCLIC LOADING REQUIREMENTS

When cyclic conditions exist, the rules for analysis are covered by HBB-3250 and HBB-3512.

HBB-3600 PIPING DESIGN

HBB-3610 GENERAL REQUIREMENTS

HBB-3611 Acceptability

(a) The requirements for acceptability of a Class A piping system design are stated in HBB-3111.1.

(b) In cases of conflict between this subarticle and the rules of HBB-3100 and HBB-3200, the requirements of HBB-3600 shall govern.

(c) The designer is cautioned to note that dimensional standards for pipe fittings control the minimum wall thickness, but do not establish maximum wall or contour. These additional dimensional controls may have to be imposed by the designer when significant thermal transients must be considered.

HBB-3612 Pressure–Temperature Ratings for Piping Components

(a) Where piping systems operating at different pressures are connected by a valve, the valve shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system may be designed to the higher pressure system requirements. If the lower pressure system is not designed to the higher pressure system requirements, pressure relief devices or safety valves shall be provided to protect the lower pressure system. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve. All valves, devices, and piping related to pressure relief functions shall meet requirements for overpressure protection of systems operating at elevated temperatures.

(b) Where pressure reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure reducing valves. The combined relieving capacity requirements and operational requirements shall be given by the rules on overpressure protection.

(c) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The design pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(d) Pump discharge piping shall be designed to withstand the maximum pressure exerted by the pump at any load, including that with a closed discharge valve, and for the highest coincident metal temperature.

(e) Where a fluid passes through heat exchangers in series, the design temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section of the system.

HBB-3620 DESIGN CONSIDERATIONS

HBB-3622 Dynamic Effects

HBB-3622.1 Impact. Impact forces caused by either external or internal conditions shall be considered in the piping design.

HBB-3622.2 Earthquake. The effects of earthquake shall be considered in the design of piping and supports. The loadings, movements (earthquake anchor movements), and number of cycles to be used in the analysis shall be part of the Design Specifications (NCA-3211.19). The stresses resulting from these earthquake effects must be included with weight, pressure, or other applied loads when making the required analysis.

HBB-3622.3 Vibration. Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial operating conditions, for ensuring that vibration of piping systems is within acceptable levels.

HBB-3623 Weight Effects

Piping systems shall be supported to provide for the dynamic effects of any contained fluid and for the fixed weights of piping, insulation, and other imposed mechanical loads in the piping.

HBB-3624 Loadings, Displacements, and Restraints

The design of piping systems shall take into account the forces and moments resulting from thermal expansion and contraction, equipment displacements and rotations, and the restraining effects of hangers, supports, and other localized loadings.

HBB-3626 Special Drainage Problems

(a) For piping systems that must be drained, consideration shall be given to creep induced sag that may develop between pipe supports in elevated temperature systems.

(b) For piping systems that drain at intermediate or elevated temperatures, consideration shall be given to load cycles associated with this condition.

HBB-3627 Considerations for Liquid Metal Piping

HBB-3627.1 Location. Routing of liquid metal piping in the vicinity of steam and water piping shall be avoided.

HBB-3627.2 Heat Tracing. Liquid metal piping shall be provided with heat tracing that shall be capable at least of maintaining the liquid metal in a molten condition. The use of steam or water for heat tracing shall not be permitted. Control of heat tracing shall provide for melting solidified liquid metal progressively from a free surface so that overpressure protection for the expansion of melting will not be required. Control shall also be adequate to assure that design rate of temperature change and temperature limits will not be exceeded.

HBB-3627.3 Filling and Draining.

(a) Liquid metal fill and drain shall be accommodated by means of an inert cover-gas purge and vent system. Volumetric expansion of liquid metal shall be provided for by a free liquid surface and a vented cover-gas space.

(b) All liquid metal piping shall be sloped to permit complete drainage by gravity into drain reservoirs. The use of small auxiliary drain lines shall be avoided.

HBB-3640 PRESSURE DESIGN OF COMPONENTS

HBB-3641

HBB-3641.1 Straight Pipe. The minimum wall thickness of pipe shall not be less than t_m, where t_m is determined from the requirements for Design Loadings analysis in HBB-3222.1.

HBB-3642 Curved Segments of Pipe

HBB-3642.1 Pipe Bends. The design of pipe bends shall provide that the completed bend will satisfy the analysis requirements of HBB-3200. In addition to the basic dimensions of the bend (i.e., pipe diameter, wall thickness, and bend radius), the designer shall consider the secondary deformations and irregularities inherent to the bending process and shall define tolerances as needed to ensure conformance of the finished piping with the rules for analysis. In particular, the considerations of (a) through (e) below shall be taken into account.

(a) Wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) Wall Thinning and Thickening. Experience has shown that with good shop practices the relationship of the finished bend thickness to that of the straight pipe from which it is bent will be in accordance with Table HBB-3642.1-1.

(c) Ovality

(d) Wrinkling (defined as the difference between the average outside diameter of any two adjacent wrinkles and the outside diameter of the enclosed valley) shall normally be held to 3%.

(e) Surface irregularities

Table HBB-3642.1-1
Bend Radius Versus Thickness

Radius of Bends	Minimum Thickness Recommended Prior to Bending [Note (1)]
6 pipe diameters or greater	$1.06t_m$
5 pipe diameters	$1.08t_m$
4 pipe diameters	$1.16t_m$
3 pipe diameters	$1.25t_m$

NOTE:
(1) t_m is the required minimum thickness of the finished bend.

HBB-3643 Intersections

The rules of HBB-3643 may be satisfied by demonstrating, by analysis or experiment or both, that the component fully complies with the requirements of HBB-3200.

HBB-3643.1 General Requirements.

(a) Openings shall be circular, elliptical, or of any other shape that results from the intersection of a circular or elliptical cylinder with a cylindrical shape.

(b) All references to dimensions in this and succeeding paragraphs apply to the finished dimensions, excluding material added for corrosion allowance.

(c) Any type of opening permitted in these rules may be located in a welded joint.

(d) The requirements of Division 1, NB-3643.3 shall be met for the branch connections listed in HBB-3643.2(b), HBB-3643.2(c), and HBB-3643.2(d), except that S_o and HBB-3641.1 should be used instead of callouts (Division 1, NB-3643.3) to S_m and Division 1, NB-3641.1, respectively.

HBB-3643.2 Branch Connections. Branch connections in piping may be made by using one of the products or methods set forth in (a), (b), and (c) below.

(a) flanged, butt weld, or socket weld in accordance with the applicable standards listed in Table NCA-7100-1, subject to the limitations or requirements stated elsewhere in this Subsection [for example, see HBB-3660(b)];

(b) contour outlet fittings having integral reinforcement and attached by butt welding, or flanged ends for attachment to the branch pipe. These are limited to types that have integral reinforcement and are attached to the main run by welding, as illustrated in figures contained in the rules of Article HBB-4000;

(c) an extruded outlet at right angles to the run pipe;

(d) For conditions where creep effects are insignificant [HBB-3211(c)], intersecting pipes may be joined by welding the branch pipe to the run pipe as shown in Division 1, Figure NB-3643.3(a)-2. For such intersections, the intersection angle shall be not less than 60 nor greater than 120 deg.

HBB-3644 Miters

Mitered joints may be used for elevated temperature service subject to meeting analysis requirements of HBB-3200 and also complying with the requirements for fabrication. Maximum angles shall be $22^1/_2$ deg or less.

HBB-3645 Attachments

The rules of HBB-3135 apply.

HBB-3646 Closures

(a) Closures in piping systems may be made by use of closure fittings, such as blind flanges or welded plugs or caps.

(b) The use of such closures in elevated temperature service shall be subject to meeting the analysis requirements of HBB-3200.

(c) For closures not subjected to elevated temperatures, the rules of Division 1, NB-3646 shall apply.

HBB-3647 Flanged Joints

(a) The use of flanged joints should be minimized.

(b) Any flanged joint shall be located where regular maintenance can be performed.

(c) Flanged joints exposed to elevated temperature service shall comply with the analysis requirements of HBB-3200.

(d) Flanged joints not exposed to elevated temperatures shall meet the requirements of Division 1, NB-3647.

HBB-3648 Reducers

Reduced fittings shall be considered suitable for use subject to complying with the analysis requirements of HBB-3200.

HBB-3649 Pressure Design of Other Pressure-Retaining Components

Other pressure-retaining components manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use provided the design is consistent with the design philosophy embodied in Subsection HB, Subpart B. Pressure-retaining components not included in Table NCA-7100-1 may be used if they satisfy the requirements of HBB-3200. The pressure design shall be based on an analysis consistent with the general design philosophy embodied in Subsection HB, Subpart B, or experimental stress analysis in accordance with HBB-3649.1.

HBB-3649.1 Experimental Analysis.

(a) An experimental analysis, if used, shall adhere to the methods and principles in Section III Appendices, Mandatory Appendix II with changes appropriate for elevated temperature conditions.

(b) As part of the experimental analysis, an ASME B16.9-type burst test shall be performed on the component. The bursting pressure shall equal or exceed that of the weakest pipe to be attached to the component, where the pipe burst pressure is calculated by the equation:

$$P = 2\,St / D_o$$

where

D_o = outside diameter of pipe
S = specified minimum tensile strength of pipe material
t = minimum specified wall thickness of pipe

HBB-3650 ANALYSIS OF PIPING COMPONENTS

HBB-3651 General Requirements

Until special rules for piping components are developed for elevated temperature service, the analysis requirements are given by (a), (b), and (c).

(a) The structural analysis shall demonstrate (by analysis or experiment or both) that the component fully complies with the requirements of HBB-3200.

(b) The primary and secondary stress indices (B and C) and corresponding stress equations of Division 1, NB-3600 may be used to determine stress intensities in satisfying the limits on load-controlled stresses (HBB-3220) and strain limits using elastic analysis (HBB-T-1320). Stress components determined from the stress indices given in Division 1, NB-3684, NB-3685, and, by reference, NB-3338 may be used in satisfying strain and creep–fatigue limits using elastic and simplified inelastic analyses (HBB-T-1320, HBB-T-1330, HBB-T-1430).

(c) Analytical methods such as finite element computer analyses may be used to provide detailed stress distributions.

HBB-3660 DESIGN OF WELDS

(a) Weld designs shall comply with the requirements of HBB-3350 and HBB-3337.

(b) Socket welds and seal welded threads are generally not permitted for joints exposed to elevated temperature service. Exceptions shall be allowed only if the analysis requirements of this Subsection are satisfied at each junction and only if each application is specifically described as part of the Design Specifications (NCA-3211.19). In almost all systems containing nuclear coolant, such crevices and cracks are undesirable due to potential for trapped radioactive particles, problems with cleaning fluids, and impurities in the coolant. Joints allowed under the rules of this paragraph shall be limited to nominal diameters of 1 in. (25 mm) and smaller.

(c) Full penetration corner welds may be used (in addition to butt welds) for attaching branch connections and closures to piping in accordance with HBB-3643.2 and HBB-3646, respectively.

HBB-3670 SPECIAL PIPING REQUIREMENTS

HBB-3671 Nonwelded Piping Joints

HBB-3671.1 Excluded Designs.

(a) Flared, flareless, and compression-type tubing fittings shall not be used.

(b) Expanded joints shall not be used.

(c) Caulked or leaded joints shall not be used.

(d) Soldered joints shall not be used.

HBB-3671.6 Brazed Joints. The rules of Division 1, NB-3671.6 apply. Any cooling liquid (or gas), including liquid sodium, is acceptable in the proximity of such joints provided the selected brazing material is compatible with the liquid.

HBB-3671.7 Patented Joints. Mechanical joints, for which no standards exist, and other patented joints may be used, provided that

(a) provision is made to prevent separation of the joints under all conditions of service.

(b) they are accessible for maintenance, removal, and replacement after operation.

(c) a prototype joint has been subjected either to performance tests to determine the safety of the joint under simulated service conditions (including the service fluid), or the joint meets all analysis requirements of HBB-3200. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock is anticipated, the applicable conditions shall be incorporated in the tests or analyses. The mechanical joints shall be sufficiently leak tight to satisfy the requirements of the Design Specifications (NCA-3211.19).

HBB-3672 Expansion and Flexibility

(a) In addition to meeting the design requirements for pressure, weight, and other loadings, piping systems shall be designed to absorb or resist thermal expansion or contraction or similar movements imposed by other sources, and shall meet the criteria as specified in HBB-3200. Piping systems shall be designed to have sufficient flexibility to prevent the movements from causing

(1) failure of piping or anchors from overstress or overstrain

(2) leakage at joints

(3) detrimental distortion of connected equipment resulting from excessive thrusts and moments

(b) In this Subsection, the effects of stresses, caused by pressure, thermal expansion and other loads, and their stress intensification factors, are considered cumulatively.

(c) When calculating the flexibility of a piping system between anchor points, the system between the anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(d) Comprehensive calculations shall take into account the flexibility factors found to exist in components other than straight pipe. Credit may be taken where extra flexibility exists in such components.

(e) Calculations shall consider line expansion as well as linear and angular movements of the equipment and supports attached to the piping.

(f) Where assumptions are used in calculations or model tests, the likelihood of attendant underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

(g) Cold springing may provide a beneficial effect in assisting a system to attain its most favorable position sooner and with the least initial inelastic straining. The effect of cold springing shall be analyzed as any other movement in the system is analyzed. The maximum stress allowed due to cold springing is $2.0S_m$ at the cold spring temperature. Since the usual erection procedures may not permit accurate determination of cold spring in a piping system, the allowable reduction of forces and moments at anchors or equipment caused by cold springing shall be limited to no more than two-thirds of the calculated reduction. At elevated temperatures, creep and creep relaxation shall be considered in the analysis of the cold sprung piping and in establishing the steady state configuration of the piping system.

HBB-3674 Design of Piping Supports

Pipe supports shall be designed in accordance with applicable rules of Division 1, Subsection NF, except for the stress analysis, which shall be in accordance with the rules of HBB-3200.

ARTICLE HBB-4000
FABRICATION AND INSTALLATION

HBB-4100 GENERAL REQUIREMENTS

HBB-4110 INTRODUCTION

(a) Those portions of the component which do not experience elevated temperature service (as defined by the rules of Article HBB-3000) may use the Division 1, Article NB-4000 rules as applicable.

(b) Those portions of the component that do not meet the conditions in (a) above shall comply with the provisions of this Subsection in addition to the rules of Division 1, Article NB-4000.

(c) Those portions of the component on which options (a) or (b) above apply shall be identified during all phases of manufacture and installation.

HBB-4200

HBB-4210

HBB-4212 Effects of Forming and Bending Processes

The rules of this paragraph shall supplement those of Division 1, NB-4212 and NB-4213. Any process may be used to form or bend pressure-retaining materials, including weld metal, provided that the requirements of the subparagraphs below are met:

(a) Post fabrication heat treatment [in accordance with (b) below] of materials that have been formed during fabrication, shall be required unless one of the following conditions are met:

(1) Maximum fabrication induced local strains[19] do not exceed 5%,[20] regardless of the service temperature.

(2) Written technical justification shall be provided in the Design Report for not performing heat treatment, subsequent to straining, or for the use of an alternate heat treatment procedure, to that specified in (b) below, for fabrication induced strains greater than 5%.

The justification should provide assurance that the resultant material property capabilities are adequate for the intended service (fatigue, creep rupture, impact toughness, etc.) and shall include consideration of property variability through the material section. This option is not permitted for certain materials if the components are subjected during Level A, B, and C service, or for design conditions when only design conditions are specified, to short-time high temperature excursions that result in accumulated temperature exposures exceeding the maximum permissible values shown in Figure HBB-4212-1. This option is also not permitted for any austenitic material that is subjected to greater than 20% strain.[19]

(3) The roll threaded portion of bolting material is exempt from the heat treatment requirement.

(b) When required, the post fabrication heat treatment shall be in accordance with the following:

(1) For ferritic materials, the post fabrication heat treatment shall consist of heating to temperatures listed in Division 1, Table NB-4622.1-1 for the appropriate alloy P-Number. Holding times shall also be in accordance with this Table based on the material thickness at the point of maximum strain. This heat treatment shall be included in material certification per Division 1, NB-2211, the forming qualifications as required by Division 1, NB-4213, and applicable weld procedure qualifications.

Alternatively, the base material and welds may be reheat treated and recertified in accordance with the applicable material specification and requirements in Division 1, NB-2400. Reheat treatment may entail appropriate cooling from hot working temperatures above the upper critical temperature of the respective material provided required material property levels are recertified.

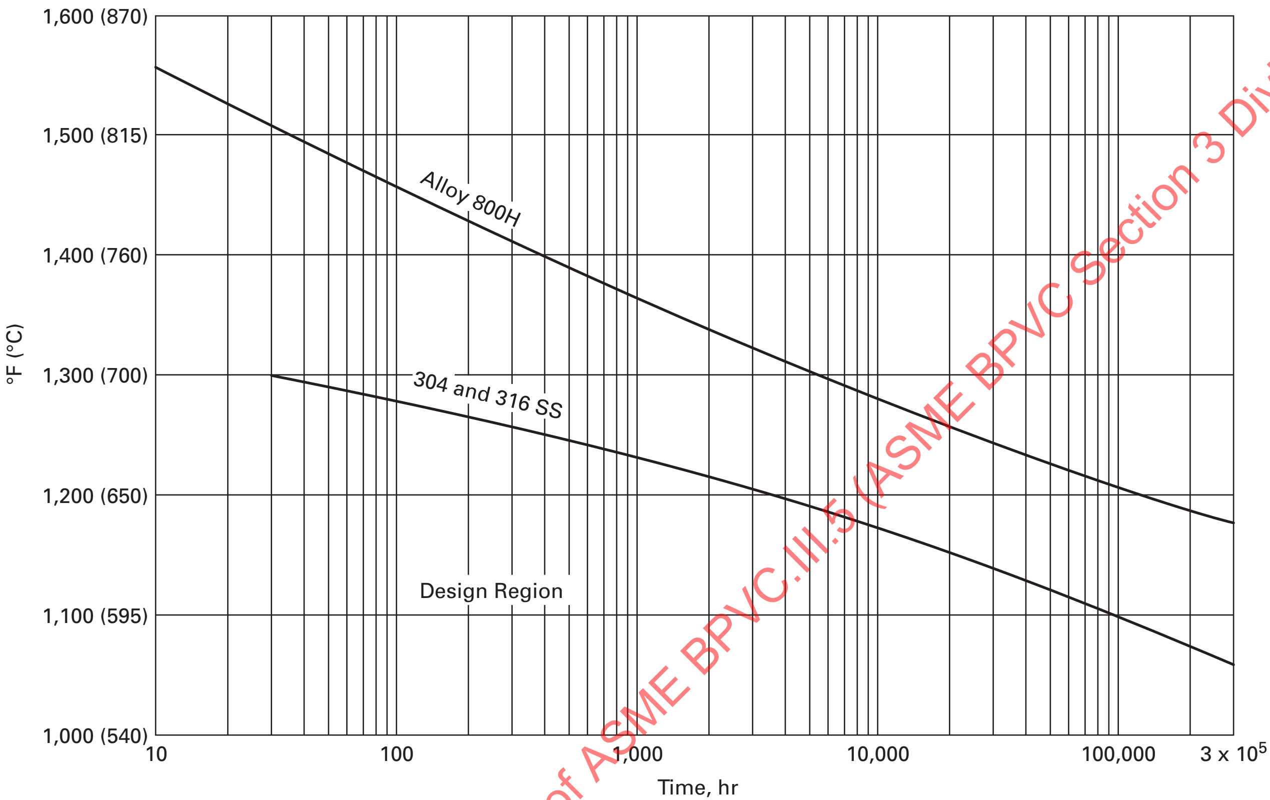
(2) For austenitic materials, the post fabrication heat treatment shall consist of the heat treatment specified in the base material specification except that Ni-Fe-Cr Alloy 800H shall be heat treated at 2,050°F (1 120°C) minimum.

Following reheat treatment, the final grain size of Alloy 800H shall be verified as being not finer than ASTM 5. If reheat treatment is employed, the designer shall be alerted to the possibility for material yield strength reductions, and the effect on buckling analysis must be accommodated as dictated by design rules.

HBB-4240 SPECIAL JOINTS AND FITTINGS — ADDED RULES FOR DIVISION 1, NB-4240

The rules of Article HBB-3000 generally discourage the use of socket weld fittings and seal welded threads. If used, the designer shall evaluate whether assembly of socket welds should allow for an axial gap after welding that will allow free thermal growth of the male coupling within the socket without bottoming out during the intended service. If a gap is deemed necessary, it shall be

Figure HBB-4212-1
Permissible Time/Temperature Conditions for Material Which Has Been Cold Worked >5% and <20% and Subjected to Short-Time High Temperature Transients



GENERAL NOTE: The sum of time at every temperature shall determine a point within the design region of the figure for the specific material. For multiple temperature/time combinations, the linear summation of life fraction shall not exceed 1.0, the material limit.

verified either by radiographic examination or by following special written procedures (see the rules of Article HBB-3000).

HBB-4400

HBB-4420

HBB-4424 Surfaces of Welds

As-welded surfaces are permitted provided that the surface geometry is considered in the stress analysis in accordance with the rules for design of Class A elevated temperature components.

ARTICLE HBB-5000 EXAMINATION

HBB-5100 GENERAL REQUIREMENTS FOR EXAMINATION

HBB-5110 GENERAL REQUIREMENTS

(a) Those portions of the component designated (in accordance with the rules of Article HBB-3000) as not to experience elevated temperature service may use the Division 1, Article NB-5000 rules unchanged by rules in later paragraphs of this Article.

(b) Those portions of the component that do not meet the conditions in (a) above shall comply with the provisions of this Article in addition to the rules of Division 1, Article NB-5000.

(c) Those portions of the component which use option (a) above shall be identified during all steps of examination.

HBB-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

The rules of this paragraph shall be substituted for the first sentence of Division 1, NB-5130.

All weld edge preparation surfaces for vessel weld joint Categories A, B, C, and D and similar pressure boundary welds in other components shall be examined by either the magnetic particle or liquid penetrant method. This requirement shall not apply to welds where the nominal thickness is 1 in. (25 mm) or less.

HBB-5200 REQUIRED EXAMINATION OF WELDS

HBB-5210 CATEGORY A VESSEL WELDED JOINTS AND LONGITUDINAL WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of Division 1, NB-5210.

All longitudinal butt welds of Category A, as defined in Division 1, NB-3351.1, and all similar pressure boundary welds in other Class A components shall be examined in accordance with the requirements of (a) and (b) below.

(a) External weld surfaces, accessible internal weld surfaces, and adjacent base material for at least $^1/_2$ in. (13 mm) outside the edges of the completed weld shall be examined by either the magnetic particle or liquid penetrant method.

(b) All weld metal and adjacent base material for at least $^1/_2$ in. (13 mm) outside the edges of each weld shall be volumetrically examined by an appropriate method from the three listed below:

(1) radiography plus ultrasonic examination, where the radiography may be performed prior to any intermediate or required postweld heat treatment, provided the ultrasonic examination is performed after the final postweld heat treatment;

(2) radiography plus eddy current examination, provided the portion of the weld being examined is less than $^1/_4$ in. (6 mm) thick;

(3) radiography at two different angles — one angle within 15 deg of perpendicular to the surface, the other at some angle appropriate for revealing any lack of fusion and cracking defects at the weld metal/base material interface near the root pass.

HBB-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of Division 1, NB-5220.

(a) For component regions with nominal diameter greater than 4 in. (100 mm), all circumferential butt welds similar to Category B, as defined in Division 1, NB-3351.2, shall be examined in accordance with the requirements of HBB-5210.

(b) For component regions with nominal diameter of 2 in. (50 mm) or less, all circumferential butt welds similar to Category B, along with adjacent base material for at least $^1/_8$ in. (3 mm) outside the edges of the completed weld, shall be radiographed. For component regions with a nominal diameter over 2 in. (50 mm) but not exceeding 4 in. (100 mm), circumferential butt welds similar to Category B welds shall be radiographed. The adjacent base material for a distance outside the edges of the completed weld equal to the greater of $^1/_8$ in. (3 mm) or t, but not to exceed $^1/_2$ in. (13 mm) where t is the thickness of the weld, shall also be radiographed. In addition, each completed weld shall undergo surface examination in accordance with the requirements of HBB-5210(a).

HBB-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of Division 1, NB-5230.

(a) For component regions with nominal diameter greater than 4 in. (100 mm), all full penetration welds similar to Category C, as defined in Division 1, NB-3351.3, shall be examined in accordance with the requirements of HBB-5210.

(b) For component regions with nominal diameter of 4 in. (100 mm) or less, all full penetration welds similar to Category C, along with adjacent base material for at least $^1/_2$ in. (13 mm) outside the edges of the completed weld, shall be radiographed. In addition, each completed weld shall undergo surface examination in accordance with the requirements of HBB-5210(a). For full penetration corner welds, the requirements of (c) and (d) below shall replace the requirements of this paragraph.

(c) For component regions with nominal diameter of 4 in. (100 mm) or less, all full penetration corner welds similar to Division 1, Figure NB-4243-1, sketches (a), (b), and (c) shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. In addition, each completed weld shall undergo surface examination in accordance with the requirements of HBB-5210(a).

(d) For component regions with nominal diameter of 4 in. (100 mm) or less, all full penetration corner welds similar to Division 1, Figure NB-4243-1, sketches (d), (e), and (f) shall be examined in accordance with the requirements of (c) above. In addition, the fusion zone and the parent metal beneath the attachment surface shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects.

HBB-5240 CATEGORY D VESSEL WELDED JOINTS AND BRANCH AND PIPING CONNECTIONS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of Division 1, NB-5240. All welded joints of Category D, as defined in Division 1, NB-3351.4, and similar pressure boundary welds in other components shall be examined in accordance with the requirements listed below.

HBB-5242 Butt-Welded Nozzles and Branch and Piping Connections

(a) Butt-welded attachment welds for nozzles and branch connections with nominal diameter greater than 4 in. (100 mm) shall be examined in accordance with the requirements of HBB-5210. These welds shall be full penetration butt welds through either the component wall or the nozzle wall, as shown in Division 1, Figure NB-4244(a)-1.

(b) Butt-welded attachment welds for nozzles and branch connections with nominal diameter of 4 in. (100 mm) or less shall be examined by radiography. The examination shall cover the weld metal and the adjacent base material for at least $^1/_2$ in. (13 mm) outside the edges of the completed weld. In addition, each completed weld shall undergo surface examination in accordance with the requirements of HBB-5210(a).

HBB-5243 Full Penetration Corner-Welded Nozzles and Branch and Piping Connections

(a) Full penetration corner-welded attachment welds for nozzles and branch connections with nominal diameter greater than 4 in. (100 mm) shall be examined in accordance with the requirements of HBB-5210.

(b) For nozzles and branch connections with nominal diameter of 4 in. (100 mm) or less, all full penetration corner-welded attachment welds similar to Division 1, Figure NB-4244(b)-1, sketch (f) shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. The examination shall cover the weld metal and the adjacent base material for at least $^1/_2$ in. (13 mm) outside the edges of the completed weld. In addition, each completed weld shall undergo surface examination in accordance with the requirements of HBB-5210(a).

(c) For nozzles and branch connections with nominal diameter of 4 in. (100 mm) or less, all full penetration corner-welded attachment welds similar to Division 1, Figure NB-4244(b)-1, sketches (a), (b), (c), (d), (e), and (g) shall be examined in accordance with the requirements of (b) above. In addition, the fusion zone and the parent material beneath the attachment surface shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects.

HBB-5244 Deposited Weld Metal as Reinforcement for Openings and Attachment of Nozzles, Branch, and Piping Connections

(a) Weld buildup deposits may be made to a surface as shown in Step 1 of Division 1, Figure NB-4244(c)-1 for nozzle and branch connections. When such weld deposits are made, the fusion zone and the parent metal beneath the weld shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects. Nozzles may then be attached as shown in Step 2 of Division 1, Figure NB-4244(c)-1.

(b) Full penetration attachment welds, similar to those shown in Division 1, Figure NB-4244(c)-1, shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. The examination shall cover the weld metal and the adjacent base material for at least $^1/_2$ in. (13 mm) outside the edges of the

completed weld. In addition, each completed weld shall undergo surface examination in accordance with the requirements of HBB-5210(a).

HBB-5245 Partial Penetration Welds

Partial penetration welds shall be used only for the small diameter applications allowed by the rules of Article HBB-3000. Partial penetration welds as shown in Division 1, Figures NB-4244(d)-1 and NB-4244(d)-2 shall be examined progressively using either the magnetic particle or the liquid penetrant method. The increments of examination shall be the lesser of one-half of the maximum weld dimension measured parallel to the center line of the connections, or $^1/_2$ in. (13 mm). In addition, each completed weld shall undergo surface examination in accordance with the requirements of HBB-5210(a).

HBB-5246 Full Penetration Category D Welds at Oblique Connections

(a) Full penetration welds shall be examined in accordance with the requirements of HBB-5210. Prior to examination, backing rings shall be removed and the nozzle bore surface finish shall be suitable for the type of examination.

(b) The radiographic examination in (a) above is not required provided all the conditions listed below are met.

(1) The weld is made as per Division 1, Figure NB-4244(e)-1, Step 1. After attachment [Step 1, sketch (a)] or after cladding [Step 1, sketch (b) or (c)], the weld, weld fusion zone, and base metal under the attachment shall have been ultrasonically examined.

(2) The weld is made as per Division 1, Figure NB-4244(e)-1, Step 2, and the magnetic particle or liquid penetrant method shall have been used to progressively examine the weld at the lesser of one-half the thickness of the weld joint, or each $^1/_2$ in. (13 mm) of weld thickness.

(3) A surface examination using the magnetic particle or liquid penetrant method shall have been made on the root pass weld.

(4) The angle which the nozzle axis makes with the component wall at the point of attachment is not smaller than 40 deg.

HBB-5260 FILLET, SOCKET, AND ATTACHMENT WELDS

HBB-5261 Fillet and Socket Welds

The rules of this paragraph shall be substituted for Division 1, NB-5260. Fillet and socket welds shall be used only for the small diameter applications allowed by the rules of Article HBB-3000. Completed surfaces of fillet and socket welds shall be examined visually and by either the magnetic particle or liquid penetrant methods. To ensure that proper fit-up and clearances were achieved in the as-welded condition, completed socket welds shall either be examined by postweld radiography oriented to verify the axial gap at the base of the socket weld, or they shall be examined in accordance with special instructions described in written procedures which comply with Division 1, NB-5112.

HBB-5262 Permanent Structural Attachment Welds

The rules of this paragraph shall be substituted for Division 1, NB-5262.

(a) Permanent structural attachment welds, as defined in Division 1, NB-4433, shall be examined by the methods listed below.

(1) radiography, unless it is excluded by (2) below. The absence of suitable radiographic equipment shall not be the justification for the rules of (2) below excluding the radiography requirements.

(2) Where radiography is impractical, the requirements of (1) above may be replaced either by using ultrasonic examination on the completed weld, or by progressively examining the weld using the magnetic particle or the liquid penetrant method.

For progressive examination of multipass welds whose final thickness will be 1 in. (25 mm), or less, the examination shall be performed after completion of one-half the final weld thickness. For progressive examination of welds whose final weld thickness will exceed 1 in. (25 mm), examinations shall be performed after the completion of each $^1/_2$ in. (13 mm) of weld thickness.

(3) Completed weld surfaces shall be examined by either a magnetic particle method or a liquid penetrant method.

(b) If it becomes necessary to cool a partially completed weld in order to perform the progressive examination of (a)(2) above, then care should be taken to keep the large structural parts from imposing large tensile loadings on partially completed welds.

HBB-5263 Nonstructural and Temporary Attachments

All completed weld surfaces on welds of nonstructural and temporary attachments, as defined in Division 1, NB-4435, shall be examined by either a liquid penetrant or magnetic particle method.

ARTICLE HBB-6000 TESTING

HBB-6100 GENERAL REQUIREMENTS

Testing of Section III, Division 5, Class A components when metal temperatures exceed those for which allowable stress values are given in Section II, Part D, Subpart 1, shall be in accordance with the rules of this Subsection.

HBB-6110 SCOPE OF TESTING

HBB-6111 General Hydrostatic and Pneumatic Test Media

(a) The selection of a particular test medium may depend upon considerations in (b), (c), and (d) below. For some items, a combination of gaseous and liquid test media may be desirable.

(b) Compared to pressurized liquids, gas under a similar pressure has a greater potential energy release. It is therefore recommended that special precautions for protection of personnel be taken when a gas under pressure is used as a test medium.

(c) Some components, appurtenances, or systems are not designed to support the liquid weight required in a hydrotest. Pneumatic tests should be considered for such components.

(d) The use of liquids for testing often results in traces of the liquid left in hard-to-clean places in the system, and these residues may be harmful to the structural material because of reactions involving the residues and the system coolant. Pneumatic tests should be considered under these circumstances.

HBB-6112 Pressure Testing of Components and Appurtenances

(a) Except as noted in (b) and (c) below, all components and appurtenances for elevated temperature service shall be static pressure tested in the presence of the Inspector.

(b) Nuts, bolts, studs, nonwelded access opening covers, and gaskets are exempt from the pressure test.

(c) A static pressure test of each line valve and pump with inlet piping connections of 4 in. (100 mm) nominal pipe size and smaller shall be performed by the Certificate Holder and so noted on the Data Report Form; however, this static pressure test need not be witnessed by the Inspector. The Inspector's review of the Certificate Holder's test records will be the Inspector's authority to sign the report. This takes precedence over NCA-5280.

(d) Under the special conditions of HBB-6117 and HBB-6118, a helium mass spectrometer leak test (plus other tests) may replace the static pressure test required in (a) above.

(e) The requirements of (a) above are met by meeting the requirement of HBB-6113(a).

(f) The component or appurtenance pressure test, when conducted in accordance with the rules of HBB-6221 or HBB-6321, shall be acceptable as a pressure test for parts and piping subassemblies.

(g) For components and appurtenances that will be subjected to external pressure loads in service, the pressure test requirement in (a) above may be performed on the basis of an internal pressure test using the rules of HBB-6221 or HBB-6321. The Design Specifications may require further tests to demonstrate structural integrity under external pressure loading.

HBB-6113 Pressure Testing of Systems

(a) Prior to initial operation, the installed Class A system shall be static pressure tested in the presence of the Inspector.

(b) Under the special restrictions of HBB-6117 and HBB-6118, a helium mass spectrometer leak test may replace the static pressure test in (a) above.

HBB-6115 Time of Pressure Test and Stamping of Components and Appurtenances

(a) The pressure tests of components and appurtenances required by HBB-6112(a) shall be performed prior to installation in the system as specified in HBB-6221(a) or HBB-6321(a).

(b) The pressure tests of components and appurtenances required by HBB-6112(a) may be performed after installation if the system pressure test is used under the provisions of HBB-6221(c) or HBB-6321(c).

(c) The Data Report Form shall not be completed nor signed by the Inspector and the components shall not be stamped until the Certificate Holder has conducted the static pressure test.

(d) Specially designed welded seals,[21] that are identified on the Data Report Form as being welded by the Certificate Holder under the rules of HBB-6118, need not be tested prior to the stamping of the component.

(e) Appurtenances containing brazed joints, pumps not designed by detailed analysis,[21] and valves shall be static pressure tested prior to installation in a system.

HBB-6116 Machining of Local Areas After Static Pressure Testing

(a) In local regions of the pressure boundary where tight tolerances are required for proper component functioning, extra wall thickness is permitted during pressure testing. If extra wall thickness is provided during fabrication, the excess material may be machined to critical dimensions and tolerances after completion of the static pressure test.

(b) The extra wall thickness permitted during pressure testing in (a) above shall not exceed 10% of the final wall thickness or $^3\!/_8$ in. (10 mm), whichever is less.

(c) The final wall thickness, after machining to critical dimensions and tolerances, shall comply with the minimum wall thickness requirements defined in the rules for design of Class A components for elevated temperature service.

HBB-6117 Alternative Tests of Closure Welds and Access Hatches

(a) Closure welds for access hatches in vessels and closure welds for connecting piping subassemblies may be tested by an alternative procedure for the pressure test requirements of HBB-6112 and HBB-6113 provided the conditions of (1) through (4) below are met:

(1) If hydrotesting were to be used, residues from the hydrotest liquid could be deleterious to the service;

(2) Closure welds are located at least $3\sqrt{RT}$ from major structural discontinuities such as flanges, large nozzles, pumps, or valves. R is the mean radius and T is the nominal thickness of the thicker material adjacent to the weld;

(3) The alternative test procedure in (b) below is specified for the closure welds; and

(4) The closure welds to which the alternative tests shall be applied, and the alternative test procedure shall be included in the Design Specification. The closure welds to which the alternative test procedure has been applied shall be identified on the Data Report.

(b) As an alternative to the pressure test procedure, closure welds may be tested by a mass spectrometer helium leak test.

HBB-6118 Alternative Tests at Specially Designed Welded Seals

(a) Specially designed welded seals, such as omega and canopy seals, need not meet the pressure test requirements of HBB-6112 and HBB-6113 when:

(1) The final weld cannot be completed until after the hydrostatic or pneumatic test because the system test pressure would exceed the limit specified for any system component; and

(2) The seal is subjected to a leak test at the maximum normal operating pressure.

(b) Welds of specially designed welded seals may be tested by a helium leak test in lieu of the pressure test requirements of HBB-6112 and HBB-6113 provided:

(1) The welds of the seal and the welds joining the seal to the component or supporting structure cannot be visually examined during testing due to access restrictions; and

(2) The welds and the alternative test procedures have been mutually agreed to by the Owner and the Certificate Holder, and the requirements appear in the Design Specifications and in the appropriate Data Report Form(s).

HBB-6120 PREPARATION FOR TESTING

HBB-6121 Exposure of Joints

All mechanical and welded joints, including welds, shall be left uninsulated and exposed for examination during the test.

HBB-6122 Addition of Temporary Supports

Components designed for vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

HBB-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraint, if required for the additional pressure load under test, or they shall be isolated from the test.

HBB-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subject to the pressure test shall be either disconnected from the component or system, or isolated by a blank flange or similar means. Valves may be used if the valve with its closure is suitable for the proposed test pressure.

HBB-6125 Treatment of Flanged Joints Containing Blinds

Flanged joints at which blinds are inserted to blank off other equipment during the test need not be tested until the blinds are removed.

HBB-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure. A small relief valve set to 1.33 times the test pressure is recommended during the pressure test.

HBB-6200 HYDROSTATIC TESTS

HBB-6210 HYDROSTATIC TESTING PROCEDURE

HBB-6211 Provision of Air Vents at High Points

Vents shall be provided at all high points of the component or system in the position in which the test is to be conducted to purge air pockets while the component or system is filling.

HBB-6212 Test Medium and Test Temperature

(a) Any nonhazardous liquid at any temperature below its boiling point may be used for the hydrostatic test. Combustible liquids having a flash point less than 100°F (38°C), such as petroleum distillates, may be used only for tests at near atmospheric temperature.

(b) No hydrostatic test shall be performed at a temperature which exceeds those for which S_m values are listed in Section II, Part D, Subpart 1, Tables 2A and 2B for any of the materials used in the pressure boundaries of components being tested.

(c) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (Division 1, NB-2330). The test pressure shall not be applied until the component, appurtenance or system, and the pressurizing medium are approximately at the same temperature.

(d) For the vessel hydrostatic test before installation, it is recommended that the test be made at a temperature not lower than [RT_{NDT} + 60°F (35°C)], (Division 1, NB-2331).

HBB-6213 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other appurtenances that should not be subjected to the test pressures have been disconnected or isolated by valves or other suitable means.

HBB-6215 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for a minimum of 10 min, as required by HBB-6224, examination for leakage shall be made of all joints, connections, and of all regions of high stress such as regions around openings and thickness transition sections. Except in the case of pumps and valves, which shall be examined while at test pressure, this examination shall be made at a pressure equal to the greater of the design pressure or three-fourths of the test pressure and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specifications. Leakage from temporary seals or leakage permitted by the Design Specifications shall be directed away from the surface of the component to avoid masking leaks from other joints.

HBB-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

HBB-6221 Minimum Required System Hydrostatic Test Pressure

(a) Except as may be otherwise required by material specifications and by the requirements of HBB-6223, all components and appurtenances shall be subjected to a hydrostatic test at a pressure not less than 1.25 times the system design pressure prior to installation in the nuclear power system.

(b) All pressure-retaining components of the completed Class A system shall be subjected to a system hydrostatic test at a pressure not less than 1.25 times the system design pressure unless specifically excepted under the provisions of HBB-6117 and HBB-6118.

(c) The system hydrostatic test of (b) may be substituted for a component hydrostatic test of (a), provided

(1) the component can be repaired by welding, if required, as a result of the system hydrostatic test, in accordance with the rules of Division 1, NB-2500

(2) the component repair can be postweld heat treated, if required, and nondestructively examined in accordance with rules of Division 1, NB-2500, NB-5100, and NB-5400, as applicable, subsequent to the system hydrostatic test

(3) the component is subjected to the required system hydrostatic test following the completion of repair and examination

HBB-6222 Maximum Permissible Hydrostatic Test Pressure

(a) The stress limits, contained in the rules of Article HBB-3000, shall be used in determining the permissible hydrostatic test pressure. In multichamber components, pressure may be simultaneously applied to the appropriate adjacent chamber to meet these stress limits. The number of test sequences for which the above provisions may be considered applicable shall not exceed ten.

(b) When hydrostatically testing a system, the test pressure shall not exceed the lowest of the maximum test pressures allowed for any of the components in the system.

HBB-6223 Hydrostatic Test Pressure for Valves, Pumps, and for Components and Appurtenances Containing Brazed Joints

(a) Prior to installation, valves, pumps not designed by detailed stress analysis, and other components and appurtenances containing brazed joints shall be hydrostatically tested at a pressure 1.5 times the system design pressure.

(b) The inlet (primary pressure containing) portion of safety and safety relief valves shall be hydrostatically tested at a pressure at least 1.5 times the set pressure marked on the valve. For closed system applications, the outlet portion of safety and safety relief valves shall be hydrostatically tested to 1.5 times the design secondary pressure of the outlet system.

HBB-6224 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained for a minimum total time of 10 min and for such additional time as may be necessary to conduct the examination for leakage required by HBB-6215. When testing pumps, valves, and other components covered by HBB-6223, the pressure shall be maintained a minimum of 15 min for each inch of design minimum wall thickness, but for not less than 10 min.

HBB-6300 PNEUMATIC TESTS

HBB-6310 PNEUMATIC TESTING PROCEDURES

HBB-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of HBB-6300 and HBB-6112.

HBB-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be non-flammable;

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (Division 1, NB-2330). The test pressure shall not be applied until the component, appurtenance or system, and the pressurizing medium are approximately the same temperature.

HBB-6313 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all appurtenances that should not be subjected to the test pressure have been disconnected or isolated by valves or other suitable means.

HBB-6314 Procedure for Applying Pressure

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. The pressure shall then be reduced to a value equal to the greater of the design pressure or three-fourths of the test pressure and held for a sufficient time to permit examination of the system in accordance with HBB-6315.

HBB-6315 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in HBB-6324, examination of leakage in accordance with HBB-6215 shall be made.

HBB-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

HBB-6321 Minimum Required System Pneumatic Test Pressure

(a) Except as may be otherwise required by material specifications and by the requirements of HBB-6323, all components and appurtenances shall be subjected to a pneumatic test at a pressure not less than 1.20 times the system design pressure prior to installation in the nuclear power system.

(b) All pressure-retaining components of the completed Class A system shall be subjected to a system pneumatic test at a pressure not less than 1.20 times the system design pressure unless specifically excepted under the provisions of HBB-6117 and HBB-6118.

(c) The system pneumatic test of (b) may be substituted for a component pneumatic test of (a), provided

(1) the component can be repaired by welding, if required as a result of the system pneumatic test, in accordance with the rules of Division 1, NB-4400;

(2) the component repair can be postweld heat treated, if required, and nondestructively examined in accordance with the rules of Division 1, NB-4400, NB-5100, and NB-5400, as applicable, subsequent to the system pneumatic test; and

(3) the component is subjected to the required system pressure test following the completion of repair and examination.

HBB-6322 Maximum Permissible Pneumatic Test Pressure

(a) The stress limits contained in the rules of Article HBB-3000 shall be used in determining the permissible pneumatic test pressure. In multichamber components, pressure may be simultaneously applied to the appropriate adjacent chamber to meet these stress limits. The number of test sequences for which the above provisions may be considered applicable shall not exceed ten.

(b) When pneumatically testing a system, the test pressure shall not exceed the lowest of the maximum test pressures allowed for any of the components in the system.

HBB-6323 Pneumatic Test Pressure for Valves, Pumps, and for Components and Appurtenances Containing Brazed Joints

(a) Prior to installation, valves, pumps not designed by detailed stress analysis, and other components and appurtenances containing brazed joints shall be pneumatically tested at a pressure 1.5 times the system design pressure.

(b) The inlet (primary pressure containing) portion of safety and safety relief valves shall be pneumatically tested at a pressure at least 1.5 times the set pressure marked on the valve. For closed system applications, the outlet portion of safety and safety relief valves shall be pneumatically tested to 1.5 times the design secondary pressure of the outlet system.

HBB-6324 Pneumatic Test Pressure Holding Time

The pneumatic test shall be maintained for a minimum total time of 10 min and for such additional time as may be necessary to conduct the examination for leakage required by HBB-6215.

HBB-6400 PRESSURE TEST GAGES

The rules of Division 1, NB-6400 shall apply.

ARTICLE HBB-7000 OVERPRESSURE PROTECTION

HBB-7100 GENERAL REQUIREMENTS

Overpressure protection for Section III, Class A components, when the metal temperature exceeds the Applicability and Max. Temp. Limits listed in Section II, Part D, Subpart 1, Tables 2A and 2B, shall be in accordance with the rules of Division 1, Article NB-7000, except as modified by Subsection HB, Subpart B.

HBB-7110 SCOPE

(a) Subsection HB, Subpart B provides Class A overpressure protection rules for those pressure boundary structures which, having been designated by the Owner [NCA-1140 and NCA-3211.4(a)] as a group of items requiring such protection, are not covered by Division 1, Article NB-7000 rules because some of the structures are expecting service temperatures above those currently allowed under the rules of Division 1, Subsection NB.

(b) Whereas the rules of Division 1, Article NB-7000 are oriented toward water and steam cooled reactor systems, the rules of Subsection HB, Subpart B encompass a wider variety of coolant fluids.

(c) The rules of Division 1, Article NB-7000 shall govern unless paragraphs are specifically altered by the rules of Subsection HB, Subpart B. All references to other Division 1, Article NB-7000 paragraphs are to be interpreted as referring to the Division 1, Article NB-7000 paragraphs as modified by Subsection HB, Subpart B.

(d) As with Division 1, Article NB-7000, the rules of this Subsection require that all system conditions, including transients, are described in the Design Specifications for the components being protected.

(e) In the evaluation of the effects of overpressure events, structural loadings shall include, but not be limited to, the types of events listed below.

(1) system overpressure due to a closed valve, a blocking object, or a solid core of metal coolant

(2) overpressure due to the addition of heat to an isolated portion of the system

(3) overpressure due to nuclear transients

(4) overpressure due to failure of a system component, including the effects of leaks from adjacent systems and possible resulting chemical reactions

(5) overpressure resulting from operator error

(6) overpressure due to constant pressure in combination with a rising overtemperature condition

(7) overpressure due to pump overspeed

(f) Events whose overpressure effects are beyond the Scope of the rules of Subsection HB, Subpart B are covered by Division 1, NB-7110(b) and include, for example:

(1) rapid closure of a check valve gate leads to fluid shock conditions in a local region

(2) earthquake motions induce sloshing of fluids contained in large tanks

(3) nuclear incident induces a severe pressure spike in a local region

(4) rapid closure of a valve during high flow rate conditions introduces pressure shocks

HBB-7130 VERIFICATION OF THE OPERATION OF PRESSURE RELIEF DEVICES

Revise Division 1, NB-7131 to read:

(a) Pressure relief devices shall be designed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

HBB-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

Revise title of Division 1, NB-7173 to read:

Valve Types Permitted for Water Service

Revise Division 1, NB-7174 to read:

Division 1, NB-7174 Nonreclosing Devices

Rupture disk devices may be used in air, gas, or liquid metal service in accordance with Division 1, NB-7600.

HBB-7200 CONTENT OF OVERPRESSURE PROTECTION REPORT

Add to Division 1, NB-7220, the listing below:

(o) the effects of any thermal dissipation or discharge storage system on the pressure relief devices;

(p) the disposition of effluent from pressure relief devices for both primary and secondary reactor coolant fluids.

HBB-7300 RELIEVING CAPACITY

Revise Division 1, NB-7321(c) to read:

The system overpressure established for setting the required total rated relieving capacity of (b) above shall be such that the calculated stress intensity and other design limitations for Service Limit C, as specified in the rules of Article HBB-3000, are not exceeded for each of the components in the protected system.

HBB-7600 NONRECLOSING PRESSURE RELIEF DEVICES

HBB-7610 USE OF RUPTURE DISK DEVICES

Revise Division 1, NB-7610 as shown below:

Rupture disk devices certified in accordance with Division 1, NB-7720 may be used as sole protection against overpressure loadings. Rupture disks shall use materials of construction approved in Article HBB-2000. Rupture disks may be used in conjunction with pressure relief valves on either the discharge side or the inlet side of the valve, provided the requirements of Division 1, NB-7700 are met.

HBB-7620

HBB-7621 Provisions for Venting or Draining Near Rupture Disks

Revise Division 1, NB-7621 as shown below:

The space between the rupture disk and any associated pressure relief valve shall be connected to a controlled disposal system as provided for the associated pressure relief valve. This space, if it exists, shall be provided with means to monitor its internal pressure during service periods.

HBB-7800 MARKING, STAMPING WITH CERTIFICATION MARK, AND DATA REPORTS

HBB-7810 PRESSURE RELIEF VALVES

HBB-7811 Marking and Stamping With Certification Mark

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data herein in such a way that the marking will not be obliterated in service. The data shall be in characters not less than $^3/_{32}$ in. (2.5 mm) high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Certification Mark shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

(a) the name, or an acceptable abbreviation, of the Certificate Holder

(b) Certificate Holder's design or type number

(c) size ________ NPS (DN) of the valve inlet

(d) set pressure ________ psi (kPa)

(e) certified capacity and overpressure in percent or psi (kPa)

(1) lb/hr (kg/h) of saturated steam for valves certified on steam

(2) scfm (standard cubic feet per minute) at 60°F (15°C) and 14.7 psia (101 kPa) of air for valves certified on air or gas, or

(3) gal/min of water at 70°F (20°C) for valves certified on water

(f) applicable official Certification Mark, as shown in Table HAA-8110-1.

In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and NB-3593.2.

ARTICLE HBB-8000
NAMEPLATES, STAMPING WITH THE CERTIFICATION MARK, AND REPORTS

HBB-8100 REQUIREMENTS

The applicable requirements given in Article HAA-8000 shall apply to Class A metallic pressure boundary components.

MANDATORY APPENDIX HBB-I-14
TABLES AND FIGURES

(23)

Table HBB-I-14.1(a)
Permissible Base Materials for Structures Other Than Bolting

Base Material	Spec. No.	Product Form	Types, Grades, or Classes
Types 304 SS and 316 SS [Note (1)], [Note (2)], [Note (3)]	SA-182	Fittings & Forgings	F 304, F 304H, F 316, F 316H
	SA-213	Smls. Tube	TP 304, TP 304H, TP 316, TP 316H
	SA-240	Plate	304, 316, 304H, 316H
	SA-249	Welded Tube	TP 304, TP 304H, TP 316, TP 316H
	SA-312	Welded & Smls. Pipe	TP 304, TP 304H, TP 316, TP 316H
	SA-358	Welded Pipe	304, 316, 304H, 316H
	SA-376	Smls. Pipe	TP 304, TP 304H, TP 316, TP 316H
	SA-403	Fittings	WP 304, WP 304H, WP 316, WP 316H, WP 304W, WP 304HW, WP 316W, WP 316HW
	SA-479	Bar	304, 304H, 316, 316H
	SA-965	Forgings	F 304, F 304H, F 316, F 316H
	SA-430	Forged & Bored Pipe	FP 304, FP 304H, FP 316, FP 316H
Ni–Fe–Cr (Alloy 800H) [Note (4)]	SB-163	Smls. Tubes	UNS N08810
	SB-407	Smls. Pipe & Tube	UNS N08810
	SB-408	Rod & Bar	UNS N08810
	SB-409	Plate, Sheet, & Strip	UNS N08810
	SB-564	Forgings	UNS N08810
$2\frac{1}{4}$Cr–1Mo [Note (5)]	SA-182	Forgings	F 22, Class 1
	SA-213	Smls. Tube	T 22
	SA-234	Piping Fittings	WP22 CL1 [Note (6)]
	SA-335	Forg. Pipe	P 22
	SA-336	Fittings, Forgings	F 22a
	SA-369	Forg. Pipe	FP 22
	SA-387	Plate	Gr 22, Class 1
	SA-691	Welded Pipe	Pipe $2\frac{1}{4}$ CR (SA-387, Gr. 22, Cl. 1)
9Cr–1Mo–V	SA-182	Forgings	F 91 Type 2
	SA-213	Smls. Tube	T 91 Type 2
	SA-335	Smls. Pipe	P 91 Type 2
	SA-387	Plate	Grade 91 Type 2

NOTES:
(1) These materials shall have a minimum specified room temperature yield strength of 30,000 psi (207 MPa) and a minimum specified carbon content of 0.04%. For use above 1,100°F (595°C), these materials shall have a 0.05% minimum nitrogen, 0.03% maximum aluminum, and 0.04% maximum titanium.
(2) For use at temperatures above 1,000°F (540°C), these materials may be used only if the material is heat treated by heating to a minimum temperature of 1,900°F (1 040°C) and quenching in water or rapidly cooling by other means.
(3) Nonmandatory Appendix HBB-U provides nonmandatory guidelines on additional specification restrictions to improve performance in certain service applications.
(4) These materials shall have a total aluminum-plus-titanium content of at least 0.50% and shall have been heat treated at a temperature of 2,050°F (1 120°C) or higher.
(5) This material shall have a minimum specified room temperature yield strength of 30,000 psi (207 MPa), a minimum specified room temperature ultimate strength of 60,000 psi (414 MPa), a maximum specified room temperature ultimate strength of 85,000 psi (586 MPa), and a minimum specified carbon content of 0.07%.
(6) The material allowed under SA-234 shall correspond to one of:
(a) SA-335, Grade P 22
(b) SA-387, Grade 22, Class 1
(c) SA-182, Grade F 22, Class 1 in compliance with Note (5).

(23)

Table HBB-I-14.1(b) Permissible Weld Materials

Base Material	Spec. No.	Class
Types 304 SS and 316 SS	SFA-5.4	E 308, E 308L, E 316, E 316L, E 16-8-2
	SFA-5.9	ER 308, ER 308L, ER 316, ER 316L, ER 16-8-2
	SFA-5.22	E 308, E 308T, E 308LT, E 316T, E316LT-1 EXXXT-G (16-8-2 chemistry)
Ni–Fe–Cr (Alloy 800H)	SFA-5.11	ENiCrFe-2
	SFA-5.14	ERNiCr-3
$2^1/_4$Cr–1Mo	SFA-5.5	E 90XX-B3 (>0.05% Carbon)
	SFA-5.23	EB 3, ECB 3
	SFA-5.28	E 90C-B3 (>0.05% Carbon), ER 90S-B3
	SFA-5.29	E 90T-B3 (>0.05% Carbon)
9Cr–1Mo–V	SFA-5.5	E90XX-B91
	SFA-5.23	EB91
	SFA-5.28	ER90S-B91

Table HBB-I-14.2
S_o — Maximum Allowable Stress Intensity, ksi (MPa), for Design Condition Calculations

U.S. Customary Units

For Metal Temperature Not Exceeding, °F	304 SS	316 SS	Ni-Fe-Cr (Solution Annealed) UNS N08810	2¼Cr-1Mo	9Cr-1Mo-V
700	...	...	...	17.9	26.7
750	...	...	...	17.9	25.9
800	15.2	15.9	15.3	16.6	24.9
850	14.8	15.7	15.1	16.6	23.7
900	14.6	15.6	14.8	13.6	21.9
950	14.2	15.5	14.6	10.8	17.8
1,000	11.1	14.0	14.1	8.0	16.3
1,050	10.1	11.2	11.2	5.7	12.9
1,100	9.8	11.1	10.0	3.8	9.6
1,150	7.7	9.8	9.3	...	7.0
1,200	6.1	7.4	7.4	...	4.3
1,250	4.7	5.5	5.9	...	...
1,300	3.7	4.1	4.7	...	...
1,350	2.9	3.1	3.8	...	...
1,400	2.3	2.3	3.0	...	...
1,450	1.8	1.7	...	...	...
1,500	1.4	1.3	...	...	...

SI Units

For Metal Temperature Not Exceeding, °C	304 SS	316 SS	Ni-Fe-Cr (Solution Annealed) UNS N08810	2¼Cr-1Mo	9Cr-1Mo-V
375	...	...	...	123	184
400	...	...	...	123	178
425	105	110	105	116	172
450	102	108	104	116	165
475	101	108	103	99	154
500	99	107	101	81	133
525	86	101	99	64	117
550	74	88	89	48	102
575	69	77	74	35	81
600	65	76	68	26 [Note (1)]	62
625	51	62	62	...	46
650	42	51	51	...	29
675	34	39	41	...	...
700	27	30	34	...	...
725	21	23	28	...	...
750	17	18	23 [Note (2)]	...	...
775	14	13	...	...	...
800	11 [Note (3)]	11 [Note (4)]	...	...	...

NOTES:
(1) This is the value of S_o for 2¼Cr-1Mo at 593°C.
(2) At 760°C the value of S_o for UNS N08810 is 21 MPa.
(3) At 816°C the value of S_o for 304 SS is 9.7 MPa.
(4) At 816°C the value of S_o for 316 SS is 9.0 MPa.

Figure HBB-I-14.3A
S_{mt} — Type 304 SS

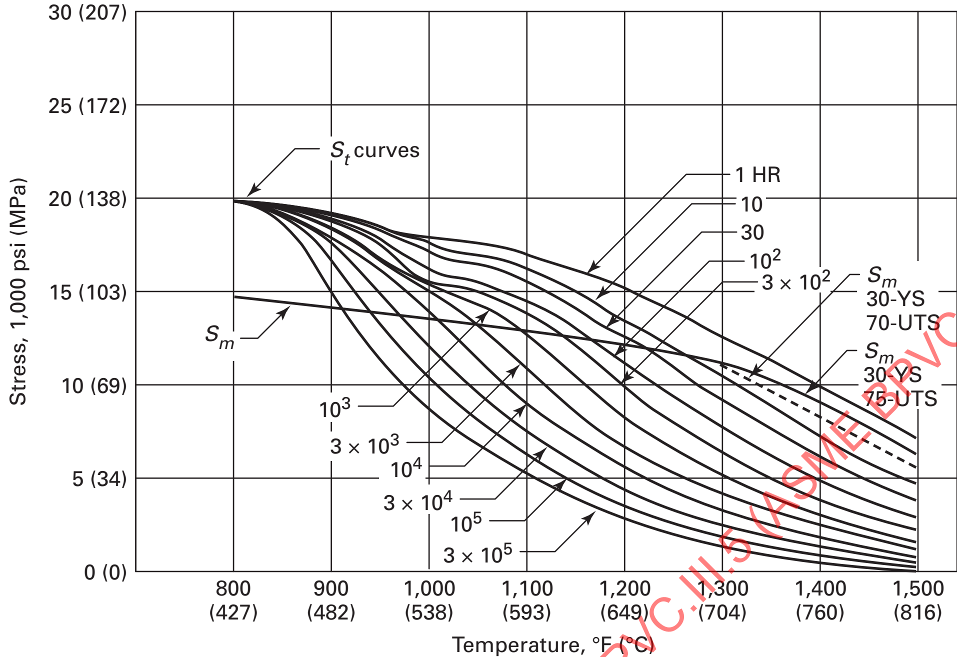


Table HBB-I-14.3A
S_{mt} — Allowable Stress Intensity Values, 1,000 psi, Type 304 SS — 30-YS, 75-UTS (30-YS, 70-UTS)

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
850	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
900	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
950	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.2	12.2
1,000	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.1	11.1	9.3
1,050	13.6	13.6	13.6	13.6	13.6	13.6	13.6	12.2	10.3	8.7	7.3
1,100	13.2	13.2	13.2	13.2	13.2	13.2	11.5	9.7	8.2	6.8	5.7
1,150	12.9	12.9	12.9	12.9	12.9	11.0	9.3	7.7	6.4	5.3	4.4
1,200	12.7	12.7	12.7	12.2	10.6	8.9	7.4	6.1	5.1	4.1	3.4
1,250	12.3	12.3	11.9	10.3	8.7	7.2	5.9	4.9	4.0	3.2	2.7
1,300	11.9 (11.8)	11.4	10.0	8.5	7.0	5.9	4.8	3.9	3.2	2.5	2.1
1,350	10.9 (10.5)	9.7	8.4	7.1	5.9	4.8	3.9	3.1	2.5	2.0	1.6
1,400	9.5 (9.0)	8.1	6.9	5.9	4.8	3.9	3.1	2.5	2.0	1.6	1.2
1,450	8.2 (7.5)	6.8	5.8	4.6	3.8	3.0	2.4	1.9	1.5	1.2	0.9
1,500	7.0 (6.4)	5.3	4.4	3.5	2.8	2.2	1.7	1.3	1.0	0.8	0.6

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	105	105	105	105	105	105	105	105	105	105	105
450	102	102	102	102	102	102	102	102	102	102	102
475	101	101	101	101	101	101	101	101	101	101	101
500	99	99	99	99	99	99	99	99	99	99	93
525	98	98	98	98	98	98	98	98	98	87	73
550	96	96	96	96	96	96	96	94	82	70	58
575	93	93	93	93	93	93	91	78	66	56	46
600	91	91	91	91	91	89	75	63	54	44	37
625	89	89	89	89	87	74	62	51	43	36	29
650	88	88	88	84	73	61	51	42	35	28	23
675	85	85	83	77	61	51	42	35	28	22	19
700	82 (81)	80	69	61	50	42	34	28	23	18	15
725	77 (74)	70	61	52	43	35	29	22	18	15	12
750	69 (66)	60	52	44	36	29	23	18	15	12	9
775	61 (57)	51	44	36	29	24	19	15	12	9	7
800	53 (49)	43	37	29	23	18	15	11	9	7	5

GENERAL NOTE: As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

Figure HBB-I-14.3B
S_{mt} — Type 316 SS

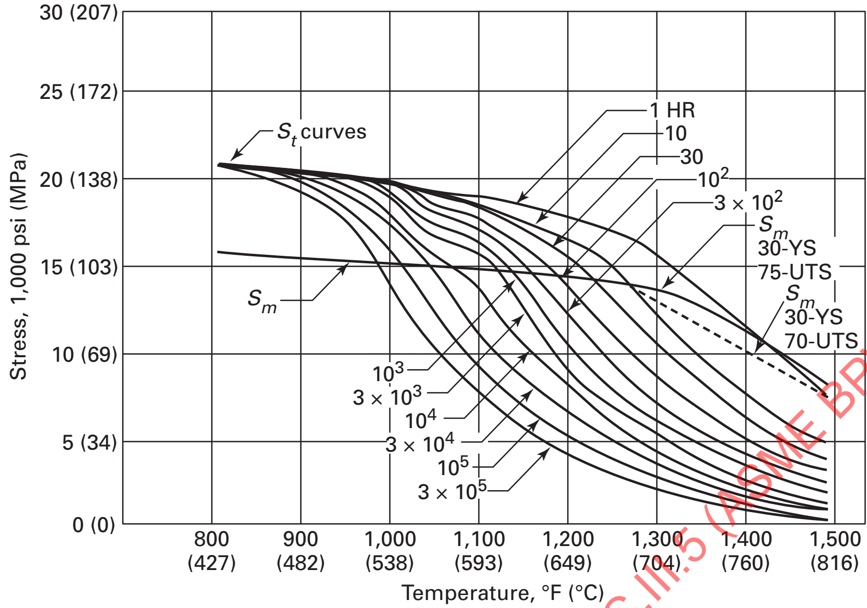


Table HBB-I-14.3B
S_{mt} — Allowable Stress Intensity Values, 1,000 psi, Type 316 SS — 30-YS, 75-UTS (30-YS, 70-UTS)
S_{mt} — Allowable Stress Intensity Values, MPa, Type 316 SS — 207-YS, 518-UTS (207-YS, 483-UTS)

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
850	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7
900	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
950	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
1,000	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	14.0
1,050	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	14.9	12.5	10.7
1,100	14.8	14.8	14.8	14.8	14.8	14.8	14.8	13.9	11.5	9.5	7.8
1,150	14.7	14.7	14.7	14.7	14.7	14.2	13.0	10.9	8.9	7.2	5.9
1,200	14.6	14.6	14.6	14.2	12.4	10.6	9.4	8.3	6.9	5.5	4.5
1,250	14.2	14.2	14.2	11.5	9.8	8.3	7.3	6.3	5.4	4.2	3.3
1,300	13.8 (13.4)	12.8	10.9	9.1	7.5	6.4	5.6	4.7	3.9	3.1	2.5
1,350	12.8 (11.9)	10.3	8.6	7.0	5.9	5.0	4.2	3.4	2.8	2.1	1.8
1,400	11.3 (10.5)	8.2	6.7	5.4	4.5	3.8	3.1	2.5	2.0	1.5	1.2
1,450	9.7 (9.0)	6.4	5.1	4.1	3.4	2.9	2.2	1.7	1.4	1.0	0.9
1,500	7.8 (7.7)	4.9	3.9	3.2	2.6	2.1	1.6	1.2	0.9	0.65	0.5

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	110	110	110	110	110	110	110	110	110	110	110
450	108	108	108	108	108	108	108	108	108	108	108
475	107	107	107	107	107	107	107	107	107	107	107
500	106	106	106	106	106	106	106	106	106	106	106
525	105	105	105	105	105	105	105	105	105	105	105
550	104	104	104	104	104	104	104	104	104	101	87
575	104	104	104	104	104	104	104	104	95	79	67
600	102	102	102	102	102	102	102	91	75	62	51
625	101	101	101	101	101	94	86	72	59	48	40
650	101	101	101	98	84	72	64	57	48	38	31
675	98	98	98	80	69	58	51	44	38	30	24
700	95 (92)	91	78	65	54	46	41	34	28	22	18
725	90 (85)	75	63	52	44	36	31	25	21	16	13
750	82 (76)	62	51	41	35	29	24	19	16	11	9
775	70 (65)	50	40	32	27	23	18	14	12	8	7
800	61 (58)	40	32	25	21	17	13	10	8	5	4

GENERAL NOTE: As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

Figure HBB-I-14.3C
S_{mt} — Ni-Fe-Cr (Alloy 800H)

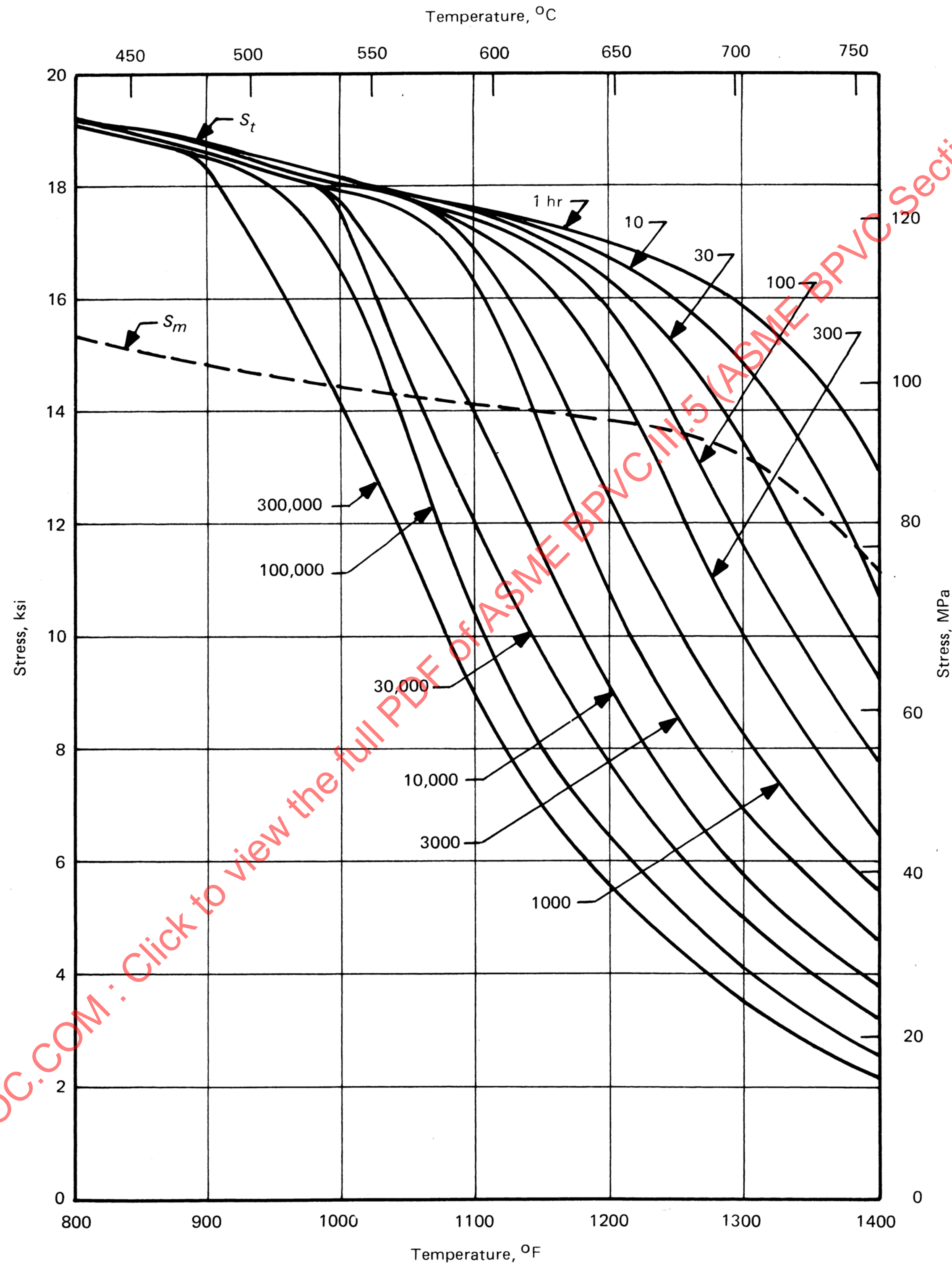


Table HBB-I-14.3C
S_{mt} — Allowable Stress Intensity Values, ksi (MPa), Ni-Fe-Cr (Alloy 800H)

U.S. Customary Units											
Temp., °F	1 hr	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
800	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
850	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
900	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
950	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
1,000	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.1
1,050	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	12.8	11.2
1,100	14.1	14.1	14.1	14.1	14.1	14.1	14.1	13.9	12.0	10.2	8.9
1,150	13.9	13.9	13.9	13.9	13.9	13.9	13.2	11.2	9.6	8.2	7.0
1,200	13.8	13.8	13.8	13.8	13.8	12.4	10.7	9.0	7.7	6.5	5.6
1,250	13.5	13.5	13.5	13.5	12.0	10.1	8.6	7.2	6.2	5.2	4.4
1,300	13.2	13.2	13.2	11.6	9.8	8.2	7.0	5.8	5.0	4.1	3.5
1,350	12.0	12.0	11.3	9.5	8.0	6.7	5.7	4.7	4.0	3.3	2.8
1,400	11.0	10.8	9.3	7.8	6.5	5.4	4.6	3.8	3.2	2.6	2.2
SI Units											
Temp., °C	1 h	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
425	105	105	105	105	105	105	105	105	105	105	105
450	104	104	104	104	104	104	104	104	104	104	104
475	103	103	103	103	103	103	103	103	103	103	103
500	101	101	101	101	101	101	101	101	101	101	101
525	100	100	100	100	100	100	100	100	100	100	98
550	99	99	99	99	99	99	99	99	99	94	88
575	98	98	98	98	98	98	98	98	94	82	72
600	97	97	97	97	97	97	96	91	79	67	58
625	96	96	96	96	96	96	92	80	68	59	50
650	95	95	95	95	95	84	73	62	53	45	39
675	93	93	93	93	84	71	60	51	44	37	31
700	91	91	91	82	70	59	50	41	35	29	25
725	85	85	81	69	58	49	41	34	30	24	20
750	78	77	69	58	49	40	34	28	24	20	16

GENERAL NOTE: As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

Figure HBB-I-14.3D
S_{mt} — 2¼Cr-1Mo

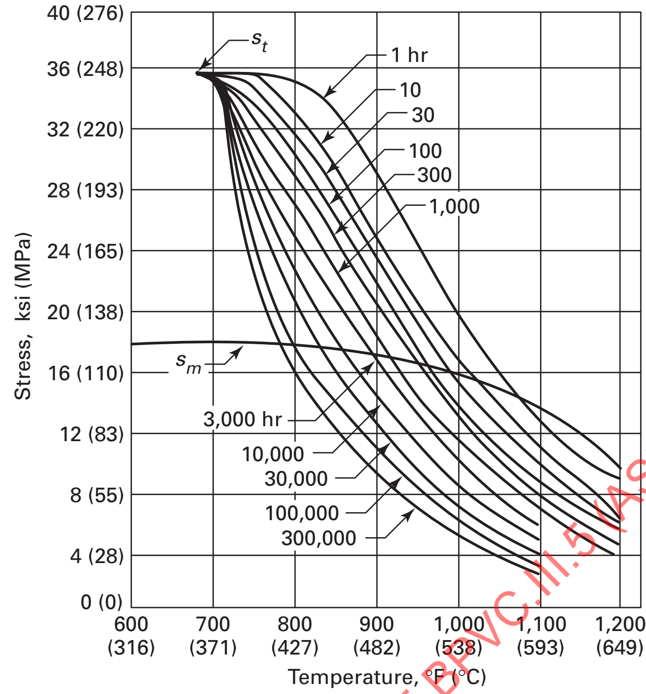


Table HBB-I-14.3D
S_{mt} — Allowable Stress Intensity Values, ksi (MPa), 2¼Cr-1Mo

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
700	...	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
750	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
800	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	16.1
850	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	16.3	14.0	12.3
900	17.2	17.2	17.2	17.2	17.2	17.2	16.5	14.4	12.5	10.9	9.6
950	16.7	16.7	16.7	16.7	16.3	14.8	13.2	11.3	9.7	8.4	7.3
1,000	15.9	15.9	15.5	14.2	13.1	11.9	10.4	8.7	7.5	6.3	5.2
1,050	14.9	13.8	12.5	11.2	10.2	9.3	7.9	6.7	5.7	4.7	4.0
1,100	13.6	11.0	10.0	9.0	8.2	7.2	6.2	5.0	4.1	3.3	2.7
1,150	10.8	8.8	8.0	7.2	6.3	5.4	...	...	...	...	...
1,200	9.0	6.2	6.1	5.9	5.1	4.1	...	...	...	...	...

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
375	...	123	123	123	123	123	123	123	123	123	123
400	123	123	123	123	123	123	123	123	123	123	123
425	123	123	123	123	123	123	123	123	123	123	112
450	122	122	122	122	122	122	122	122	116	101	89
475	119	119	119	119	119	119	114	106	92	80	71
500	116	116	116	116	116	111	99	85	74	64	56
525	112	112	112	106	97	89	78	66	57	48	41
550	107	107	98	89	81	74	64	54	46	38	33
575	100	89	80	72	66	59	50	42	35	29	25
600	89	72	66	59	53	47	...	...	...	...	...
625	72	58	53	49	42	36	...	...	...	...	...
650	62	43	42	41	35	28	...	...	...	...	...

GENERAL NOTE: As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

Figure HBB-I-14.3E
S_{mt} — 9Cr-1Mo-V

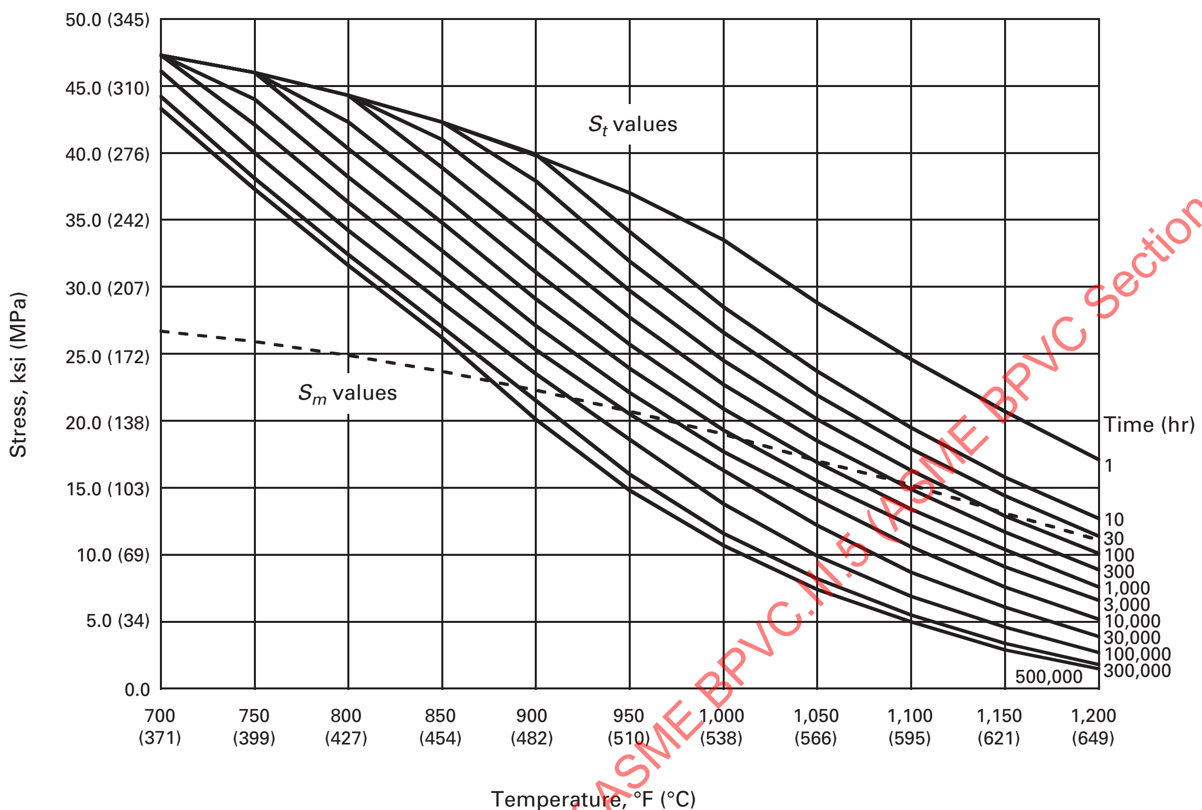


Table HBB-I-14.3E
S_{mt} — Allowable Stress Intensity Values, ksi (MPa), 9Cr-1Mo-V

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr	5×10^5 hr
700	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
750	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
800	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9
850	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
900	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	21.5	20.1
950	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.5	18.6	16.0	14.8
1,000	19.0	19.0	19.0	19.0	19.0	19.0	19.0	17.7	16.3	13.8	11.6	10.7
1,050	17.1	17.1	17.1	17.1	17.1	16.9	15.5	14.1	12.2	9.9	8.2	7.4
1,100	15.2	15.2	15.2	15.2	14.9	13.4	12.2	10.6	8.7	6.9	5.5	5.0
1,150	13.1	13.1	13.1	12.9	11.7	10.4	9.1	7.6	6.1	4.6	3.4	2.9
1,200	11.1	11.1	11.1	10.1	8.9	7.6	6.5	5.2	3.9	2.7	1.8	1.5

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h	5×10^5 h
375	183	183	183	183	183	183	183	183	183	183	183	183
400	179	179	179	179	179	179	179	179	179	179	179	179
425	172	172	172	172	172	172	172	172	172	172	172	172
450	165	165	165	165	165	165	165	165	165	165	165	165
475	156	156	156	156	156	156	156	156	156	156	154	149
500	147	147	147	147	147	147	147	147	147	138	123	115
525	136	136	136	136	136	136	136	132	126	109	93	86
550	125	125	125	125	125	125	119	111	100	83	69	63
575	114	114	114	114	114	108	99	89	75	61	50	45
600	101	101	101	101	97	86	78	68	55	44	34	31
625	88	88	88	86	78	69	60	50	40	30	22	18
650	76	76	76	69	61	52	44	35	27	18	12	10

GENERAL NOTE: As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

Figure HBB-I-14.4A
S_t — Type 304 SS

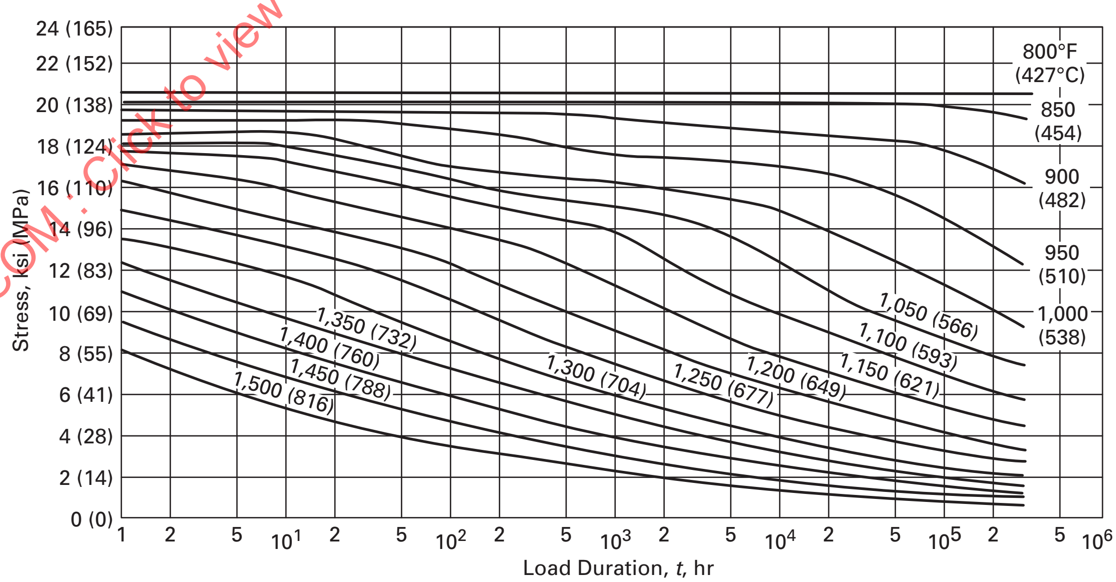


Table HBB-I-14.4A
S_t — Allowable Stress Intensity Values, 1,000 psi (MPa), Type 304 SS

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
850	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.9	19.8	19.3
900	19.6	19.6	19.5	19.5	19.4	19.2	18.8	18.5	18.3	17.7	16.0
950	19.1	19.1	19.0	18.7	18.2	17.5	17.2	16.9	16.2	14.2	12.2
1,000	18.5	18.4	17.8	16.9	16.2	15.9	15.5	14.7	13.1	11.1	9.3
1,050	18.0	17.7	17.1	16.2	15.5	14.9	14.1	12.2	10.3	8.7	7.3
1,100	17.6	17.1	16.3	15.3	14.5	13.5	11.5	9.7	8.2	6.8	5.7
1,150	17.0	15.7	14.8	13.8	12.9	11.0	9.3	7.7	6.4	5.3	4.4
1,200	16.0	14.2	13.3	12.2	10.6	8.9	7.4	6.1	5.1	4.1	3.4
1,250	14.7	12.9	11.9	10.3	8.7	7.2	5.9	4.9	4.0	3.2	2.7
1,300	13.4	11.4	10.0	8.5	7.0	5.9	4.8	3.9	3.2	2.5	2.1
1,350	12.2	9.7	8.4	7.1	5.9	4.8	3.9	3.1	2.5	2.0	1.6
1,400	10.8	8.1	6.9	5.9	4.8	3.9	3.1	2.5	2.0	1.6	1.2
1,450	9.3	6.8	5.9	4.6	3.8	3.0	2.4	1.9	1.5	1.2	0.9
1,500	7.9	5.3	4.4	3.5	2.8	2.2	1.7	1.3	1.0	0.8	0.6

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	141	141	141	141	141	141	141	141	141	141	141
450	138	138	138	138	138	138	138	138	138	137	134
475	136	136	135	135	135	134	132	130	129	126	116
500	133	133	132	131	128	125	123	121	117	107	93
525	130	129	127	122	118	115	113	108	100	87	73
550	126	125	121	115	110	107	103	94	82	70	58
575	123	121	116	110	105	100	91	78	66	56	46
600	120	115	109	102	97	88	75	63	54	44	37
625	116	107	101	93	87	74	62	51	43	36	29
650	110	98	92	84	73	61	51	42	35	28	23
675	102	90	83	72	61	51	42	35	28	22	19
700	93	80	71	61	50	42	34	28	23	18	15
725	86	70	61	52	43	35	29	22	18	15	12
750	78	60	52	44	36	29	23	18	15	12	9
775	69	51	44	36	29	24	19	15	12	9	7
800	60	43	37	29	23	18	15	11	9	7	5

Figure HBB-I-14.4B
S_t — Type 316 SS

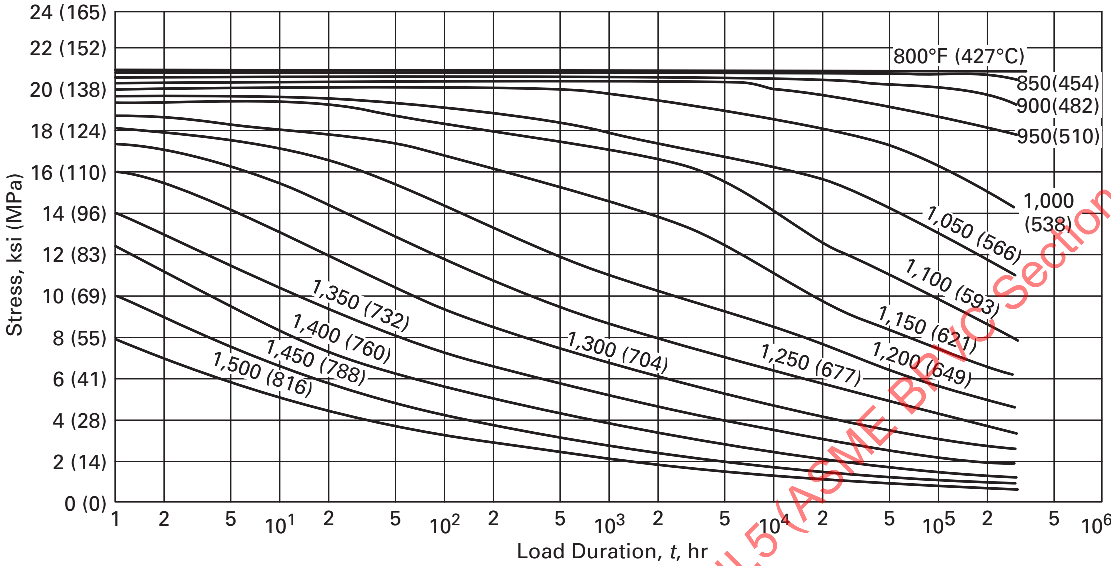


Table HBB-I-14.4B
S_t — Allowable Stress Intensity Values, 1,000 psi (MPa), Type 316 SS

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8
850	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.3
900	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.2	19.9	19.3
950	20.1	20.1	20.1	20.1	20.1	20.0	20.0	19.7	19.2	18.4	17.6
1,000	19.8	19.8	19.8	19.8	19.8	19.5	19.0	18.2	17.5	16.2	14.0
1,050	19.4	19.4	19.2	18.7	18.3	17.6	16.8	15.9	14.9	12.5	10.7
1,100	19.1	19.0	18.5	17.8	17.3	16.6	15.9	13.9	11.5	9.5	7.8
1,150	18.5	17.7	17.3	16.4	15.4	14.2	13.0	10.9	8.9	7.2	5.9
1,200	17.8	16.8	15.8	14.2	12.4	10.6	9.4	8.3	6.9	5.5	4.5
1,250	17.1	15.2	13.5	11.5	9.8	8.3	7.3	6.3	5.4	4.2	3.3
1,300	16.1	12.8	10.9	9.1	7.5	6.4	5.6	4.7	3.9	3.1	2.5
1,350	14.2	10.3	8.6	7.0	5.9	5.0	4.2	3.4	2.8	2.1	1.8
1,400	12.0	8.2	6.7	5.4	4.5	3.8	3.1	2.5	2.0	1.5	1.2
1,450	9.7	6.4	5.1	4.1	3.4	2.9	2.2	1.7	1.4	1.0	0.8
1,500	7.8	4.9	3.9	3.2	2.6	2.1	1.6	1.2	0.9	0.65	0.5

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	143	143	143	143	143	143	143	143	143	143	143
450	142	142	142	142	142	142	142	142	142	142	140
475	141	141	141	141	141	141	141	141	140	138	135
500	140	140	140	140	140	139	139	138	134	131	125
525	138	138	138	138	138	136	134	130	126	118	108
550	136	136	135	134	132	128	125	119	113	101	87
575	133	133	131	127	124	119	114	105	95	79	67
600	131	129	126	121	116	110	105	91	75	62	51
625	127	121	118	111	103	94	86	72	59	48	40
650	123	116	108	97	84	72	64	57	48	38	31
675	118	106	94	80	69	58	51	44	38	30	24
700	112	91	78	65	54	46	41	34	28	22	18
725	101	75	63	52	44	36	31	25	21	16	13
750	88	62	51	41	35	29	24	19	16	11	9
775	74	50	40	32	27	23	18	14	12	8	7
800	61	40	32	25	21	17	13	10	8	5	4

Figure HBB-I-14.4C
S_t — Ni-Fe-Cr (Alloy 800H)

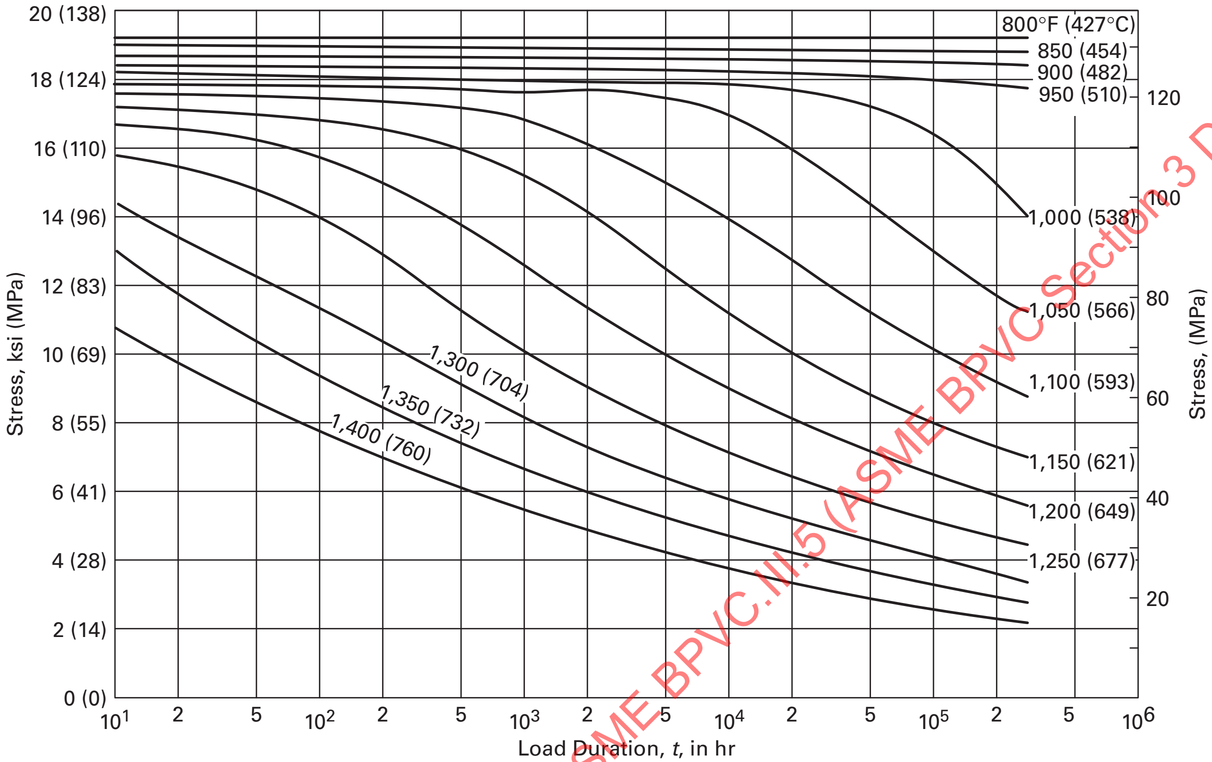


Table HBB-I-14.4C
S_t — Allowable Stress Intensity Values, ksi (MPa), Ni-Fe-Cr (Alloy 800H)

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
800	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.1	19.1
850	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.8	18.8
900	18.7	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.6	18.5	18.4
950	18.4	18.4	18.4	18.4	18.4	18.4	18.3	18.2	18.2	18.0	17.8
1,000	18.2	18.1	18.1	18.1	18.1	18.0	17.9	17.8	17.6	16.5	14.1
1,050	17.9	17.9	17.8	17.8	17.7	17.6	17.4	17.1	15.0	12.9	11.1
1,100	17.6	17.6	17.5	17.4	17.2	16.9	16.3	13.9	12.0	10.3	8.9
1,150	17.3	17.2	17.0	16.8	16.4	15.3	13.2	11.2	9.6	8.1	7.0
1,200	17.0	16.7	16.3	15.8	14.7	12.4	10.7	9.0	7.7	6.5	5.6
1,250	16.5	15.8	15.2	14.1	12.0	10.1	8.6	7.2	6.2	5.2	4.4
1,300	15.8	14.4	13.4	11.5	9.8	8.2	7.0	5.8	5.0	4.1	3.5
1,350	14.7	13.1	11.3	9.5	8.0	6.7	5.7	4.7	4.0	3.3	2.8
1,400	13.0	10.8	9.3	7.8	6.5	5.4	4.6	3.8	3.2	2.6	2.2

SI Units

Temp., °C	1 h	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
425	132	132	132	132	132	132	132	132	132	132	132
450	130	130	130	130	130	130	130	130	130	130	130
475	129	129	129	129	129	129	128	128	128	127	126
500	128	128	128	128	128	128	127	126	126	125	124
525	126	126	126	126	126	125	124	124	122	119	109
550	124	124	124	124	124	123	122	121	113	103	88
575	123	123	123	122	121	120	117	111	96	83	72
600	121	121	120	119	117	114	107	91	79	67	58
625	119	118	116	115	109	102	89	75	64	55	47
650	117	115	112	109	101	85	74	62	53	45	39
675	114	109	105	98	85	72	61	52	44	37	31
700	110	100	94	82	70	59	50	41	35	29	25
725	99	88	82	70	58	49	41	34	29	24	20
750	94	80	69	58	49	40	34	28	24	20	16

Figure HBB-I-14.4D
S_t — 2¼Cr-1Mo

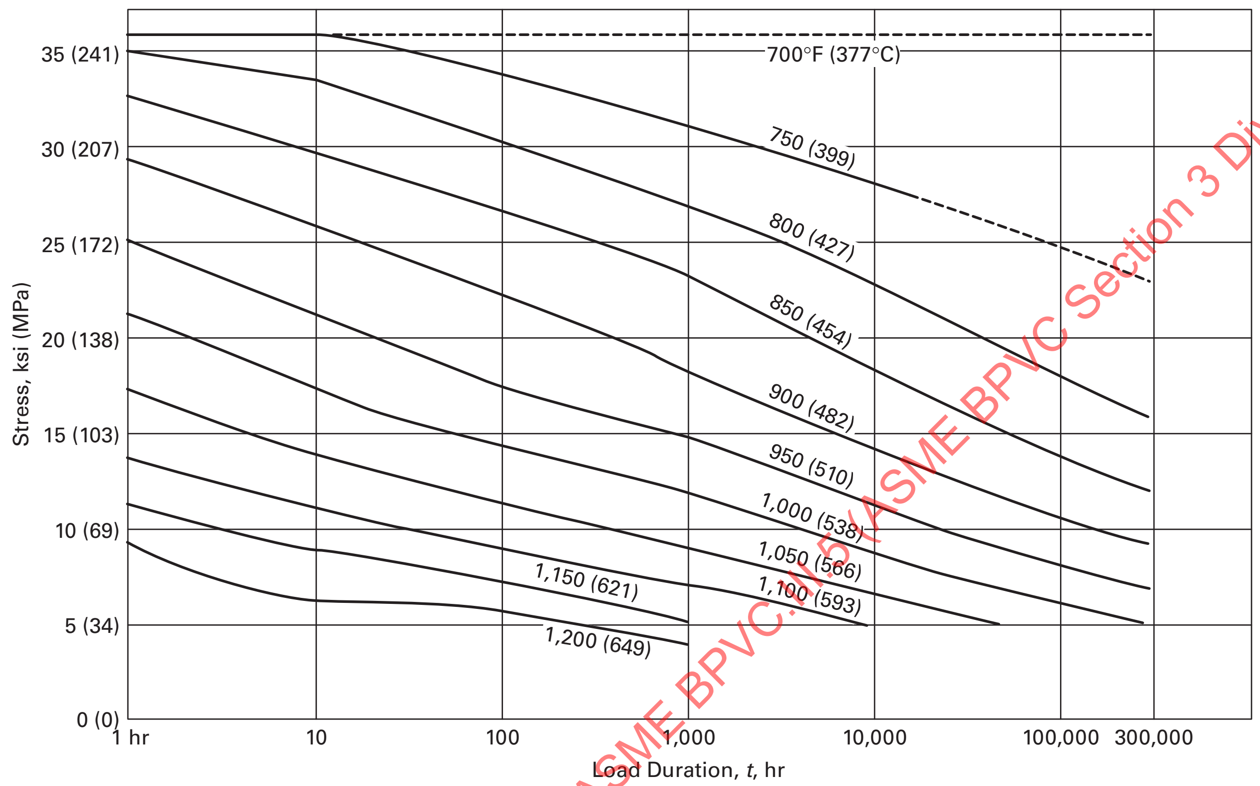


Table HBB-I-14.4D
S_t — Allowable Stress Intensity Values, ksi (MPa), 2¼Cr-1Mo

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3 × 10^2 hr	10^3 hr	3 × 10^3 hr	10^4 hr	3 × 10^4 hr	10^5 hr	3 × 10^5 hr
700	...	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
750	35.3	35.2	34.6	33.5	32.5	31.3	29.7	28.4	26.6	25.0	23.3
800	35.0	33.2	31.8	30.4	28.8	26.8	25.0	23.0	20.5	18.0	16.1
850	32.3	29.4	28.0	26.4	25.0	23.2	21.0	18.3	16.3	14.0	12.3
900	29.0	25.5	23.7	22.0	20.2	18.5	16.5	14.4	12.5	10.9	9.6
950	25.0	21.0	19.3	17.5	16.3	14.8	13.2	11.3	9.7	8.4	7.3
1,000	20.7	17.1	15.5	14.2	13.1	11.9	10.4	8.7	7.5	6.3	5.2
1,050	16.8	13.8	12.5	11.2	10.2	9.3	7.9	6.7	5.7	4.7	4.0
1,100	13.6	11.0	10.0	9.0	8.2	7.2	6.2	5.0	4.1	3.3	2.7
1,150	10.8	8.8	8.0	7.2	6.3	5.4	...	...	...	...	...
1,200	9.0	6.2	6.1	5.9	5.1	4.1	...	...	...	...	...

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3 × 10^2 h	10^3 h	3 × 10^3 h	10^4 h	3 × 10^4 h	10^5 h	3 × 10^5 h
375	...	245	245	245	245	245	245	245	245	245	245
400	243	243	239	231	224	216	205	196	183	172	161
425	241	230	220	211	200	186	173	160	142	125	112
450	226	207	197	186	176	164	149	130	116	101	89
475	206	183	170	159	147	136	122	106	92	80	71
500	182	156	144	132	122	111	99	85	74	64	56
525	153	127	116	106	97	89	78	66	57	48	41
550	131	108	98	89	81	74	64	54	46	38	33
575	109	89	80	72	66	59	50	42	35	29	25
600	89	72	66	59	53	47	...	...	...	...	...
625	72	58	53	49	42	36	...	...	...	...	...
650	62	43	42	41	35	28	...	...	...	...	...

Figure HBB-I-14.4E
S_t — 9Cr-1Mo-V

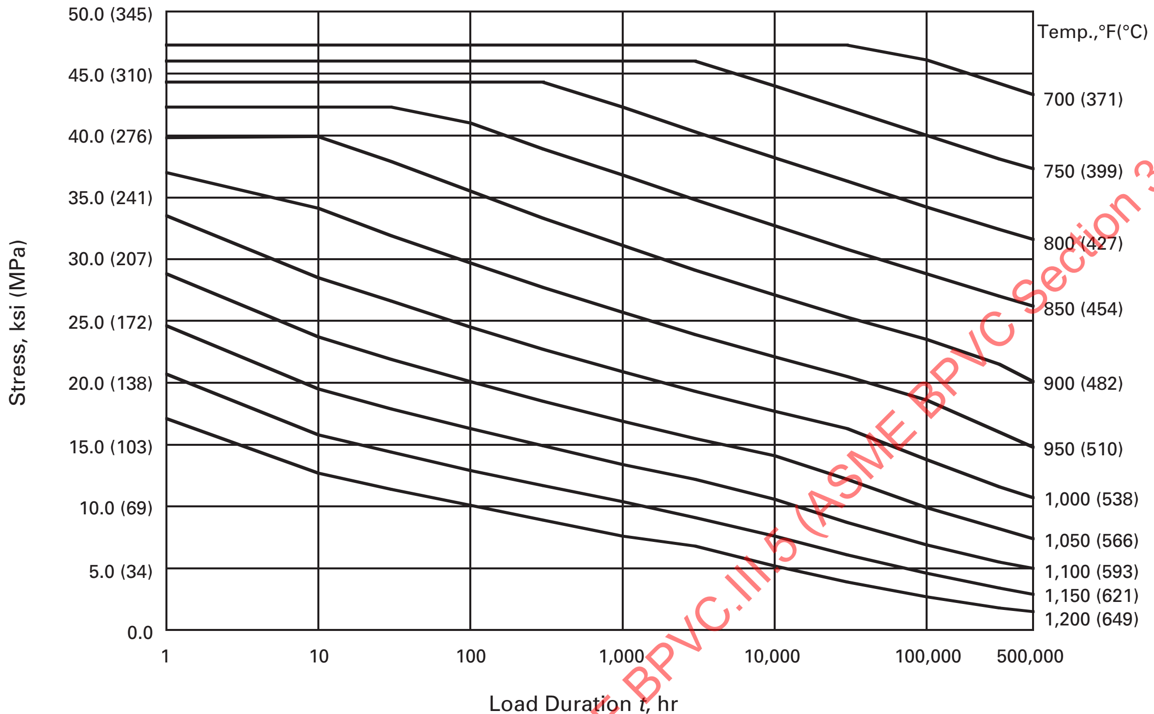


Table HBB-I-14.4E
S_t — Allowable Stress Intensity Values, ksi (MPa), 9Cr-1Mo-V

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr	5×10^5 hr
700	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	46.1	44.2	43.3
750	46.0	46.0	46.0	46.0	46.0	46.0	46.0	44.0	42.1	40.0	38.1	37.3
800	44.3	44.3	44.3	44.3	44.3	42.3	40.3	38.2	36.3	34.2	32.4	31.6
850	42.3	42.3	42.3	41.0	38.9	36.8	34.8	32.7	30.8	28.8	27.0	26.2
900	39.8	38.8	37.9	35.5	33.3	31.1	29.1	27.1	25.3	23.5	21.5	20.1
950	37.0	34.1	31.9	29.7	27.7	25.7	23.9	22.1	20.5	18.6	16.0	14.8
1,000	33.5	28.5	26.6	24.5	22.7	20.9	19.3	17.7	16.3	13.8	11.6	10.7
1,050	28.8	23.7	21.9	20.1	18.5	16.9	15.5	14.1	12.2	9.9	8.2	7.4
1,100	24.6	19.5	17.9	16.3	14.9	13.4	12.2	10.6	8.7	6.9	5.5	5.0
1,150	20.7	15.8	14.4	12.9	11.7	10.4	9.1	7.6	6.1	4.6	3.4	2.9
1,200	17.1	12.7	11.4	10.1	8.9	7.6	6.6	5.2	3.9	2.7	1.8	1.5

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h	5×10^5 h
375	325	325	325	325	325	325	325	325	325	312	299	293
400	317	317	317	317	317	317	316	302	289	274	261	255
425	307	307	307	307	307	294	281	266	253	238	226	220
450	294	294	294	289	275	259	246	231	218	204	192	186
475	279	275	271	255	241	225	211	197	184	171	159	149
500	262	249	235	219	205	191	178	165	153	141	123	115
525	242	214	200	185	172	160	148	136	126	109	93	86
550	217	182	168	156	144	132	119	111	100	83	69	63
575	189	154	142	130	119	108	99	89	75	61	50	45
600	164	126	115	107	97	86	78	68	55	44	34	31
625	139	106	96	86	78	69	60	50	40	30	22	18
650	117	87	78	69	61	52	45	35	27	18	12	10

Table HBB-I-14.5
Yield Strength Values, S_y, Versus Temperature

U.S. Customary Units

	Stresses, ksi					
Temp., °F	304 SS	316 SS	Ni-Fe-Cr UNS N08810	$2^{1}/_{4}$Cr-1Mo	9Cr-1Mo-1V	Ni-Cr-Fe-Mo-Cb UNS N07718
RT						150.0
100						148.4
200						143.9
300						140.7
400						138.3
500						136.7
600	See Section II, Part D, Subpart 1, Table Y-1 for Values up to 1,000°F					135.4
700						134.3
750						133.7
800						133.1
850						132.4
900						131.5
950						130.5
1,000						129.4
1,050	15.2	16.8	15.5	22.4	36.6	128.0
1,100	14.9	16.6	15.5	20.7	32.7	...
1,150	14.5	16.3	15.5	18.6	28.6	...
1,200	14.1	16.0	15.5	16.1	24.2	...
1,250	13.6	15.5	15.2	...	...	...
1,300	13.1	14.9	14.8	...	...	...
1,350	12.4	14.2	14.2	...	...	...
1,400	11.6	13.3	13.6	...	...	...
1,450	10.6	12.3	12.9	...	...	...
1,500	9.3	10.9	12.2	...	...	...
1,550	...	...	11.3	...	...	...
1,600	...	...	10.3	...	...	...
1,650	...	...	9.3	...	...	...

SI Units

	Stresses, MPa					
Temp., °C	304 SS	316 SS	Ni-Fe-Cr UNS N08810	$2^{1}/_{4}$Cr-1Mo	9Cr-1Mo-1V	Ni-Cr-Fe-Mo-Cb UNS N07718
RT						1034
50						1016
100						989
150						970
200						955
250						945
300						937
350	See Section II, Part D, Subpart 1, Table Y-1 for Values up to 538°C					929
375						925
400						922
425						918
450						914
475						909
500						902
525						896
550	106	116	108	160	269	888
575	104	115	108	151	243	883 [Note (1)]
600	102	114	108	139	218	...
625	100	112	108	126	193	...
650	97	110	107	110	165	...
675	94	107	105	...	...	...
700	91	103	102	...	...	...
725	87	99	99.1	...	...	...
750	82	94	95.6	...	...	...

Table HBB-I-14.5
Yield Strength Values, S_y, Versus Temperature (Cont'd)

SI Units						
	Stresses, MPa					
Temp., °C	304 SS	316 SS	Ni-Fe-Cr UNS N08810	$2^1/_4$Cr-1Mo	9Cr-1Mo-1V	Ni-Cr-Fe-Mo-Cb UNS N07718
775	76	88	91.5	...	...	...
800	69 [Note (2)]	81 [Note (3)]	86.9	...	...	...
825	...	...	81.8	...	...	...
850	...	...	76.3	...	...	...
875	...	...	70.3	...	...	...
900	...	...	64.0	...	...	...

GENERAL NOTE: The tabulated values of yield strength are those which are suitable for use in design calculations required by this Subsection. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. The yield strength values do not correspond exactly to either *average* or *minimum* as these terms are applied to a statistical treatment of a homogeneous set of data.
Neither the ASME Materials Specifications nor the rules of this Subsection require elevated temperature testing for yield strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retests or other means should be considered.

NOTES:
(1) At 566°C the yield strength, S_y, is 883 MPa for UNS N07718.
(2) At 816°C the yield strength, S_y, is 64 MPa for 304 SS.
(3) At 816°C the yield strength, S_y, is 75 MPa for 316 SS.

Figure HBB-I-14.6A
Minimum Stress-to-Rupture

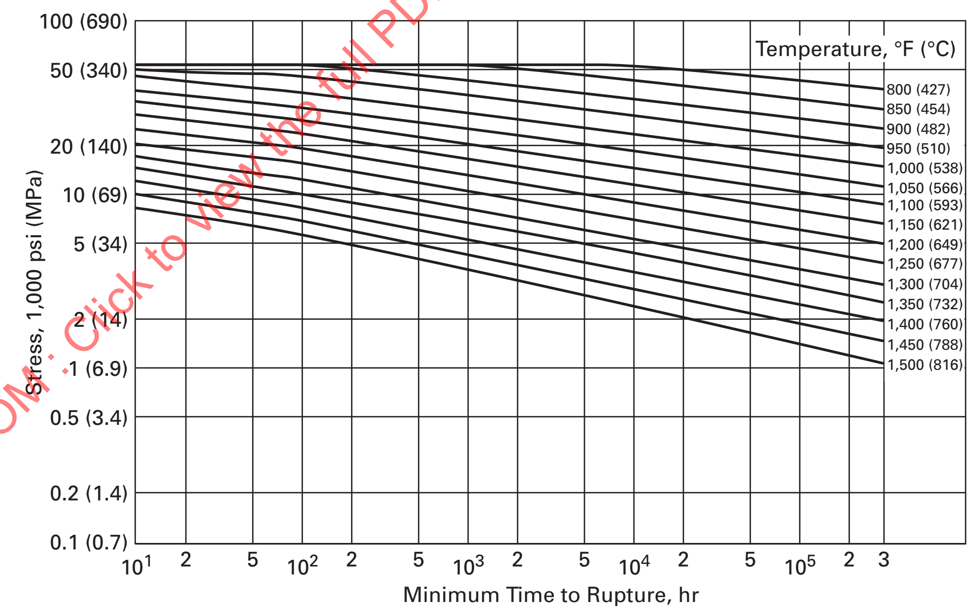


Table HBB-I-14.6A
Expected Minimum Stress-to-Rupture Values, 1,000 psi (MPa), Type 304 SS

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	57	57	57	57	57	57	57	57	51	44.3	39
850	56.5	56.5	56.5	56.5	56.5	56.5	50.2	45.4	40	34.7	30.5
900	55.5	55.5	55.5	55.5	51.5	46.9	41.2	36.1	31.5	27.2	24
950	54.2	54.2	51	48.1	43	38.0	33.5	28.8	24.9	21.2	18.3
1,000	52.5	50	44.5	39.8	35	30.9	26.5	22.9	19.7	16.6	14.9
1,050	50	41.9	37	32.9	28.9	25.0	21.6	18.2	15.5	13.0	11.0
1,100	45	35.2	31	27.2	23.9	20.3	17.3	14.5	12.3	10.2	8.6
1,150	38	29.5	26	22.5	19.3	16.5	13.9	11.6	9.6	8.0	6.6
1,200	32	24.7	21.5	18.6	15.9	13.4	11.1	9.2	7.6	6.2	5.0
1,250	27	20.7	17.9	15.4	13	10.8	8.9	7.3	6.0	4.9	4.0
1,300	23	17.4	15	12.7	10.5	8.8	7.2	5.8	4.8	3.8	3.1
1,350	19.5	14.6	12.6	10.6	8.8	7.2	5.8	4.6	3.8	3.0	2.4
1,400	16.5	12.1	10.3	8.8	7.2	5.8	4.7	3.7	3.0	2.3	1.9
1,450	14.0	10.2	8.8	7.3	5.8	4.6	3.8	2.9	2.3	1.8	1.4
1,500	12.0	8.6	7.2	6.0	4.9	3.8	3.0	2.4	1.8	1.4	1.1

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	393	393	393	393	393	393	393	393	354	308	272
450	390	390	390	390	390	390	353	325	287	249	219
475	385	385	385	385	364	340	300	265	232	201	176
500	377	377	363	350	317	284	250	217	188	161	140
525	368	358	328	301	267	236	205	177	153	129	114
550	355	321	285	254	223	195	168	144	124	104	91
575	333	274	241	214	188	161	139	113	100	83	59
600	298	233	205	180	157	134	113	95	80	66	56
625	256	198	175	151	130	111	93	78	64	53	44
650	220	169	147	127	110	92	77	63	52	43	34
675	189	145	125	108	91	75	62	51	42	35	28
700	162	123	106	91	75	63	52	41	34	27	22
725	140	106	91	77	64	53	43	34	28	22	18
750	121	89	77	67	54	44	35	28	23	18	14
775	105	76	66	55	45	36	29	23	18	14	11
800	91	65	56	46	37	29	24	19	14	10	9

Figure HBB-I-14.6B
Minimum Stress-to-Rupture

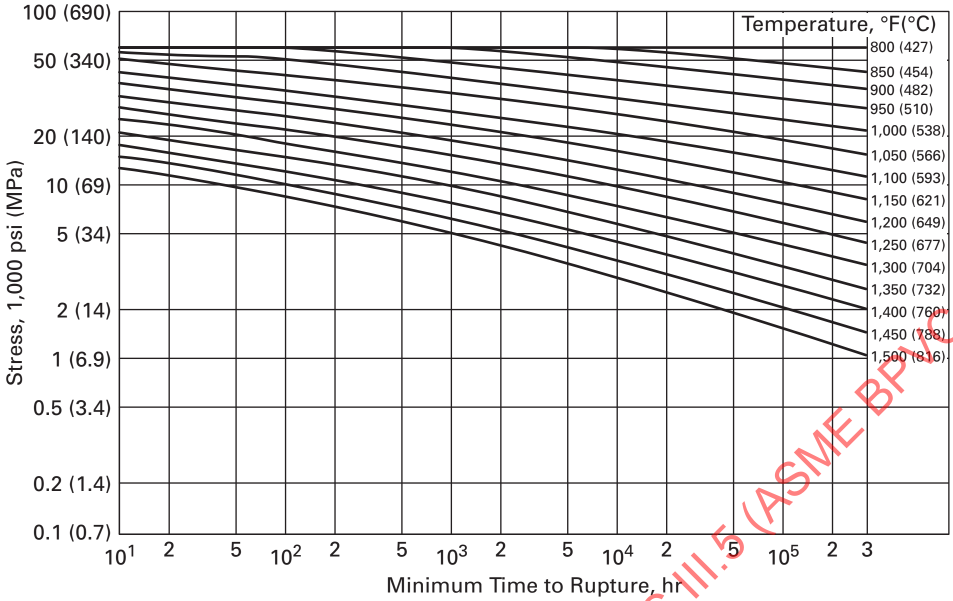


Table HBB-I-14.6B
Expected Minimum Stress-to-Rupture Values, 1,000 psi (MPa), Type 316 SS

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5
850	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	60	56	52
900	62.2	62.2	62.2	62.2	62.1	62	58	54.1	48	42.6	38
950	60	60	60	60	56	51.6	46.5	42.6	37.5	32.4	28.3
1,000	58.5	58.5	55	51.7	47	42.1	37.5	33.6	28.8	24.6	21
1,050	56	52.9	47.5	43.4	38.2	34.4	30.2	26.4	22.3	18.8	16
1,100	53.5	45.1	40	36.4	32.2	28.1	24.2	20.8	17.3	14.3	11.7
1,150	46.5	38.4	34	30.5	26.6	23.0	19.5	16.4	13.4	10.9	8.8
1,200	40	32.7	29	25.6	22	18.8	15.6	12.9	10.3	8.3	6.7
1,250	35	27.8	24.3	21.4	18.1	15.4	12.7	10.2	8.1	6.3	4.9
1,300	30	23.7	20.8	18.0	15	12.5	10.0	8.0	6.2	4.8	3.7
1,350	26	20.0	17.5	15.0	12.7	10.4	8.2	6.4	4.9	3.6	2.7
1,400	22.5	17.1	14.8	12.4	10.2	8.4	6.6	5.0	3.8	2.8	2.1
1,450	19.5	14.6	12.6	10.5	8.6	6.8	5.2	3.9	2.9	2.1	1.5
1,500	17	12.5	10.6	8.8	7.2	5.6	4.2	3.1	2.3	1.6	1.2

SI Units

Temp., °C	1 h	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	445	445	445	445	445	445	445	445	445	445	445
450	437	437	437	437	437	437	437	437	419	395	372
475	431	431	431	431	430	429	409	389	352	317	286
500	419	419	419	419	401	381	349	322	285	248	219
525	406	406	388	371	340	307	275	248	226	183	158
550	393	381	350	323	289	268	230	203	173	147	125
575	380	347	311	283	249	223	194	169	142	120	100
600	357	300	266	241	212	185	159	136	112	94	79
625	315	259	229	205	179	155	130	110	89	72	59
650	275	224	199	176	151	129	107	88	70	57	46
675	244	194	170	150	127	108	89	71	57	44	35
700	212	167	147	128	106	89	72	57	45	34	27
725	186	144	127	108	92	76	60	47	36	27	21
750	163	125	109	91	76	63	50	38	29	21	16
775	144	109	94	78	64	52	41	30	23	16	12
800	124	92	79	65	54	42	32	24	18	12	9

Figure HBB-I-14.6C
Minimum Stress-to-Rupture — Ni-Fe-Cr (Alloy 800H)

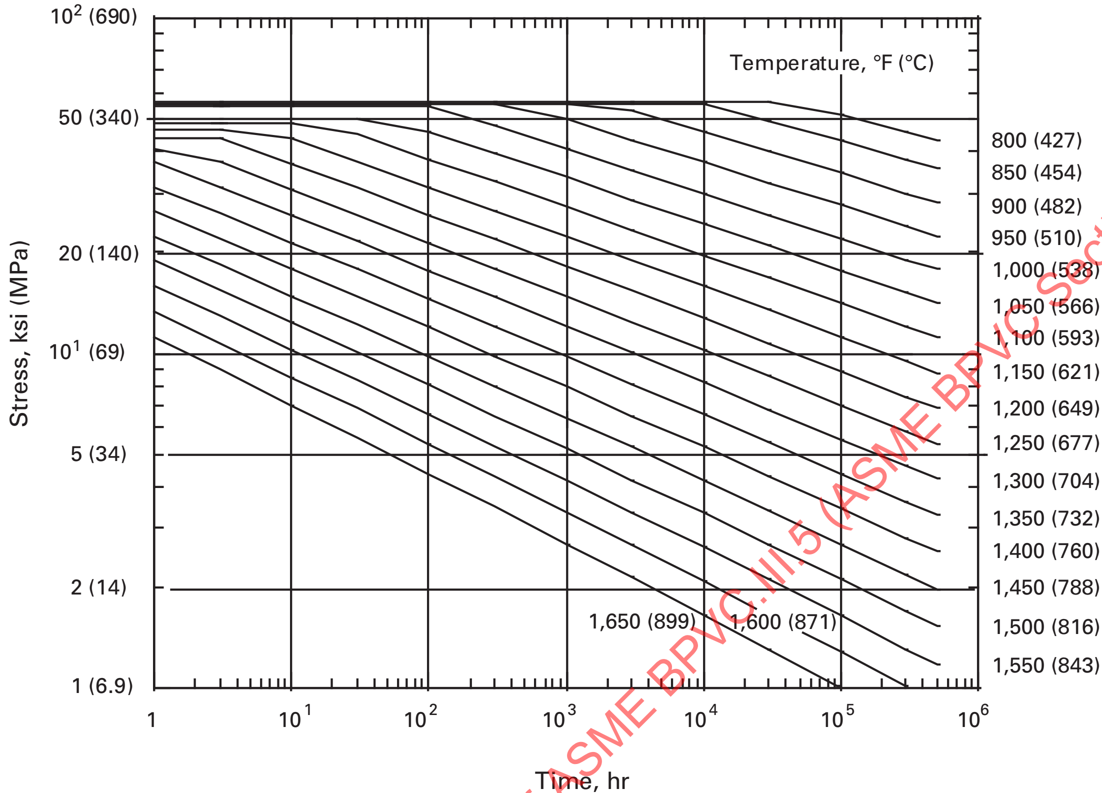


Table HBB-I-14.6C
Expected Minimum Stress-to-Rupture Values, ksi (MPa), Ni-Fe-Cr (Alloy 800H)

U.S. Customary Units

Temp., °F	1 hr	3 hr	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr	500,000 hr
800	56.2	56.2	56.2	56.2	56.2	56.2	56.2	56.2	56.2	56.2	51.9	45.9	43.3
850	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	49.6	43.0	37.8	35.6
900	55.6	55.6	55.6	55.6	55.6	55.6	55.6	53.0	45.8	40.1	34.5	30.2	28.3
950	55.3	55.3	55.3	55.3	55.3	55.3	49.8	43.4	37.2	32.3	27.7	24.0	22.5
1,000	54.7	54.7	54.7	54.7	54.7	47.9	40.9	35.4	30.1	26.0	22.1	19.1	17.8
1,050	50.2	50.2	50.2	50.2	45.9	39.5	33.5	28.8	24.4	20.9	17.7	15.1	14.1
1,100	48.4	48.4	48.4	45.0	38.0	32.5	27.4	23.4	19.7	16.8	14.1	12.0	11.1
1,150	46.3	46.3	44.0	37.5	31.5	26.8	22.4	19.0	15.9	13.4	11.2	9.5	8.7
1,200	43.9	43.9	36.8	31.2	26.0	22.0	18.3	15.4	12.8	10.7	8.9	7.5	6.9
1,250	41.1	37.1	30.8	25.9	21.5	18.0	14.9	12.5	10.3	8.6	7.0	5.9	5.4
1,300	37.2	31.2	25.7	21.5	17.7	14.8	12.1	10.1	8.2	6.8	5.6	4.6	4.2
1,350	31.4	26.2	21.5	17.8	14.6	12.1	9.8	8.1	6.6	5.4	4.4	3.6	3.3
1,400	26.5	22.0	17.9	14.8	12.0	9.9	8.0	6.5	5.3	4.3	3.4	2.8	2.6
1,450	22.4	18.4	14.9	12.2	9.8	8.0	6.4	5.2	4.2	3.4	2.7	2.2	2.0
1,500	18.9	15.4	12.4	10.1	8.0	6.5	5.2	4.2	3.3	2.7	2.1	1.7	1.5
1,550	15.9	12.9	10.3	8.3	6.6	5.3	4.2	3.4	2.6	2.1	1.6	1.3	1.2
1,600	13.3	10.8	8.5	6.8	5.4	4.3	3.4	2.7	2.1	1.7	1.3	1.0	0.91
1,650	11.2	9.0	7.0	5.6	4.4	3.5	2.7	2.1	1.6	1.3	1.0	0.78	0.70

SI Units

Temp., °C	1 h	3 h	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h	500 000 h
425	387	387	387	387	387	387	387	387	387	387	374	330	312
450	385	385	385	385	385	385	385	385	385	354	307	270	254
475	384	384	384	384	384	384	384	384	333	292	252	220	207
500	382	382	382	382	382	382	369	321	276	241	207	180	168
525	379	379	379	379	379	361	309	268	229	198	169	146	137
550	352	352	352	352	351	303	258	223	189	163	138	119	111
575	342	342	342	342	297	255	216	185	156	134	113	96	90
600	331	331	331	297	250	214	180	154	129	110	92	78	72
625	317	317	296	252	211	180	150	127	106	90	75	63	58
650	302	302	252	214	178	150	125	105	87	73	61	51	47
675	285	259	215	181	150	126	104	87	72	60	49	41	38
700	264	221	183	153	126	105	86	72	59	49	40	33	30
725	227	189	155	129	106	88	71	59	48	40	32	26	24
750	195	162	132	109	89	73	59	49	39	32	26	21	19
775	167	138	112	92	74	61	49	40	32	26	21	17	15
800	143	118	95	77	62	51	40	33	26	21	17	13	12
825	123	100	80	65	52	42	33	27	21	17	13	11	9.7
850	105	85	68	55	43	35	27	22	17	14	11	8.5	7.6
875	90	72	57	46	36	29	23	18	14	11	8.5	6.7	6.0
900	77	61	48	38	30	24	18	15	11	8.9	6.8	5.3	4.7

Figure HBB-I-14.6D
2¼Cr-1Mo — 100% of the Minimum Stress-to-Rupture

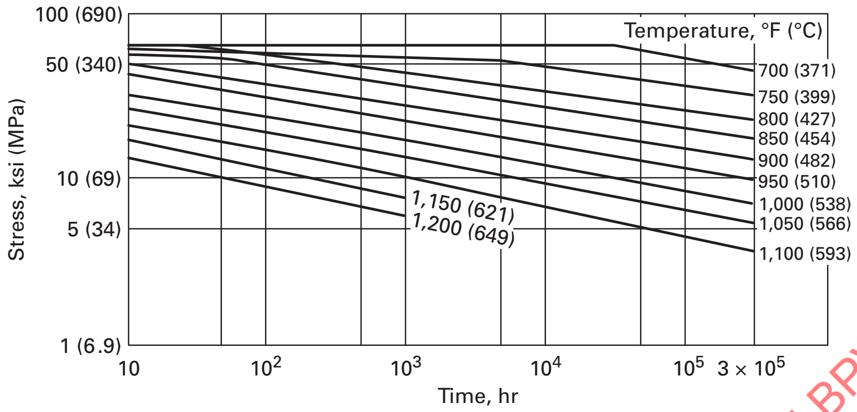


Table HBB-I-14.6D
2¼Cr-1Mo — Expected Minimum Stress-to-Rupture Values, ksi (MPa)

U.S. Customary Units

Temp., °F	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
700	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	54.0	49.0
750	58.0	57.0	56.0	54.6	53.0	51.2	48.0	43.3	37.5	34.1
800	56.0	55.5	54.0	48.5	43.0	37.5	34.5	30.5	27.0	24.0
850	52.0	50.5	46.0	40.5	35.0	31.0	27.5	24.0	21.0	18.5
900	46.0	41.0	36.0	32.0	28.0	25.0	21.6	19.0	16.4	14.1
950	40.0	35.0	30.0	26.0	22.2	19.5	17.0	14.6	12.6	11.0
1,000	31.5	27.5	24.0	21.0	17.9	15.2	13.1	11.0	9.4	7.9
1,050	26.0	22.5	19.0	16.5	14.0	12.0	10.0	8.3	7.0	5.8
1,100	21.0	18.0	15.1	13.0	10.8	9.1	7.5	6.2	5.0	4.1
1,150	17.0	14.1	11.8	9.8	8.0	...	...	...	...	...
1,200	13.5	11.1	9.2	7.6	6.2	...	...	...	...	...

SI Units

Temp., °C	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
375	406	405	404	403	401	399	396	392	356	323
400	400	393	386	375	363	350	328	296	256	233
425	387	384	373	337	301	266	245	216	191	170
450	363	353	325	287	249	221	197	172	151	133
475	328	299	265	236	205	183	159	140	121	105
500	291	256	222	194	167	148	128	112	96	83
525	244	214	184	161	137	118	103	88	71	70
550	196	175	150	132	112	96	81	68	58	48
575	168	145	122	106	89	76	63	52	43	36
600	138	117	98	85	69	...	...	...	...	...
625	114	94	77	65	52	...	...	...	...	...
650	92	76	62	51	43	...	...	...	...	...

Figure HBB-I-14.6E
Minimum Stress-to-Rupture, Alloy 718

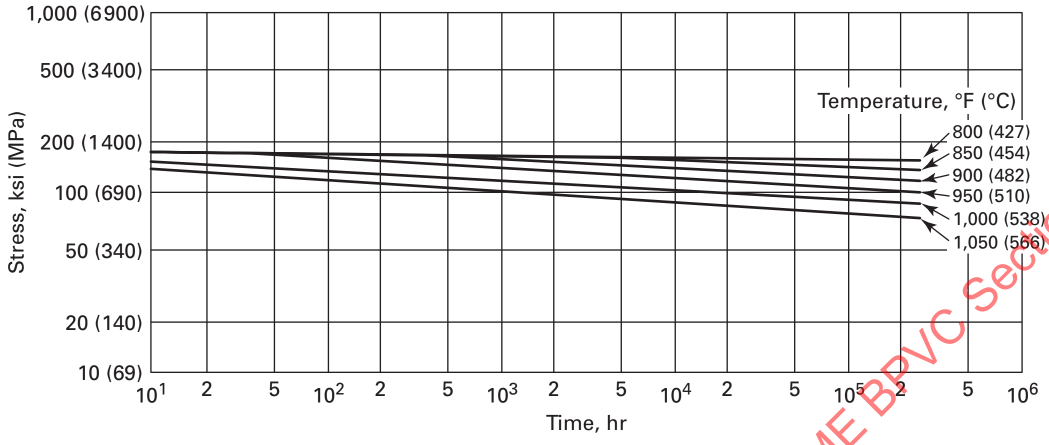


Table HBB-I-14.6E
Expected Minimum Stress-to-Rupture Values, ksi (MPa), Ni-Cr-Fe-Mo-Cb (Alloy 718)

U.S. Customary Units

Temp., °F	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	168	168	168	168	168	168	168	168	160	154
850	172	172	172	172	172	166	159	151	146	140
900	170	170	170	166	158	151	144	138	130	124
950	170	166	158	150	144	136	129	122	114	106
1,000	160	150	144	136	130	122	114	106	98	90
1,050	146	138	130	124	114	106	98	91	81	74

SI Units

Temp., °C	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	1 160	1 160	1 160	1 160	1 160	1 160	1 160	1 160	1 100	1 060
450	1 180	1 180	1 180	1 180	1 180	1 150	1 110	1 060	1 020	985
475	1 180	1 180	1 180	1 150	1 110	1 070	1 020	974	924	883
500	1 170	1 150	1 120	1 070	1 030	975	926	881	825	775
525	1 123	1 060	1 020	962	920	865	812	759	704	649
550	1 050	987	938	891	833	778	723	672	609	558

Figure HBB-I-14.6F
9Cr-1Mo-V — Expected Minimum Stress-to-Rupture, ksi (MPa)

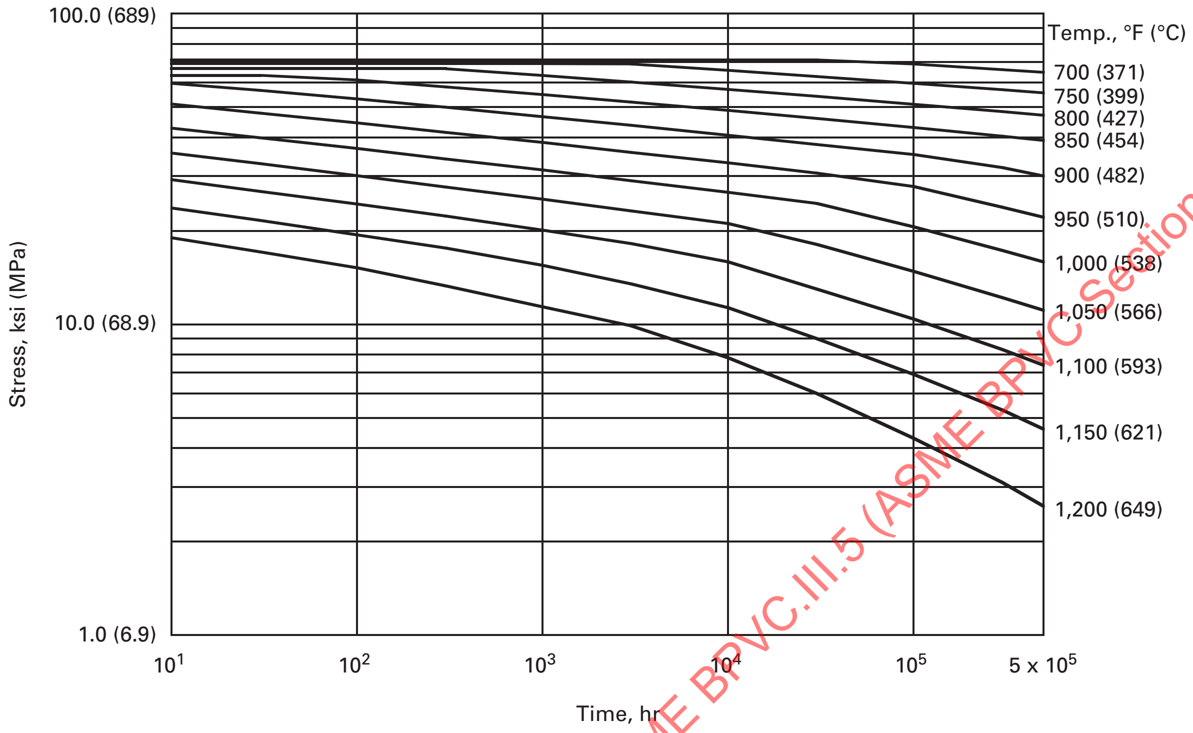


Table HBB-I-14.6F
9Cr-1Mo-V, S_r — Expected Minimum Stress-to-Rupture Values, ksi (MPa)

U.S. Customary Units

Temp., °F	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr	5×10^5 hr
700	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	68.8	66.0	64.7
750	69.0	69.0	69.0	69.0	69.0	68.9	65.7	62.8	59.7	56.9	55.6
800	66.5	66.5	66.5	66.5	63.2	60.2	57.0	54.2	51.1	48.4	47.1
850	63.4	63.4	61.2	58.1	54.9	51.9	48.8	46.0	43.0	40.3	39.1
900	59.7	56.6	53.2	50.0	46.6	43.7	40.6	37.9	35.2	32.0	30.0
950	51.2	47.9	44.5	41.5	38.5	35.8	33.1	30.7	27.8	23.8	22.1
1,000	42.8	39.9	36.8	34.1	31.4	29.0	26.6	24.5	20.6	17.3	15.9
1,050	35.6	32.9	30.1	27.7	25.3	23.2	21.1	18.1	14.8	12.2	11.1
1,100	29.2	26.8	24.4	22.3	20.1	18.2	15.9	13.0	10.4	8.3	7.4
1,150	23.7	21.6	19.4	17.6	15.5	13.5	11.3	9.0	6.9	5.3	4.6
1,200	19.0	17.1	15.2	13.3	11.4	9.9	7.8	6.0	4.3	3.1	2.6

SI Units

Temp., °C	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h	5×10^5 h
375	487	487	487	487	487	487	487	487	465	446	437
400	475	475	475	475	475	473	451	431	409	390	381
425	459	459	459	459	439	419	397	377	356	337	328
450	440	440	431	410	387	367	345	326	305	287	278
475	419	404	381	360	338	317	295	276	257	238	223
500	374	353	329	307	285	266	247	229	212	183	171
525	322	301	278	259	239	222	204	189	163	139	128
550	274	251	234	216	198	178	166	149	123	103	94
575	231	213	194	179	163	149	133	112	91	74	67
600	192	176	160	146	132	117	101	83	65	51	46
625	159	145	130	117	102	89	74	59	45	34	30
650	130	117	104	91	78	67	53	40	29	21	17

Table HBB-I-14.10A-1
Stress Rupture Factors for Type 304 Stainless Steel Welded With SFA-5.22 E 308T and E 308LT; SFA-5.4 E 308 and E 308L; and SFA-5.9 ER 308 and ER 308L

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97
900	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.97	0.95	0.94
950	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.95	0.93	0.91
1,000	1.00	0.98	0.96	0.94	0.93	0.93	0.93	0.93	0.91	0.88
1,050	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.95	0.91	0.85
1,100	1.00	0.99	0.98	1.00	1.00	1.00	0.99	0.95	0.89	0.82
1,150	1.00	1.00	1.00	1.00	1.00	0.99	0.95	0.90	0.81	0.72
1,200	1.00	1.00	1.00	1.00	0.98	0.95	0.88	0.81	0.71	0.60
1,250	1.00	1.00	0.97	0.97	0.92	0.87	0.78	0.69	0.57	0.46

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97
475	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.97	0.96	0.95
500	1.00	0.98	0.97	0.96	0.96	0.96	0.96	0.96	0.94	0.92
525	1.00	0.98	0.96	0.95	0.94	0.94	0.94	0.94	0.92	0.89
550	1.00	0.99	0.97	0.96	0.95	0.95	0.95	0.94	0.91	0.87
575	1.00	0.99	0.98	0.98	0.98	0.98	0.98	0.95	0.90	0.84
600	1.00	0.99	0.98	1.00	1.00	1.00	0.98	0.94	0.87	0.80
625	1.00	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.80	0.70
650	1.00	1.00	1.00	1.00	0.98	0.95	0.88	0.81	0.71	0.60
675	1.00	1.00	0.97	0.97	0.92	0.88	0.79	0.70	0.58	0.47

Table HBB-I-14.10A-2
Stress Rupture Factors for Type 304 Stainless Steel Welded With SFA-5.22 EXXXT-G (16-8-2 Chemistry); SFA-5.4 E 16-8-2; and SFA-5.9 ER 16-8-2

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
525	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
550	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
575	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
600	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
625	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
650	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table HBB-I-14.10A-3
Stress Rupture Factors for Type 304 Stainless Steel Welded With SFA-5.22 E 316T and E 316LT-1, -2, and -3; SFA-5.4 E 316 and E 316L; and SFA-5.9 ER 316 and ER 316L

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.98	0.94
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.95	0.90
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.92	0.86
1,000	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.89	0.82
1,050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.89	0.80
1,100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.89	0.79
1,150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.83	0.74
1,200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.79	0.68
1,250	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.85	0.72	0.61
1,300	1.00	1.00	1.00	1.00	1.00	1.00	0.89	0.78	0.65	0.54
1,350	1.00	1.00	1.00	1.00	1.00	0.92	0.81	0.70	0.59	0.49
1,400	1.00	1.00	1.00	1.00	0.93	0.85	0.73	0.63	0.51	0.45

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.98	0.95
475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.96	0.91
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.93	0.87
525	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95	0.90	0.84
550	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.89	0.81
575	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.89	0.79
600	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.87	0.77
625	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.84	0.75
650	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.79	0.68
675	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.86	0.73	0.62
700	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.79	0.66	0.55
725	1.00	1.00	1.00	1.00	1.00	0.94	0.83	0.72	0.61	0.50
750	1.00	1.00	1.00	1.00	0.95	0.87	0.76	0.65	0.54	0.46

Table HBB-I-14.10B-1
Stress Rupture Factors for Type 316 Stainless Steel Welded With SFA-5.22 E 308T and E 308L T; SFA-5.4 E 308 and E 308L; and SFA-5.9 ER 308 and ER 308L

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	0.98	0.95	0.95	0.95	0.94	0.92	0.92	0.92	0.92
900	1.00	0.94	0.88	0.88	0.88	0.87	0.84	0.84	0.82	0.82
950	1.00	0.90	0.81	0.81	0.81	0.80	0.77	0.76	0.73	0.72
1,000	1.00	0.87	0.75	0.75	0.74	0.73	0.70	0.68	0.64	0.62
1,050	1.00	0.89	0.78	0.78	0.77	0.76	0.74	0.72	0.67	0.60
1,100	1.00	0.90	0.81	0.81	0.79	0.79	0.76	0.73	0.69	0.63
1,150	0.90	0.88	0.86	0.82	0.79	0.77	0.74	0.70	0.64	0.57
1,200	0.81	0.80	0.79	0.79	0.76	0.75	0.70	0.64	0.57	0.49
1,250	0.79	0.78	0.76	0.74	0.72	0.68	0.63	0.56	0.48	0.39
1,300	0.75	0.73	0.70	0.68	0.63	0.59	0.53	0.46	0.38	0.30

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450	1.00	0.98	0.96	0.96	0.96	0.95	0.93	0.93	0.93	0.93
475	1.00	0.95	0.90	0.90	0.90	0.89	0.86	0.86	0.85	0.85
500	1.00	0.91	0.83	0.83	0.83	0.83	0.79	0.79	0.76	0.76
525	1.00	0.88	0.78	0.78	0.77	0.76	0.73	0.72	0.68	0.67
550	1.00	0.88	0.76	0.76	0.75	0.74	0.72	0.70	0.65	0.61
575	1.00	0.89	0.79	0.79	0.78	0.77	0.75	0.72	0.68	0.61
600	0.98	0.90	0.82	0.81	0.79	0.79	0.76	0.72	0.68	0.62
625	0.91	0.88	0.85	0.82	0.79	0.77	0.74	0.70	0.65	0.58
650	0.81	0.80	0.79	0.79	0.76	0.75	0.70	0.64	0.57	0.49
675	0.79	0.78	0.76	0.74	0.73	0.69	0.64	0.57	0.49	0.40
700	0.75	0.74	0.71	0.69	0.64	0.60	0.54	0.47	0.39	0.31

Table HBB-I-14.10B-2
Stress Rupture Factors for Type 316 Stainless Steel Welded With SFA-5.22 EXXXT-G (16-8-2 Chemistry); SFA-5.4 E 16-8-2; and SFA-5.9 ER 16-8-2

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	0.96	0.91	0.91	0.91	0.90	0.89	0.88	0.87	0.86
900	1.00	0.94	0.88	0.82	0.81	0.80	0.77	0.76	0.74	0.72
950	1.00	0.93	0.86	0.86	0.85	0.83	0.83	0.81	0.79	0.78
1,000	1.00	0.93	0.90	0.90	0.90	0.89	0.87	0.87	0.85	0.85
1,050	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.90	0.86
1,100	0.91	0.91	0.93	0.94	0.94	0.96	0.96	0.96	0.97	0.96
1,150	0.91	0.91	0.93	0.95	0.95	0.96	0.98	0.99	0.99	1.00
1,200	0.89	0.89	0.90	0.92	0.93	0.97	0.99	1.00	1.00	1.00

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450	1.00	0.97	0.92	0.92	0.92	0.91	0.91	0.90	0.89	0.88
475	1.00	0.95	0.89	0.84	0.84	0.83	0.80	0.79	0.77	0.76
500	1.00	0.93	0.87	0.85	0.84	0.82	0.81	0.79	0.77	0.76
525	1.00	0.93	0.88	0.88	0.88	0.86	0.85	0.84	0.83	0.82
550	0.97	0.93	0.91	0.91	0.91	0.90	0.89	0.90	0.87	0.85
575	0.92	0.92	0.92	0.93	0.93	0.93	0.93	0.94	0.92	0.89
600	0.91	0.91	0.93	0.94	0.94	0.96	0.96	0.97	0.97	0.97
625	0.91	0.91	0.93	0.95	0.95	0.96	0.98	0.99	0.99	1.00
650	0.89	0.89	0.90	0.92	0.93	0.97	0.99	1.00	1.00	1.00

Table HBB-I-14.10B-3
Stress Rupture Factors for Type 316 Stainless Steel Welded With SFA-5.22 E 316T and E 316LT-1 and -2; SFA-5.4 E 316 and E 316L; and SFA-5.9 ER 316 and ER 316L

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.92	0.88
900	1.00	1.00	0.97	0.94	0.91	0.89	0.88	0.86	0.82	0.78
950	1.00	1.00	0.95	0.90	0.87	0.84	0.81	0.78	0.72	0.68
1,000	1.00	1.00	0.88	0.86	0.83	0.79	0.74	0.70	0.62	0.58
1,050	1.00	1.00	0.92	0.89	0.87	0.83	0.78	0.74	0.66	0.56
1,100	1.00	1.00	0.96	0.94	0.90	0.87	0.81	0.75	0.68	0.61
1,150	1.00	1.00	1.00	0.96	0.91	0.87	0.81	0.75	0.66	0.59
1,200	1.00	1.00	0.96	0.95	0.90	0.87	0.81	0.72	0.64	0.55
1,250	1.00	1.00	0.96	0.93	0.89	0.84	0.77	0.69	0.60	0.51
1,300	1.00	0.98	0.93	0.89	0.83	0.79	0.72	0.65	0.56	0.48
1,350	0.99	0.96	0.89	0.84	0.77	0.72	0.65	0.59	0.52	0.45
1,400	0.95	0.90	0.82	0.77	0.71	0.66	0.60	0.55	0.47	0.42

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.95	0.93	0.90
475	1.00	1.00	0.98	0.96	0.93	0.91	0.90	0.88	0.85	0.81
500	1.00	1.00	0.96	0.91	0.88	0.86	0.83	0.81	0.76	0.72
525	1.00	1.00	0.91	0.88	0.85	0.81	0.77	0.74	0.67	0.63
550	1.00	1.00	0.90	0.87	0.85	0.81	0.76	0.72	0.64	0.57
575	1.00	1.00	0.93	0.92	0.88	0.84	0.79	0.74	0.67	0.57
600	1.00	1.00	0.97	0.95	0.90	0.87	0.81	0.75	0.68	0.61
625	1.00	1.00	1.00	0.96	0.91	0.87	0.81	0.75	0.65	0.58
650	1.00	1.00	0.96	0.95	0.90	0.87	0.81	0.72	0.64	0.55
675	1.00	1.00	0.96	0.93	0.89	0.84	0.77	0.69	0.60	0.51
700	1.00	0.98	0.93	0.90	0.84	0.80	0.73	0.66	0.57	0.48
725	0.99	0.96	0.90	0.85	0.79	0.74	0.67	0.61	0.53	0.46
750	0.96	0.92	0.84	0.79	0.73	0.69	0.62	0.56	0.49	0.43

Table HBB-I-14.10C-1
Stress Rupture Factors for Alloy 800H Welded With SFA-5.11 ENiCrFe-2 (INCO A)

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850–900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	1.00	1.00	1.00	1.00	0.98	0.95	0.92	0.90	0.86	0.83
1,000	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.82	0.78
1,050	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.85	0.81	0.76
1,100	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.84	0.79	0.75
1,150	1.00	1.00	1.00	1.00	0.98	0.93	0.88	0.83	0.77	0.72
1,200	1.00	1.00	1.00	1.00	0.98	0.93	0.87	0.81	0.75	0.70
1,250	1.00	1.00	1.00	1.00	0.98	0.92	0.85	0.80	0.73	0.68
1,300	1.00	1.00	1.00	1.00	0.97	0.91	0.84	0.77	0.71	0.65
1,350	1.00	1.00	1.00	1.00	0.96	0.89	0.82	0.75	0.68	0.62
1,400	1.00	1.00	1.00	1.00	0.95	0.87	0.80	0.73	0.65	0.59

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450–475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	0.99	0.97	0.95	0.94	0.91	0.89
525	1.00	1.00	1.00	1.00	0.98	0.94	0.91	0.88	0.84	0.80
550	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.82	0.77
575	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.85	0.80	0.76
600	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.84	0.79	0.74
625	1.00	1.00	1.00	1.00	0.98	0.93	0.88	0.83	0.77	0.72
650	1.00	1.00	1.00	1.00	0.98	0.93	0.87	0.81	0.75	0.70
675	1.00	1.00	1.00	1.00	0.98	0.92	0.85	0.80	0.73	0.68
700	1.00	1.00	1.00	1.00	0.97	0.91	0.84	0.77	0.71	0.65
725	1.00	1.00	1.00	1.00	0.96	0.90	0.83	0.76	0.69	0.63
750	1.00	1.00	1.00	1.00	0.95	0.88	0.81	0.74	0.66	0.60

Table HBB-I-14.10C-2
Stress Rupture Factors for Alloy 800H Welded With SFA-5.14 ERNiCr-3 (INCO 82)

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850–900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	0.89	0.90	0.90	0.90	0.89	0.89	0.88	0.87	0.86	0.86
1,000	0.85	0.86	0.86	0.86	0.85	0.85	0.84	0.84	0.82	0.81
1,050	0.88	0.88	0.88	0.88	0.87	0.86	0.85	0.84	0.83	0.81
1,100	0.91	0.91	0.91	0.90	0.89	0.88	0.87	0.85	0.83	0.81
1,150	0.94	0.93	0.93	0.92	0.90	0.89	0.87	0.85	0.83	0.81
1,200	0.96	0.96	0.95	0.93	0.92	0.90	0.88	0.86	0.83	0.81
1,250	0.99	0.98	0.96	0.95	0.93	0.91	0.88	0.85	0.82	0.80
1,300	1.00	1.00	0.98	0.96	0.93	0.91	0.88	0.85	0.82	0.78
1,350	1.00	1.00	0.99	0.96	0.94	0.91	0.87	0.84	0.77	0.68
1,400	1.00	1.00	1.00	0.97	0.94	0.89	0.79	0.71	0.62	0.54

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450–475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	0.93	0.94	0.94	0.94	0.93	0.93	0.92	0.92	0.91	0.91
525	0.87	0.88	0.88	0.88	0.87	0.87	0.86	0.85	0.84	0.83
550	0.86	0.87	0.87	0.87	0.86	0.85	0.84	0.84	0.82	0.81
575	0.89	0.89	0.89	0.89	0.88	0.88	0.86	0.84	0.83	0.81
600	0.92	0.92	0.92	0.91	0.89	0.88	0.87	0.85	0.83	0.81
625	0.94	0.93	0.93	0.92	0.90	0.89	0.87	0.85	0.83	0.81
650	0.96	0.96	0.95	0.93	0.92	0.90	0.88	0.86	0.83	0.81
675	0.99	0.98	0.96	0.95	0.93	0.91	0.88	0.85	0.82	0.80
700	1.00	1.00	0.98	0.96	0.93	0.91	0.88	0.85	0.82	0.78
725	1.00	1.00	0.99	0.96	0.94	0.91	0.87	0.84	0.78	0.71
750	1.00	1.00	1.00	0.97	0.94	0.90	0.82	0.76	0.67	0.59

Table HBB-I-14.10D-1
Stress Rupture Factors for 2$\frac{1}{4}$Cr-1Mo (60/30) Welded With SFA-5.28 E 90C-B3; SFA-5.28 ER 90S-B3; SFA-5.5 E 90XX-B3 (>0.05C); SFA-5.23 EB 3; SFA-5.23 ECB 3 (>0.05C); SFA-5.29 E 90T1-B3 (>0.05C)

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
750–850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96
1,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.93
1,050	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.91	0.87
1,100	1.00	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.81
1,150	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.85	0.79	0.74
1,200	1.00	1.00	1.00	0.98	0.93	0.89	0.83	0.78	0.71	0.66

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
400–450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97
525	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.94
550	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.94	0.90
575	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.93	0.89	0.85
600	1.00	1.00	1.00	1.00	0.99	0.97	0.93	0.89	0.84	0.79
625	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.80	0.75
650	1.00	1.00	1.00	0.98	0.93	0.89	0.83	0.78	0.71	0.66

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Table HBB-I-14.10E-1
Stress Rupture Factors for 9Cr–1Mo–V Welded With SFA-5.28 ER90S-B91; SFA-5.5 E90XX-B91; SFA-5.23 EB91

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr	500,000 hr
800	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.97	0.96	0.96
850	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.95	0.94	0.94
900	1.00	1.00	1.00	1.00	0.99	0.98	0.96	0.95	0.94	0.92	0.92
950	1.00	1.00	1.00	0.99	0.97	0.96	0.95	0.93	0.92	0.91	0.88
1,000	1.00	1.00	0.99	0.97	0.96	0.95	0.93	0.91	0.84	0.79	0.77
1,050	1.00	0.99	0.98	0.96	0.95	0.93	0.87	0.79	0.74	0.72	0.71
1,100	0.99	0.98	0.96	0.95	0.92	0.85	0.75	0.71	0.69	0.68	0.68
1,150	0.99	0.97	0.95	0.92	0.84	0.75	0.68	0.67	0.67	0.67	0.67
1,200	0.97	0.95	0.90	0.84	0.76	0.69	0.65	0.65	0.65	0.65	0.65

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h	500 000 h
425	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.96	0.96
450	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.96	0.94	0.94
475	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.95	0.94	0.93	0.92
500	1.00	1.00	1.00	0.99	0.98	0.97	0.95	0.94	0.93	0.92	0.92
525	1.00	1.00	0.99	0.98	0.97	0.95	0.94	0.92	0.90	0.84	0.82
550	1.00	0.99	0.98	0.97	0.95	0.94	0.92	0.85	0.79	0.75	0.74
575	1.00	0.99	0.97	0.96	0.94	0.92	0.82	0.76	0.72	0.70	0.70
600	0.99	0.98	0.96	0.94	0.92	0.82	0.72	0.70	0.68	0.68	0.68
625	0.98	0.97	0.94	0.91	0.82	0.74	0.67	0.66	0.66	0.66	0.66
650	0.97	0.94	0.90	0.84	0.75	0.68	0.65	0.65	0.65	0.65	0.65

GENERAL NOTES:

(a) Longitudinal seam welds are not recommended above 1,000°F (537°C) and the tabulated values are not applicable for such welds for service temperatures greater than 1,000°F (537°C). For longitudinal seam welds operating above 1,000°F (537°C) appropriate stress rupture factors shall be included in the Design Specifications and justified in the Design Report.

(b) The values in this table are extrapolated from shorter term test data using an engineering model. For longer design lives, the designer should consider further strength reductions to account for potential in-service material degradation per HBB-2160(a). In addition, enhanced material surveillance programs and/or heightened in-service inspection per the rules of Section XI may be warranted.

Table HBB-I-14.11
Permissible Materials for Bolting

Material	Spec. No.	Grades
Type 304 SS	SA-193	B8, Class 1 and B8A, Class 1A [Note (1)]
Type 316 SS	SA-193	B8M, Class 1 and B8MA, Class 1A [Note (1)]
Ni-Cr-Fe-Mo-Cb Alloy 718 [Note (2)], [Note (3)], [Note (4)]	SB-637	NO 7718

GENERAL NOTE: If bolting temperatures do not exceed those given in Section II, Part D, Subpart 1, Table 4 for the bolting material, the S_m values in Section II, Part D, Subpart 1, Table 4 shall apply. For elevated temperatures, the list of materials shown above can be used in bolting applications.

NOTES:

(1) For use at temperatures above 1,000°F (540°C), these materials may be used only if the material is heat treated by heating to a minimum temperature of 1,900°F (1 040°C) and quenching in water or rapidly cooling by other means.

(2) Maximum forging diameter shall be limited to 6 in. (150 mm).

(3) Welding is not permitted.

(4) Precautionary Note: In use of Alloy 718, consideration shall be given to a reduction in toughness caused by long-term exposure at a temperature of 1,000°F (540°C) or greater.

Table HBB-I-14.12
S_o Values for Design Conditions Calculation of Bolting Materials S_o Maximum Allowable Stress Intensity, ksi (MPa)

U.S. Customary Units				SI Units			
For Metal Temperature Not Exceeding, °F	304 SS	316 SS	Alloy 718	For Metal Temperature Not Exceeding, °C	304 SS	316 SS	Alloy 718
800	5.5	5.8	33.3	425	38	40	230
850	5.5	5.8	33.1	450	38	40	228
900	5.4	5.7	32.9	475	37	39	227
950	5.3	5.7	32.6	500	37	39	226
1,000	5.2	5.6	32.3	525	36	39	224
1,050	5.1	5.6	32.0	550	35	39	222
1,100	4.9	5.5	...	575	35	39	...
1,150	4.8	5.4	...	600	34	38	...
1,200	4.7	5.4	...	625	33	37	...
1,250	4.7	5.3	...	650	32	37	...
1,300	3.7	4.1	...	675	32	37	...
				700	27	29	...

Figure HBB-I-14.13A
S_{mt} — Allowable Stress Intensity, Type 304 SS, Bolting

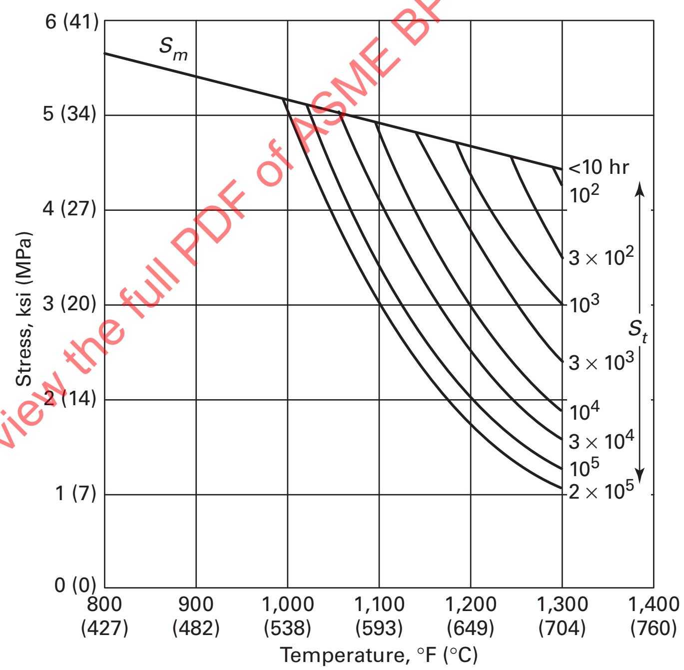


Figure HBB-I-14.13B
S_{mt} — Allowable Stress Intensity, Type 316 SS, Bolting

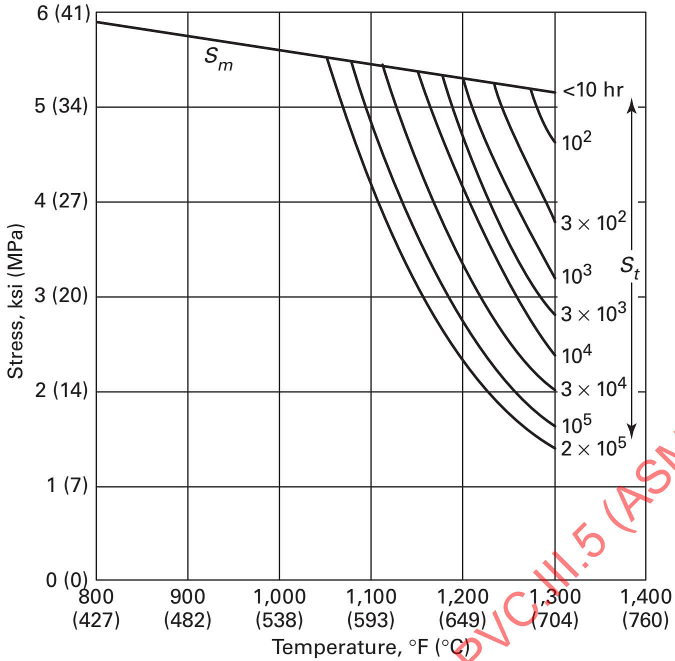


Figure HBB-I-14.13C
S_{mt} — Allowable Stress, Alloy 718, Bolting

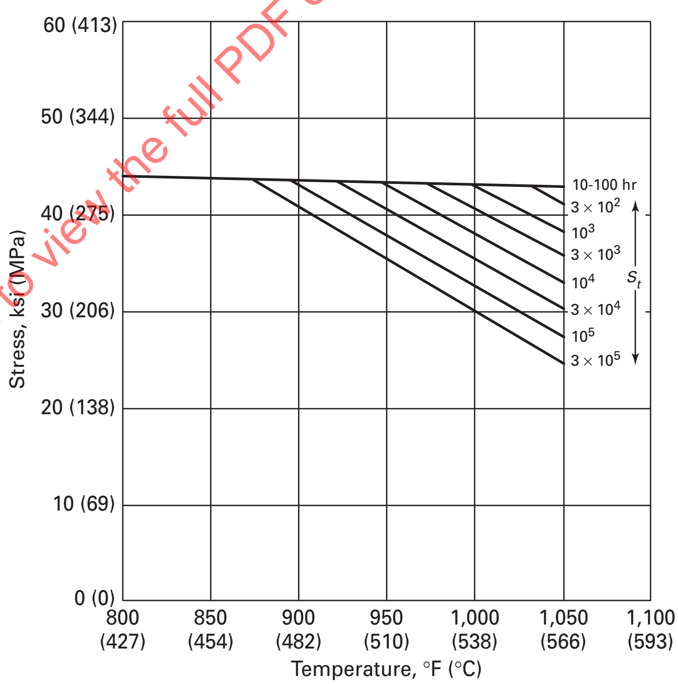


Table HBB-I-14.13C
S_{mt} — Allowable Stress Values, ksi (MPa), Alloy 718, Bolting

U.S. Customary Units

Temp., °F	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4
850	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1
900	43.8	43.8	43.8	43.8	43.8	43.8	43.8	43.8	43.3	43.3
950	43.5	43.5	43.5	43.5	43.5	43.5	43.0	40.7	38.0	35.3
1,000	43.1	43.1	43.1	43.1	43.1	40.7	38.0	35.3	32.7	30.0
1,050	42.7	42.7	42.7	41.3	38.0	35.3	32.7	30.3	27.0	24.7

SI Units

Temp., °C	10 h	30 h	10^2 h	3×10^2 h	10^3 h	3×10^3 h	10^4 h	3×10^4 h	10^5 h	3×10^5 h
425	306	306	306	306	306	306	306	306	306	306
450	304	304	304	304	304	304	304	304	304	304
475	303	303	303	303	303	303	303	303	300	300
500	301	301	301	301	301	301	298	288	275	263
525	298	298	298	298	298	290	282	261	242	224
550	296	296	296	292	282	265	250	228	208	191

MANDATORY APPENDIX HBB-II
USE OF SA-533 TYPE B, CLASS 1 PLATE AND SA-508 GRADE 3, CLASS 1 FORGINGS AND THEIR WELDMENTS FOR LIMITED ELEVATED TEMPERATURE SERVICE

ARTICLE HBB-II-1000
SCOPE

Class A nuclear components, fabricated from SA-533 Type B, Class 1 plates; SA-508 Grade 3, Class 1 forgings; and their weldments may be used when metal temperatures exceed 700°F (370°C) during operating conditions associated with Level B, C, and D Service Limits in accordance with the considerations in Articles HBB-II-2000 and HBB-II-7000.

ARTICLE HBB-II-2000
MATERIAL

The rules for materials in Division 1, Article NB-2000 and in Article HBB-2000 for Class A components in elevated temperature service shall apply to the materials of this Appendix with the following additions:

(a) The material specifications permitted by this Appendix are SA-533 Type B, Class 1; SA-508 Grade 3, Class 1; and their weldments.

(b) The allowable stress intensities in Table HBB-II-3000-3 of this Appendix shall be considered as extensions to the values of Section II, Part D, Subpart 1, Table 2A for the materials and conditions addressed by this Appendix.

ARTICLE HBB-II-3000
DESIGN

The rules for design are presented in (a) through (i). Refer to Figures HBB-II-3000-1 through HBB-II-3000-14 and Tables HBB-II-3000-1 through HBB-II-3000-8.

(a) The design rules of Division 1, Article NB-3000 shall be satisfied for all Design, Service, and Test Loadings for which metal temperatures do not exceed 700°F (370°C). The design conditions shall be as defined in Division 1, Article NB-3000.

(b) Metal temperatures exceeding 700°F (370°C) are permitted only for loadings associated with Level B, C, and D Service Limits. The applicable rules of Article HBB-3000 shall be satisfied for these conditions.

(c) Metal temperatures shall not exceed 800°F (425°C) for loadings associated with Level B Service Limits. Metal temperatures shall not exceed 1,000°F (540°C) for loadings associated with Level C or Level D Service Limits.

(d) The component design shall be based on a maximum cumulative time of 3,000 hr at metal temperatures in the range of 700°F (370°C) to 800°F (425°C) and 1,000 hr at metal temperatures exceeding 800°F (425°C) up to 1,000°F (540°C).

(e) The number of anticipated operating conditions where metal temperatures exceed 800°F (425°C) shall be limited to a total of three.

(f) The creep–fatigue interaction damage envelope shown in Figure HBB-II-3000-12 shall be used for the materials of this Appendix.

(g) The mechanical and physical property values at elevated temperatures are provided in the figures and tables of this Appendix. The properties include

(1) isochronous stress–strain curves

(2) yield strengths

(3) stress-to-rupture values

(4) elevated temperature fatigue strength

(5) moduli of elasticity

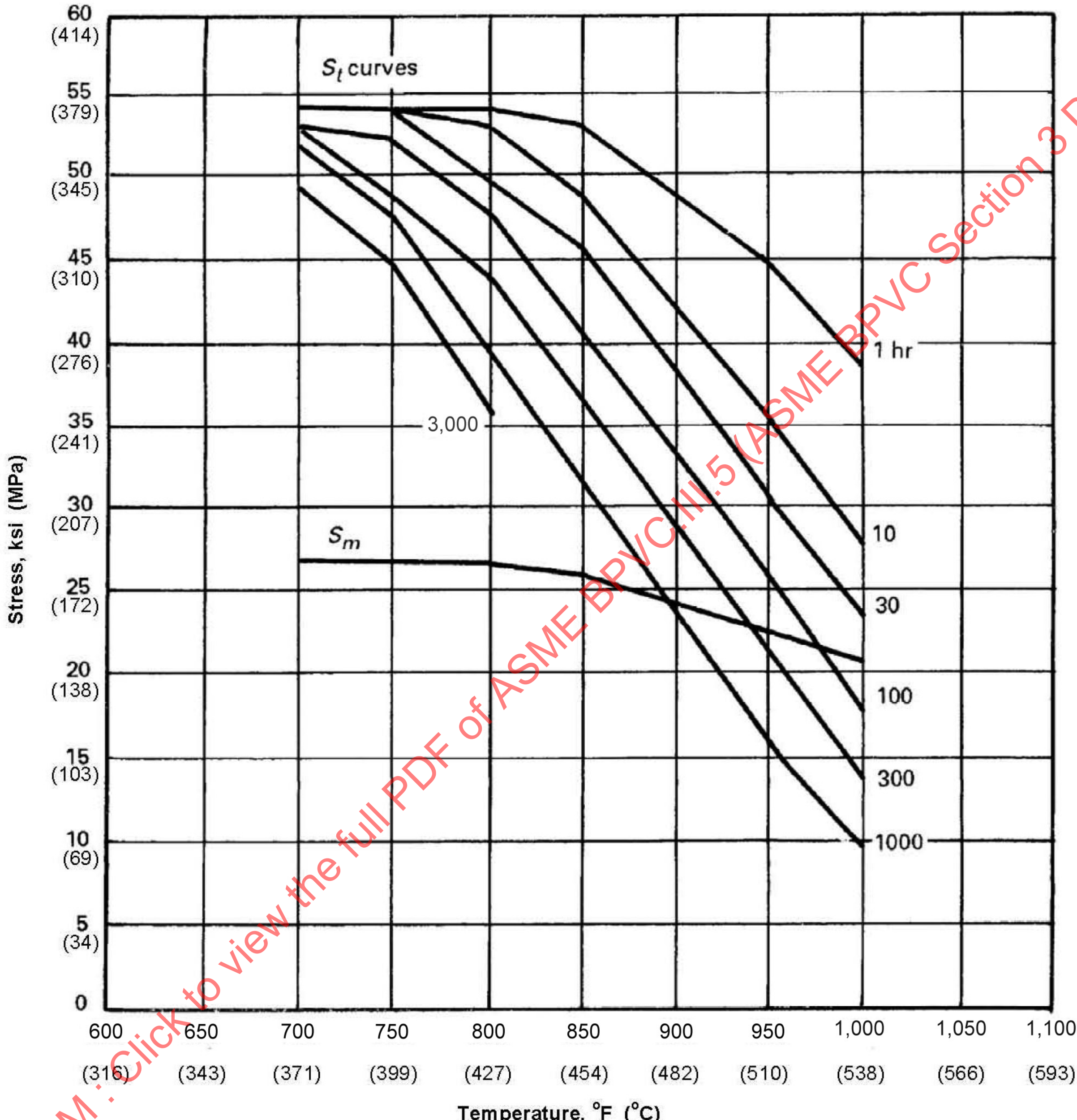
(6) instantaneous and mean coefficients of thermal expansion

(h) The stress rupture factors for welds shall have a value of 1.0 for the materials and conditions of this Appendix.

(i) In addition, the sum of the creep damage and fatigue damage, summed over the entire lifetime, shall not exceed the limit of Figure HBB-II-3000-12 anywhere in the structure. When performing the creep–fatigue interaction analysis, load history effects and residual stresses from prior low-temperature operation shall be considered in the evaluation. Since the fatigue curve at temperatures above 700°F (370°C) is more restrictive than that for temperatures below 700°F (370°C), strain cycles that have one extremum at elevated temperature and one extremum at low temperature shall be evaluated using the values in Figure HBB-II-3000-11 and Table HBB-II-3000-8.

(23)

Figure HBB-II-3000-1
S_{mt} Values for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1



GENERAL NOTE: S_{mt} is the lower of S_m and S_t at any given temperature.

(23)

Figure HBB-II-3000-2
S_t Allowable Stress Intensity Values for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

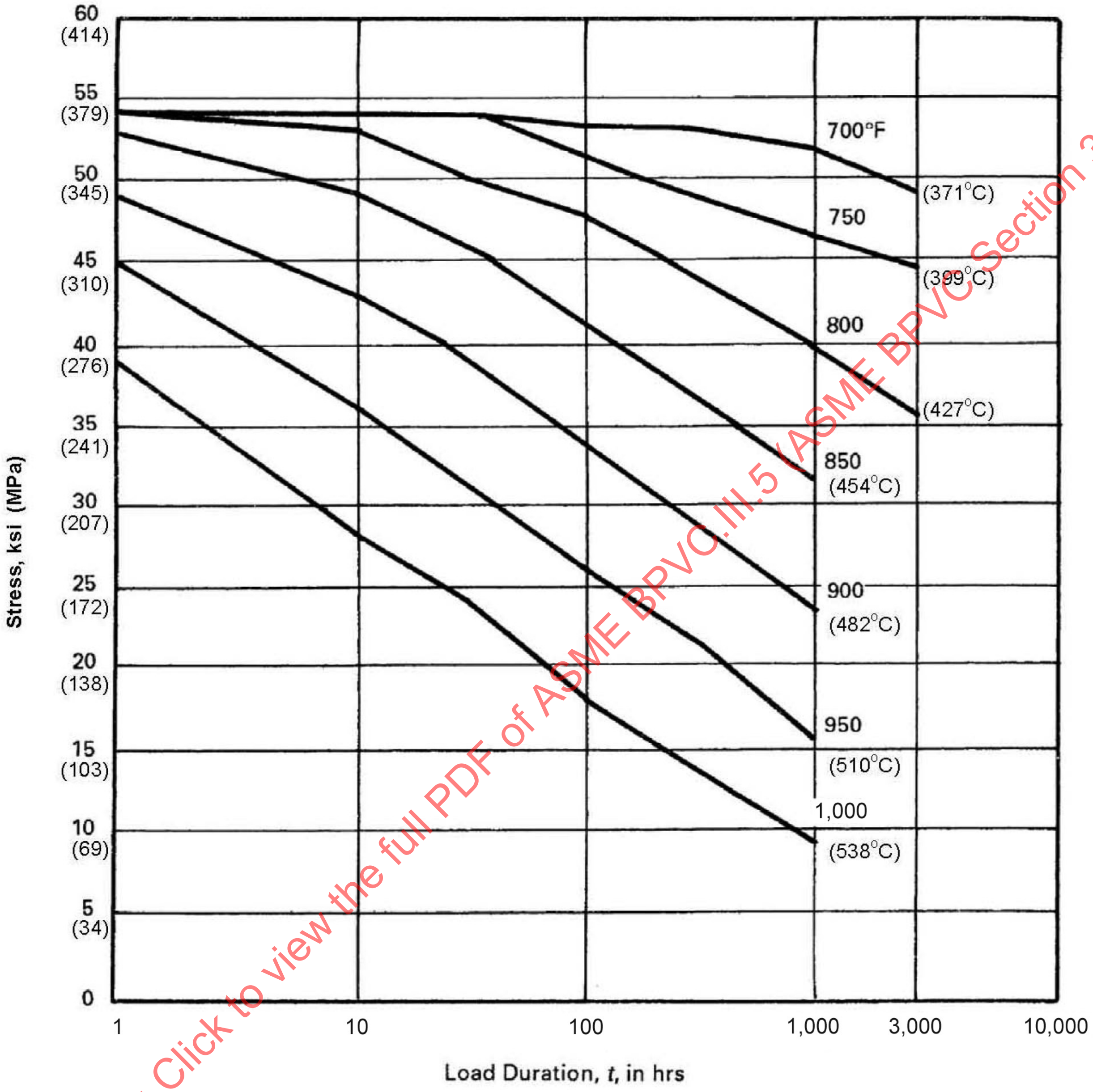


Figure HBB-II-3000-3
Stress-to-Rupture (Minimum) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

(23)

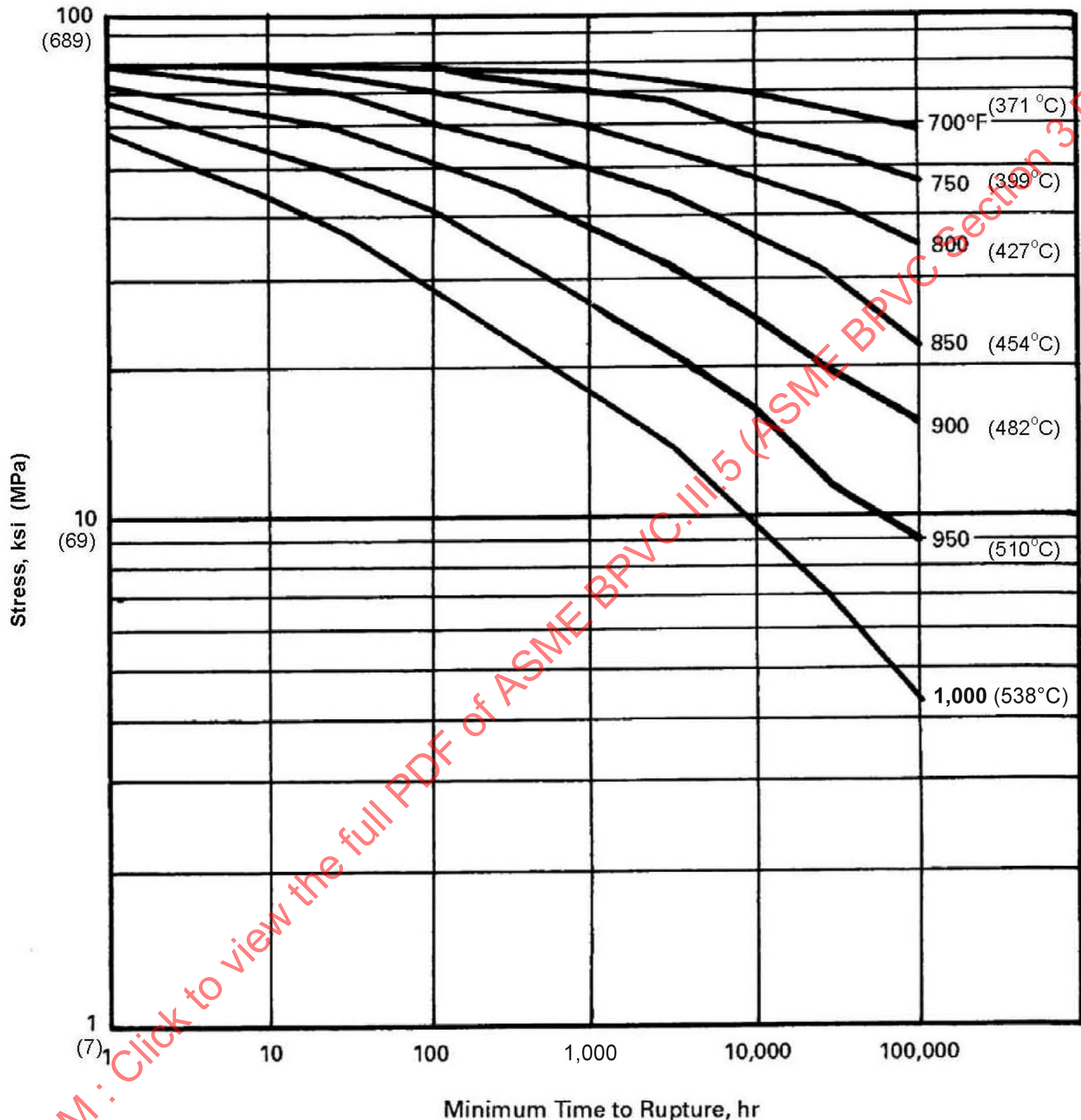


Figure HBB-II-3000-4
Isochronous Stress–Strain Curves for 700°F (371°C) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

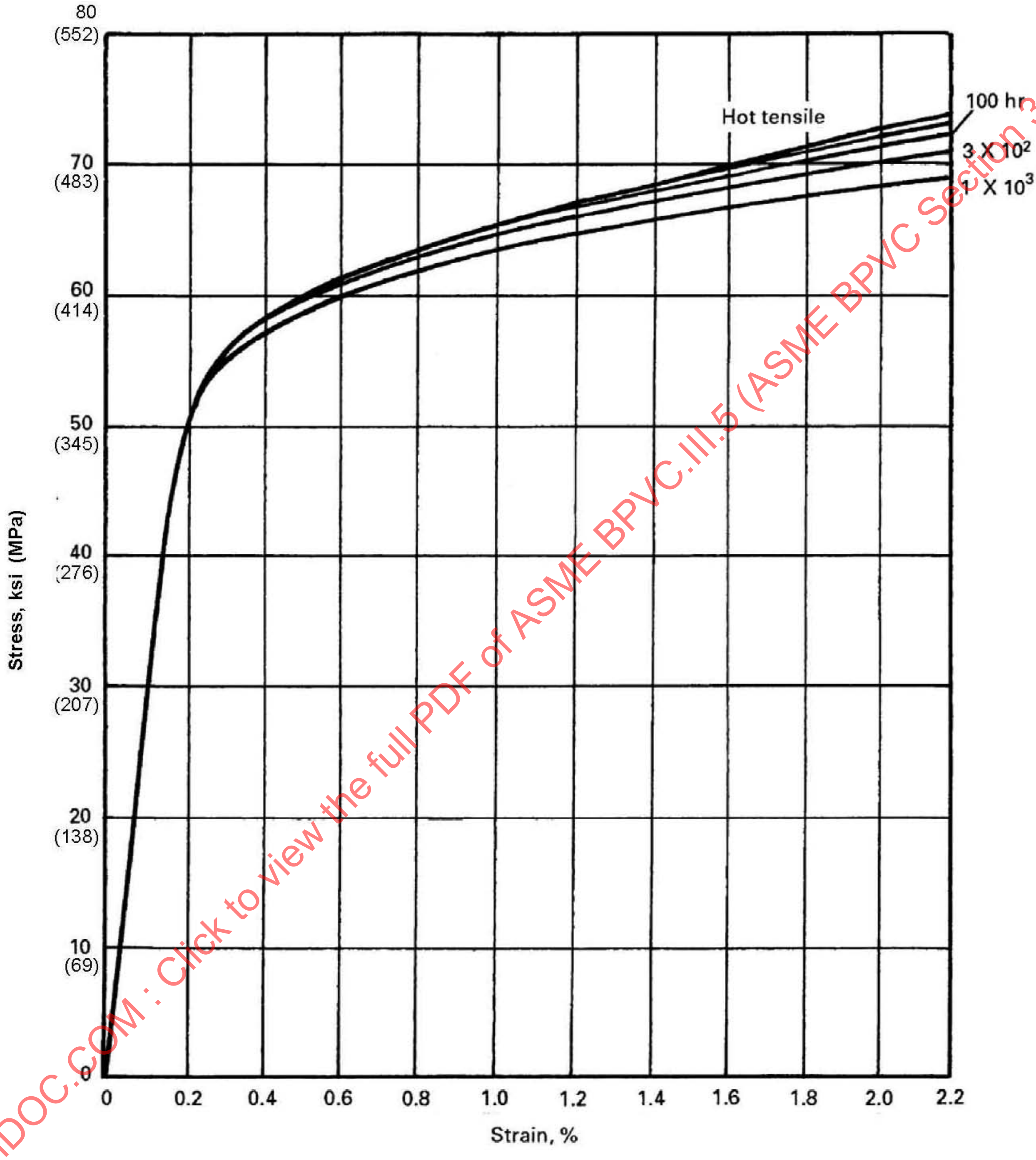


Figure HBB-II-3000-5
Isochronous Stress–Strain Curves for 750°F (399°C) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

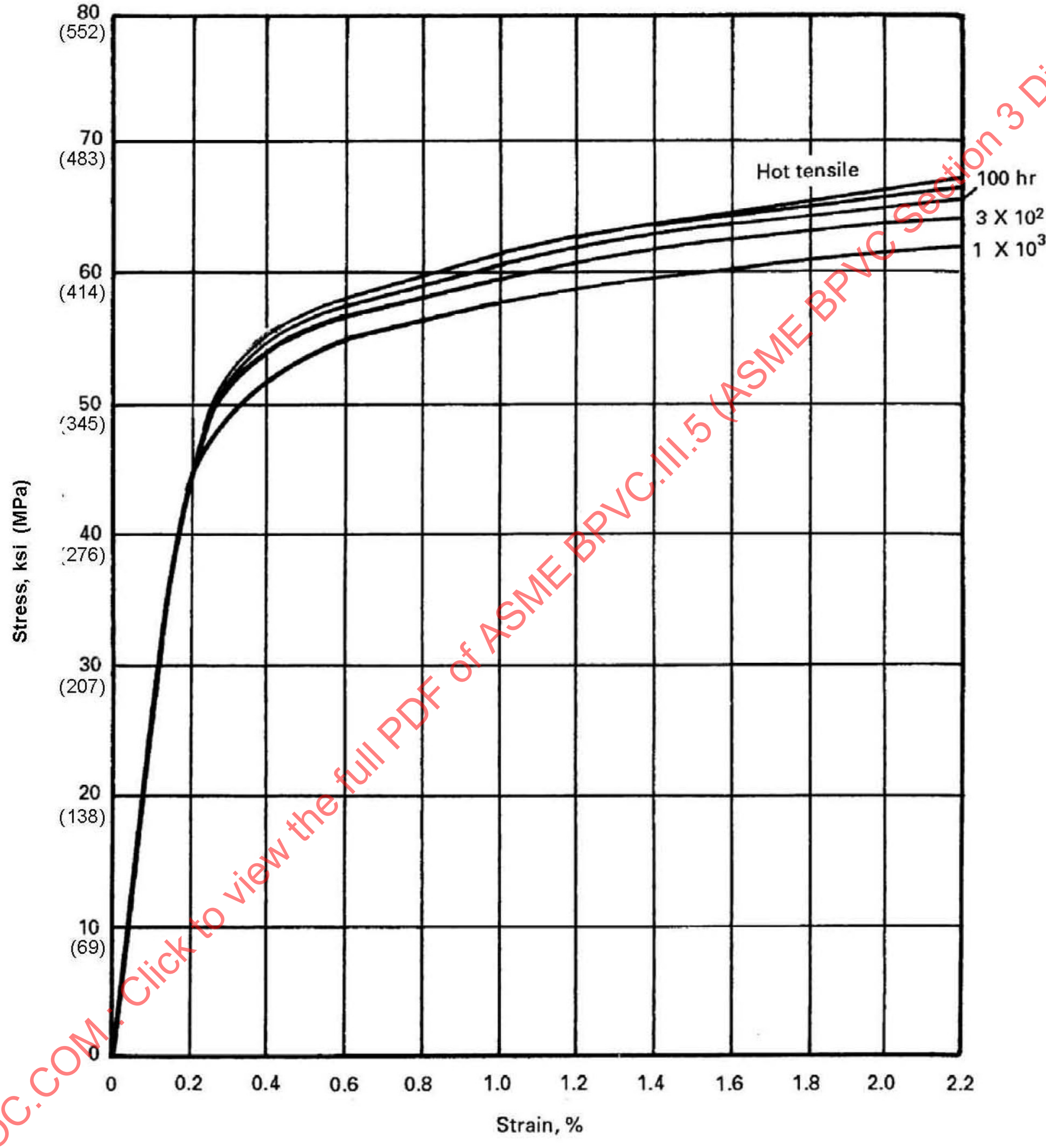


Figure HBB-II-3000-6
Isochronous Stress–Strain Curves for 800°F (427°C) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

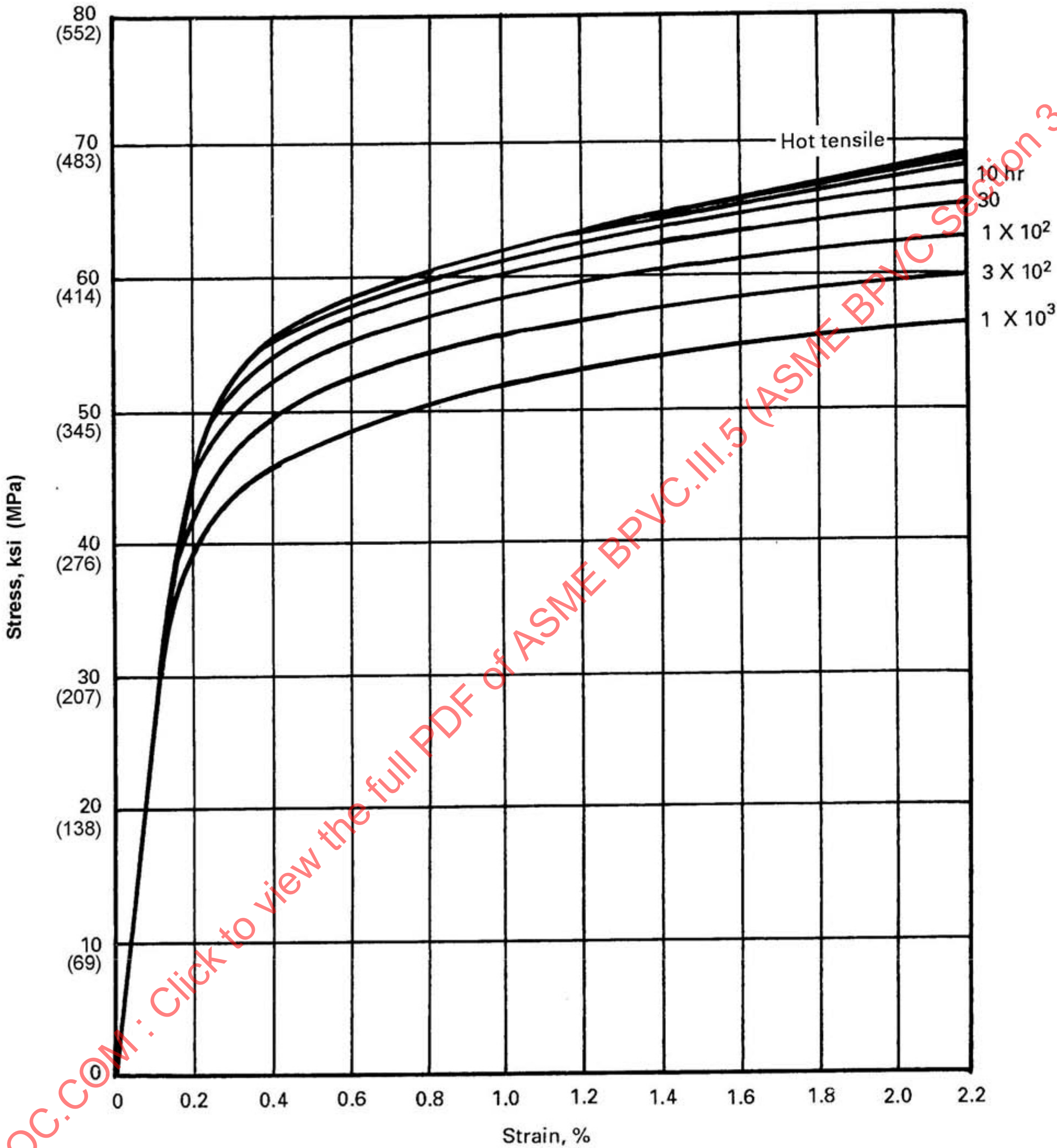


Figure HBB-II-3000-7
Isochronous Stress–Strain Curves for 850°F (454°C) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

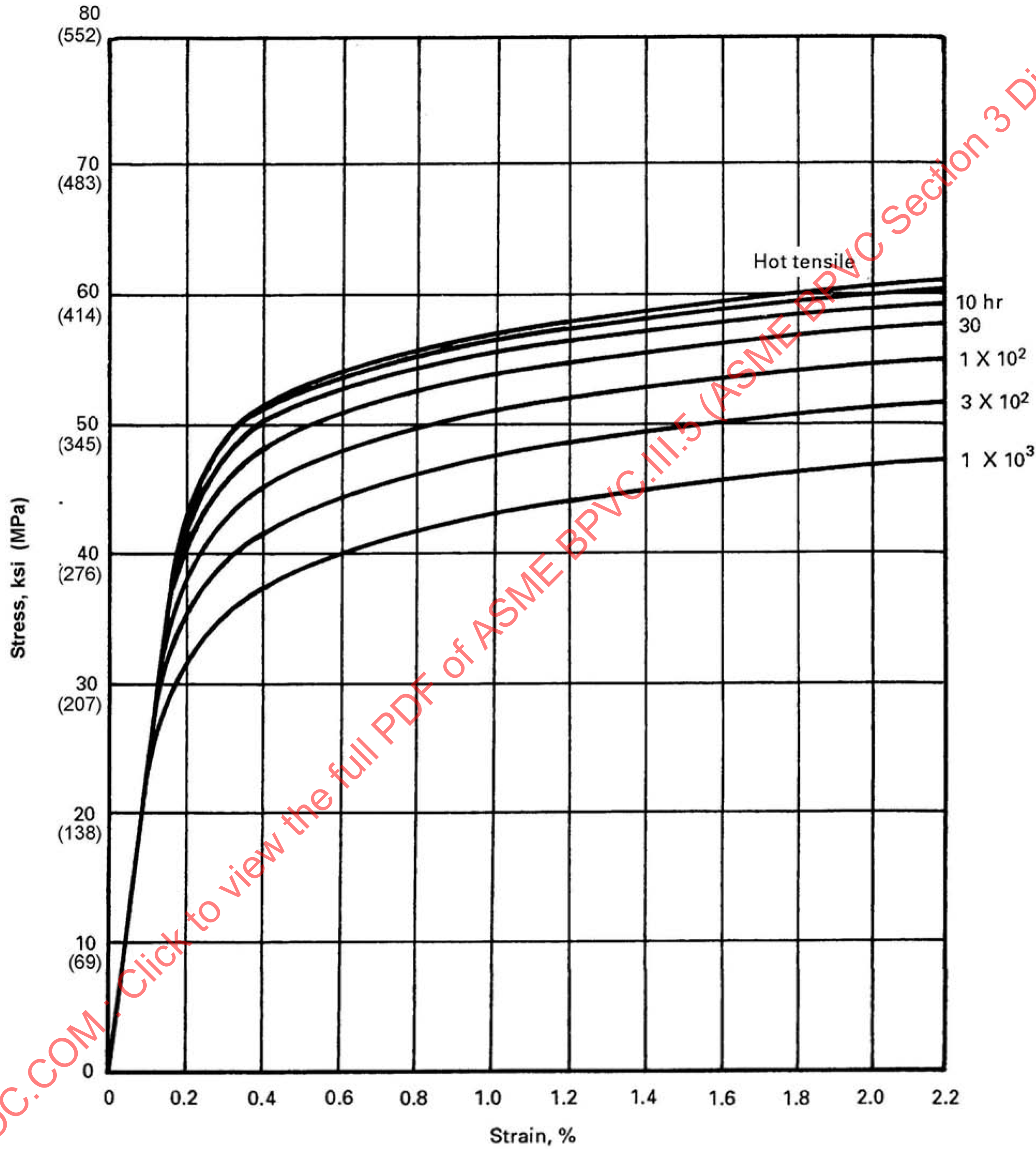


Figure HBB-II-3000-8
Isochronous Stress–Strain Curves for 900°F (482°C) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

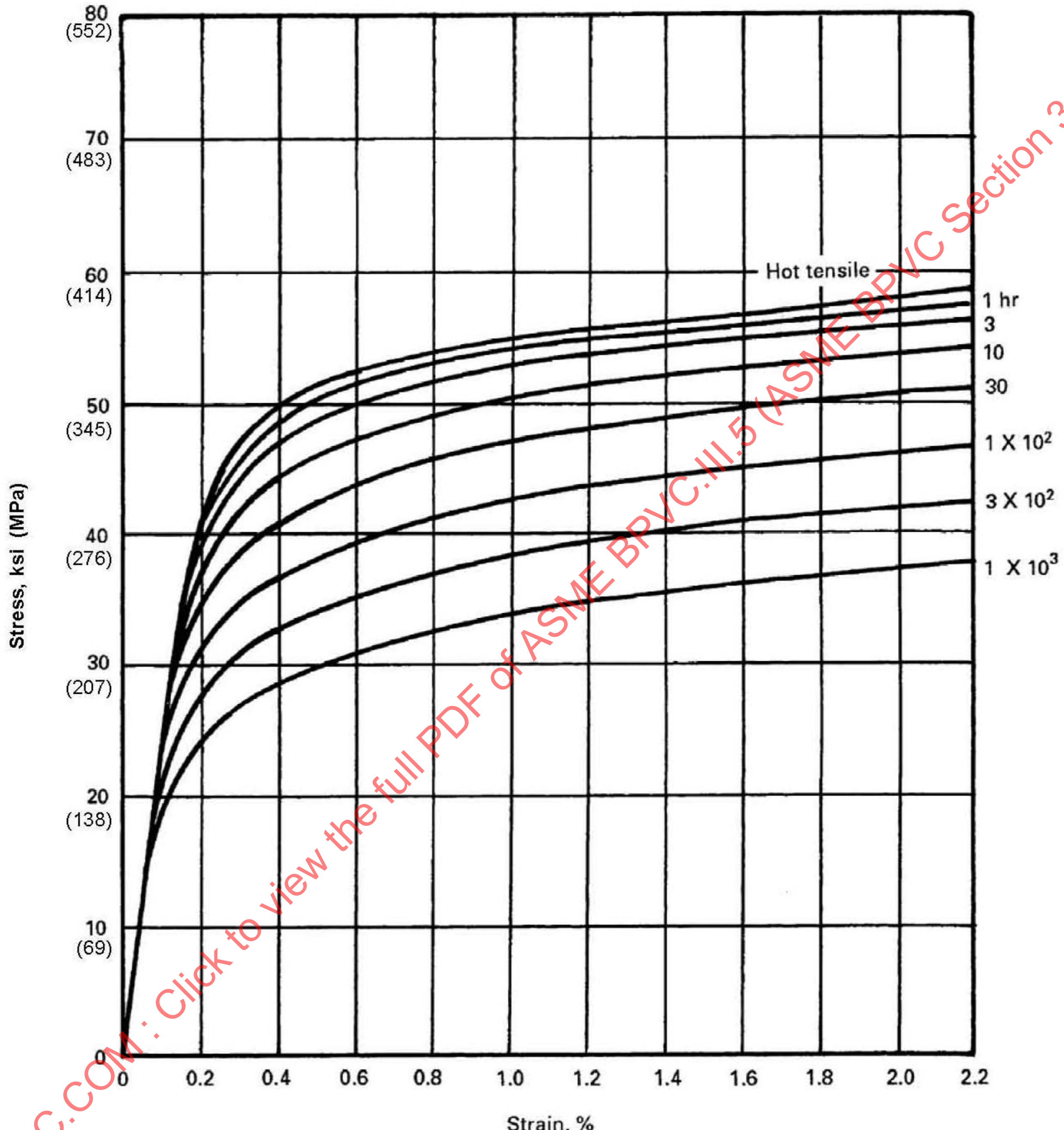


Figure HBB-II-3000-9
Isochronous Stress–Strain Curves for 950°F (510°C) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

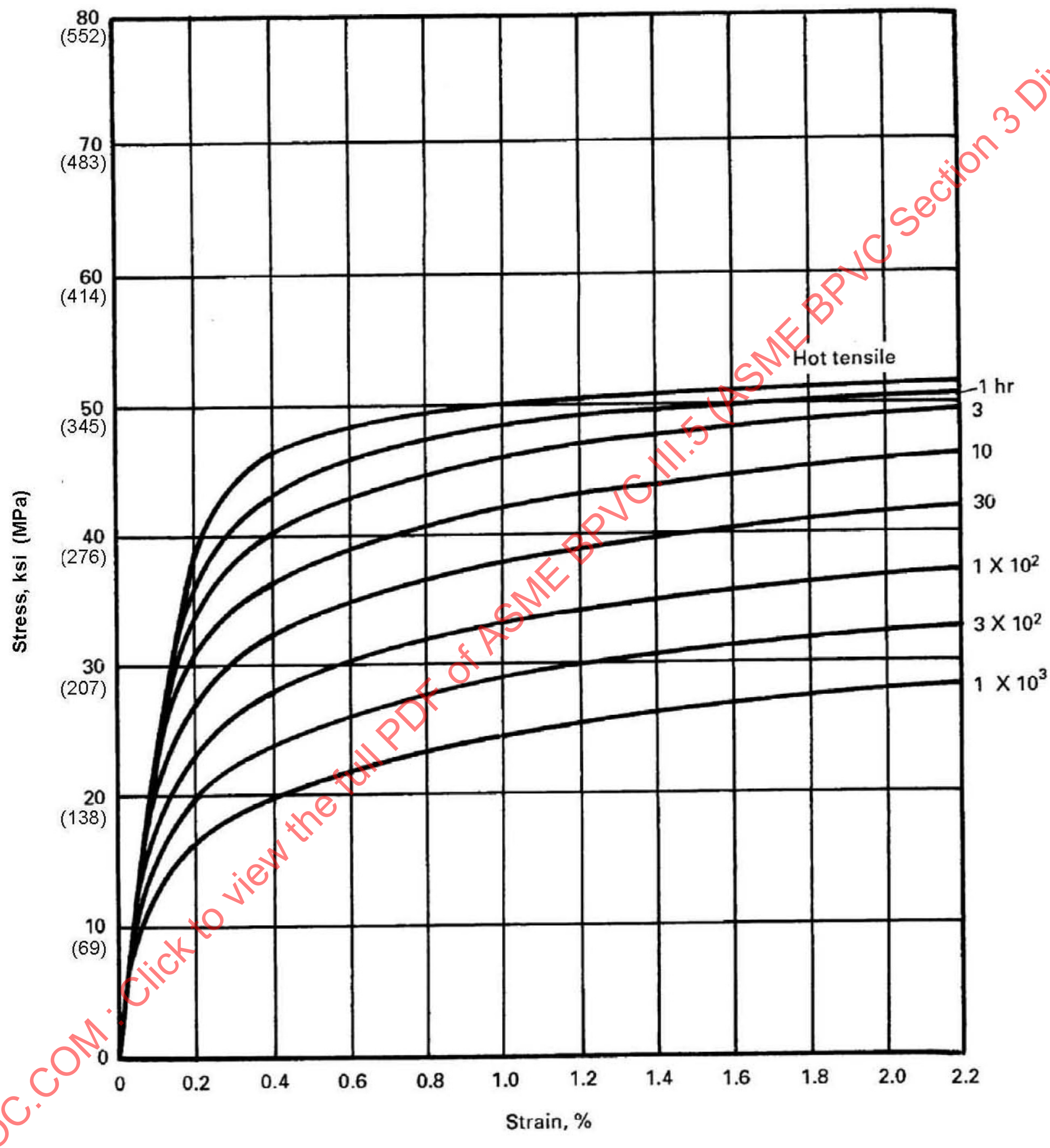
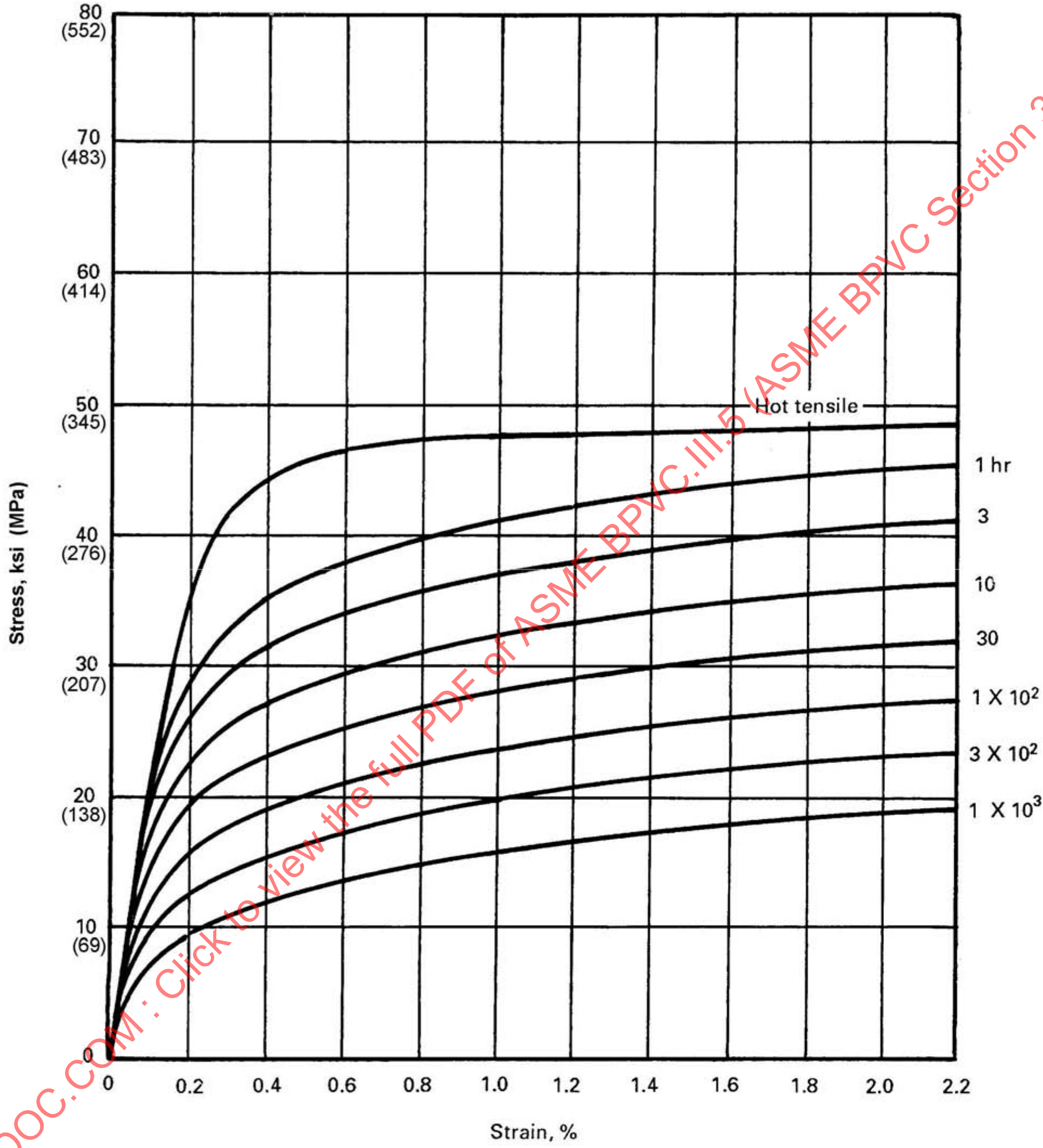


Figure HBB-II-3000-10
Isochronous Stress–Strain Curves for 1,000°F (538°C) for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1



(23)

Figure HBB-II-3000-11
Design Fatigue Strain Range for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

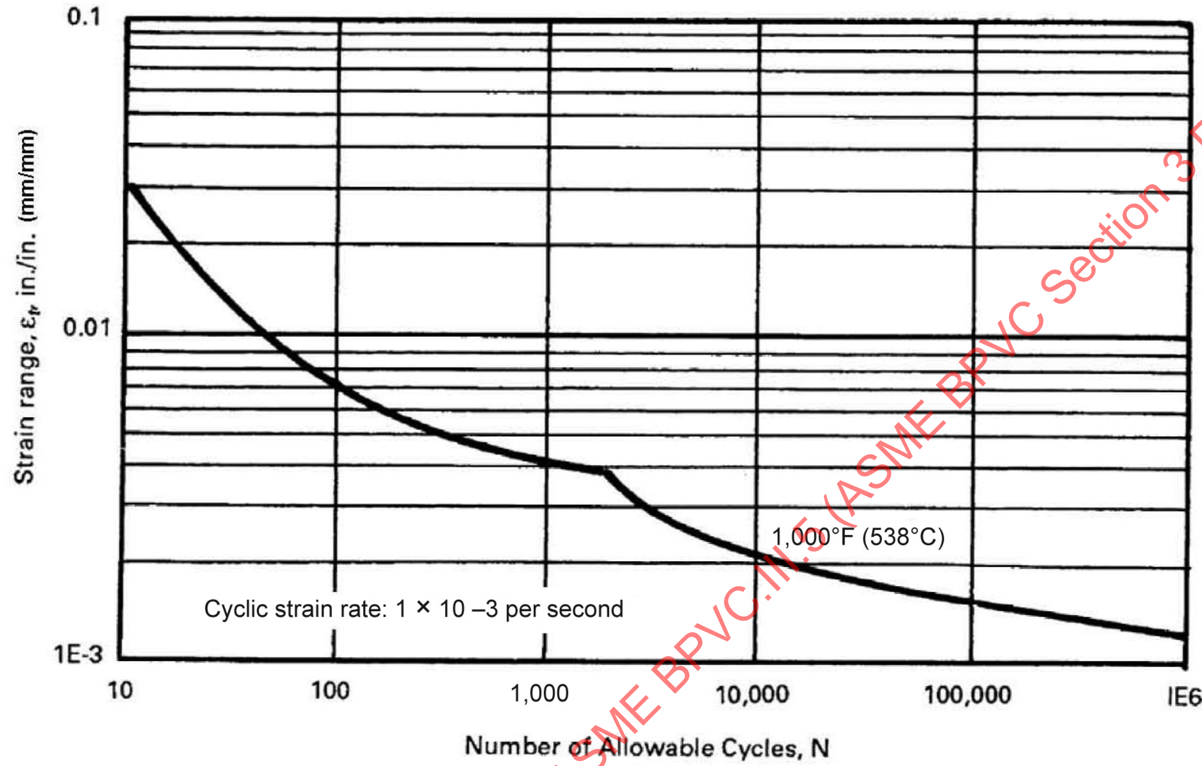
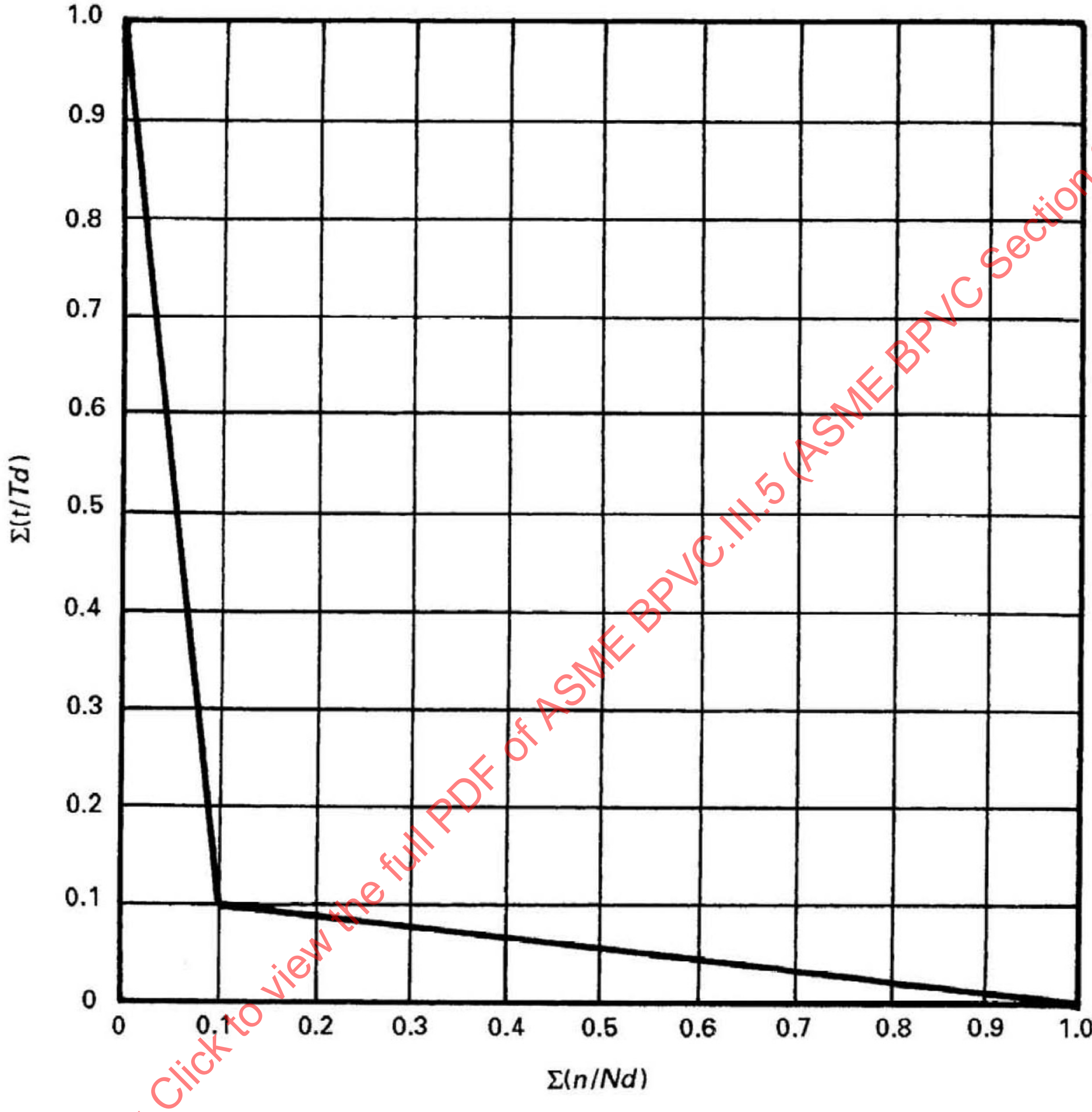
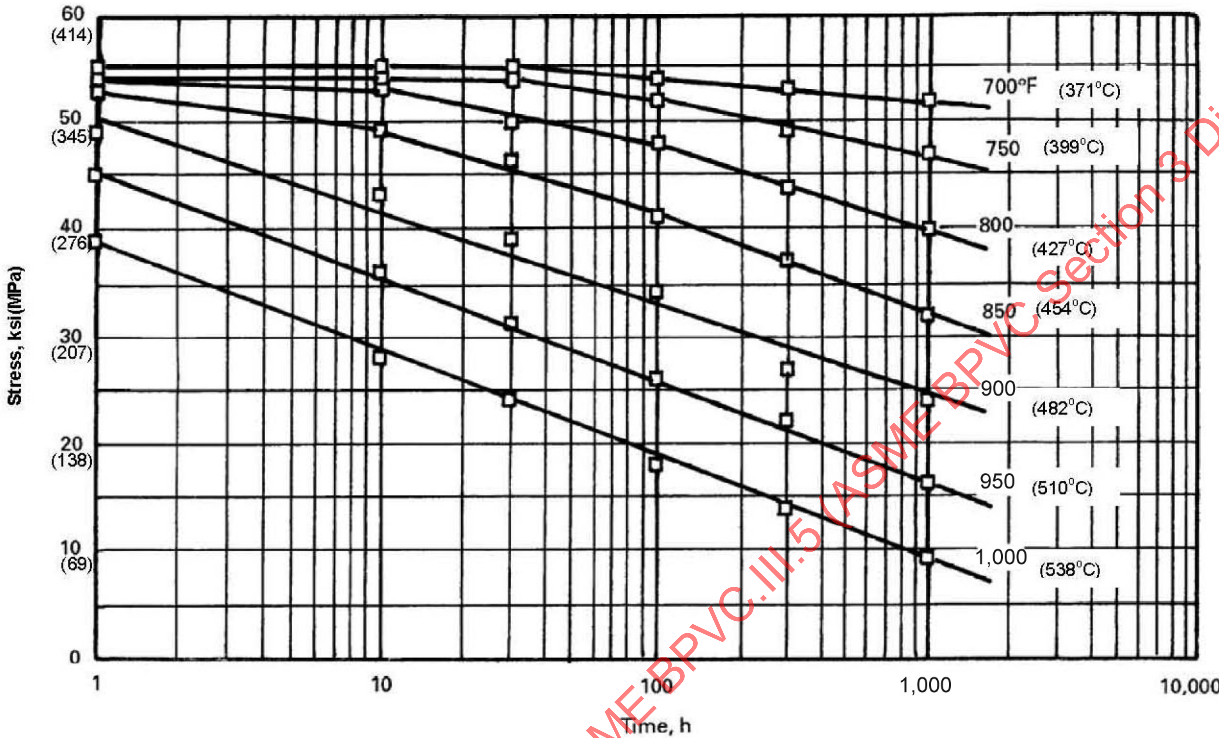


Figure HBB-II-3000-12
Creep–Fatigue Damage Envelope for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1



(23)

Figure HBB-II-3000-13
S_t Versus Time-Isothermal Curves for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1



(23)

Figure HBB-II-3000-14
Minimum Stress Rupture as a Function of Time and Temperature for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

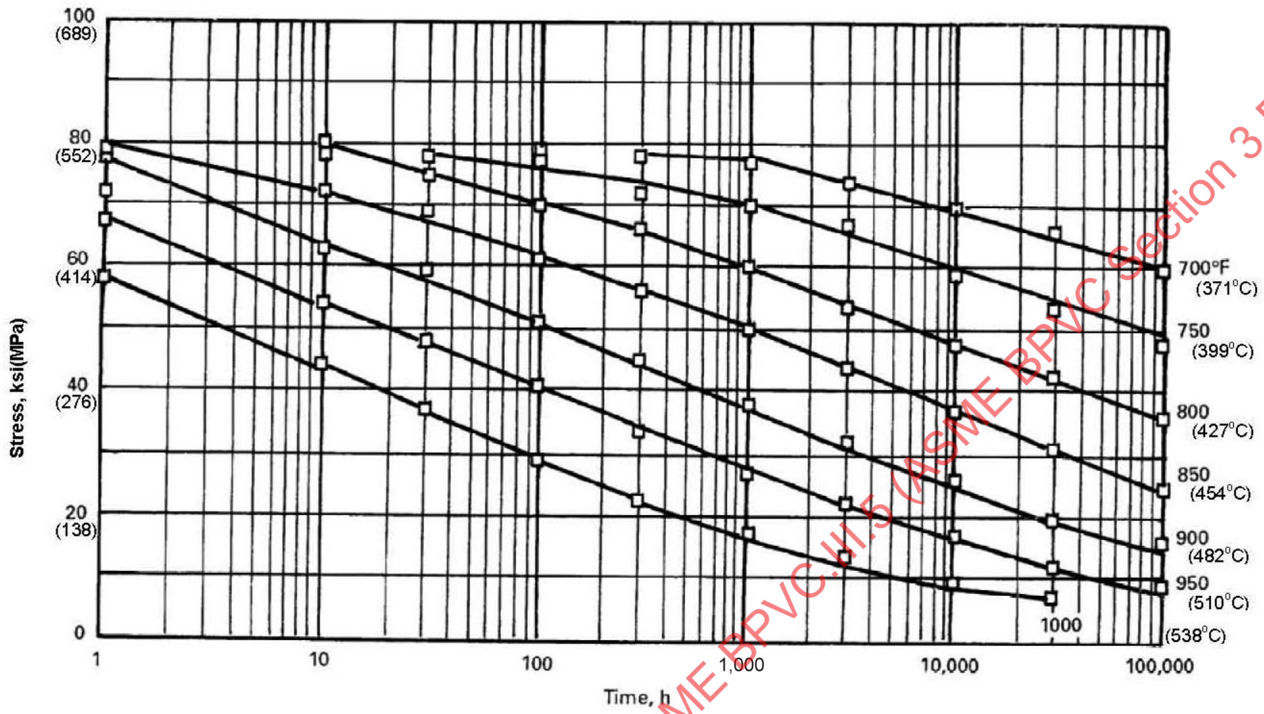


Table HBB-II-3000-1
S_{mt} — Allowable Stress Intensity Values for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1, ksi (MPa)

Temperature, °F (°C)	Time at Temperature, hr 1	10	30	100	300	1,000	3,000
700 (371)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)
750 (399)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)
800 (427)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)	26.7 (184)
850 (454)	25.5 (176)	25.5 (176)	25.5 (176)	25.5 (176)	25.5 (176)	25.5 (176)	...
900 (482)	24.3 (168)	24.3 (168)	24.3 (168)	24.3 (168)	24.3 (168)	24.0 (165)	...
950 (510)	22.5 (155)	22.5 (155)	22.5 (155)	22.5 (155)	22.0 (152)	16.0 (110)	...
1,000 (538)	20.7 (143)	20.7 (143)	20.7 (143)	18.0 (124)	14.0 (97)	9.5 (66)	...

GENERAL NOTE: The S_{mt} values are the lower of the two stress intensity values, S_m (time independent) and S_t (time dependent).

Table HBB-II-3000-2
S_t — Allowable Stress Intensity Values for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1, ksi (MPa)

Temperature, °F (°C)	Time at Temperature, hr						
	1	10	30	100	300	1,000	3,000
700 (371)	54 (372)	54 (372)	54 (372)	53 (365)	53 (365)	52 (358)	49 (338)
750 (399)	54 (372)	54 (372)	54 (372)	52 (358)	49 (338)	47 (324)	45 (310)
800 (427)	54 (372)	53 (365)	50 (345)	48 (331)	44 (303)	40 (276)	36 (248)
850 (454)	53 (365)	49 (338)	46 (317)	41 (283)	37 (255)	32 (221)	...
900 (482)	49 (338)	43 (296)	39 (269)	34 (234)	29 (200)	24 (165	...
950 (510)	45 (310)	36 (248)	31 (214)	26 (179)	22 (152)	16 (110)	...
1,000 (538)	39 (269)	28 (193)	24 (165)	18 (124)	14 (97)	9.5 (66)	...

Table HBB-II-3000-3
Allowable Stress Intensity Values for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1, S_m Yield Strength and Tensile Strength Versus Temperature

Temperature, °F (°C)	S_m, ksi (MPa)
700 (371)	26.7 (184)
750 (399)	26.7 (184)
800 (427)	26.7 (184)
850 (454)	25.5 (176)
900 (482)	24.3 (168)
950 (510)	22.5 (155)
1,000 (538)	20.7 (143)

GENERAL NOTES:

(a) For yield strength, ksi (MPa), see Section II, Part D, Subpart 1, Table Y-1.

(b) For tensile strength, ksi (MPa), see Section II, Part D, Subpart 1, Table U.

Table HBB-II-3000-4
Expected Minimum Stress-to-Rupture Values for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1, ksi (MPa)

Temperature, °F (°C)	Time to Rupture, hr									
	1	10	30	100	300	1,000	3,000	10,000	30,000	100,000
700 (371)	80 (552)	80 (552)	80 (552)	79 (545)	78 (538)	77 (531)	74 (510)	70 (482)	66 (455)	60 (414)
750 (399)	80 (552)	80 (552)	78 (538)	77 (531)	72 (496)	70 (482)	67 (462)	59 (407)	54 (372)	48 (331)
800 (427)	79 (545)	78 (538)	75 (517)	70 (482)	66 (455)	60 (414)	54 (372)	48 (331)	43 (296)	36 (248)
850 (454)	78 (538)	72 (496)	69 (476)	61 (421)	56 (386)	50 (345)	44 (303)	37 (255)	31 (214)	23 (159)
900 (482)	72 (496)	63 (434)	59 (407)	51 (352)	45 (310)	38 (262)	32 (221)	26 (179)	20 (138)	16 (110)
950 (510)	67 (462)	54 (372)	48 (331)	41 (283)	34 (234)	27 (186)	22 (152)	17 (117)	12 (83)	9 (62)
1,000 (538)	58 (400)	44 (303)	37 (255)	29 (200)	23 (159)	18 (124)	14 (97)	9.5 (66)	7 (48)	4.5 (31)

Table HBB-II-3000-5
Modulus of Elasticity Versus Temperature for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

SA-533 Type B, Class 1 (See Section II, Part D, Subpart 2, Table TM-1, Group A)
SA-508 Grade 3, Class 1 (See Section II, Part D, Subpart 2, Table TM-1, Group B)

Table HBB-II-3000-6
Instantaneous Coefficient of Thermal Expansion Versus Temperature for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

Instantaneous Coefficient of Thermal Expansion	
SA-533 Type B, Class 1 (Mn–½Mo–½Ni) (See Section II, Part D, Subpart 2, Table TE-1, Group 2, Column A)	SA-508 Grade 3, Class 1 (¾Ni–½Mo–Cr–V) (See Section II, Part D, Subpart 2, Table TE-1, Group 1, Column A)

Table HBB-II-3000-7
Mean Coefficient of Thermal Expansion Versus Temperature for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1

Mean Coefficient of Thermal Expansion	
SA-533 Type B, Class 1 (Mn–½Mo–½Ni) (See Section II, Part D, Subpart 2, Table TE-1, Group 2, Column B)	SA-508 Grade 3, Class 1 (¾Ni–½Mo–Cr–V) (See Section II, Part D, Subpart 2, Table TE-1, Group 1, Column B)

GENERAL NOTE: The mean coefficient of thermal expansion at temperature, T, is given by

$$\frac{\text{Length at } T - \text{Length at } 70^\circ\text{F } (20^\circ\text{C})}{\text{Length at } 70^\circ\text{F } (20^\circ\text{C}) \times [T - 70^\circ\text{F } (20^\circ\text{C})]}$$

Table HBB-II-3000-8
Design Fatigue Strain Range for SA-533 Type B, Class 1 and SA-508 Grade 3, Class 1 Up to 1,000°F (540°C)

Number of Cycles, N_D [Note (1)]	Strain Range, E_t, in./in. (mm/mm), at Temperature
10^1	0.030
4×10^1	0.011
10^2	0.0071
2×10^2	0.0056
4×10^2	0.0048
10^3	0.0042
2×10^3	0.0037
4×10^3	0.0027
10^4	0.0021
2×10^4	0.00190
4×10^4	0.00170
10^5	0.00155
2×10^5	0.00145
4×10^5	0.00130
10^6	0.00120

NOTE:
(1) Cycle strain rate: 1×10^{-3}/sec.

ARTICLE HBB-II-4000
FABRICATION AND INSTALLATION

The rules of Article HBB-4000 shall apply.

ARTICLE HBB-II-5000
EXAMINATION

The rules of Article HBB-5000 shall apply.

ARTICLE HBB-II-6000
TESTING

The rules of Article HBB-6000 shall apply.

ARTICLE HBB-II-7000
OVERPRESSURE PROTECTION

The rules of Article HBB-7000 shall apply.

NONMANDATORY APPENDIX HBB-T
RULES FOR STRAIN, DEFORMATION, AND FATIGUE LIMITS AT ELEVATED TEMPERATURES

HBB-T-1100 INTRODUCTION

HBB-T-1110 OBJECTIVE

The objective of this Appendix is to provide rules that may be used by Owners and N Certificate Holders with respect to evaluation by analysis of strain, deformation, and fatigue limits for components whose load-controlled stresses are evaluated by the rules of Subsection HB, Subpart B.

HBB-T-1120 GENERAL REQUIREMENTS

HBB-T-1121 Type of Analysis

Where creep effects are presumed significant, inelastic analysis is generally required to provide a quantitative assessment of deformations and strains. However, elastic and simplified inelastic methods of analysis may sometimes be justified and used to establish conservative bounds for deformations, strains, strain ranges, and maximum stress in order to reduce the number of locations in a structure requiring detailed inelastic analysis.

HBB-T-1122 Analysis Required

The rules for design against gross distortion and fatigue are illustrated in Figure HBB-3221-1. The Design Loadings and Level D Service Loadings are exempted from strain and deformation limits as summarized below.

Loadings	Requirement
Design	No deformation analysis required.
Service Levels A, B, and C	Apply the strain and deformation limits of Nonmandatory Appendix HBB-T. Regions not expecting any service time under elevated temperatures may use the secondary stress and fatigue limits of Section III Appendices, Mandatory Appendix XIII, XIII-3400, and XIII-3500 in place of the rules in HBB-T-1300, HBB-T-1400, and HBB-T-1700.
Service Level D	Strain and deformation limits not applicable except as necessary to satisfy Level D Service Loadings functional requirements.
Test	Consider as additional Level B Service Loadings.

HBB-T-1200 DEFORMATION LIMITS FOR FUNCTIONAL REQUIREMENTS

HBB-T-1210 STATEMENT IN DESIGN SPECIFICATION

Deformation limits to ensure proper component functioning shall be specified in the Design Specification (NCA-3211.19) for the component or shall be established by the N Certificate Holder for the proper performance of the component. Any such limits may restrict the design more severely than those specified for load-controlled stresses in HBB-3220.

HBB-T-1220 ELASTIC ANALYSIS METHOD

The limitations on loads from the rules and the other limits contained in HBB-3200 are intended to restrict the accumulated inelastic strain (averaged across a wall thickness) to 1% or less. However, when elastic analysis is used, the occurrence of inelastic strains of this magnitude may not be apparent. If functional deformation requirements are specified, the designer shall ensure that they are not violated by assuming that strains of 1% occur within the structure in that distribution which leads to the worst possible deformation state consistent with the directions of loading. If this deformation state does not lead to deformations greater than the specified limits, then all functional requirements shall be considered as demonstrated for the design.

HBB-T-1230 USE OF INELASTIC ANALYSIS

Inelastic analysis of deformations shall be used to demonstrate that deformations do not exceed specified limits, unless the elastic method of HBB-T-1220 has demonstrated compliance.

HBB-T-1300 DEFORMATION AND STRAIN LIMITS FOR STRUCTURAL INTEGRITY

HBB-T-1310 LIMITS FOR INELASTIC STRAINS

In regions expecting elevated temperatures, the maximum accumulated inelastic strain shall not exceed the following values.

(a) strains averaged through the thickness, 1%;

(b) strains at the surface, due to an equivalent linear distribution of strain through the thickness, 2%;

(c) local strains at any point, 5%.

The above limits apply to computed strains accumulated over the expected operating lifetime of the element under consideration, and computed for some steady-state period at the end of this time during which significant transients are not occurring. These limits apply to the maximum positive value of the three principal strains. A positive strain is defined as one for which the length of the element in the direction of the strain is increased. The principal strains are computed for the strain components (ϵ_x, ϵ_y, ϵ_z, ϵ_{xy}, ϵ_{xz}, ϵ_{yz}). When the strain is computed at several locations through the thickness, the strains are first averaged and linearized on a component level and then combined to determine the principal strains for comparison to the limits on average and surface strains defined above. The limits for local strains are based on the computed strains at the point of interest.

HBB-T-1320 SATISFACTION OF STRAIN LIMITS USING ELASTIC ANALYSIS

HBB-T-1321 General Requirements

The strain limits of HBB-T-1310 are considered to have been satisfied if the limits of any one of HBB-T-1322, HBB-T-1323, or HBB-T-1324 are satisfied. The guidelines of (a) through (d) below should be used in establishing the appropriate cycle to be evaluated in HBB-T-1322 and HBB-T-1323.

(a) An individual cycle, as defined in the Design Specification, cannot be split into subcycles to satisfy these requirements.

(b) At least one cycle must be defined that includes the maximum secondary stress intensity range, Q_R, and the maximum value of $(P_L + P_b/K_t)$, which occur during *all* Level A, B, and C Service Loadings. The value of K_t may be determined using HBB-3223, eq. (c)(6).

(c) Any number of cycles can be grouped together and evaluated according to the conditions of HBB-T-1322 or HBB-T-1323, whichever is applicable.

(d) The following definitions apply to HBB-T-1322 and HBB-T-1323:

$$X \equiv \left(P_L + \frac{P_b}{K_t}\right)\max \div S_y$$

where

$(P_L + P_b/K_t)_{\max}$ = the maximum value of the primary stress intensity, adjusted for bending via K_t, during the cycle being evaluated

S_y = the average of the S_y values at the maximum and minimum wall averaged temperatures during the cycle being evaluated

$$Y \equiv \frac{(Q_R)_{\max}}{S_y}$$

where

$(Q_R)_{\max}$ = the maximum range of the secondary stress intensity during the cycle being considered

S_y = the average of the S_y values at the maximum and minimum wall averaged temperatures during the cycle

HBB-T-1322 Test No. A-1

For Test Number A-1:

$$X + Y \leq S_a / S_y \tag{1}$$

where S_a is the lesser of:

(a) $1.25S_t$ using the highest wall averaged temperature during the cycle and a time value of 10^4 hr, and

(b) the average of the two S_y values associated with the maximum and minimum wall averaged temperatures during the cycle

HBB-T-1323 Test No. A-2

For Test Number A-2:

$$X + Y \leq 1 \tag{2}$$

for those cycles during which the average wall temperature at one of the stress extremes defining the maximum secondary stress range $(Q_R)_{\max}$ is below the applicable temperature of Table HBB-T-1323.

HBB-T-1324 Test No. A-3

For Test Number A-3, the limits of Section III Appendices, Mandatory Appendix XIII, XIII-3410, XIII-3420, and XIII-3430 shall be met and, in addition, the requirements of (a) through (c) below shall be satisfied.

(a)

$$\sum_i \frac{t_i}{rt_{id}} \leq 0.1$$

where

t_i = total duration of time during the service lifetime that the metal is at temperature, T_i. Note that the service lifetime shall never be greater than the sum of all t_i.

t_{id} = maximum allowable time as determined by entering Figures HBB-I-14.6A through HBB-I-14.6F at temperature T_i and a stress value of s times the S_y associated with T_i, denoted as $s(S_y|T_i)$. The values of s and the effective rupture time parameter, r, are given in Table HBB-T-1324. If $s(S_y|T_i)$ is above the stress values provided in Figures HBB-I-14.6A through HBB-I-14.6F, this test cannot be satisfied. When $s(S_y|T_i)$ is below the lowest stress value provided in Figures HBB-I-14.6A through HBB-I-14.6F, the constant temperature line may be extrapolated to larger t_{id} values using the steepest slope on Figures HBB-I-14.6A through HBB-I-14.6F for that material.

(b) See below.

$$\sum_i \epsilon_i \leq 0.2\%$$

where ϵ_i is the creep strain that would be expected from a stress level of $1.25S_y|T_i$ applied for the total duration of time during the service lifetime that the metal is at T_i. When the design lifetime is separated into several time periods, then the service lifetime shall not be greater than the sum of all the time periods. That is:

$$\sum_i t_i \Big| T_i \geq \text{service lifetime}$$

Table HBB-T-1323
Temperatures at Which $S_m = S_t$ at 10^5 hr

Material	Temp., °F (°C)
Type 304 SS	948 (509)
Type 316 SS	1,011 (544)
Alloy 800H	1,064 (573)
2¹⁄₄Cr-1Mo	801 (427)
9Cr-1Mo-V	940 (504)

Table HBB-T-1324
Values of the *r* and *s* Parameters

Material	*r*	*s*
Type 304 SS	1.0	1.5
Type 316 SS	1.0	1.5
Alloy 800H	1.0	1.5
$2^1/_4$Cr-1Mo	1.0	1.5
9Cr-1Mo-V	0.1	1.0

(c) For the $3S_m$ limit in Section III Appendices, Mandatory Appendix XIII, XIII-3410, and XIII-3420, use the lesser of $3S_m$ and $3\bar{S}_m$, where

$3\bar{S}_m$ = $(1.5S_m + S_{rH})$ when only one extreme of the stress difference (that produces the maximum range of the primary plus secondary stress intensity, $P + Q$) occurs at a temperature above those covered by Division 1, Subsection NB rules; $(S_{rH} + S_{rL})$ when both extremes of the stress differences (that define the maximum range of $P + Q$) occur at temperatures above those covered by Division 1, Subsection NB rules;

S_{rH}, S_{rL} = relaxation strengths associated with the temperatures at the *hot* and *cold* extremes of the stress cycle. The *hot* temperature condition is defined as the maximum operating temperature of the stress cycle. The *hot* time is equal to the portion of service life when wall averaged temperatures exceed 800°F (425°C) [700°F (370°C) for $2^1/_4$Cr-1Mo and 9Cr-1Mo-V]. The *cold* temperature is defined as the colder of the two temperatures corresponding to the two stress extremes in the stress cycle. The *cold* time is again equal to the portion of service life when wall averaged temperatures exceed 800°F (425°C) [700°F (370°C) for $2^1/_4$Cr-1Mo and 9Cr-1Mo-V].

In this criterion, total service life may *not* be further subdivided into temperature-time blocks. The two relaxation strengths, S_{rH} and S_{rL}, may be determined by performing a pure uniaxial relaxation analysis starting with an initial stress of 1.5 S_m and holding the initial strain throughout the time interval equal to the time of service above 800°F (425°C) [700°F (370°C) for $2^1/_4$Cr-1Mo and 9Cr-1Mo-V].

HBB-T-1325 Special Requirements for Piping Components

(a) Piping evaluations using the provisions of HBB-3651(b) to satisfy the limits of HBB-T-1322, HBB-T-1323, or HBB-T-1330 shall include the stress term:

$$\frac{E\,\alpha\,\left|\Delta T_1\right|}{2(1-\nu)}$$

when computing the secondary stress intensity range, Q_R. The definitions of E, α, ΔT_1, and ν are as given in Division 1, NB-3650.

(b) For purposes of applying the limits of HBB-T-1324 to piping components, satisfaction of the Division 1, NB-3650 requirements may be used in lieu of meeting Section III Appendices, Mandatory Appendix XIII, XIII-3410, XIII-3420, and XIII-3430, provided that S_m is replaced by $\bar{S}_m$ and the ratchet check of Division 1, NB-3653.7 is satisfied whenever:

$$S_n > 3\bar{S}_m - \frac{E\,\alpha\,\left|\Delta T_1\right|}{2(1-\nu)}$$

S_n, E, α, ΔT, and ν are defined in Division 1, NB-3650, and $\bar{S}_m$ is the lesser of S_m or $\left(3\bar{S}_m\right) \div 3$, with $3\bar{S}_m$ as defined in HBB-T-1324(c).

HBB-T-1330 SATISFACTION OF STRAIN LIMITS USING SIMPLIFIED INELASTIC ANALYSIS

HBB-T-1331 General Requirements

The strain limits of HBB-T-1310 are considered to have been satisfied if the limits of HBB-T-1332 are satisfied in addition to (a) through (g) below.

(a) HBB-T-1332 contains two tests, B-1 and B-2. Test B-1 shall only be used for structures in which the peak stress is negligible. Test B-2, which is more conservative, is applicable to any structure and loading.

(b) The individual cycle as defined in the Design Specification cannot be split into subcycles. Unless otherwise specified (see HBB-3114), earthquakes and other transient conditions should be uniformly distributed over the lifetime of the plant for this strain evaluation.

(c) As an alternate to the use of HBB-T-1332, the inelastic strains due to any number of selected operational cycles may be evaluated separately using detailed inelastic analysis. The resulting sum of the inelastic strains must satisfy the limits of HBB-T-1310.

(d) Secondary stresses with elastic followup (i.e., pressure-induced membrane and bending stresses and thermal induced membrane stresses) are classified as primary stresses for purposes of this evaluation. Alternatively, the strains due to such stresses may be calculated separately and added to the strains from HBB-T-1332, the sum being limited to the values of HBB-T-1310.

(e) The time used in HBB-T-1332 to enter the isochronous curves for individual cycles or timeblocks shall always sum to the entire life regardless of whether all or only part of the cycles are evaluated under these procedures.

(f) For HBB-T-1332, the definitions of X and Y in HBB-T-1321(d) apply except that the S_y value is replaced by the S_{yL} value that corresponds to the lower of the wall averaged temperatures for the stress extremes defining the secondary stress range, Q_R. The S_{yH} value corresponds to the higher of the wall averaged temperatures for the stress extremes defining the secondary stress range. The above defined extremes denoted by subscripts L and H are also referred to later as the cold and hot ends respectively.

(g) When applying the procedures of HBB-T-1332 (Test No. B-1), wall membrane forces from overall bending of a pipe section or vessel can be conservatively included as axisymmetrical forces.

HBB-T-1332 Test Nos. B-1 and B-2

(a) These tests can be used to satisfy the strain limits provided that the average wall temperature at one of the stress extremes defining each secondary stress intensity range Q_R is below the applicable temperature of Table HBB-T-1323. The limits of this paragraph restrict the amount of inelastic creep strain that can be accumulated over the service life of the component including Level A, B, and C Service Loadings so that the strain limits of HBB-T-1310 are not exceeded. In this paragraph, the elastically calculated primary and secondary stress intensities are used to determine an effective creep stress $\sigma_c = Z \cdot S_{yL}$, which in turn is used to determine a total ratcheting creep strain. The dimensionless effective creep stress parameter Z for any combination of loading is given in Figure HBB-T-1332-1 for Test No. B-1 and in Figure HBB-T-1332-2 for Test No. B-2.

(b) The creep ratcheting strain is determined by multiplying σ_c by 1.25 and evaluating the creep strain associated with the $1.25\sigma_c$ stress held constant throughout the temperature-time history of the entire service life. The isochronous stress-strain curves of HBB-T-1800 shall be used to obtain the creep ratcheting strain. The total service life may be subdivided into temperature-time blocks. The value of σ_c may differ from one block to another, but remains constant throughout each block service time. When σ_c is reduced at the end of a block of loading, the time of the block of loading must be longer or equal to the time needed for σ_c to relax at constant total strain to the σ_c value for the subsequent block. The creep strain increment for each block may be evaluated separately. The times used in selecting the isochronous curves shall sum to the total service life. For each block, the isochronous curves can be entered at the initial strain accumulated throughout the prior load history. The creep strain increments for each time-temperature block shall be added to obtain the total ratcheting creep strain. The resulting value shall be limited to 1% for parent metal and $\frac{1}{2}$% for weld metal.

(c) The dimensionless expressions for the effective creep stress parameter is $Z = \sigma_c / S_{yL}$ in regimes S_1, S_2, and P of Figure HBB-T-1332-1, and:

$$Z = X \cdot Y \tag{3}$$

in regimes S_2 and P, and:

$$Z = Y + 1 - 2\sqrt{(1 - X)Y} \tag{4}$$

in regime S_1. In regime E, $Z = X$. The equations defining the boundaries of the regimes P, S_1, and S_2 are shown in Figure HBB-T-1332-1. Test No. B-1 can only be applied when σ_c is less than the yield stress of S_{yH} (see regimes E, S_1, S_2, and P).

(d) For Test No. B-2, the effective creep stress σ_c shall be obtained from Figure HBB-T-1332-2.

Figure HBB-T-1332-1
Effective Creep Stress Parameter Z for Simplified Inelastic Analysis Using Test No. B-1
[for use only when the restrictions of HBB-T-1331(a) for Test No. B-1 are met]

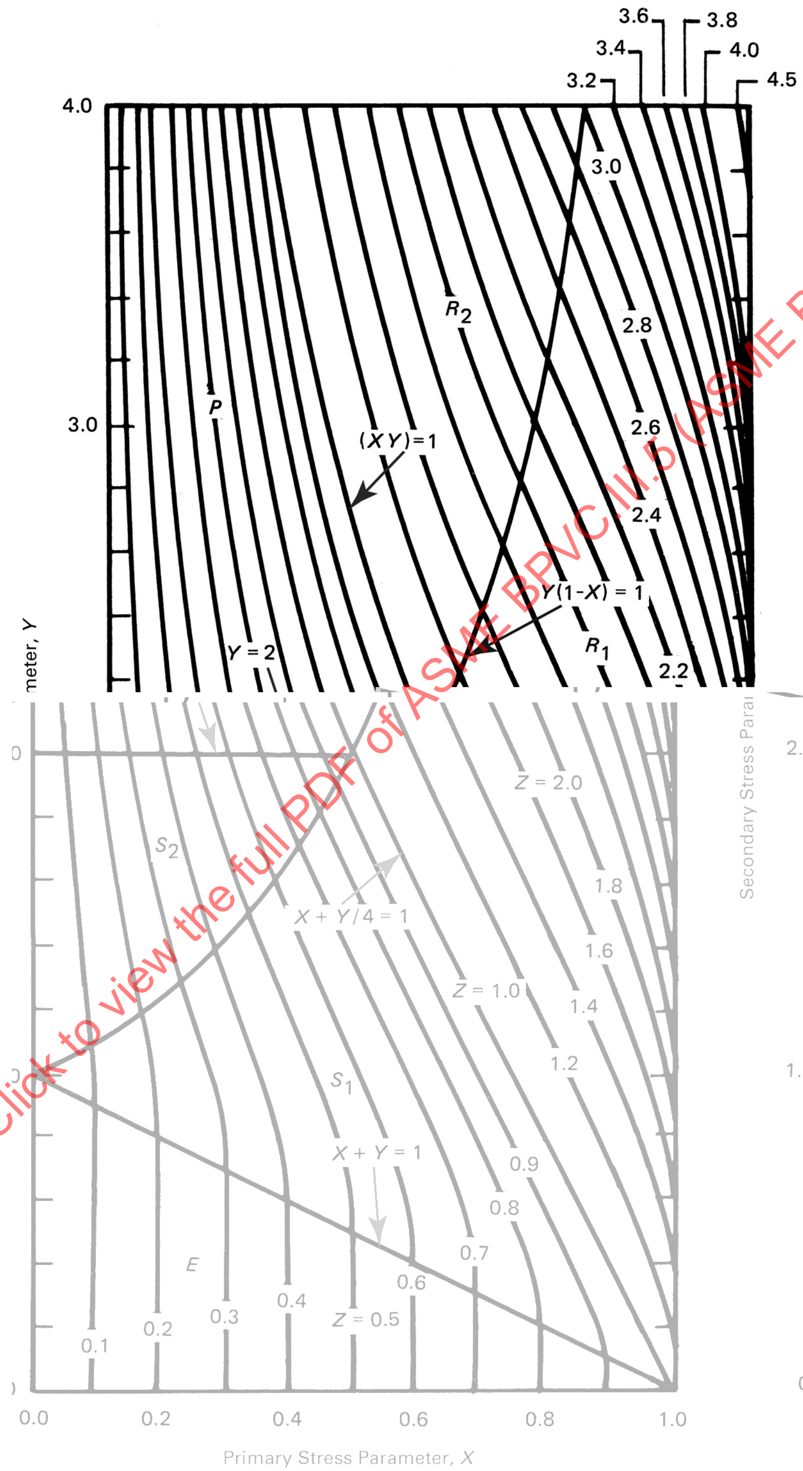
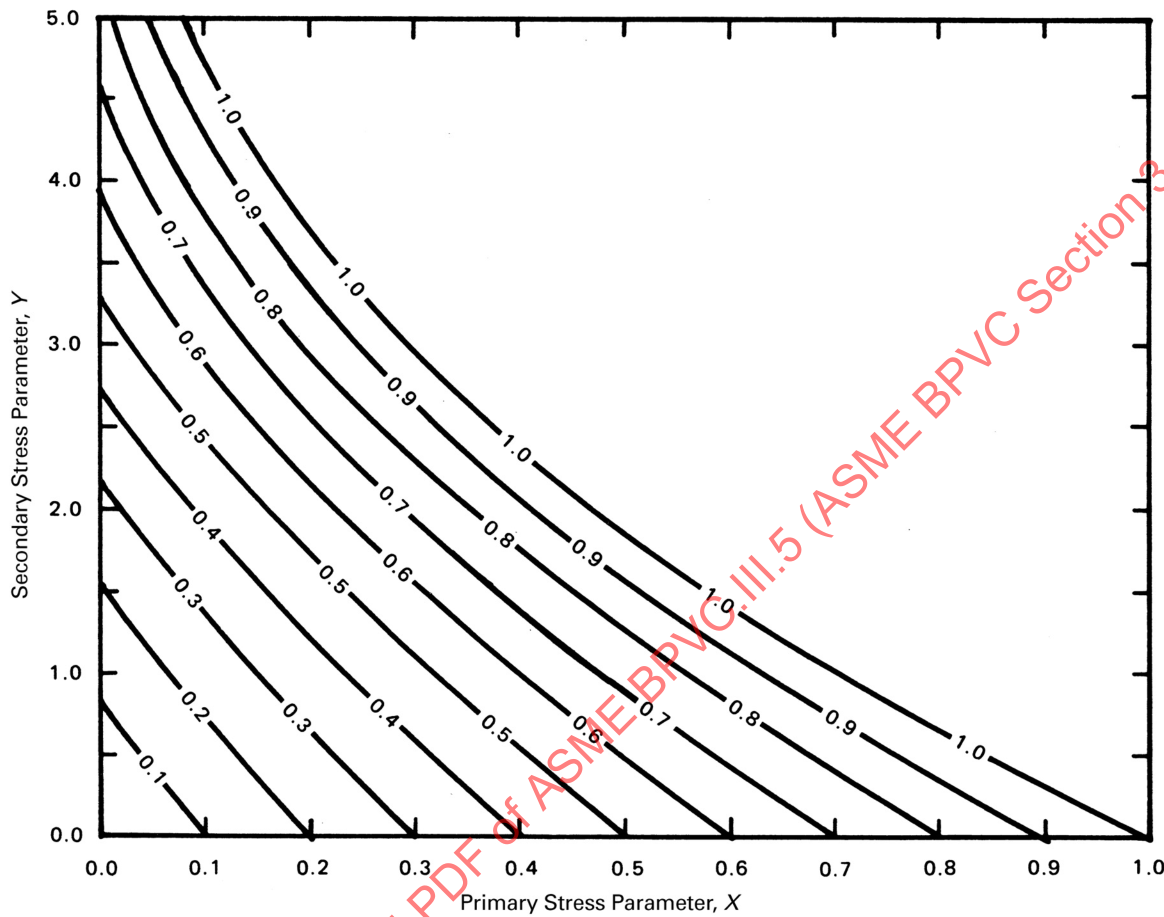


Figure HBB-T-1332-2
Effective Creep Stress Parameter Z for Simplified Inelastic Analysis Using Test No. B-2



GENERAL NOTE: Applicable to general structures.

HBB-T-1400 CREEP–FATIGUE EVALUATION

HBB-T-1410 GENERAL REQUIREMENTS (23)

HBB-T-1411 Damage Equation

The combination of Level A, B, and C Service Loadings shall be evaluated for accumulated creep and fatigue damage, including hold time and strain rate effects. For a design to be acceptable, the creep and fatigue damage shall satisfy the following relation:

$$\sum_{j=1}^{p}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_k \leq D \tag{10}$$

where

D = total creep–fatigue damage

$(N_d)_j$ = number of design allowable cycles for cycle type, j, determined from one of the design fatigue curves (Figures HBB-T-1420-1A through HBB-T-1420-1E) corresponding to the maximum metal temperature occurring during the cycle. The design fatigue curves were determined from completely reversed loading conditions at strain rates greater than, or equal to, those noted on the curves.

$(T_d)_k$ = allowable time duration determined from Figures HBB-I-14.6A through HBB-I-14.6F (stress-to-rupture curves) for a given stress and the maximum temperature at the point of interest and occurring during the time interval, k. For elastic analysis, the appropriate stress measure is defined in HBB-T-1433. For inelastic analysis, the following equivalent stress quantity should be used:

$$\sigma_e = \bar{\sigma} \exp\left[C\left(\frac{J_1}{S_s} - 1\right)\right]$$

where

$J_1 = \sigma_1 + \sigma_2 + \sigma_3$
$S_s = [\sigma_1{}^2 + \sigma_2{}^2 + \sigma_3{}^2]^{1/2}$

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[\begin{array}{l}\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 \\ + \left(\sigma_3 - \sigma_1\right)^2\end{array}\right]^{1/2}$$

and σ_i (i = 1, 2, or 3) are the principal stresses. The constant C is defined as follows:

(a) For Types 304 and 316 stainless steels, C = 0.24.

(b) For Alloy 800H, C = 0.

(c) For $2^1/_4$Cr-1Mo and 9Cr-1Mo-V:

(1) If $J_1/S_s \geq 1.0$, C = 0.16;

(2) If $J_1/S_s < 1.0$, C = 0.

For both elastic and inelastic analyses, the allowable time duration is determined by entering Figures HBB-I-14.6A through HBB-I-14.6F at that stress value determined by dividing the maximum stress (at the point of interest during the time interval, k) by the factor, K' (Table HBB-T-1411-1).

$(n)_j$ = number of applied cycles of cycle type, j

q = number of time intervals (each with a unique stress-temperature combination) needed to represent the specified elevated temperature service life at the point of interest for the creep damage calculation

p = number of stress/temperature time histories

$(\Delta t)_k$ = duration of the time interval, k

Note that the sum of the "q" time intervals must equal or exceed the total specified elevated temperature service life.

HBB-T-1412 Exemption From Fatigue Analysis

The rules in Section III Appendices, Mandatory Appendix XIII, XIII-3510 that permit exemption from fatigue analysis do not apply to temperatures above the limits of Division 1, Subsection NB, except where the service loadings have been qualified as not introducing significant time-dependent effects under the procedure of HBB-3211(c).

HBB-T-1413 Equivalent Strain Range

An equivalent strain range is used to evaluate the fatigue damage sum for both elastic and inelastic analysis. Conceptual guidance on methods of combining cycles for a cyclic loading histogram is provided in Section III Appendices, Mandatory Appendix XIII, XIII-3520(e).The cycle counting procedures are described in ASTM E1049 using the original

Table HBB-T-1411-1

Material	K' Elastic Analysis	K' Inelastic Analysis
Austenitic Stainless Steel	0.9	0.67
Ni-Fe-Cr (Alloy 800H)	0.9	0.67
$2^1/_4$Cr-1Mo	0.9	0.67
9Cr-1Mo-V	1.0	0.67

rainflow cycle counting approach and in API 579-1/ASME FFS-1, using the Wang-Brown cycle counting approach. If other cycle counting methods are used, technical justification shall be provided in the Design Report. When these methods are used, the equivalent strain range for cycle counting and fatigue damage sum shall be computed as follows:

Step 1. Calculate all strain components for each point, i, in time $(\epsilon_{xi}, \epsilon_{yi}, \epsilon_{zi}, \gamma_{xyi}, \gamma_{yzi}, \gamma_{zxi})$ for the complete cycle. When conducting inelastic analysis, the stress and strain concentration effects of local geometric discontinuities are included in this step. When conducting elastic analysis, peak strains arising from geometric discontinuities are not included, since these effects are added in the procedures of HBB-T-1432.

Step 2. Select a point when conditions are at an extreme for the cycle, either maximum or minimum. Refer to this time point by a subscript o. If the extremes for the cycle cannot be identified, then calculate the equivalent strain range for each point, i, in time per Steps 3 and 4. Identify the time point with maximum equivalent strain range as the new reference point, o. If there are multiple points with the same maximum equivalent strain range, choose the time point with the maximum effective strain (von Mises) as the new reference point, o.

Step 3. Calculate the history of the change in strain components by subtracting the values at the time, o, from the corresponding components at each point in time, i, during the cycle.

$$\Delta\epsilon_{xi} = \epsilon_{xi} - \epsilon_{xo}$$
$$\Delta\epsilon_{yi} = \epsilon_{yi} - \epsilon_{yo}$$
$$\text{etc;}$$

Step 4. Calculate the equivalent strain range for each point in time as:

$$\Delta\epsilon_{\text{equiv.}i} = \frac{\sqrt{2}}{2\left(1 + \nu^*\right)}\left[\begin{array}{l}\left(\Delta\epsilon_{xi} - \Delta\epsilon_{yi}\right)^2 + \left(\Delta\epsilon_{yi} - \Delta\epsilon_{zi}\right)^2 \\ + \left(\Delta\epsilon_{zi} - \Delta\epsilon_{xi}\right)^2 \\ + \frac{3}{2}\left(\Delta\gamma_{xyi}^2 + \Delta\gamma_{yzi}^2 + \Delta\gamma_{zxi}^2\right)\end{array}\right]^{1/2} \tag{11}$$

where

ν^* = 0.5 when using the rules of HBB-T-1420
ν^* = 0.3 when using the rules of HBB-T-1430

Step 5. Define $\Delta\epsilon_{\max}$ as the maximum value of the above calculated equivalent strain ranges, $\Delta\epsilon_{\text{equiv.}i}$.

The above five step procedure may be used regardless of whether principal strains change directions. When principal strains do not rotate, an alternative to the above sequence is given in HBB-T-1414.

HBB-T-1414 Alternative Calculation Method — Equivalent Strain Range

An alternative calculational method for equivalent strain range determination — applicable only when principal strains do not rotate — is as follows:

Step 1. No change from HBB-T-1413, Step 1.

Step 2. Determine the principal strains versus time for the cycle.

Step 3. At each time interval of Step 2, determine the strain differences $\epsilon_1 - \epsilon_2$, $\epsilon_2 - \epsilon_3$, $\epsilon_3 - \epsilon_1$.

Step 4. Select a point when conditions are at an extreme for the cycle, either maximum or minimum. Refer to this time point by a subscript o. If the extremes for the cycle cannot be identified, then calculate the equivalent strain range for each point, i, in time per Steps 5 and 6. Identify the time point with maximum equivalent strain range as the new reference point, o. If there are multiple points with the same maximum equivalent strain range, choose the time point with the maximum effective strain (von Mises) as the new reference point, o.

Step 5. Determine the history of the change in strain differences by subtracting the values at the time, o, from the corresponding values at each point in time, i, during the cycle. Designate these strain difference changes as:

$$\Delta\left(\epsilon_1 - \epsilon_2\right)_i = \left(\epsilon_1 - \epsilon_2\right)_i - \left(\epsilon_1 - \epsilon_2\right)_o$$

$$\Delta\left(\epsilon_2 - \epsilon_3\right)_i = \left(\epsilon_2 - \epsilon_3\right)_i - \left(\epsilon_2 - \epsilon_3\right)_o$$

$$\Delta\left(\epsilon_3 - \epsilon_1\right)_i = \left(\epsilon_3 - \epsilon_1\right)_i - \left(\epsilon_3 - \epsilon_1\right)_o$$

Step 6. For each time point, i, calculate the equivalent strain range as:

$$\Delta\varepsilon_{\text{equiv.}\,i} = \frac{\sqrt{2}}{2\left(1 + \nu^*\right)}\left\{\left[\Delta\left(\varepsilon_1 - \varepsilon_2\right)_i\right]^2 + \left[\Delta\left(\varepsilon_2 - \varepsilon_3\right)_i\right]^2 + \left[\Delta\left(\varepsilon_3 - \varepsilon_1\right)_i\right]^2\right\}^{1/2}$$

where ν^* is defined as in HBB-T-1413.

Step 7. Define $\Delta\epsilon_{max}$ as the maximum value of the above calculated equivalent strain ranges, $\Delta\epsilon_{equiv.i}$.

(23) HBB-T-1420 LIMITS USING INELASTIC ANALYSIS

When inelastic analysis is used to satisfy the requirements of HBB-T-1411, the rules of (a), (b), and (c) below apply.

(a) The creep damage term of eq. HBB-T-1411(10) may also be calculated by using the integral form:

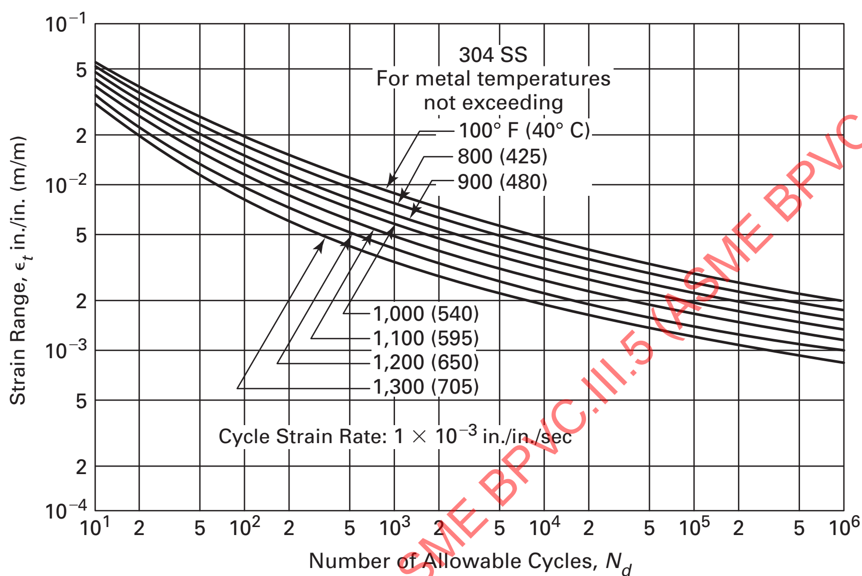
$$\int_o^t \frac{dt}{T_d}$$

When the Design Specification contains a histogram delineating a specific loading sequence, the creep damage shall be calculated for the cycles described by the histogram. If the sequence of loading is not defined by the Design Specification, then the procedures of HBB-T-1433(a) Steps 1, 3, and 8 may be applied to define the stress and temperature histogram.

(b) The fatigue damage term of eq. HBB-T-1411(10) is evaluated by entering a design fatigue curve at the strain range ϵ_t. The strain range ϵ_t is defined as $\epsilon_t = \Delta\epsilon_{max}$; where $\Delta\epsilon_{max}$ is the value calculated in either HBB-T-1413 or HBB-T-1414. The appropriate design fatigue curve is selected from Figures HBB-T-1420-1A through HBB-T-1420-1E and corresponds to the maximum metal temperature experienced during the cycle.

(c) The total damage, D, shall not exceed the creep-fatigue damage envelope of Figure HBB-T-1420-2.

Figure HBB-T-1420-1A
Design Fatigue Strain Range, ϵ_t, for 304 SS



Number of Cycles, N_d [Note (1)]	U.S. Customary Units						
	Strain Range, ϵ_t, in./in., at Temperature						
	100°F	800°F	900°F	1,000°F	1,100°F	1,200°F	1,300°F
10	0.051	0.050	0.0465	0.0425	0.0382	0.0335	0.0297
20	0.036	0.0345	0.0315	0.0284	0.025	0.0217	0.0186
40	0.0263	0.0246	0.0222	0.0197	0.017	0.0146	0.0123
10^2	0.018	0.0164	0.0146	0.0128	0.011	0.0093	0.0077
2×10^2	0.0142	0.0125	0.011	0.0096	0.0082	0.0069	0.0057
4×10^2	0.0113	0.00965	0.00845	0.00735	0.0063	0.00525	0.00443
10^3	0.00845	0.00725	0.0063	0.0055	0.0047	0.00385	0.00333
2×10^3	0.0067	0.0059	0.0051	0.0045	0.0038	0.00315	0.00276
4×10^3	0.00545	0.00485	0.0042	0.00373	0.0032	0.00263	0.0023
10^4	0.0043	0.00385	0.00335	0.00298	0.0026	0.00215	0.00185
2×10^4	0.0037	0.0033	0.0029	0.00256	0.00226	0.00187	0.00158
4×10^4	0.0032	0.00287	0.00254	0.00224	0.00197	0.00162	0.00138
10^5	0.00272	0.00242	0.00213	0.00188	0.00164	0.00140	0.00117
2×10^5	0.0024	0.00215	0.0019	0.00167	0.00145	0.00123	0.00105
4×10^5	0.00215	0.00192	0.0017	0.0015	0.0013	0.0011	0.00094
10^6	0.0019	0.00169	0.00149	0.0013	0.00112	0.00098	0.00084

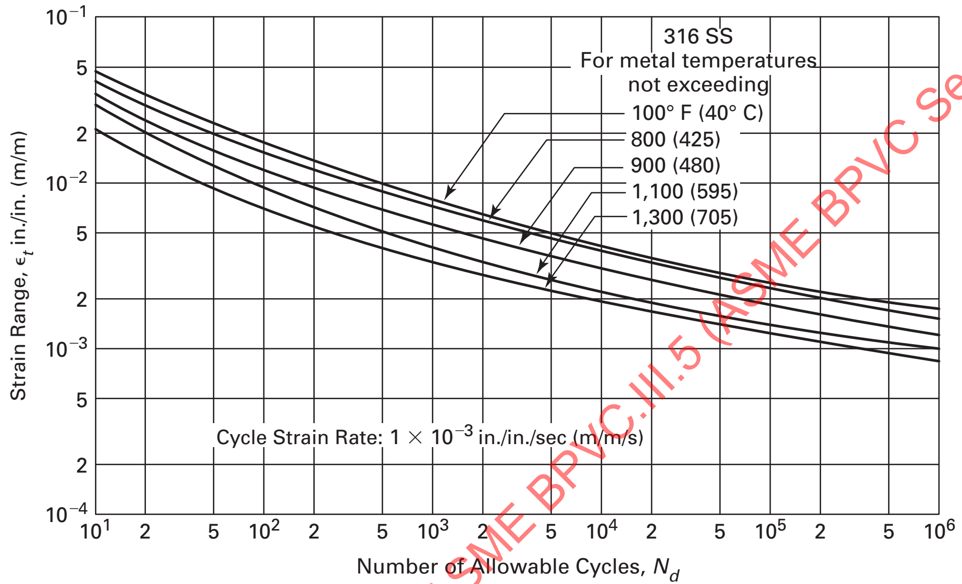
Figure HBB-T-1420-1A
Design Fatigue Strain Range, ϵ_t, for 304 SS (Cont'd)

Table continued

Number of Cycles, N_d [Note (1)]	SI Units						
	Strain Range, ϵ_t, m/m, at Temperature						
	40°C	425°C	480°C	540°C	595°C	650°C	705°C
10	0.051	0.050	0.0465	0.0425	0.0382	0.0335	0.0297
20	0.036	0.0345	0.0315	0.0284	0.025	0.0217	0.0186
40	0.0263	0.0246	0.0222	0.0197	0.017	0.0146	0.0123
10^2	0.018	0.0164	0.0146	0.0128	0.011	0.0093	0.0077
2×10^2	0.0142	0.0125	0.011	0.0096	0.0082	0.0069	0.0057
4×10^2	0.0113	0.00965	0.00845	0.00735	0.0063	0.00525	0.00443
10^3	0.00845	0.00725	0.0063	0.0055	0.0047	0.00385	0.00333
2×10^3	0.0067	0.0059	0.0051	0.0045	0.0038	0.00315	0.00276
4×10^3	0.00545	0.00485	0.0042	0.00373	0.0032	0.00263	0.0023
10^4	0.0043	0.00385	0.00335	0.00298	0.0026	0.00215	0.00185
2×10^4	0.0037	0.0033	0.0029	0.00256	0.00226	0.00187	0.00158
4×10^4	0.0032	0.00287	0.00254	0.00224	0.00197	0.00162	0.00138
10^5	0.00272	0.00242	0.00213	0.00188	0.00164	0.0014	0.00117
2×10^5	0.0024	0.00215	0.0019	0.00167	0.00145	0.00123	0.00105
4×10^5	0.00215	0.00192	0.0017	0.0015	0.0013	0.0011	0.00094
10^6	0.0019	0.00169	0.00149	0.0013	0.00112	0.00098	0.00084

NOTE:
(1) Cyclic strain rate: 1×10^{-3} in./in./sec. (1×10^{-3} m/m/s).

Figure HBB-T-1420-1B
Design Fatigue Strain Range, ϵ_t, for 316 SS



Number of Cycles, N_d [Note (1)]	U.S. Customary Units				
	Strain Range, ϵ_t, in./in., at Temperature				
	100°F	800°F	900°F	1,000°F–1,200°F	1,300°F
10^1	0.0507	0.0438	0.0378	0.0318	0.0214
2×10^1	0.0357	0.0318	0.0251	0.0208	0.0149
4×10^1	0.026	0.0233	0.0181	0.0148	0.0105
10^2	0.0177	0.0159	0.0123	0.00974	0.00711
2×10^2	0.0139	0.0125	0.00961	0.00744	0.00551
4×10^2	0.0110	0.00956	0.00761	0.00574	0.00431
10^3	0.00818	0.00716	0.00571	0.00424	0.00328
2×10^3	0.00643	0.00581	0.00466	0.00339	0.00268
4×10^3	0.00518	0.00476	0.00381	0.00279	0.00226
10^4	0.00403	0.00376	0.00301	0.00221	0.00186
2×10^4	0.00343	0.00316	0.00256	0.00186	0.00162
4×10^4	0.00293	0.00273	0.00221	0.00161	0.00144
10^5	0.00245	0.00226	0.00182	0.00136	0.00121
2×10^5	0.00213	0.00196	0.00159	0.00121	0.00108
4×10^5	0.00188	0.00173	0.00139	0.00109	0.000954
10^6	0.00163	0.00151	0.00118	0.000963	0.000834

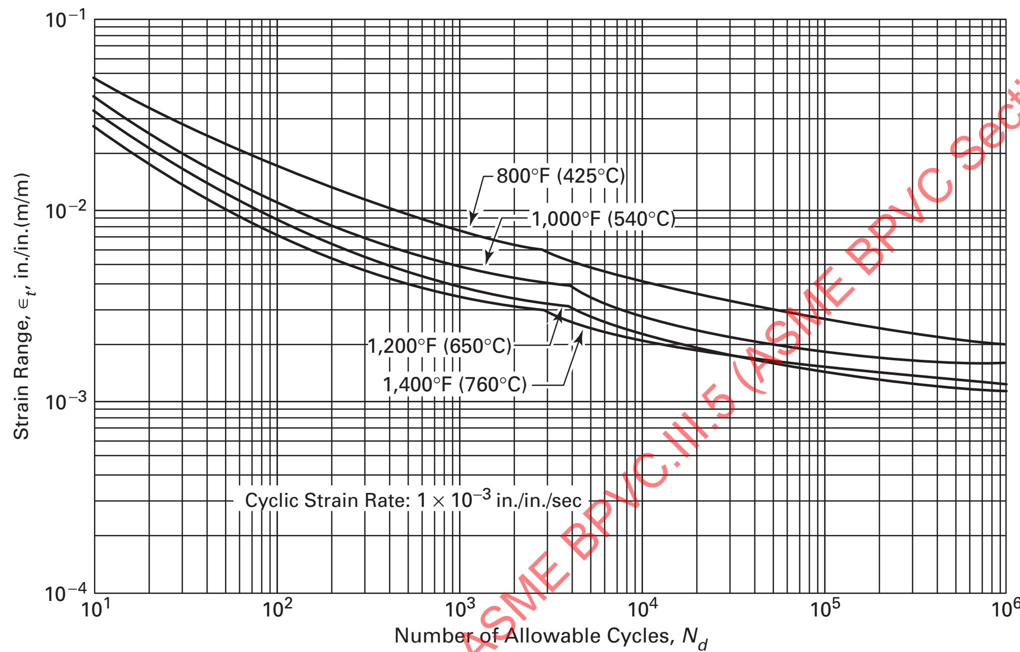
Figure HBB-T-1420-1B
Design Fatigue Strain Range, ϵ_t, for 316 SS (Cont'd)

Table continued

Number of Cycles, N_d [Note (1)]	SI Units — Strain Range, ϵ_t, m/m, at Temperature				
	40°C	425°C	480°C	540°C–650°C	705°C
10^1	0.0507	0.0438	0.0378	0.0318	0.0214
2×10^1	0.0357	0.0318	0.0251	0.0208	0.0149
4×10^1	0.026	0.0233	0.0181	0.0148	0.0105
10^2	0.0177	0.0159	0.0123	0.00974	0.00711
2×10^2	0.0139	0.0125	0.00961	0.00744	0.00551
4×10^2	0.0110	0.00956	0.00761	0.00574	0.00431
10^3	0.00818	0.00716	0.00571	0.00424	0.00328
2×10^3	0.00643	0.00581	0.00466	0.00339	0.00268
4×10^3	0.00518	0.00476	0.00381	0.00279	0.00226
10^4	0.00403	0.00376	0.00301	0.00221	0.00186
2×10^4	0.00343	0.00316	0.00256	0.00186	0.00162
4×10^4	0.00293	0.00273	0.00221	0.00161	0.00144
10^5	0.00245	0.00226	0.00182	0.00136	0.00121
2×10^5	0.00213	0.00196	0.00159	0.00121	0.00108
4×10^5	0.00188	0.00173	0.00139	0.00109	0.000954
10^6	0.00163	0.00151	0.00118	0.000963	0.000834

NOTE:
(1) Cyclic strain rate: 1×10^{-3} in./in./sec. (1×10^{-3} m/m/s).

Figure HBB-T-1420-1C
Design Fatigue Strain Range, ϵ_t, for Ni-Fe-Cr Alloy 800H



Number of Cycles, N_d [Note (1)]	U.S. Customary Units			
	Strain Range, ϵ_t, in./in., at Temperature			
	800°F	1,000°F	1,200°F	1,400°F
10^1	0.0500	0.0424	0.03414	0.02841
2×10^1	0.0362	0.02735	0.02199	0.01829
4×10^1	0.0270	0.01849	0.01483	0.01233
10^2	0.0184	0.01164	0.00932	0.00774
2×10^2	0.0142	0.00849	0.00678	0.00562
4×10^2	0.0113	0.00660	0.00533	0.00469
10^3	0.00841	0.00515	0.00417	0.00388
2×10^3	0.00685	0.00454	0.00366	0.00349
3×10^3	0.00644	0.00433	0.00347	0.00309
4×10^3	0.00572	0.00409	0.00327	0.00270
10^4	0.00452	0.00293	0.00234	0.00212
2×10^4	0.00392	0.00243	0.00197	0.00183
4×10^4	0.00343	0.00212	0.00175	0.00164
10^5	0.00288	0.00194	0.00155	0.00149
2×10^5	0.00254	0.00186	0.00147	0.00140
4×10^5	0.00229	0.00178	0.00140	0.00132
10^6	0.00200	0.00169	0.00131	0.00122

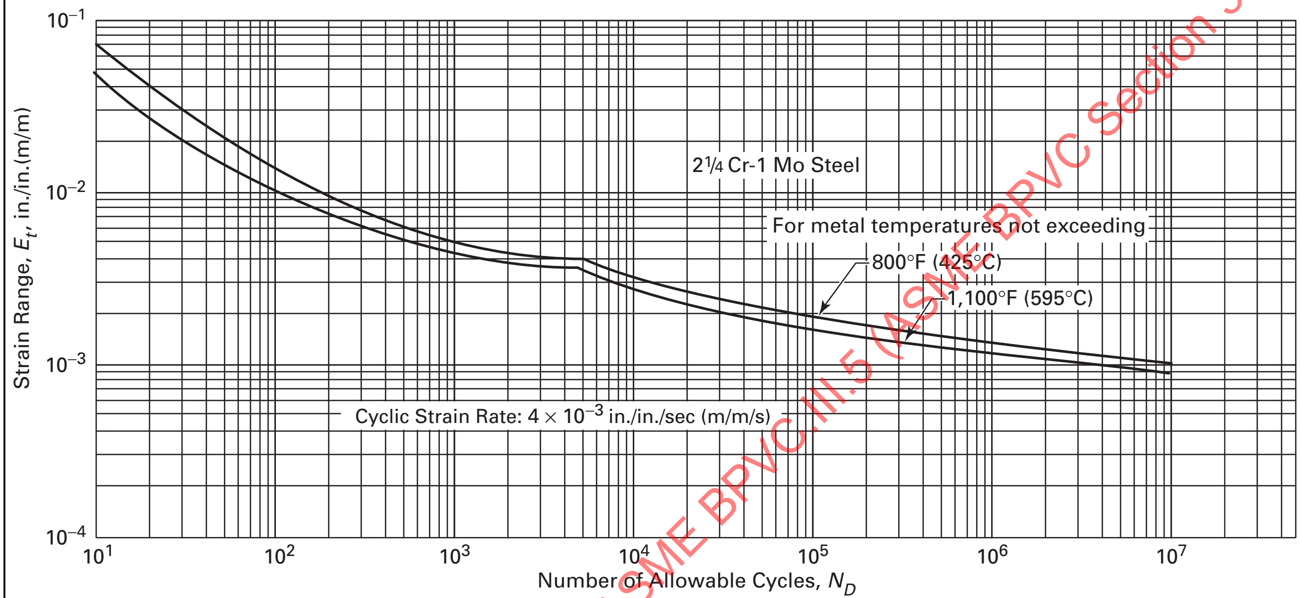
Figure HBB-T-1420-1C
Design Fatigue Strain Range, ϵ_t, for Ni-Fe-Cr Alloy 800H (Cont'd)

Table continued

Number of Cycles, N_d [Note (1)]	SI Units			
	Strain Range, ϵ_t, m/m, at Temperature			
	425°C	540°C	650°C	760°C
10^1	0.0500	0.0424	0.03414	0.02841
2×10^1	0.0362	0.02735	0.02199	0.01829
4×10^1	0.0270	0.01849	0.01483	0.01233
10^2	0.0184	0.01164	0.00932	0.00774
2×10^2	0.0142	0.00849	0.00678	0.00562
4×10^2	0.0113	0.00660	0.00533	0.00469
10^3	0.00841	0.00515	0.00417	0.00388
2×10^3	0.00685	0.00454	0.00366	0.00349
3×10^3	0.00644	0.00433	0.00347	0.00309
4×10^3	0.00572	0.00409	0.00327	0.00270
10^4	0.00452	0.00293	0.00234	0.00212
2×10^4	0.00392	0.00243	0.00197	0.00183
4×10^4	0.00343	0.00212	0.00175	0.00164
10^5	0.00288	0.00194	0.00155	0.00149
2×10^5	0.00254	0.00186	0.00147	0.00140
4×10^5	0.00229	0.00178	0.00140	0.00132
10^6	0.00200	0.00169	0.00131	0.00122

NOTE:
(1) Cyclic strain rate: 1×10^{-3} in./in./sec (1×10^{-3} m/m/s).

Figure HBB-T-1420-1D
Design Fatigue Strain Range, ϵ_t, for 2¼Cr-1Mo Steel

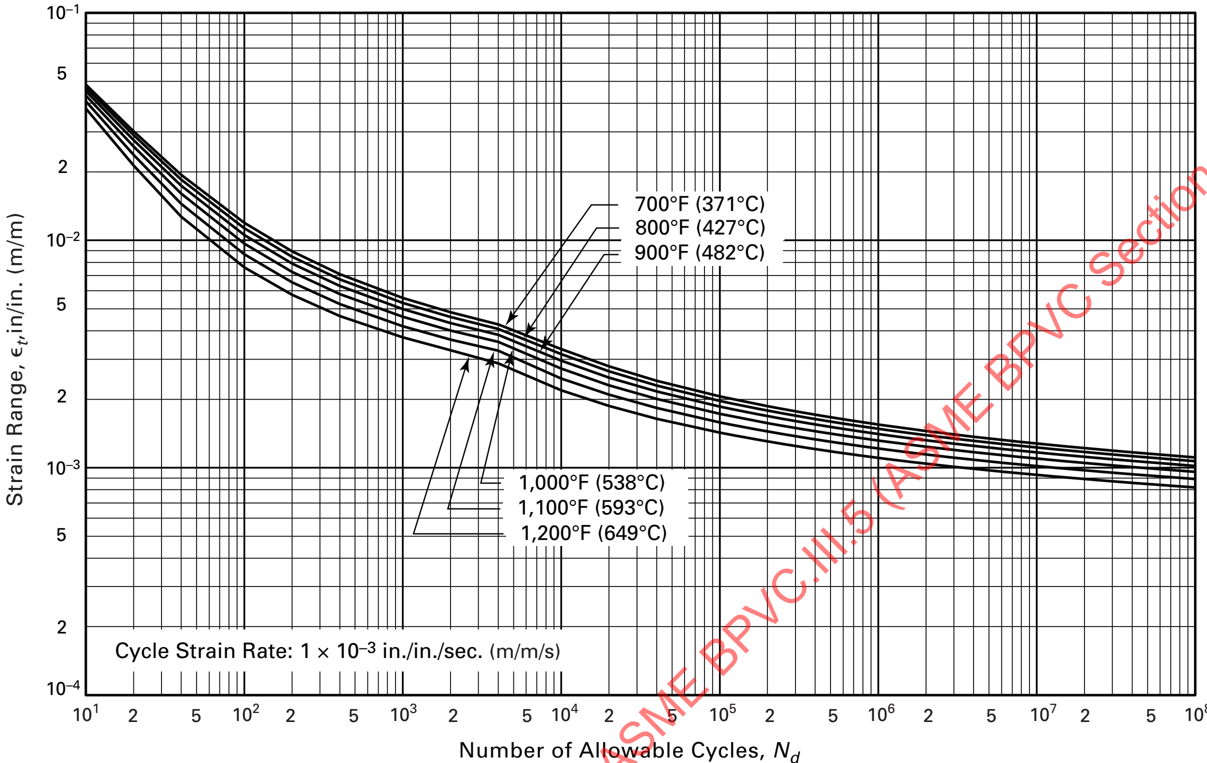


Number of Cycles, N_d [Note (1)]	Strain Range, ϵ_t, in./in. (m/m), at Temperature 800°F (425°C)	900°F–1,000°F (480°C–595°C)
10^1	0.056	0.040
4×10^1	0.023	0.0163
10^2	0.013	0.0097
2×10^2	0.0094	0.0070
4×10^2	0.0070	0.0056
10^3	0.0052	0.0042
2×10^3	0.0044	0.0039
4×10^3	0.0040	0.0035
10^4	0.0032	0.00265
2×10^4	0.0026	0.00215
4×10^4	0.0023	0.00182
10^5	0.00195	0.00158
2×10^5	0.00173	0.00142
4×10^5	0.00155	0.00130
10^6	0.00137	0.00118

NOTE:
(1) Cycle strain rate: 4×10^{-3} in./in./sec (m/m/s).

(23)

Figure HBB-T-1420-1E
Design Fatigue Strain Range, ϵ_t, for 9Cr-1Mo-V Steel



Number of Cycles, N_d [Note (1)]	U.S. Customary Units — Strain Range, ϵ_t, in./in., at Temperature [Note (2)] 700°F	800°F	900°F	1,000°F	1,100°F	1,200°F
10	4.83605 E−02	4.70094 E−02	4.53395 E−02	4.33107 E−02	4.08767 E−02	3.79821 E−02
20	3.01297 E−02	2.89751 E−02	2.75445 E−02	2.58086 E−02	2.37388 E−02	2.13107 E−02
40	1.94065 E−02	1.84929 E−02	1.73699 E−02	1.60272 E−02	1.44645 E−02	1.26981 E−02
10^2	1.19253 E−02	1.13046 E−02	1.05526 E−02	9.67285 E−03	8.67904 E−03	7.59738 E−03
2×10^2	8.93528 E−03	8.47050 E−03	7.91083 E−03	7.26167 E−03	6.53573 E−03	5.75390 E−03
4×10^2	7.09096 E−03	6.73165 E−03	6.29996 E−03	5.80082 E−03	5.24448 E−03	4.64680 E−03
10^3	5.57865 E−03	5.30853 E−03	4.98397 E−03	4.60877 E−03	4.19048 E−03	3.74047 E−03
2×10^3	4.82456 E−03	4.59882 E−03	4.32732 E−03	4.01310 E−03	3.66230 E−03	3.28405 E−03
4×10^3	4.26918 E−03	4.07569 E−03	3.84266 E−03	3.57260 E−03	3.26787 E−03	2.87695 E−03
10^4	3.32416 E−03	3.15749 E−03	2.95730 E−03	2.72590 E−03	2.46805 E−03	2.19104 E−03
2×10^4	2.78933 E−03	2.65426 E−03	2.49199 E−03	2.30438 E−03	2.09524 E−03	1.87024 E−03
4×10^4	2.41228 E−03	2.29941 E−03	2.16366 E−03	2.00655 E−03	1.83115 E−03	1.64203 E−03
10^5	2.06036 E−03	1.96787 E−03	1.85644 E−03	1.72724 E−03	1.58264 E−03	1.42623 E−03
2×10^5	1.86482 E−03	1.78342 E−03	1.68522 E−03	1.57117 E−03	1.44331 E−03	1.30469 E−03
4×10^5	1.70989 E−03	1.63711 E−03	1.54919 E−03	1.44695 E−03	1.33211 E−03	1.20734 E−03
10^6	1.54885 E−03	1.48484 E−03	1.40740 E−03	1.31717 E−03	1.21562 E−03	1.10501 E−03
2×10^6	1.45099 E−03	1.39220 E−03	1.32100 E−03	1.23794 E−03	1.14432 E−03	1.04218 E−03
4×10^6	1.36846 E−03	1.31401 E−03	1.24798 E−03	1.17088 E−03	1.08387 E−03	9.88771 E−04
10^7	1.27740 E−03	1.22764 E−03	1.16724 E−03	1.09661 E−03	1.01677 E−03	9.29353 E−04
2×10^7	1.21915 E−03	1.17235 E−03	1.11548 E−03	1.04893 E−03	9.73622 E−04	8.91061 E−04
4×10^7	1.16817 E−03	1.12392 E−03	1.07011 E−03	1.00709 E−03	9.35702 E−04	8.57351 E−04
10^8	1.10979 E−03	1.06842 E−03	1.01807 E−03	9.59039 E−04	8.92094 E−04	8.18515 E−04

Figure HBB-T-1420-1E
Design Fatigue Strain Range, ϵ_t, for 9Cr-1Mo-V Steel (Cont'd)

Table continued

Number of Cycles, N_d [Note (1)]	SI Units — Strain Range, ϵ_t, m/m, at Temperature [Note (2)] 375°C	425°C	480°C	540°C	600°C	650°C
10	4.82755 E−02	4.70544 E−02	4.54129 E−02	4.32215 E−02	4.05549 E−02	3.79190 E−02
20	3.00572 E−02	2.90136 E−02	2.76074 E−02	2.57324 E−02	2.34667 E−02	2.12584 E−02
40	1.93491 E−02	1.85233 E−02	1.74190 E−02	1.59689 E−02	1.42627 E−02	1.26609 E−02
10^2	1.18861 E−02	1.13251 E−02	1.05851 E−02	9.63516 E−03	8.55321 E−03	7.57511 E−03
2×10^2	8.90585 E−03	8.48584 E−03	7.93499 E−03	7.23400 E−03	6.44437 E−03	5.73788 E−03
4×10^2	7.06819 E−03	6.74350 E−03	6.31857 E−03	5.77958 E−03	5.17457 E−03	4.63456 E−03
10^3	5.56154 E−03	5.31743 E−03	4.99796 E−03	4.59280 E−03	4.13789 E−03	3.73125 E−03
2×10^3	4.81027 E−03	4.60627 E−03	4.33903 E−03	3.99972 E−03	3.61815 E−03	3.27629 E−03
4×10^3	4.25694 E−03	4.08208 E−03	3.85272 E−03	3.56109 E−03	3.22218 E−03	2.86894 E−03
10^4	3.31360 E−03	3.16299 E−03	2.96593 E−03	2.71606 E−03	2.43566 E−03	2.18536 E−03
2×10^4	2.78077 E−03	2.65872 E−03	2.49898 E−03	2.29640 E−03	2.06895 E−03	1.86562 E−03
4×10^4	2.40513 E−03	2.30313 E−03	2.16951 E−03	1.99986 E−03	1.80907 E−03	1.63814 E−03
10^5	2.05451 E−03	1.97093 E−03	1.86125 E−03	1.72173 E−03	1.56441 E−03	1.42301 E−03
2×10^5	1.85967 E−03	1.78611 E−03	1.68946 E−03	1.56631 E−03	1.42717 E−03	1.30183 E−03
4×10^5	1.70529 E−03	1.63952 E−03	1.55299 E−03	1.44258 E−03	1.31760 E−03	1.20477 E−03
10^6	1.54481 E−03	1.48696 E−03	1.41075 E−03	1.31331 E−03	1.20278 E−03	1.10272 E−03
2×10^6	1.44728 E−03	1.39415 E−03	1.32408 E−03	1.23438 E−03	1.13247 E−03	1.04006 E−03
4×10^6	1.36503 E−03	1.31581 E−03	1.25084 E−03	1.16758 E−03	1.07284 E−03	9.86802 E−04
10^7	1.27426 E−03	1.22929 E−03	1.16986 E−03	1.09358 E−03	1.00664 E−03	9.27542 E−04
2×10^7	1.21620 E−03	1.17390 E−03	1.11795 E−03	1.04608 E−03	9.64062 E−04	8.89348 E−04
4×10^7	1.16538 E−03	1.12538 E−03	1.07245 E−03	1.00439 E−03	9.26635 E−04	8.55725 E−04
10^8	1.10718 E−03	1.06979 E−03	1.02026 E−03	9.56506 E−04	8.83585 E−04	8.16987 E−04

NOTES:
(1) Cyclic strain rate: 1×10^{-3} in./in./sec (m/m/s).
(2) The following equations can be used to determine the allowable cycles, N_d, using the design fatigue strain range, ε_t, in the range of the tabulated values:

$$N_d = \text{lesser of}\left(N_{\frac{f}{20}},\ N_{2S}\right)$$

$$N_{\frac{f}{20}} = \frac{10^{\left[A_0 + A_1\cdot\log_{10}\epsilon_t + A_2\cdot\left(\log_{10}\epsilon_t\right)^2 + A_3\cdot\left(\log_{10}\epsilon_t\right)^4\right]^{-2}}}{20}$$

$$N_{2S} = 10^{\left(A_0 + A_1\cdot\log_{10}\left(2\epsilon_t\right) + A_2\cdot\left[\log_{10}\left(2\epsilon_t\right)\right]^2 + A_3\cdot\left[\log_{10}\left(2\epsilon_t\right)\right]^4\right)^{-2}}$$

$$A_0 = 1.182614 + 2.422424 \times 10^{-8} \times T^2$$

$$A_1 = 6.475966 \times 10^{-1}$$

$$A_2 = 2.065574 \times 10^{-1} + 3.103560 \times 10^{-11} \times T^3$$

$$A_3 = 1.168810 \times 10^{-2}$$

where

N_d = number of allowable cycles

Figure HBB-T-1420-1E
Design Fatigue Strain Range, ϵ_t, for 9Cr-1Mo-V Steel (Cont'd)

Table continued

NOTES (CONT'D):

$N_{f/2\sigma}$, N_{2S}, A_0,
A_1, A_2, A_3 = numerical parameters

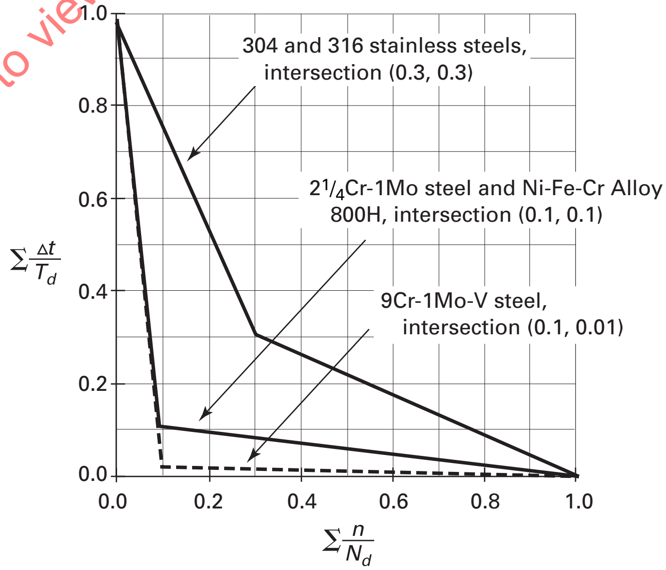
T = temperature in degrees celsius for SI units

$= \dfrac{T_F - 32}{1.8}$

T_F = temperature in degrees fahrenheit for U.S. Customary units

ε_t = design fatique strain range (in./in. or m/m)

Figure HBB-T-1420-2
Creep–Fatigue Damage Envelope



HBB-T-1430 LIMITS USING ELASTIC ANALYSIS

HBB-T-1431 General Requirements

(a) The elastic analysis rules in this paragraph may be used only when:

(1) the elastic ratcheting rules of HBB-T-1320 or HBB-T-1330 with Z less than, or equal to, 1.0 have been satisfied;

(2) the $3S_m$ limit in Section III Appendices, Mandatory Appendix XIII, XIII-3420 is met using for $3S_m$ the lesser of $3S_m$ and $3\bar{S}_m$ as defined in HBB-T-1324; and

(3) pressure-induced membrane and bending stresses and thermal induced membrane stresses are classified as primary (load-controlled) stresses.

The secondary stress range due to radial thermal gradients may be excluded from $(Q_R)_{\max}$ in either HBB-T-1322 or HBB-T-1323 in determining the applicability of elastic creep–fatigue rules.

(b) Linearly elastic analysis methods may significantly underestimate the actual strain range incurred during plastic or creep deformation. The method of HBB-T-1432 may be used to account for these increased strain ranges due to inelastic behavior in the region under consideration. The resulting strain range, ϵ_t, is used to enter a design fatigue curve to evaluate the fatigue damage term of eq. HBB-T-1411(10). The appropriate design fatigue curve is selected from Figures HBB-T-1420-1A through HBB-T-1420-1E and corresponds to the maximum metal temperature occurring during the cycle.

(c) The creep damage term of eq. HBB-T-1411(10) is evaluated using the procedure of HBB-T-1433.

(d) The total damage, D, shall not exceed the creep-fatigue damage envelope of Figure HBB-T-1420-2.

HBB-T-1432 Strain Range Determination

(a) Calculate $\Delta\epsilon_{\max}$ using HBB-T-1413 or HBB-T-1414. The strain components to be used in HBB-T-1413 or HBB-T-1414 are elastically calculated and do not include local geometric stress concentration effects. Alternatively, calculate $\Delta\epsilon_{\max}$ using the stress difference procedure described in Section III Appendices, Mandatory Appendix XIII, XIII-2400. However, for the purpose of calculating $\Delta\epsilon_{\max}$, the effects of local geometric stress concentrations are omitted. The strain range $\Delta\epsilon_{\max}$ is defined as equal to $2S_{\mathrm{alt}}/E$, where E equals the modulus of elasticity at the maximum metal temperature experienced during the cycle.

(b) Calculate the modified maximum equivalent strain range, $\Delta\epsilon_{\mathrm{mod}}$, using the procedure specified in any one of (c), (d), or (e).

(c) The modified maximum equivalent strain range, $\Delta\epsilon_{\mathrm{mod}}$, may be calculated as:

$$\Delta\epsilon_{\mathrm{mod}} = \left(\frac{S^*}{\bar{S}}\right) K^2 \Delta\epsilon_{\max} \tag{12}$$

where (see Figure HBB-T-1432-1)

K = either the equivalent stress concentration factor, as determined by test or analysis, or, the maximum value of the theoretical elastic stress concentration factor in any direction for the local area under consideration. The equivalent stress concentration factor is defined as the effective (von Mises) primary plus secondary plus peak stress divided by the effective primary plus secondary stress. Note that fatigue strength reduction factors developed from low temperature continuous cycling fatigue tests may not be acceptable for defining K when creep effects are not negligible.

S^* = the stress indicator determined by entering the stress-strain curve of Figure HBB-T-1432-1 at a strain range of $\Delta\epsilon_{\max}$

$\bar{S}$ = the stress indicator determined by entering the stress-strain curve of Figure HBB-T-1432-1 at a strain range of $K\Delta\epsilon_{\max}$

$\Delta\epsilon_{\max}$ = the maximum equivalent strain range as determined above in (a)

$\Delta\epsilon_{\mathrm{mod}}$ = the modified maximum equivalent strain range that accounts for the effects of local plasticity and creep

The composite stress-strain curve used for this analysis is shown in Figure HBB-T-1432-1, and it is constructed by adding the elastic stress-strain curve for the stress range, S_{rH}, to the appropriate time-independent isochronous stress-strain curve (σ', ϵ') in HBB-T-1830. The appropriate curve in HBB-T-1830 corresponds to the maximum metal temperature occurring during the cycle.

O = origin of the composite isochronous stress-strain curve (Figure HBB-T-1432-1) used in this analysis

O' = origin of the time-independent isochronous stress-strain curve in HBB-T-1830

S_{rH} = a relaxation strength defined in HBB-T-1324

ϵ' = strain abscissa of the time-independent isochronous stress-strain curve in HBB-T-1830

σ' = stress ordinate of the time-independent isochronous stress-strain curve in HBB-T-1830

(d) Equation (c)(12) results in a conservative determination of the modified maximum equivalent strain range, $\Delta\epsilon_{mod}$, relative to the maximum equivalent strain range, $\Delta\epsilon_{max}$. A more accurate and less conservative determination of the modified maximum equivalent strain range, $\Delta\epsilon_{mod}$, may then be obtained by use of eq. (13):

$$\Delta\epsilon_{\mathrm{mod}} = \frac{K^2 S^* \Delta\epsilon_{\mathrm{max}}}{\Delta\sigma_{\mathrm{mod}}} \tag{13}$$

where (see Figure HBB-T-1432-1) $\Delta\epsilon_{mod}$, $\Delta\epsilon_{max}$, K, and S^* are as defined in (c) above, and $\Delta\sigma_{mod}$ = the range of effective stress that corresponds to the strain range, $\Delta\epsilon_{mod}$, in the composite stress-strain curve of Figure HBB-T-1432-1. The unknowns of eq. (13), i.e., $\Delta\sigma_{mod}$ and $\Delta\epsilon_{mod}$, can be solved graphically or analytically by curve fitting the appropriate composite stress-strain curve. Note that the appropriate composite stress-strain curve is constructed as described above in (c).

(e) The most conservative estimate of the modified maximum equivalent strain range, $\Delta\epsilon_{mod}$, may be obtained as:

$$\Delta\epsilon_{\mathrm{mod}} = K_e K \Delta\epsilon_{\mathrm{max}} \tag{14}$$

where $\Delta\epsilon_{mod}$, K, and $\Delta\epsilon_{max}$ are defined in (c) above, and

K_e = 1 if $K\Delta\epsilon_{\mathrm{max}} \leq 3\bar{S}_m / E$

$K_e = K\Delta\epsilon_{\mathrm{max}}E / 3\bar{S}_m$ for $K\Delta\epsilon_{\mathrm{max}} > 3\bar{S}_m / E$

(f) Determine the multiaxial plasticity and Poisson ratio adjustment factor, K_ν, defined in eq. (15):

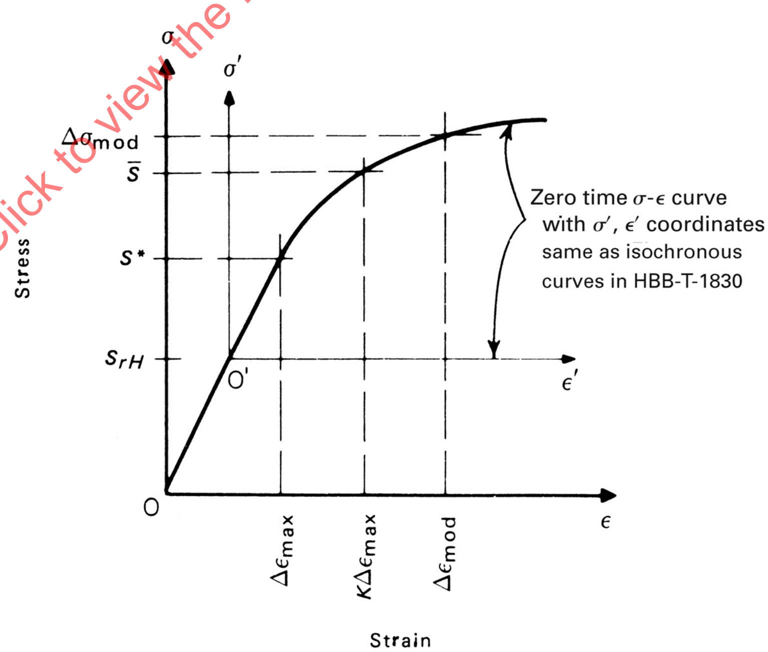
$$K_\nu = 1.0 + f\left(K_\nu' - 1.0\right), \text{ but not less than } 1.0 \tag{15}$$

where

f = factor determined by entering Figure HBB-T-1432-2 at the Triaxiality Factor, T.F., for the stress state at each of the two extremes of the stress cycle. The larger magnitude of f shall be used in eq. (15).

K_ν' = plastic Poisson ratio adjustment factor determined by entering Figure HBB-T-1432-3 at the ratio of $K_e K \Delta\epsilon_{\mathrm{max}} E / 3\bar{S}_m$ with the terms as defined in eq. (e)(14)

Figure HBB-T-1432-1
Stress–Strain Relationship



(g) Determine the creep strain increment $\Delta\epsilon_c$ for the stress cycle due to load-controlled stresses by using a stress intensity equal to 1.25 times the effective creep stress $\sigma_c = Z \cdot S_{yL}$ as defined in HBB-T-1332. The rules of HBB-T-1321, HBB-T-1331, and HBB-T-1332 apply to determining $\Delta\epsilon_c$ except that the stress cycle time, including hold time between transients, shall be used instead of the entire service life. The restriction on Q_R in HBB-T-1323 relative to Table HBB-T-1323 does not apply to determining $\Delta\epsilon_c$. Enter the isochronous stress-strain curve (HBB-T-1830) for the maximum metal temperature during the stress cycle time-temperature block with the $1.25\sigma_c$ stress held constant throughout each temperature-time block of the stress cycle. The $\Delta\epsilon_c$ equals the sum of the creep strain increment accumulated in one stress cycle time. Alternatively, the creep strain accumulated during the entire service life divided by the number of stress cycles during the entire service life may be used for the creep strain increment $\Delta\epsilon_c$. Based on satisfaction of HBB-T-1320 and the HBB-T-1431(a) rules, the $\Delta\epsilon_c$ value used need not exceed 1% divided by the total number of stress cycles:

$$\sum_{j=1}^{P}(n)_j$$

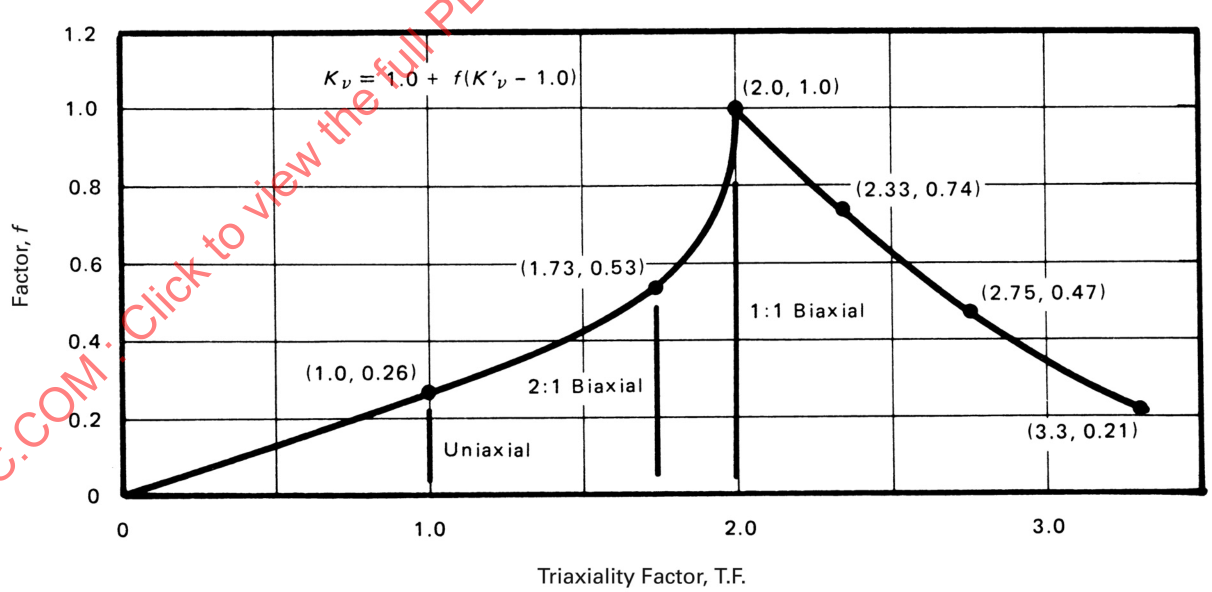
(h) The total strain range, ϵ_t, that is used to enter one of the design fatigue curves of Figures HBB-T-1420-1A through HBB-T-1420-1E, is calculated as:

$$\epsilon_t = K_v \Delta\epsilon_{\text{mod}} + K\Delta\epsilon_c \tag{16}$$

where

K = local geometric concentration factor determined above in (c), (d), or (e)
K_v = the multiaxial plasticity and Poisson ratio adjustment factor determined above in (f)
$\Delta\epsilon_c$ = the creep strain increment as determined above in (g)
$\Delta\epsilon_{\text{mod}}$ = the modified maximum equivalent strain range as determined above in any one of (c), (d), or (e)

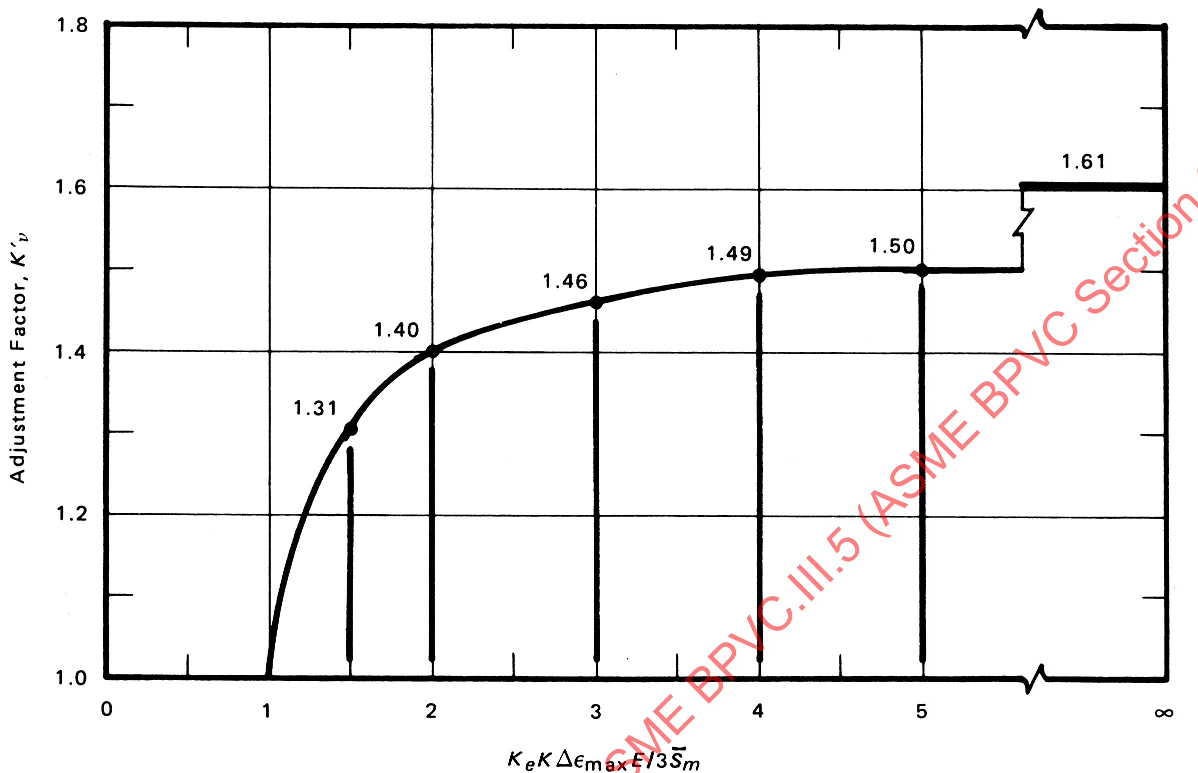
Figure HBB-T-1432-2
Inelastic Multiaxial Adjustments



GENERAL NOTE: $$\text{T.F.} = \frac{\left|\sigma_1 + \sigma_2 + \sigma_3\right|}{\frac{1}{\sqrt{2}}\left[\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2\right]^{1/2}}$$

where σ's are principal stresses at the extreme of the stress cycle.

Figure HBB-T-1432-3
Adjustment for Inelastic Biaxial Poisson's Ratio



ϵ_t = the total strain range that is used to enter one of the design fatigue curves of Figures HBB-T-1420-1A through HBB-T-1420-1E to determine the allowable number of cycles, N_d

HBB-T-1433 Creep Damage Evaluation

The creep damage term of eq. HBB-T-1411(10) is to be evaluated using either the general procedure defined in (a) below or the alternate procedure defined in (b) below. As noted in (b), the alternate procedure cannot be used for any portion of the service life if the total strain range, ϵ_t [as determined in HBB-T-1432(h)], exceeds $3\bar{S}_m / E$ for any of the specified cycle types, j.

(a) A general procedure for evaluating the creep damage term of eq. HBB-T-1411(10) is provided in Steps 1 through 10 below. Steps 3 through 7 are to be repeated for each cycle type j that was evaluated in HBB-T-1432. Recall that j extends from 1 to P as defined in HBB-T-1411.

Step 1. Considering the entire specified service life, define the total number of hours expended at temperatures above 800°F (425°C) [700°F (370°C) for 2¼Cr-1Mo] as t_H.

Step 2. Define the hold temperature, T_{HT}, to be equal to the local metal temperature that occurs during sustained normal operation.

Step 3. For each cycle type j, define the average cycle time, $\bar{t}_j$, as

$$\bar{t}_j = t_H / n_j$$

where

n_j = specified number of applied repetitions of cycle type j
t_H = total number of hours at elevated temperatures (for the entire service life) as defined in Step 1 above
$\bar{t}_j$ = average cycle time for cycle type j

Step 4. Select the time-independent isochronous stress-strain curve in HBB-T-1830 that corresponds to the hold-time temperature T_{HT}. Enter that stress-strain curve at a strain level equal to the strain range ϵ_t, where ϵ_t is that value calculated in HBB-T-1432(h) for cycle type j. Establish the corresponding stress level, S_j. Note that the same isochronous stress-strain curve is used for all cycle types, since T_{HT} is independent of cycle definition.

Step 5. Account for stress relaxation during the average cycle time $\bar{t}_j$. This stress relaxation evaluation is to be performed at a constant temperature equal to T_{HT}. The initial stress is S_j for cycle type j. The stress relaxation history may be determined by

(a) an adjusted uniaxial relaxation analysis where the multiaxial stress state is accounted for by using the following equation [depicted in Figure HBB-T-1433-1 illustration (b)]:

$$S_r = S_j - 0.8G\left(S_j - \bar{S}_r\right)$$

where

G = the smallest value of the multiaxiality factor as determined for the stress state at each of the two extremes of the stress cycle. The multiaxiality factor is defined as

$$\frac{\left[\sigma_1 - 0.5\left(\sigma_2 + \sigma_3\right)\right]}{\left[\sigma_1 - 0.3\left(\sigma_2 + \sigma_3\right)\right]}$$

where σ_1, σ_2, and σ_3 are principal stresses, exclusive of local geometric stress concentration factors, at the extremes of the stress cycle, and are defined by

$$\left|\sigma_1\right| \geq \left|\sigma_2\right| \geq \left|\sigma_3\right|$$

Values of G greater than 1.0 shall be taken as 1.0.

S_j = the initial stress level for cycle type j
S_r = relaxed stress level at time t adjusted for the multiaxial stress state
$\bar{S}_r$ = relaxed stress level at time t based on a uniaxial relaxation model

or

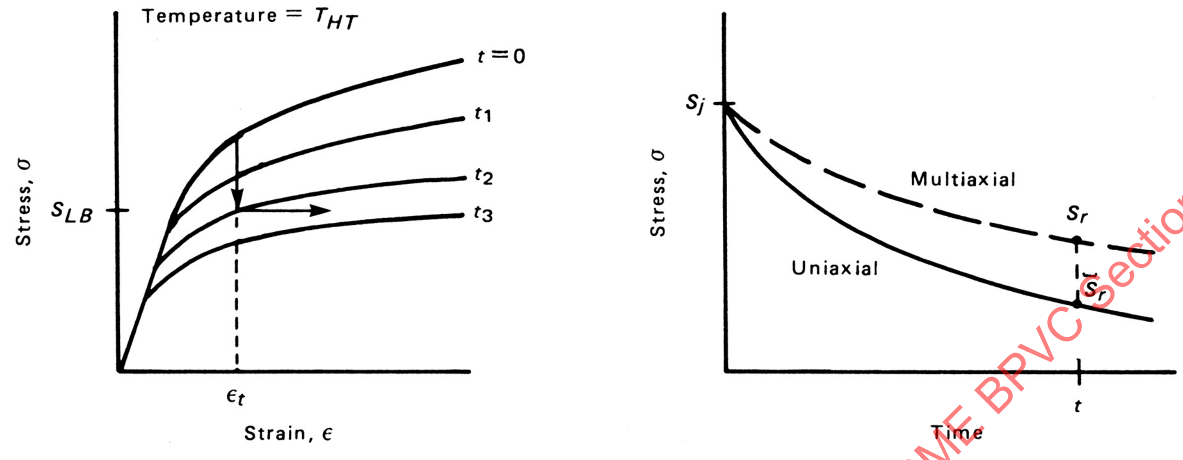
(b) by entering the appropriate isochronous stress-strain curves in HBB-T-1830 at a strain level equal to ϵ_t and determining corresponding stress levels at varying times (see Figure HBB-T-1433-1). The appropriate isochronous stress-strain curves correspond to the temperature T_{HT}. This stress relaxation process shall not be permitted to proceed to a stress level less than S_{LB}. This lower bound stress level, S_{LB}, is defined to be equal to 1.25 times the core stress σ_c [see HBB-T-1432(g)] intensity that exists during sustained normal operation. Note that the same value of S_{LB} is used for all cycle types. This stress relaxation procedure results in a stress-time history similar to that illustrated in Figure HBB-T-1433-2.

Step 6. The average cycle time, $\bar{t}_j$, includes the time expended during elevated temperature transient conditions in addition to the time at the sustained normal operating conditions. Define that portion of $\bar{t}_j$ that represents time expended during elevated temperature transient conditions, as $(t_{\mathrm{TRAN}})_j$. Determine the time point, during the transient conditions, for which the load-controlled stresses are at maximum conditions. Define $(S_{\mathrm{TRAN}})_j$ to be equal to the load-controlled stress intensity at that time point. Indicate both $(t_{\mathrm{TRAN}})_j$ and $(S_{\mathrm{TRAN}})_j$ on the stress-time history (determined in Step 5 above) as shown in Figure HBB-T-1433-3, sketch (a). If $(S_{\mathrm{TRAN}})_j$ does not exceed the stress-time history within the time duration $(t_{\mathrm{TRAN}})_j$ [as is illustrated in Figure HBB-T-1433-3, sketch (a)], then no further modification of the stress-time history is required. If $(S_{\mathrm{TRAN}})_j$ exceeds the stress-time history within the time duration $(t_{\mathrm{TRAN}})_j$, then the stress-time history must be modified by a simple translation in time, as shown in Figure HBB-T-1433-3, sketch (b).

Step 7. Define the cycle transient temperature, $(T_{\mathrm{TRAN}})_j$, to be equal to the maximum metal temperature that occurs during cycle type j. In no case shall $(T_{\mathrm{TRAN}})_j$ be defined as less than the hold time temperature, T_{HT}. Note that the temperature $(T_{\mathrm{TRAN}})_j$ is not considered in the determination of the stress relaxation history; however, it is considered in the subsequent determination of the creep damage during the time duration $(t_{\mathrm{TRAN}})_j$.

Step 8. The repetition of the above Steps 3 through 7 for j = 1 to P will result in P stress/temperature time histories. These stress/temperature time histories are to be superimposed as shown in Figure HBB-T-1433-4.

Figure HBB-T-1433-1
Methods of Determining Relaxation



(a) Stress Relaxation From Isochronous Stress–Strain Curves

(b) Multiaxial Relaxation, S_r, Calculated From Uniaxial Relaxation, $\overline{S}_r$

Figure HBB-T-1433-2
Stress-Relaxation Limits for Creep Damage

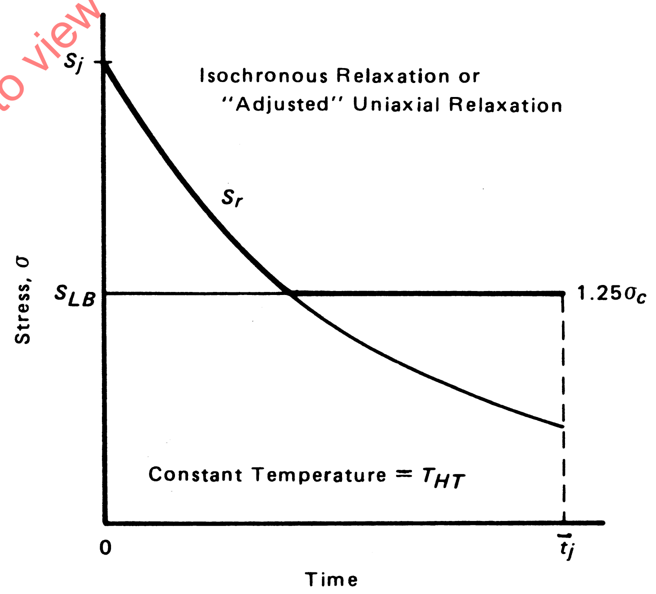


Figure HBB-T-1433-3
Stress-Relaxation Limits for Creep Damage

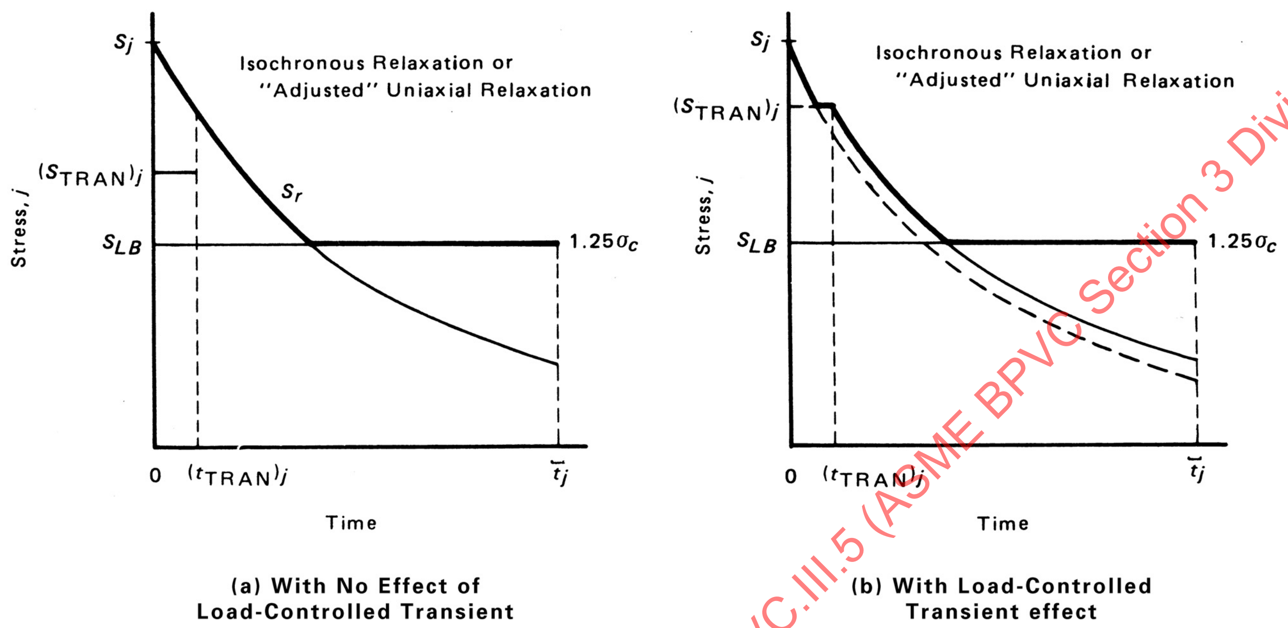
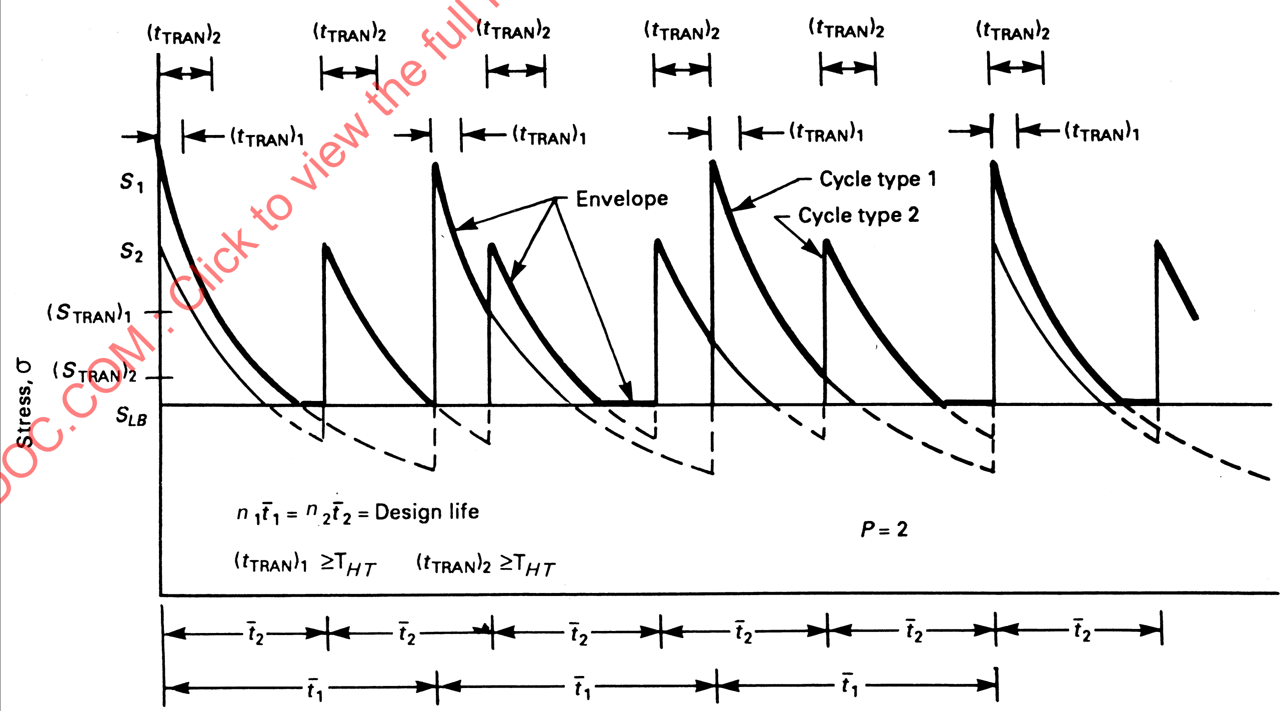


Figure HBB-T-1433-4
Envelope Stress-Time History for Creep Damage Assessment



Step 9. The resulting, composite, stress/temperature time history envelope is divided into q time intervals to facilitate the evaluation of the creep damage term of eq. HBB-T-1411(10). These q time intervals are selected to conveniently represent the composite stress/temperature history as a step-wise function of time. During each of these time intervals, $(\Delta t)_k$, the stress, $(S)_k$, and temperature, $(T)_k$, are assumed to be constant and are selected to represent the most damaging stress/temperature combination that could exist during that time interval.

Step 10. For each time interval, $(\Delta t)_k$, the allowable time duration $(T_d)_k$ of eq. HBB-T-1411(10) is obtained from the expected minimum stress-to-rupture curve of Figures HBB-I-14.6A through HBB-I-14.6F. The appropriate temperature is $(T)_k$ and the appropriate stress is $(S)_k/K'$, where K' is selected from Table HBB-T-1411-1.

(b) Alternatively, the stress/temperature time history can be defined on the basis of a single relaxation cycle for the entire design life. This alternate procedure can be used only if the total strain range ϵ_t [as determined in HBB-T-1432(h)] is less than or equal to $3\bar{S}_m/E$ for all specified cycle types, j, considered in HBB-T-1432. The stress-time history for this single relaxation curve is to be constructed using the procedure defined in (a) Steps 1 through 5. For the purposes of this calculation, the average cycle time $\bar{t}_j$ [of (a) Step 5] is to be defined as

$$\bar{t}_j = t_H$$

where t_H is as defined in (a) Step 1. Similarly, the initial stress, S_j [calculated in (a) Step 4], is to be based on the maximum value of ϵ_t that was calculated in HBB-T-1432(h). The lower bound stress, S_{LB}, is as defined in (a) Step 5. The hold-time temperature, T_{HT}, is as defined in (a) Step 2. The resulting stress-time history will be similar to that shown in Figure HBB-T-1433-2.

This single cycle, stress-time history is divided into q time intervals to conveniently represent the history as a step-wise function. During each of these time intervals $(\Delta t)_k$, the stress $(S)_k$ is assumed to be constant and is equal to the value at the start of that interval. The temperature $(T)_k$ is constant for the entire design life and is equal to T_{HT}.

For each time interval $(\Delta t)_k$, the allowable time duration $(T_d)_k$ of eq. HBB-T-1411(10) is obtained from the expected minimum stress-to-rupture curve of Figures HBB-I-14.6A through HBB-I-14.6F. The appropriate temperature is $(T)_k$ and the appropriate stress is $(S)_k/K'$; where K' is selected from Table HBB-T-1411-1.

HBB-T-1434 Calculation of Strain Range for Piping

When simplified elastic rules are used for piping analysis utilizing the stress indices of Division 1, Table NB-3681(a)-1, the equivalent strain range may be calculated directly from eq. HBB-T-1432(c)(12) or eq. HBB-T-1432(e)(14) by scalar addition of elastic and inelastic strain. The calculation of temperature distributions for use in the simplified analysis must reflect the actual component geometry.

Piping systems shall be assessed for thermal expansion elastic follow-up and its effects shall be accounted for in the strain range ϵ_t and stress intensity S_k assessments of HBB-T-1430. The follow-up analysis shall be disclosed and justified in the Design Report.

HBB-T-1435 Alternate Creep–Fatigue Evaluation

Providing the limits of HBB-T-1324 are satisfied, the rules of HBB-T-1431, HBB-T-1432, and HBB-T-1433 may be replaced by Section III Appendices, Mandatory Appendix XIII, XIII-3500, except:

(a) The reference to Section III Appendices, Mandatory Appendix I may be replaced by Figures HBB-T-1420-1A through HBB-T-1420-1E, where S_a is one half the product of ϵ_t and Young's Modulus E at the metal temperature of the cycle for the point under consideration.

(b) The S_n value in Section III Appendices, Mandatory Appendix XIII, XIII-3450, and Division 1, NB-3653.6 shall be taken as S_p.

(c) The cumulative usage factor U shall not exceed 0.90.

(d) Note the exception of HBB-T-1412.

HBB-T-1500 BUCKLING AND INSTABILITY

HBB-T-1510 GENERAL REQUIREMENTS

(a) The stability limits in Division 1, NB-3133 of Section III pertain only to specific geometrical configurations under specific loading conditions. For example, column mode buckling is not evaluated by Division 1, NB-3133. These Section III limits include the effects of initial geometrical imperfections permitted by fabrication tolerances on vessel shells. However, Section III limits do not consider the effects of creep due to long term loadings at elevated temperatures and the effects of the other loads or other geometries. The HBB-T-1500 rules provide additional limits which are

applicable to general configurations and loading conditions that may cause buckling or instability due to time-independent as well as time-dependent creep behavior of the material. These additional limits are applicable to all specified Design and Service Loadings.

(b) For the limits specified in HBB-T-1520, distinction is made between load-controlled buckling and strain-controlled buckling. Load-controlled buckling is characterized by continued application of an applied load in the post-buckling regime, leading to failure, e.g., collapse of a tube under external pressure. Strain controlled buckling is characterized by the immediate reduction of strain induced load upon initiation of buckling, and by the self-limiting nature of the resulting deformations. Even though it is self-limiting, strain controlled buckling must be avoided to guard against failure by fatigue, excessive strain, and interaction with load-controlled instability.

(c) For conditions under which strain controlled and load-controlled buckling may interact, the Load Factors applicable to load-controlled buckling shall be used for the combination of load-controlled and strain controlled loads to guard against buckling in the interactive mode.

(d) For conditions where significant elastic follow-up may occur, the Load Factors applicable to load-controlled buckling shall also be used for strain controlled buckling.

(e) For load-controlled buckling, the effects of initial geometrical imperfections and tolerances shall be considered in the time-independent calculations of HBB-T-1521; and the effects of the geometrical imperfections and tolerances, whether initially present or induced by service, shall be considered in the time-dependent calculations of HBB-T-1522.

(f) For purely strain controlled buckling, the effects of geometrical imperfections and tolerances, whether initially present or induced by service, need not be considered in the calculation of the instability strain. However, if significant geometrical imperfections are present initially, enhancement due to creep may cause excessive deformation or strain. These effects shall be considered in the application of deformation and strain limits of HBB-T-1200 and HBB-T-1300.

(g) The expected minimum stress-strain curve for the material at the specified temperatures shall be used. The expected minimum values may be obtained by normalizing the inelastic portion of the appropriate average hot tensile curve in HBB-T-1830 to the tabulated yield strength given in Table HBB-I-14.5.

When re-solution annealed Type 300 series austenitic stainless steel is utilized, the tabulated yield strength shall be further reduced by 17%. This reduction is not required if it is demonstrated by test that the room temperature yield strength meets the specified minimum values following resolution annealing. For 9Cr-1Mo-V, the minimum stress-strain curve to be used for buckling analysis will generally be dependent on the expected loading rate. At higher temperatures, unified constitutive equations, which do not distinguish between rate-dependent plasticity and time-dependent creep, should be used for satisfying the buckling limits of HBB-T-1520.

(h) The limits of both HBB-T-1521 and HBB-T-1522 shall be satisfied for the specified Design and Service Loadings.

HBB-T-1520 BUCKLING LIMITS

HBB-T-1521 Time-Independent Buckling

For load-controlled buckling, the Load Factor, and for strain controlled buckling, the Strain Factor, shall equal or exceed the values given in Table HBB-T-1521-1 for the specified Design and Service Loadings to guard against time-independent (instantaneous) buckling. Alternatively, for cylindrical shells under external pressure or axial compression, with or without stiffeners, and for spherical shells under external pressure, the design limits of Division 1, NB-3133 may be applied.

HBB-T-1522 Time-Dependent Buckling

To protect against load-controlled time-dependent creep buckling, it shall be demonstrated that instability will not occur during the specified lifetime for a load history obtained by multiplying the specified Service Loadings by the factors given in Table HBB-T-1522-1. A design factor is not required for purely strain controlled buckling because strain controlled loads are reduced concurrently with resistance of the structure to buckling when creep is significant. Alternatively, for temperatures below the limits of Figure HBB-T-1522-1, Figure HBB-T-1522-2, or Figure HBB-T-1522-3, the design limits of Division 1, NB-3133 or of HBB-T-1521 may be applied without consideration of creep effects. The temperature limits of Figures HBB-T-1522-1 and HBB-T-1522-2 are given in terms of design life and are applicable for any radius-to-thickness ratio. The temperature limits of Figure HBB-T-1522-3 are given in terms of radius-to-thickness ratio and are applicable for any design life.

Table HBB-T-1521-1
Time-Independent Buckling Factors

	Load Factor [Note (1)]	Strain Factor [Note (1)], [Note (2)]
Design Loadings	3.0	1.67
Service Loadings		
Level A	3.0	1.67
Level B	3.0	1.67
Level C	2.5	1.4
Level D	1.5	1.1
Test Loadings [Note (3)]	2.25	1.67

NOTES:

(1)

$$\text{Load (Strain) Factor} = \left[\begin{array}{c}\text{Load (strain) which}\\ \text{would cause instant}\\ \text{instability at the}\\ \text{Design (or actual}\\ \text{Service) Temperature}\end{array}\right] \div \left[\begin{array}{c}\text{Design or}\\ \text{expected}\\ \text{load}\\ \text{(strain)}\end{array}\right]$$

Changes in configuration induced by service need not be considered in calculating the buckling load.

(2) For thermally induced strain controlled buckling, the Strain Factor is applied to loads induced by thermal strain. To determine the buckling strain, it may be necessary to artificially induce high strains concurrent with the use of realistic stiffness properties. The use of an *adjusted* thermal expansion coefficient is one technique for enhancing the applied strains without affecting the associated stiffness characteristics.

(3) These factors apply to hydrostatic, pneumatic, and leak tests. Other types of tests shall be classified according to HBB-3113.7.

Table HBB-T-1522-1
Time-Dependent Load-Controlled Buckling Factors

Service Loadings	Factors
Level A	1.5
Level B	1.5
Level C	1.5
Level D	1.25

Figure HBB-T-1522-1
Time–Temperature Limits for Application of Section II External Pressure Charts

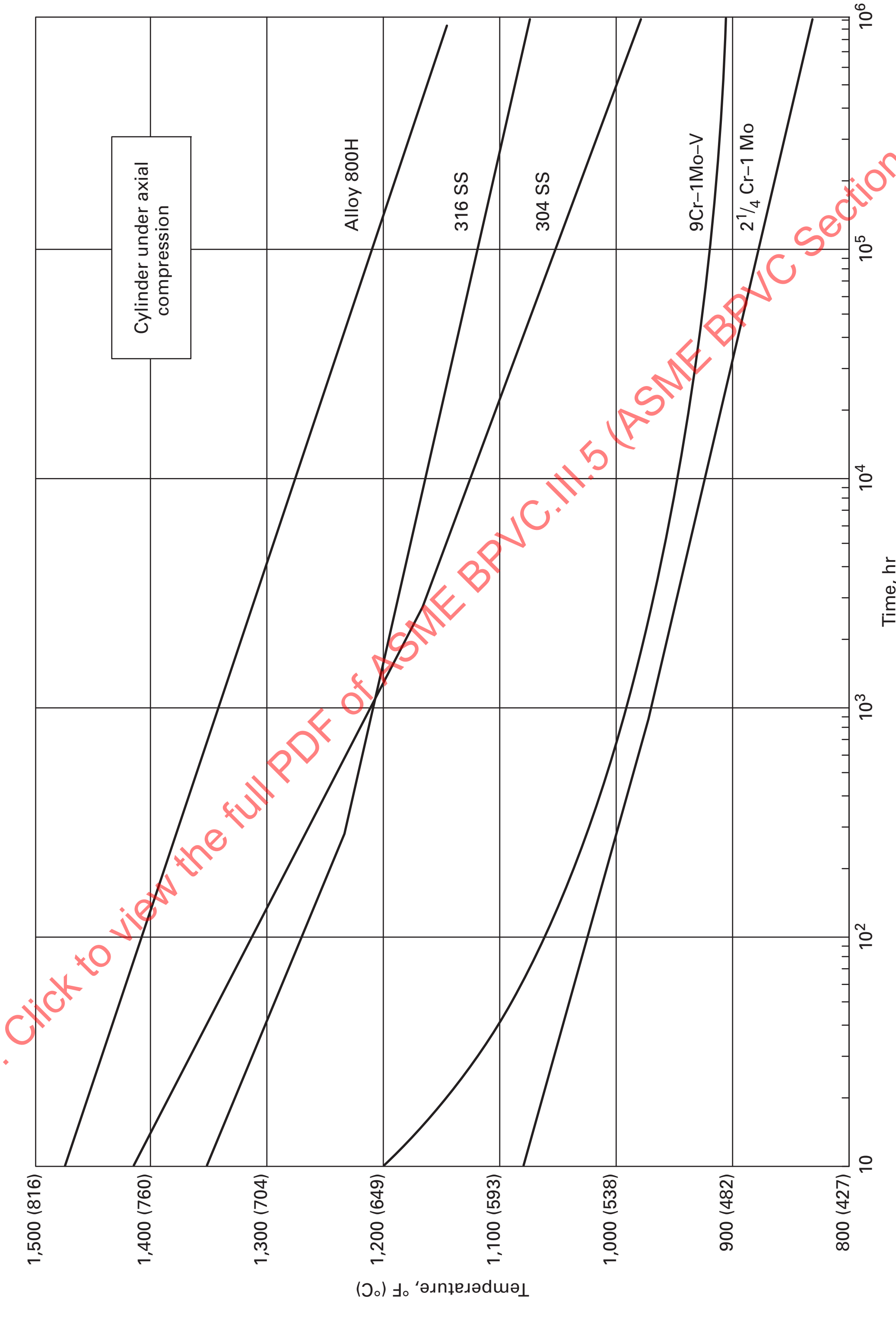


Figure HBB-T-1522-2
Time–Temperature Limits for Application of Section II External Pressure Charts

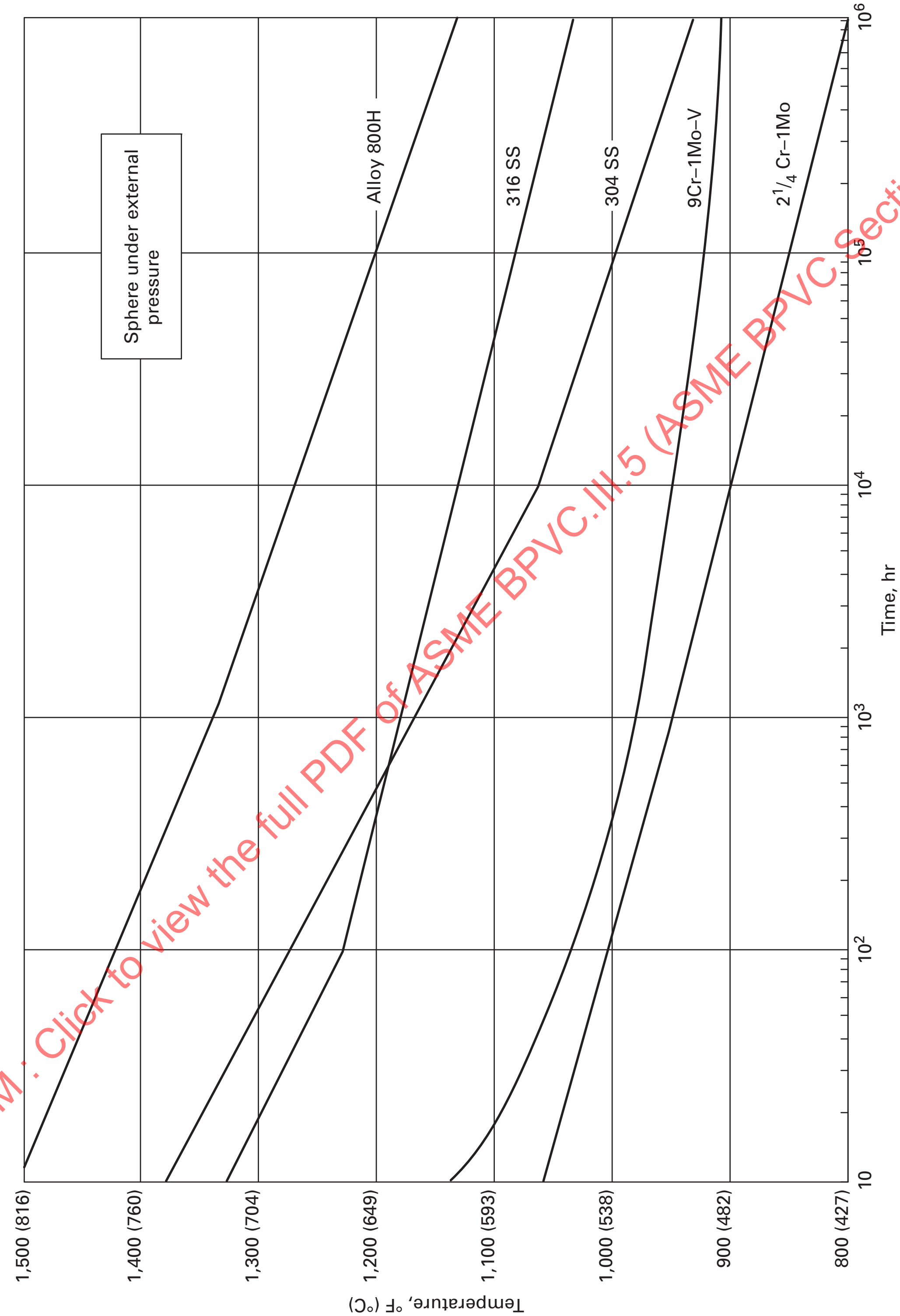
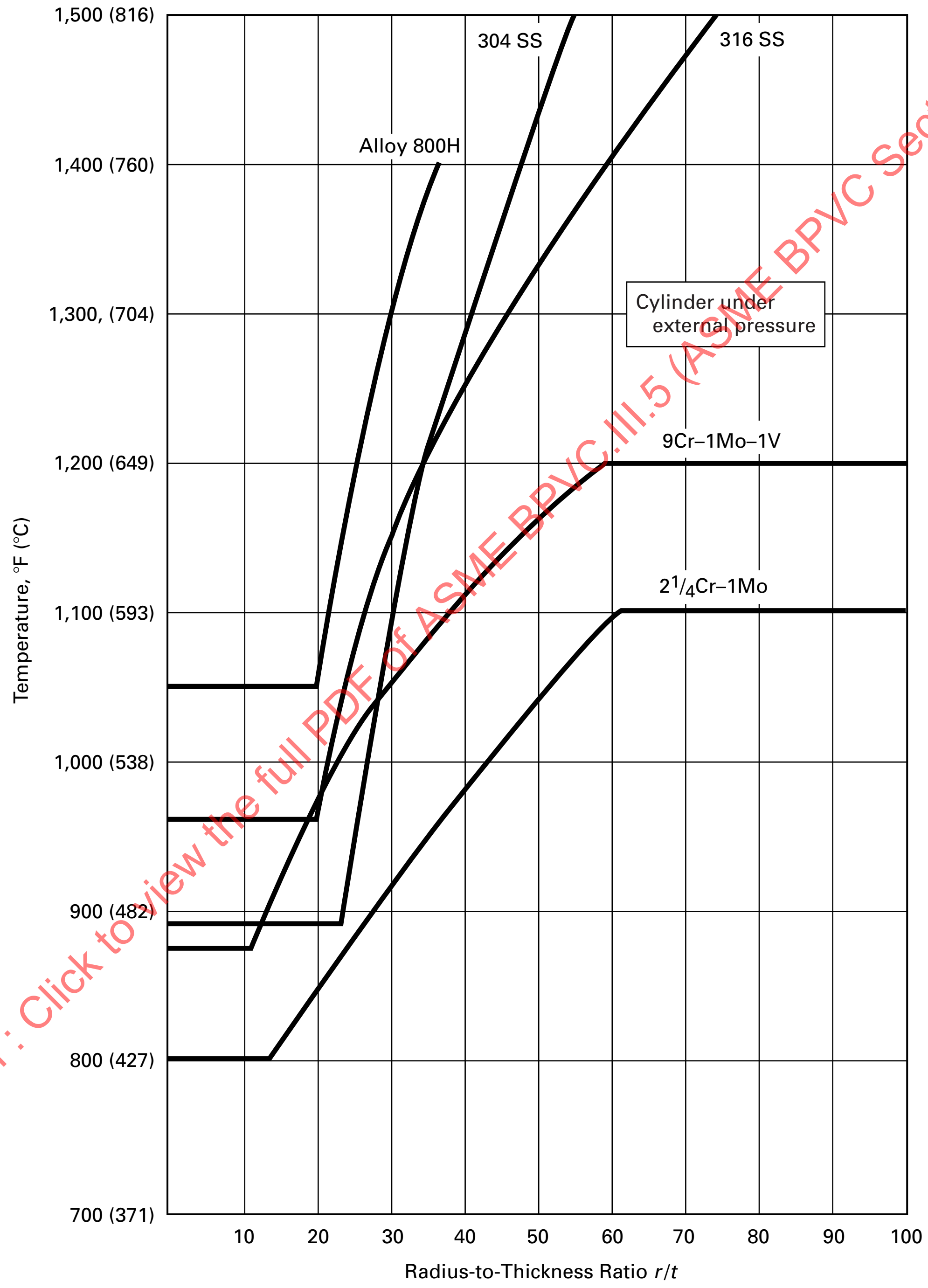


Figure HBB-T-1522-3
Temperature Limits for Application of Section II External Pressure Charts



HBB-T-1700 SPECIAL REQUIREMENTS

HBB-T-1710 SPECIAL STRAIN REQUIREMENTS AT WELDS

HBB-T-1711 Scope

Because of the potential for limited ductility of weld metal at elevated temperatures and the potential for high strain concentrations (both metallurgical and geometric) in the heat-affected zone of weldments, the additional analysis requirements of this Appendix shall be satisfied for all pressure boundary and other primary structural welds subjected under Service Level A, B, and C Loadings to metal temperatures where creep effects are significant (see HBB-3211). The potential for reduced ductility often precludes locating welds in regions of high loading.

HBB-T-1712 Material Properties

In calculating strain deformations in a weld region, the parent material properties shall be used up to the centerline of the weld.

HBB-T-1713 Strain Limits

Inelastic strains accumulated in the weld region shall not exceed one-half the strain values permitted for the parent material (see HBB-T-1310).

HBB-T-1714 Analysis of Geometry

The analysis for strains and creep–fatigue interactions at welds shall use stress and strain concentration factors appropriate for the worst surface geometry and shall be included in the Design Report (NCA-3211.40). The worst surface geometry for a given weld shall be determined by the methods described in HBB-3353.

HBB-T-1715 Creep–Fatigue Reduction Factors

In the vicinity of a weld (defined by ±3 times the thickness to either side of the weld centerline), the creep-fatigue evaluation of HBB-T-1400 shall utilize reduced values of the allowable number of design cycles N_d and the allowable time duration T_d in eq. HBB-T-1411(10). The N_d value shall be one-half the value permitted for the parent material (Figures HBB-T-1420-1A through HBB-T-1420-1E). The T_d value shall be determined from a stress-to-rupture curve obtained by multiplying the parent material stress-to-rupture values (Tables HBB-I-14.6A through HBB-I-14.6F) by the weld strength reduction factors given in Tables HBB-I-14.10A-1 through HBB-I-14.10E-1, and defined in HBB-3220. The factor K' (Table HBB-T-1411-1) must still be applied in this determination of T_d.

HBB-T-1720 STRAIN REQUIREMENTS FOR BOLTING

HBB-T-1721 Strain Limits

The limits of HBB-T-1300 shall apply.

HBB-T-1722 Creep–Fatigue Damage Accumulation

The fatigue analysis exemptions in Section III Appendices, Mandatory Appendix XIII, XIII-3510 shall not apply. Creep and fatigue damage shall be assessed using eq. HBB-T-1411(10). The total damage factor, D, shall be set at the appropriate value determined from Figure HBB-T-1420-2. Additional requirements are given in (a) and (b) below.

(a) Unless it can be shown by analysis or tests that a lower fatigue strength reduction factor and/or a lower stress rupture reduction factor is appropriate, the reduction factors shall be not less than 4.0 and 1.8, respectively, for the threaded region.

(b) The geometrical restriction of the thread and fillet radii at the end of the shank as described in Section III Appendices, Mandatory Appendix XIII, XIII-4230(b)(2) and XIII-4230(b)(3) shall apply.

HBB-T-1800 ISOCHRONOUS STRESS–STRAIN RELATIONS

HBB-T-1810 OBJECTIVE

This subarticle presents isochronous stress–strain relations to provide the Designer with information about the total strain caused by stress under elevated temperature conditions, assuming average material properties. The isochronous-stress–strain curves are provided as equations in HBB-T-1830 for the materials and the temperature and time limits specified in Table HBB-T-1820-1. Figures HBB-T-1831-1 through HBB-T-1835-11 show the isochronous stress–strain curves for these materials at specific temperatures and times.

HBB-T-1820 MATERIALS AND TEMPERATURE LIMITS

Table HBB-T-1820-1 provides temperature and time limits for the use of the isochronous stress–strain relations.

The isochronous stress–strain relations provided herein shall not be used to compute values of stress corresponding to total strains greater than 2.2%.

HBB-T-1830 ISOCHRONOUS CURVES

The equations describing each material are given as relations between stress and temperature and elastic and plastic strain and stress, temperature, and time and creep strain. All materials use an additive model

$$\varepsilon = \varepsilon_e + \varepsilon_p + \varepsilon_c$$

where

ε = the total strain
ε_c = the creep strain
ε_e = the elastic strain
ε_p = the plastic strain

Hot tensile curves are the stress–strain relation for each material for a fixed temperature and zero creep strain (ε_c = 0). The isochronous curves are the stress–strain relation for each material for a fixed temperature and time.

The equations use the following units: for time (t), hours; for temperature (T), degrees Celsius; for stress (σ), MPa; and for strain (ε), nominal values (mm/mm). All strain and stress values are in the engineering convention of strain, referencing the original gauge length, and the engineering convention for stress, referencing the original sample cross-section.

The equations for determining the elastic strain, plastic strain and creep strain are expressed in terms of temperature and stress in SI units. When working in U.S. Customary units or other local customary units, the temperature and stress values should first be converted to °C and MPa units, respectively, and then be entered into the equations to obtain the appropriate strain values.

In the following, ln denotes the natural logarithm and log denotes a logarithm base 10. The notation max { } means take the value in the bracketed list with the maximum value.

HBB-T-1831 304 SS (23)

Use Tables HBB-T-1831-1 through HBB-T-1831-4 as indicated to determine the value of the specified parameters. Figures HBB-T-1831-1 through HBB-T-1831-17 show the isochronous stress–strain curve for each fixed temperature.

(a) Elastic Strain

Table HBB-T-1820-1 (23)
Temperature and Time Limits for Alloys in Isochronous Stress–Strain Curves

Material	Minimum Temperature, °F (°C)	Maximum Temperature, °F (°C)	Maximum Time, hr
304 SS	800 (427)	1,500 (816)	300,000
316 SS	800 (427)	1,500 (816)	300,000
Alloy 800H	800 (427)	1,400 (760)	300,000
$2^1/_4$Cr–1Mo	700 (371)	1,200 (649)	300,000
9Cr–1Mo–V	700 (371)	1,200 (649)	500,000

$$\varepsilon_e = \frac{\sigma}{E}$$

where

E = 232,181 − 95.3063(T + 273.15)

(b) *Plastic Strain*

$$\begin{aligned}\varepsilon_p &= 0 \text{ for } \sigma \le \sigma_p \\ &= \left(\frac{\sigma - \sigma_p}{K}\right)^{1/m} \text{ for } \sigma > \sigma_p\end{aligned}$$

where

K = 482.38 − 0.17547(T + 273.15)
m = 0.25 824 + 7.749 × 10^{-5}(T + 273.15)
σ_p = σ_y + [−84.1023 + 0.046259(T + 273.15)]

σ_y = 222.79 − 0.11047(T + 273.15)

(c) *Creep Strain*

$$\varepsilon_c = \frac{1}{100}\left[\varepsilon_s\left(1 - e^{-st}\right) + \varepsilon_r\left(1 - e^{-rt}\right) + \dot{\varepsilon}_m t\right]$$

where

$$s = D\left[\sinh\left(\frac{145.037681\beta_r\sigma}{n_r}\right)\right]^{n_r} e^{\left(\frac{-Q}{R(T + 273.15)}\right)}$$

D = Table HBB-T-1831-3
Q = 67,000
R = 1.987
β_r = −2.252 × 10^{-4} + 5.401 × 10^{-7}(T + 273.15)
n_r = 3.5

$$\dot{\varepsilon}_m = A\left[\sinh\left(\frac{145.037681\beta_e\sigma}{n_e}\right)\right]^{n_e} e^{\left(\frac{-Q}{R(T + 273.15)}\right)}$$

A = 1.38 × 10^{13}
β_e = −3.652 × 10^{-4} + 7.518 × 10^{-7}(T + 273.15)
n_e = 6

$$\varepsilon_r = \frac{C\dot{\varepsilon}_m}{r}$$

C = Table HBB-T-1831-4

$$r = B\left[\sinh\left(\frac{145.037681\beta_r\sigma}{n_r}\right)\right]^{n_r} e^{\left(\frac{-Q}{R(T + 273.15)}\right)}$$

B = 2.518 × 10^{13}

ε_s = 0 for $\sigma \le$ 41.3683
= G + 145.037681$H\sigma$ for σ > 41.3683

G = Table HBB-T-1831-1
H = Table HBB-T-1831-2

Table HBB-T-1831-1

Temperature Range	G
$800 \le T_F < 850$	0.0
$850 \le T_F \le 1{,}000$	$2.24449 - 3.08547 \times 10^{-3} T_K$
$1{,}000 < T_F < 1{,}100$	−0.257143
$1{,}100 \le T_F \le 1{,}500$	−0.257143

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1831-2

Temperature Range	H
$800 \le T_F < 850$	0.0
$850 \le T_F \le 1{,}000$	$-3.74081 \times 10^{-4} + 5.14\,244 \times 10^{-7} T_K$
$1{,}000 < T_F < 1{,}100$	4.28571×10^{-5}
$1{,}100 \le T_F \le 1{,}500$	4.28571×10^{-5}

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1831-3

Temperature Range	D
$800 \le T_F < 850$	2.266×10^{15}
$850 \le T_F \le 1{,}000$	2.266×10^{15}
$1{,}000 < T_F < 1{,}100$	$3.19663 \times 10^{16} e^{-(3.66218 \times 10^{-3} T_K)}$
$1{,}100 \le T_F \le 1{,}500$	2.518×10^{14}

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1831-4

Temperature Range	C
$800 \leq T_F < 850$	$2.469 \times 10^{-3} e^{6580.986/T_K}$
$850 \leq T_F \leq 1{,}000$	$2.469 \times 10^{-3} e^{6580.986/T_K}$
$1{,}000 < T_F < 1{,}100$	$56.2405 - 5.91691 \times 10^{-2} T_K$
$1{,}100 \leq T_F \leq 1{,}500$	5.0

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Figure HBB-T-1831-1
Average Isochronous Stress–Strain Curves

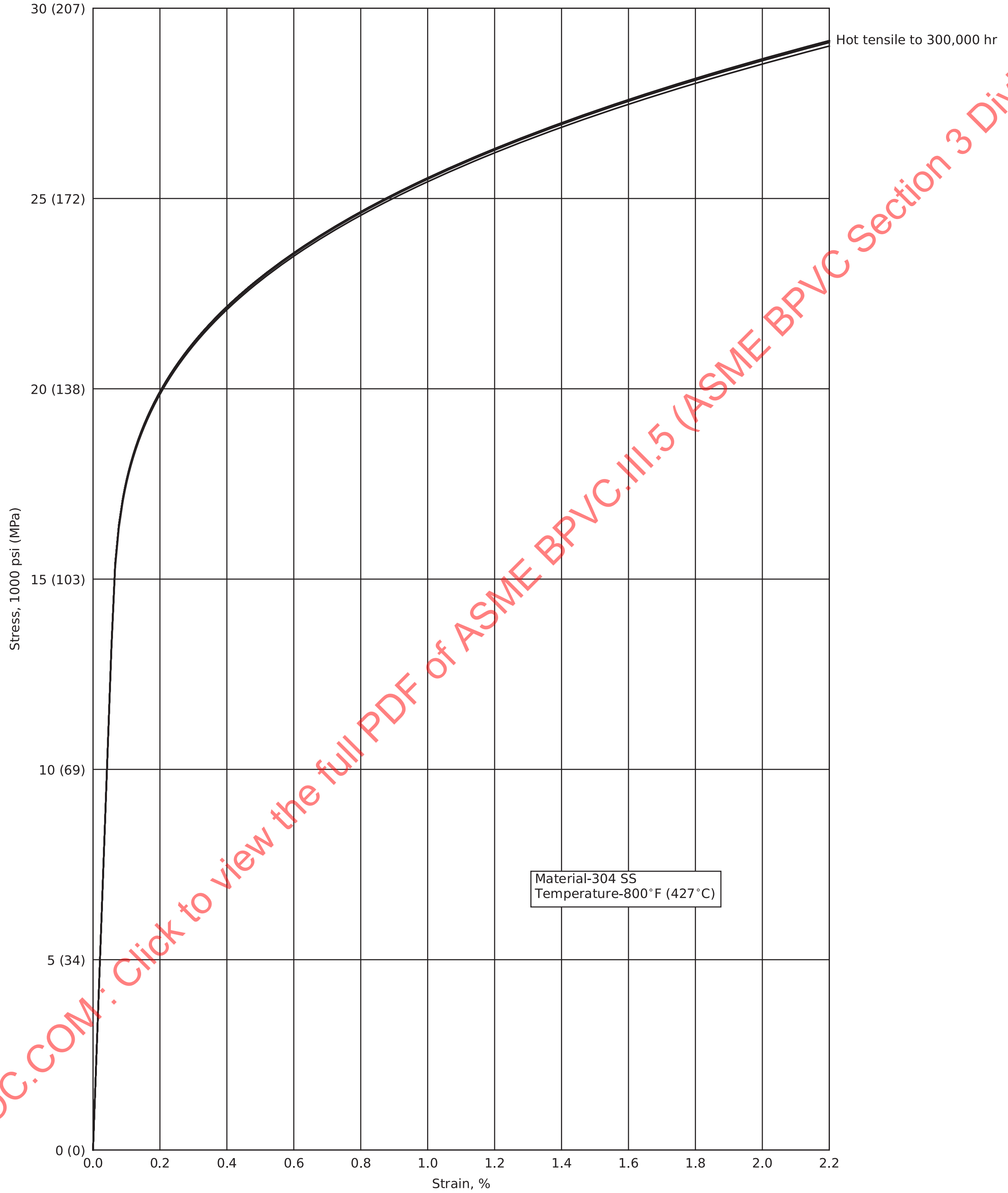


Figure HBB-T-1831-2
Average Isochronous Stress–Strain Curves

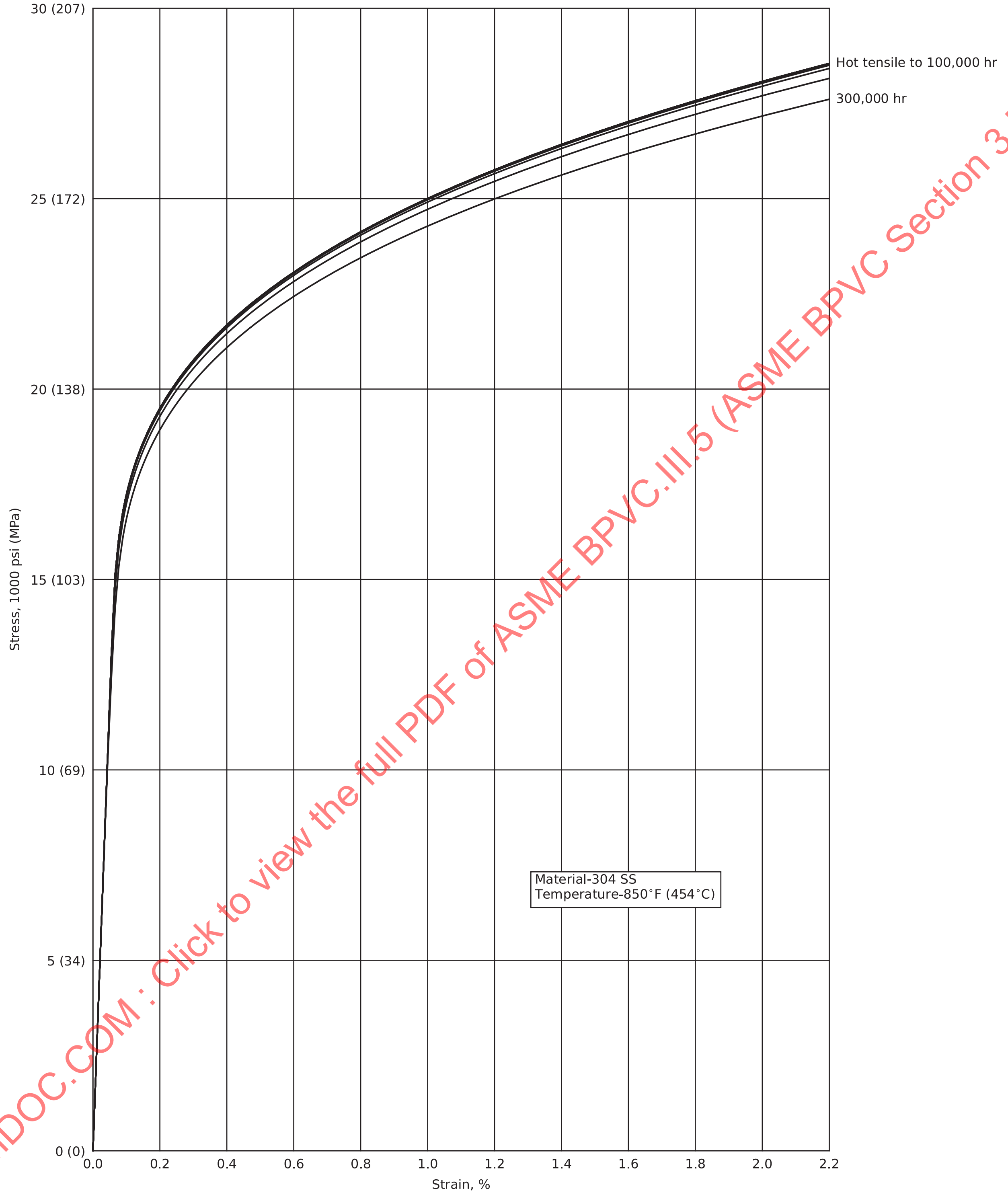


Figure HBB-T-1831-3
Average Isochronous Stress–Strain Curves

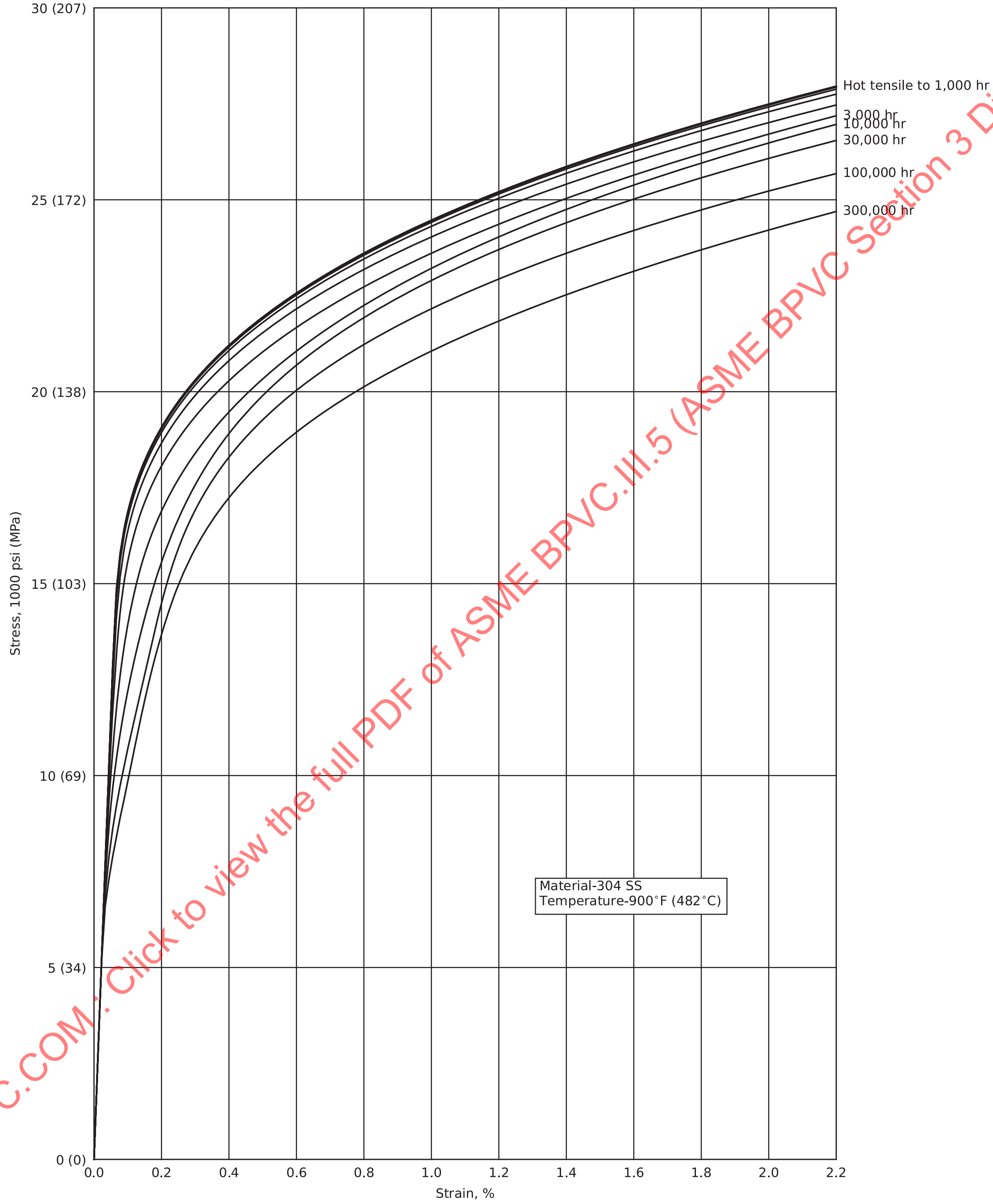


Figure HBB-T-1831-4
Average Isochronous Stress–Strain Curves

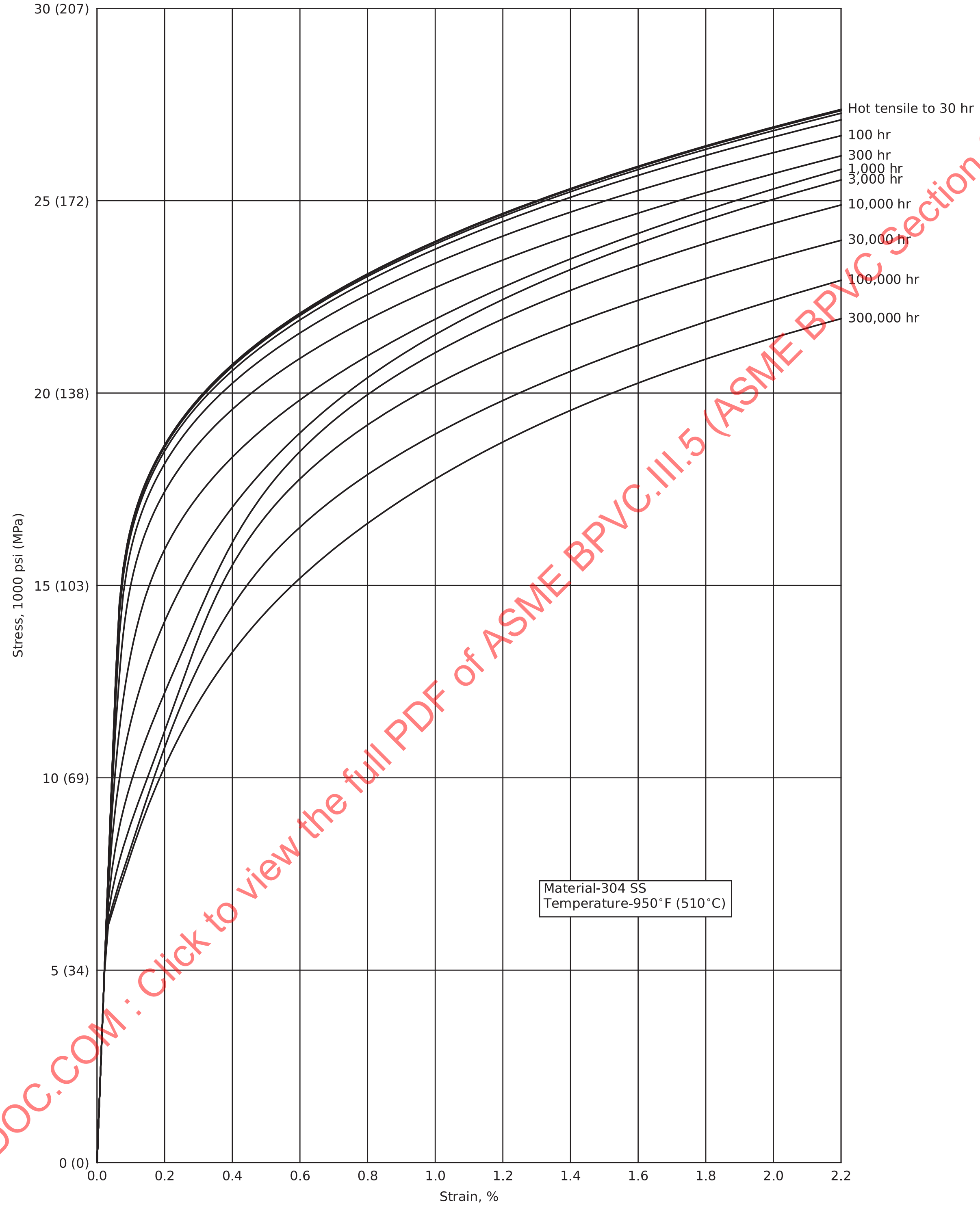


Figure HBB-T-1831-5
Average Isochronous Stress–Strain Curves

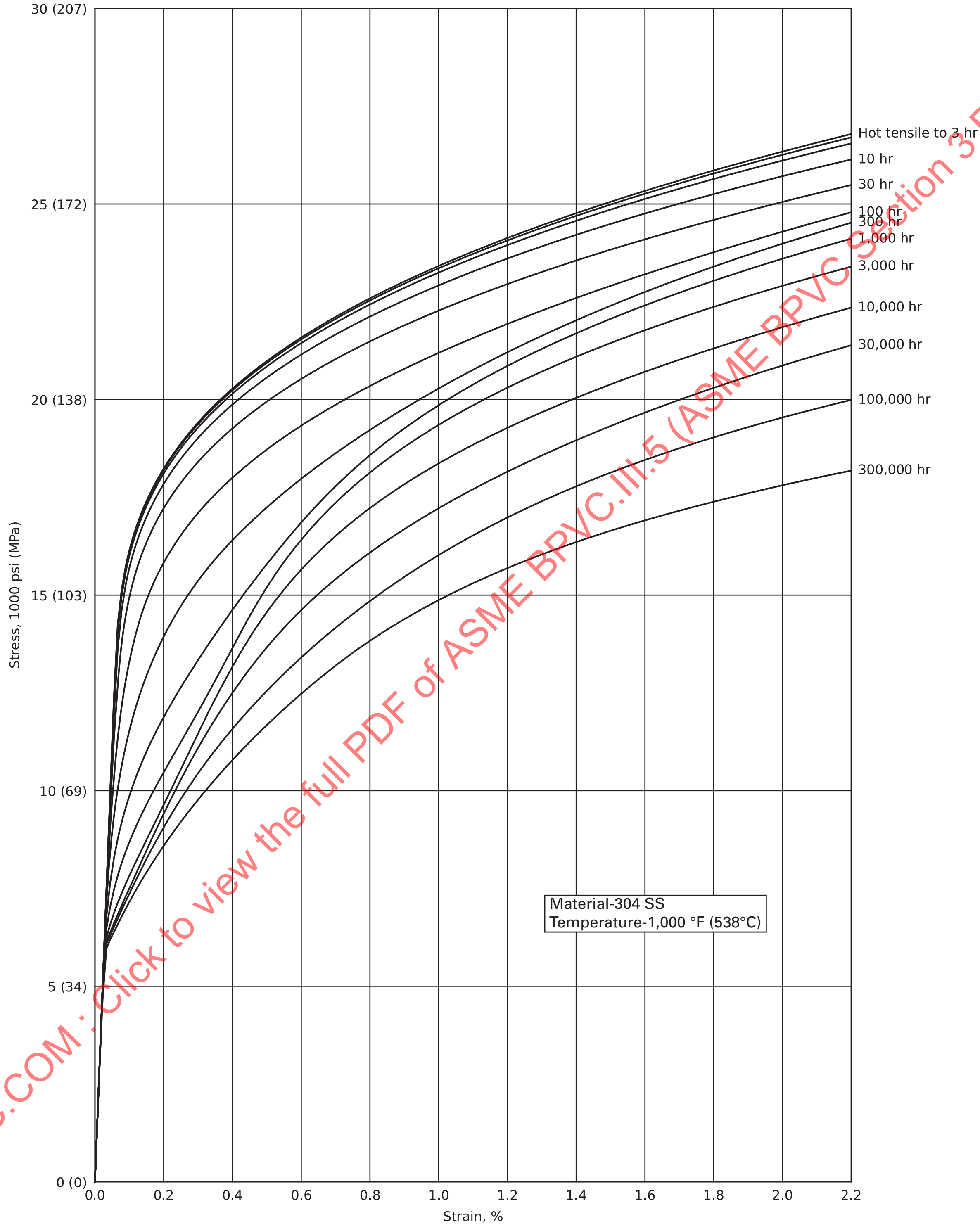


Figure HBB-T-1831-6
Average Isochronous Stress–Strain Curves

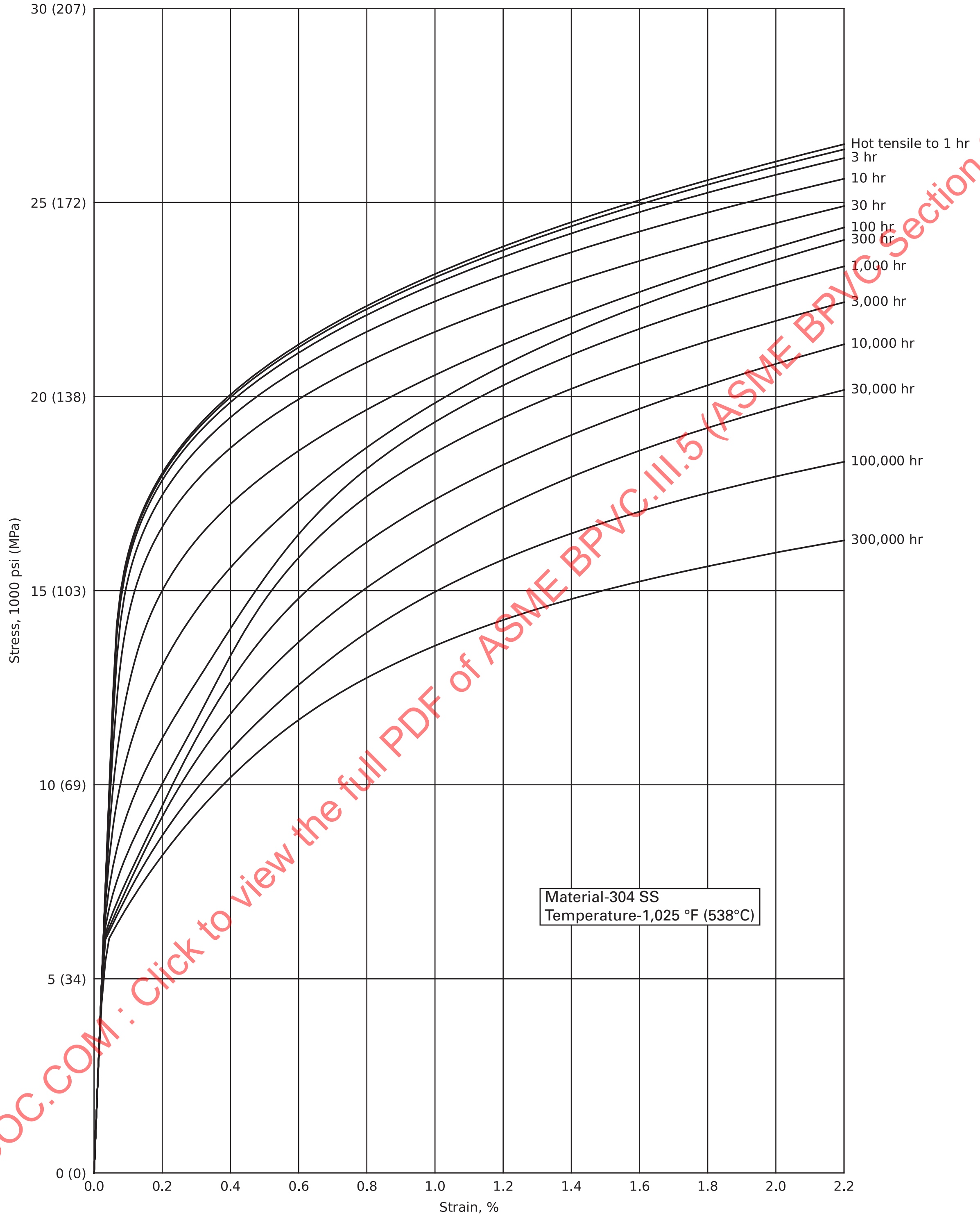


Figure HBB-T-1831-7
Average Isochronous Stress–Strain Curves

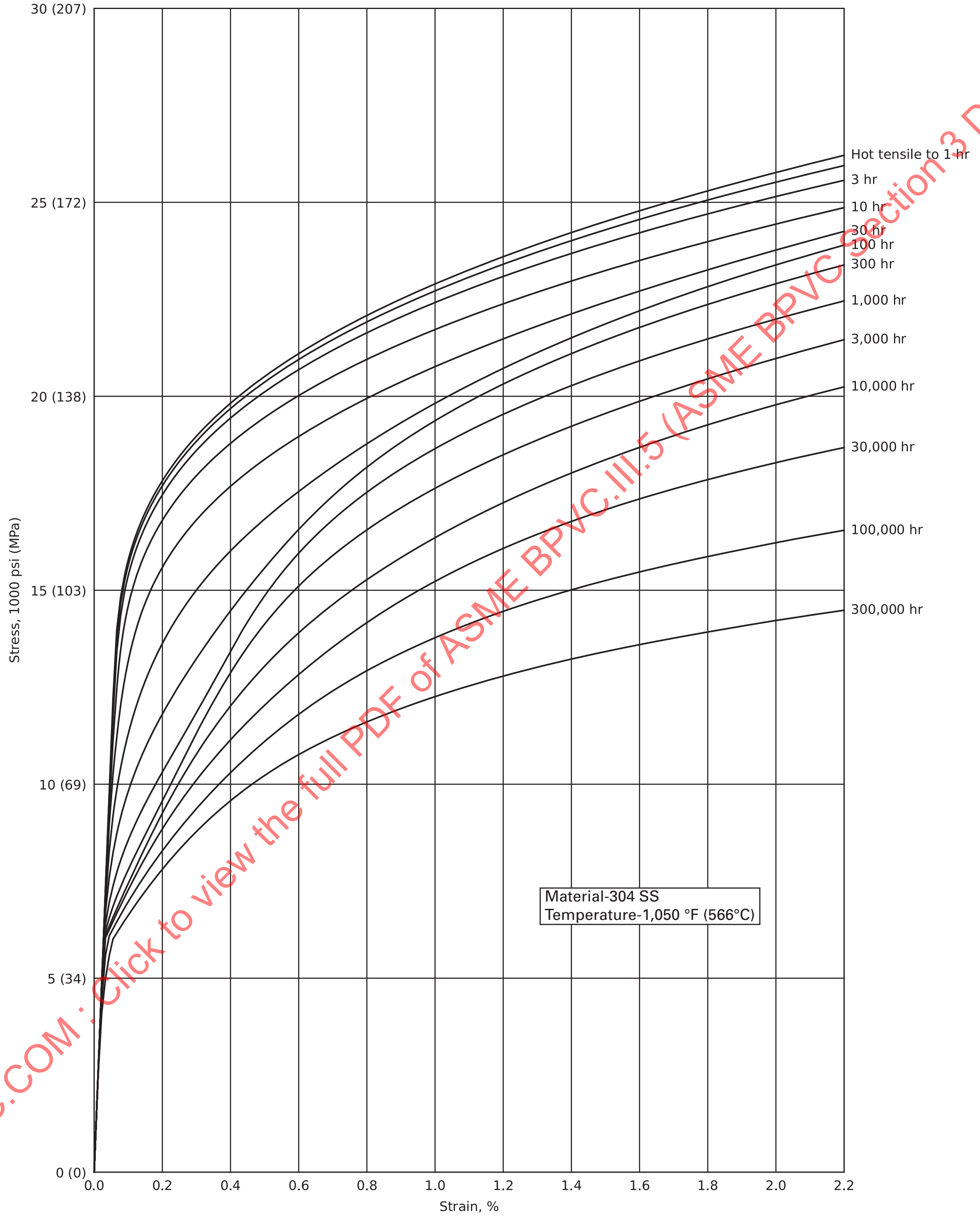


Figure HBB-T-1831-8
Average Isochronous Stress–Strain Curves

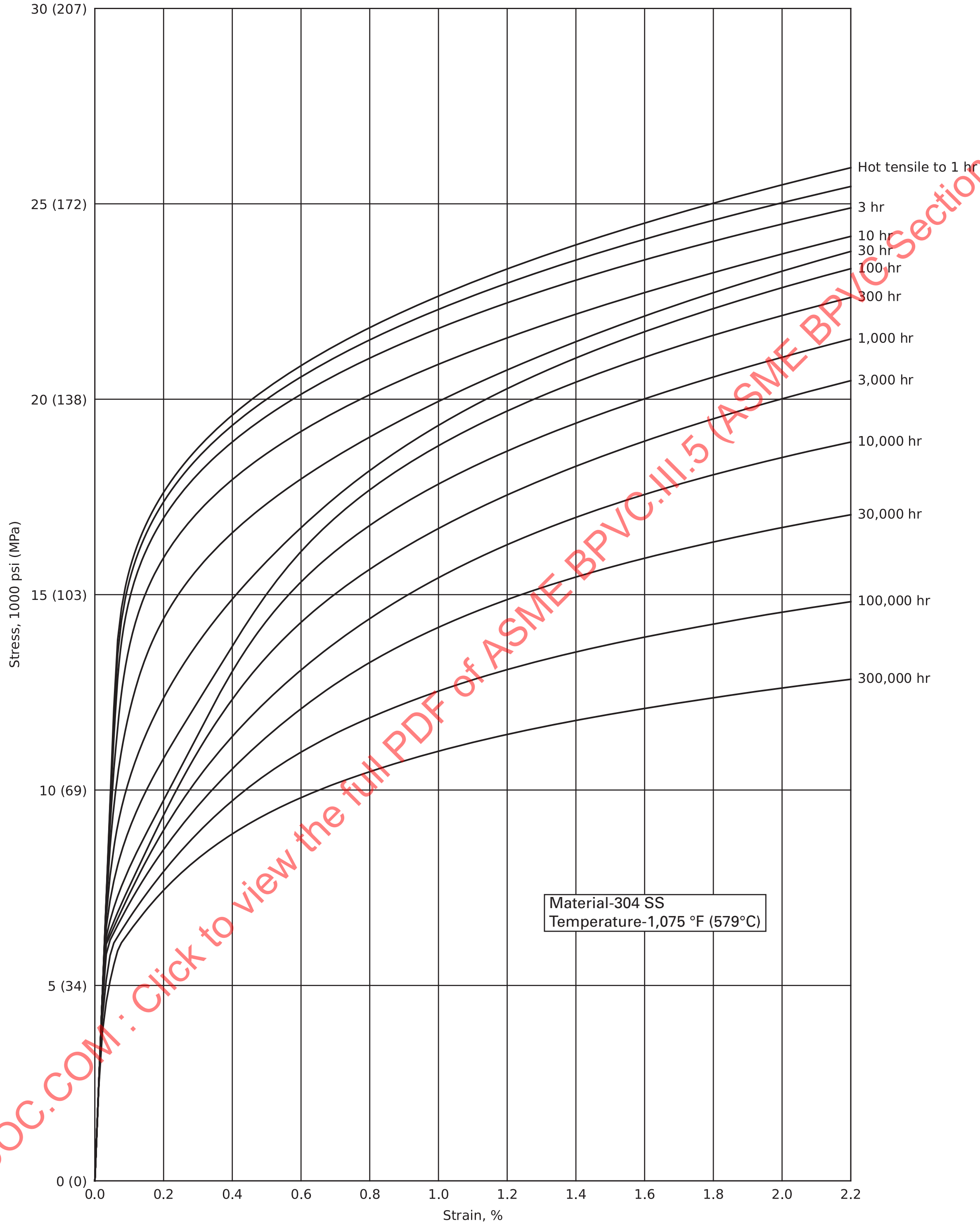


Figure HBB-T-1831-9
Average Isochronous Stress–Strain Curves

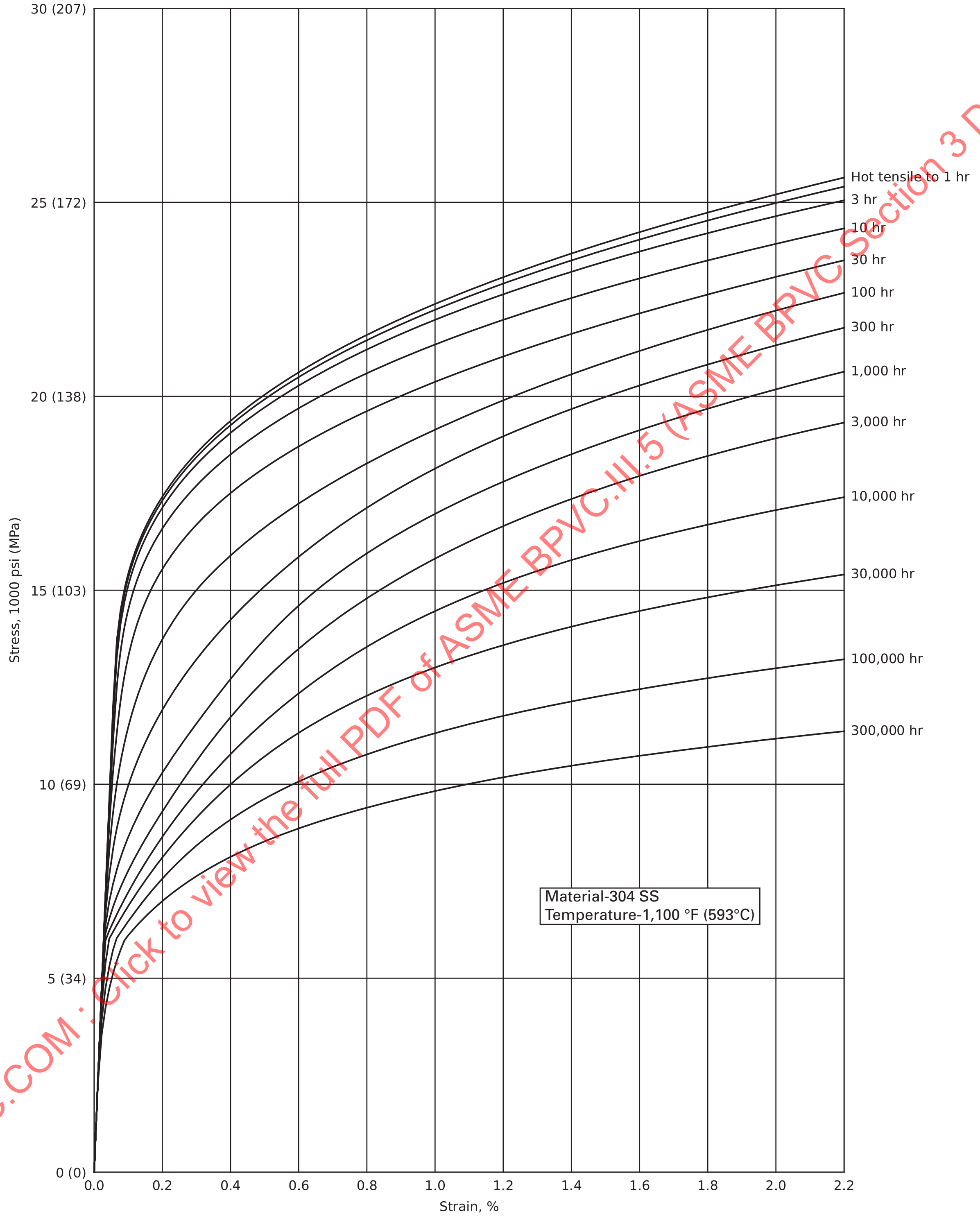


Figure HBB-T-1831-10
Average Isochronous Stress–Strain Curves

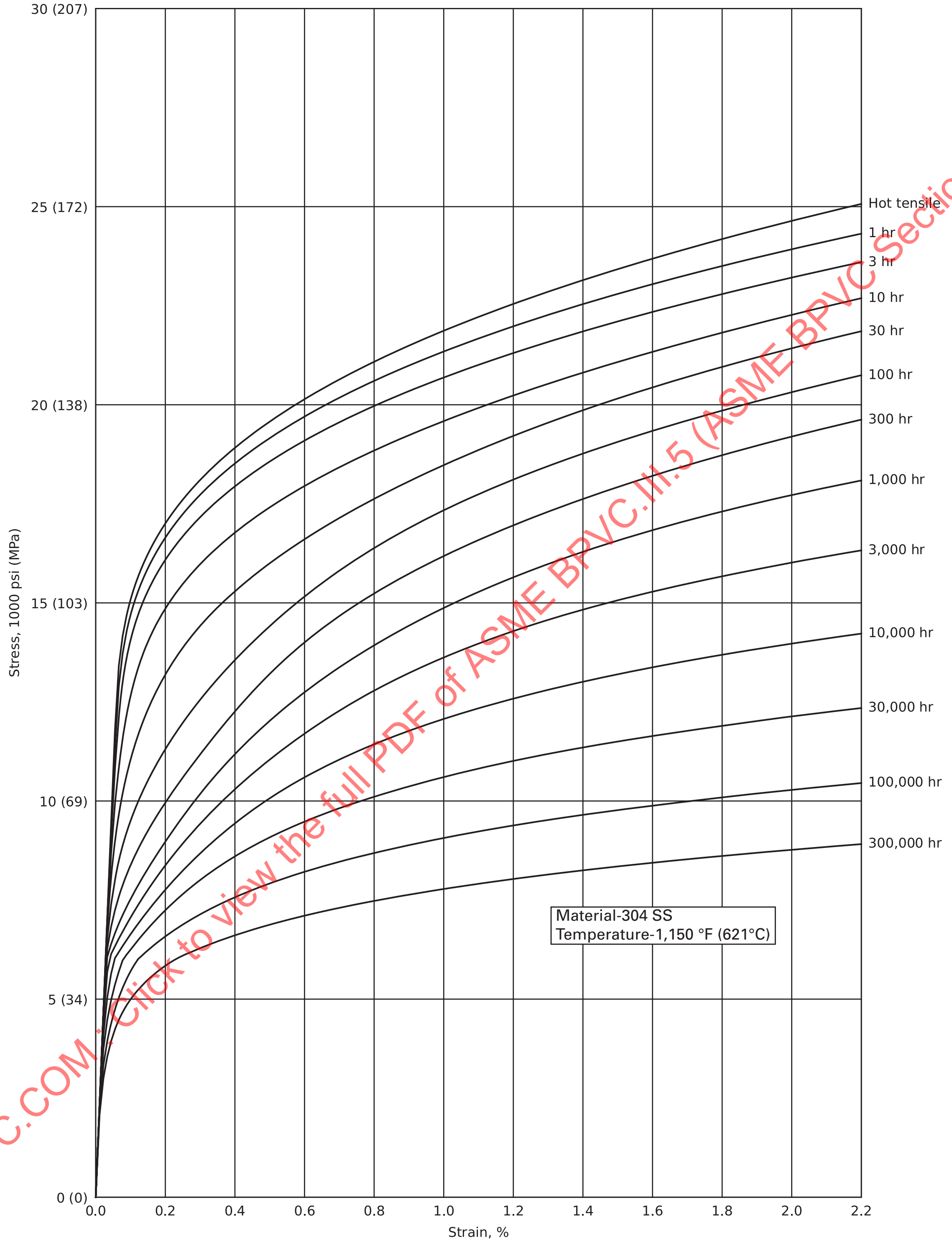


Figure HBB-T-1831-11
Average Isochronous Stress–Strain Curves

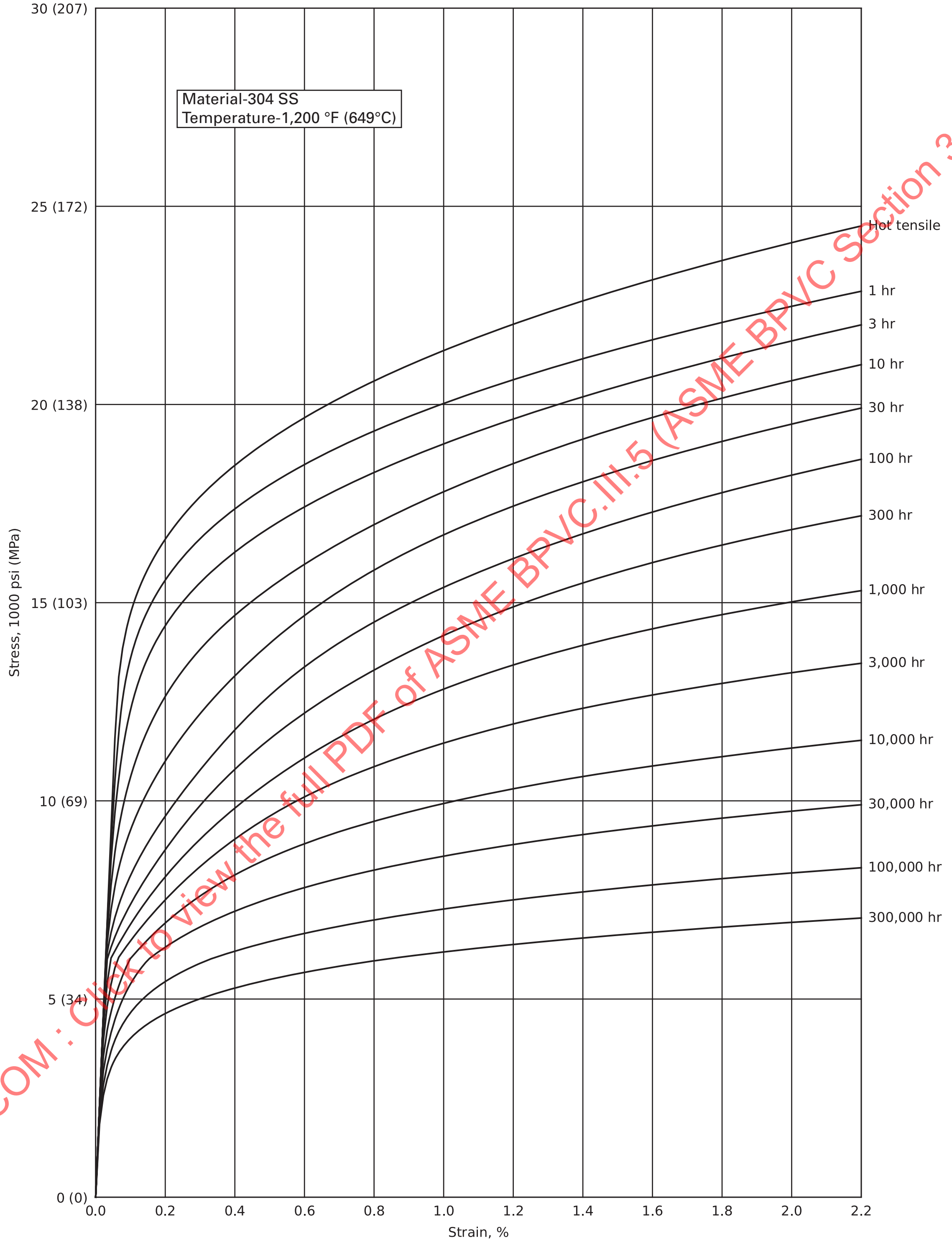


Figure HBB-T-1831-12
Average Isochronous Stress–Strain Curves

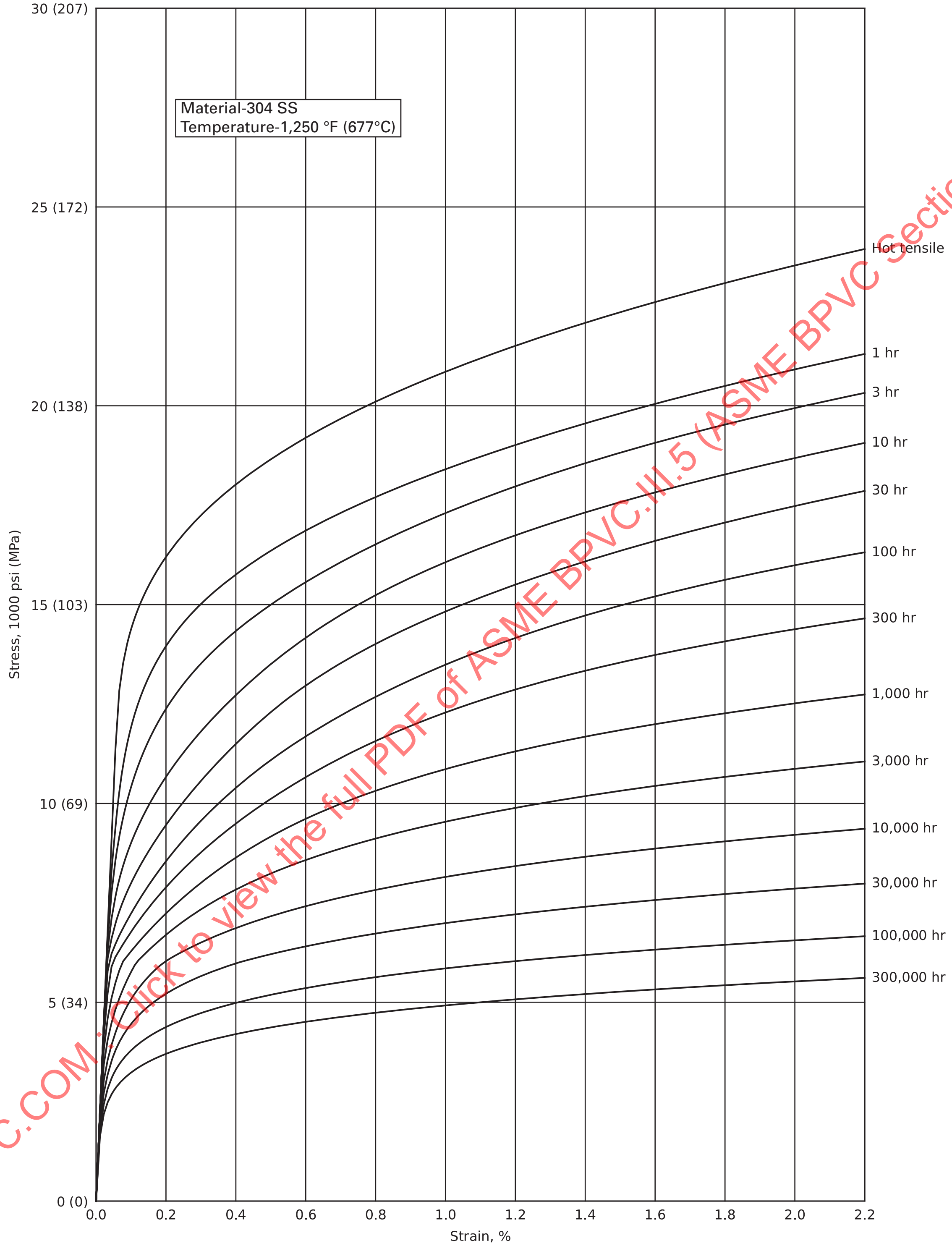


Figure HBB-T-1831-13
Average Isochronous Stress–Strain Curves

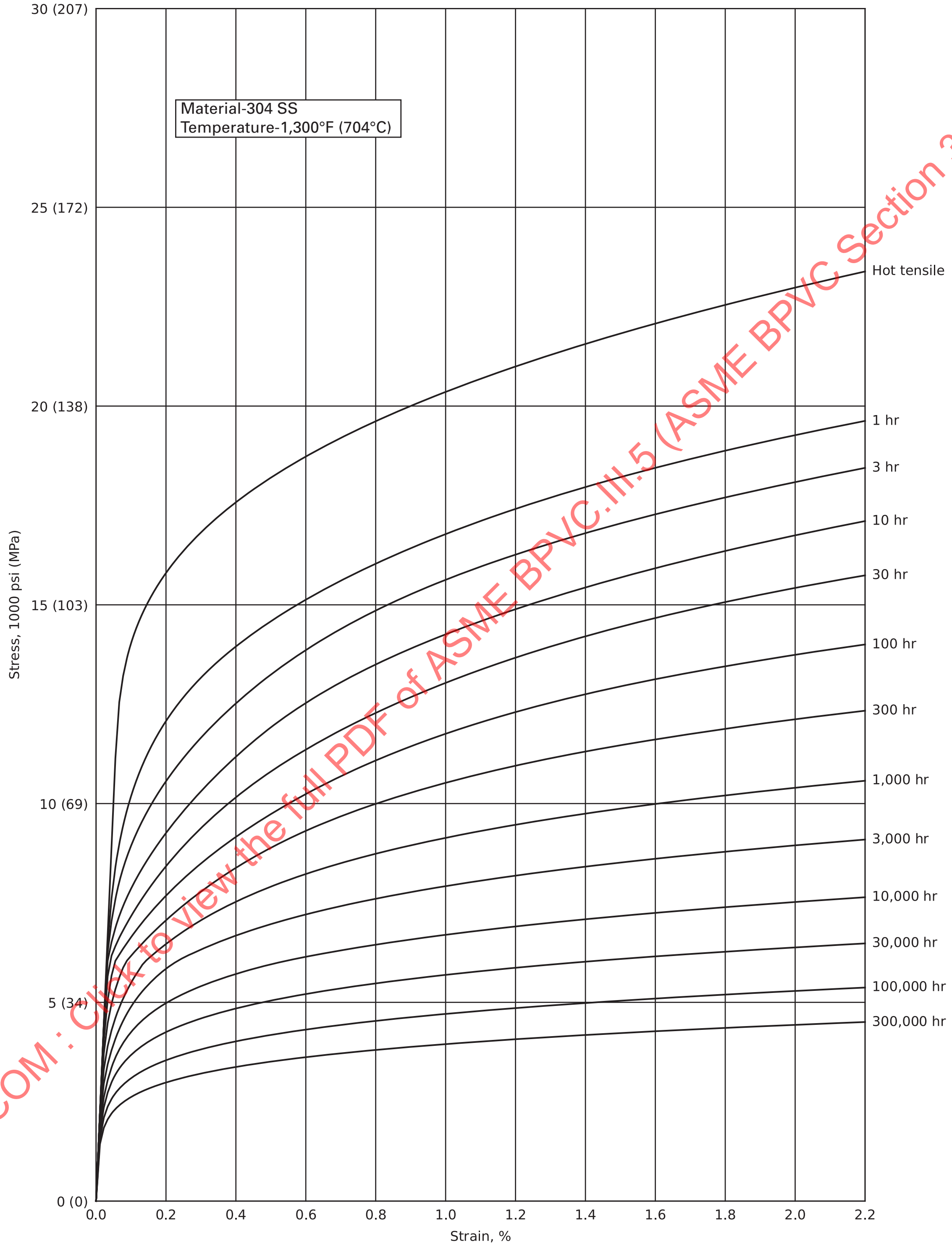


Figure HBB-T-1831-14
Average Isochronous Stress–Strain Curves

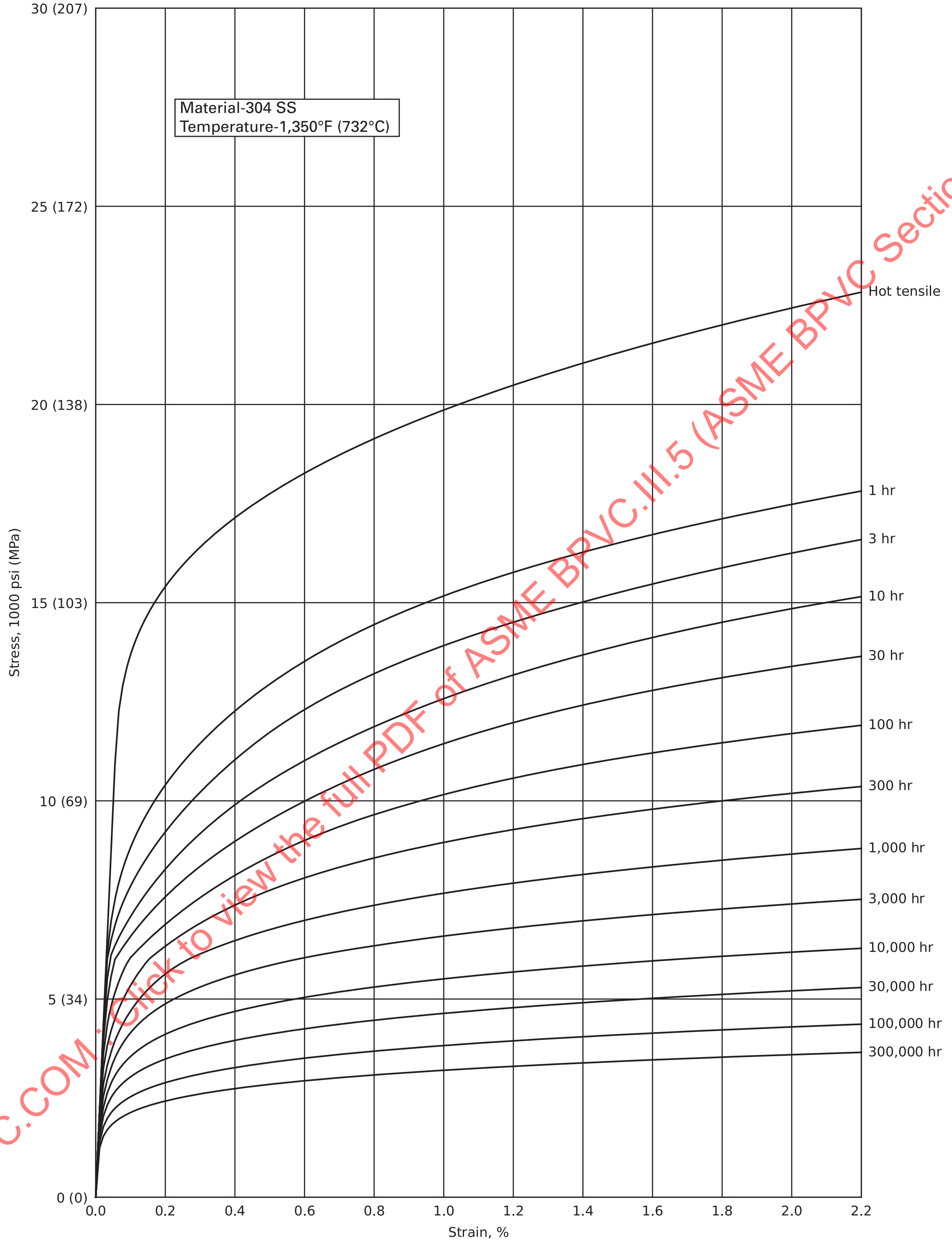


Figure HBB-T-1831-15
Average Isochronous Stress–Strain Curves

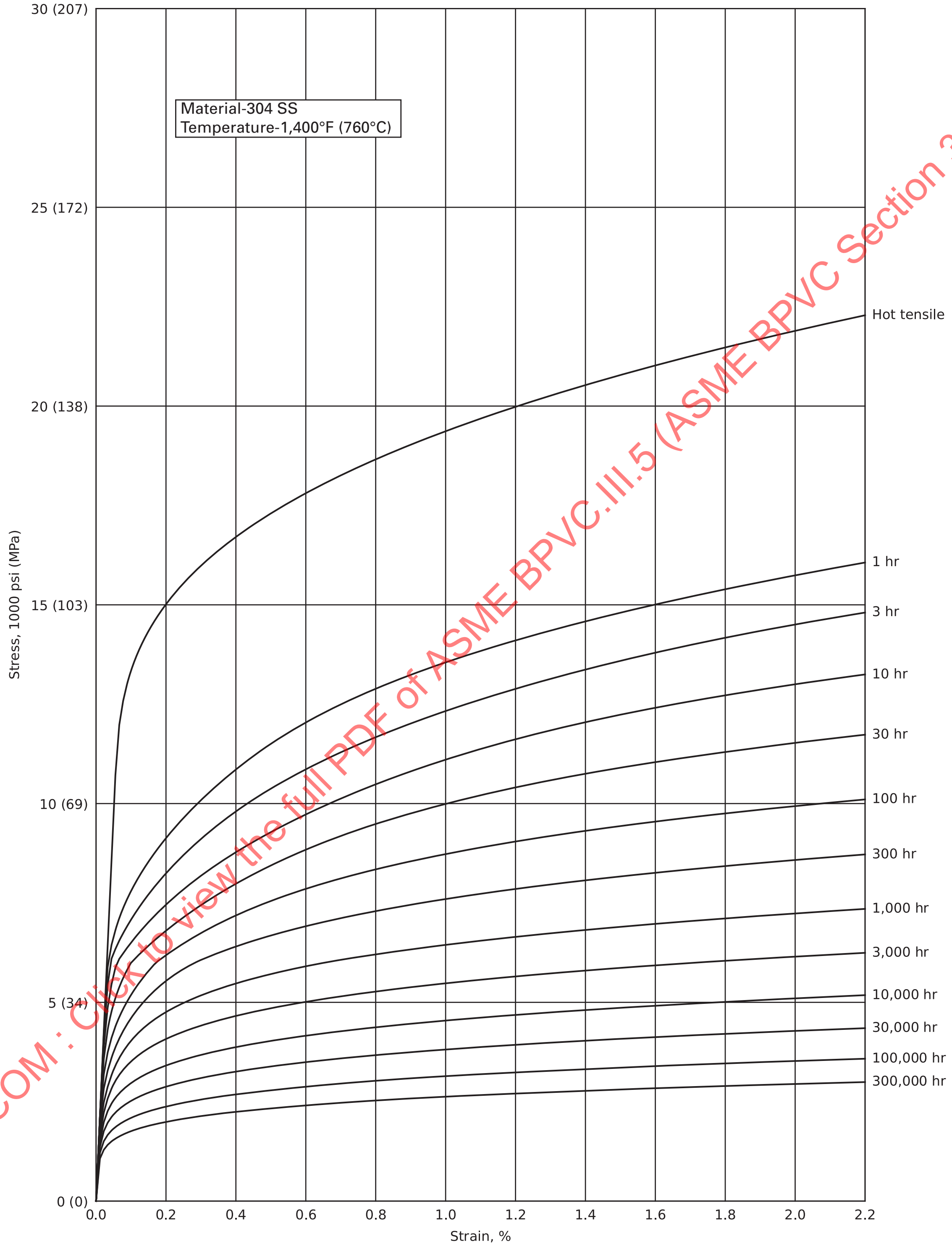


Figure HBB-T-1831-16
Average Isochronous Stress–Strain Curves

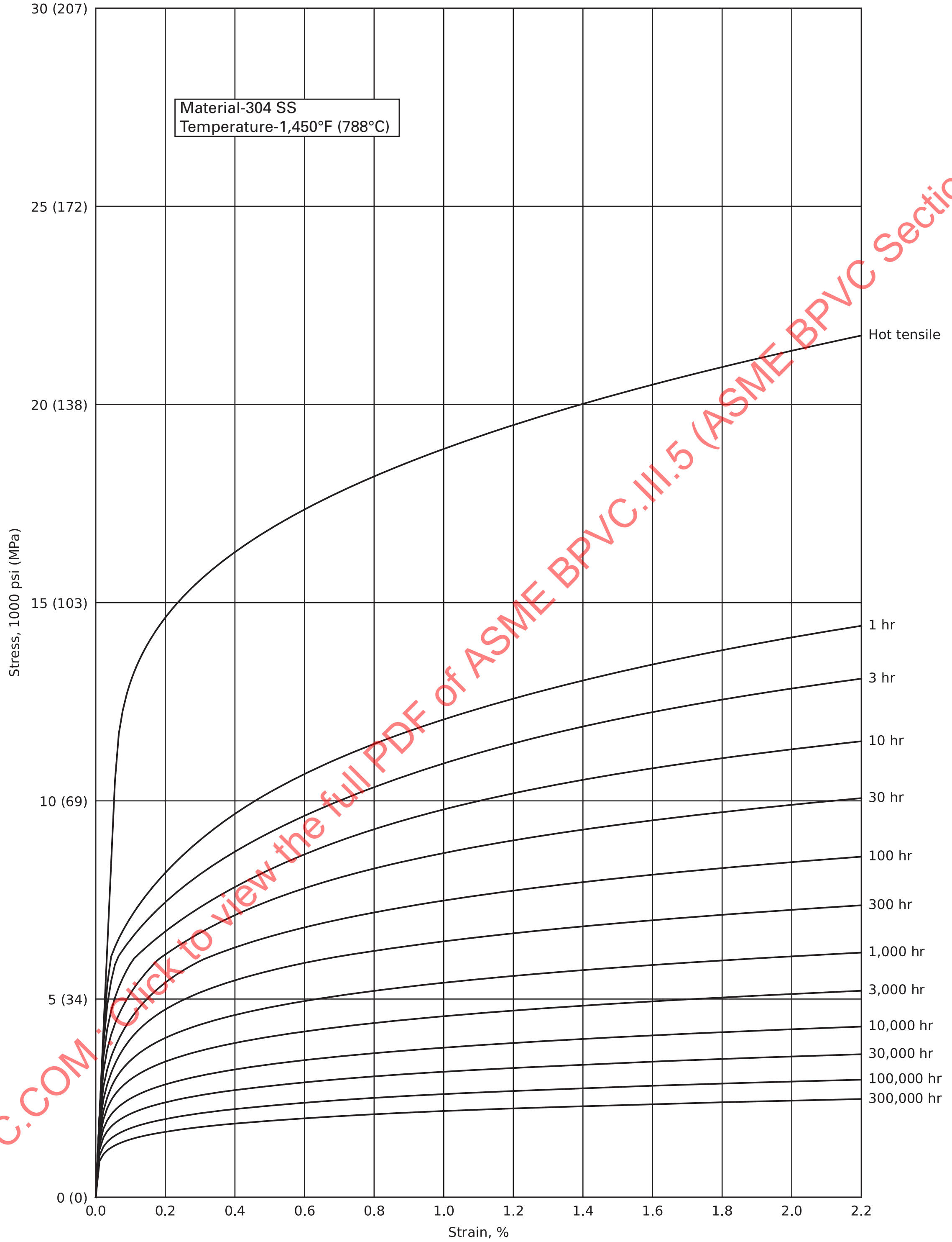
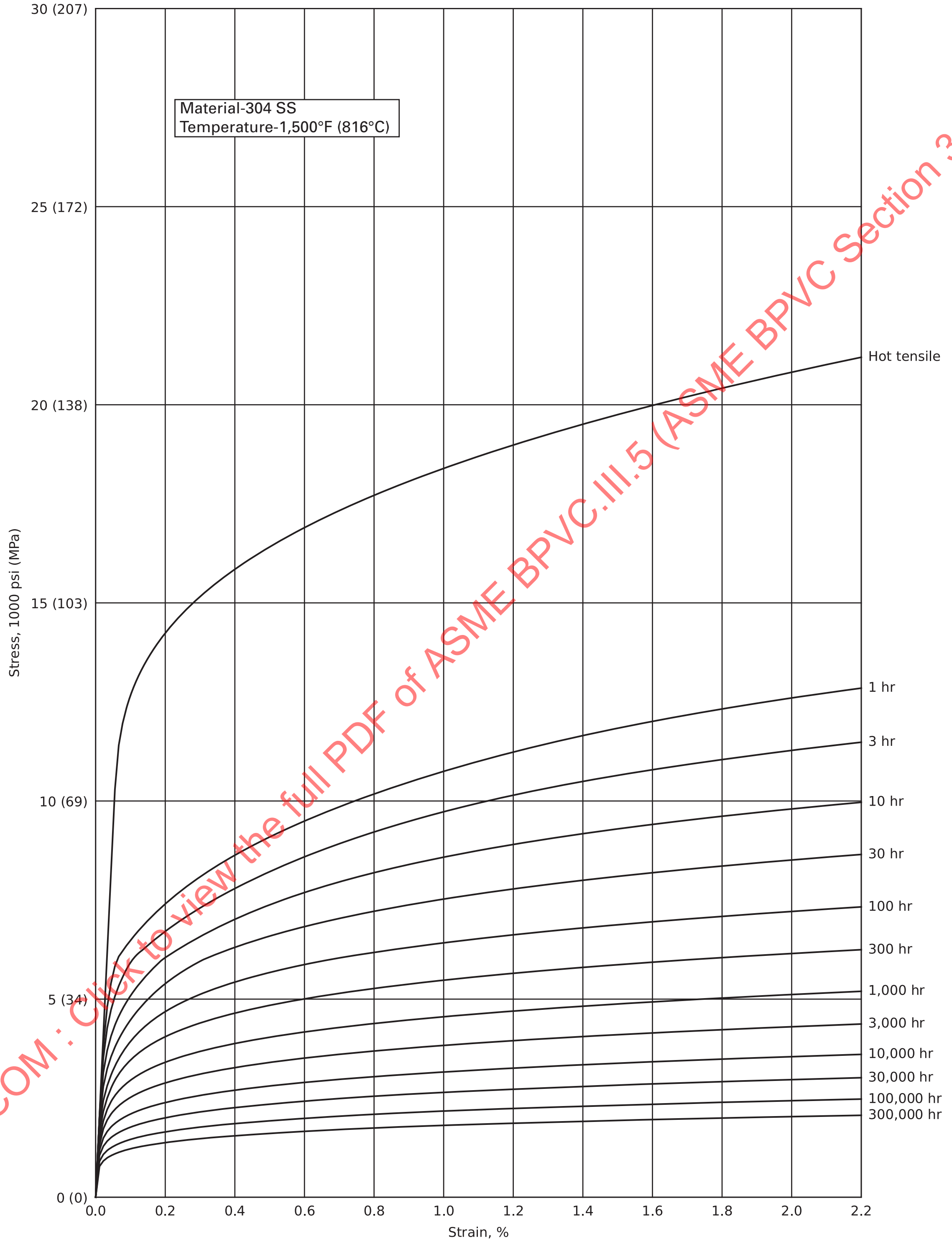


Figure HBB-T-1831-17
Average Isochronous Stress–Strain Curves



(23) HBB-T-1832 316 SS

Figures HBB-T-1832-1 through HBB-T-1832-17 illustrate the stress–strain curve for 316 SS.

(a) Elastic Strain

$$\varepsilon_e = \frac{\sigma}{E}$$

where

E = 232,181 − 95.3063(T + 273.15)

(b) Plastic Strain

$$\begin{aligned}\varepsilon_p &= 0 \text{ for } \sigma \le \sigma_p \\ &= \left(\frac{\sigma - \sigma_p}{K}\right)^{1/m} \text{ for } \sigma > \sigma_p\end{aligned}$$

where

K = 419.11 − 0.095119(T + 273.15)
m = 0.30950 + 6.1328 × 10^{-5}(T + 273.15)
σ_p = σ_y + [−56.4598 + 0.024225(T + 273.15)]

σ_y = 201.69 − 0.069361(T + 273.15)

(c) Creep Strain

Use Tables HBB-T-1832-1 through HBB-T-1832-7 to determine values of variables.

$$\varepsilon_c = \frac{1}{100}\left[\varepsilon_s\left(1 - e^{-st}\right) + \varepsilon_r\left(1 - e^{-rt}\right) + \dot{\varepsilon}_m t\right]$$

where

$$\dot{\varepsilon}_m = A\left[\sinh\left(\frac{145.037681\beta\sigma}{n}\right)\right]^n e^{\left(\frac{-Q}{R(T + 273.15)}\right)}$$

A = Table HBB-T-1832-8

$$\varepsilon_r = \frac{C\dot{\varepsilon}_m}{r}$$

C = Table HBB-T-1832-5
r = max{r_1, r_2}

r_1 = $L(145.037681\sigma)^{n-3.6}$

L = Table HBB-T-1832-7

$$r_2 = B\left[\sinh\left(\frac{145.037681\beta\sigma}{n}\right)\right]^n e^{\left(\frac{-Q}{R(T + 273.15)}\right)}$$

B = Table HBB-T-1832-6

ε_s = 0 for σ ≤ 27.5790
= G + 145.037681$H\sigma$ for σ > 27.5790

G = Table HBB-T-1832-1
H = Table HBB-T-1832-2
s = max{s_1, s_2}

$$s_1 = 2.5 \times 10^{-2}$$

$$s_2 = D\left[\sinh\left(\frac{145.037681\beta\sigma}{n}\right)\right]^n e^{\frac{-Q}{R(T + 273.15)}}$$

D = Table HBB-T-1832-3
n = Table HBB-T-1832-4
Q = 67,000
R = 1.987
$\beta = -4.257 \times 10^{-4} + 7.733 \times 10^{-7}(T + 273.15)$

Table HBB-T-1832-1

Temperature Range	G
$800 \le T_F < 1{,}000$	0.0
$1{,}000 \le T_F < 1{,}075$	$1.28221 - 1.58103 \times 10^{-3} T_K$
$1{,}075 \le T_F < 1{,}100$	$1.28221 - 1.58103 \times 10^{-3} T_K$
$1{,}100 \le T_F \le 1{,}200$	$-0.271855 + 2.13509 \times 10^{-4} T_K$
$1{,}200 < T_F < 1{,}300$	$-0.692411 + 6.69643 \times 10^{-4} T_K$
$1{,}300 \le T_F \le 1{,}500$	$-0.704318 + 6.61818 \times 10^{-4} T_K$

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1832-2

Temperature Range	H
$800 \le T_F < 1{,}000$	0.0
$1{,}000 \le T_F < 1{,}075$	$-3.2055 \times 10^{-4} + 3.95256 \times 10^{-7} T_K$
$1{,}075 \le T_F < 1{,}100$	$-3.2055 \times 10^{-4} + 3.95256 \times 10^{-7} T_K$
$1{,}100 \le T_F \le 1{,}200$	$6.796 \times 10^{-5} - 5.338 \times 10^{-8} T_K$
$1{,}200 < T_F < 1{,}300$	$1.731 \times 10^{-4} - 1.674 \times 10^{-7} T_K$
$1{,}300 \le T_F \le 1{,}500$	$1.7608 \times 10^{-4} - 1.70455 \times 10^{-7} T_K$

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

(23)

Table HBB-T-1832-3

Temperature Range	D
$800 \le T_F < 1{,}000$	5.7078×10^{13}
$1{,}000 \le T_F < 1{,}075$	$-4.499 \times 10^{17} + 5.548 \times 10^{14} T_K$
$1{,}075 \le T_F < 1{,}100$	$2.869 \times 10^{17} - 3.093 \times 10^{14} T_K$
$1{,}100 \le T_F \le 1{,}200$	$2.869 \times 10^{17} - 3.093 \times 10^{14} T_K$
$1{,}200 < T_F < 1{,}300$	$1.3369 \times 10^{10} e^{10878.5/T_K}$
$1{,}300 \le T_F \le 1{,}500$	$1.3369 \times 10^{10} e^{10878.5/T_K}$

GENERAL NOTE:

$$T_F = \frac{9}{5} T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1832-4

Temperature Range	n
$800 \le T_F < 1{,}000$	4.6
$1{,}000 \le T_F < 1{,}075$	$-80.9263 + 0.105455 T_K$
$1{,}075 \le T_F < 1{,}100$	$50.1136 - 0.0482143 T_K$
$1{,}100 \le T_F \le 1{,}200$	$50.1136 - 0.0482143 T_K$
$1{,}200 < T_F < 1{,}300$	$14.4647 - 9.54954 \times 10^{-3} T_K$
$1{,}300 \le T_F \le 1{,}500$	$14.4647 - 9.54954 \times 10^{-3} T_K$

GENERAL NOTE:

$$T_F = \frac{9}{5} T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1832-5

Temperature Range	C
$800 \le T_F < 1{,}000$	7.1
$1{,}000 \le T_F < 1{,}075$	$25.5318 - 0.0227273T_K$
$1{,}075 \le T_F < 1{,}100$	$25.5318 - 0.0227273T_K$
$1{,}100 \le T_F \le 1{,}200$	$54.5625 - 0.05625T_K$
$1{,}200 < T_F < 1{,}300$	$7.68378 - 5.4054 \times 10^{-3}T_K$
$1{,}300 \le T_F \le 1{,}500$	$7.68378 - 5.4054 \times 10^{-3}T_K$

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1832-6

Temperature Range	B
$800 \le T_F < 1{,}000$	5.7078×10^{13}
$1{,}000 \le T_F < 1{,}075$	$-3.922 \times 10^{16} + 4.84416 \times 10^{13}T_K$
$1{,}075 \le T_F < 1{,}100$	$1.44225 \times 10^{-8}e^{45475.8/T_K}$
$1{,}100 \le T_F \le 1{,}200$	$1.44225 \times 10^{-8}e^{45475.8/T_K}$
$1{,}200 < T_F < 1{,}300$	$2.85517 \times 10^{8}e^{10878.5/T_K}$
$1{,}300 \le T_F \le 1{,}500$	$2.85517 \times 10^{8}e^{10878.5/T_K}$

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Table HBB-T-1832-7

Temperature Range	L
$800 \le T_F < 1{,}000$	$e^{43.1255} e^{-49995.0/T_K}$
$1{,}000 \le T_F < 1{,}075$	$e^{-1153.4 + 16.446 T_z - 0.075433 T_z^2 + 0.000107956 T_z^3}$
$1{,}075 \le T_F < 1{,}100$	$e^{-274.235 + 1.1560 T_z - 0.001160 T_z^2}$
$1{,}100 \le T_F \le 1{,}200$	$e^{-274.235 + 1.1560 T_z - 0.001160 T_z^2}$
$1{,}200 < T_F < 1{,}300$	$e^{-54.603 + 0.1185 T_w - 8.6357 \times 10^{-6} T_w^2}$
$1{,}300 \le T_F \le 1{,}500$	$e^{-54.603 + 0.1185 T_w - 8.6357 \times 10^{-6} T_w^2}$

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

$$T_w = T_K - 680$$

$$T_z = T_K - 610$$

Table HBB-T-1832-8

Temperature Range	A
$800 \le T_F < 1{,}000$	5.6229×10^{12}
$1{,}000 \le T_F < 1{,}075$	$-7.8535 \times 10^{15} + 9.6933 \times 10^{12} T_K$
$1{,}075 \le T_F < 1{,}100$	$5.28787 \times 10^{-6} e^{39057.1/T_K}$
$1{,}100 \le T_F \le 1{,}200$	$5.28787 \times 10^{-6} e^{39057.1/T_K}$
$1{,}200 < T_F < 1{,}300$	$6.03371 \times 10^{10} e^{4967.76/T_K}$
$1{,}300 \le T_F \le 1{,}500$	$6.03371 \times 10^{10} e^{4967.76/T_K}$

GENERAL NOTE:

$$T_F = \frac{9}{5}T + 32$$

$$T_K = T + 273.15$$

Figure HBB-T-1832-1
Average Isochronous Stress–Strain Curves

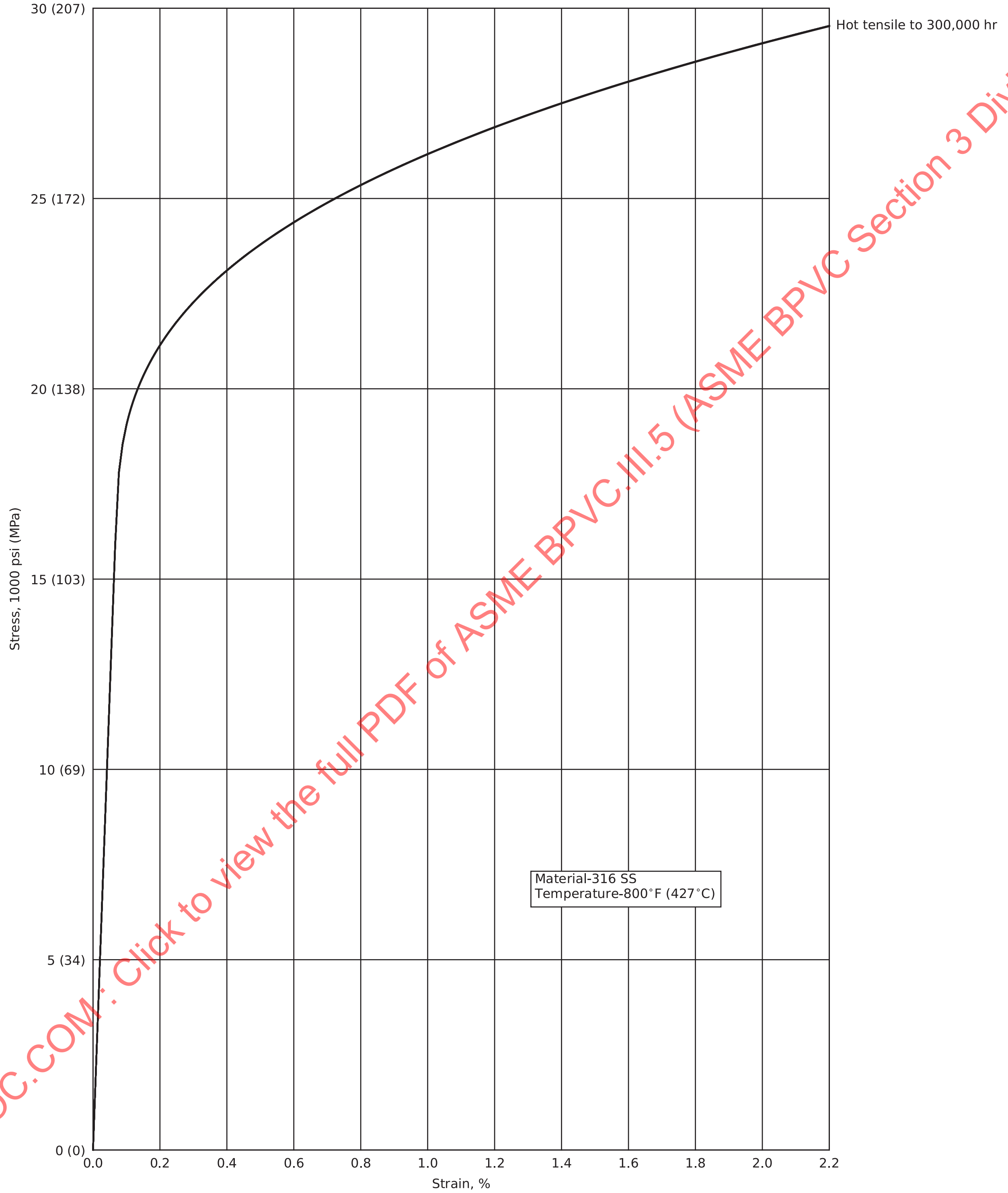


Figure HBB-T-1832-2
Average Isochronous Stress–Strain Curves

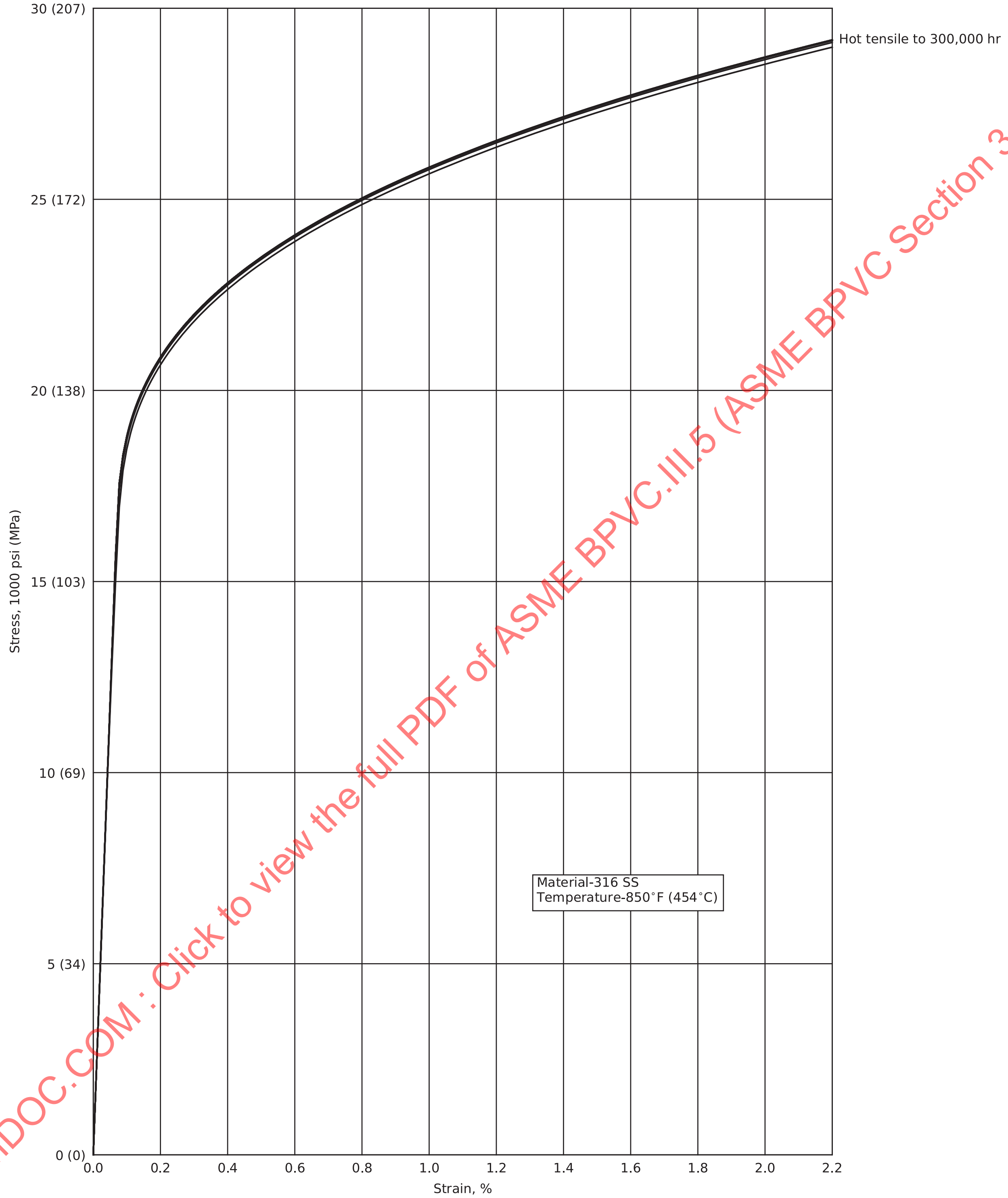


Figure HBB-T-1832-3
Average Isochronous Stress–Strain Curves

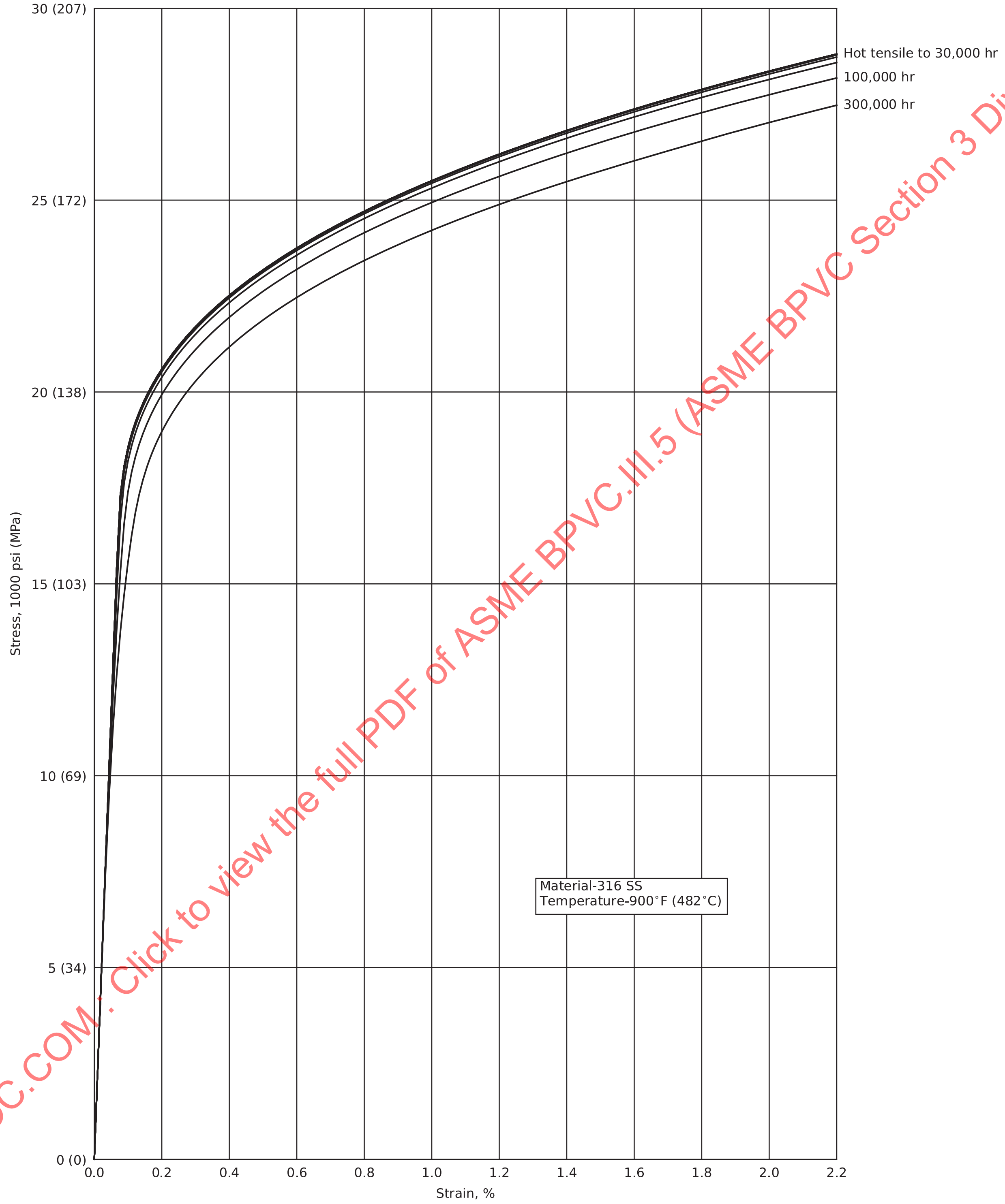


Figure HBB-T-1832-4
Average Isochronous Stress–Strain Curves

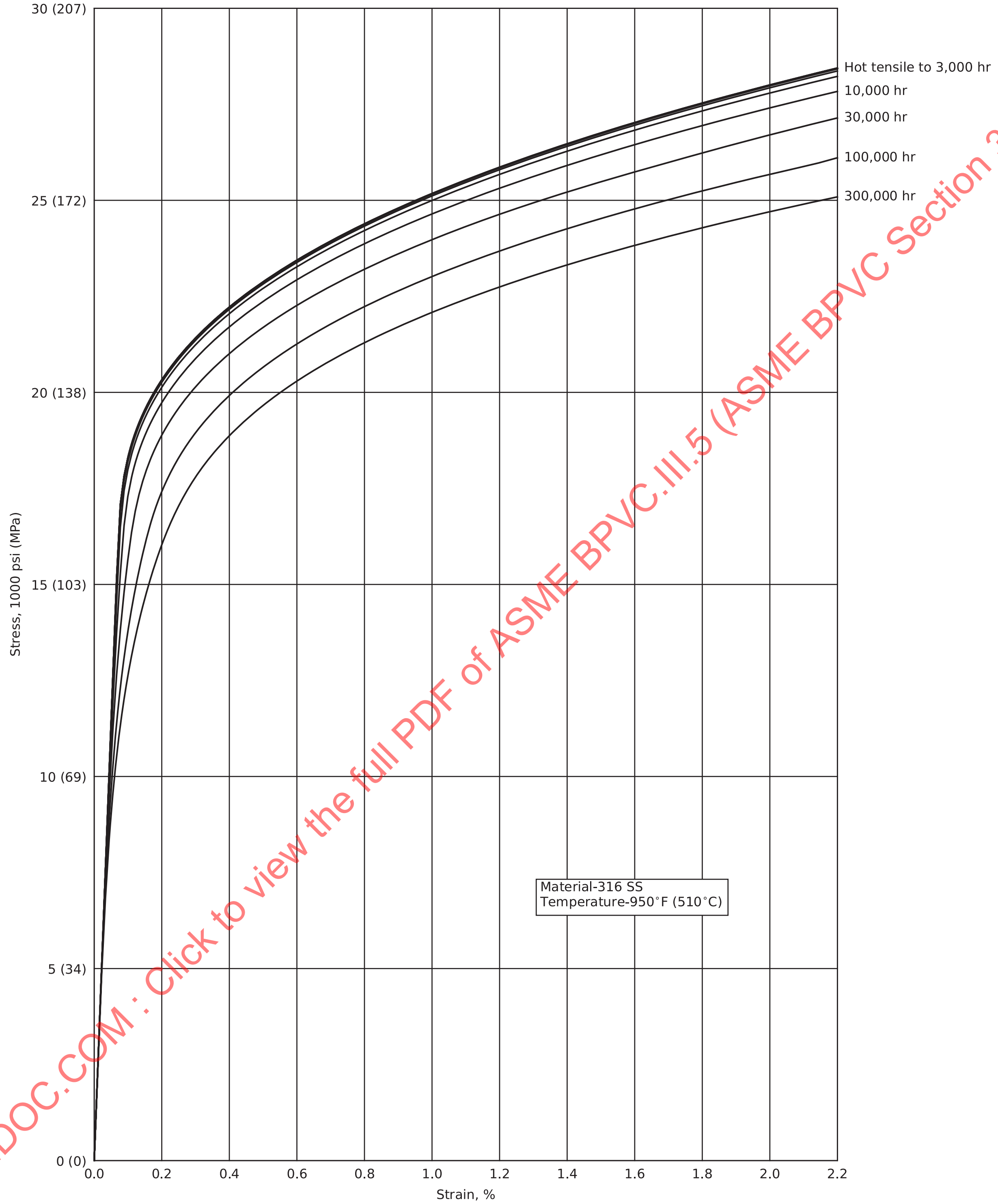
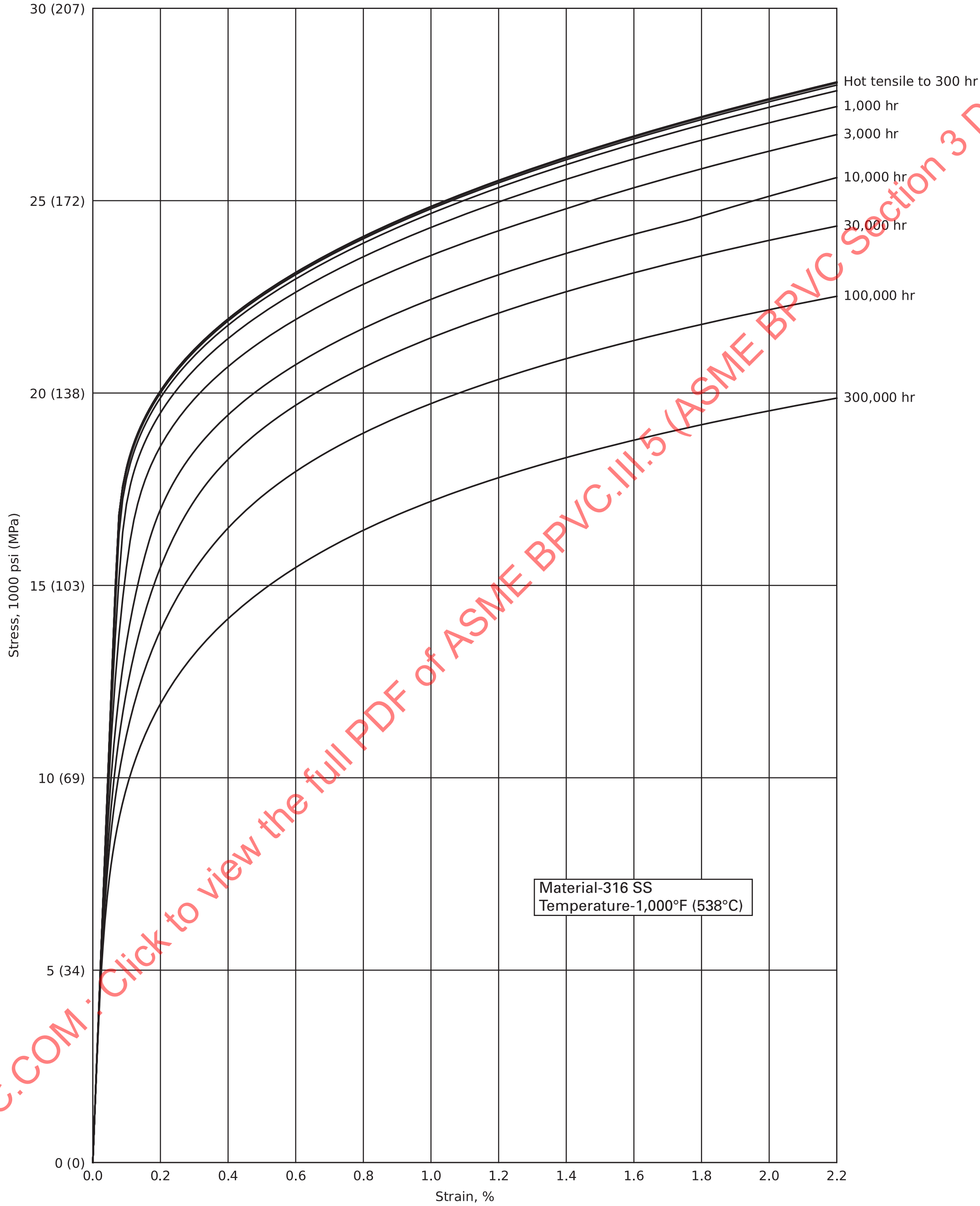


Figure HBB-T-1832-5
Average Isochronous Stress–Strain Curves



(23)

Figure HBB-T-1832-6
Average Isochronous Stress–Strain Curves

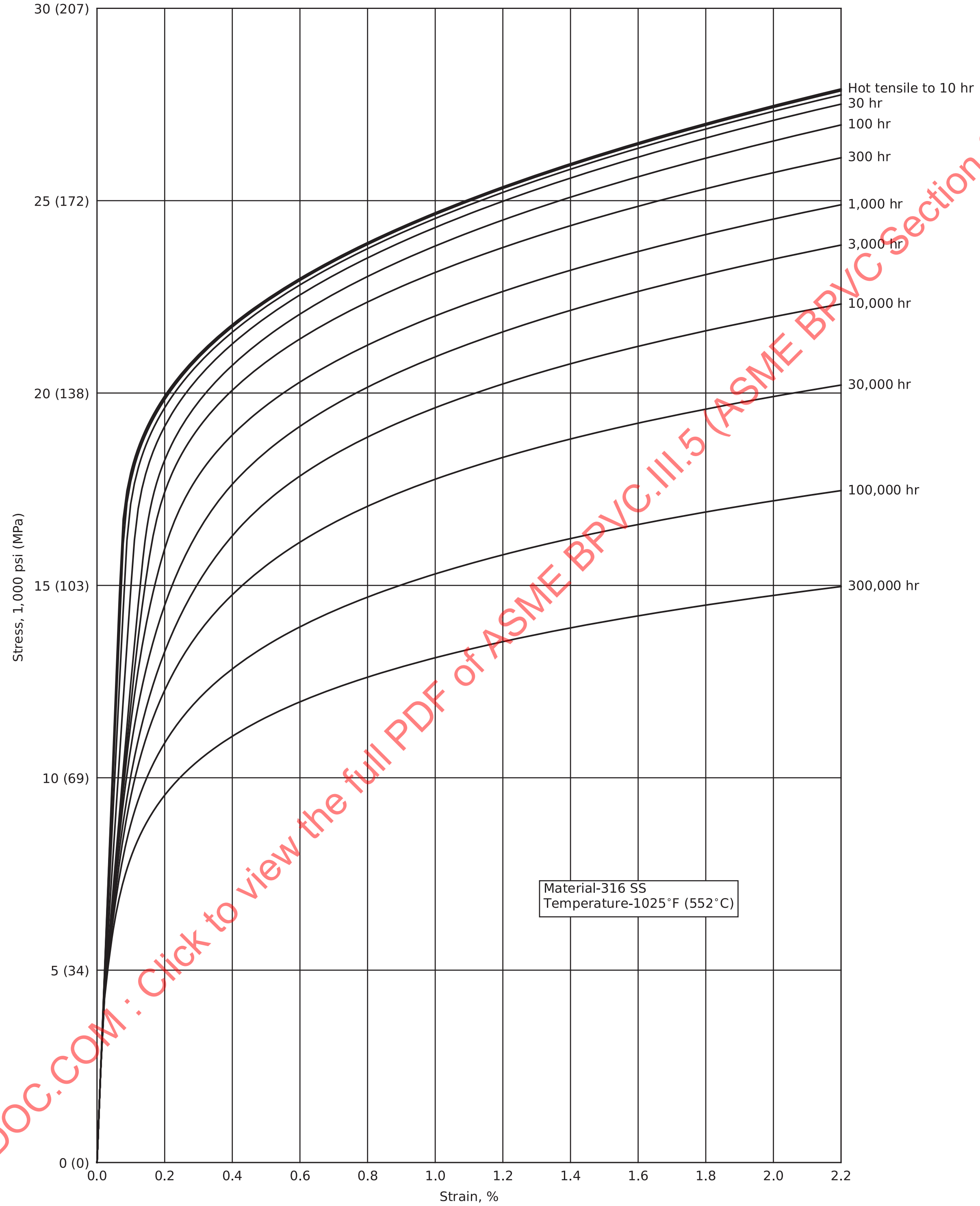


Figure HBB-T-1832-7
Average Isochronous Stress–Strain Curves

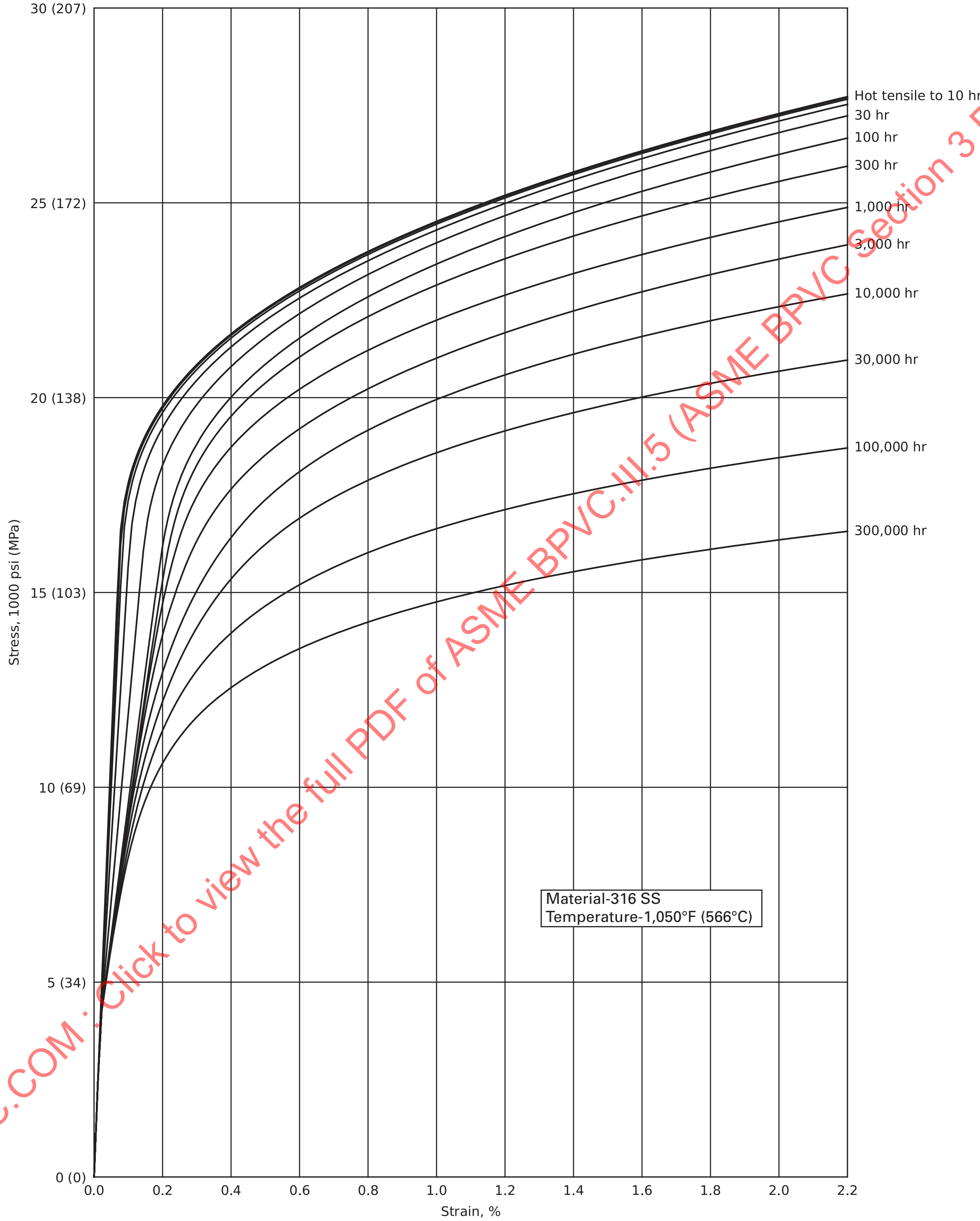


Figure HBB-T-1832-8
Average Isochronous Stress–Strain Curves

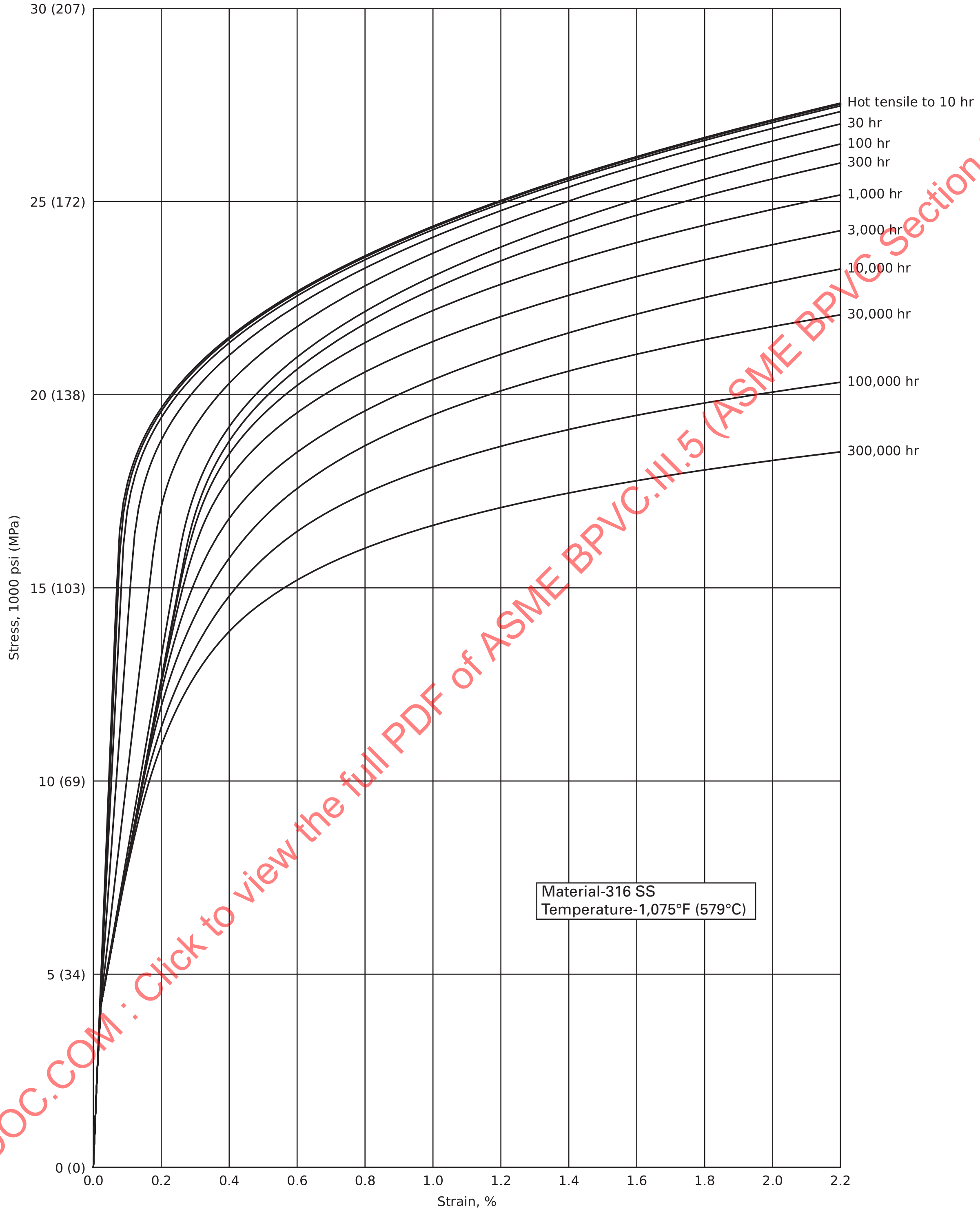


Figure HBB-T-1832-9
Average Isochronous Stress–Strain Curves

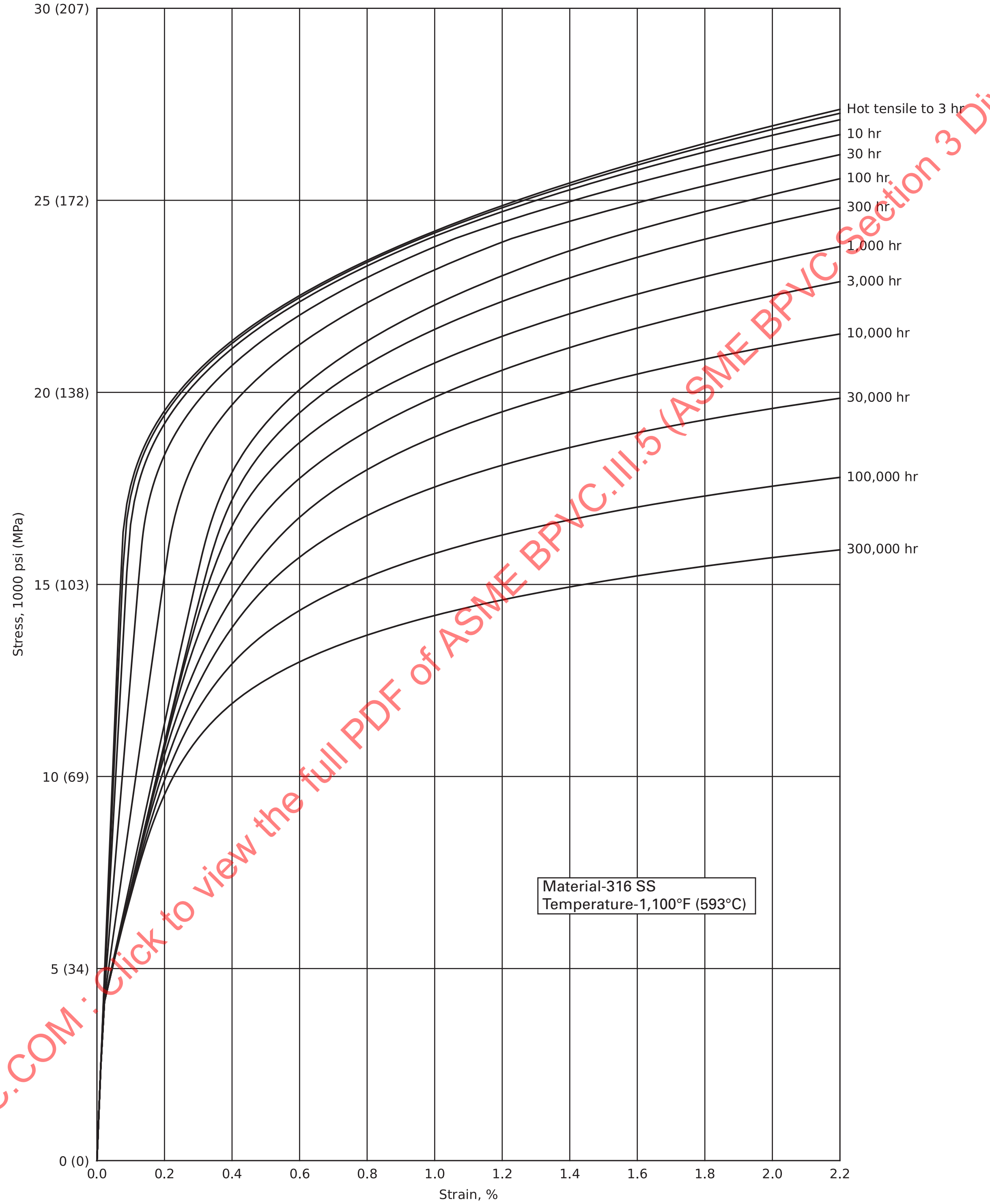


Figure HBB-T-1832-10
Average Isochronous Stress–Strain Curves

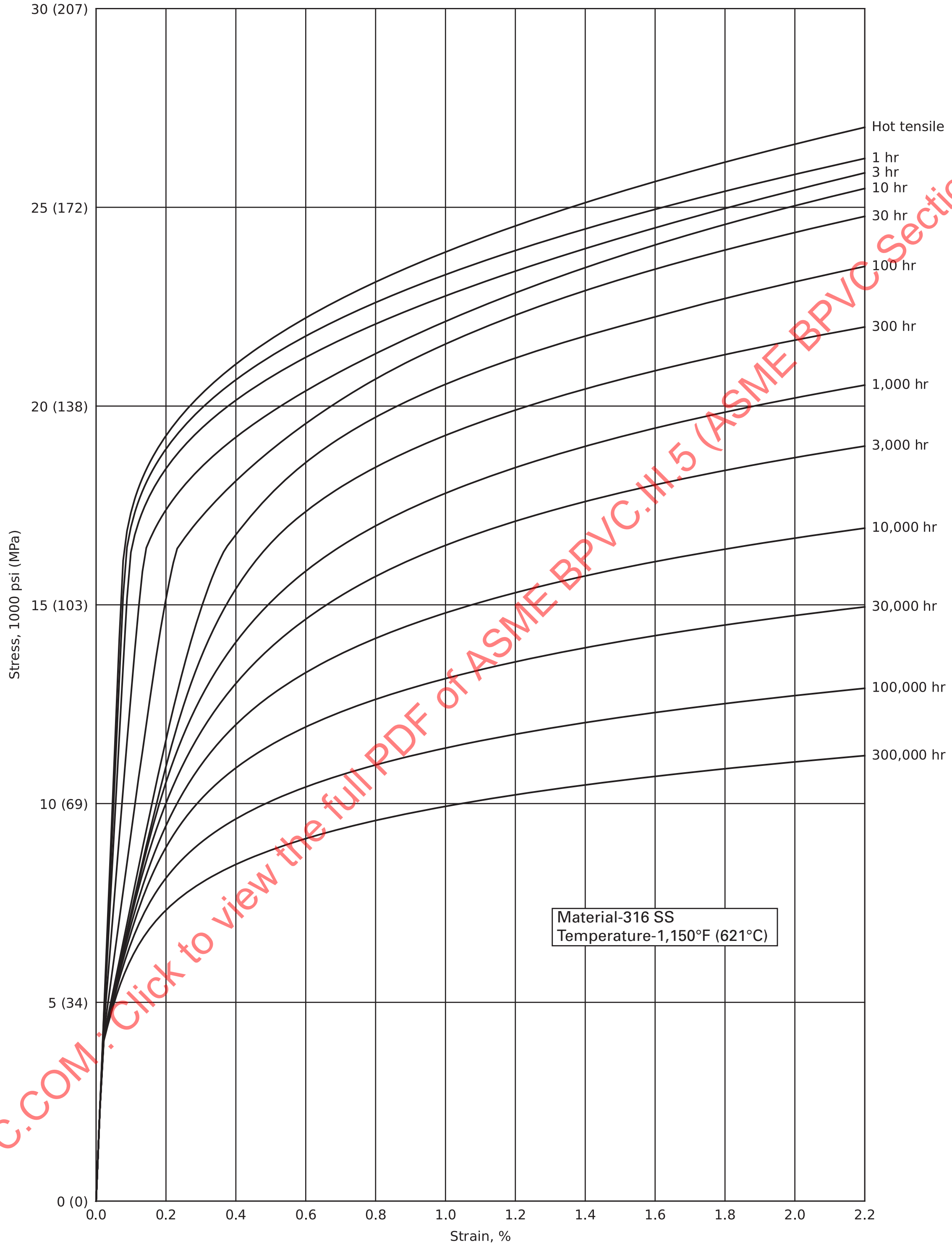


Figure HBB-T-1832-11
Average Isochronous Stress–Strain Curves

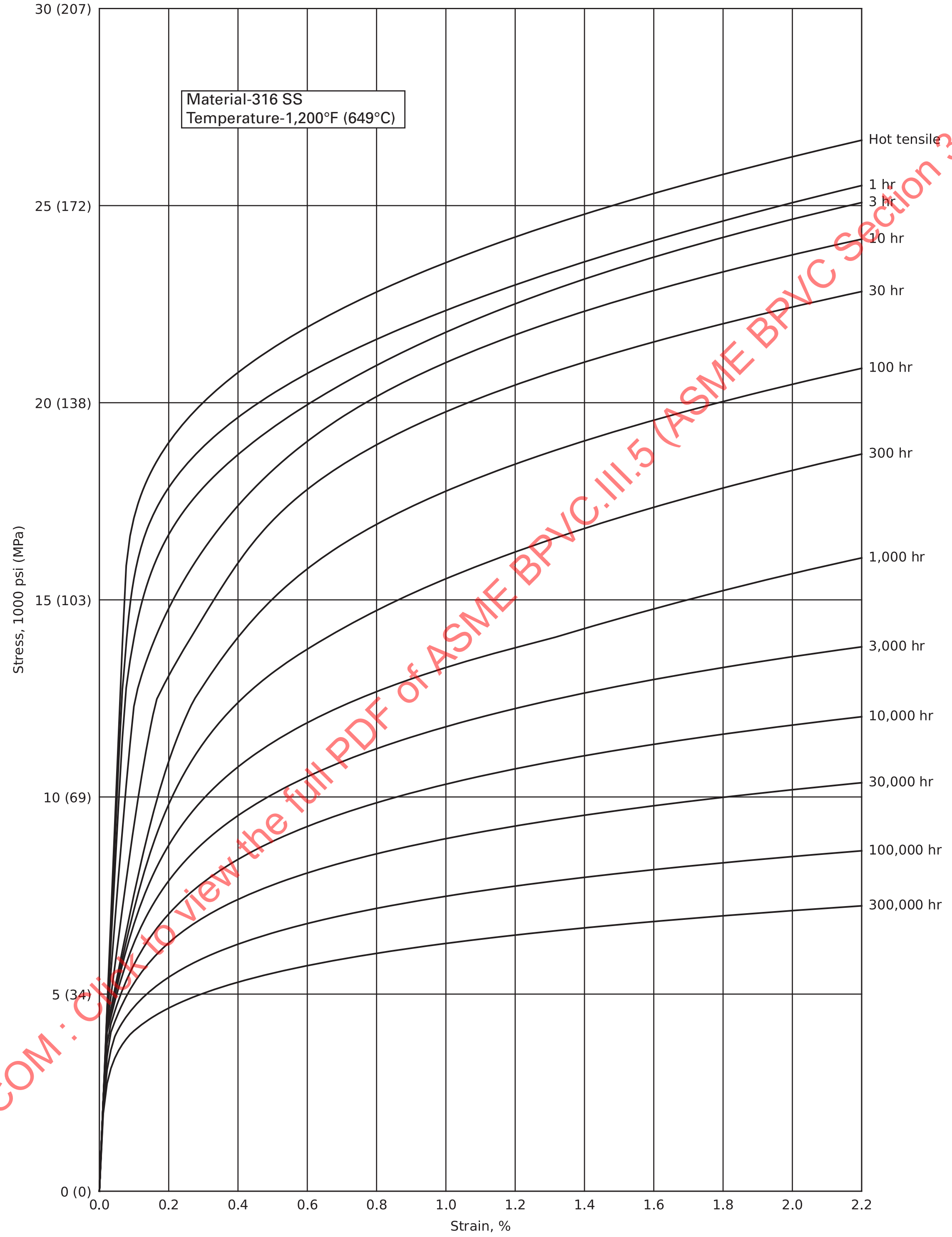


Figure HBB-T-1832-12
Average Isochronous Stress–Strain Curves

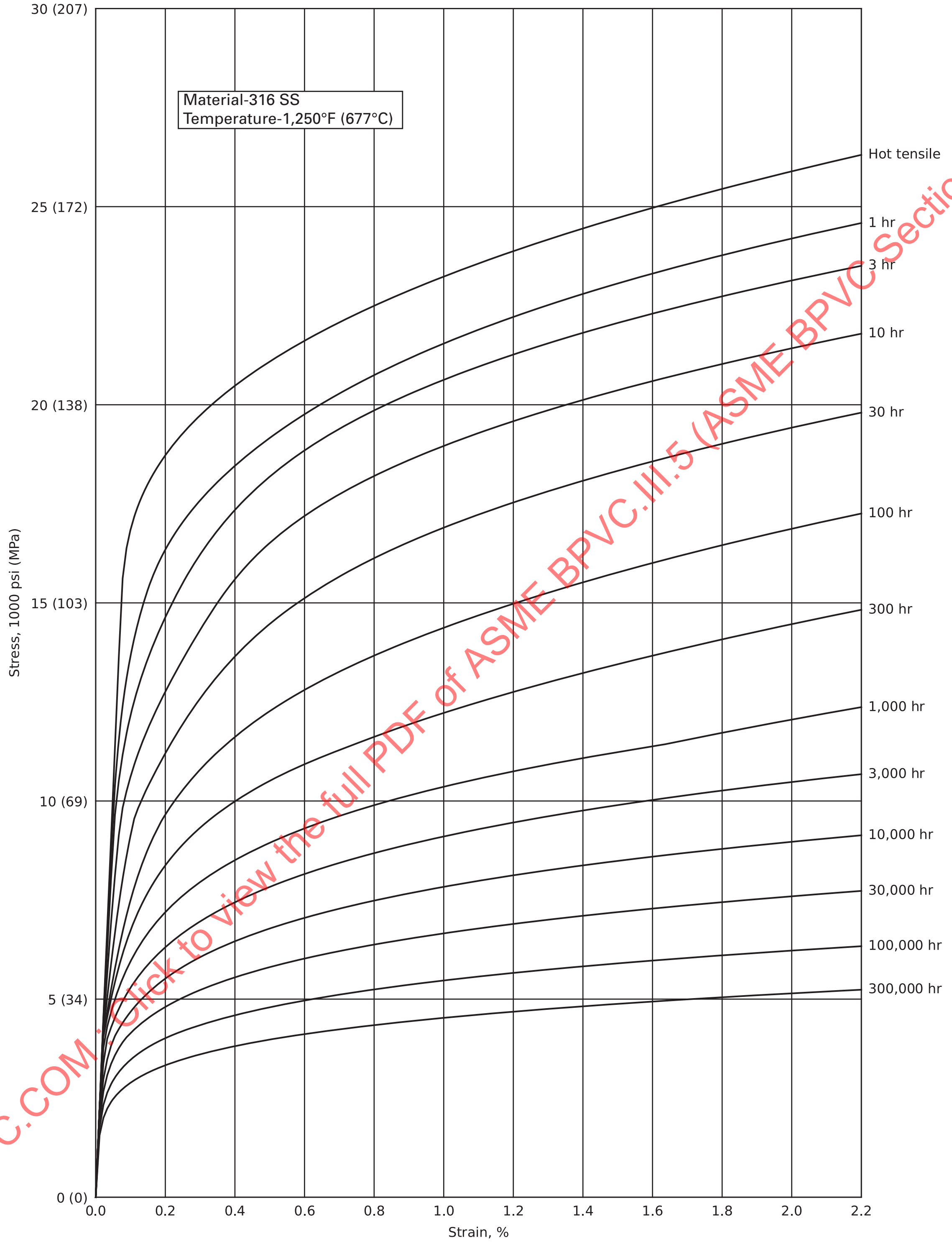


Figure HBB-T-1832-13
Average Isochronous Stress–Strain Curves

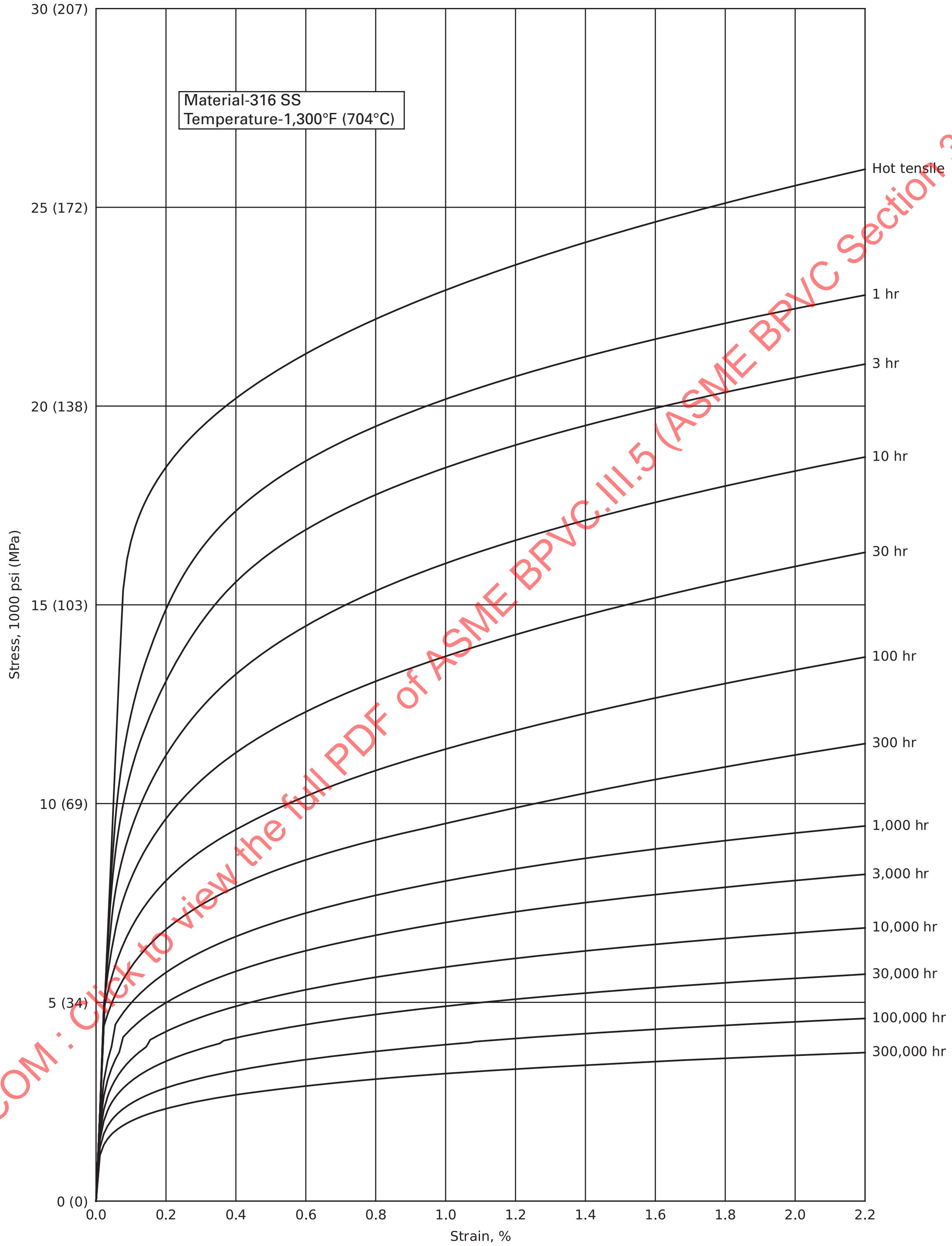


Figure HBB-T-1832-14
Average Isochronous Stress–Strain Curves

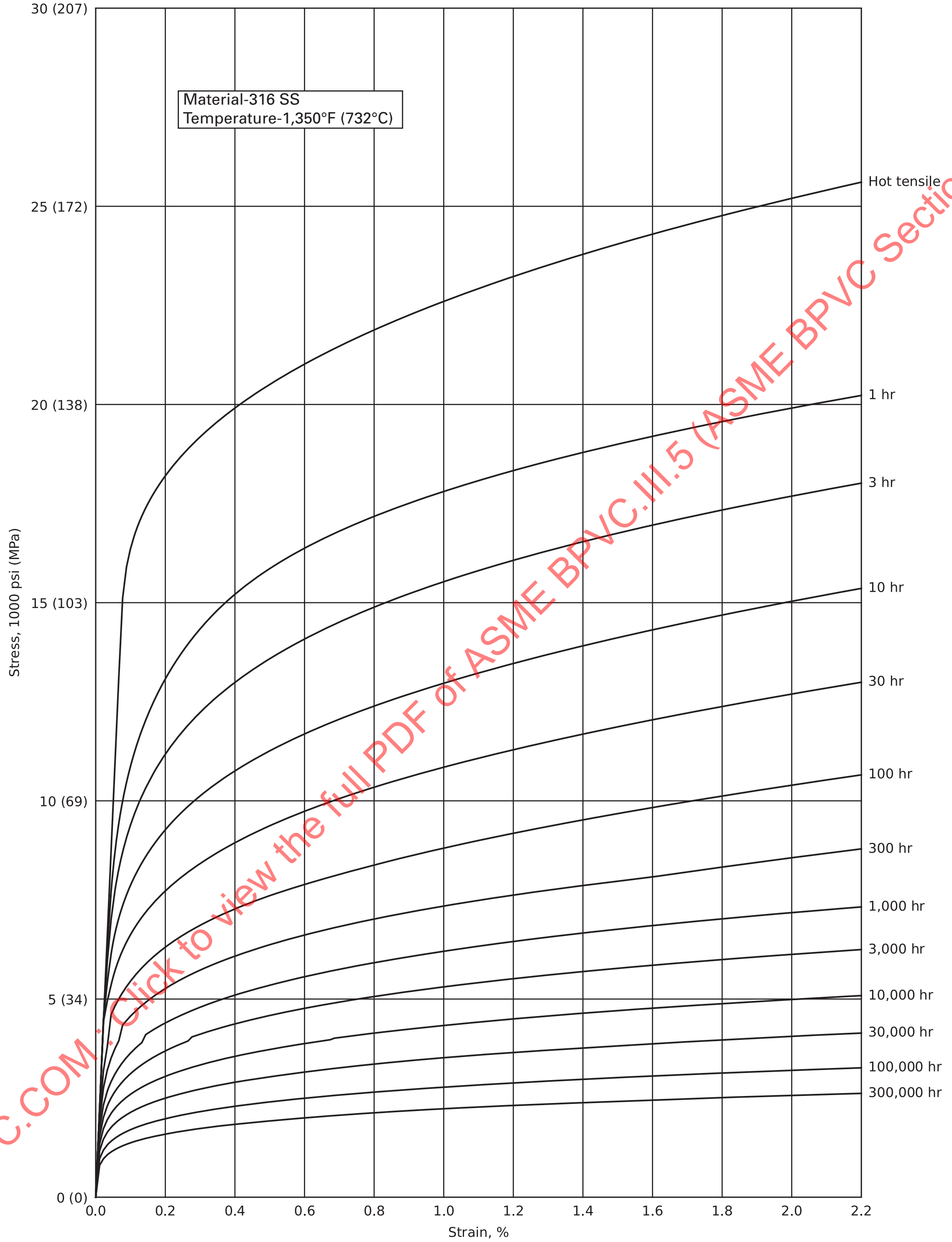


Figure HBB-T-1832-15
Average Isochronous Stress–Strain Curves

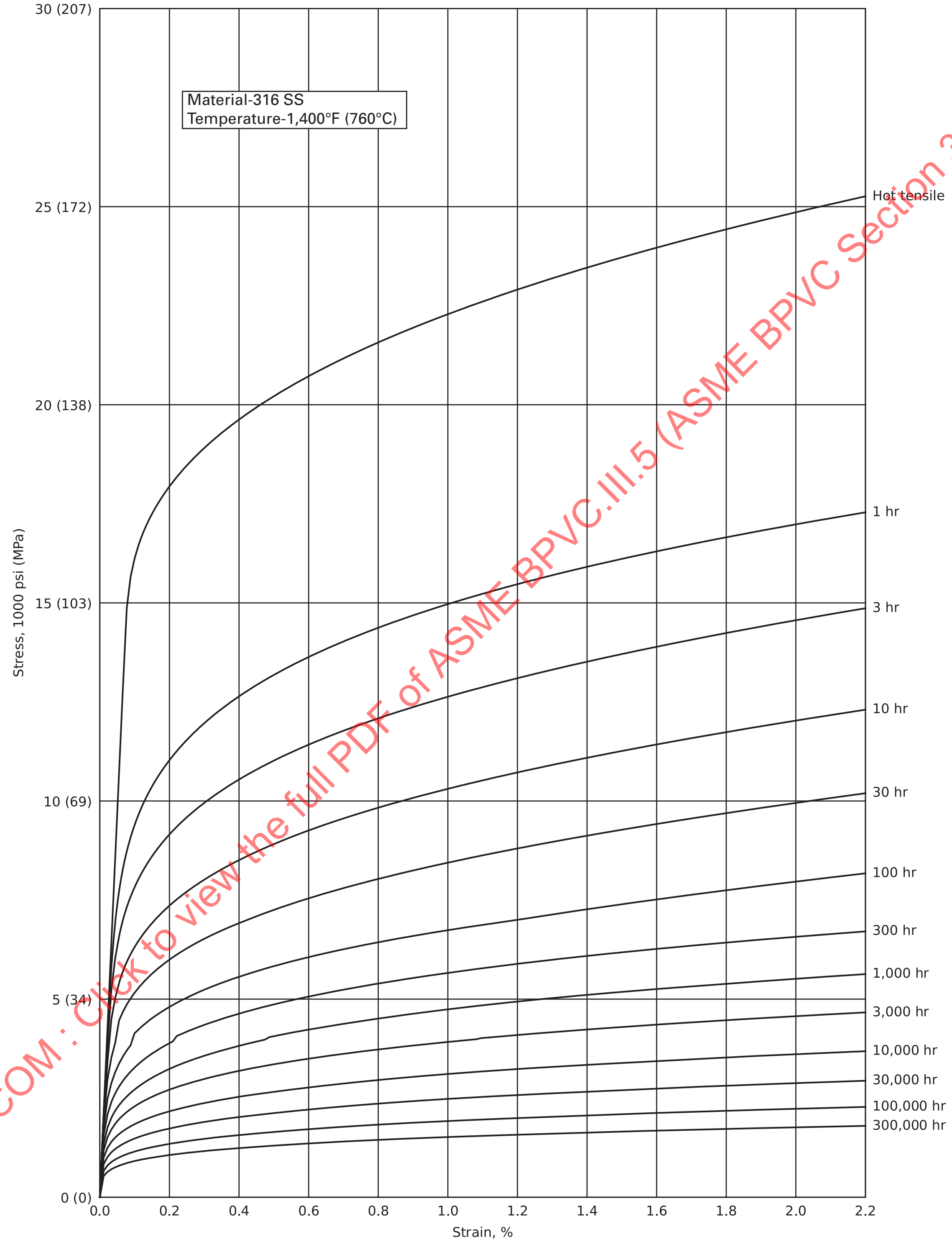


Figure HBB-T-1832-16
Average Isochronous Stress–Strain Curves

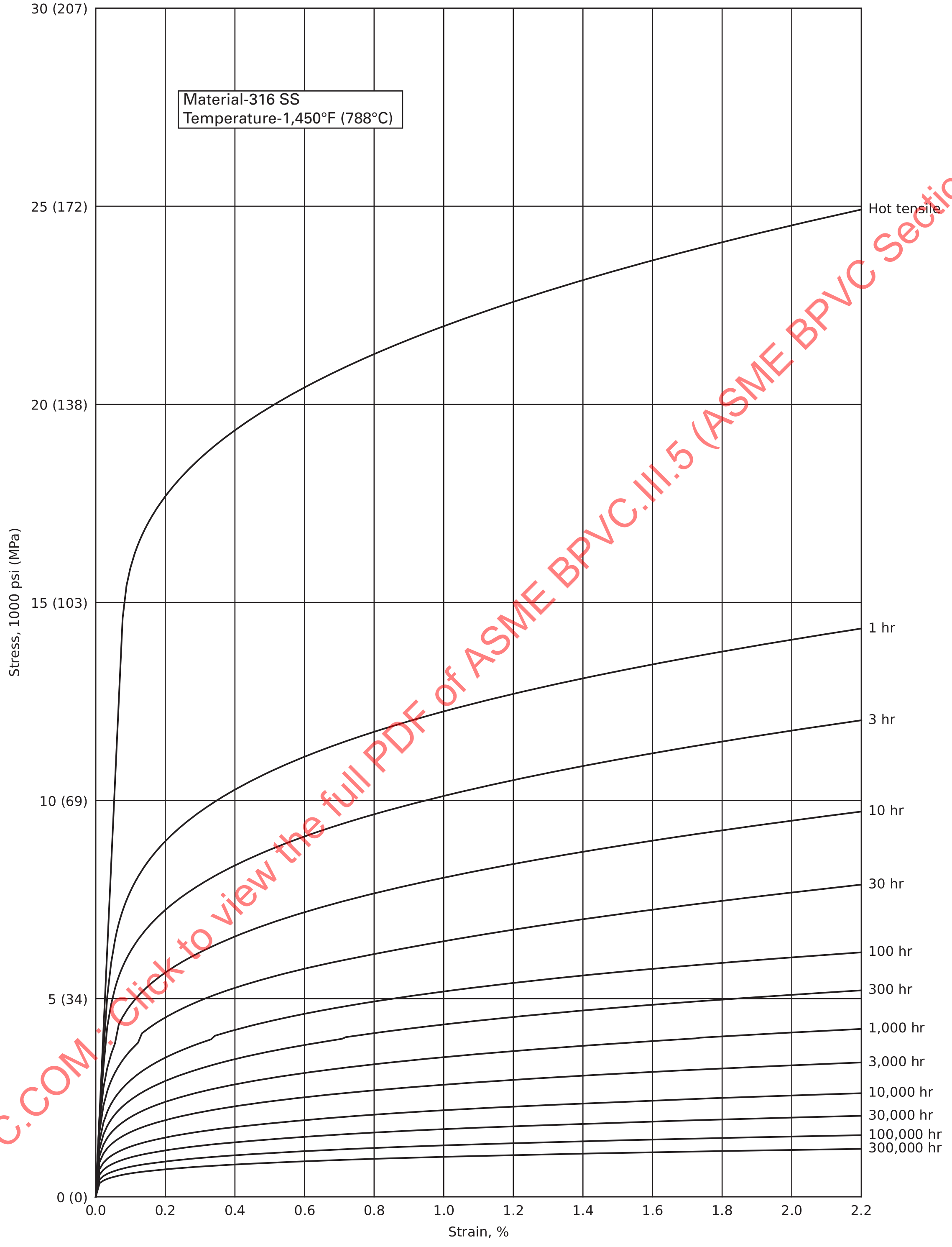
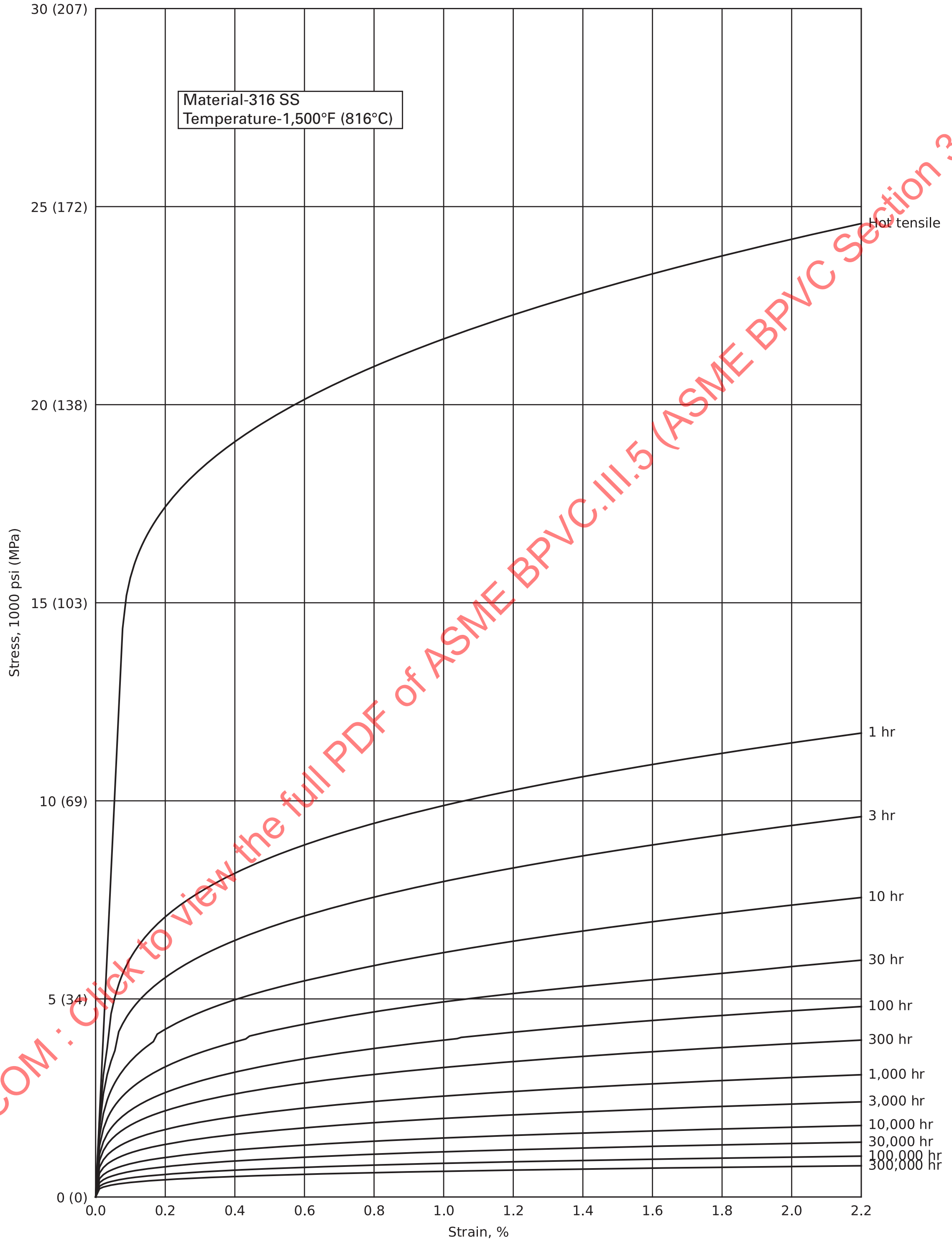


Figure HBB-T-1832-17
Average Isochronous Stress–Strain Curves



HBB-T-1833 Ni-Fe-Cr (Alloy 800H)

Figures HBB-T-1833-1 through HBB-T-1833-13 illustrate the stress-strain curve for Ni-Fe-CR (Alloy 800H).

(a) Elastic Strain

$$\varepsilon_e = \frac{\sigma}{E}$$

where

E = the values in Section II, Part D (Metric), Subpart 2, Table TM-4 interpolated linearly between temperature values and extrapolated linearly from the last two points from 750°C to 761°C

(b) Plastic Strain

$$\begin{aligned} \varepsilon_p &= 0 \text{ for } \sigma \le \sigma_p\left(\varepsilon_p\right) \\ &= \varepsilon_i - \varepsilon_e \text{ for } \sigma > \sigma_p\left(\varepsilon_p\right) \end{aligned}$$

where

$$\begin{aligned} \sigma_p\left(\varepsilon_i\right) &= \sigma \\ &= 6.895e^{B_1 + B_2\ln\left(100\varepsilon_i\right) + B_3\ln^2\left(100\varepsilon_i\right) + B_4\ln^3\left(100\varepsilon_i\right)} \end{aligned}$$

with

$$\begin{aligned} B_1 &= B_1^{(1)} + B_1^{(2)}x + B_1^{(3)}x^2 + B_1^{(4)}x^3 + B_1^{(5)}x^4 \\ B_2 &= B_2^{(1)} + B_2^{(2)}x + B_2^{(3)}x^2 + B_2^{(4)}x^3 + B_2^{(5)}x^4 \\ B_3 &= B_3^{(1)} + B_3^{(2)}x + B_3^{(3)}x^2 + B_3^{(4)}x^3 + B_3^{(5)}x^4 \\ B_4 &= B_4^{(1)} + B_4^{(2)}x + B_4^{(3)}x^2 + B_4^{(4)}x^3 + B_4^{(5)}x^4 \end{aligned}$$

where Table HBB-T-1833-1 gives the coefficients of these polynomials and

$$x = \frac{(1.8T - 768)}{600}$$

The relation $\sigma(\varepsilon_i)$ gives stress as a function of the unknown strain ε_i. The equation $\sigma = \sigma(\varepsilon_i)$ must be solved numerically to find the value of plastic strain as a function of stress.

(c) Creep Strain

$$\varepsilon_c = \frac{1}{100}\left[\exp\left(\frac{\ln t - C_1 \ln\left(\frac{\sigma}{6.895}\right) - C_3}{C_2}\right)\right]$$

where

$$C_1 = \frac{-1.84503305 \times 10^4}{1.8(T + 273.15)}$$

$$C_2 = \frac{1.09662615 \times 10^4}{1.8(T + 273.15)} - 4.62117596$$

$$C_3 = \frac{1.77459417 \times 10^5}{1.8(T + 273.15)} - 67.5590904$$

Table HBB-T-1833-1

Coefficient	B_1	B_2	B_3	B_4
(1)	3.18312201 E+00	1.72297330 E−01	3.75671539 E−02	4.50390345 E−03
(2)	−1.94465649 E−01	−6.54008012 E−04	1.32897986 E−02	4.98519009 E−03
(3)	−2.53179862 E−02	2.66280150 E−02	−2.96225929 E−02	4.82573850 E−02
(4)	7.99351461 E−02	−9.36658919 E−02	6.14678657 E−03	−1.01054504 E−01
(5)	−4.54091288 E−02	5.86915202 E−02	5.12025443 E−03	5.47052447 E−02

Figure HBB-T-1833-1
Average Isochronous Stress–Strain Curves

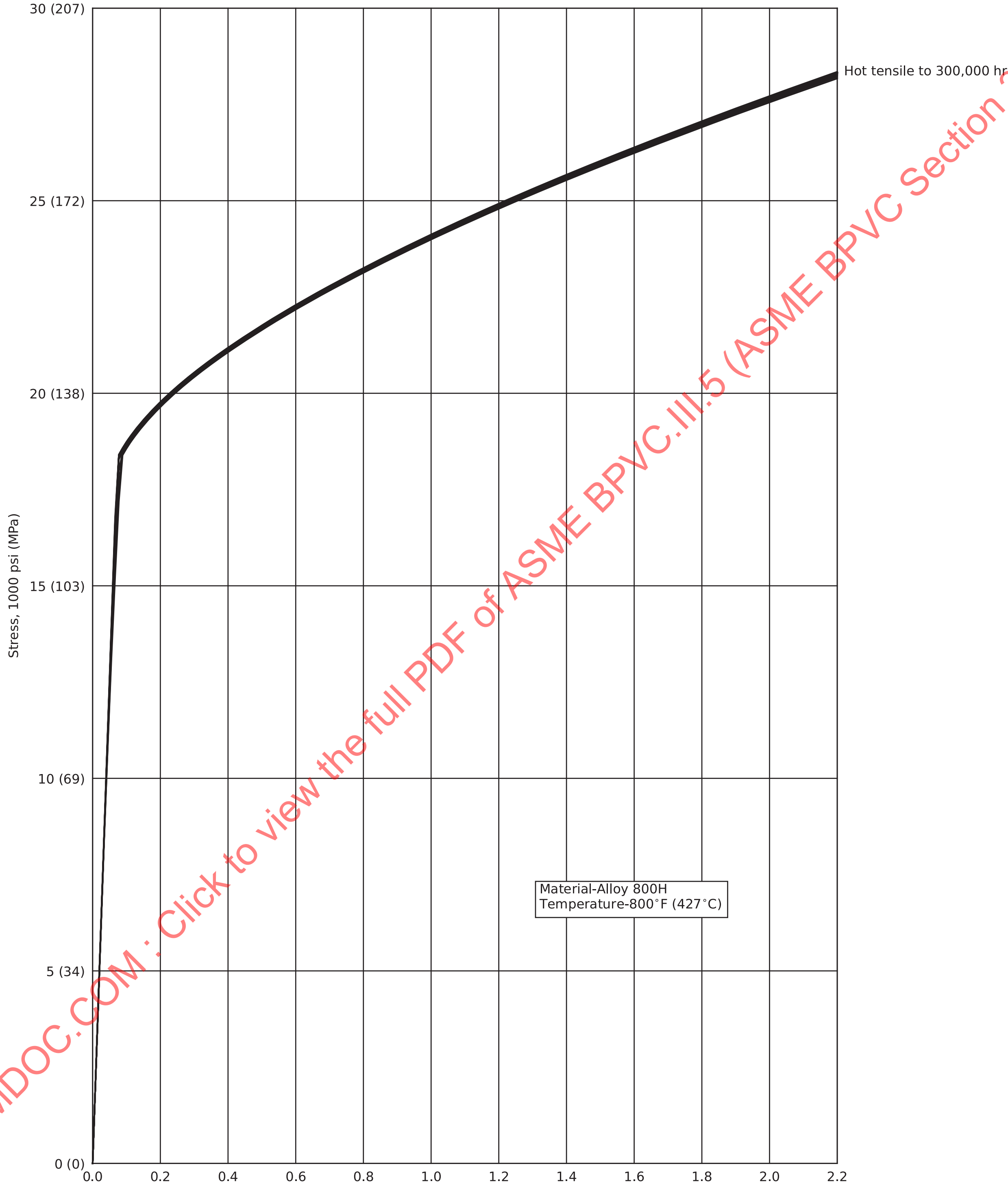


Figure HBB-T-1833-2
Average Isochronous Stress–Strain Curves

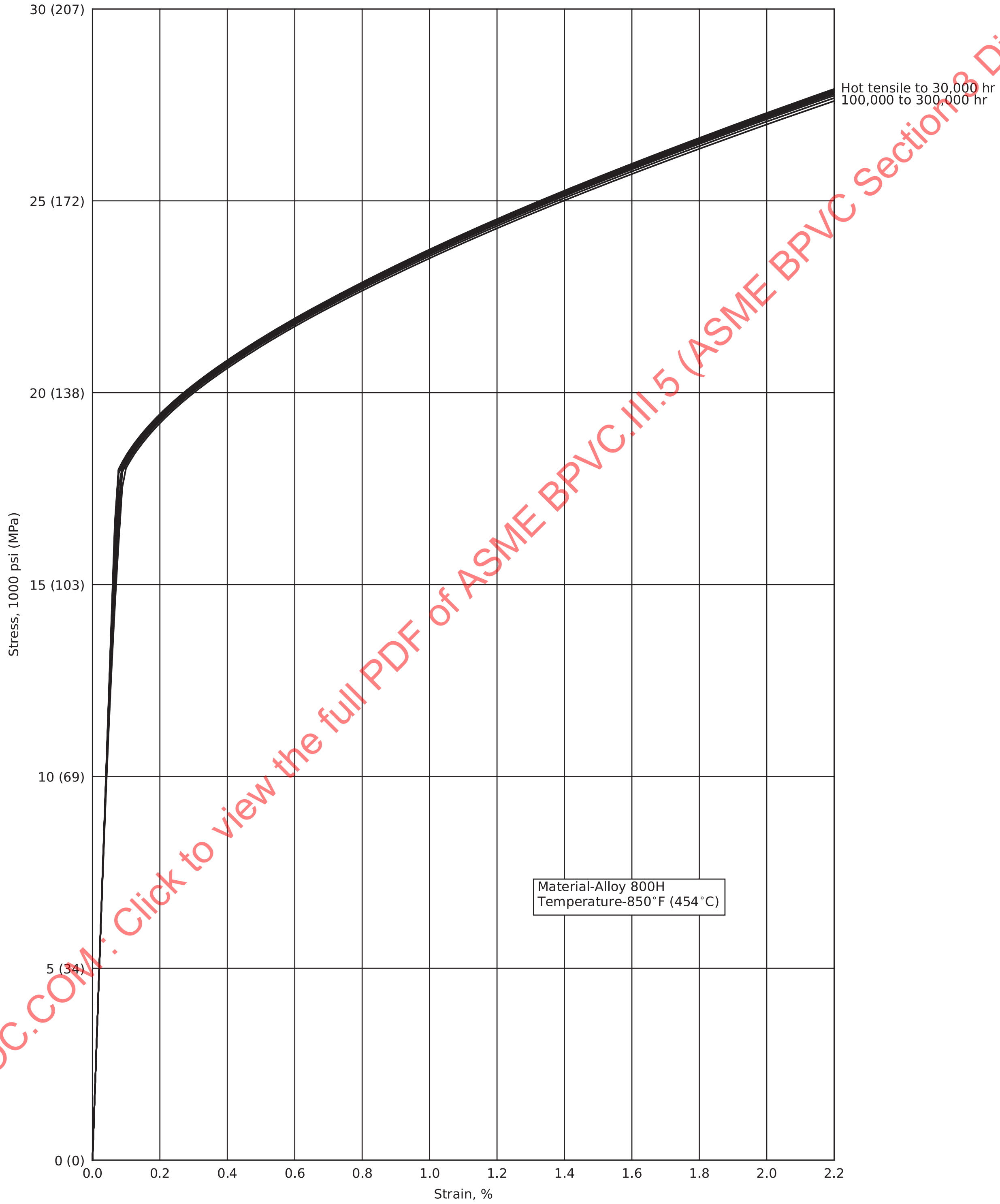


Figure HBB-T-1833-3
Average Isochronous Stress–Strain Curves

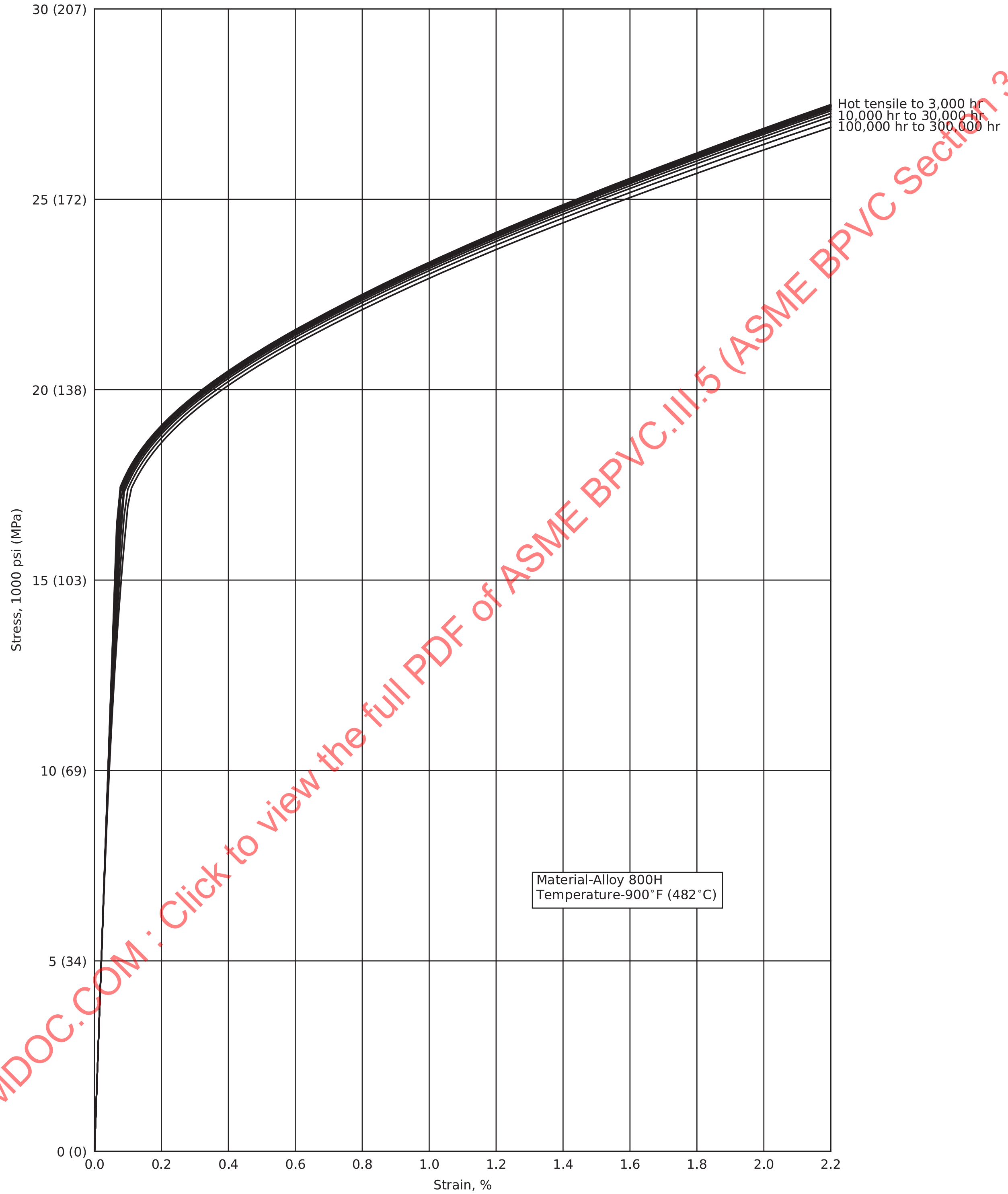


Figure HBB-T-1833-4
Average Isochronous Stress–Strain Curves

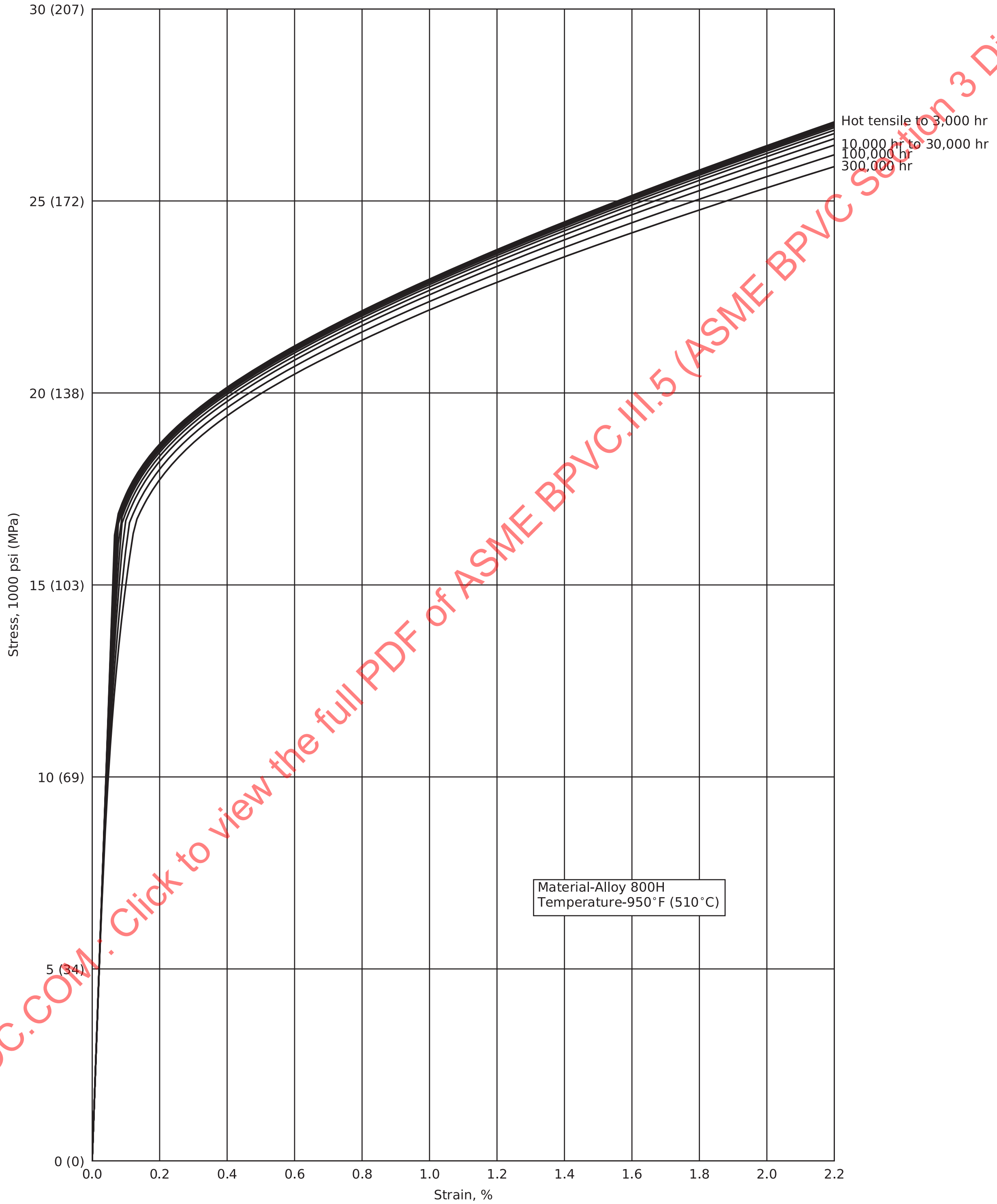


Figure HBB-T-1833-5
Average Isochronous Stress–Strain Curves

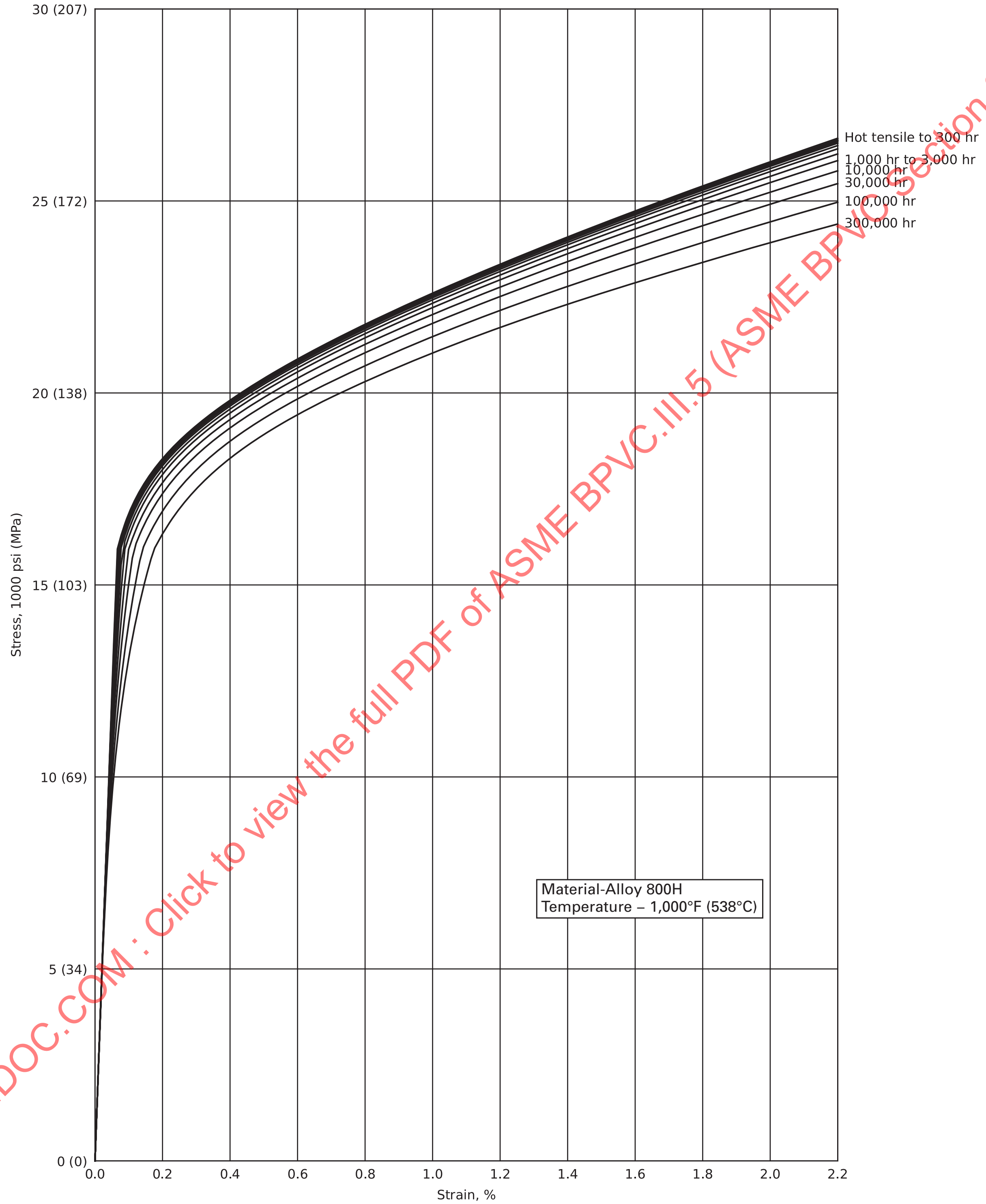


Figure HBB-T-1833-6
Average Isochronous Stress–Strain Curves

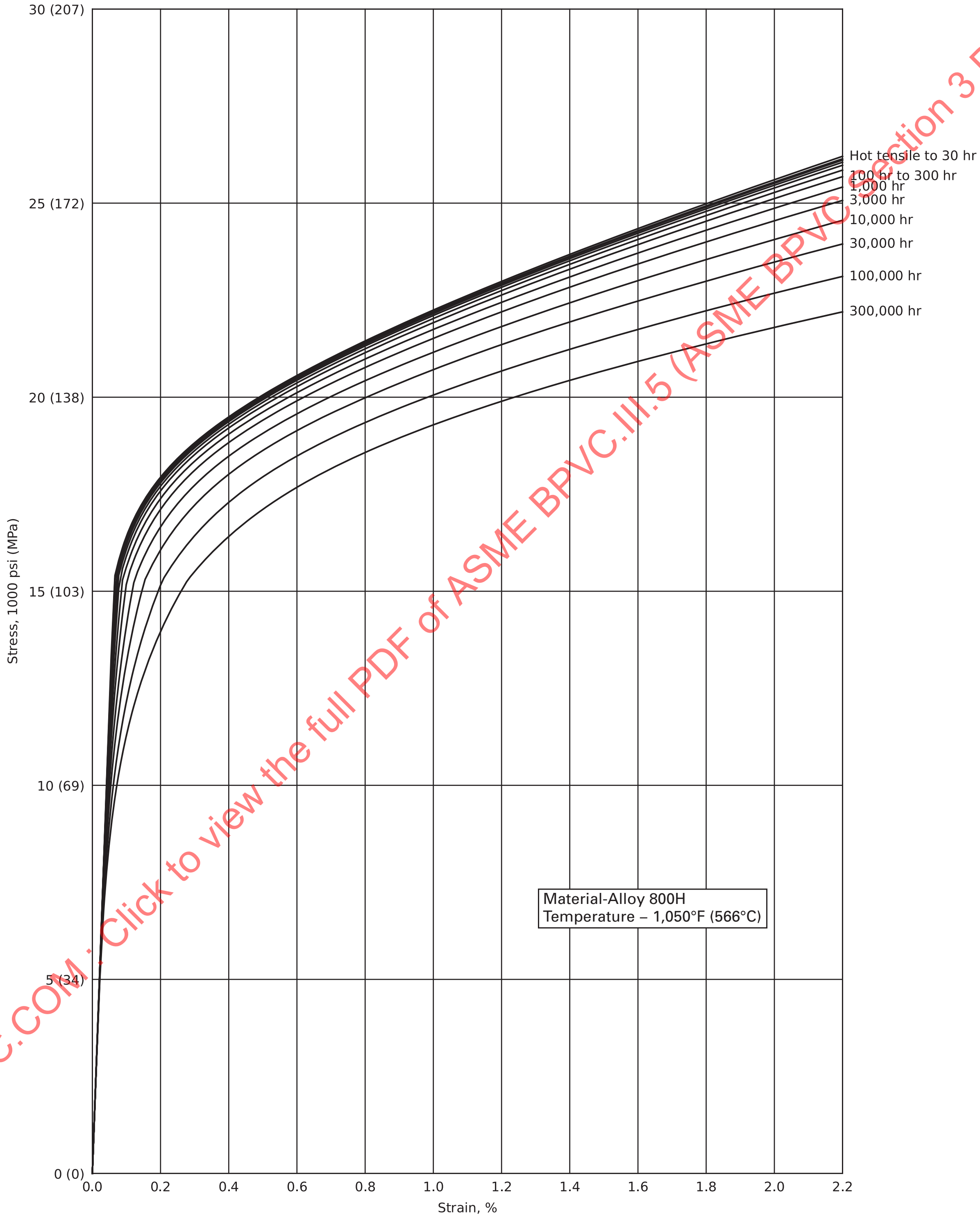


Figure HBB-T-1833-7
Average Isochronous Stress–Strain Curves

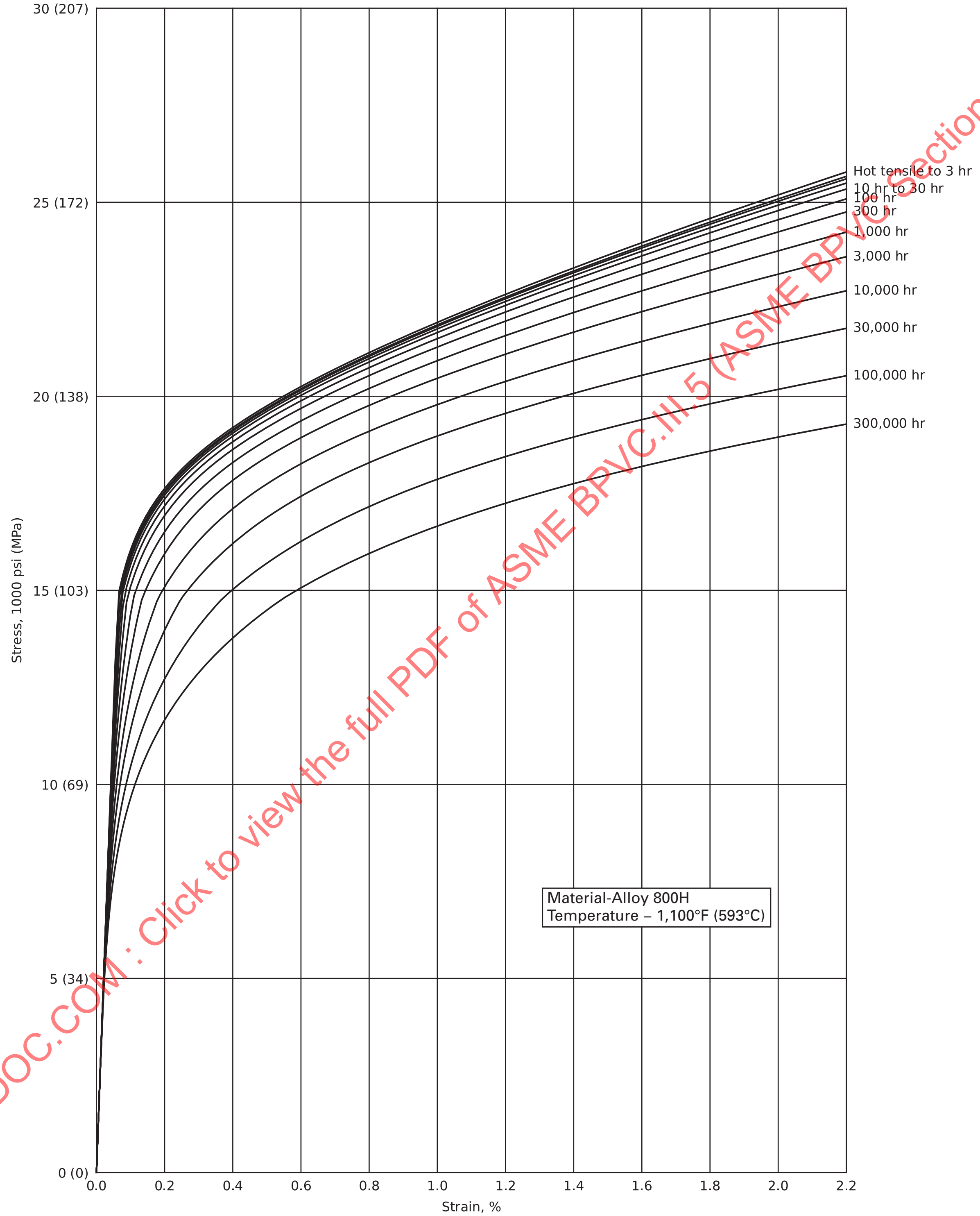


Figure HBB-T-1833-8
Average Isochronous Stress–Strain Curves

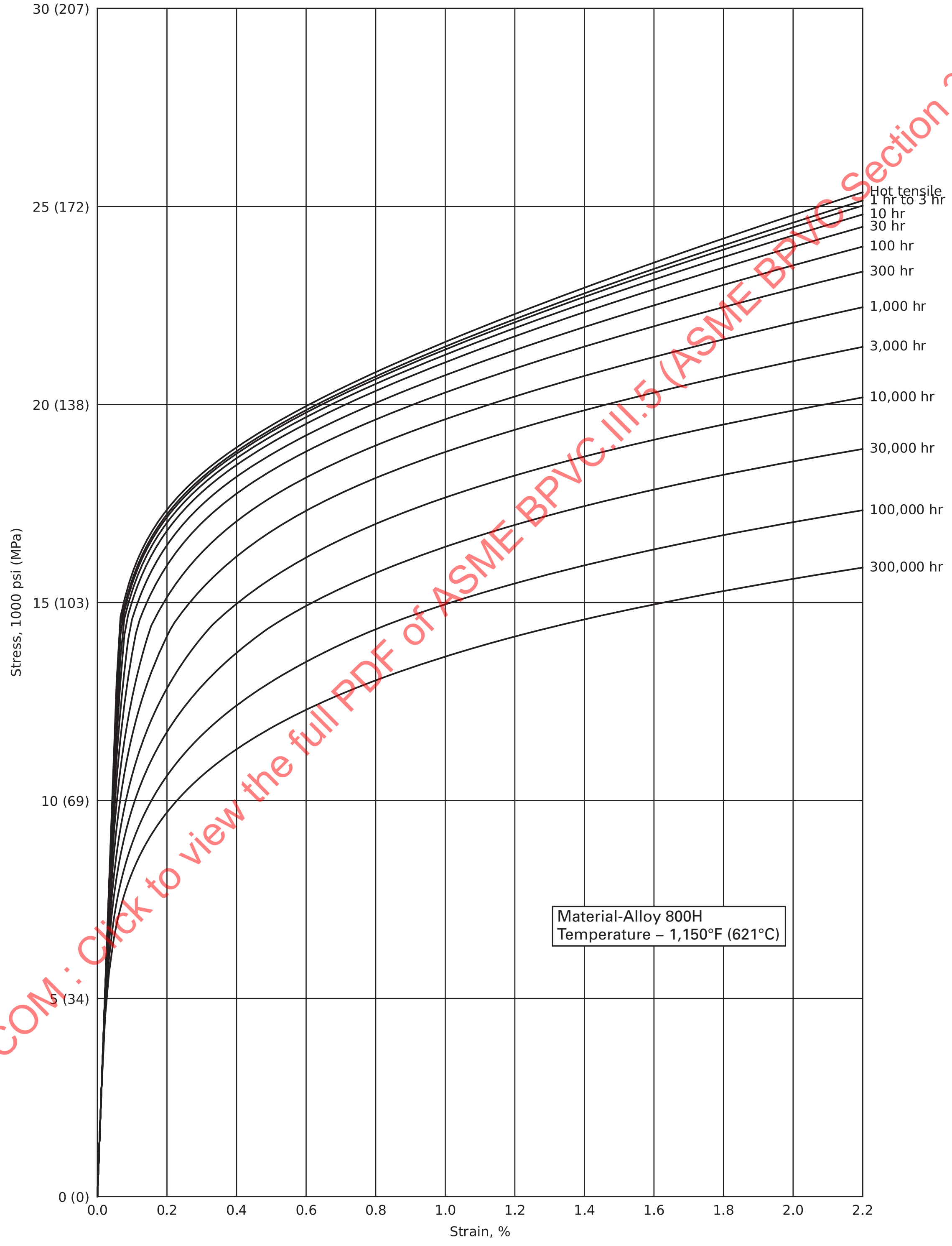


Figure HBB-T-1833-9
Average Isochronous Stress–Strain Curves

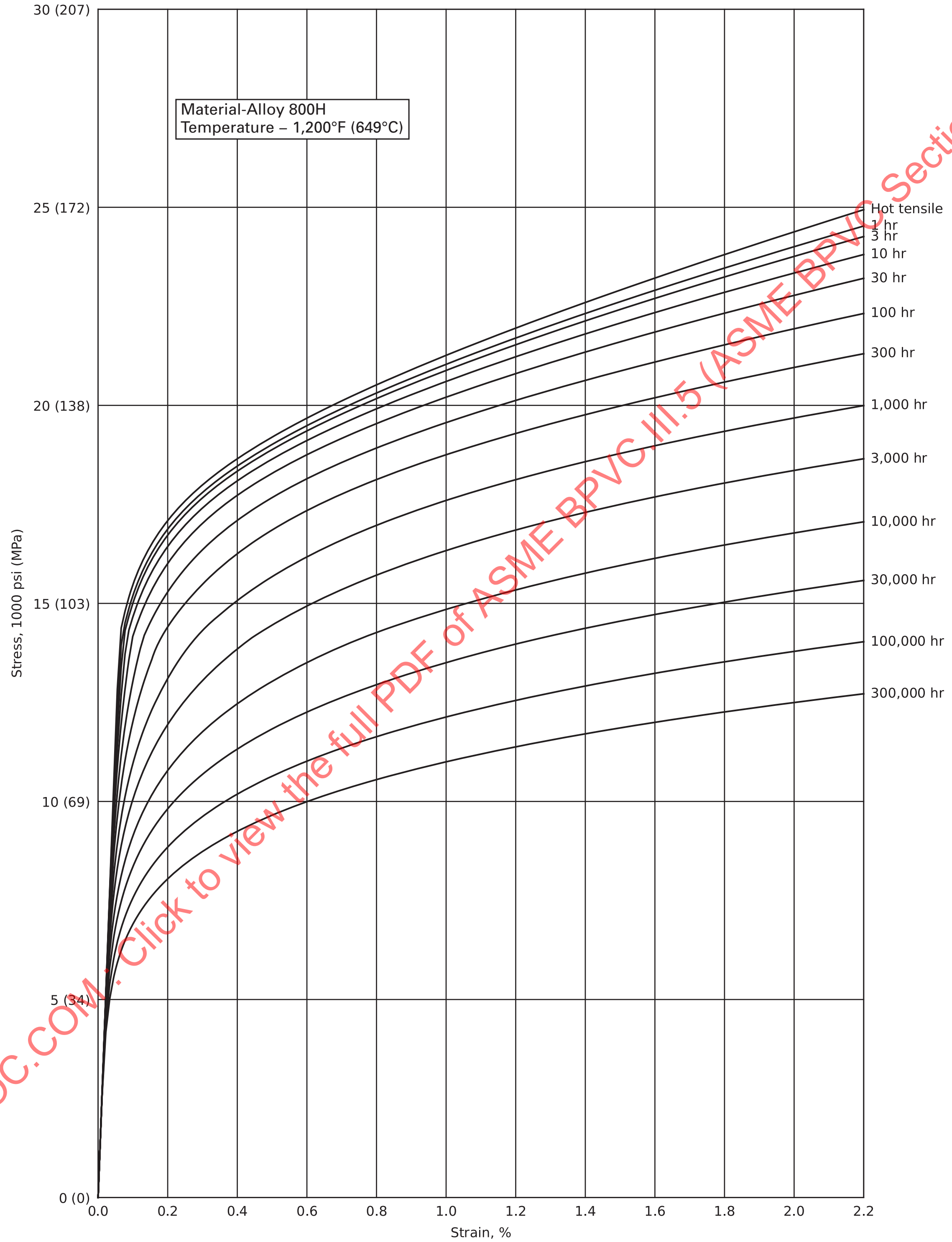


Figure HBB-T-1833-10
Average Isochronous Stress–Strain Curves

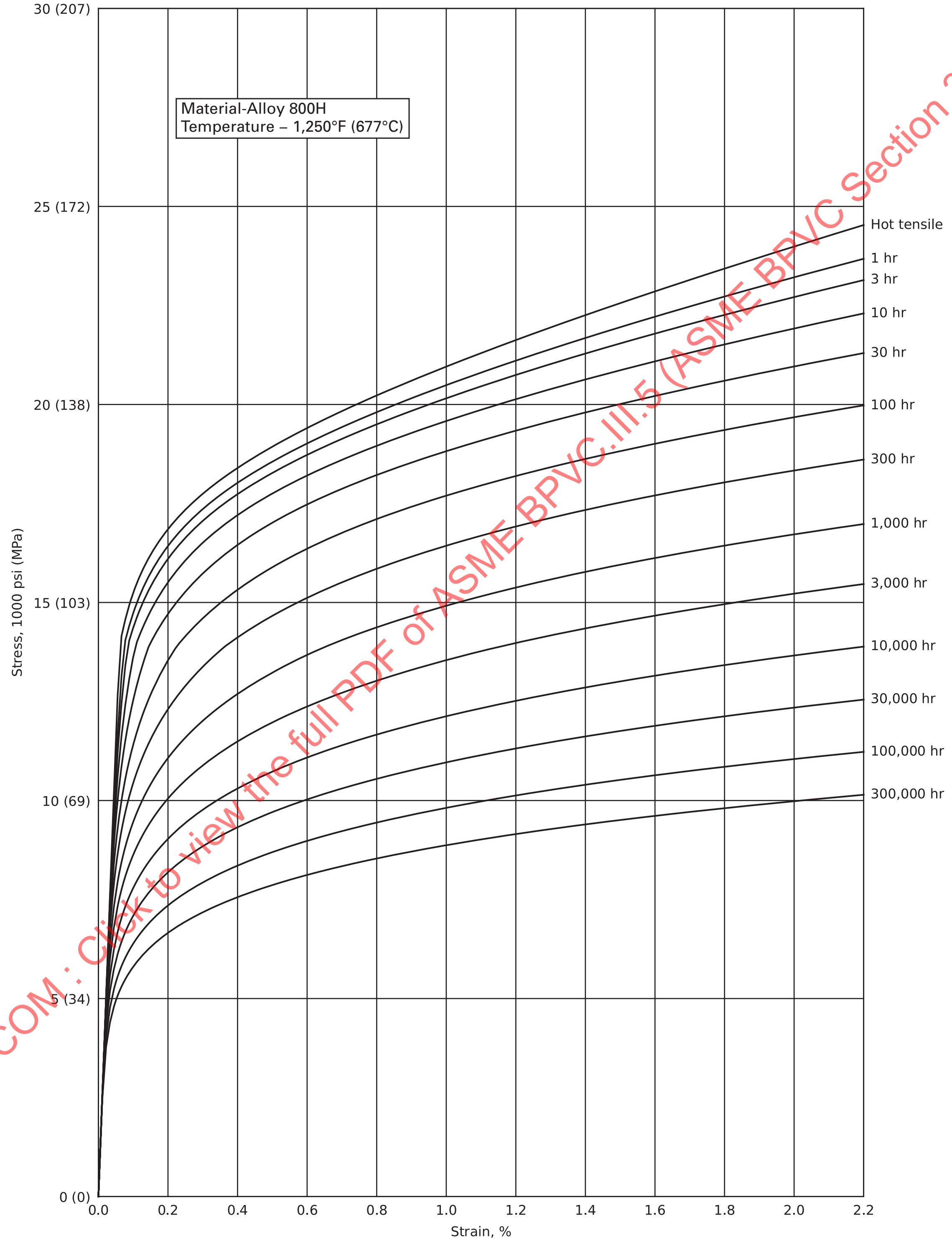


Figure HBB-T-1833-11
Average Isochronous Stress–Strain Curves

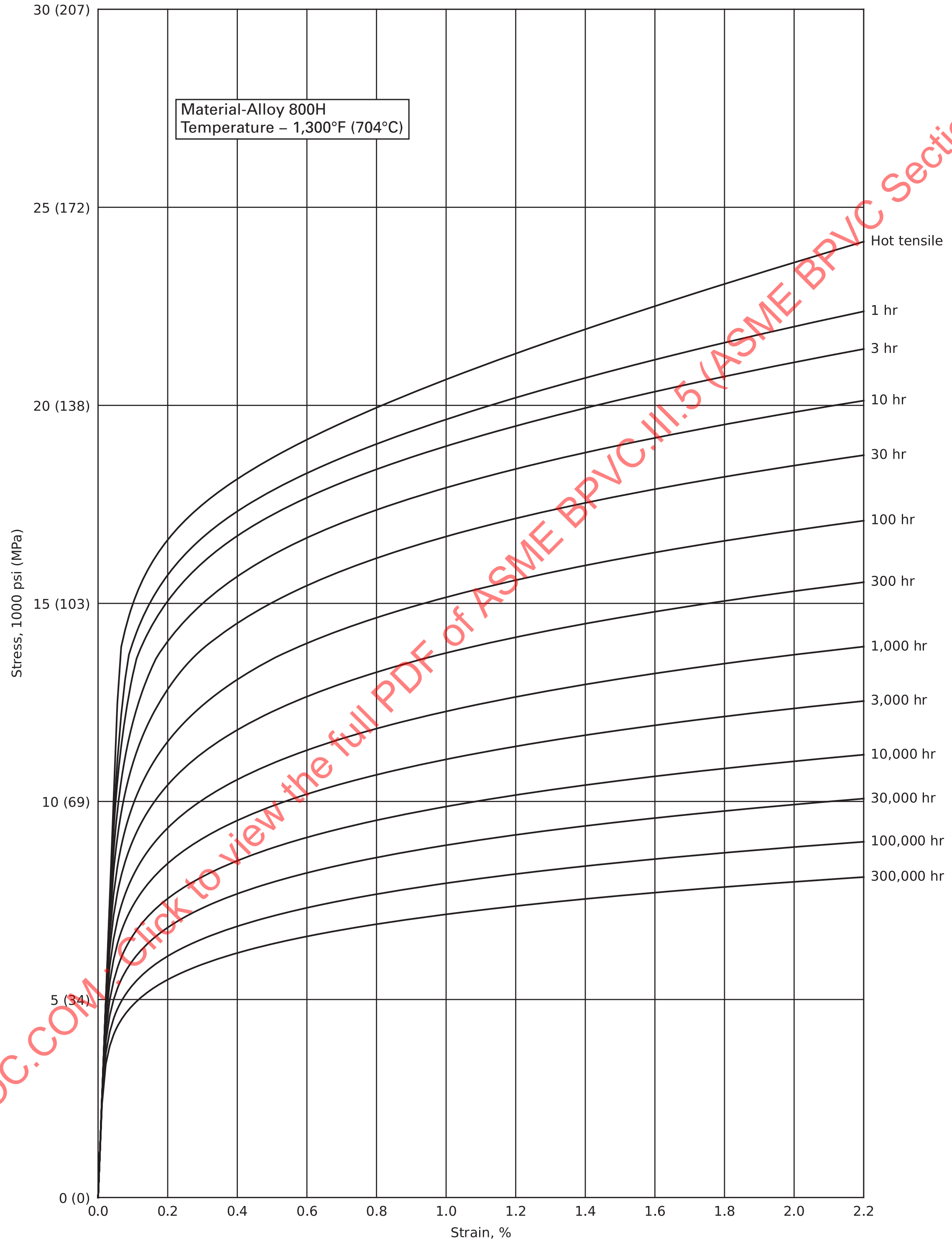


Figure HBB-T-1833-12
Average Isochronous Stress–Strain Curves

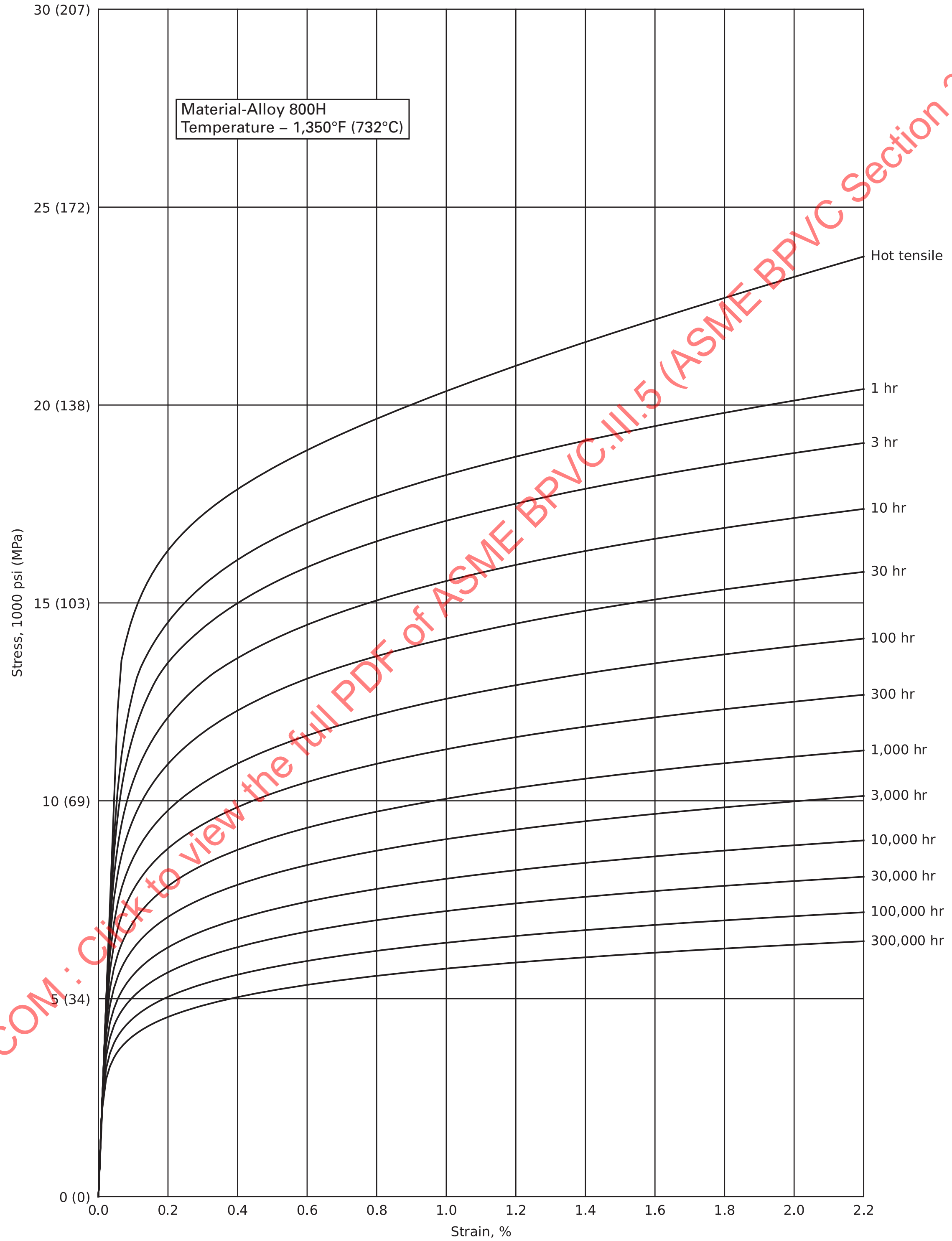
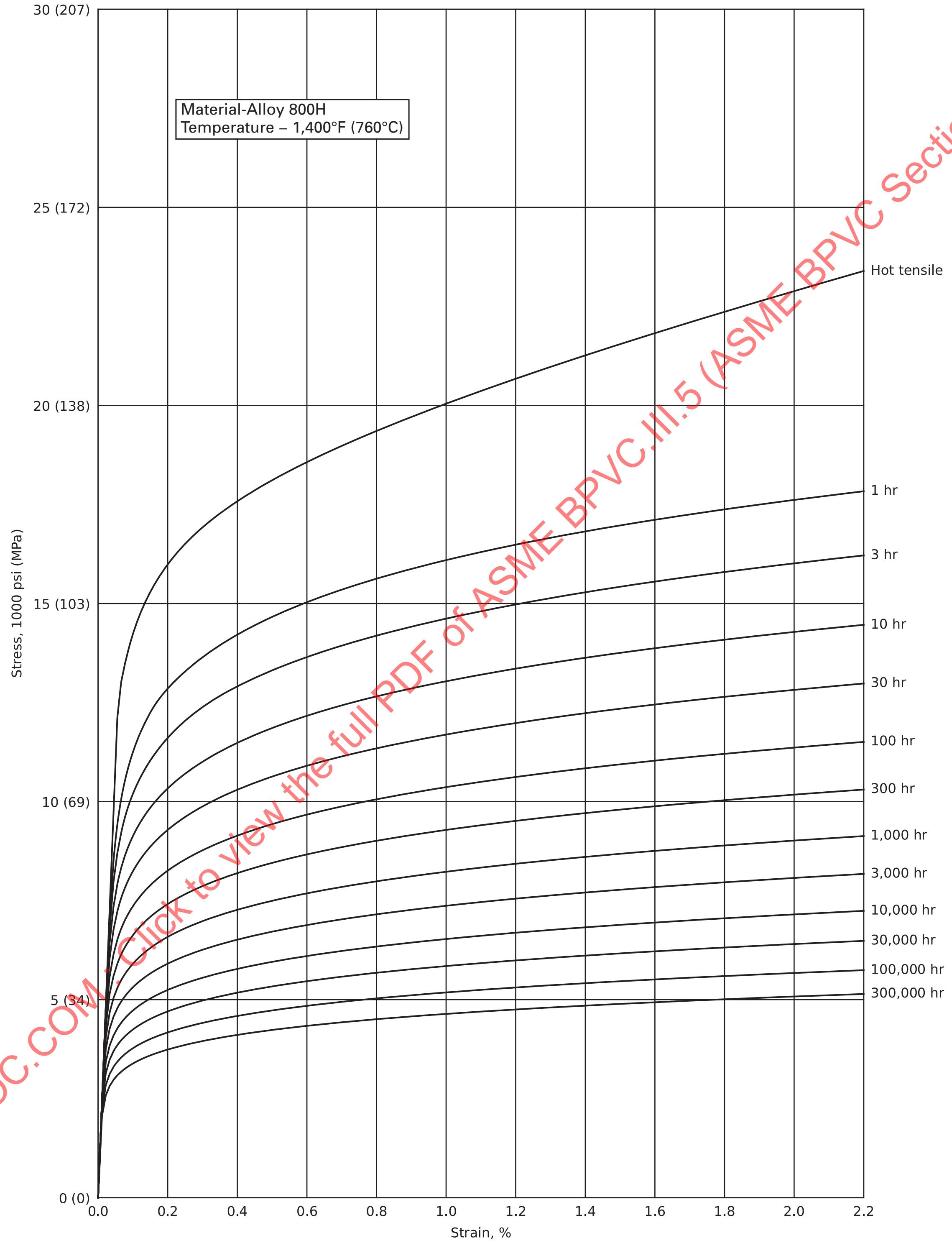


Figure HBB-T-1833-13
Average Isochronous Stress–Strain Curves



HBB-T-1834 2¼Cr–1Mo (23)

Figures HBB-T-1834-1 through HBB-T-1834-11 illustrate the isochronous stress–strain curves for 2¼Cr–1Mo.

(a) Elastic Strain

$$\varepsilon_e = \frac{\sigma}{E}$$

where

E = the values in Section II, Part D (Metric), Subpart 2, Table TM-1 interpolated linearly between temperature values

(b) Plastic Strain

$$\begin{aligned} \varepsilon_p &= 0 \text{ for } \sigma \le \sigma_y \\ &= \frac{1}{C}\ln\left(\frac{\sigma - B}{\sigma_y - B}\right) \text{ for } \sigma > \sigma_y \end{aligned}$$

where Table HBB-T-1834-1 tabulates values of the parameters σ_y, B, and C as functions of temperature. This table should be linearly interpolated to provide values in between the listed temperatures.

(c) Creep Strain. Use the creep strain model in the following list corresponding to the first of the logical conditions in the right column that is true for the particular combination of temperature and time. If none of the logical conditions apply, use the model described in the last row of ε_c below.

$$\begin{aligned} \varepsilon_c &= 0 \text{ for } T < 372 \\ &= \varepsilon_2/100 \text{ for } \varepsilon_2 < \varepsilon_1 \\ &= \varepsilon_1/100 \text{ for } t < t_1 \\ &= \varepsilon_3/100 \text{ otherwise} \end{aligned}$$

where

$$\begin{aligned} \varepsilon_1 &= \frac{C_1 p_1 t}{1 + p_1 t} + \dot{\varepsilon}_1 t \\ \varepsilon_2 &= \frac{C_2 p_2 t}{1 + p_2 t} + \dot{\varepsilon}_2 t \\ \varepsilon_3 &= \frac{C_2 p_2 t'}{1 + p_2 t} + \dot{\varepsilon}_2 t' \end{aligned}$$

$$C_1 = 10^{d_1}$$

$$d_1 = 1.0328 + \frac{168,680}{U\left(T + 273.15\right)} - 0.023772U + 0.0079141U \log\sigma$$

$$p_1 = 10^{q_1}$$

$$q_1 = 7.6026 + 3.3396 \log\sigma - \frac{12,323}{\left(T + 273.15\right)}$$

$$\dot{\varepsilon}_1 = 10^{e_1}$$

$$e_1 = 6.7475 + 0.01142\sigma + \frac{987.72}{U}\log\sigma - \frac{13,494}{\left(T + 273.15\right)}$$

$$C_2 = 10^{d_2}$$

$$d_2 = -0.051086 + \frac{140,730}{U\left(T + 273.15\right)} - 0.01U + 0.0037345U \log\sigma$$

$$p_2 = 10^{q_2}$$

$$q_2 = 8.1242 + 0.0179678\sigma + \frac{404.63}{U}\log\sigma - \frac{11,659}{\left(T + 273.15\right)}$$

$$\dot{\varepsilon}_2 = 10^{e_2}$$

$$e_2 = 11.498 - \frac{8.2226U}{\left(T + 273.15\right)} - \frac{20,448}{\left(T + 273.15\right)} + \frac{5,862.4}{\left(T + 273.15\right)}\log\sigma$$

$$t_1^{(a)} = 10^{a}$$

$$a = -13.528 + \frac{6.5196U}{\left(T + 273.15\right)} + \frac{23,349}{\left(T + 273.15\right)} - \frac{5,693.8}{\left(T + 273.15\right)}\log\sigma$$

$$t_1^{(b)} = 10^{b}$$

$$b = -11.098 - \frac{4.0951\sigma}{U} + \frac{11,965}{\left(T + 273.15\right)}$$

$$\begin{aligned} t_1 &= t_1^{(a)} \text{ for } T \le 454 \\ &= t_1^{(b)} \text{ for } T > 510 \\ &= t_1^{(a)} + \frac{t_1^{(b)} - t_1^{(a)}}{56}\left(T - 454\right) \text{ for } 454 < T \le 510 \end{aligned}$$

$$t' = t - \left(t_1 - t_c\right)$$

$$t_c = \left\{-\dot{\varepsilon}_2 - C_2 p_2 + \varepsilon_1' p_2 + \sqrt{4\varepsilon_1'\dot{\varepsilon}_2 p_2 + \left[\dot{\varepsilon}_2 + \left(C_2 - \varepsilon_1'\right)p_2\right]^2}\right\} \Big/ \left\{2\dot{\varepsilon}_2 p_2\right\}$$

$$\varepsilon_1' = \frac{C_1 p_1 t_1}{1 + p_1 t_1} + \dot{\varepsilon}_1 t_1$$

The values of the parameter U are tabulated in Table HBB-T-1834-2. Values in this table should be linearly interpolated between the enumerated temperatures.

Table HBB-T-1834-1

T	σ_y	B	C
371	210.96	576.81	−25.59
399	193.42	541.04	−32.09
427	199.53	477.98	−39.90
454	194.18	487.86	−35.38
482	183.83	601.37	−26.45
510	180.78	418.51	−45.35
538	183.29	389.23	−40.45
566	173.76	317.16	−60.25
593	169.40	300.79	−52.16
621	153.30	277.60	−58.78
649	133.88	239.85	−65.17

Table HBB-T-1834-2

T	U
371	471
400	468
450	452
500	418
550	364
600	284
621	300
649	270

Figure HBB-T-1834-1
Average Isochronous Stress–Strain Curves

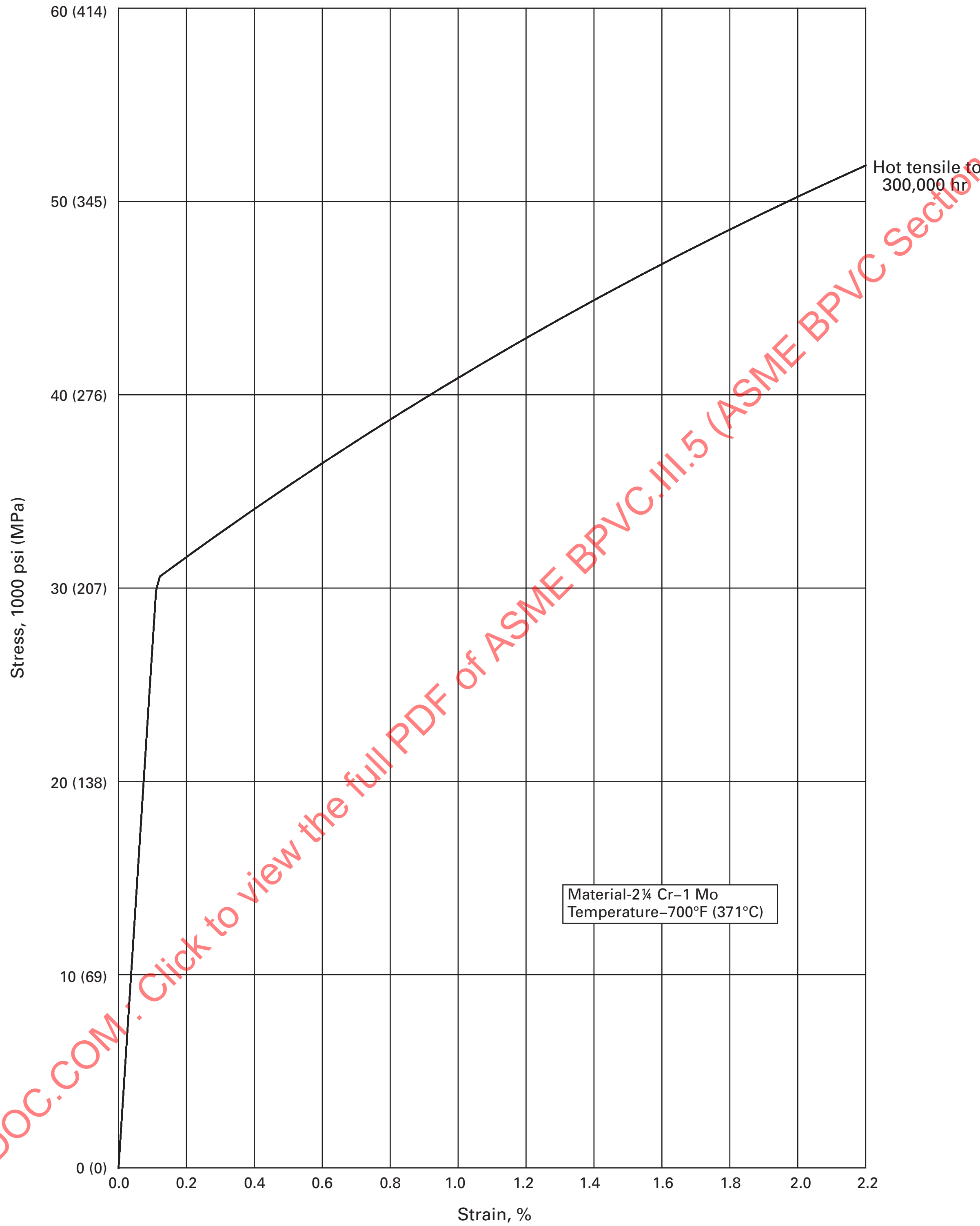


Figure HBB-T-1834-2
Average Isochronous Stress–Strain Curves

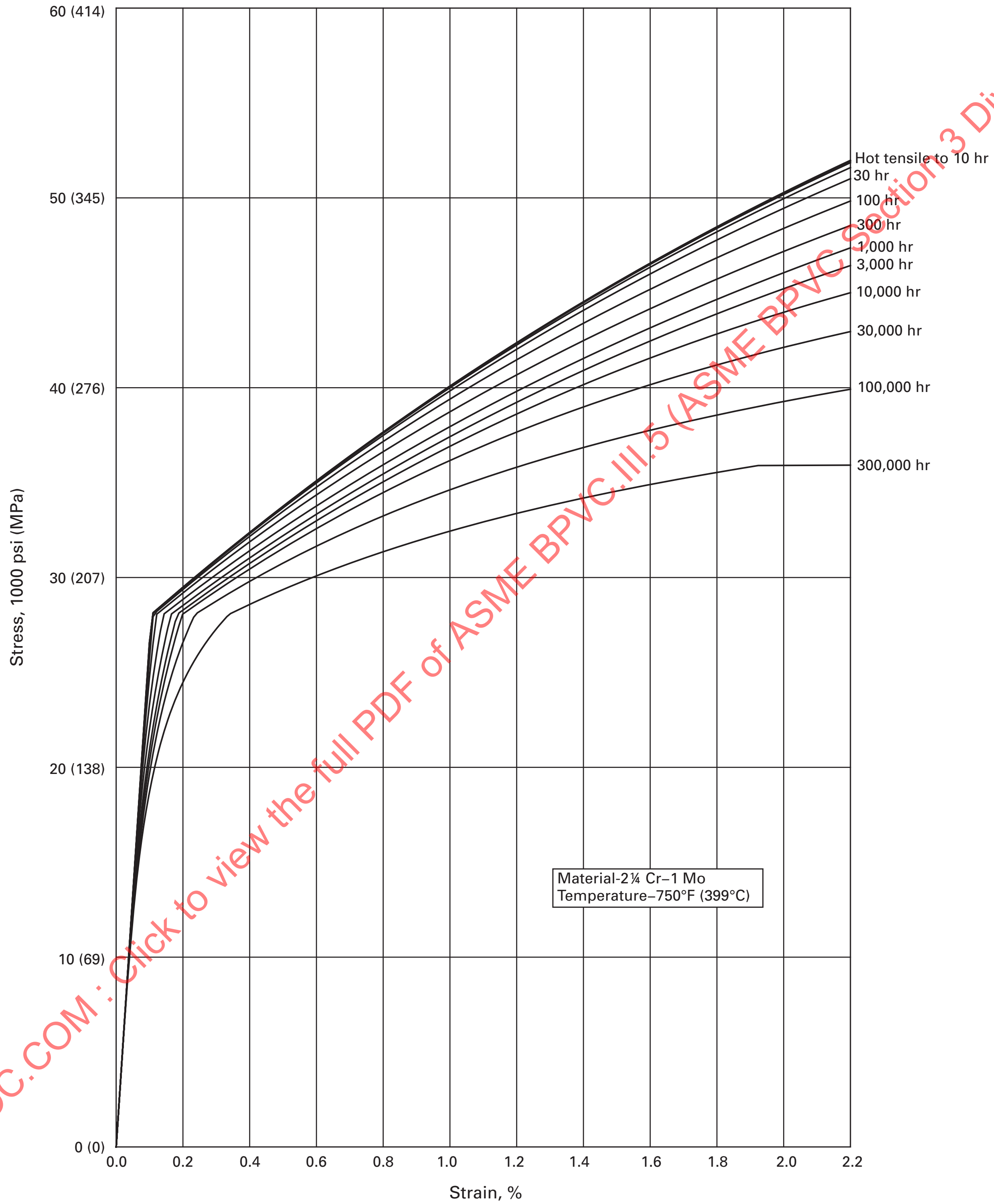


Figure HBB-T-1834-3
Average Isochronous Stress–Strain Curves

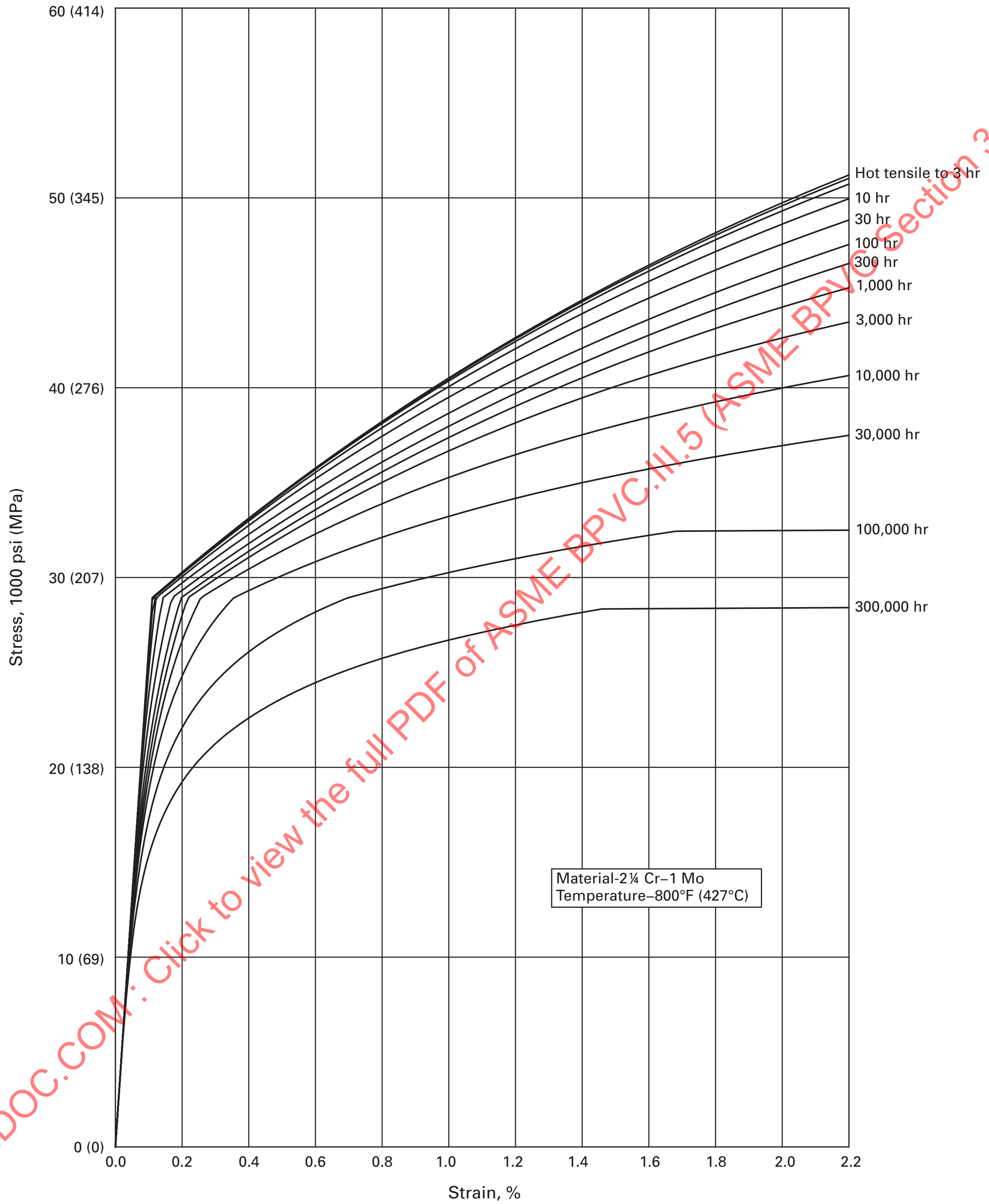


Figure HBB-T-1834-4
Average Isochronous Stress–Strain Curves

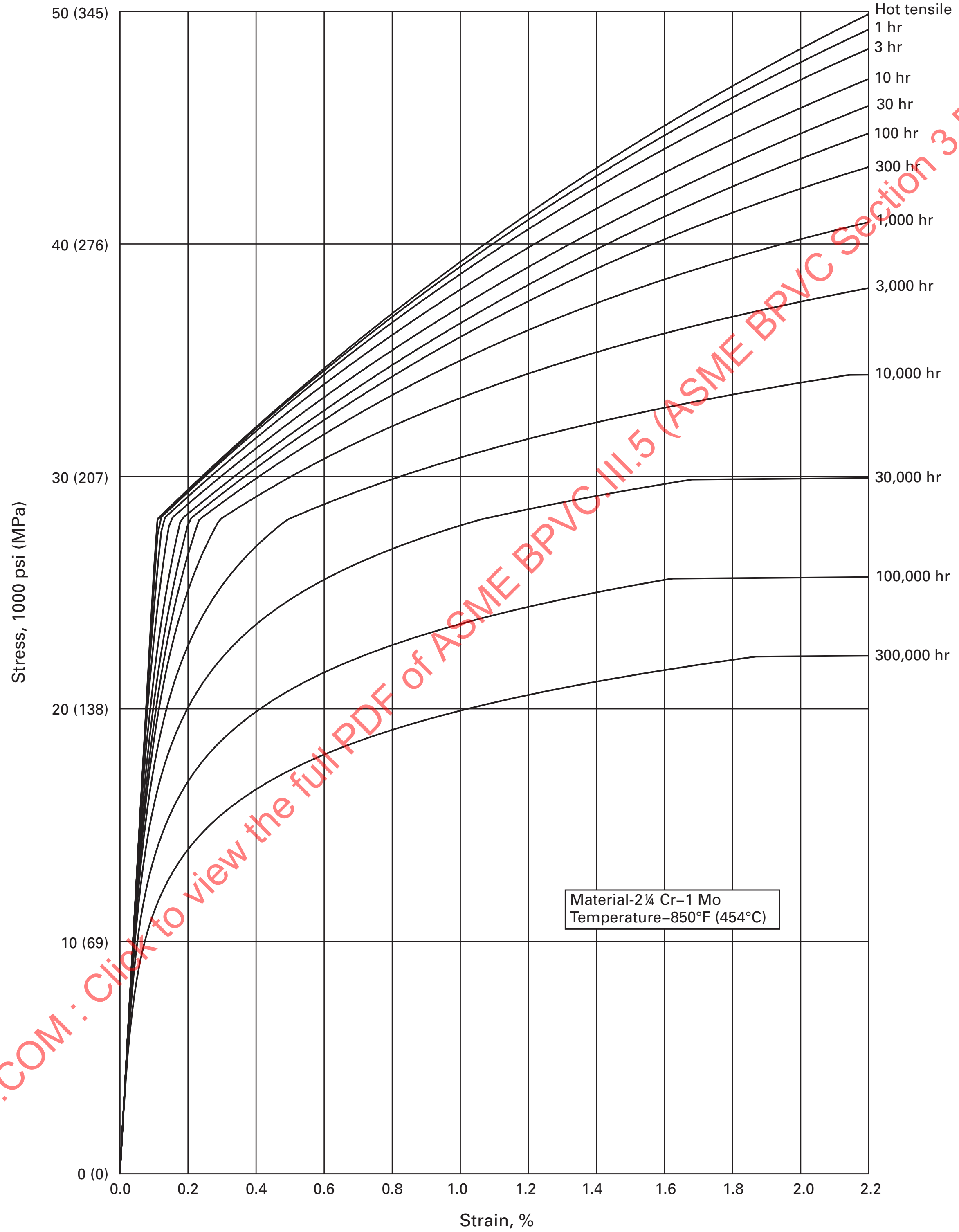


Figure HBB-T-1834-5
Average Isochronous Stress–Strain Curves

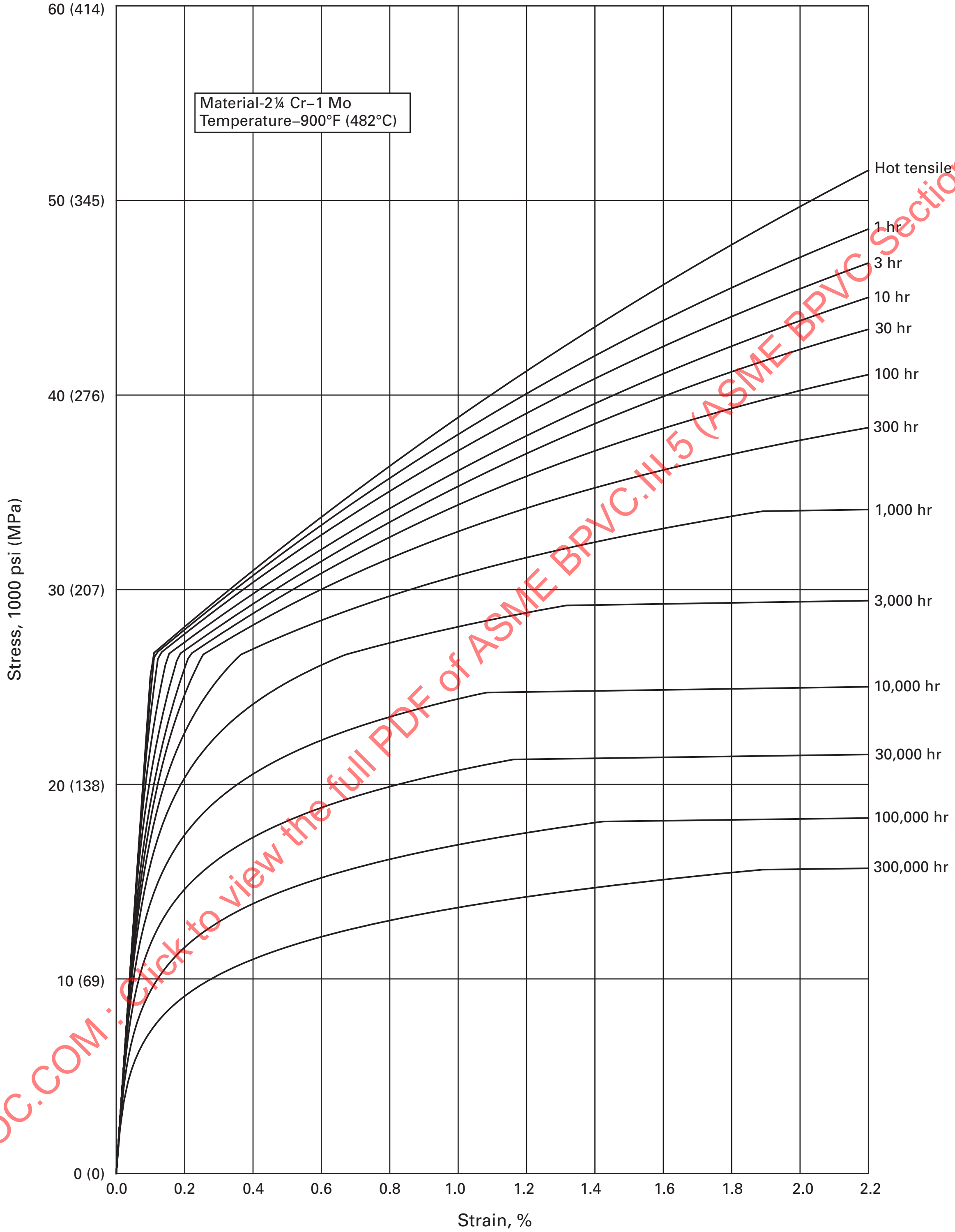


Figure HBB-T-1834-6
Average Isochronous Stress–Strain Curves

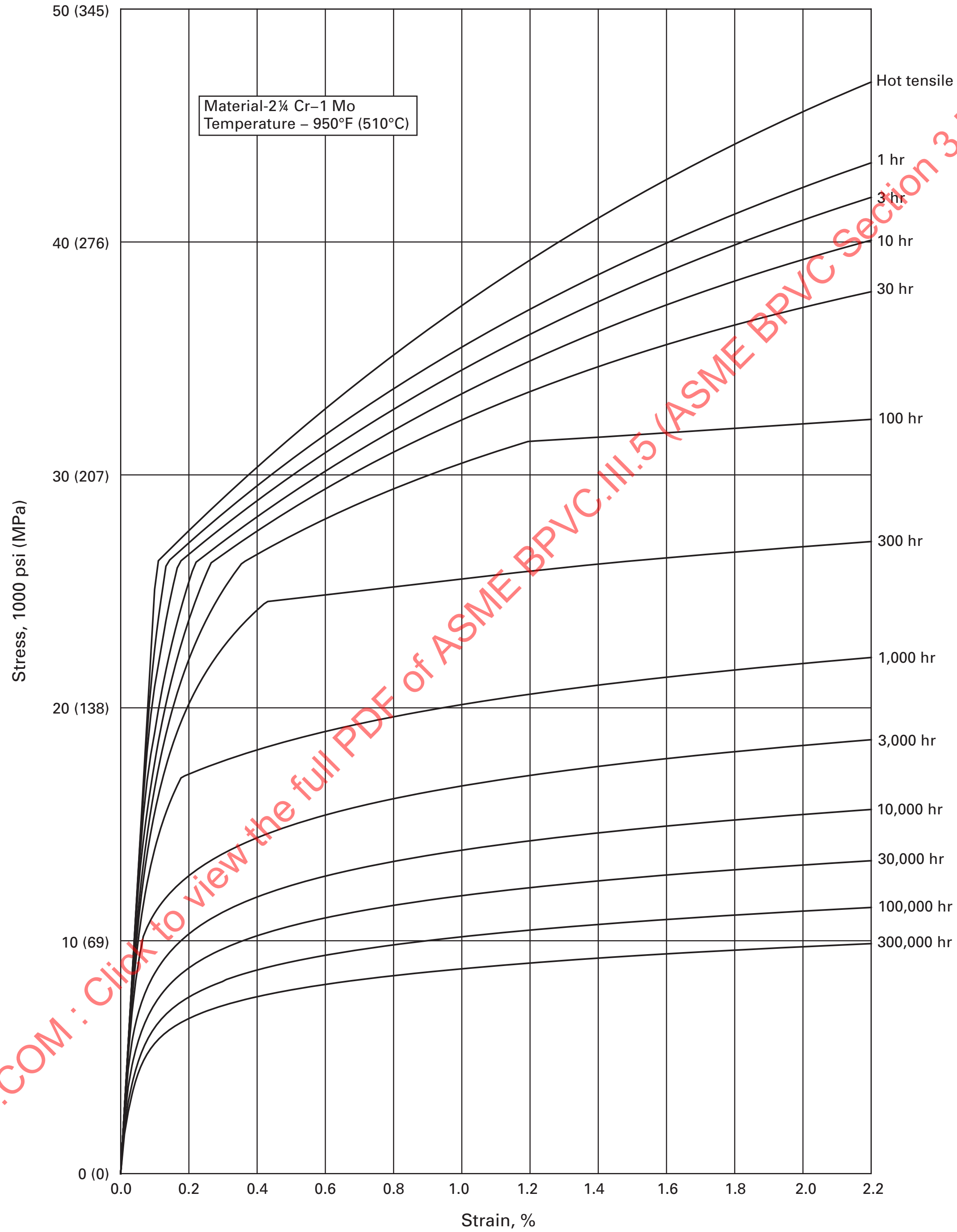


Figure HBB-T-1834-7
Average Isochronous Stress–Strain Curves

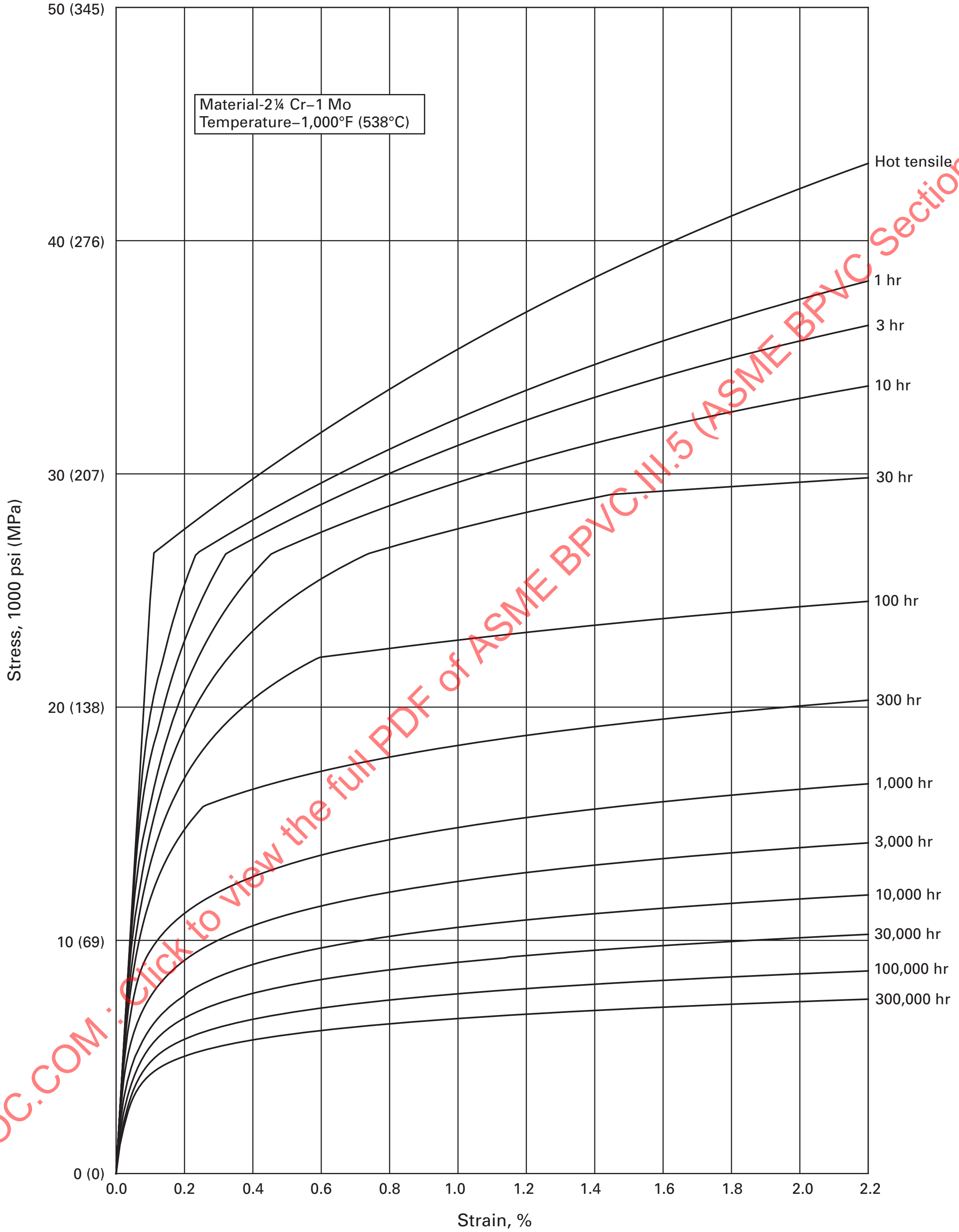


Figure HBB-T-1834-8
Average Isochronous Stress–Strain Curves

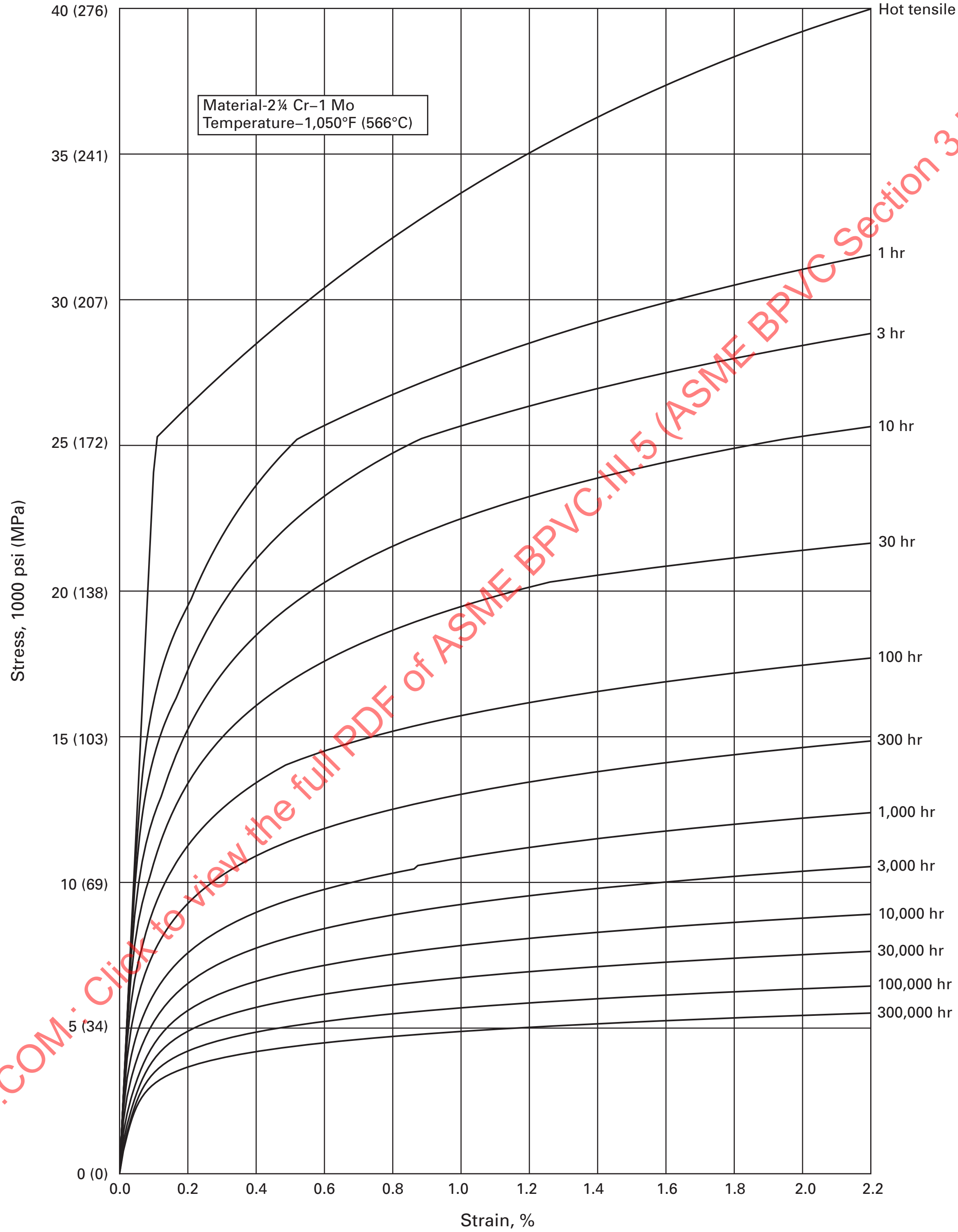


Figure HBB-T-1834-9
Average Isochronous Stress–Strain Curves

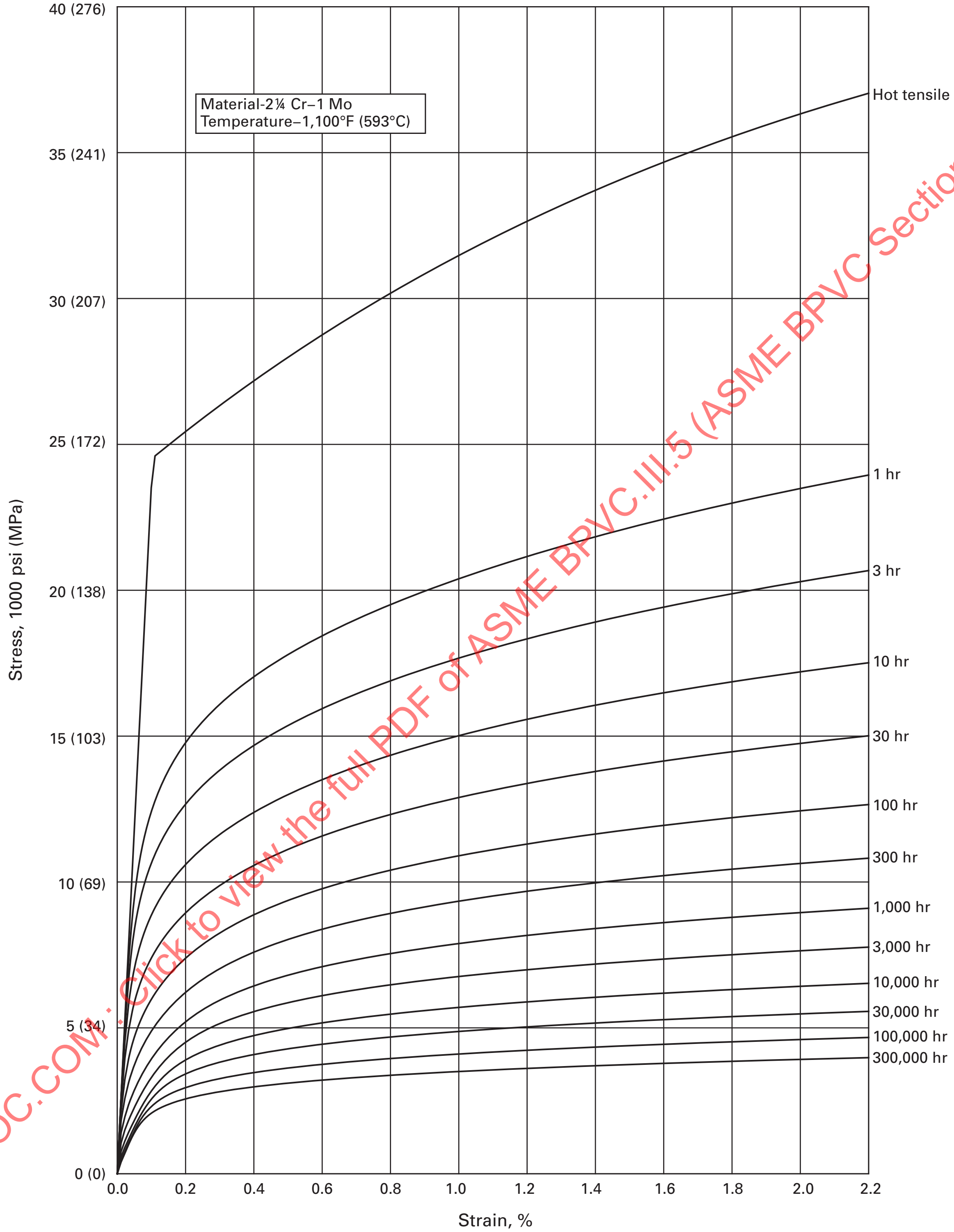


Figure HBB-T-1834-10
Average Isochronous Stress–Strain Curves

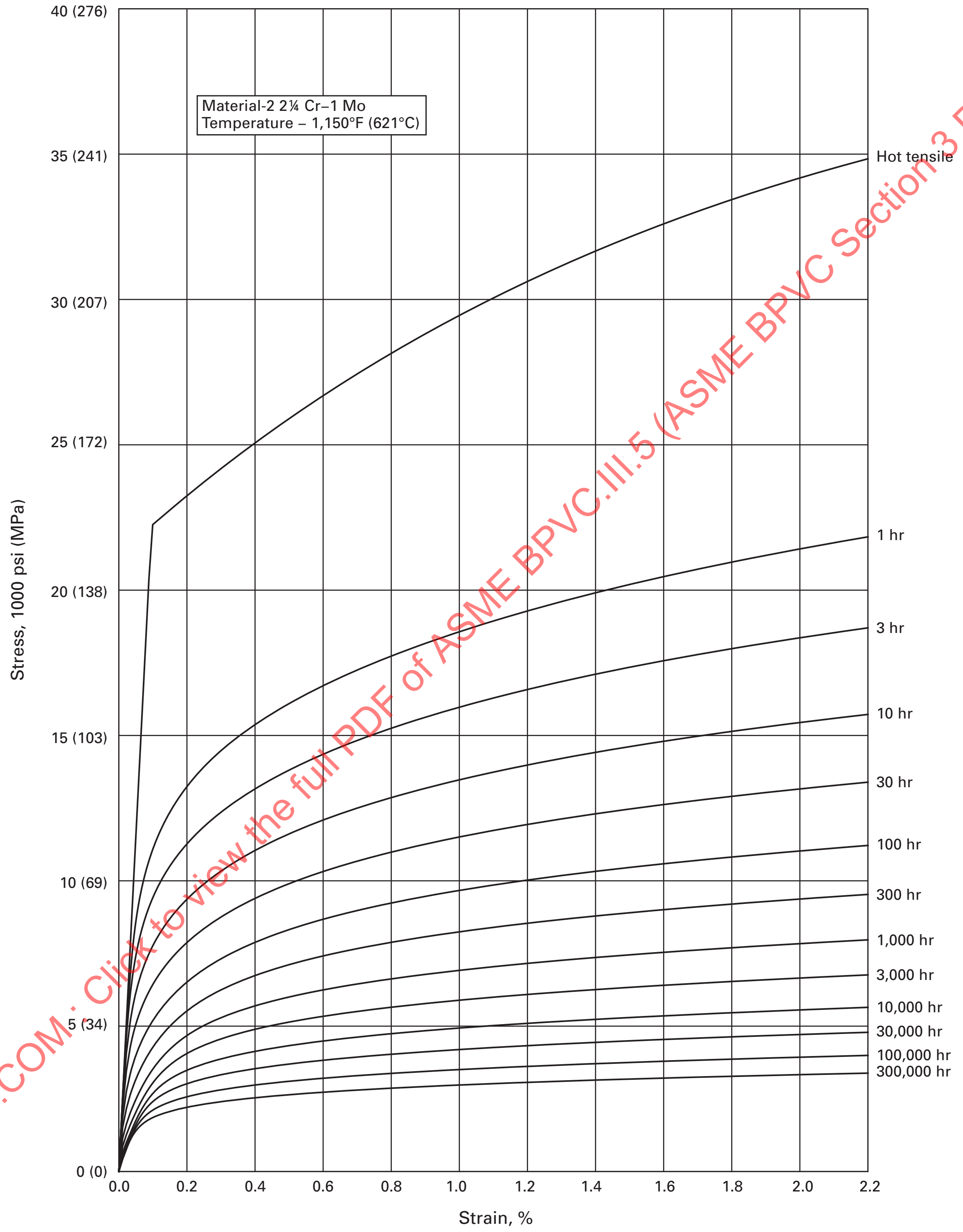
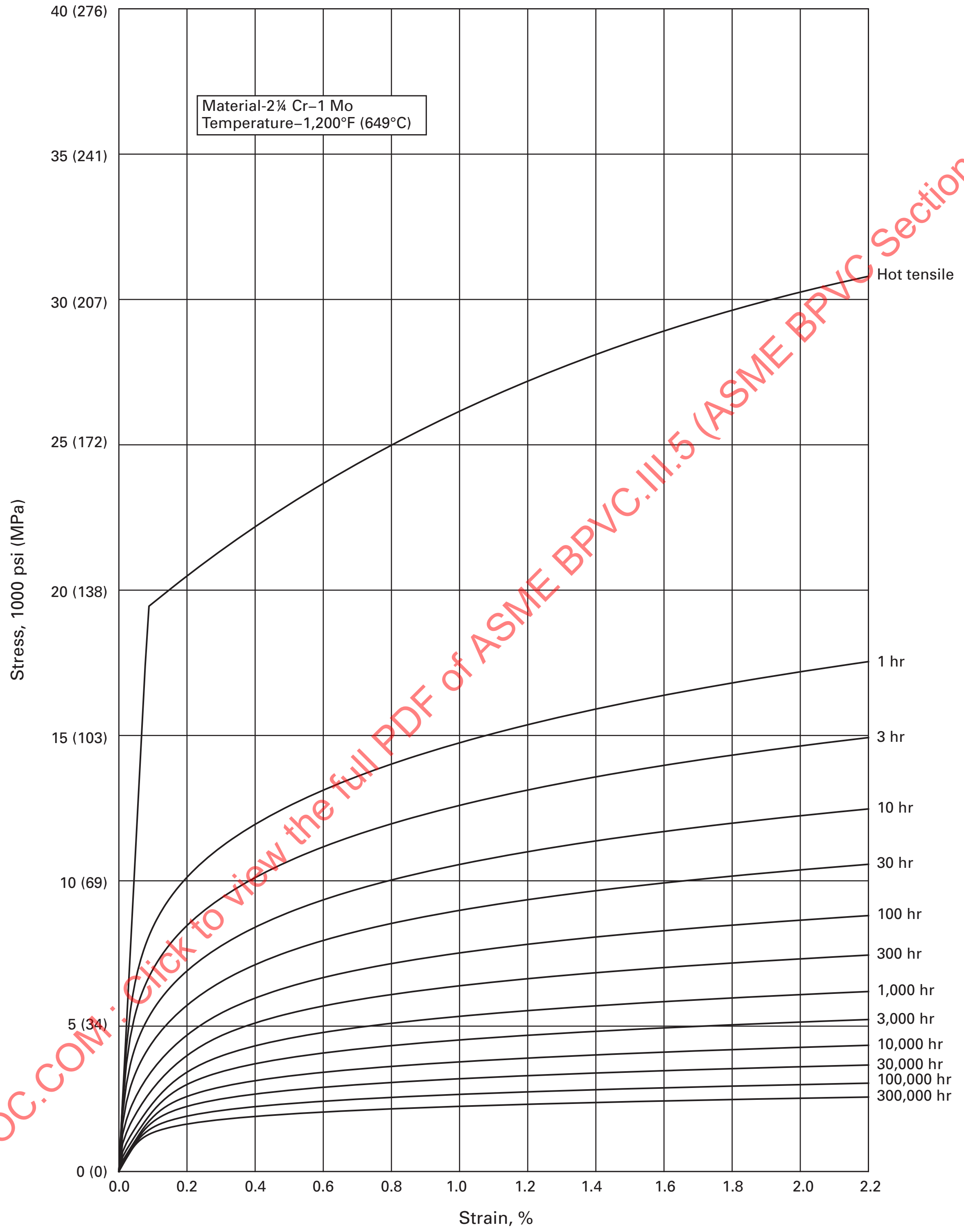


Figure HBB-T-1834-11
Average Isochronous Stress–Strain Curves



HBB-T-1835 9Cr–1Mo–V (23)

(a) Elastic Strain

$$\varepsilon_e = \frac{\sigma}{E}$$

where

E = the values in Table HBB-T-1835-1, interpolated linearly between the provided points

(b) Plastic Strain

$$\begin{aligned}\varepsilon_p &= 0 \text{ for } \sigma \le RP \\ &= \frac{1}{100b}\left[\ln\left(\frac{RP - RU}{\sigma - RU}\right)\right]^2 \text{ for } RP < \sigma < RU\end{aligned}$$

otherwise $\varepsilon_p = \infty$ where $R = 1.25(Y_1/Y)$

Table HBB-T-1835-2 tabulates the remaining parameters as a function of temperature. All these parameters should be linearly interpolated between enumerated temperatures.

(c) Creep Strain

$$\varepsilon_c = \frac{1}{100}\left[D\sigma e^{V_0\sigma}e^{-Q_0/(T + 273.15)}t^{1/3} + C\sigma^n e^{V\sigma}e^{-Q/(T + 273.15)}t\right]$$

where

$$\begin{aligned}C &= 2.25 \times 10^{22} \\ D &= 847,000 \text{ for } T < 482 \\ &= 82,196(T - 482) + 847,000 \text{ for } 482 \le T < 537 \\ &= 5,450,000 \text{ for } T \ge 537 \\ Q &= 77,280 \\ Q_0 &= 25,330 \text{ for } T < 537 \\ &= 23,260 \text{ for } T \ge 537 \\ V &= 0.038 \\ V_0 &= 0.023 \\ n &= 5.0\end{aligned}$$

Figures HBB-T-1835-1 through HBB-T-1835-11 illustrate the isochronous stress–strain curves for 9Cr–1Mo–V.

Table HBB-T-1835-1

T	E
371	188,000
399	184,000
427	180,000
454	175,000
482	170,000
500	166,000
510	163,000
538	157,000
550	150,000
566	149,000
593	141,000
600	139,000
621	133,000
649	125,000

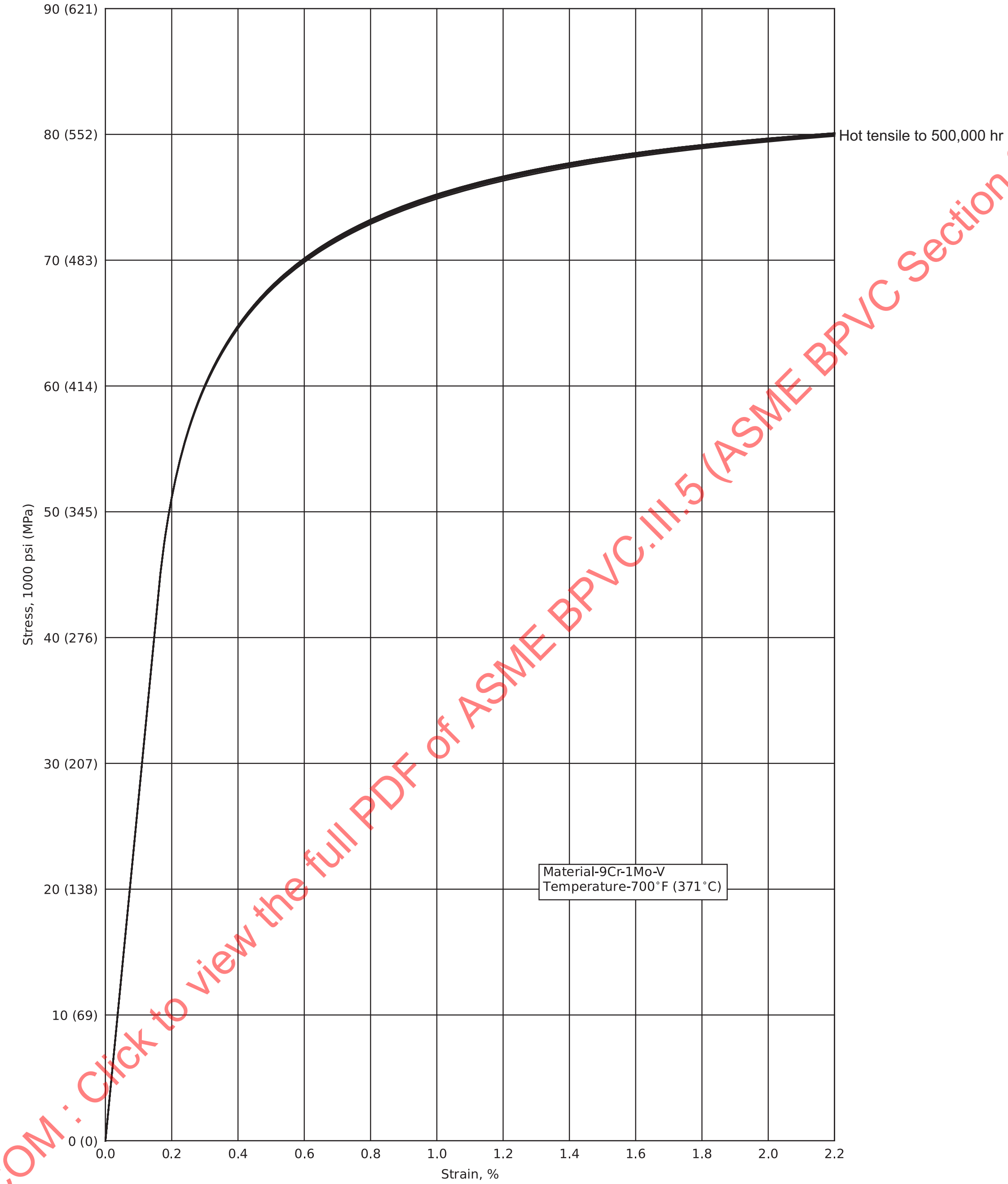
(23)

Table HBB-T-1835-2

T	P	U	b	Y	Y_1
371	317	603	3.73	483	366
399	310	586	4.49	479	358
427	303	569	4.77	469	350
454	296	541	5.88	459	336
482	283	507	8.24	445	319
500	269	483	9.30	431	307
510	262	469	10.59	421	298
538	228	431	14.11	393	273
550	207	410	15.70	376	262
566	186	386	17.36	355	245
593	145	338	14.84	303	214
600	138	324	14.80	296	206
621	110	283	14.70	252	183
649	83	234	10.97	200	152

(23)

Figure HBB-T-1835-1
Average Isochronous Stress–Strain Curves



(23)

Figure HBB-T-1835-2
Average Isochronous Stress–Strain Curves

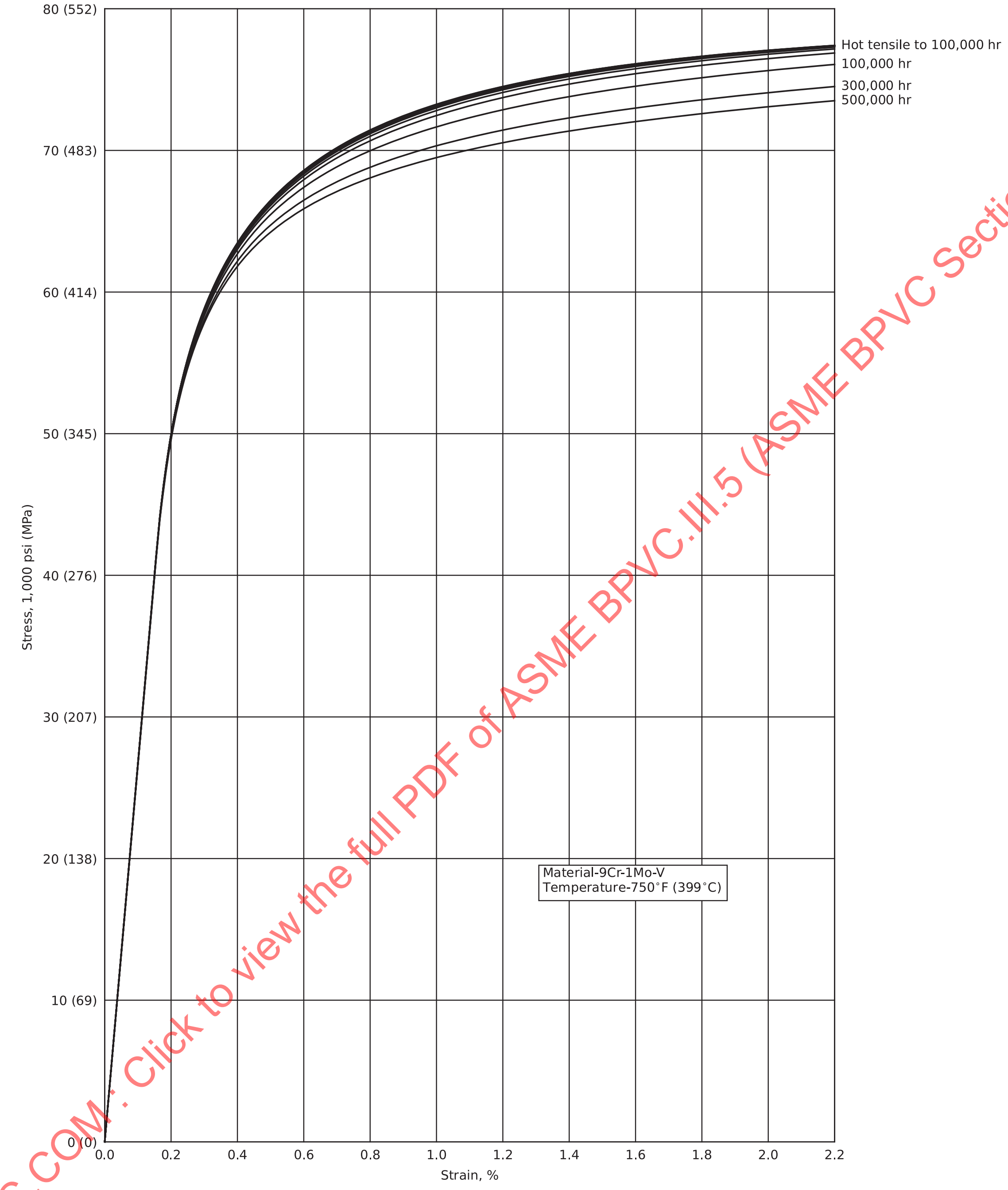
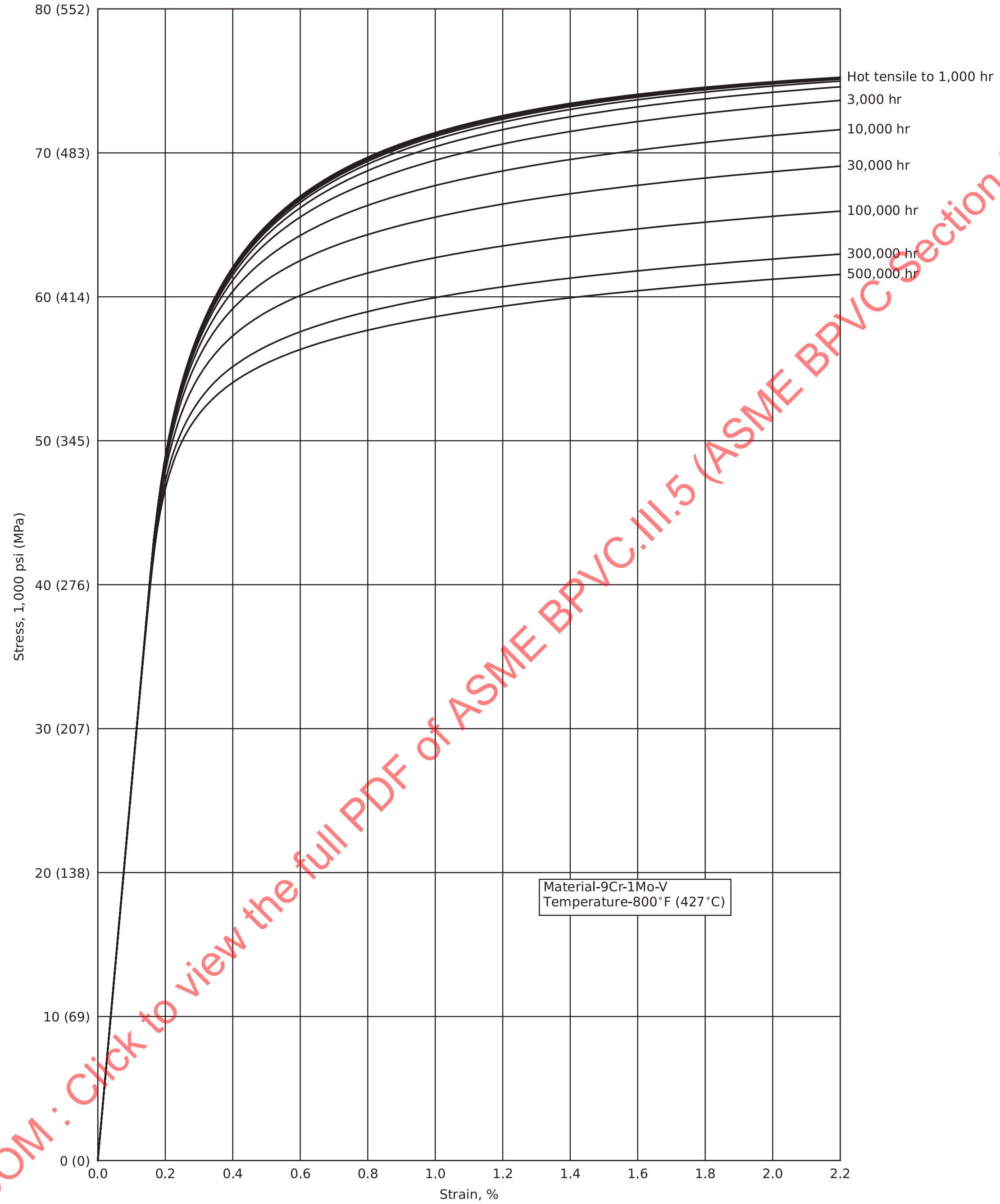


Figure HBB-T-1835-3
Average Isochronous Stress–Strain Curves

(23)



(23)

Figure HBB-T-1835-4
Average Isochronous Stress–Strain Curves

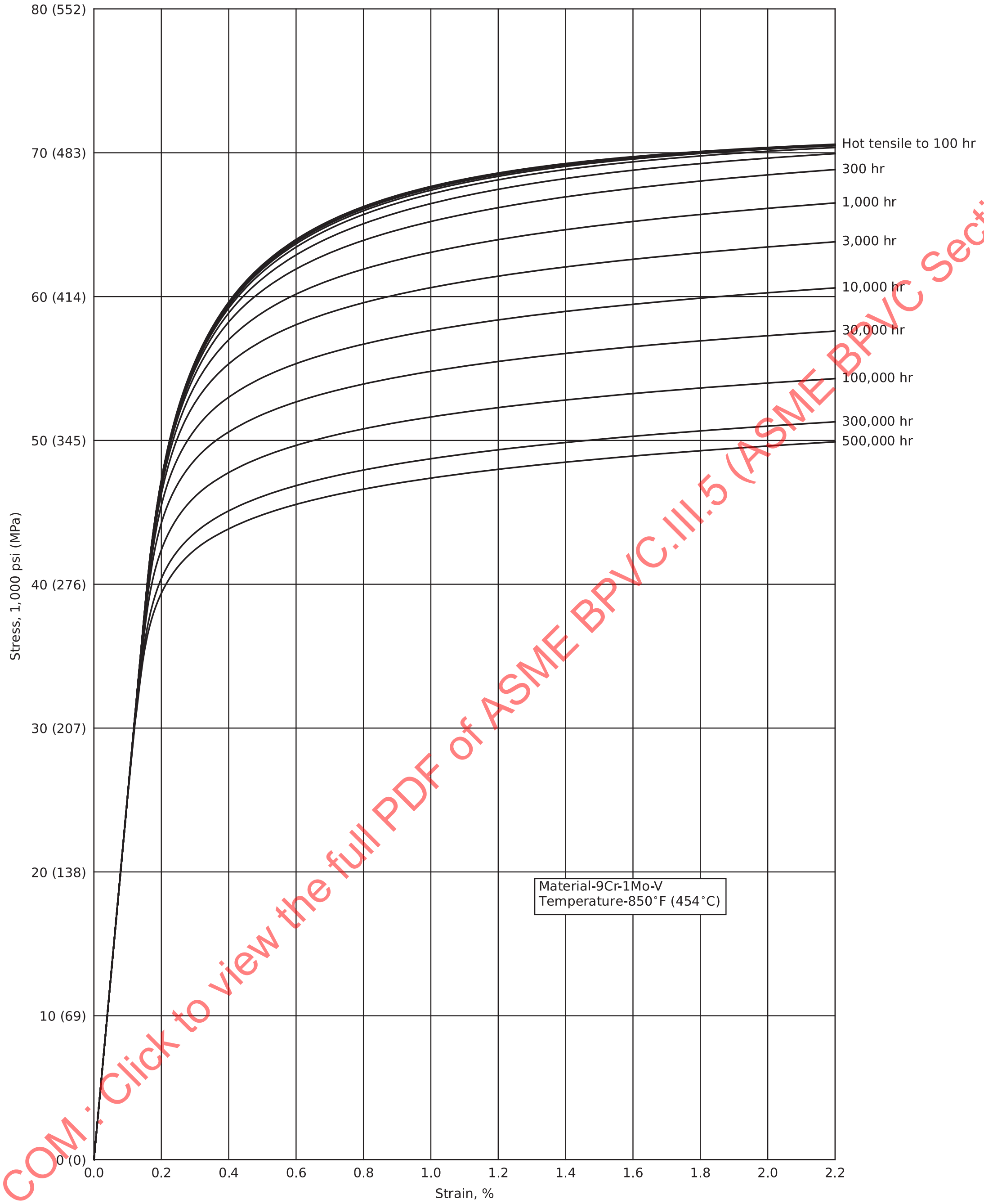
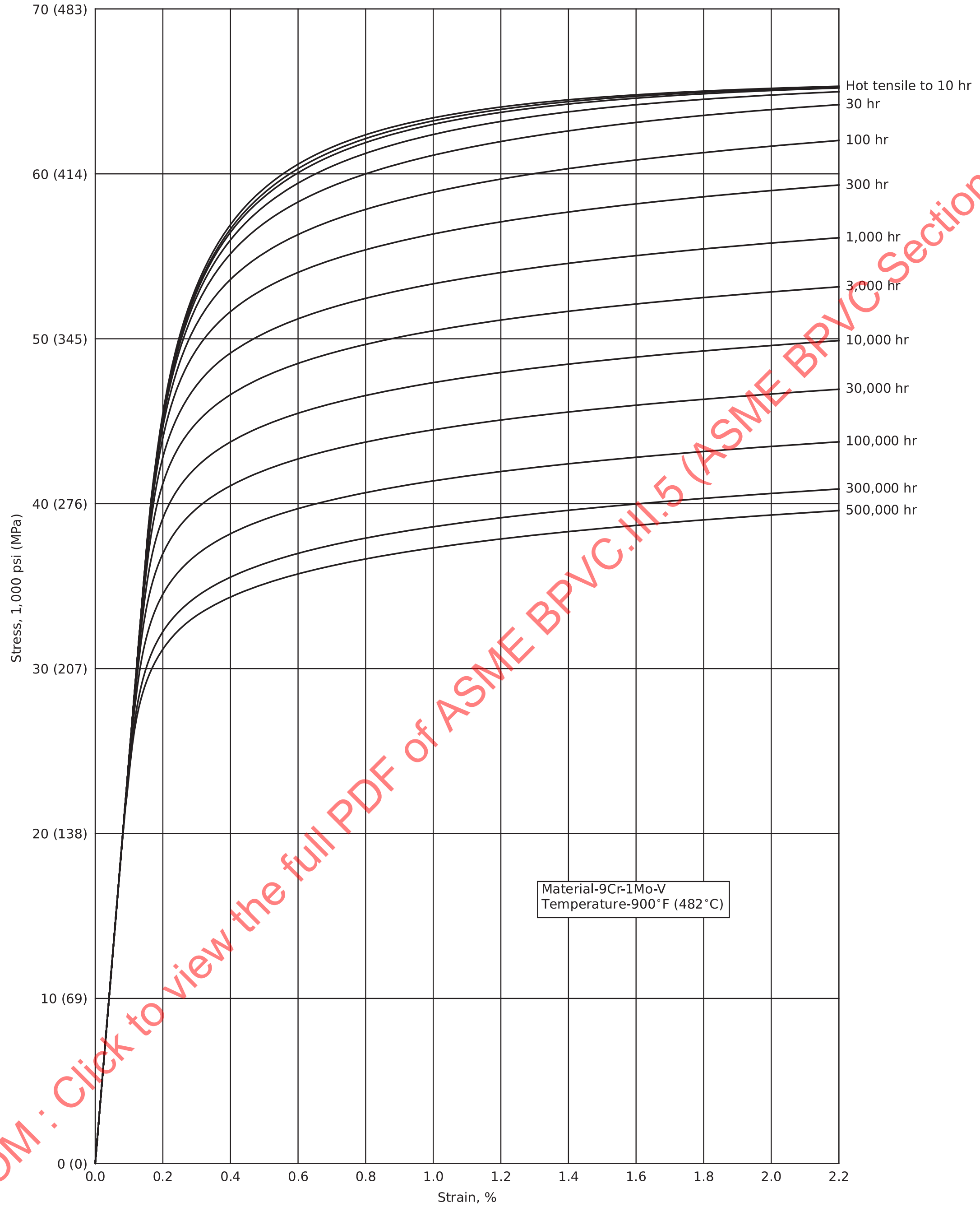
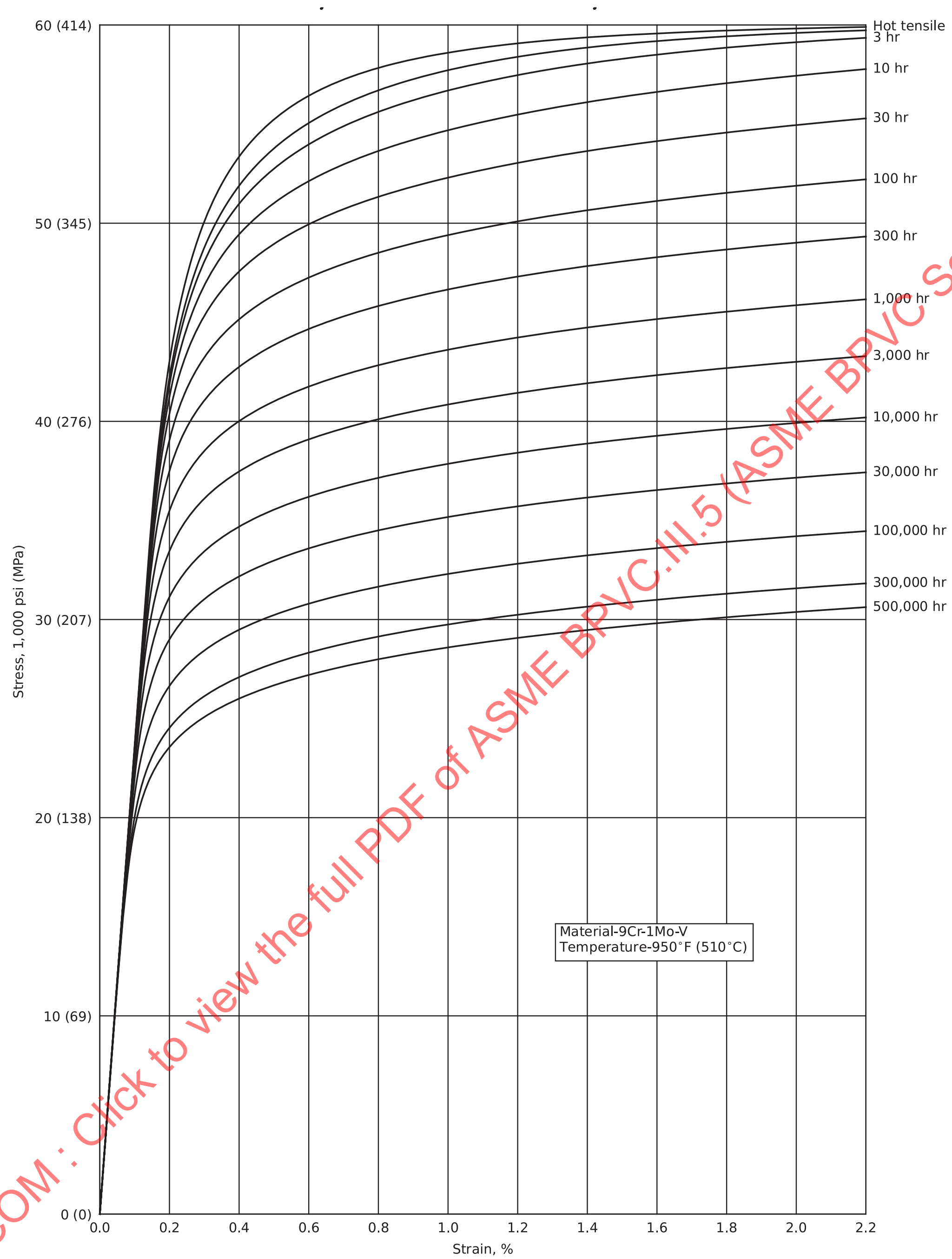


Figure HBB-T-1835-5 Average Isochronous Stress–Strain Curves (23)



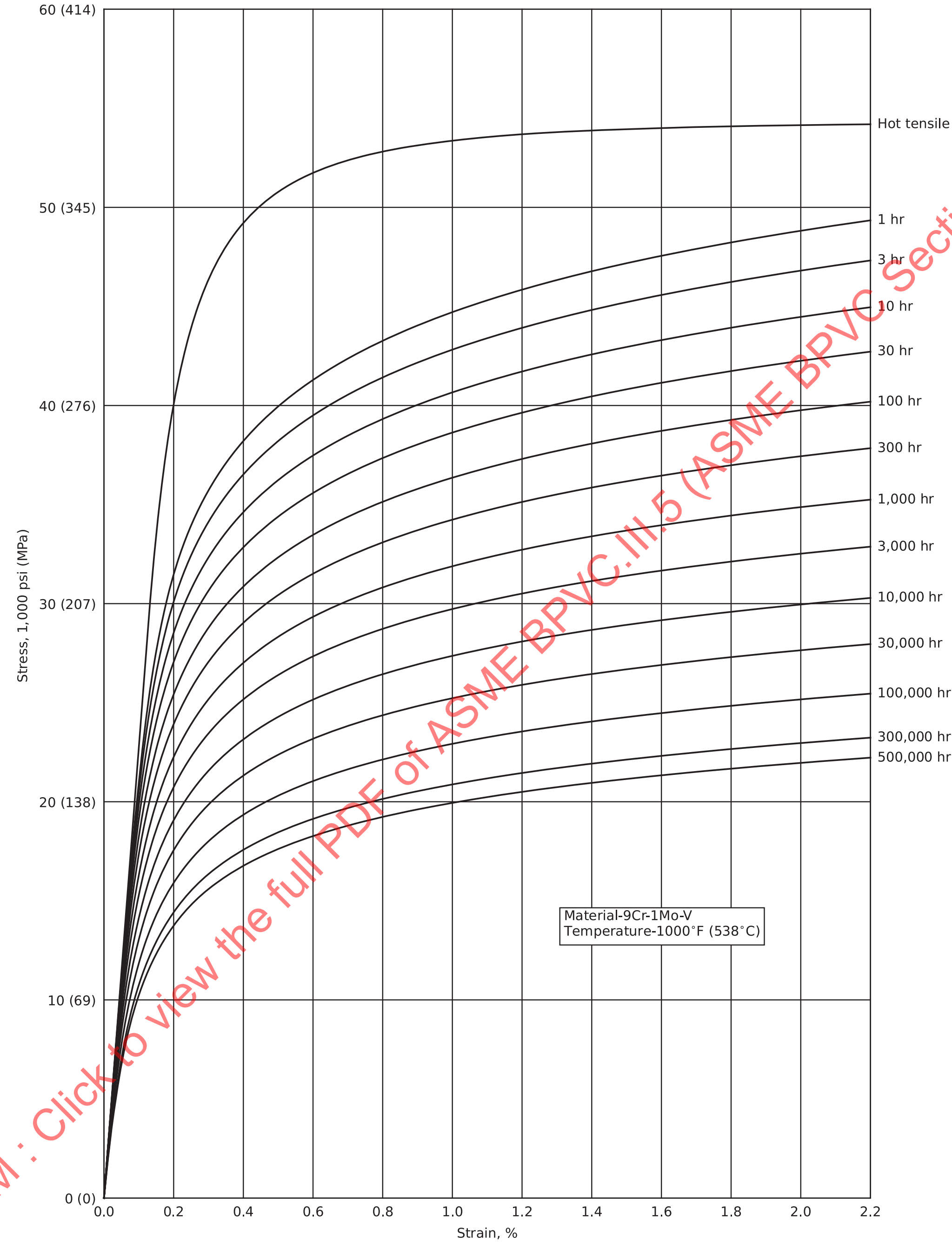
(23)

Figure HBB-T-1835-6
Average Isochronous Stress–Strain Curves



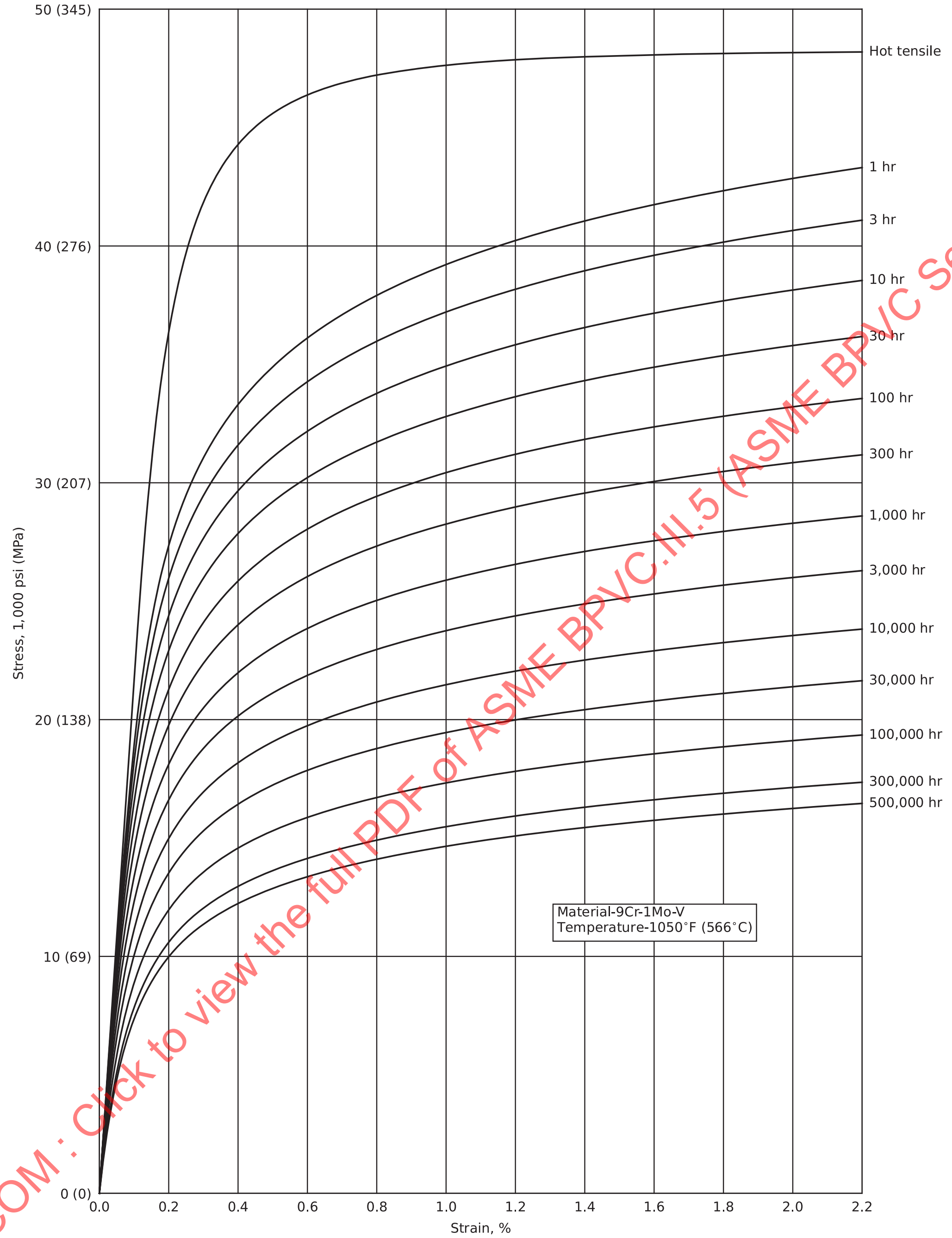
(23)

Figure HBB-T-1835-7
Average Isochronous Stress–Strain Curves



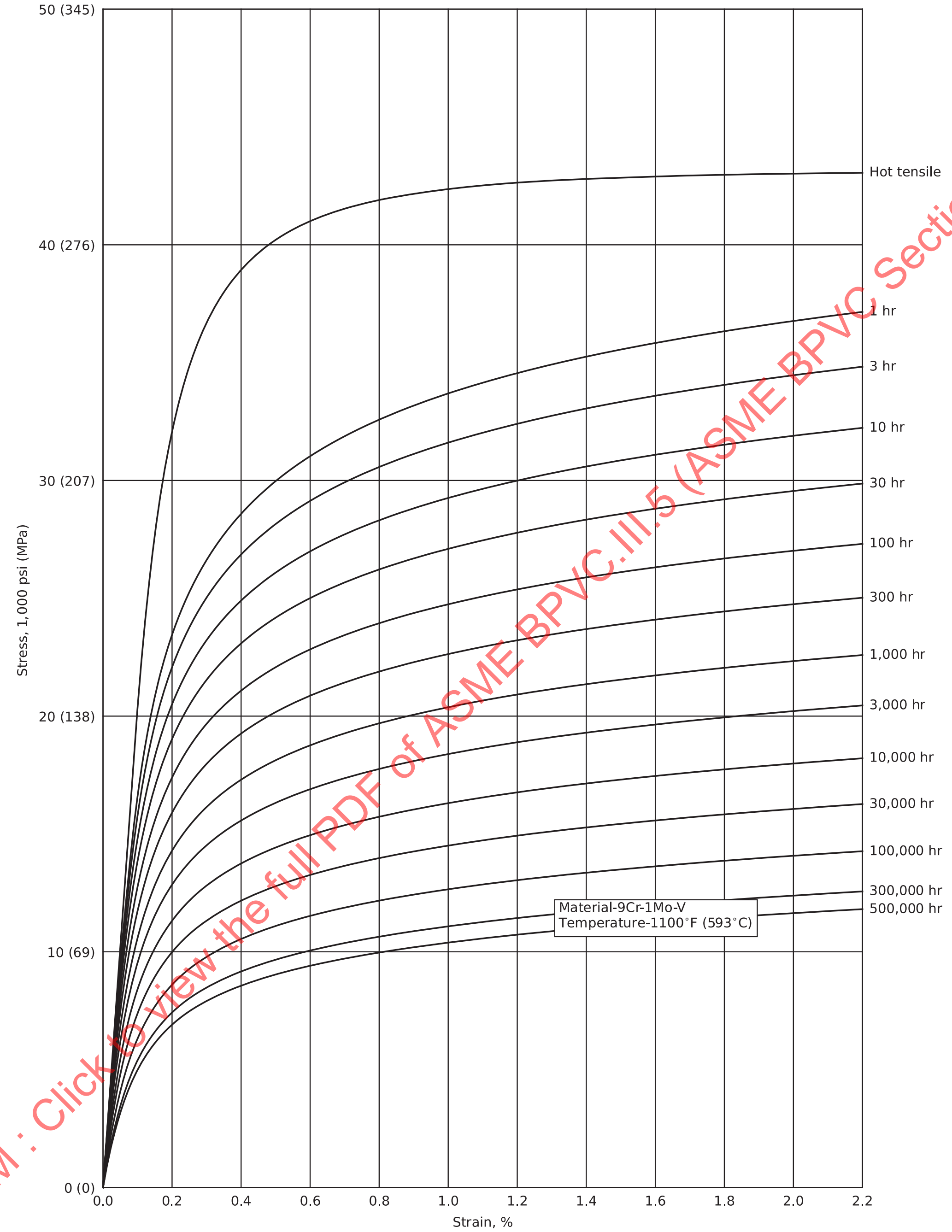
(23)

Figure HBB-T-1835-8
Average Isochronous Stress–Strain Curves



(23)

Figure HBB-T-1835-9
Average Isochronous Stress–Strain Curves



(23)

Figure HBB-T-1835-10
Average Isochronous Stress–Strain Curves

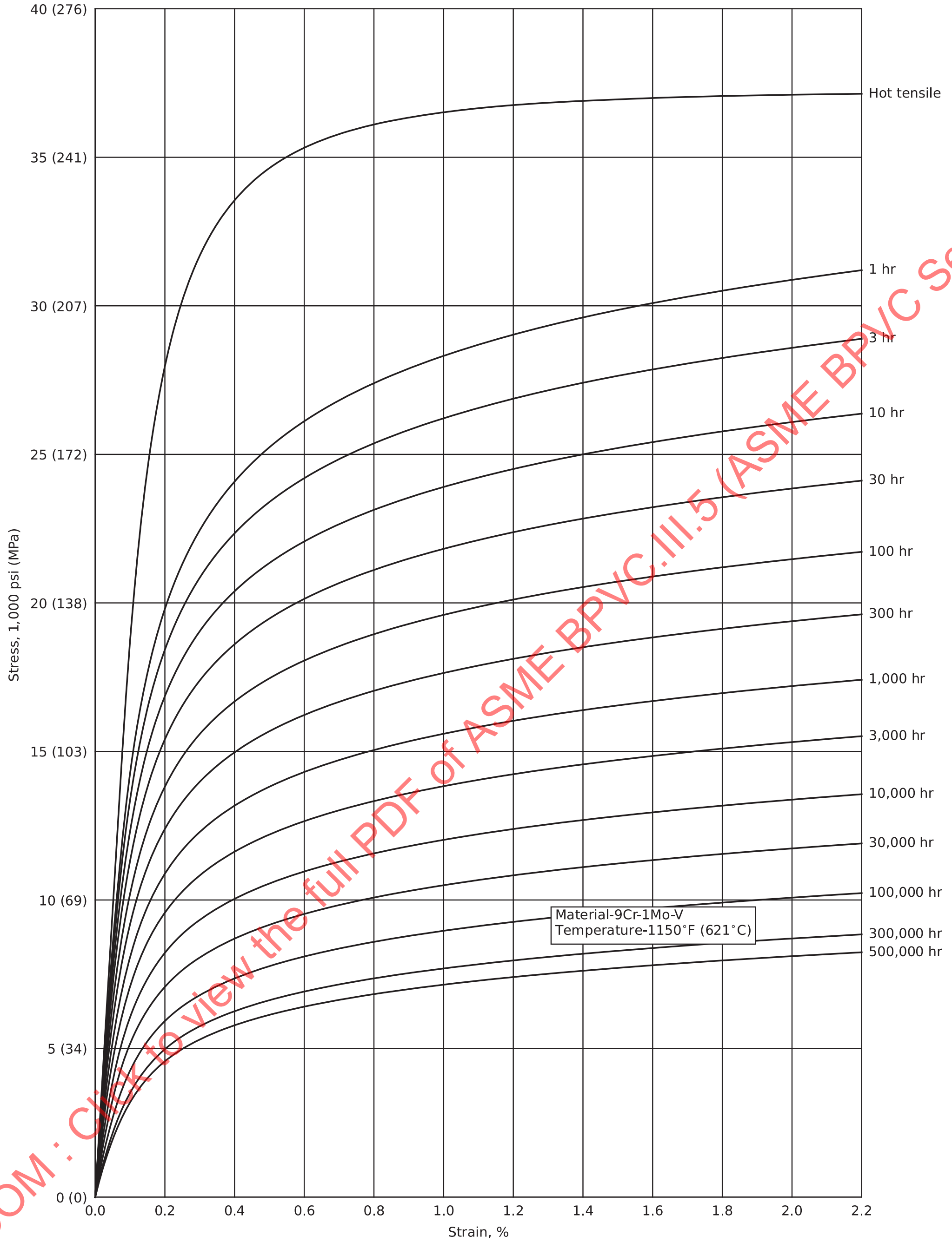
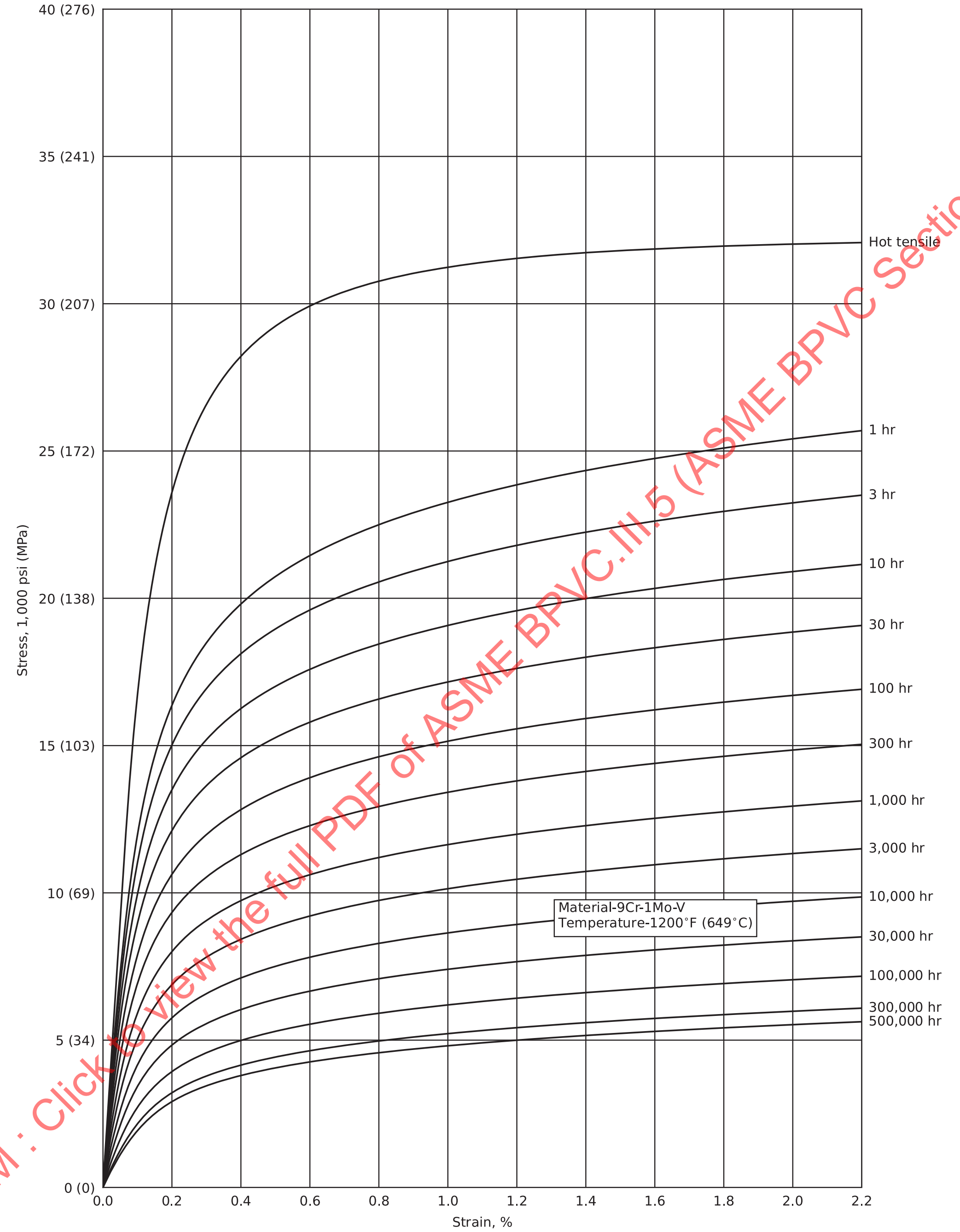


Figure HBB-T-1835-11
Average Isochronous Stress–Strain Curves

(23)



NONMANDATORY APPENDIX HBB-U GUIDELINES FOR RESTRICTED MATERIAL SPECIFICATIONS TO IMPROVE PERFORMANCE IN CERTAIN SERVICE APPLICATIONS

HBB-U-1100 SCOPE

This Appendix provides guidelines on specification restrictions for Types 304 and 316 stainless steels, which will, in the opinion of the Committee, improve the performance of the permitted materials in certain elevated temperature nuclear applications where creep effects are significant. The restrictions have the effect of narrowing chemical composition, grain size, and other aspects of material quality while staying within the broader specification limits defined in Table HBB-I-14.1(a) and its notes.

HBB-U-1110 OBJECTIVES

The purpose of these restrictions is to achieve materials which have significantly reduced scatter in creep and rupture properties, with mean strength values consistent with or better than the current database, while maintaining satisfactory weldability and fabricability.

HBB-U-1200 SERVICE CONDITIONS

The restrictions of this Appendix will provide improved performance when materials are used within the temperature regimes of 800°F to 1,100°F (425°C to 595°C). For application outside of those regimes, this Appendix provides no guidance.

HBB-U-1300 RECOMMENDED RESTRICTIONS

The recommended restrictions are shown in Table HBB-U-1.

Table HBB-U-1
Recommended Restrictions

Element	Type 304	Type 316
(a) Chemical Composition [Note (1)]		
Carbon	0.04–0.06	0.04–0.06
Nitrogen	0.04–0.07	0.04–0.07
Silicon	0.6	0.6
Manganese	1.0–2.0	1.0–2.0
Nickel	8.00–10.00	11.00–12.5
Chromium	18.5–20.00	17.00–18.00
Molybdenum	0.2	2.5–3.0
Sulfur	0.02	< 0.02
Phosphorus	0.045	< 0.03
Niobium	0.02 [Note (2)]	...
Aluminum	0.05	0.05
Antimony	0.02	0.02
Boron	...	0.003 [Note (3)]
Lead	0.003	0.003
Selenium	0.015	0.015
Tin	0.015	0.015
Vanadium	0.05	0.05
Zinc	0.01	0.01
(b) Grain Size (ASTM)	3–6	3–6
(c) Melt Practice	AOD or AOD/ESR	AOD or AOD/ESR
(d) Suggested upper long-term use limit for improved performance:		
Temperature, °F (°C)	1,100 (595)	1,100 (595)

NOTES:
(1) All values are maximum percentages unless indicated as ranges.
(2) To further reduce data scatter, a minimum value of 0.005% should be specified.
(3) To further reduce data scatter, a minimum value of 0.0015% should be specified.

NONMANDATORY APPENDIX HBB-Y GUIDELINES FOR DESIGN DATA NEEDS FOR NEW MATERIALS

ARTICLE HBB-Y-1000 INTRODUCTION

HBB-Y-1100 SCOPE

This Appendix provides guidelines for design data needs for new materials in support of the rules of this Subsection for elevated temperature nuclear applications where creep effects are significant. Some of the rules in this Subsection invoke rules and relevant material properties from Section III, Division 1, Subsection NB and may also be based on other Sections of the Boiler and Pressure Vessel (BPV) Code. Some provisions of Subsection HB, Subpart B are mandatory and others are nonmandatory. As such, the identification of mandatory and nonmandatory rules is outside the scope of this Appendix. However, where data requirements for rules are based on requirements from other Sections (e.g., Section II), those requirements are specifically identified.

The data needs for Class A[22] nuclear facility components in elevated temperature service are substantially more than for other applications in the ASME Code. The intent of this Appendix is to raise such awareness that provisions are made for an adequate data package to support successful codification. As material behaviors at elevated temperatures, particularly under cyclic service, are complex and material specific, the judgment on the adequacy of a data package is subject to deliberation by cognizant Code committees on a case-by-case basis.

HBB-Y-1110 CONSTRUCTION RULES FOR DIFFERENT SECTIONS OF ASME CODE

Section III of the ASME BPV Code contains rules for construction of nuclear facility components. Division 1, Subsection NB contains rules for construction of Class 1 components at 700°F (371°C) or below for ferritic steels, and at 800°F (427°C) or below for austenitic stainless steels and nonferrous alloys. Subsection HB, Subpart B contains rules for construction of Class A components in elevated temperature service. Division 1, Subsection NB rules are invoked in Subsection HB, Subpart B by reference, when needed.

Although other Sections of the ASME BPV Code cover elevated temperature service, Subsection HB, Subpart B is unique in providing explicit rules for evaluation of cyclic service and providing allowable stress levels that are a function of the specified service life. The allowable stress values and their basis for elevated temperature service for Class A nuclear facility components are listed in Subsection HB, Subpart B whereas the allowable stress values and their basis for Sections I and VIII applications are listed in Section II, Part D. The time-dependent allowable stress values in Section II are based on expected properties at 100,000 hr. Those in Subsection HB, Subpart B are listed as a function of time and temperature and are usually tabulated up to 300,000 hr, although longer design lives may be provided with appropriate supporting data.

A recognized national or international material specification as described in Section II, Part D, Mandatory Appendix 5, Article 5-100 is required for submittal of the data required to codify a new material for elevated temperature Class A applications. The submitted data must conform to the cited specification requirements.

An overview of applicable design requirements as related to material properties is provided in this Appendix. However, a detailed discussion of specific design limits and their related properties is beyond the scope of this document. Additional information on elevated temperature design criteria and their application can be found in various publications such as Companion Guide to the ASME Boiler & Pressure Vessel Code, Chapter 12.[23]

ARTICLE HBB-Y-2000 LOAD-CONTROLLED LIMITS

HBB-Y-2100 TIME-INDEPENDENT DATA

(a) In general, it is the intent of these guidelines that the time-independent data requirements for Subsection HB, Subpart B materials shall comply with the requirements established in Section II, Part D, Mandatory Appendix 5. The information to be included in the data package for time-independent data for each heat and representative product, per Section II, Part D, Mandatory Appendix 5, 2013 Edition, are as follows:

(1) sizes and product forms to be covered by the data sets

(2) compositional ranges to be covered by the data sets

(3) yield strength from room temperature at 100°F (50°C) intervals to 100°F (50°C) above maximum use temperature

(4) ultimate tensile strength from room temperature at 100°F (50°C) intervals to 100°F (50°C) above maximum use temperature

(5) tensile elongation from room temperature at 100°F (50°C) intervals to 100°F (50°C) above maximum use temperature

(6) reduction of area from room temperature at 100°F (50°C) intervals to 100°F (50°C) above maximum use temperature

(7) impact toughness, if required by construction code and product

(b) A minimum of three commercial heats are required to be tested. The yield strength and ultimate tensile strength are used to determine the *time-independent primary stress limits*, S_m. Later editions of Section II, Part D, Mandatory Appendix 5 should be consulted for any changes in time-independent data requirements.

The following time-independent data are required for characterization, including physical properties:

(1) monotonic tensile stress–strain curves

(2) coefficient of thermal expansion from room temperature to maximum use temperature

(3) thermal conductivity from room temperature to maximum use temperature

(4) thermal diffusivity from room temperature to maximum use temperature

(5) density

(6) Poisson's ratio

(7) Young's modulus from room temperature to maximum use temperature

HBB-Y-2110 TENSILE REDUCTION FACTORS FOR AGING

During long-time elevated temperature service, the yield and ultimate tensile strengths of metallic structural materials may be reduced due to metallurgical aging; see HBB-2160(d). Data on yield strength and ultimate tensile strength are needed to demonstrate that a new material is not susceptible to thermal aging over the intended time and temperature range of applications. If the material is susceptible to thermal aging, yield and ultimate tensile strengths data from thermally aged materials are needed to establish *tensile reduction factors for aging* as functions of exposure time and exposure temperature. For design lives of 40 yr to 60 yr, extrapolation of shorter-term data would be necessary to establish these reduction factors.

HBB-Y-2200 TIME-DEPENDENT DATA

There are two categories of time-dependent allowable stress levels in Subsection HB, Subpart B. The first category, identified as S_o, applies to Design Loadings, and the second category applies to Service Loadings. The information to be included in the data package for S_o for each heat and representative product form shall comply with the requirements established in Section II, Part D, Mandatory Appendix 5, except as modified by HBB-3221(b)(1) for those few cases where the values of S_{mt} at 300,000 hr, described below, exceed the values provided in Section II, Part D, Subpart 1, Tables 1A and 1B.

The time-dependent allowable stress values for Service Loadings, S_t, as a function of time and temperature are provided in Subsection HB, Subpart B. The criteria for establishing S_t for base metal are given in HBB-3221(b)(1), and for each specified time, t, are the lesser of

(a) 100% of the average stress required to obtain 1% total strain

(b) 80% of the minimum stress to cause the initiation of tertiary creep

(c) 67% of the minimum stress to cause rupture

Minimum stress-to-rupture curves are also required [e.g., for creep–fatigue evaluation (HBB-T-1400)]. The data needed to establish these time-dependent allowable stresses are obtained from creep rupture tests at various temperature and stress levels. Since time to 1% total strain and time to the initiation of tertiary creep are required, full creep curve data are needed.

The creep rupture data from a minimum of three commercial heats, representing the compositional ranges, sizes, and product forms for the applications, are necessary.

Data are needed to support the development of the minimum stress-to-rupture values as a function of time and temperature. Typically, times from 10 hr to 300,000 hr, or longer, are covered while temperatures range from the creep threshold to 100°F (50°C) above the maximum use temperature for the material. The scope of the database needed to establish these stress values varies with the complexity of the material and the intended use conditions. The current Code approach in extrapolating life data from 40-yr to 60-yr design lives is by means of engineering time–temperature parameters such as the Larson-Miller parameter. A robust and representative database is necessary for extrapolation using such an empirical approach.

Although there is no verified, unique way to specify the allowable limits of time-wise extrapolation of test data, the following general guidance is provided. Well-behaved, solid-solution alloys may require data at 100°F (50°C) intervals extending to times that will require an extrapolation in time of no more than a factor of 5 to reach the intended life. Metastable alloys, such as the creep-strength enhanced ferritic/martensitic steels, may require data at 50°F (25°C) intervals in the region of expected instability. Extrapolations by more than a factor of 3 will require metallurgical justification.

For these purposes, the creep threshold may be estimated from preliminary scoping data as the temperature at which time-dependent properties begin to govern the allowable stress values for the intended design life.

In a recent assessment[24] of the stress rupture databases for the Subsection HB, Subpart B materials, the following information was identified:

- 304H stainless steel — 75 lots; 1,170 data; 179,000 hr longest life
- 316H stainless steel — 106 lots; 1,940 data; 222,000 hr longest life
- 2¹⁄₄Cr–1Mo steel — 189 lots; 1,632 data; 213,000 hr longest life
- 9Cr–1Mo–V steel — 104 lots; 1,600 data; 110,000 hr longest life
- Alloy 800H — 83 lots; 1,170 data; 179,000 hr longest life

The conclusion of the assessment was that these databases contain sufficient data to extrapolate the stress-to-rupture limits from the current 300,000-hr limit to 500,000 hr for some temperatures.

HBB-Y-2300 REQUIREMENTS FOR WELDED CONSTRUCTION

The intent of the *stress rupture factors* for weldments is to provide a reasonable approximation of the loss of creep rupture strength in welded construction. Although, conceptually, the data needed to develop such stress rupture factors for weldments would correspond to the requirements for base metal, in practice, the requirements are less rigorous. The following information and data are needed for welded construction:

(a) identification of the types of joints

(b) identification of weld processes

(c) identification of filler metals and composition

(d) identification of weld qualification procedures (side bend, tensile)

(e) postweld heat treatment

(f) delta ferrite determination

(g) data on weldments conforming to the time-independent data requirements described above for wrought material

(h) stress rupture data determined from cross-weld specimens, each containing weld metal, heat-affected zone, and base metal in the test section, are needed to establish the stress rupture factors for weldments. This is a measure of the degradation in the stress rupture strength of the weldment as compared to base metal.

ARTICLE HBB-Y-3000 DEFORMATION-CONTROLLED LIMITS

The deformation-controlled quantities are stresses, strains, and deformations resulting from load, deflection, and strain compatibility. Acceptable deformation-controlled limits are given in Nonmandatory Appendix HBB-T, and they cover strain limits/ratcheting, creep–fatigue damage, buckling, and welds. Strain limits and creep–fatigue damage rules can be satisfied using either elastic or inelastic analysis methods. The elastic analysis approach, sometimes referred to as simplified methods (HBB-T-1320, HBB-T-1330, and HBB-T-1420), was originally envisioned as a simpler, more conservative, and less costly screening method. The inelastic approach, which required inelastic analyses, was envisioned as more costly and time consuming, but more accurate and less restrictive. Experience from the Clinch River Breeder Reactor (CRBR) Project showed that the elastic analysis approach was often found to be too conservative, leading to nonviable designs. Plasticity-creep constitutive models for stainless steels were developed and implemented into finite element programs. These methodologies were incorporated into the Nuclear Standard NE F 9-5T[25] by the U.S. Department of Energy for use by the vendor. Many high temperature components of the CRBR were designed using the inelastic approach.

HBB-Y-3100 ISOCHRONOUS STRESS–STRAIN CURVES

Isochronous stress–strain curves provided in HBB-T-1800 are used to satisfy strain limits using simplified inelastic analysis. They are also used to compute the initial stress at the start of the hold time, and its relaxation during the strain hold, in the elastic analysis creep–fatigue procedure. The isochronous stress–strain curves are cross-plots of stress versus strain for fixed times, using creep curve data. The “hot” tensile curve, which anchors the isochronous stress–strain curves, is obtained from the monotonic stress–strain curve at temperature.

HBB-Y-3200 RELAXATION STRENGTH

Relaxation strength at temperature is needed to provide the limit to ensure that shakedown takes place so ratcheting does not occur in the design regime where a modification of the rules of Division 1, Subsection NB may be applied; see HBB-T-1324. Stress relaxation test data for determining the relaxation strengths from 50°F (25°C) below the creep threshold to 100°F (50°C) above the maximum use temperature at 100°F (50°C) intervals are required. Alternatively, relaxation strength can be determined by performing a pure uniaxial relaxation analysis starting with an initial stress of $1.5S_m$ and holding the initial strain throughout the time interval equal to the time of service above 800°F (427°C). To support this analysis method in determining the relaxation strength, general constitutive equations, or special equations for uniaxial stress relaxation, are needed and their technical basis documented in the Design Report.

HBB-Y-3300 CREEP–FATIGUE DATA

Creep–fatigue damage is one of the most severe structural failure modes in elevated temperature design. The realization that this is indeed a significant failure mode that needs to be addressed in design came from low-cycle fatigue test data at elevated temperatures. It was observed that the strain versus fatigue life curves obtained from cyclic tests with hold times shifted to the left of the strain versus fatigue life curve obtained from continuous cycling tests (i.e., without hold time), indicating that cyclic life is reduced due to creep damage accumulated during the hold times.

Creep–fatigue life is evaluated with a linear summation of fractions of fatigue damage and creep damage. The creep–fatigue criterion is in HBB-T-1411 given by:

$$\underbrace{\sum_i \left(\frac{n}{N_d}\right)_j}_{\text{Fatigue Damage}} + \underbrace{\sum_k \left(\frac{\Delta t}{T_d}\right)_k}_{\text{Creep Damage}} \le D$$

where

D = allowable combined damage fraction

n and N_d = number of cycles of type j and the allowable number of cycles of the same cycle type, respectively

Δt and T_d = actual time at stress level k and the allowable time at that stress level, respectively

Since the creep damage term is evaluated as a ratio of the actual time versus the allowable time, it is generally referred to as time-fraction.

The fatigue-damage and creep damage terms on the left hand side of the above equation are evaluated in an uncoupled manner, and the interaction of creep and fatigue is accounted for empirically by the D term on the right side of the equation. The average behavior of the interaction can be represented graphically by the creep–fatigue interaction diagram, which is shown conceptually in Figure HBB-Y-3000-1.

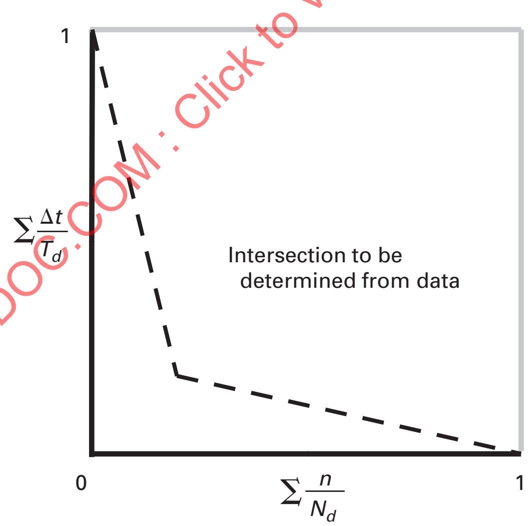
Data needed to support the creep–fatigue design procedure involve the following:

(a) In Nonmandatory Appendix HBB-T, the creep damage fraction is evaluated by using the stress rupture time and the stress relaxation information during hold time in the simplified method approach. The former can be obtained from the minimum stress-to-rupture curves, which have been described previously. There are two methods for estimating the latter; either from the isochronous stress-strain curves provided in HBB-T-1800, or from a uniaxial relaxation model (see also HBB-Y-3200). The starting stress for the simplified approach is also based on the use of isochronous curves and strain estimates.

(b) For the evaluation of the fatigue damage, strain versus fatigue life curves from continuous cycling tests that cover the application temperatures are needed. Usually, a scoping test program to obtain data at a fixed strain range and different strain rates is employed to identify the most restrictive strain rate to generate the continuous cycling data for the fatigue design curves. For the current Subsection HB, Subpart B Code materials, strain rates of 1×10^{-3} in./in./sec (m/m/s) were used to generate continuous cycling data for 304 and 316 stainless steels and Alloy 800H, and strain rates of 4×10^{-3} in./in./sec (m/m/s) were used for $2^1/_4$Cr–1Mo and 9Cr–1Mo–V steels.

(c) To establish the creep–fatigue interaction envelope, strain-controlled creep–fatigue test data from various temperatures, strain ranges, and hold times (tensile and/or compressive holds) are needed.

Figure HBB-Y-3000-1
Conceptual Creep–Fatigue Damage Envelope



(d) Since the hold times in creep–fatigue tests are typically shorter than the sustained operation periods, creep–fatigue test data are needed with hold times sufficient to assess the reduction in cyclic life as hold time increases. Ideally, the hold time should be long enough to capture "saturation" where the decrease in cycles to failure becomes negligible as the hold time increases. However, this may not be achievable for all materials and test temperatures.

HBB-Y-3400 CREEP–FATIGUE DATA FOR WELDMENTS

The creep–fatigue procedure in Nonmandatory Appendix HBB-T is established based on creep–fatigue data for base metal. It does not have a separate creep–fatigue procedure for welds. Instead, a number of conservative requirements are relied upon, including

(a) limiting the inelastic accumulated strains to one-half the allowable strain limits for the base metal

(b) limiting the allowable fatigue at weldments to one-half the design cycles allowed for the base metal

(c) reducing the allowable creep rupture strength at weldments to a fraction of the base metal value through the weld strength rupture factor when determining the time-to-rupture

Thus, creep–fatigue data for the weldments of a new material are needed to assess the adequacy of the treatment of welds per the Nonmandatory Appendix HBB-T procedures under creep–fatigue conditions. The weldment creep–fatigue data are to be developed from applicable filler metals and welding processes. Both deposited filler metal and cross-weld specimens will need to be tested. Weldment creep–fatigue test data are needed with hold times sufficient to assess the reduction in cyclic life as hold time increases. Ideally, the hold time should be long enough to capture "saturation" where the decrease in cycles to failure becomes negligible as the hold time increases. However, this may not be achievable for all weldments and test temperatures.

HBB-Y-3500 CYCLIC STRESS–STRAIN CURVES

Cyclic stress–strain curves from the creep threshold to 100°F (50°C) above the maximum use temperature, in 100°F (50°C) increments are needed to characterize the cyclic behavior of a new material. These data are needed to assess the role of cyclic hardening or softening on the negligible creep criteria and creep–fatigue interaction.

HBB-Y-3600 INELASTIC CONSTITUTIVE MODEL

The rules for strain, deformation, and fatigue limits in Subsection HB, Subpart B were established with the expectation that inelastic analyses would sometimes be required as simplified methods based on elastic analysis results become increasingly restrictive as temperature increases and inapplicable in some instances at very high temperatures. Currently, there is no guidance on the development of material models in Subsection HB, Subpart B to support inelastic analyses. The technical basis for selected inelastic analysis methods and relations used in a design analysis should be included in the Design Report. At very high temperatures, decoupling of plastic and creep strains in the classical constitutive framework is generally a poor representation of the true material behavior. Unified constitutive equations, which do not distinguish between rate-dependent plasticity and time-dependent creep, represent the rate dependence and softening that occur. Testing to support the development of unified constitutive equations for very high temperature applications involve various tests specifically designed to probe the time-dependent mechanical response of the material. Examples of these tests include

(a) monotonic constant strain rate stress–strain curves.

(b) cyclic stress–strain curves.

(c) strain rate change tensile tests.

(d) stress dip test — successive sequence of straining at a given strain rate to a given strain level, then switch to stress relaxation for a fixed, relatively short, period. The sequence is repeated with a different strain rate for each sequence.

(e) short-term creep test — successive sequence of loading at a given stress rate to a given stress level, then switch to creep for a fixed, relatively short, period. The sequence is repeated with a different stress rate for each sequence.

(f) tensile loading/unloading/creep sequence — successive sequence of loading, unloading to a nonzero load, then switch to creep for a fixed, relatively short, period. The sequence is repeated with a different nonzero load after unloading for each sequence.

(g) uniaxial and multiaxial ratcheting tests.

(h) intermediate-term creep and stress relaxation tests.

(i) out-of-phase thermomechanical cycling tests to determine the nonisothermal response.

HBB-Y-3700 HUDDLESTON MULTIAXIAL FAILURE CRITERION

In using the inelastic analysis approach to satisfy the deformation-controlled limits, HBB-T-1411 employs a multiaxial failure criterion developed by Huddleston.[26] The parameters in the equivalent stress quantity of HBB-T-1411 are determined from multiaxial creep rupture data that involve tension, torsion, and internal pressure. Note that the Huddleston criteria reduce to a von Mises effective stress when the parameter C is zero. Other multiaxial failure criteria may also be established if there is sufficient supporting data.

HBB-Y-3800 TIME–TEMPERATURE LIMITS FOR EXTERNAL PRESSURE CHARTS

Creep buckling analysis per HBB-T-1500 is required when a component is under compressive loads. In Division 1, Subsection NB, the procedure for determining the buckling limit is through the use of external pressure charts and tables of Section II, Part D, Subpart 3. These charts and tables are derived from monotonic time-independent stress–strain curves at temperature for cylinders under axial compression, and spheres and cylinders under external pressure. The reduction in material strength due to increase in temperature is accounted for in these charts and tables, but not that due to creep deformation.

HBB-T-1522 provides the time–temperature limit for using the Division 1, Subsection NB procedure in determining the buckling limit without consideration of creep effects. The time–temperature limit is obtained by equating the allowable stresses from instantaneous and creep buckling. In the creep buckling problem, the strain-rate dependent stress–strain curves are replaced by the isochronous stress–strain curves, as an approximation, for the determination of the tangent and secant moduli.

Thus, for a new material, stress–strain curve data are needed to establish the external pressure charts and tables, and isochronous stress–strain curves, constructed from creep curve data, are required in establishing the time–temperature limit for using these charts and tables.

ARTICLE HBB-Y-4000 OTHER CONSIDERATIONS

HBB-Y-4100 COLD-FORMING LIMITS

Cold work can degrade material properties such as fatigue, creep rupture, impact toughness, etc. HBB-4212 requires a post-fabrication heat treatment that depends on the amount of cold work to guard against such degradations. For the Code materials in Subsection HB, Subpart B, components with cold work less than 5% do not require post-fabrication heat treatment. Components with cold work greater than 20% are not permitted. For the amount of cold work within these limits, post-fabrication heat treatment at specified temperature and time is required. Analogous cold work limits and corresponding post-fabrication heat treatment specification for a new material are needed. Data to support the adequacy of these proposed limits and specification are necessary.

HBB-Y-4200 ENVIRONMENTAL EFFECTS

The data needs described in this Appendix are for tests conducted in air. If these properties and the derived allowables are negatively impacted by the coolant environment and/or the irradiation environment, the degradations need to be properly characterized. Currently, Subsection HB, Subpart B rules do not explicitly address issues such as degradation of properties because of service conditions or environment. The exception is the degradation of yield and ultimate tensile strengths due to long-time elevated temperature service; see HBB-2160(d). However, issues on environmental effects are highlighted in the Code, and it is the responsibility of the owner/operator to demonstrate to the jurisdictional regulatory body that these additional issues are adequately addressed by the design. Additional environmental testing to support Section III Appendices, Nonmandatory Appendix W, Environmental Effects on Components, is strongly encouraged.

NONMANDATORY APPENDIX HBB-Z GUIDANCE ON CONSTITUTIVE MODELS FOR DESIGN BY INELASTIC ANALYSIS

(23)

HBB-Z-1100 INTRODUCTION

HBB-Z-1110 OBJECTIVE

The objective of this Appendix is to provide guidance on constitutive models used for the design by inelastic analysis ratcheting (see HBB-T-1300) and creep-fatigue (see HBB-T-1400) provisions of Nonmandatory Appendix HBB-T. Such models are used to analyze the component when designing against ratcheting strain accumulation as described in HBB-T-1200 and creep-fatigue damage as described in HBB-T-1400. This Appendix provides general guidance in HBB-Z-1200 on developing a constitutive model along with a specific set of constitutive models in HBB-Z-1300 for the Class A materials deemed suitable for use with Nonmandatory Appendix HBB-T for strain limits and creep-fatigue damage evaluations.

HBB-Z-1120 SUBSECTION HB, SUBPART B REQUIREMENTS

HBB-3214.2 provides the requirements for inelastic analysis. This Appendix expands upon the basic requirements described in HBB-3214.2.

Mandatory Appendix HBB-I-14, Table HBB-I-14.1(a) provides the requirements for permissible base materials covered by this Appendix.

HBB-Z-1130 SPECIFICATION OF A CONSTITUTIVE MODEL

No part of this Appendix restricts the Owner from specifying the use of a particular constitutive model or set of models in the Owner's Design Specification. No part of this Appendix restricts a Designer from developing a suitable constitutive model provided the model is justified in the Design Report per HBB-3214.2. The guidance given in HBB-Z-1200 provides a general set of criteria to consider when developing or specifying a constitutive model. The models described in HBB-Z-1300 are considered acceptable for use with the Nonmandatory Appendix HBB-T design by inelastic analysis method without further justification; however, the Designer is not required to use these models. The models in HBB-Z-1300 are valid for operating time and temperature regimes within the range of the parameters provided.

HBB-Z-1200 GUIDANCE ON CONSTRUCTING A CONSTITUTIVE MODEL

HBB-Z-1210 GENERAL GUIDANCE

As described in HBB-3214.2, an inelastic model must represent the response of the material to time-dependent, thermomechanical load. The model must represent cyclic hardening or softening, as appropriate, primary creep, the effect of prior creep on subsequent plastic deformation, and the effect of prior plasticity on subsequent creep.

HBB-Z-1211 Validity of the Constitutive Model

The constitutive model should be validated across the entire temperature range experienced by the component for all Level A, Level B, and Level C Service Loadings. If Level D Service Loadings are considered in the inelastic analysis, the model must be further validated for these conditions; athough, per HBB-T-1122, Service Level D loadings need not meet the deformation limits criteria (but must meet the creep-fatigue limits). The model must be validated for the strain rates experienced by the component in service. These strain rates cannot be determined prior to the development of the constitutive model and so the designer should check the design analysis for all Service Loadings to verify the model remains within the validated range of strain rates. A typical component will experience very slow strain rates during hold conditions, typically on the order of $10^{-10}s^{-1}$ and will experience much faster strain rates on the order of $10^{-7}s^{-1}$ during loading.

The Service Loadings may cause portions of the component to descend below the T_{max} temperatures given by Table HAA-1130-1. If so, the constitutive model must accurately represent plastic deformation down to the lowest temperature experienced by the component in service. Below T_{max} the component will not accumulate creep deformation or damage but may accumulate plastic strain causing additional fatigue damage and ratcheting strain accumulation. The constitutive model must ensure continuity into the low temperature regime in order to execute the required design analysis.

HBB-Z-1212 Key Features to Represent

HBB-Z-1212.1 Cycle Response. The design by inelastic analysis methods require an accurate representation of the material's response under cyclic thermomechanical loading. Considering a single material point, the constitutive model must accurately represent the cyclic temperature–stress–strain–time hysteresis undergone by that material point under the loading provided by the surrounding material. In general, this loading is neither fully strain nor stress controlled but rather some mix of both, exemplified by a load including elastic follow up. A suitable constitutive model should therefore capture this hysteretic response for general thermomechanical cyclic load with the most important features being the strain range, the stress relaxation profile during any holds in the loading, and the accumulated ratcheting strain.

HBB-Z-1212.2 Material Batch Variation. By default, a constitutive model should capture the average response of all acceptable Class A material. There can be a wide range of material properties causing cyclic responses that differ greatly across multiple heats of material even for material meeting the specifications given in Mandatory Appendix HBB-I-14, Table HBB-I-14.1(a). The procedure used to develop the constitutive model must account for this variability and represent the average behavior of all acceptable heats of material. If material variability in actual construction is reduced, e.g., by using a limited number of material heats, the constitutive model may be calibrated to represent only the average behavior of the material batches used in construction. Such a calibration must be justified in the Design Report.

Buckling evaluation (see Nonmandatory Appendix HBB-T, HBB-T-1500) requires the use of minimum-property curves per HBB-T-1510(g). As noted in HBB-Z-1110, the guidance in this Appendix applies only to inelastic models used for ratcheting and creep-fatigue design.

HBB-Z-1212.3 Accumulated Damage. The constitutive model must account for the interaction of creep and plasticity, including cyclic softening effects. However, some softening effects are caused by the development of damage in the material affecting its elastic properties. For example, during prolonged creep cavitation, voids will open in the material leading to a loss of material strength and eventual failure.

When evaluating creep-fatigue damage per Nonmandatory Appendix HBB-T, HBB-T-1400 the constitutive model does not need to account for the softening caused by the development of damage in a material. It must, however, account for all other material softening mechanisms, such as those caused by rearrangements of the material's dislocation or grain structure. The rationale is that the procedure for creep-fatigue design by inelastic analysis, per Nonmandatory Appendix HBB-T, explicitly and separately accounts for the accumulation of damage in the material using the Code rules. As such, representing damage development in the constitutive model double counts damage and may lead to an overly conservative design. This means, for example, that a constitutive model used to assess creep-fatigue damage using the provisions, per Nonmandatory Appendix HBB-T, does not need to represent tertiary creep.

A constitutive model used to check for strain accumulation using Nonmandatory Appendix HBB-T, HBB-T-1200 must represent the development of damage in the material. Damage will tend to accelerate cyclic strain accumulation; therefore, a model must represent the development of damage in order to accurately simulate ratcheting strain accumulation.

This means that two constitutive models for a given material could be specified or developed, one for creep-fatigue damage and one for ratcheting strain accumulation. However, it is conservative to use a single constitutive model, representing damage accumulation, for both the ratcheting strain and creep-fatigue design checks. The models provided in HBB-Z-1300 are of this type.

HBB-Z-1212.4 Coupled Creep and Plasticity. A constitutive model must account for the interaction of creep and plasticity in the material. At the very least, this implies a nonunified model representing inelastic deformation through a combination of a rate-independent plastic strain added to a rate-dependent creep strain and must include a mechanism for the creep model to affect the plasticity model and vice-versa.

At sufficiently high temperatures, creep and plasticity are inherently coupled and cannot be distinguished. Table HBB-Z-1212.4-1 provides guidance on this temperature threshold for the Class A materials. Above this threshold temperature nonunified, additive models are unsuitable and the constitutive model should have a unified viscoplastic formulation.

HBB-Z-1212.5 Stress Multiaxiality. Actual components experience multiaxial stress states, while model forms are commonly developed from uniaxial test data. Hence, an adequate constitutive model must accurately represent the effect of multiaxial stress states on material deformation and, in addition, documentation and justification of the assumptions used to develop the 3D form of the model should be included in the Design Report.

Table HBB-Z-1212.4-1
Temperature Threshold for Class A Materials

Material	Threshold Temperature, °F (°C)
304 SS	1,160 (625)
316 SS	1,180 (640)
Ni–Fe–Cr (Alloy 800H)	1,300 (710)
$2^1/_4$Cr–1Mo	1,020 (550)
9Cr–1Mo–V	840 (450)

HBB-Z-1213 Model Validation

If not specified in the Owner's Design Specification, or for constitutive models other than those provided in HBB-Z-1300, the designer should justify the models used in the design analysis in the Design Report. HBB-Z-1212 enumerates the key features a constitutive model must capture. Generally, a constitutive model can be validated by comparison to cyclic tests that include hold periods and creep test data. Cyclic tests best represent the actual loading a component will see in service. However, actual material points in components experience neither pure load nor pure displacement controlled loading. Therefore, a constitutive model should be validated against both stress- and strain-controlled cyclic test data. Generally, cyclic tests do not include hold times commensurate with actual steady operation durations in operating components. Therefore, a constitutive model should also be validated against long-term creep test data in order to assess its response for realistic creep and stress-relaxation periods. These validation tests should span the required temperature and strain rate range, as described in HBB-Z-1211.

A constitutive model should also be validated against at least one test sampling a nonuniaxial stress state in order to assess the assumptions used to generalize 1D uniaxial test data into a 3D model.

Actual components experience nonisothermal loading. Materials may have a temperature rate effect that cannot be sampled using a series of isothermal tests at different temperatures. As such, a constitutive model should be validated against at least one nonisothermal experiment, e.g., a standard thermomechanical test, spanning the temperature range outlined in HBB-Z-1211.

HBB-Z-1220 MATERIAL SPECIFIC CONSIDERATIONS

HBB-Z-1221 304 SS

There are no special considerations to be made for 304 SS.

HBB-Z-1222 316 SS

There are no special considerations to be made for 316 SS.

HBB-Z-1223 Ni–Fe–Cr (Alloy 800H)

There are no special considerations to be made for Ni–Fe–Cr (Alloy 800H).

HBB-Z-1224 2¼Cr–1Mo

There are no special considerations to be made for 2¼Cr–1Mo.

HBB-Z-1225 9Cr–1Mo–V

As described in HBB-3214.2, 9Cr–1Mo–V undergoes cyclic softening at relatively low temperatures and a nonunified model of creep and plasticity does not adequately capture the material's inelastic response. Table HBB-Z-1212.4-1 reflects coupling between creep and plasticity with a very low value of the threshold temperature.

HBB-Z-1300 ACCEPTABLE MATERIAL MODELS

HBB-Z-1310 INTRODUCTION

Designers may use the reference constitutive models described in HBB-Z-1300 for the inelastic stress analysis required for fulfilling the design by inelastic analysis provisions, per Nonmandatory Appendix HBB-T, without further validation. As described in HBB-Z-1130, this Appendix does not require the designer to use the constitutive models in HBB-Z-1320 and an alternate model may be used if properly validated as described in HBB-Z-1213.

HBB-Z-1320 MODELS

In the following equations, a variable with an under tilde (e.g., $\underset{\sim}{S}$) represents a tensor quality. Symbols typeset normally are scalers.

HBB-Z-1321 304 SS

The model for 304 SS is under preparation.

HBB-Z-1322 316 SS

The reference model for 316 SS is defined by the following equations in rate form. The implementation of the model will require selecting an appropriate numerical time integration scheme. Table HBB-Z-1322-1 lists the notation used in HBB-Z-1322.

This model uses metric units of meters for length, °C for temperature, MPa for stress, mm/mm for strain, and hours for time, and the definition here assumes a small strain constitutive response. To fully define the model requires a definition of the stress rate and the rate of each history variable. An implementation then numerically integrates the rate form definition. The model as presented here is given in strain space, where the input is the strain, strain rate, temperature, and temperature rate and the output is the stress rate. All logarithms in the subsequent definitions are natural logarithms.

Table HBB-Z-1322-1
Nomenclature

Variable	Description	Type [Note (1)]
A	Damage model prefactor	Parameter
α	Coefficient of thermal expansion	Parameter
$\underset{\sim}{C}$	Elasticity tensor	Descriptive
C_1	First Chaboche hardening parameter	Parameter
C_2	Second Chaboche hardening parameter	Parameter
X	Damage model exponent	Parameter
δ	Voce parameter	Parameter
E	Young's modulus	Parameter
$\dot{\underset{\sim}{\varepsilon}}$	Strain rate	Descriptive
$\dot{\underset{\sim}{\varepsilon}}_{\text{inelastic}}$	Inelastic strain rate	Descriptive
φ	Damage model exponent	Parameter
Υ_1	First Chaboche dynamic recovery parameter	Parameter
Υ_2	Second Chaboche dynamic recovery parameter	Parameter
$\dot{\gamma}$	Plastic multiplier	Descriptive
η	Viscoplastic fluidity	Parameter
I	Identity tensor	Descriptive
n	Rate sensitivity exponent	Parameter
ν	Poisson's ratio	Parameter
Q	Voce saturation stress	Parameter
s	Stress deviator	Descriptive
σ	Stress	Descriptive
σ_0	Threshold stress	Parameter
σ_1	Isotropic hardening	Descriptive
$\dot{\sigma}$	Stress rate	Rate
$\dot{\sigma}_1$	Isotropic hardening rate	Rate
T	Temperature in Celsius	Descriptive
$\dot{T}$	Temperature rate	Descriptive
$\dot{\omega}$	Damage rate	Rate
ω	Damage	Descriptive
x	Kinematic hardening	Descriptive
x_1	First backstress	Descriptive
$\dot{x}_1$	First backstress rate	Rate
x_2	Second backstress	Descriptive
$\dot{x}_2$	Second backstress rate	Rate

NOTE:
(1) Variables indicated by "Rate" in the "Type" column comprise the rate-form definition of the model.
Variables indicated by "History" in the "Type" column are internal history variables maintained by the model.
Variables indicated by "Parameter" in the "Type" column are model parameters, defined in Table HBB-Z-1322-2.
Variables indicated by "Descriptive" in the "Type" column are neither model parameters nor history variables and are used in the model exposition.

The model is defined by the rate equations:

$$
\begin{aligned}
\dot{\underset{\sim}{\sigma}} &= \left(1-\omega\right)\underset{\sim}{C}:\left(\dot{\underset{\sim}{\varepsilon}}-\dot{\underset{\sim}{\varepsilon}}_{\text{inelastic}}-\alpha\dot{T}\underset{\sim}{I}\right)\\
\dot{\sigma}_1 &= -\delta\left(\sigma_1-Q\right)\dot{\gamma}\\
\dot{\underset{\sim}{x}}_1 &= \left(\frac{2}{3}C_1\frac{\partial f}{\partial \underset{\sim}{\sigma}}-\sqrt{\frac{2}{3}}\gamma_1\underset{\sim}{x}_1\right)\dot{\gamma}\\
\dot{\underset{\sim}{x}}_2 &= \left(\frac{2}{3}C_2\frac{\partial f}{\partial \underset{\sim}{\sigma}}-\sqrt{\frac{2}{3}}\gamma_2\underset{\sim}{x}_2\right)\dot{\gamma}\\
\dot{\omega} &= \frac{\left(\sqrt{\frac{3}{2}\underset{\sim}{S}:\underset{\sim}{S}}\right)^{X}}{\left(1-\omega\right)^{\varphi}}
\end{aligned}
$$

where ":" indicates double contraction of the elasticity tensor on the strain rate. The elasticity tensor is isotropic, defined by the temperature-dependent values of E given in Table HBB-Z-1322-2 and ν is the Poisson's ratio given in Section II, Part D (Metric), Subpart 2, Table PRD. Section II, Part D (Metric), Subpart 2, Table TE-1 defines the values of the temperature dependent instantaneous coefficient of thermal expansion.

The flow surface is

$$f=\sqrt{\frac{3}{2}\left(\underset{\sim}{S}-\underset{\sim}{x}\right):\left(\underset{\sim}{S}-\underset{\sim}{x}\right)}-\sqrt{\frac{2}{3}}\left(\sigma_0+\sigma_1\right)$$

where $\underset{\sim}{S}$ is the stress deviator

$$\underset{\sim}{s}=\underset{\sim}{\sigma}-\frac{1}{3}tr\underset{\sim}{\sigma}\underset{\sim}{I}$$

with tr indicating the trace of a tensor and with ":" indicating double contraction on the tensor, and

$$\underset{\sim}{x}=\underset{\sim}{x}_1+\underset{\sim}{x}_2$$

The inelastic strain rate is

$$
\begin{aligned}
\dot{\underset{\sim}{\varepsilon}}_{\text{inelastic}} &= \dot{\gamma}\frac{\partial f}{\partial \underset{\sim}{\sigma}}\\
\dot{\gamma} &= \sqrt{\frac{3}{2}}\left\langle\frac{f}{\sqrt{2/3}\,\eta}\right\rangle^{n}
\end{aligned}
$$

with "⟨ ⟩" representing the Macaulay brackets defined as

$$
\begin{aligned}
\langle x\rangle &= 0 \text{ for } x<0\\
&= x \text{ for } x\geq 0
\end{aligned}
$$

These equations completely define the model. Table HBB-Z-1322-3 defines the temperature-dependent material model parameters. Values should be interpolated linearly between the temperatures provided in the table.

HBB-Z-1323 Ni–Fe–Cr (Alloy 800H)

The model for Ni–Fe–Cr (Alloy 800H) is under preparation.

Table HBB-Z-1322-2
Temperature Dependent Young's Modulus

Temperature, °C	E, MPa
25	195 000
427	166 840
550	156 000
600	151 000
650	146 000
700	140 000
816	126 080

HBB-Z-1324 2¼Cr–1Mo

The model for $2^1\!/_4$Cr–1Mo is under preparation.

HBB-Z-1325 9Cr–1Mo–V

The reference model for 9Cr–1Mo–V is defined by the following equations in rate form. The implementation of the constitutive model will require selecting an appropriate numerical time integration scheme. Table HBB-Z-1325-1 lists the notation used in HBB-Z-1325.

This model uses metric units of meters for length, °C for temperature, MPa for stress, mm/mm for strain, and hours for time, and the definition here assumes a small strain constitutive response. To fully define the model requires a definition of the stress rate and the rate of each history variable. An implementation then numerically integrates the rate form definition. The model as presented here is given in strain space, where the input is the strain, strain rate, temperature, and temperature rate and the output is the stress rate. All logarithms in the subsequent definitions are natural logarithms.

The model is defined by the rate equations:

$$\begin{aligned}
\dot{\underset{\sim}{\sigma}} &= \underset{\sim}{C}:\left(\dot{\underset{\sim}{\varepsilon}} - \dot{\underset{\sim}{\varepsilon}}_{\text{inelastic}} - \alpha \dot{T} \underset{\sim}{I}\right) \\
\dot{\sigma}_1 &= -\delta\left(Q - \sigma_1\right)\dot{\gamma} \\
\dot{\underset{\sim}{x}}_1 &= \left(\frac{2}{3}C_1\frac{\partial f}{\partial \underset{\sim}{\sigma}} - \sqrt{\frac{2}{3}}\gamma_1 \underset{\sim}{x}_1\right)\dot{\gamma} - S_1\sqrt{\frac{3}{2}}\left\|\underset{\sim}{x}_1\right\|^{s_1 - 1}\underset{\sim}{x}_1 \\
\dot{\underset{\sim}{x}}_2 &= \left(\frac{2}{3}C_2\frac{\partial f}{\partial \underset{\sim}{\sigma}} - \sqrt{\frac{2}{3}}\gamma_2 \underset{\sim}{x}_2\right)\dot{\gamma} - S_2\sqrt{\frac{3}{2}}\left\|\underset{\sim}{x}_2\right\|^{s_2 - 1}\underset{\sim}{x}_2
\end{aligned}$$

where ":" indicates double contraction of the elasticity tensor on the strain rate. The elasticity tensor is isotropic, defined by the temperature-dependent values of E given in Section II, Part D (Metric), Subpart 2, Table TM-1 and the value of the Poisson's ratio, ν, given in Section II, Part D (Metric), Subpart 2, Table PRD. Section II, Part D (Metric), Subpart 2, Table TE-1 defines the values of the temperature-dependent instantaneous coefficient of thermal expansion.

The flow surface is

$$f = \left\| \underset{\sim}{s} - \underset{\sim}{x} \right\| - h \ \text{sign}\left(p\right)p^l - \sqrt{\frac{2}{3}}\left(\sigma_0 + \sigma_1\right)$$

where $\underset{\sim}{s}$ is the stress deviator

$$\underset{\sim}{s} = \underset{\sim}{\sigma} - \frac{1}{3}\text{tr}\ \underset{\sim}{\sigma}\ \underset{\sim}{I}$$

with "tr" indicating the trace of a tensor and the double-brackets indicating $\left\|\underset{\sim}{Y}\right\| = \sqrt{\underset{\sim}{Y}:\underset{\sim}{Y}}$ with ":" indicating double contraction on the tensor.

The inelastic strain rate, plastic multiplier, and definition of the threshold stress depend on the applied strain rate and temperature:

$$\begin{aligned}
\dot{\underset{\sim}{\varepsilon}}_{\text{inelastic}} &= \dot{\underset{\sim}{\varepsilon}}_{\text{ri}} \text{ for } g \le g_0 \\
&= \dot{\underset{\sim}{\varepsilon}}_{\text{rd}} \text{ for } g > g_0
\end{aligned}$$

Table HBB-Z-1322.3
Temperature-Dependent Material Model Parameters

Parameter	Units	25°C	427°C	550°C	600°C	650°C	700°C	816°C
A	MPa	21 545	2 313.6	1 220.9	803.73	574.55	417.47	244.43
C_1	MPa	6 111.5	7 385.8	26 960	15 118	5 028.3	1 612.0	106.46
C_2	MPa	20 167	7 385.8	2 925.6	2 782.8	3 980.9	6 080.3	9 946.9
X	...	20.619	8.2140	7.2670	6.5517	6.1535	5.7778	5.1900
δ	...	7.1487	1.1807	1.0421	1.9878	4.4547	3.3879	0.010000
φ	...	1.5000	1.5000	1.1149	1.7100	1.2227	1.5000	1.5000
Y_1	...	416.45	480.68	506.44	309.63	89.906	12.092	2.5278
Y_2	...	165.57	93.685	10.256	18.239	120.46	311.97	150.53
η	MPa	170.68	79.303	67.700	94.436	105.54	118.4	90.51
n	...	19.419	19.011	15.842	9.2861	8.8989	7.9975	7.9000
Q	MPa	20.808	214.05	158.00	153.90	71.460	71.317	1.0000
σ_0	MPa	32.792	39.182	29.353	7.4851	16.074	13.961	12.000

Table HBB-Z-1325-1 Nomenclature

Variable	Description	Type [Note (1)]
A	Rate sensitivity slope	Parameter
α	Coefficient of thermal expansion	Parameter
B	Rate sensitivity intercept	Parameter
b	Burgers vector	Parameter
C	Rate independent flow strength	Parameter
$\underset{\sim}{C}$	Elasticity tensor	Descriptive
C_1	First Chaboche hardening parameter	Parameter
C_2	Second Chaboche hardening parameter	Parameter
δ	Voce parameter	Parameter
E	Young's modulus	Parameter
$\underset{\sim}{\dot{\varepsilon}}$	Strain rate tensor	Descriptive
$\dot{\varepsilon}_0$	Reference strain rate	Parameter
$\dot{\varepsilon}_{\mathrm{eff}}$	Effective strain rate	Descriptive
$\underset{\sim}{\dot{\varepsilon}}_{\mathrm{inelastic}}$	Inelastic strain rate tensor	Descriptive
$\underset{\sim}{\dot{\varepsilon}}_{\mathrm{rd}}$	Rate dependent inelastic rate tensor	Descriptive
$\underset{\sim}{\dot{\varepsilon}}_{\mathrm{ri}}$	Rate independent inelastic rate tensor	Descriptive
f	Yield and flow function	Descriptive
g	Kocks-Mecking parameter	Descriptive
g_0	Rate dependent/independent transition	Parameter
$\dot{\gamma}$	Plastic multiplier	Descriptive
γ_1	First Chaboche dynamic recovery parameter	Parameter
γ_2	Second Chaboche dynamic recovery parameter	Parameter
h	Stress measure parameter	Parameter
η	Viscoplastic fluidity	Descriptive
$\underset{\sim}{I}$	Identity tensor	Descriptive
k	Boltzmann constant	Parameter
l	Stress measure parameter	Parameter
μ	Shear modulus	Descriptive
n	Rate sensitivity exponent	Descriptive
υ	Poisson's ratio	Parameter
p	Pressure	Descriptive
Q	Voce saturation stress	Parameter
$\underset{\sim}{s}$	Stress deviator tensor	Descriptive
S_1	First Chaboche static recovery prefractor	Parameter
S_2	Second Chaboche static recovery prefractor	Parameter
s_1	First Chaboche static recovery exponent	Parameter
s_2	Second Chaboche static recovery exponent	Parameter
$\underset{\sim}{\sigma}$	Stress tensor	Descriptive
$\underset{\sim}{\dot{\sigma}}$	Stress rate tensor	Rate
σ_0	Threshold stress	Descriptive
σ_1	Isotropic hardening	History
$\dot{\sigma}_1$	Isotropic hardening rate	Rate
T	Temperature in Celsius	Descriptive
$\dot{T}$	Temperature rate	Descriptive
$\underset{\sim}{x}$	Kinematic hardening tensor	Descriptive
$\underset{\sim}{x}_1$	First backstress tensor	History
$\underset{\sim}{x}_2$	Second backstress tensor	History
$\underset{\sim}{\dot{x}}_1$	First backstress rate tensor	Rate
$\underset{\sim}{\dot{x}}_2$	Second backstress rate tensor	Rate

NOTE:

(1) Variables indicated by "Rate" comprise the rate-form definition of the model.

Table HBB-Z-1325-1 Nomenclature (Cont'd)

NOTE (CONT'D):

Variables indicated by "History" are internal history variables maintained by the model.

Variables indicated by "Parameter" are model parameters, defined in Tables HBB-Z-1325-2 and HBB-Z-1325-3.

Variables indicated by "Descriptive" are neither model parameters nor history variables and are used in the model exposition.

with

$$g = \frac{k\left(T + 273.15\right)}{\mu b^3}\log\left(\frac{\dot{\varepsilon}_0}{\dot{\varepsilon}_{\mathrm{eff}}}\right)$$

with

$$\dot{\varepsilon}_{\mathrm{eff}} = \sqrt{\frac{2}{3}\underset{\sim}{\dot{\varepsilon}}:\underset{\sim}{\dot{\varepsilon}}}$$

with ":" again indicating double contraction and the shear modulus defined in terms of the Young's modulus and Poisson's ratio:

$$\mu = \frac{E}{2\left(1 + \nu\right)}$$

The strain rate and plastic multiplier are given by a standard rate-independent update defined by the Kuhn-Tucker and consistency conditions for the rate independent case ($g \le g_0$):

$$\underset{\sim}{\dot{\varepsilon}}_{\mathrm{ri}} = \dot{\gamma}\frac{\partial f}{\partial \underset{\sim}{\sigma}}$$

$$\dot{\gamma} > 0$$

$$f \le 0$$

$$\gamma f = 0$$

$$\gamma \dot{f} = 0$$

The strain rate and plastic multiplier are given by a Perzyna viscoplastic update for the rate dependent case ($g > g_0$):

$$\dot{\varepsilon}_{\mathrm{rd}} = \dot{\gamma}\frac{\partial f}{\partial \underset{\sim}{\sigma}}$$

$$\dot{\gamma} = \frac{\langle f \rangle^{n}}{\eta}$$

$$n = -\frac{\mu b^{3}}{k\left(T + 273.15\right)A}$$

$$\eta = e^{B}\mu\dot{\varepsilon}_{0}^{-1/n}$$

Here "⟨ ⟩" represents the Macaulay brackets with

$$\begin{aligned} \langle x \rangle &= 0 \text{ for } x < 0 \\ &= x \text{ for } x \geq 0 \end{aligned}$$

The threshold stress likewise has a different definition in the rate dependent and rate independent regimes

$$\begin{aligned} \sigma_{0} &= \mu e^{C} \text{ for } g \leq g_{0} \\ &= 0 \text{ for } g \leq g_{0} \end{aligned}$$

These equations completely describe the model. Table HBB-Z-1325-2 gives the temperature independent model parameters. Table HBB-Z-1325-3 gives the temperature dependent parameters, which should be interpolated linearly between the provided temperature values, with the exception of parameters S_1 and S_2 which should be interpolated log-linearly.

Table HBB-Z-1325-2
Temperature-Independent Parameters

Parameter	Value	Units
k	1.38068×10^{-29}	MJ/C
$\dot{\varepsilon}_0$	3.6×10^{13}	1/hr
b	2.48×10^{-10}	m
g_0	0.3496	dimensionless
A	9.698	dimensionless
B	8.509	dimensionless
C	5.119	dimensionless

Table HBB-Z-1325-3
Temperature-Dependent Parameters

Parameter	Units	25°C	371°C	400°C	500°C	550°C	600°C	650°C
h	dimensionless	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
l	dimensionless	1.91	1.91	1.91	1.71	1.69	1.61	1.51
Q	MPa	-96	-96	-96	-150	-151	-151	-131
δ	dimensionless	2.00	1.73	1.71	1.71	1.51	1.51	1.00
C_1	MPa	14 500	14 961	15 000	19 000	19 200	19 900	19 000
γ_1	dimensionless	141	141	141	802	792	803	803
S_1	MPa^{1-s1}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}
s_1	dimensionless	3.5	3.5	3.5	5.97	5.97	7.47	9.46
C_2	MPa	12 500	12 500	12 500	12 500	12 600	12 400	12 400
γ_2	dimensionless	60.6	60.4	60.4	200	200	202	202
S_2	MPa^{1-s2}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}	1×10^{-15}
s_2	dimensionless	3.5	3.5	3.5	5.96	5.96	7.51	9.53

SUBSECTION HC
CLASS B METALLIC PRESSURE BOUNDARY COMPONENTS

SUBPART A
LOW TEMPERATURE SERVICE

ARTICLE HCA-1000
INTRODUCTION

HCA-1100 GENERAL

HCA-1110 SCOPE

The rules of this Subsection HC, Subpart A constitute the requirements associated with Class B metallic components used in the construction of high temperature reactor systems and their supporting systems when subjected to low temperature service.

(a) Subsection HC, Subpart A provides rules for the material, design, fabrication, examination, installation, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of metallic pressure boundary components that are intended to conform to the requirements for Class B construction for service when Service Loading temperatures do not exceed the appropriate temperature limits established in Table HAA-1130-1 for the material under consideration.

(b) The rules of Subsection HC, Subpart A are contained in Division 1, Subsection NCD, except for those paragraphs or subparagraphs (with numbered headers) replaced by corresponding numbered HCA paragraphs or subparagraphs in this Subpart or new numbered HCA paragraphs or subparagraphs added to this Subpart. References to Division 1, Subsection NCD apply to the applicable Class 2 rules in NCD.

(c) Division 1 rules may use different terminology than Division 5 (e.g., Class 2 versus Class B, etc.), but the application of these rules is identical for Division 5 use.

(d) The rules of this Subpart cover the strength and pressure integrity of items the failure of which would violate the pressure-retaining boundary. The rules cover load stresses but do not cover deterioration that may occur in service as a result of corrosion, radiation effects, or instability of materials.

(e) This Subpart does not contain rules to cover all details of construction of Class B vessels and components. Where complete details are not provided in this Subpart, it is intended that the N Certificate Holder, subject to the approval of the Owner or its designee and acceptance by the Inspector, shall provide details of construction that will be consistent with those provided by the rules of this Subpart.

(f) Class B vessels are to be designed using the standard design method in NCD-3300 or the alternative design rules of NCD-3200, which allow the use of analysis with the higher design stress intensity values of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(g) As an alternative for Class B components, the requirements in HAA-2134 may be used for construction utilizing higher class requirements.

ARTICLE HCA-8000 NAMEPLATES, STAMPING WITH THE CERTIFICATION MARK, AND REPORTS

HCA-8100 REQUIREMENTS

The applicable requirements given in Article HAA-8000 shall apply to Class B metallic pressure boundary components.

SUBPART B
ELEVATED TEMPERATURE SERVICE

ARTICLE HCB-1000
INTRODUCTION

HCB-1100 GENERAL

HCB-1110 SCOPE

The rules of this Subsection HC, Subpart B constitute the requirements associated with Class B metallic components used in the construction of high temperature reactor systems and their supporting systems when subjected to elevated temperature service.

(a) Subsection HC, Subpart B provides rules for the material, design, fabrication, examination, installation, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of metallic pressure boundary components or portions of those components that are intended to conform to the requirements for Class B construction for service when Service Loading temperatures exceed the appropriate temperature limits established in Table HAA-1130-1 for the material under consideration. These zones of elevated temperature service shall have their finalized geometry descriptions and temperature profile details finalized in the Design Report prior to any fabrication and examination efforts.

(b) The rules of Subsection HC, Subpart B are contained in Division 1, Subsection NCD, except for those paragraphs or subparagraphs (with numbered headers) replaced by corresponding numbered HCB paragraphs or subparagraphs in this Subpart or new numbered HCB paragraphs or subparagraphs added to this Subpart. References to Division 1, Subsection NCD apply to the applicable Class 2 rules in NCD..

(c) Division 1 rules may use different terminology than Division 5 (e.g., Class 2 versus Class B, etc.), but the application of these rules is identical for Division 5 use.

(d) References to Appendices are to the Section III Appendices, unless otherwise identified as a Subsection HC, Subpart B Appendix, or other subsection-specific Appendix.

(e) The rules of this Subpart cover the strength and pressure integrity of items the failure of which would violate the pressure-retaining boundary. The rules cover load stresses but do not cover deterioration that may occur in service as a result of corrosion, radiation effects, or instability of materials.

(f) This Subpart does not contain rules to cover all details of construction of Class B components. Where complete details are not provided in this Subpart, it is intended that the N Certificate Holder, subject to the approval of the Owner or its designee and acceptance by the Inspector, shall provide details of construction that will be consistent with those provided by the rules of this Subpart.

(g) The rules of this Subpart are independent of the type of nonlethal fluid contained by the component. However, if the Owner (or its designee) specifies in the Design Specification that the component will contain lethal substances[27] or other hazardous substances such as sodium, then the additional requirements of HCB-3160, HCB-4160, and HCB-5160 shall also apply. The limited weld joint types and requirement that the welds shall be properly examined by radiography (HCB-3160 and HCB-5160, respectively) are intended to yield weld joints with no crevices.

(h) Design procedures and material data not contained in this Subpart may be required to ensure the structural integrity or continued functioning of the structural part during the specified service life. For example, the rules do not provide methods to evaluate deterioration that may occur in service as a result of corrosion, mass transfer phenomena, radiation effects, or other material instabilities. Nor do the rules ensure continued functional performance of deformation-sensitive structures such as valves and pumps.

(i) This Subpart is not applicable to storage tanks constructed in accordance with Division 1, NCD-3800 and NCD-3900. This Subpart is not applicable to internal structures outside the scope of (j) below.

(j) The rules of this Subpart apply to those permanent attachments as described in the Design Specifications and to portions of components covered by the Code, as explained as follows:

(1) Divisions 1 and 2, NCA-3211.19(b)(1): Code Boundary Description in Design Specification

(2) Divisions 1 and 2, NCA-3211.19(c)(2): Limits on Code Boundaries of Attachments

(3) HAA-1130: Parts Excluded From Code Coverage

HCB-1120 ALTERNATIVE RULES

(a) The alternative design rules of Division 1, NCD-3200 are not permitted to be used in this Subpart B.

(b) As an alternative, the requirements in HAA-2134 may be used to construct Class B components utilizing higher class requirements.

ARTICLE HCB-2000
MATERIAL

HCB-2100 GENERAL REQUIREMENTS FOR MATERIAL

All pressure-retaining material and material welded thereto shall meet the requirements of Division 1, Article NCD-2000, except as modified herein. In addition, the material shall also conform to the specification, grade, class, and type requirements of the tables in Mandatory Appendix HCB-II.

HCB-2400

HCB-2430

HCB-2433

HCB-2433.2 Acceptance Standards. For Design Temperatures up to and including 800°F (425°C), the minimum acceptable delta ferrite shall be 5 FN (Ferrite Number). For Design Temperatures exceeding 800°F (425°C), the delta ferrite shall be limited to the range 3 FN to 10 FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of Division 1, NCD-2130 or NCD-4120.

HCB-2500

HCB-2570

HCB-2571 Required Examination

(a) Cast products shall be examined by volumetric and/or surface methods, including repairs, as required for the product form by Division 1, Table NCD-2571.1-1.

(b) For cast valves furnished to ASME B16.34 Special Class category, neither the size exclusions nor the quality factor pressure ratings of Division 1, Table NCD-2571.1-1 shall be applied so as to reduce the required examinations of that standard. The required examinations by ASME B16.34 for Special Class category valves shall be performed in accordance with the procedures and acceptance standards of this Subsection.

(c) In addition to the requirements of Division 1, NCD-2571, a determination of delta ferrite shall be performed on each heat of austenitic-type stainless steel castings. These determinations shall conform to the rules in the subparagraphs below.

HCB-2571.1 Method. The delta ferrite determinations shall be performed by use of the chemical analysis required by the material specification in conjunction with Division 1, Figure NCD-2433.1-1.

HCB-2571.2 Acceptance Standards. For Design Temperatures exceeding 800°F (425°C), the delta ferrite shall be limited to a maximum of 12 FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of Division 1, NCD-2130 or NCD-4120.

ARTICLE HCB-3000 DESIGN

HCB-3100 GENERAL DESIGN

All pressure-retaining material and material welded thereto shall meet the requirements of Division 1, Article NCD-3000, except as modified herein.

HCB-3110

HCB-3114 Acceptability

An acceptable component design is one that meets the requirements of (a) through (c) below. Alternative methods are provided under (d) below.

(a) The design satisfies the general design requirements of HCB-3100.

(b) The design satisfies the appropriate component rules in either HCB-3300 (vessels designed by formula), HCB-3400 (pumps), HCB-3500 (valves), or HCB-3600 (piping). The Design Specification shall state which subarticle (HCB-3300, HCB-3400, HCB-3500, or HCB-3600) is appropriate for the particular component.

(c) The design shall guard against failure from low-energy fracture. The Design Specification may contain additional requirements as to tests, analyses, or other methods by which the designer can demonstrate proper consideration of this failure mode.

(d) The Certificate Holder may invoke alternative methods for demonstrating compliance to those portions of (a) and (b) above that relate to buckling, ratcheting, and creep–fatigue failure. However, these alternative methods shall be approved by the Owner. The Owner's approval shall be indicated by incorporating the alternative methods and criteria into the Design Specifications.

HCB-3115 Design Report and Certification

(a) In addition to the requirements of Divisions 1 and 2, NCA-3211.40, a Design Report shall be prepared for a component if any portion (zone of elevated temperature service) is

(1) designed in accordance with the rules in HCB-3630 of this Article

(2) designed using either buckling rules in HCB-3114(d), HCB-3142, or HCB-3143 of this Article

(b) In addition to the applicable requirements from Divisions 1 and 2, NCA-3211.40, the contents of the Design Report shall include an evaluation of those zones of elevated temperature service of the component (and the details related to failure modes) described in (a)(1) and (a)(2) above.

(c) Design Reports shall be certified as being complete and correct by Certifying Engineers competent in elevated temperature component design.

HCB-3140 BUCKLING INSTABILITY LOADINGS

HCB-3141 General Requirements

(a) If a portion (zone of elevated temperature service) of a Class B component is subjected to buckling instability loadings and the conditions of Mandatory Appendix HCB-III are satisfied, then the rules of Division 1, NCD-3133 shall apply for external pressure loadings.

(b) If Mandatory Appendix HCB-III is not satisfied, the limits on buckling loadings given in the remaining rules of HCB-3141, HCB-3142, and HCB-3143 shall be satisfied.

HCB-3141.1 Scope of Rules. The stability limits in Division 1, NCD-3133 pertain only to specific geometrical configurations under specific loading conditions. These limits include the effects of initial geometrical imperfections permitted by fabrication tolerances. However, they do not consider the effects of creep due to long-term loadings at elevated temperatures and the effects of the other loads or other geometries. The rules in HCB-3141, HCB-3142, and HCB-3143 provide additional limits that are applicable to general configurations and loading conditions that may cause buckling or instability due to time-dependent creep behavior of the material. These additional limits are applicable to all loading conditions.

HCB-3141.2 Load-Controlled and Strain-Controlled Buckling. For the limits specified here, distinction is made between load-controlled buckling and strain-controlled buckling. Load-controlled buckling is characterized by continued application of an applied load in the post-buckling regime leading to failure, as exemplified by collapse of a tube under external pressure. Strain-controlled buckling is characterized by the immediate reduction of load due to strain-induced deformations. Even though it is self-limiting, strain-controlled buckling must be avoided to guard against failure by fatigue, excessive strain, loss of function due to excessive deformation, and interaction with load-controlled buckling.

HCB-3141.3 Interaction of Load-Controlled and Strain-Controlled Buckling. For conditions under which strain-controlled and load-controlled buckling may interact, as exemplified by elastic follow-up, the higher Load

Factors applicable to load-controlled buckling shall be used for the combinations of load-controlled and strain-controlled loadings.

HCB-3141.4 Effects of Initial Geometry Imperfections. The requirements listed in (a) and (b) below shall be addressed.

(a) For load-controlled buckling, the effects of initial geometrical imperfections and tolerances shall be considered in the time-independent calculations according to the requirements of HCB-3142. The effects of geometrical imperfections and tolerances, whether initially present or induced by service, shall be considered in the time-dependent calculations of HCB-3143.

(b) In calculating the instability strain under pure strain-controlled buckling, the effects of geometrical imperfections and tolerances, whether initially present or induced by service, need not be considered. However, if significant geometrical imperfections are initially present, enhancement due to creep may cause excessive deformation or strain, and these effects shall be considered in the application of deformation and strain limits.

HCB-3141.5 Stress–Strain Data. The expected minimum stress–strain curve for the material at the specified temperatures shall be used. The expected minimum curve values may be obtained by taking the inelastic portion of the average hot tensile strength values (shown on isochronous stress–strain curves) and normalizing them to the tabulated yield strength values at the specified temperature. Properties data are available in the rules for Class A components in elevated temperature service.

When re-solution annealed (see HCB-4215) Type 300 series austenitic stainless steel is utilized, the tabulated yield strength shall be further reduced by 17%. This reduction is not required if it is demonstrated by test that the room temperature yield strength meets the specified minimum values following re-solution annealing.

HCB-3142 Time-Independent Buckling Limits

For load-controlled buckling, the Load Factor, and for strain-controlled buckling, the Strain Factor, shall equal or exceed the values given in Table HBB-T-1521-1 for the specified Design and Service Loadings to protect against time-independent (instantaneous) buckling.

HCB-3143 Time-Dependent Buckling Limits

To protect against load-controlled time-dependent creep buckling, it shall be demonstrated that instability will not occur during the specified lifetime for a load history obtained by multiplying the specified service loads by the factors given in Table HBB-T-1522-1. A design factor is not required for purely strain-controlled buckling because strain-controlled loads are reduced concurrently with resistance of the structure to buckling when creep is significant.

HCB-3150 LIMITATIONS ON USE

(a) Unless the requirements of Mandatory Appendix HCB-III are satisfied, components with non-integral reinforcement, such as pad-type nozzles and pad-type branch connections, are not acceptable for elevated temperature service. The reinforcement requirements of Division 1, NCD-3300 shall be satisfied only by material that is integral with either the nozzle, or vessel, or both. Weld metal added as reinforcement may be considered as integral metal.

(b) Socket welds may be used only for nominal diameter 2 in. (50 mm) or less.

HCB-3160 COMPONENTS CONTAINING LETHAL OR HAZARDOUS SUBSTANCES

For those components containing lethal substances or other hazardous substances such as sodium, the acceptable weld types shall comply with requirements (a) through (c) listed below.

(a) Category A weld joints in vessels and similar weld joints in other components shall be Type No. (1) (see Division 1, Subsection NCD, NCD-4262 for definitions).

(b) Category B and C weld joints in vessels and similar weld joints in other components shall be Type No. (1) or Type No. (2).

(c) Category D weld joints in vessels and similar weld joints in other components shall be full penetration welds extending through the entire thickness of the pressure boundary wall.

HCB-3300 VESSEL DESIGN

HCB-3310 GENERAL REQUIREMENTS

Class B vessel requirements for elevated temperature service as stipulated in the Design Specifications (Divisions 1 and 2, NCA-3211.19) shall conform to the design requirements of this Article.

(a) Elevated temperature Class B vessels designed by equation shall satisfy the requirements of Division 1, NCD-3300, except as modified per HCB-3100.

(b) The rules of (a) above do not explicitly address fatigue damage resulting from cyclic service.

(c) For design calculations, the allowable stress values, S, at elevated temperatures shall be obtained from the tables of Mandatory Appendix HCB-II. These tables are extensions of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

HCB-3400 PUMP DESIGN

(a) Elevated temperature Class B pumps designed by equation shall satisfy the requirements of Division 1, NCD-3400, except as modified per HCB-3100.

(b) For a pump that has a pipe-like configuration (such as an electromagnetic pump that conforms to a length of pipe), the requirements of (a) above may be satisfied by using the rules of HCB-3600.

(c) The rules of (a) above do not explicitly address fatigue damage resulting from cyclic service.

(d) For design calculations, the allowable stress values, S, at elevated temperatures shall be obtained from the tables of Mandatory Appendix HCB-II. These tables are extensions of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

HCB-3500 VALVE DESIGN

HCB-3510 GENERAL REQUIREMENTS

(a) Elevated temperature Class B valves designed by equation shall satisfy the requirements of Division 1, NCD-3500 except as modified per HCB-3100.

(b) The rules of (a) above do not explicitly address fatigue damage resulting from cyclic service.

(c) For design calculations, the allowable stress values, S, at elevated temperatures shall be obtained from the Tables of Mandatory Appendix HCB-II. These tables are extensions of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

HCB-3600 PIPING DESIGN

HCB-3630 GENERAL REQUIREMENTS

Elevated temperature Class B piping design shall conform to the rules of either HCB-3632 for piping with negligible creep effects or HCB-3634 for piping with creep effects.

HCB-3632 Piping With Negligible Creep Effects

For a particular component, the requirements are given in (a) and (b) below.

(a) The exemption criteria of Mandatory Appendix HCB-III shall be satisfied.

(b) The Design and Service Limits of Division 1, NCD-3600 shall be satisfied for Class B piping with the exceptions and additions listed in (1) through (4) below.

(1) NCD-3611.1: The allowable stress values in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 may be extended by using values in Table HCB-II-2000-1 of Mandatory Appendix HCB-II.

(2) NCD-3611.2(b): The rules of HCB-3140 of this Article may satisfy this requirement on external pressure loadings.

(3) NCD-3641.2: Limits may be satisfied by the rules of HCB-3140.

(4) NCD-3643.3(c)(7): Nonintegral reinforcements are excluded by HCB-3100.

HCB-3634 Piping With Creep Effects

(a) The requirements of Division 1, NCD-3600, as modified by this subarticle, shall be satisfied for all specified Design and Service Loadings on Class B piping. The allowable stress values in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 may be extended to elevated temperatures using the values of the tables in Mandatory Appendix HCB-II. In this subarticle and for all Division 1, NCD-3600 references, eqs. (10a) and (11) of Division 1, NCD-3653.2 shall be modified as in (b) and (c) below.

(b) The allowable stress values, S_A, for thermal expansion stresses in eq. (10a) of Division 1, NCD-3653.2 shall be determined by the form of eq. (10b) listed below:

$$S_A = f(1.25S_c + 0.25S_h) \tag{10b}$$

The stress range reduction factor, f, shall be determined as per Mandatory Appendix HCB-I.

In addition, all thermal cycles shall satisfy the following stress criteria:

$$\frac{\Delta T_i}{\Delta T_E}\left\{\begin{array}{l}\text{Calculated thermal}\\ \text{expansion stress}\\ \text{for the full temperature}\\ \text{change}\end{array}\right\} + \frac{E\alpha\left|\Delta T_1{}^i\right|}{4(1-\nu)} \le (0.75S_{yc} + 0.25S_h) \tag{10c}$$

where

S_{yc} = specified (Section II, Part D, Subpart 1, Table Y-1) yield strength at the minimum (cold) temperature of the i^{th} thermal cycle.

$\left|\Delta T_1{}^i\right|$ = $|\Delta T_1|$ for the i^{th} cycle (Division 1, NB-3653.2)

ΔT_i = temperature range for the i^{th} cycle

ΔT_E = maximum temperature range for all Service Level A, B, and C events. That is, the highest temperature during all events less the minimum temperature during all events.

(c) The allowable stress values in eq. (11) of Division 1, NCD-3653.2 shall be determined by the modified eq. (11) listed below

$$S_{TE} \le [\text{lesser of } (S_A + S_h) \text{ or } (0.75S_{yc} + 0.25S_h)] \tag{11}$$

where S_A and S_{yc} are stress values as defined in (b).

(d) The definitions of other terms used above in (b) and (c) are provided in Division 1, NCD-3611.2(c).

(e) Additional modifications for Division 1, NCD-3600 rules are stated in (1) through (6) below.

(1) NCD-3611.2(b): The requirements are satisfied by the rules of HCB-3100.

(2) NCD-3641.2: The requirements are satisfied by the rules of HCB-3140.

(3) NCD-3643(c)(7): Nonintegral reinforcements are excluded by HCB-3100.

(4) NCD-3643.6: Burst or proof tests and short-term experiments are not acceptable for "other designs."

(5) NCD-3649: Proof tests and short-time experiments are not adequate proof of acceptable designs.

(6) NCD-3671.2; NCD-3671.4(d)(2); NCD-3671.7: All durations of elevated temperature service shall also be duplicated in the tests.

ARTICLE HCB-4000 FABRICATION AND INSTALLATION

HCB-4100 GENERAL REQUIREMENTS

All pressure-retaining material and material welded thereto shall meet the requirements of Division 1, Article NCD-4000, except as modified herein.

(a) Those portions of the component that do not experience elevated temperature service shall either use the rules of this Article or Division 1, Article NCD-4000 as applicable.

(b) Those portions or zones of elevated temperature service of a component that meet the condition that creep and stress rupture effects need not be considered (as defined by Mandatory Appendix HCB-III) shall either use the rules of this Article or Division 1, Article NCD-4000, as applicable.

(c) Those zones of elevated temperature service of the component that do not meet the conditions in (a) or (b) above shall comply with the provisions of this Article.

(d) Those portions or zones of elevated temperature service of the component that use either options (a) and (b), or (c) above, shall be so identified during all steps of fabrication and installation.

HCB-4160 COMPONENTS CONTAINING LETHAL OR HAZARDOUS SUBSTANCES

For those components containing lethal substances or other hazardous substances such as sodium, the component shall be postweld heat treated in accordance with this Article when the pressure boundary material includes either carbon or low alloy steels.

HCB-4200

HCB-4210

HCB-4215 Additional Requirements for Forming and Bending Processes

The rules of this paragraph shall supplement those of Division 1, NCD-4212 and NCD-4213, as applicable. Any process may be used to form pressure-retaining materials at temperatures exceeding those for which allowable stresses are given in this Subpart, including weld metal, provided that the requirements of the subparagraphs below are met.

(a) Post-fabrication heat treatment [in accordance with (b) below] of materials that have been formed during fabrication shall be required unless one of the following conditions are met:

(1) Maximum fabrication-induced local strains[28] do not exceed 5%[29] regardless of the service temperature.

(2) For fabrication-induced strains greater than permitted in (1) above, written technical justification shall be included in the Design Report for not performing heat treatment subsequent to straining, or for the use of an alternate heat treatment procedure to that specified in (b) below. The justification shall provide assurance that the resultant material property capabilities are adequate for the intended service (fatigue, creep rupture, impact toughness, etc.) and shall include consideration of property variability through the material section. This option is not permitted for certain materials if the components are subjected (during Level A, B, and C Service Loadings, or for design conditions when only design conditions are specified) to short-time, high-temperature excursions that result in accumulated temperature exposures exceeding the maximum permissible values shown in Figure HCB-4215-1. This option is not permitted for ferritic material. This option is also not permitted for any austenitic material that is subjected to greater than 20% strain.

(3) The roll-threaded portion of bolting material is exempt from the heat treatment requirement.

(b) When required, the post-fabrication heat treatment shall be in accordance with (1) and (2) below.

(1) For ferritic materials, the post-fabrication heat treatment shall consist of exposure to temperatures listed in Division 1, Table NCD-4622.1-1, as applicable, for the appropriate alloy P-Number. Holding times shall also be in accordance with the appropriate table based on the material thickness at the point of maximum strain. This heat treatment shall be included in the material certification per Division 1, NCD-2211, as applicable, and the forming qualifications as required by Division 1, NCD-4213 and applicable weld procedure qualifications. Alternatively, the base material and welds may be reheat treated and recertified in accordance with the applicable material specification and requirements in Division 1, NCD-2400. Reheat treatment may entail appropriate cooling from hot working temperatures above the upper critical temperature of the respective material provided required material property levels are achieved.

(2) For austenitic materials, the post-fabrication heat treatment shall consist of the heat treatment specified in the base material specification except that Alloy 800H shall be heat treated at 2,050°F (1 120°C) minimum. The final grain size of Alloy 800H shall not be finer than micrograin size #5 as defined in ASTM E112.

HCB-4400

HCB-4420

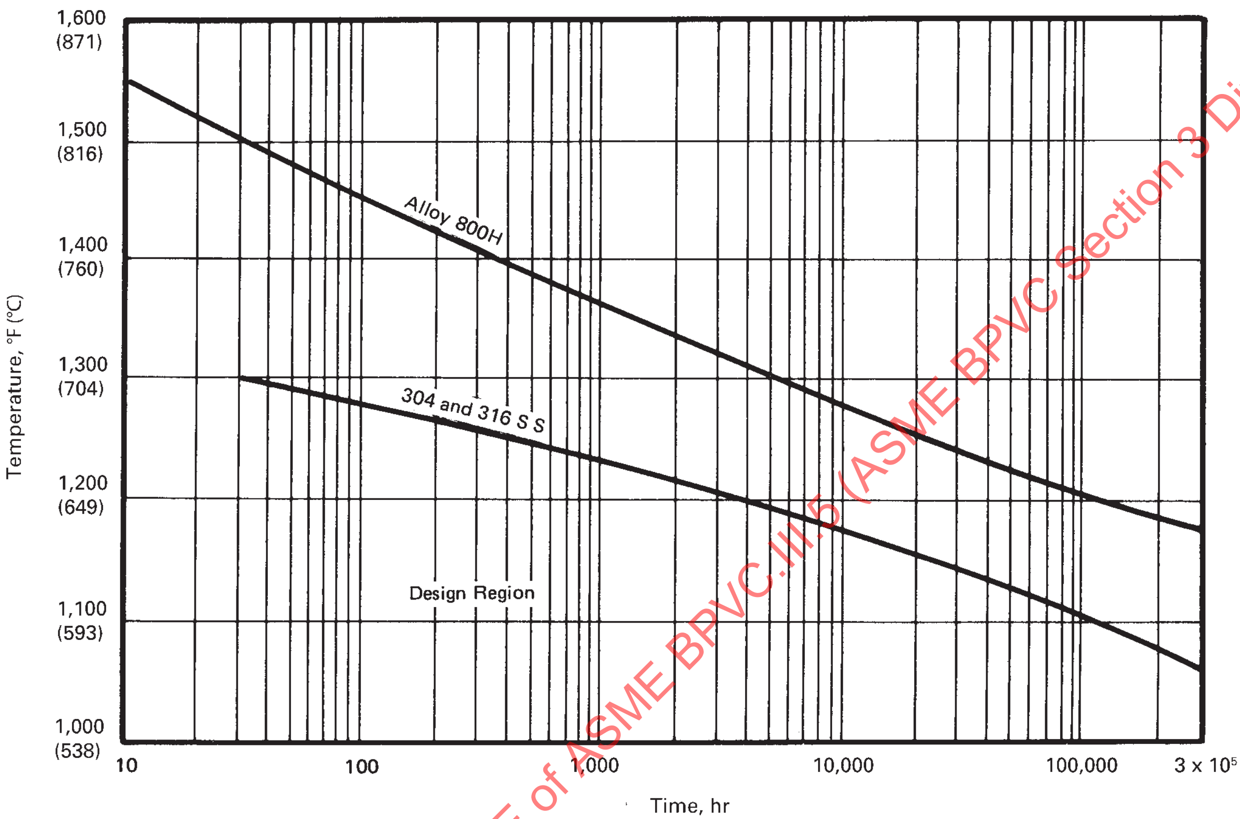
HCB-4427 Shape and Size of Fillet Welds

(a) Fillet welds may vary from convex to concave. Except as permitted in (b) below, the shape and size of the weld shall be in accordance with the requirements of Division 1, Figure NCD-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $^1/_{16}$ in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length. In making socket welds, a gap as shown in Division 1, Figure NCD-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding. For sleeve type joints without internal shoulder, the gap shall be between the butting ends of the pipe or tube.

(b) Socket welds smaller than those specified in Division 1, Figure NCD-4427-1 may be used provided the requirements of Division 1, Article NCD-3000 are met.

(c) The designer shall evaluate whether assembly of socket welds should allow for an axial gap after welding that will allow free thermal growth of the male coupling within the socket without bottoming out during the intended service. If a gap is deemed necessary, it shall be verified in accordance with the rules for the examination of Class B components for elevated temperature service (Article HCB-5000).

Figure HCB-4215-1
Permissible Time/Temperature Conditions for Material That Has Been Cold Worked >5% and <20% and Subjected to Short-Time, High-Temperature Transients



GENERAL NOTE: The sum of time at every temperature shall determine a point within the design region of the figure for the specific material. For multiple temperature/time combinations, the linear summation of life fraction shall not exceed 1.0, the material limit.

ARTICLE HCB-5000 EXAMINATION

HCB-5100 GENERAL REQUIREMENTS FOR EXAMINATION

All pressure-retaining material and material welded thereto shall meet the requirements of Division 1, Article NCD-5000.

HCB-5160 COMPONENTS CONTAINING LETHAL OR HAZARDOUS SUBSTANCES

For those components containing lethal substances or other hazardous substances such as sodium, all permitted weld joints at the pressure boundary shall be fully radiographed.

ARTICLE HCB-6000
TESTING

HCB-6100 GENERAL REQUIREMENTS

The requirements of Division 1, Article NCD-6000 shall be met, except as modified herein.

HCB-6110

HCB-6111 Scope of Pressure Testing

All pressure-retaining components, appurtenances, and completed systems shall be pressure tested, except as specified in (a) through (d) below. Portions of piping systems that are exempt shall be identified in the Design Specification and the Data Report Form N-5 (see Section III Appendices, Mandatory Appendix V). The Design Specification shall be available to the Authorized Nuclear Inspector when the balance of the system is pressure tested.

(a) Bolts, studs, nuts, washers, and gaskets are exempt.

(b) The following portions of piping systems whose only function is to transport fluids to and from spray ponds, lakes, reservoirs, or tanks that are open to the atmosphere are exempt:

(1) piping downstream of the last isolation valve preceding the pipe discharge to the spray pond, lake, reservoir, or tank

(2) piping upstream of the intake pump inlet isolation valve

(c) Where systems discharge into Class B vessels, only that portion of the system external to the vessel is required to be pressure tested.

(d) Under the special conditions of HCB-6630 and HCB-6640, a helium mass spectrometer test (per the requirements of Section V, Article 10 for an allowable volumetric leakage rate that shall be defined in the Design Specification) may replace the required pressure test.

HCB-6600

HCB-6630 ALTERNATIVE TESTS OF CLOSURE WELDS AND ACCESS HATCHES

Closure welds for access hatches in vessels and closure welds for connecting piping subassemblies may be tested by a helium mass spectrometer test as an alternative to the pressure test requirements of Division 1, NCD-6110 provided the conditions of (a) and (b) below are met.

(a) Closure welds are located at least $3(RT)^{1/2}$ from major structural discontinuities such as flanges, nozzles, pumps, or valves. R is the mean radius and T is the nominal thickness of the thicker material adjacent to the weld.

(b) The closure welds to which the alternative test procedure has been applied shall be identified on the Data Report.

HCB-6640 ALTERNATIVE TESTS AT SPECIALLY DESIGNED WELDED SEALS

Welds of specially designed welded seals may be tested by a helium mass spectrometer test in lieu of the pressure test requirements of Division 1, NCD-6110 provided the following:

(a) The welds of the seal, and the welds joining the seal to the component or supporting structure, cannot be visually examined during pressure testing due to access restrictions.

(b) The welds and the alternative test procedures have been mutually agreed to by the Owner and Certificate Holder, and the requirements appear in the Design Specification and are reported in the Certificate Holder's Data Report Form.

ARTICLE HCB-7000 OVERPRESSURE PROTECTION

HCB-7100 GENERAL REQUIREMENTS

All pressure-retaining material and material welded thereto shall meet the requirements of Division 1, Article NCD-7000, except as modified herein.

(a) This Article provides Class B overpressure protection rules for those pressure boundary components, which having been designated by the Owner (Divisions 1 and 2, NCA-1140 and Table NCA-3200-1) as a group of items requiring such protection, are not covered by Division 1, Article NCD-7000 rules because some of the components are expecting service temperatures above those currently allowed under the rules of Division 1, Subsection NCD.

(b) Whereas the rules of Division 1, Article NCD-7000 are oriented toward water and steam-cooled reactor systems, the rules of this Article envision a wider variety of coolant fluids.

(c) All references to other Division 1, Article NCD-7000 paragraphs are to be interpreted as referring to the Division 1, Article NCD-7000 paragraphs as modified by this Article.

(d) As with Division 1, Article NCD-7000, the rules of this Article presume that all system conditions, including transients, are accurately described in the Design Specifications for the components being protected.

(e) In the evaluation of the effects of overpressure events, structural loadings shall include, but not be limited to, the types of events listed in (1) through (7) below.

(1) system overpressure due to a closed valve, a blocking object, or a solid core of metal coolant

(2) overpressure due to the addition of heat to an isolated portion of the system

(3) overpressure due to nuclear transient effects

(4) overpressure due to failure of a system component, including the effects of leaks from adjacent systems and possible resulting chemical reactions

(5) overpressure resulting from operator error

(6) overpressure due to constant pressure in combination with a rising over-temperature condition

(7) overpressure due to pump overspeed

HCB-7110 SCOPE

(a) A system[30] shall be protected from the consequences arising from the application of conditions of pressure and coincident temperature that would cause either the Design Pressure or the Service Limits specified in the Design Specification to be exceeded.

(b) Pressure relief devices[31] are required when the operating conditions considered in the Overpressure Protection Report would cause the Service Limits specified in the Design Specification to be exceeded.

(c) Protection of components in the system from the effects of pressure increases of extremely short duration, such as water hammer resulting from the rapid closing of a valve, is beyond the scope of this Article. These effects shall be included in the Design Specification. Some examples of events whose overpressure transients are not considered in detail by the rules of this Article are

(1) rapid closure of a check valve leading to fluid shock conditions in a local region

(2) earthquake motions inducing sloshing of fluids contained in large tanks

(3) nuclear incidents inducing a severe pressure spike in a local region

(4) rapid closure of a valve during high flow rate conditions introducing pressure shocks

Note that each of the above events may lead to loss of coolant in systems utilizing nonreclosing overpressure relief devices.

HCB-7140

HCB-7143 Draining of Pressure Relief Devices

(a) A pressure relief device installation shall be fitted with a drain at its lowest point where liquid or residue can collect if such liquid or residue could interfere with proper relieving operation.

(b) If the design of a pressure relief device permits liquid or residue to collect on the discharge side of the disk and could interfere with proper relieving operation, the device shall be fitted with a drain to minimize the collection of liquid or residue.

(c) Such drains shall discharge to a controlled thermal dissipation or discharge storage system, such as those provided for pressure relief devices.

HCB-7200

HCB-7220 CONTENT OF REPORT

The Overpressure Protection Report shall define the protected systems and the integrated overpressure protection provided. As a minimum, the report shall include the following:

(a) identification of specific Article HCB-7000, Edition and Addenda, and applicable Code Cases used in the design of the overpressure protection system.

(b) drawings showing arrangement of protected systems including the pressure relief devices.

(c) the analysis of the effect of the range of operating conditions, including the effect of discharge piping back pressure.

(d) an analysis of the conditions that give rise to the maximum pressure or vacuum relieving requirements, except when the basis for establishing relieving capacity is the loss of the heat sink of the protected system when the thermal input to the system is at a maximum.

(e) the relief capacity required to prevent a pressure or vacuum rise in any component from exceeding the limitations of Division 1, NCD-7300.

(f) the operating controls or safety controls of the protected system upon which the anticipated required relief capacity of (d) and the maximum pressure, vacuum, and temperature of (c) are predicted.

(g) the redundancy and independence of the pressure relief devices and their associated pressure or vacuum sensors and controls employed to preclude a loss of overpressure protection in the event of a failure of any pressure relief device, sensing element, associated control, or external power sources.

(h) the extent that an individual component can be isolated from the overall system overpressure protection and the analysis of the conditions under which additional individual overpressure protection is necessary.

(i) the design secondary pressure including a justification of the value identified in the Design Specification for pressure relief devices.

(j) the analysis of pressure transient conditions, including those associated with the response time of pressure or vacuum relief valves, taking into account the effect of coolant fluid, including liquid, gas, and two-phase flow.

(k) consideration of set pressure and blow down limitations, taking into account opening pressure tolerances and overpressure of the pressure relief device.

(l) consideration of burst pressure tolerance and manufacturing design range of the rupture disk device.

(m) verification that pressure relief devices are not required, if applicable. Verification shall include reference to each component's Design Report and applicable requirements in Article HCB-3000 that demonstrate the calculated stress levels do not exceed the Service Limits specified in the component Design Specification for all system service loadings.

(n) the effects of any thermal dissipation of discharge storage system on the pressure relief devices.

(o) the disposition of effluent from pressure relief devices for both primary and secondary reactor coolant fluids.

(p) an analysis of the transient conditions and operating conditions that give rise to the maximum pressure and pressure-relieving requirements, except where the basis for establishing relieving capacity is the loss of 100% of the heat sink of the nuclear power system when the thermal output of the nuclear reactor is at 100% of its rated power.

HCB-7600

HCB-7610

HCB-7611 General Requirements

Rupture disk devices certified in accordance with Division 1, NCD-7720 and NCD-7750 are subject to the following:

(a) Rupture disk devices may be used as the sole pressure relief devices, except for main steam or liquid service (Division 1, NCD-7625).

(b) Rupture disk devices may be used on the inlet side of pressure relief valves only when such valves are of the full bore[32] type (Division 1, NCD-7623).

(c) Rupture disk devices may be used in conjunction with pressure relief valves on the outlet side (Division 1, NCD-7624).

(d) Rupture disks shall use materials of construction approved for Class B pressure boundaries in elevated temperature service as applicable.

HCB-7620

HCB-7621 Provisions for Venting or Draining

When a rupture disk is used in conjunction with a pressure relief valve, the space between the rupture disk and the associated pressure relief valve shall be vented and/or drained (e.g., connected to a controlled disposal system). This space shall be provided with means to monitor its internal pressure during service periods.

ARTICLE HCB-8000
NAMEPLATES, STAMPING WITH THE CERTIFICATION MARK, AND REPORTS

HCB-8100 REQUIREMENTS

The applicable requirements given in Article HAA-8000 shall apply to Class B metallic pressure boundary components.

MANDATORY APPENDIX HCB-I STRESS RANGE REDUCTION FACTOR FOR PIPING

ARTICLE HCB-I-1000 STRESS RANGE REDUCTION FACTOR

The stress range reduction factor, f, for cyclic conditions shall be determined from Table HCB-I-2000-1.

The maximum number of allowable cycles, N_1, with f = 1 and the total number of equivalent full temperature cycles, N, can be determined as per Articles HCB-I-2000 and HCB-I-3000, respectively.

ARTICLE HCB-I-2000
MAXIMUM NUMBER OF ALLOWABLE CYCLES WITH f = 1

The maximum number of cycles, N_1, permissible with f = 1 is determined from Table HCB-I-2000-2.

For temperatures intermediate to the values given in Table HCB-I-2000-2, the corresponding value of $(N_1)_i$ shall be obtained using the equation below:

$$\ln(N_1)_i = \ln(N_1) + \left(\frac{\left[\ln(N_1)_2 - \ln(N_1)_1\right]}{(T_2 - T_1)}\right)(T_i - T_1)$$

where

$(N_1)_1$ = N_1 value for temperature T_1 from Table HCB-I-2000-2

$(N_1)_2$ = N_1 value for temperature T_2 from Table HCB-I-2000-2

$(N_1)_i$ = N_1 value for temperature T_i

T_1 = temperature value in Table HCB-I-2000-2 immediately below T_i

T_2 = temperature value in Table HCB-I-2000-2 immediately above T_i

T_i = intermediate temperature

NOTE: $T_1 < T_i < T_2$ and T_1 and T_2 are adjacent values in Table HCB-I-2000-2.

Table HCB-I-2000-1
Stress Range Reduction Factor

Number of Equivalent Full Temperature Cycles, N	f
0 through N_1	1.0
N_1 through $1.69N_1$	0.9
$1.69N_1$ through $3.05N_1$	0.8
$3.05N_1$ through $5.95N_1$	0.7
$5.95N_1$ through $12.86N_1$	0.6
$12.86N_1$ through $32N_1$	0.5
$32N_1$ through $411N_1$	0.4
$411N_1$ through $3{,}125N_1$	0.3
$>3{,}125N_1$	0.2

Table HCB-I-2000-2
Maximum Number of Cycles, N_1, Permissible With f = 1

Material	Maximum Service Temperature, °F (°C) 700 (371)	750 (399)	800 (427)	850 (454)	900 (482)	950 (510)	1,000 (538)	1,100 (593)	1,200 (649)	1,300 (704)	1,400 (760)	1,500 (816)
Carbon steels		50	25	10	5	5	5	...	...	...	...	...
Low alloy steels		1,000	50	25	10	5	5	5	5	...	...	...
Cast austenitic stainless steels	Covered by rules of Division 1, Subsection NCD-3600			25	10	5	5	5	5	...	...	...
304 SS (wrought)				6,300	1,000	150	50	25	10	5	5	5
316 SS (wrought)				7,000	6,300	800	125	50	25	10	5	5
Other wrought austenitic stainless steels				1,000	150	50	25	10	5	5	5	...
Alloy 800H				7,000	7,000	6,300	800	125	50	25	10	...
Other high nickel alloys				6,300	1,000	150	50	25	10	5	...	...

ARTICLE HCB-I-3000 EQUIVALENT CYCLE

If a range of temperature varies in time, the total number of equivalent cycles (based on the full temperature range) may be calculated as

$$N = \sum r_i^5 N_i$$

where

$$r_i = \frac{\Delta T_i}{\Delta T_E}\left[\begin{array}{l}\text{either } [1.25S_c + 0.25S_h] \\ \qquad\text{or} \\ \text{calculated thermal} \\ \text{expansion stresses} \\ \text{for the full temperature} \\ \text{change}\end{array}\right]\left[\frac{1}{(1.25S_c + 0.25S_h)}\right]$$

$$+\left[\text{larger of}\left(\frac{K_3 E\alpha\left|\Delta T_1{}^i\right|}{4(1-\nu)} + \frac{E\alpha\left|\Delta T_2{}^i\right|}{2(1-\nu)}\right)\text{or}\right.$$

$$\left.\left(\frac{K_3 C_3 E_{ab}\left|\alpha_a T_a^i - \alpha_b T_b^i\right|}{2}\right)\right]\frac{1}{(1.25S_c + 0.25S_h)}$$

where

N_i = number of cycles for the i^{th} temperature change
$|\Delta T_1{}^i|$ = $|\Delta T_1|$ for the i^{th} cycle (Division 1, NB-3653.2)
$|\Delta T_2{}^i|$ = $|\Delta T_2|$ for the i^{th} cycle (Division 1, NB-3653.2)
$T_a{}^i$ = T_a for the i^{th} cycle (Division 1, NB-3653.1)
$T_b{}^i$ = T_b for the i^{th} cycle (Division 1, NB-3653.1)
ΔT_E = maximum temperature range for all Service Level A, B, and C events [see HCB-3634(b)]
ΔT_i = temperature range for the i^{th} cycle

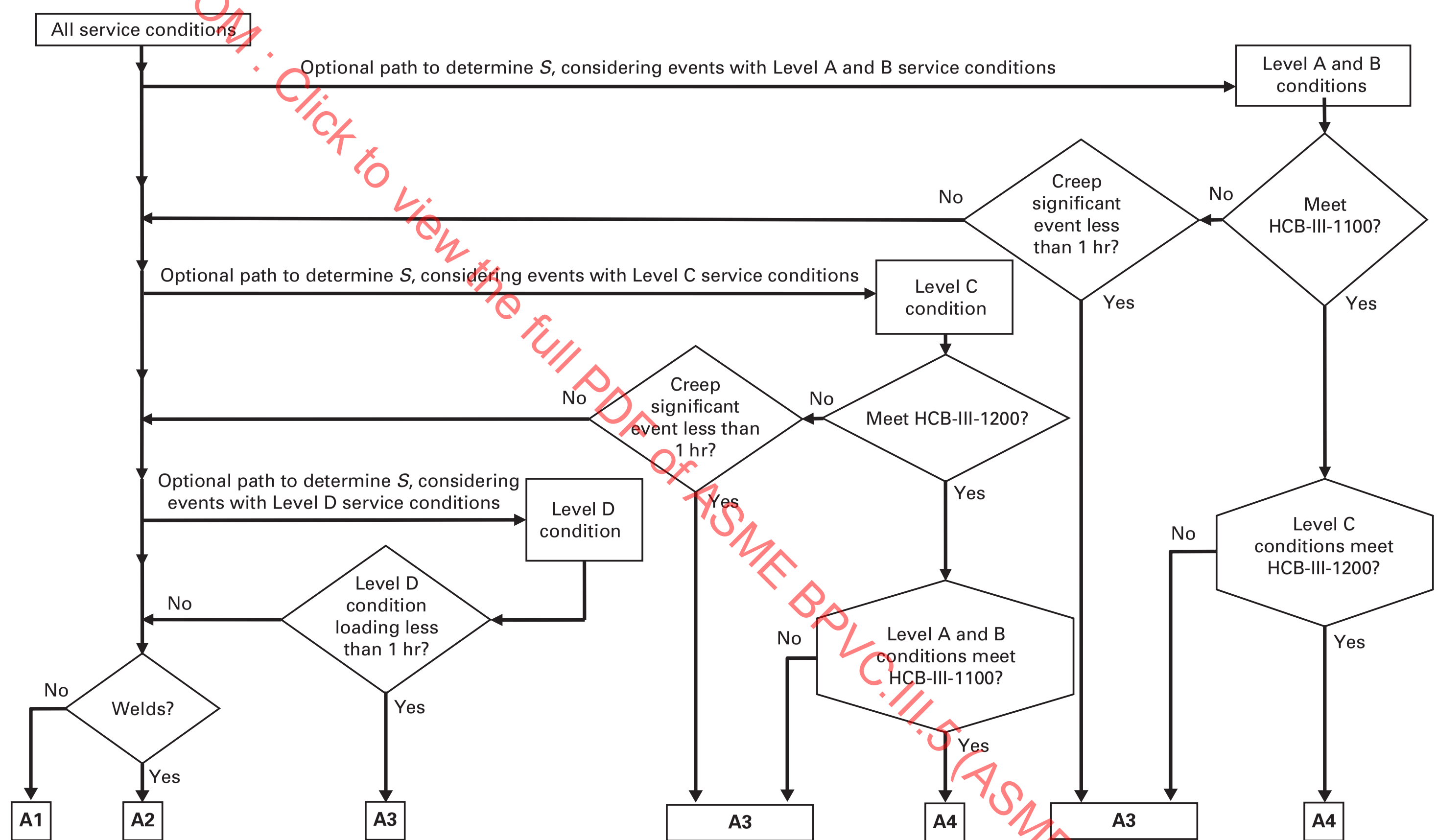
The terms K_3 and C_3 are defined in Division 1, NB-3680. The terms E_{ab}, α_a, α_b, T_a, and T_b are defined in Division 1, NB-3653.1. The terms S_c and S_h are defined in Division 1, NCD-3611.2.

MANDATORY APPENDIX HCB-II
ALLOWABLE STRESS VALUES FOR CLASS B COMPONENTS

ARTICLE HCB-II-1000
SCOPE

The allowable stress values in Section II, Part D, Subpart 1, Tables 1A and 1B are extended to elevated temperatures using the values of the Tables in this Appendix and shown in Figure HCB-II-1000-1.

Figure HCB-II-1000-1
Determination of Allowable Stress, S, for Class B Components



Legend:

A1 = allowable stress from Tables HCB-II-3000-1 through HCB-II-3000-4

A2 = allowable stress from Tables HCB-II-3000-1 through HCB-II-3000-4 multiplied by weld reduction factor from Tables HCB-II-3000-5 through HCB-II-3000-9

A3 = allowable stress from Tables HCB-II-2000-1 through HCB-II-2000-4 multiplied by aging factor from Table HCB-II-2000-5

A4 = allowable stress from Tables HCB-II-2000-1 through HCB-II-2000-4

GENERAL NOTE: This flowchart provides optional paths to determine the proper allowable stress, S, to be used for the evaluation of Class B components. For any or all service conditions, the user always has the option of moving straight down the flowchart on the left and choosing the more conservative allowable stresses per designator A1 or, for welds, choosing the more conservative allowable stresses per designator A2. Three other optional paths permit the use of higher allowable stress values applicable to the various specified Level A, B, C, and D service conditions, provided additional evaluations from Mandatory Appendix HCB-III and consideration of events lasting less than 1 hr are properly determined per the flowchart.

ARTICLE HCB-II-2000
SERVICE WITH NEGLIGIBLE CREEP EFFECTS

The allowable stresses of Tables HCB-II-2000-1 through HCB-II-2000-4 may be used when the time–temperature limits of Mandatory Appendix HCB-III are satisfied.

Table HCB-II-2000-1
Allowable Stress Values for Ferritic Steel Class B Components

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	U.S. Customary Units — Stress Values, ksi, for Metal Temperatures, °F, Not to Exceed: 700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200
Carbon steel	1	1	Forging	SA-181	...	60	30/60	(7)(8)	A	14.3	13.1	12.4	12.1	11.2	9.9	8.6	...	...	...	...
Carbon steel	1	1	Casting	SA-216	WCA	...	30/60	(2)(5)(8)	A	14.3	13.1	12.4	12.1	11.2	9.9	8.6	...	...	...	...
Carbon steel	1	1	Plate	SA-515	60	...	32/60	(5)(8)	A	14.3	13.9	13.3	12.6	11.2	9.9	8.6	...	...	...	...
Carbon steel	1	1	Plate	SA-516	60	...	32/60	(5)(8)	A	14.3	13.9	13.3	12.6	11.2	9.9	8.6	...	...	...	...
Carbon steel	1	1	Smls. pipe	SA-106	B	...	35/60	(5)(8)	A	14.3	14.1	13.8	12.6	11.2	9.9	8.6	...	...	...	...
Carbon steel	1	1	Smls. tube	SA-210	A-1	...	37/60	(5)(8)	A	14.3	14.1	13.8	12.6	11.2	9.9	8.6	...	...	...	...
Carbon steel	1	1	Wld. tube	SA-178	C	...	37/60	(5)(8)	A	14.3	14.1	13.8	12.6	11.2	9.9	8.6	...	...	...	...
Carbon steel	1	1	Plate	SA-515	65	...	35/65	(5)(8)	A	15.2	14.9	14.6	13.6	12.1	10.7	9.3	...	...	...	...
Carbon steel	1	1	Plate	SA-516	65	...	35/65	(5)(8)	A	15.2	14.9	14.6	13.6	12.1	10.7	9.3	...	...	...	...
Carbon steel	1	2	Forging	SA-266	2	...	36/70	(5)(8)	A	16.6	15.6	14.6	14.1	13.0	11.6	10.1	...	...	...	...
Carbon steel	1	2	Forging	SA-105	...	...	36/70	(5)(7)(8)	A	16.6	15.7	14.9	14.4	13.0	11.6	10.1	...	...	...	...
Carbon steel	1	2	Forging	SA-181	...	70	36/70	(5)(7)(8)	A	16.6	15.7	14.9	14.4	13.0	11.6	10.1	...	...	...	...
Carbon steel	1	2	Casting	SA-216	WCB	...	36/70	(2)(5)(8)	A	16.6	15.7	14.9	14.4	13.0	11.6	10.1	...	...	...	...
Carbon steel	1	2	Plate	SA-515	70	...	38/70	(5)(8)	A	16.6	16.2	15.8	14.7	13.0	11.6	10.1	...	...	...	...
Carbon steel	1	2	Plate	SA-516	70	...	38/70	(5)(8)	A	16.6	16.2	15.8	14.7	13.0	11.6	10.1	...	...	...	...
Carbon steel	1	2	Smls. pipe	SA-106	C	...	40/70	(8)	A	16.6	16.4	16.1	...	...	...	...	...	...	...	...
Carbon steel	1	2	Casting	SA-216	WCC	...	40/70	(2)(8)	A	16.6	16.4	16.1	14.7	13.0	...	...	...	...	...	...
C–$^1/_2$Mo	3	1	Smls. pipe	SA-335	P1	...	30/55	(5)(9)	B	13.8	13.8	13.5	13.1	12.8	12.0	11.1	...	...	...	...
C–$^1/_2$Mo	3	1	Forg. pipe	SA-369	FP1	...	30/55	(9)	B	13.8	13.8	13.5	13.1	12.8	12.0	11.1	...	...	...	...
C–$^1/_2$Mo	3	1	Casting	SA-217	WC1	...	35/65	(2)(3)(9)	B	16.3	16.2	15.8	15.3	14.9	14.1	13.1	...	...	...	...
C–$^1/_2$Mo	3	1	Plate	SA-204	A	...	37/65	(5)(9)	B	16.3	16.3	16.3	15.8	15.1	14.1	13.1	...	...	...	...
C–$^1/_2$Mo	3	2	Forging	SA-182	F1	...	40/70	(9)	B	17.5	17.5	17.5	17.1	16.3	15.2	14.2	...	...	...	...
C–$^1/_2$Mo	3	2	Forging	SA-336	F1	...	40/70	(9)	B	17.5	17.5	17.5	17.1	16.3	15.2	14.2	...	...	...	...
C–$^1/_2$Mo	3	2	Plate	SA-204	B	...	40/70	(9)	B	17.5	17.5	17.5	17.1	16.3	15.2	14.2	...	...	...	...
C–$^1/_2$Mo	3	2	Plate	SA-204	C	...	43/75	(9)	B	18.8	18.8	18.8	18.3	17.4	16.3	15.2	...	...	...	...
Mn–$^1/_2$Mo	3	3	Plate	SA-302	B	...	50/80	...	B	20.0	20.0	20.0	19.1	18.2	16.8	15.6	...	...	...	...
$^3/_4$Ni–$^1/_2$Mo–$^1/_3$Cr–V	3	3	Forging	SA-508	2	1	50/80	...	B	20.0	20.0	20.0	...	...	...	...	...	...	...	...
Mn–$^1/_2$Mo–$^3/_4$Ni	3	3	Plate	SA-533	C	1	50/80	...	B	20.0	20.0	20.0	...	...	...	...	...	...	...	...
$^3/_4$Ni–$^1/_2$Mo–$^1/_3$Cr–V	3	3	Forging	SA-541	2	1	50/80	...	B	20.0	20.0	20.0	...	...	...	...	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Plate	SA-387	12	1	33/55	...	B	13.8	13.8	13.8	13.4	12.8	12.0	11.1	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Smls. tube	SA-213	T12	...	32/60	...	B	14.2	13.9	13.5	13.1	12.8	12.3	11.8	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Smls. pipe	SA-335	P12	...	32/60	...	B	14.2	13.9	13.5	13.1	12.8	12.3	11.8	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Forg. pipe	SA-369	FP12	...	32/60	...	B	14.2	13.9	13.5	13.1	12.8	12.3	11.8	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Plate	SA-387	12	2	40/65	...	B	16.3	16.3	16.3	15.8	15.1	...	...	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Forging	SA-182	F12	2	40/70	...	B	17.5	17.5	17.5	17.1	16.3	...	...	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Forging	SA-336	F12	...	40/70	...	B	17.5	17.5	17.5	17.1	16.3	...	...	...	...	...	...
1$^1/_4$Cr–$^1/_2$Mo	4	1	Casting	SA-217	WC6	...	40/70	(2)(3)	B	17.5	17.5	17.5	17.1	16.3	...	...	...	...	...	...
2$^1/_4$Cr–1Mo	5A	1	Forging	SA-182	F22	1	30/60	(10)(11)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...

Table HCB-II-2000-1
Allowable Stress Values for Ferritic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	U.S. Customary Units — Stress Values, ksi, for Metal Temperatures, °F, Not to Exceed: 700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200
$2^1/_4$Cr–1Mo	5A	1	Fitting	SA-234	WP22	1	30/60	(10)(12)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Fitting	SA-234	WP22W	1	30/60	(10)(12)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Smls. tube	SA-213	T22	...	30/60	(10)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Wld. pipe	SA-691	$2^1/_4$CR	...	30/60	(10)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Smls. pipe	SA-335	P22	...	30/60	(10)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forging	SA-336	F22	1	30/60	(10)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forg. pipe	SA-369	FP22	...	30/60	(10)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	30/60	(10)	B	14.5	14.5	14.5	14.5	14.5	14.5	13.7	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Casting	SA-217	WC9	...	40/70	(2)(3)(10)	B	16.6	16.1	15.7	15.0	14.2	13.2	12.0	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forging	SA-182	F22	3	45/75	(10)	B	17.5	17.2	16.9	16.4	15.8	14.9	...	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forging	SA-336	F22	3	45/75	(10)	B	17.5	17.2	16.9	16.4	15.8	14.9	...	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	2	45/75	(4)(10)	B	17.5	17.2	16.9	16.4	15.8	14.9	...	...	...	...	...
9Cr–1Mo	5B	1	Smls. tube	SA-213	T9	...	30/60	...	B	13.7	12.7	12.4	12.0	11.5	10.9	10.0	...	...	...	...
9Cr–1Mo	5B	1	Smls. pipe	SA-335	P9	...	30/60	...	B	13.7	12.7	12.4	12.0	11.5	10.9	10.0	...	...	...	...
9Cr–1Mo	5B	1	Forg. pipe	SA-369	FP9	...	30/60	...	B	13.7	12.7	12.4	12.0	11.5	10.9	10.0	...	...	...	...
9Cr–1Mo–V	5B	2	Smls. tube	SA-213	T91	...	60/85	(13)(14)	B	20.0	19.4	18.7	17.8	16.7	15.5	14.3	12.9	10.3	7.0	4.3
9Cr–1Mo–V	5B	2	Smls. pipe	SA-335	P91	...	60/85	(13)(14)	B	20.0	19.4	18.7	17.8	16.7	15.5	14.3	12.9	10.3	7.0	4.3
9Cr–1Mo–V	5B	2	Plate	SA-387	91	2	60/85	(13)(14)	B	20.0	19.4	18.7	17.8	16.7	15.5	14.3	12.9	10.3	7.0	4.3
9Cr–1Mo–V	5B	2	Forging	SA-182	F91	...	60/85	(13)(14)	B	20.0	19.4	18.7	17.8	16.7	15.5	14.3	12.9	10.3	7.0	4.3

Table HCB-II-2000-1
Allowable Stress Values for Ferritic Steel Class B Components (Cont'd)

Nominal Composition	P- No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	SI Units: Stress Values, MPa, for Metal Temperatures, °C, Not to Exceed 371	399	427	454	482	510	538	566	593	621	649
Carbon steel	1	1	Forging	SA-181	...	60	205/415	(7)(8)	A	99	90	85	83	77	68	59	...	...	...	...
Carbon steel	1	1	Casting	SA-216	WCA	...	205/415	(2)(5)(8)	A	99	90	85	83	77	68	59	...	...	...	...
Carbon steel	1	1	Plate	SA-515	60	...	220/415	(5)(8)	A	99	96	92	87	77	68	59	...	...	...	...
Carbon steel	1	1	Plate	SA-516	60	...	220/415	(5)(8)	A	99	96	92	87	77	68	59	...	...	...	...
Carbon steel	1	1	Smls. pipe	SA-106	B	...	240/415	(5)(8)	A	99	97	95	87	77	68	59	...	...	...	...
Carbon steel	1	1	Smls. tube	SA-210	A-1	...	255/415	(5)(8)	A	99	97	95	87	77	68	59	...	...	...	...
Carbon steel	1	1	Wld. tube	SA-178	C	...	255/415	(5)(8)	A	99	97	95	87	77	68	59	...	...	...	...
Carbon steel	1	1	Plate	SA-515	65	...	240/450	(5)(8)	A	105	103	101	94	83	74	64	...	...	...	...
Carbon steel	1	1	Plate	SA-516	65	...	240/450	(5)(8)	A	105	103	101	94	83	74	64	...	...	...	...
Carbon steel	1	2	Forging	SA-266	2	...	250/485	(5)(8)	A	114	108	101	97	90	80	70	...	...	...	...
Carbon steel	1	2	Forging	SA-105	...	...	250/485	(5)(7)(8)	A	114	108	103	99	90	80	70	...	...	...	...
Carbon steel	1	2	Forging	SA-181	...	70	250/485	(5)(7)(8)	A	114	108	103	99	90	80	70	...	...	...	...
Carbon steel	1	2	Casting	SA-216	WCB	...	250/485	(2)(5)(8)	A	114	108	103	99	90	80	70	...	...	...	...
Carbon steel	1	2	Plate	SA-515	70	...	260/485	(5)(8)	A	114	112	109	101	90	80	70	...	...	...	...
Carbon steel	1	2	Plate	SA-516	70	...	260/485	(5)(8)	A	114	112	109	101	90	80	70	...	...	...	...
Carbon steel	1	2	Smls. pipe	SA-106	C	...	275/485	(8)	A	114	113	111	...	...	...	...	...	...	...	...
Carbon steel	1	2	Casting	SA-216	WCC	...	275/485	(2)(8)	A	114	113	111	101	90	...	...	...	...	...	...
C–$^1/_2$Mo	3	1	Smls. pipe	SA-335	P1	...	205/380	(5)(9)	B	95	95	93	90	88	83	77	...	...	...	...
C–$^1/_2$Mo	3	1	Forg. pipe	SA-369	FP1	...	205/380	(9)	B	95	95	93	90	88	83	77	...	...	...	...
C–$^1/_2$Mo	3	1	Casting	SA-217	WC1	...	240/450	(2)(3)(9)	B	112	112	109	105	103	97	90	...	...	...	...
C–$^1/_2$Mo	3	1	Plate	SA-204	A	...	255/450	(5)(9)	B	112	112	112	109	104	97	90	...	...	...	...
C–$^1/_2$Mo	3	2	Forging	SA-182	F1	...	275/485	(9)	B	121	121	121	118	112	105	98	...	...	...	...
C–$^1/_2$Mo	3	2	Forging	SA-336	F1	...	275/485	(9)	B	121	121	121	118	112	105	98	...	...	...	...
C–$^1/_2$Mo	3	2	Plate	SA-204	B	...	275/485	(9)	B	121	121	121	118	112	105	98	...	...	...	...
C–$^1/_2$Mo	3	2	Plate	SA-204	C	...	295/515	(9)	B	130	130	130	126	120	112	105	...	...	...	...
Mn–$^1/_2$Mo	3	3	Plate	SA-302	B	...	345/550	...	B	138	138	138	132	125	116	108	...	...	...	...
$^3/_4$Ni–$^1/_2$Mo–$^1/_3$Cr–V	3	3	Forging	SA-508	2	1	345/550	...	B	138	138	138	...	...	...	...	...	...	...	...
Mn–$^1/_2$Mo–$^3/_4$Ni	3	3	Plate	SA-533	C	1	345/550	...	B	138	138	138	...	...	...	...	...	...	...	...
$^3/_4$Ni–$^1/_2$Mo–$^1/_3$Cr–V	3	3	Forging	SA-541	2	1	345/550	...	B	138	138	138	...	...	...	...	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Plate	SA-387	12	1	230/380	...	B	95	95	95	92	88	83	77	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Smls. tube	SA-213	T12	...	220/415	...	B	98	96	93	90	88	85	81	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Smls. pipe	SA-335	P12	...	220/415	...	B	98	96	93	90	88	85	81	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Forg. pipe	SA-369	FP12	...	220/415	...	B	98	96	93	90	88	85	81	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Plate	SA-387	12	2	275/450	...	B	112	112	112	109	104	...	...	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Forging	SA-182	F12	2	275/485	...	B	121	121	121	118	112	...	...	...	...	...	...
1Cr–$^1/_2$Mo	4	1	Forging	SA-336	F12	...	275/485	...	B	121	121	121	118	112	...	...	...	...	...	...
1$^1/_4$Cr–$^1/_2$Mo	4	1	Casting	SA-217	WC6	...	275/485	(2)(3)	B	121	121	121	118	112	...	...	...	...	...	...
2$^1/_4$Cr–1Mo	5A	1	Forging	SA-182	F22	1	205/415	(10)(11)	B	100	100	100	100	100	100	94	...	...	...	...

Table HCB-II-2000-1
Allowable Stress Values for Ferritic Steel Class B Components (Cont'd)

Nominal Composition	P- No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	SI Units — Stress Values, MPa, for Metal Temperatures, °C, Not to Exceed: 371	399	427	454	482	510	538	566	593	621	649
$2^1/_4$Cr–1Mo	5A	1	Fitting	SA-234	WP22	1	205/415	(10)(12)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Fitting	SA-234	WP22W	1	205/415	(10)(12)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Smls. tube	SA-213	T22	...	205/415	(10)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Wld. pipe	SA-691	$2^1/_4$CR	...	205/415	(10)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Smls. pipe	SA-335	P22	...	205/415	(10)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forging	SA-336	F22	1	205/415	(10)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forg. pipe	SA-369	FP22	...	205/415	(10)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	205/415	(10)	B	100	100	100	100	100	100	94	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Casting	SA-217	WC9	...	275/485	(2)(3)(10)	B	114	111	108	103	98	91	83	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forging	SA-182	F22	3	310/515	(10)	B	121	119	117	113	109	103	...	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Forging	SA-336	F22	3	310/515	(10)	B	121	119	117	113	109	103	...	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	2	310/515	(4)(10)	B	121	119	117	113	109	103	...	...	...	...	...
9Cr–1Mo	5B	1	Smls. tube	SA-213	T9	...	205/415	...	B	94	88	85	83	79	75	69	...	...	...	...
9Cr–1Mo	5B	1	Smls. pipe	SA-335	P9	...	205/415	...	B	94	88	85	83	79	75	69	...	...	...	...
9Cr–1Mo	5B	1	Forg. pipe	SA-369	FP9	...	205/415	...	B	94	88	85	83	79	75	69	...	...	...	...
9Cr–1Mo–V	5B	2	Smls. tube	SA-213	T91	...	415/585	(13)(14)	B	138	134	129	123	115	107	99	89	71	48	30
9Cr–1Mo–V	5B	2	Smls. pipe	SA-335	P91	...	415/585	(13)(14)	B	138	134	129	123	115	107	99	89	71	48	30
9Cr–1Mo–V	5B	2	Plate	SA-387	91	2	415/585	(13)(14)	B	138	134	129	123	115	107	99	89	71	48	30
9Cr–1Mo–V	5B	2	Forging	SA-182	F91	...	415/585	(13)(14)	B	138	134	129	123	115	107	99	89	71	48	30

NOTES:

(1) The following are the abbreviations used for Product Form:
  (a) Wld. — Welded
  (b) Smls. — Seamless
  (c) Forg. — Forged

(2) Statically and centrifugally cast products meeting the requirements of Division 1, NCD-2571.1(a) and NCD-2571.1(b), and cast pipe fittings, pumps, and valves with inlet piping connections of NPS 2 (DN 50) and less shall receive a casting quality factor of 1.00. Other casting quality factors shall be in accordance with the following:

Method of Examination	Quality Factor
(a) Visual	0.80
(b) Magnetic Particle	0.85
(c) Liquid Penetrant	0.85
(d) Radiography	1.00
(e) Ultrasonic	1.00
(f) Magnetic Particle or Liquid Penetrant — plus — Ultrasonic or Radiography	1.00

(3) Normalized and Tempered, only.

(4) Normalized and Tempered.

Table HCB-II-2000-1
Allowable Stress Values for Ferritic Steel Class B Components (Cont'd)

NOTES (CONT'D):

(5) For external pressure charts, see Section II, Part D, Subpart 3.

(6) Note no longer used.

(7) For service temperatures above 850°F (454°C) for periods in excess of 1 hr, it is recommended that killed steels containing not less than 0.10% silicon by heat analysis be used. Killed steels that have been deoxidized with large amounts of aluminum and rimmed steels may have creep and stress rupture properties, in the temperature range above 850°F (454°C), which are somewhat less than those on which the values in the above Table are based.

(8) If cumulative service times (i.e., sum of event times during the entire service life) are expected to exceed 1 hr with concurrent temperatures above 800°F (425°C), then the problems of corrosion and material transformation should be considered before selecting this alloy for the application. For example, the carbide phase of the carbon steel may be converted to graphite (graphitization).

(9) Note (8) above applies to this alloy, except that the range of temperatures of concern begins at 875°F (468°C) instead of 800°F (425°C).

(10) This material shall have a maximum specified room temperature ultimate strength of 85,000 psi (586 MPa) and a minimum specified carbon content of 0.07%.

(11) The tensile requirements shall meet those for F22A in Material Specification SA-336 instead of those for F22 in Specification SA-182.

(12) The material allowed under SA-234 shall correspond to one of the following:

(a) SA-335, Grade P22

(b) SA-387, Grade 22, Class 1

(c) SA-182, Grade F22 in compliance with Note (11).

(13) The material shall be normalized at 1,900°F through 2,000°F (1 040°C through 1 095°C) and tempered at 1,350°F (730°C), minimum. The requirements for PWHT shall satisfy the rules in Section VIII, Division 1, Part UCS, UCS-56. The material shall be considered P-No. 5B Group 2, except that the minimum holding temperature shall be 1,300°F (705°C).

(14) For external pressure design, Section II, Part D, Subpart 3, Figure CS-3 shall be used.

Table HCB-II-2000-2
Allowable Stress Values for Class B Bolting Materials

Nominal Composition	Minimum Tempering Temperature, °F	Diameter, in.	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	U.S. Customary Units — Stress Values, ksi, for Metal Temperatures, °F, Not to Exceed: 700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250
5Cr–$^1/_2$Mo	1,100	≤4	SA-193	B5	...	80/100	(1)	B	20.0	20.0	20.0	20.0	19.1	18.2	16.7	...	...	...	...	...
1Cr–$^1/_5$Mo	1,100	≤2 $^1/_2$	SA-193	B7	...	105/125	(1)	None	25.0	25.0	25.0	25.0	23.7	21.7	19.6	...	...	...	...	...
1Cr–$^1/_5$Mo	1,100	$2^1/_2 < D \le 4$	SA-193	B7	...	95/115	(1)	None	23.0	23.0	23.0	23.0	21.8	20.0	18.0	...	...	...	...	...
1Cr–$^1/_5$Mo	1,100	$4 < D \le 7$	SA-193	B7	...	75/100	(1)	None	18.7	18.7	18.7	18.7	18.7	17.4	15.7	...	...	...	...	...
1Cr–$^1/_2$Mo–V	1,200	≤ $2^1/_2$	SA-193	B16	...	105/125	(1)	B	25.0	25.0	25.0	25.0	23.7	21.7	19.6	...	...	...	...	...
1Cr–$^1/_2$Mo–V	1,200	$2^1/_2 < D \le 4$	SA-193	B16	...	95/110	(1)	B	22.0	22.0	22.0	22.0	20.8	19.1	17.3	...	...	...	...	...
1Cr–$^1/_2$Mo–V	1,200	$4 < D \le 7$	SA-193	B16	...	85/100	(1)	B	20.0	20.0	20.0	20.0	18.9	17.4	15.7	...	...	...	...	...
18Cr–8Ni	(2)	...	SA-193	B8	1	30/75	(1)(3)(4)	E	...	...	10.5	10.3	10.1	9.9	9.8	9.5	9.2	9.0	8.8	...
16Cr–12Ni–2Mo	(2)	...	SA-193	B8M	1	30/75	(1)(3)(4)	F	...	...	11.0	10.9	10.8	10.7	10.6	10.5	10.3	10.2	10.1	...
18Cr–10Ni–Ti	(2)	...	SA-193	B8T	1	30/75	(1)(3)(4)	C	...	...	10.7	10.6	10.6	10.5	10.4	10.4	10.3	10.1	9.9	...
19Cr–9Ni–Mo–W	1,200	≤3	SA-453	651	A	70/100	(1)	E	...	...	11.6	11.4	11.2	11.0	10.7	...	...	...	...	...
19Cr–9Ni–Mo–W	1,200	>3	SA-453	651	A	60/100	(1)	E	...	...	10.0	9.8	9.6	9.4	9.2	...	...	...	...	...
19Cr–9Ni–Mo–W	1,350	≤3	SA-453	651	B	60/95	(1)	E	...	...	10.0	9.8	9.6	9.4	9.2	...	...	...	...	...
19Cr–9Ni–Mo–W	1,350	>3	SA-453	651	B	50/95	(1)	E	...	...	8.3	8.2	8.0	7.9	7.7	...	...	...	...	...
25Ni–15Cr–2Ti	1,325	...	SA-453	660	A	85/130	(1)	E	...	...	20.0	19.9	19.9	19.8	19.8	...	...	...	...	...
25Ni–15Cr–2Ti	1,325	...	SA-453	660	B	85/130	(1)	E	...	...	20.0	19.9	19.9	19.8	19.8	...	...	...	...	...
53Ni–19Cr–19Fe–Cb–Mo (see Spec.)	1,150	≤6	SB-637	718	...	150/185	(5)	E	...	...	33.3	33.1	32.9	32.6	32.3	32.0	...	...	...	...

Table HCB-II-2000-2
Allowable Stress Values for Class B Bolting Materials (Cont'd)

Nominal Composition	Minimum Tempering Temperature, °C	Diameter, mm	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	SI Units: Stress Values, MPa, for Metal Temperatures, °C, Not to Exceed 371	399	427	454	482	510	538	566	593	621	649
5Cr–$^1/_2$Mo	595	≤100	SA-193	B5	...	550/690	(1)	B	138	138	138	138	132	125	115	...	...	...	...
1Cr–$^1/_5$Mo	595	≤64	SA-193	B7	...	720/860	(1)	None	172	172	172	172	163	150	135	...	...	...	...
1Cr–$^1/_5$Mo	595	64 < D ≤ 100	SA-193	B7	...	655/795	(1)	None	159	159	159	159	150	138	124	...	...	...	...
1Cr–$^1/_5$Mo	595	100 < D ≤ 180	SA-193	B7	...	515/690	(1)	None	129	129	129	129	129	120	108	...	...	...	...
1Cr–$^1/_2$Mo–V	650	≤48	SA-193	B16	...	725/860	(1)	B	172	172	172	172	163	150	135	...	...	...	...
1Cr–$^1/_2$Mo–V	650	64 < D ≤ 100	SA-193	B16	...	655/760	(1)	B	152	152	152	152	143	132	119	...	...	...	...
1Cr–$^1/_2$Mo–V	650	100 < D ≤ 180	SA-193	B16	...	585/690	(1)	B	138	138	138	138	130	120	108	...	...	...	...
18Cr–8Ni	(2)	...	SA-193	B8	1	205/515	(1)(3)(4)	E	...	...	72	71	70	68	68	66	63	62	61
16Cr–12Ni–2Mo	(2)	...	SA-193	B8M	1	205/515	(1)(3)(4)	F	...	...	76	75	74	74	73	72	71	70	70
18Cr–10Ni–Ti	(2)	...	SA-193	B8T	1	205/515	(1)(3)(4)	C	...	...	74	73	73	72	72	72	71	70	68
19Cr–9Ni–Mo–W	650	≤75	SA-453	651	A	485/690	(1)	E	...	...	80	79	77	76	74	...	...	...	...
19Cr–9Ni–Mo–W	650	>75	SA-453	651	A	415/690	(1)	E	...	...	69	68	66	65	63	...	...	...	...
19Cr–9Ni–Mo–W	730	≤75	SA-453	651	B	415/655	(1)	E	...	...	69	68	66	65	63	...	...	...	...
19Cr–9Ni–Mo–W	730	>75	SA-453	651	B	345/655	(1)	E	...	...	57	57	55	54	53	...	...	...	...
25Ni–15Cr–2Ti	715	...	SA-453	660	A	585/895	(1)	E	...	...	138	137	137	137	137	...	...	...	...
25Ni–15Cr–2Ti	715	...	SA-453	660	B	585/895	(1)	E	...	...	138	137	137	137	137	...	...	...	...
53Ni–19Cr–19Fe–Cb–Mo (see Spec.)	620	≤150	SB-637	718	...	1 034/1 275	(5)	E	...	...	230	228	227	225	223	221	...	...	...

NOTES:
(1) These 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 relative flexibility of the flanges and bolts and concomitant relaxation properties.
(2) Solution treated at 1,900°F (1 040°C).
(3) For temperatures above 1,000°F (538°C), these stress values may be used only if the material is heat treated by heating it to a minimum temperature of 1,900°F (1 040°C) and quenching in water or rapidly cooling by other means.
(4) At temperatures above 1,000°F (538°C), these stress values apply only when the carbon content is 0.04% or higher.
(5) This material is solution treated and precipitation hardened. No welding is permitted.

Table HCB-II-2000-3
Allowable Stress Values for Austenitic Steel Class B Components

Nominal Composition	P- No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	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
										U.S. Customary Units — Stress Values [Note (2)], ksi, for Metal Temperatures, °F, Not to Exceed														
18Cr–8Ni	8	1	Casting	SA-351	CF8	...	30/70	(4)(5)(7)	C	14.6	14.4	14.2	13.9	13.5	12.8	12.1	11.4	10.6	...	...	...	...	...	...
18Cr–8Ni	8	1	Forging	SA-182	F304	...	30/70	(5)(7)(8)	E	14.6	14.4	14.2	13.9	13.5	12.8	12.1	11.4	10.6	...	...	...	...	...	...
					F304H	...	30/70	(5)	E	14.6	14.4	14.2	13.9	13.5	12.8	12.1	11.4	10.6	...	...	...	...	...	...
18Cr–8Ni	8	1	Forging	SA-965	F304	...	30/70	(7)(8)	E	14.6	14.4	14.2	13.9	13.5	12.8	12.1	11.4	10.6	...	...	...	...	...	...
					F304H	...	30/70	(7)(8)	E	14.6	14.4	14.2	13.9	13.5	12.8	12.1	11.4	10.6	...	...	...	...	...	...
18Cr–8Ni	8	1	Forging	SA-182	F304H	...	30/75	(9)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					F304	...	30/75	(7)(9)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Smls. tube	SA-213	TP304H	...	30/75	(5)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					TP304	...	30/75	(5)(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Plate	SA-240	304H	...	30/75	(5)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					304	...	30/75	(5)(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Smls. pipe	SA-312	TP304H	...	30/75	(3)(5)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					TP304	...	30/75	(3)(5)(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Smls. pipe	SA-376	TP304H	...	30/75	(5)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					TP304	...	30/75	(5)(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Bar	SA-479	304H	...	30/75	...	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					304	...	30/75	(7)(8)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Wld. tube	SA-249	TP304H	...	30/75	(3)(5)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					TP304	...	30/75	(3)(5)(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Wld. pipe	SA-312	TP304H	...	30/75	(3)(5)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
					TP304	...	30/75	(3)(5)(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni–N	8	1	Smls. tube	SA-213	TP304N	...	35/80	(7)	E	16.6	16.3	15.9	15.6	15.2	14.9	14.6	14.1	13.4	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Plate	SA-240	304N	...	35/80	(7)	E	16.6	16.3	15.9	15.6	15.2	14.9	14.6	14.1	13.4	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Smls. pipe	SA-312	TP304N	...	35/80	(7)	E	16.6	16.3	15.9	15.6	15.2	14.9	14.6	14.1	13.4	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Smls. pipe	SA-376	TP304N	...	35/80	(7)	E	16.6	16.3	15.9	15.6	15.2	14.9	14.6	14.1	13.4	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Wld. pipe	SA-312	TP304N	...	35/80	(3)(7)	E	16.6	16.3	15.9	15.6	15.2	14.9	14.6	14.1	13.4	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Wld. pipe	SA-358	304N	1	35/80	(3)(7)	E	16.6	16.3	15.9	15.6	15.2	14.9	14.6	14.1	13.4	...	...	...	...	...	...
18Cr–8Ni	8	1	Fitting	SA-403	WP304	...	30/75	(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Fitting	SA-403	WP304W	...	30/75	(3)(7)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Fitting	SA-403	WP304H	...	30/75	...	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2
18Cr–8Ni	8	1	Fitting	SA-403	WP304HW	...	30/75	(3)	E	15.2	14.9	14.6	14.3	14.0	13.7	13.0	12.3	11.4	10.4	9.5	8.4	7.2	6.2	5.2

Table HCB-II-2000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	U.S. Customary Units — Stress Values [Note (2)], ksi, for Metal Temperatures, °F, Not to Exceed: 800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316L	...	25/65	...	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Plate	SA-240	316L	...	25/70	(5)	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Smls. tube	SA-213	TP316L	...	25/70	(5)	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-249	TP316L	...	25/70	(3)(5)	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Wld. pipe	SA-312	TP316L	...	25/70	(3)(5)	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Smls. pipe	SA-312	TP316L	...	25/70	(5)	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Bar	SA-479	316L	...	25/70	...	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Fitting	SA-403	WP316L	...	25/70	...	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
					WP316LW	...	25/70	(3)	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Casting	SA-351	CF3M	...	30/70	(4)(10)	D	12.4	12.2	11.9	11.6	11.3	10.9	...	...	...	...
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316	...	30/70	(7)	F	15.9	15.7	15.6	15.4	15.0	14.3	13.7	12.7	11.9	...
					F316H	...	30/70	...	F	15.9	15.7	15.6	15.4	15.0	14.3	13.7	12.7	11.9	...
16Cr–12Ni–2Mo	8	1	Forging	SA-965	F316	...	30/70	(7)(8)	F	15.9	15.7	15.6	15.4	15.0	14.3	13.7	12.7	11.9	...
					F316H	...	30/70	(7)(8)	F	15.9	15.7	15.6	15.4	15.0	14.3	13.7	12.7	11.9	...
16Cr–12Ni–2Mo	8	1	Casting	SA-351	CF8M	...	30/70	(4)(10)	D	15.9	15.7	15.6	15.4	15.0	14.3	13.7	12.7	11.9	...
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316	...	30/75	(7)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					F316H	...	30/75	...	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo	8	1	Smls. tube	SA-213	TP316	...	30/75	(5)(7)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					TP316H	...	30/75	(5)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo	8	1	Plate	SA-240	316	...	30/75	(5)(7)(8)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					316H	...	30/75	(5)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-249	TP316	...	30/75	(3)(5)(7)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					TP316H	...	30/75	(3)(5)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-312	TP316	...	30/75	(5)(7)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					TP316H	...	30/75	(5)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo	8	1	Smls. pipe	SA-376	TP316	...	30/75	(5)(7)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					TP316H	...	30/75	(5)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo	8	1	Bar	SA-479	316	...	30/75	(7)(8)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					316H	...	30/75	...	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo	8	1	Fitting	SA-403	WP316	...	30/75	(7)(8)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					WP316W	...	30/75	(3)(7)(8)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					WP316H	...	30/75	...	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
					WP316HW	...	30/75	(3)	F	15.9	15.7	15.6	15.4	15.3	15.1	14.7	13.6	12.8	...
16Cr–12Ni–2Mo–N	8	1	Smls. tube	SA-213	TP316N	...	35/80	(7)	F	18.4	18.3	18.1	17.8	17.4	16.8	16.0	15.2	14.4	...
16Cr–12Ni–2Mo–N	8	1	Plate	SA-240	316N	...	35/80	(7)	F	18.4	18.3	18.1	17.8	17.4	16.8	16.0	15.2	14.4	...
16Cr–12Ni–2Mo–N	8	1	Wld. pipe	SA-312	TP316N	...	35/80	(3)(7)	F	18.4	18.3	18.1	17.8	17.4	16.8	16.0	15.2	14.4	...
16Cr–12Ni–2Mo–N	8	1	Smls. pipe	SA-312	TP316N	...	35/80	(7)	F	18.4	18.3	18.1	17.8	17.4	16.8	16.0	15.2	14.4	...
16Cr–12Ni–2Mo–N	8	1	Smls. pipe	SA-376	TP316N	...	35/80	(7)	F	18.4	18.3	18.1	17.8	17.4	16.8	16.0	15.2	14.4	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321	...	30/70	(7)(9)	C	15.5	15.3	15.2	15.1	15.0	14.8	13.7	13.0	11.8	...
18Cr–10Ni–Ti	8	1	Forging	SA-965	F321	...	30/70	(7)(8)	C	15.5	15.3	15.2	15.1	15.0	14.8	13.7	13.0	11.8	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321	...	30/75	(7)(9)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Smls. tube	SA-213	TP321	...	30/75	(5)(7)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Plate	SA-240	321	...	30/75	(5)(7)(8)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Wld. pipe	SA-312	TP321	...	30/75	(3)(5)(7)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-312	TP321	...	30/75	(5)(7)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-376	TP321	...	30/75	(5)(7)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Fitting	SA-403	WP321	...	30/75	(3)(7)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
					WP321W	...	30/75	(3)(7)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Bar	SA-479	321	...	30/75	(7)(8)	C	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321H	...	30/70	(9)	E	15.5	15.3	15.2	15.1	15.0	14.8	13.7	13.0	11.8	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321H	...	30/75	(9)	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Smls. tube	SA-213	TP321H	...	30/75	(5)	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...

Table HCB-II-2000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	U.S. Customary Units — Stress Values [Note (2)], ksi, for Metal Temperatures, °F, Not to Exceed: 800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250
18Cr–10Ni–Ti	8	1	Plate	SA-240	321H	...	30/75	(5)	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Wld. pipe	SA-312	TP321H	...	30/75	(3)(5)	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-312	TP321H	...	30/75	(5)	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-376	TP321H	...	30/75	(5)	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Fitting	SA-403	WP321H	...	30/75	...	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
					WP321HW	...	30/75	(3)	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...
18Cr–10Ni–Ti	8	1	Bar	SA-479	321H	...	30/75	...	E	15.5	15.3	15.2	15.1	15.0	14.9	14.7	13.9	12.6	...

Table HCB-II-2000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	SI Units — Stress Values [Note (2)], MPa, for Metal Temperatures, °C, Not to Exceed: 427	454	482	510	538	566	593	621	649	677	704	732	760	788	816
18Cr–8Ni	8	1	Casting	SA-351	CF8	...	205/485	(4)(5)(7)	C	101	99	98	96	93	88	83	79	73	...	...	...	...	...	...
18Cr–8Ni	8	1	Forging	SA-182	F304	...	205/485	(5)(7)(8)	E	101	99	98	96	93	88	83	79	73	...	...	...	...	...	...
					F304H	...	205/485	(5)	E	101	99	98	96	93	88	83	79	73	...	...	...	...	...	...
18Cr–8Ni	8	1	Forging	SA-965	F304	...	205/485	(7)(8)	E	101	99	98	96	93	88	83	79	73	...	...	...	...	...	...
					F304H	...	205/485	(7)(8)	E	101	99	98	96	93	88	83	79	73	...	...	...	...	...	...
18Cr–8Ni	8	1	Forging	SA-182	F304H	...	205/515	(9)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					F304	...	205/515	(7)(9)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Smls. tube	SA-213	TP304H	...	205/515	(5)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					TP304	...	205/515	(5)(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Plate	SA-240	304H	...	205/515	(5)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					304	...	205/515	(5)(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Smls. pipe	SA-312	TP304H	...	205/515	(3)(5)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					TP304	...	205/515	(3)(5)(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Smls. pipe	SA-376	TP304H	...	205/515	(5)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					TP304	...	205/515	(5)(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Bar	SA-479	304H	...	205/515	...	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					304	...	205/515	(7)(8)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Wld. tube	SA-249	TP304H	...	205/515	(3)(5)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					TP304	...	205/515	(3)(5)(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Wld. pipe	SA-312	TP304H	...	205/515	(3)(5)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
					TP304	...	205/515	(3)(5)(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni–N	8	1	Smls. tube	SA-213	TP304N	...	240/550	(7)	E	114	112	110	108	105	103	101	97	92	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Plate	SA-240	304N	...	240/550	(7)	E	114	112	110	108	105	103	101	97	92	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Smls. pipe	SA-312	TP304N	...	240/550	(7)	E	114	112	110	108	105	103	101	97	92	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Smls. pipe	SA-376	TP304N	...	240/550	(7)	E	114	112	110	108	105	103	101	97	92	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Wld. pipe	SA-312	TP304N	...	240/550	(3)(7)	E	114	112	110	108	105	103	101	97	92	...	...	...	...	...	...
18Cr–8Ni–N	8	1	Wld. pipe	SA-358	304N	1	240/550	(3)(7)	E	114	112	110	108	105	103	101	97	92	...	...	...	...	...	...
18Cr–8Ni	8	1	Fitting	SA-403	WP304	...	205/515	(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Fitting	SA-403	WP304W	...	205/515	(3)(7)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Fitting	SA-403	WP304H	...	205/515	...	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36
18Cr–8Ni	8	1	Fitting	SA-403	WP304HW	...	205/515	(3)	E	105	103	101	99	97	94	90	85	79	72	66	58	50	43	36

Table HCB-II-2000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	SI Units: Stress Values [Note (2)], in MPa, for Metal Temperatures, °C, Not to Exceed: 427	454	482	510	538	566	593	621	649	677
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316L	...	170/450	...	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Plate	SA-240	316L	...	170/485	(5)	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Smls. tube	SA-213	TP316L	...	170/485	(5)	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-249	TP316L	...	170/485	(3)(5)	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Wld. pipe	SA-312	TP316L	...	170/485	(3)(5)	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Smls. pipe	SA-312	TP316L	...	170/485	(5)	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Bar	SA-479	316L	...	170/485	...	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Fitting	SA-403	WP316L	...	170/485	...	D	85	84	82	80	78	75	...	...	...	...
					WP316LW	...	170/485	(3)	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Casting	SA-351	CF3M	...	205/485	(4)(10)	D	85	84	82	80	78	75	...	...	...	...
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316	...	205/485	(7)	F	110	108	108	106	103	99	94	88	82	...
					F316H	...	205/485	...	F	110	108	108	106	103	99	94	88	82	...
16Cr–12Ni–2Mo	8	1	Forging	SA-965	F316	...	205/485	(7)(8)	F	110	108	108	106	103	99	94	88	82	...
					F316H	...	205/485	(7)(8)	F	110	108	108	106	103	99	94	88	82	...
16Cr–12Ni–2Mo	8	1	Casting	SA-351	CF8M	...	205/485	(4)(10)	D	110	108	108	106	103	99	94	88	82	...
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316	...	205/515	(7)	F	110	108	108	106	105	104	101	94	88	...
					F316H	...	205/515	...	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo	8	1	Smls. tube	SA-213	TP316	...	205/515	(5)(7)	F	110	108	108	106	105	104	101	94	88	...
					TP316H	...	205/515	(5)	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo	8	1	Plate	SA-240	316	...	205/515	(5)(7)(8)	F	110	108	108	106	105	104	101	94	88	...
					316H	...	205/515	(5)	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-249	TP316	...	205/515	(3)(5)(7)	F	110	108	108	106	105	104	101	94	88	...
					TP316H	...	205/515	(3)(5)	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-312	TP316	...	205/515	(5)(7)	F	110	108	108	106	105	104	101	94	88	...
					TP316H	...	205/515	(5)	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo	8	1	Smls. pipe	SA-376	TP316	...	205/515	(5)(7)	F	110	108	108	106	105	104	101	94	88	...
					TP316H	...	205/515	(5)	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo	8	1	Bar	SA-479	316	...	205/515	(7)(8)	F	110	108	108	106	105	104	101	94	88	...
					316H	...	205/515	...	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo	8	1	Fitting	SA-403	WP316	...	205/515	(7)(8)	F	110	108	108	106	105	104	101	94	88	...
					WP316W	...	205/515	(3)(7)(8)	F	110	108	108	106	105	104	101	94	88	...
					WP316H	...	205/515	...	F	110	108	108	106	105	104	101	94	88	...
					WP316HW	...	205/515	(3)	F	110	108	108	106	105	104	101	94	88	...
16Cr–12Ni–2Mo–N	8	1	Smls. tube	SA-213	TP316N	...	240/550	(7)	F	127	126	125	123	120	116	110	105	99	...
16Cr–12Ni–2Mo–N	8	1	Plate	SA-240	316N	...	240/550	(7)	F	127	126	125	123	120	116	110	105	99	...
16Cr–12Ni–2Mo–N	8	1	Wld. pipe	SA-312	TP316N	...	240/550	(3)(7)	F	127	126	125	123	120	116	110	105	99	...
16Cr–12Ni–2Mo–N	8	1	Smls. pipe	SA-312	TP316N	...	240/550	(7)	F	127	126	125	123	120	116	110	105	99	...
16Cr–12Ni–2Mo–N	8	1	Smls. pipe	SA-376	TP316N	...	240/550	(7)	F	127	126	125	123	120	116	110	105	99	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321	...	205/485	(7)(9)	C	107	105	105	104	103	102	94	90	81	...
18Cr–10Ni–Ti	8	1	Forging	SA-965	F321	...	205/485	(7)(8)	C	107	105	105	104	103	102	94	90	81	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321	...	205/515	(7)(9)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Smls. tube	SA-213	TP321	...	205/515	(5)(7)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Plate	SA-240	321	...	205/515	(5)(7)(8)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Wld. pipe	SA-312	TP321	...	205/515	(3)(5)(7)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-312	TP321	...	205/515	(5)(7)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-376	TP321	...	205/515	(5)(7)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Fitting	SA-403	WP321	...	205/515	(3)(7)	C	107	105	105	104	103	103	101	96	87	...
					WP321W	...	205/515	(3)(7)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Bar	SA-479	321	...	205/515	(7)(8)	C	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321H	...	205/485	(9)	E	107	105	105	104	103	102	94	90	81	...
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321H	...	205/515	(9)	E	107	105	105	104	103	103	101	96	87	...

Table HCB-II-2000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	SI Units Stress Values [Note (2)], in MPa, for Metal Temperatures, °C, Not to Exceed 427	454	482	510	538	566	593	621	649	677
18Cr–10Ni–Ti	8	1	Smls. tube	SA-213	TP321H	...	205/515	(5)	E	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Plate	SA-240	321H	...	205/515	(5)	E	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Wld. pipe	SA-312	TP321H	...	205/515	(3)(5)	E	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-312	TP321H	...	205/515	(5)	E	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-376	TP321H	...	205/515	(5)	E	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Fitting	SA-403	WP321H	...	205/515	...	E	107	105	105	104	103	103	101	96	87	...
					WP321HW	...	205/515	(3)	E	107	105	105	104	103	103	101	96	87	...
18Cr–10Ni–Ti	8	1	Bar	SA-479	321H	...	205/515	...	E	107	105	105	104	103	103	101	96	87	...

NOTES:

(1) The following are the abbreviations used for Product Form:
- *(a)* Wld. — Welded
- *(b)* Smls. — Seamless
- *(c)* Forg. — Forged

(2) At temperatures above 100°F (40°C), the allowable stress values may exceed $62\frac{1}{2}$% and may also reach 90% yield strength (0.2% offset) at temperature. This may result in a permanent strain of as much as 0.1%. When this amount of deformation is not acceptable, the designer shall reduce the design stress to obtain an acceptable deformation. Section II, Part D, Subpart 1, Table Y-2 lists multiplying factors that, when applied to the yield strength values shown in Section II, Part D, Subpart 1, Tables Y-1 and Y-2 will give an allowable stress that will result in lower levels of permanent strain. These stress values are not recommended for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

(3) These S values do not include a weld efficiency factor. For materials welded without filler metal, ultrasonic examination in accordance with Division 1, NCD-2550 or eddy current examination in accordance with Division 1, NCD-2550 shall provide a longitudinal weld efficiency factor of 1.00. Materials (welded with filler metal) meeting the requirements of Division 1, NCD-2560 shall receive a weld efficiency factor of 1.00. Other weld efficiency factors shall be in accordance with the following:

Type of Joint	Efficiency Factor
Single Butt Weld	0.80
Butt, without Filler Material	0.85
Double Butt Weld	0.90
Single or Double Butt Weld with Radiography	1.00

(4) For Class B, these S values do not include a casting quality factor. Statically and centrifugally cast products meeting the requirements of Division 1, NCD-2570 shall receive a casting quality factor of 1.00. Statically and centrifugally cast products meeting the requirements of Division 1, NCD-2571.1(a) and NCD-2571.1(b) and cast pipe, fittings, pumps, and valves with inlet piping connections of NPS 2 (DN 50) and less, shall receive a casting quality factor of 1.00. Other casting quality factors shall be in accordance with the following:

Method of Examination	Quality Factor
(a) Visual	0.80
(b) Magnetic Particle	0.85
(c) Liquid Penetrant	0.85
(d) Radiography	1.00
(e) Ultrasonic	1.00
(f) Magnetic Particle or Liquid Penetrant — plus — Ultrasonic or Radiography	1.00

(5) For external pressure chart references, see Section II, Part D, Subpart 3 or Division 1, Figure NCD-3133.8-1 as applicable.

Table HCB-II-2000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

NOTES (CONT'D):

(6) Note no longer used.

(7) At temperatures above 1,000°F (538°C), these stress values apply only when the carbon content is 0.04% or higher.

(8) For temperatures above 1,000°F (538°C), these stress values apply only if the material has been heat treated by heating it to a minimum temperature of 1,900°F (1 040°C) and quenching in water or rapidly cooling by other means.

(9) 5 in. (125 mm) and under.

(10) At temperatures above 800°F (425°C), these stress values apply only when the carbon content is 0.04% or higher.

Table HCB-II-2000-4
Allowable Stress Values for High-Nickel Alloy Class B Components

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	U.S. Customary Units: Stress Values [Note (2)], ksi, for Metal Temperatures, °F, Not to Exceed: 800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300
33Ni–42Fe–21Cr	45	...	Smls. tube	SB-163	800H	...	25/65	(3)(4)(5)	G	15.3	14.9	14.5	14.1	13.7	13.4	13.2	12.7	12.0	11.2	10.0
33Ni–42Fe–21Cr	45	...	Smls. pipe & tube	SB-407	800H	...	25/65	(3)(4)(6)	G	15.3	14.9	14.5	14.1	13.7	13.4	13.2	12.7	12.0	11.2	10.0
33Ni–42Fe–21Cr	45	...	Forging	SB-564	800H	...	25/65	(3)(4)(5)	G	15.3	14.9	14.5	14.1	13.7	13.4	13.2	12.7	12.0	11.2	10.0
33Ni–42Fe–21Cr	45	...	Bar	SB-408	800H	...	25/65	(3)(4)(5)	G	15.3	14.9	14.5	14.1	13.7	13.4	13.2	12.7	12.0	11.2	10.0
33Ni–42Fe–21Cr	45	...	Plate	SB-409	800H	...	25/65	(3)(4)(5)	G	15.3	14.9	14.5	14.1	13.7	13.4	13.2	12.7	12.0	11.2	10.0

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u	Notes	Applicable Line in Figure HCB-III-1000-1	SI Units: Stress Values [Note (2)], MPa, for Metal Temperatures, °C, Not to Exceed: 427	454	482	510	538	566	593	621	649	677	704
33Ni–42Fe–21Cr	45	...	Smls. tube	SB-163	800H	...	170/450	(3)(4)(5)	G	105	103	100	97	94	92	91	88	83	77	69
33Ni–42Fe–21Cr	45	...	Smls. pipe & tube	SB-407	800H	...	170/450	(3)(4)(6)	G	105	103	100	97	94	92	91	88	83	77	69
33Ni–42Fe–21Cr	45	...	Forging	SB-564	800H	...	170/450	(3)(4)(5)	G	105	103	100	97	94	92	91	88	83	77	69
33Ni–42Fe–21Cr	45	...	Bar	SB-408	800H	...	170/450	(3)(4)(5)	G	105	103	100	97	94	92	91	88	83	77	69
33Ni–42Fe–21Cr	45	...	Plate	SB-409	800H	...	170/450	(3)(4)(5)	G	105	103	100	97	94	92	91	88	83	77	69

NOTES:

(1) The following abbreviation is used for Product Form: Smls. — Seamless.

(2) Due to the relatively low yield strength of these materials, these higher stress values were established, at temperatures where the short-time tensile properties govern, to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed $66^2/_3$%, but not 90%, of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where a slight amount of distortion can cause leakage or malfunction.

(3) These materials shall have a total aluminum-plus-titanium content of at least 0.50% and shall have been heat treated at a temperature of 2,050°F (1 120°C) or higher.

(4) For external pressure charts, see Section II, Part D, Subpart 3.

(5) Solution treated/annealed.

(6) Hot finished/annealed.

Table HCB-II-2000-5
Reduction Factors for Aging

Nominal Composition	Table HCB-II-2000-	Reduction Factors for Metal Temperatures, °F (°C), Not to Exceed																
		700 (371)	750 (399)	800 (427)	850 (454)	900 (482)	950 (510)	1,000 (538)	1,050 (566)	1,100 (593)	1,150 (621)	1,200 (649)	1,250 (677)	1,300 (704)	1,350 (732)	1,400 (760)	1,450 (788)	1,500 (816)
Carbon Steel	1	1.0	0.90	0.85	0.80	0.70	0.65	0.60	...	...	...	...	...	...	...	...	...	...
C–$^{1}/_{2}$Mo	1	1.0	0.90	0.85	0.80	0.70	0.65	0.60	...	...	...	...	...	...	...	...	...	...
Mn–$^{1}/_{2}$Mo	1	1.0	0.90	0.85	0.80	0.70	0.65	0.60	...	...	...	...	...	...	...	...	...	...
$^{3}/_{4}$Ni–$^{1}/_{2}$Mo–$^{1}/_{3}$Cr–V	1	1.0	0.90	0.85	0.80	0.70	0.65	0.60	...	...	...	...	...	...	...	...	...	...
Mn–$^{1}/_{2}$Mo–$^{3}/_{4}$Ni	1	1.0	0.90	0.85	0.80	0.70	0.65	0.60	...	...	...	...	...	...	...	...	...	...
1Cr–$^{1}/_{2}$Mo	1	1.0	1.0	0.94	0.88	0.82	0.77	0.72	...	...	...	...	...	...	...	...	...	...
2$^{1}/_{4}$Cr–1Mo	1	1.0	1.0	0.94	0.88	0.82	0.77	0.72	...	...	...	...	...	...	...	...	...	...
9Cr–1Mo	1	1.0	1.0	1.0	1.0	0.97	0.93	0.90	0.87	0.84	0.81	0.78	...	...	...	...	...	...
All materials (bolting)	2	No reduction factors available — designer must take prudent actions																
18Cr–8Ni	3	...	...	1.0	1.0	1.0	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
18Cr–8Ni–N	3	...	...	1.0	1.0	1.0	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
16Cr–12Ni–2Mo	3	...	...	1.0	1.0	0.80	0.80	0.80	0.80	0.80	0.80	0.80	...	...	...	...	...	...
16Cr–12Ni–2Mo–N	3	...	...	1.0	1.0	0.80	0.80	0.80	0.80	0.80	0.80	0.80	...	...	...	...	...	...
18Cr–10Ni–Ti	3	...	...	1.0	1.0	0.80	0.80	0.80	0.80	0.80	0.80	0.80	...	...	...	...	...	...
33Ni–42Fe–21Cr	4	...	...	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	...	...	...

ARTICLE HCB-II-3000
SERVICE THAT MAY INCLUDE CREEP EFFECTS

(a) The allowable stresses of Tables HCB-II-3000-1 through HCB-II-3000-4 may be used for any service history.

(b) For weldments, the allowable stresses of Tables HCB-II-3000-1 through HCB-II-3000-4 must be adjusted by multiplying them by the welding reduction factor of Tables HCB-II-3000-5 through HCB-II-3000-9 corresponding to the specified Design Temperature. Linear interpolation shall be used for intermediate temperatures. Under these rules, welded construction is not permitted for materials and temperatures for which weldment reduction factors are not provided in Tables HCB-II-3000-5 through HCB-II-3000-9.

(c) Up to 1 hr of this service history may alternatively be evaluated with the allowable stresses of Tables HCB-II-2000-1 through HCB-II-2000-4 modified in accordance with (d) below.

(d) When using the allowable stresses of Tables HCB-II-2000-1 through HCB-II-2000-4, they must be reduced to reflect other elevated temperature service history. The allowable stresses are reduced by multiplying them by the aging reduction factor of Table HCB-II-2000-5 that corresponds to the specified Design Temperature or the coincident Level C service condition temperature, as applicable. Linear interpolation shall be used for intermediate temperatures. The use of allowable stresses of Tables HCB-II-2000-1 through HCB-II-2000-4 for service that may include creep effects shall not apply for materials and temperatures for which allowable stresses and aging reduction factors are not provided in Tables HCB-II-2000-1 through HCB-II-2000-5.

Table HCB-II-3000-1
Allowable Stress Values for Ferritic Steel Class B Components

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u, ksi (MPa)	Notes	Allowable Stress Values
									See Section II, Part D, Subpart 1, Table 1A, but disregard the Notes.
Carbon steel	1	1	Forging	SA-181	...	60	30/60 (205/415)	(7)(8)	
Carbon steel	1	1	Casting	SA-216	WCA	...	30/60 (205/415)	(2)(5)(8)	
Carbon steel	1	1	Plate	SA-515	60	...	32/60 (220/415)	(5)(8)	
Carbon steel	1	1	Plate	SA-516	60	...	32/60 (220/415)	(5)(8)	
Carbon steel	1	1	Smls. pipe	SA-106	B	...	35/60 (240/415)	(5)(8)	
Carbon steel	1	1	Smls. tube	SA-210	A-1	...	37/60 (255/415)	(5)(8)	
Carbon steel	1	1	Wld. tube	SA-178	C	...	37/60 (255/415)	(5)(8)	
Carbon steel	1	1	Plate	SA-515	65	...	35/65 (240/450)	(5)(8)	
Carbon steel	1	1	Plate	SA-516	65	...	35/65 (240/450)	(5)(8)	
Carbon steel	1	2	Forging	SA-266	2	...	36/70 (250/485)	(5)(8)	
Carbon steel	1	2	Forging	SA-105	...	...	36/70 (250/485)	(5)(7)(8)	
Carbon steel	1	2	Forging	SA-181	...	70	36/70 (250/485)	(5)(7)(8)	
Carbon steel	1	2	Casting	SA-216	WCB	...	36/70 (250/485)	(2)(5)(8)	
Carbon steel	1	2	Plate	SA-515	70	...	38/70 (260/485)	(5)(8)	
Carbon steel	1	2	Plate	SA-516	70	...	38/70 (260/485)	(5)(8)	
Carbon steel	1	1	Smls. pipe	SA-106	C	...	40/70 (275/485)	(8)	
Carbon steel	1	1	Casting	SA-216	WCC	...	40/70 (275/485)	(2)(8)	
C–$\frac{1}{2}$Mo	3	1	Smls. pipe	SA-335	P1	...	30/55 (205/380)	(5)(9)	

Table HCB-II-3000-1
Allowable Stress Values for Ferritic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u, ksi (MPa)	Notes	Allowable Stress Values
									See Section II, Part D, Subpart 1, Table 1A, but disregard the Notes.
C–$^1/_2$Mo	3	1	Forg. pipe	SA-369	FP1	...	30/55 (205/380)	(9)	
C–$^1/_2$Mo	3	1	Casting	SA-217	WC1	...	35/65 (240/450)	(2)(3)(9)	
C–$^1/_2$Mo	3	1	Plate	SA-204	A	...	37/65 (255/450)	(5)(9)	
C–$^1/_2$Mo	3	2	Forging	SA-182	F1	...	40/70 (275/485)	(9)	
C–$^1/_2$Mo	3	2	Forging	SA-336	F1	...	40/70 (275/485)	(9)	
C–$^1/_2$Mo	3	2	Plate	SA-204	B	...	40/70 (275/485)	(9)	
C–$^1/_2$Mo	3	2	Plate	SA-204	C	...	43/75 (295/515)	(9)	
Mn–$^1/_2$Mo	3	3	Plate	SA-302	B	...	50/80 (345/550)	...	
$^3/_4$Ni–$^1/_2$Mo–$^1/_3$Cr–V	3	3	Forging	SA-508	2	1	50/80 (345/550)	...	
Mn–$^1/_2$Mo–$^3/_4$Ni	3	3	Plate	SA-533	C	1	50/80 (345/550)	...	
$^3/_4$Ni–$^1/_2$Mo–$^1/_3$Cr–V	3	3	Forging	SA-541	2	1	50/80 (345/550)	...	
1Cr–$^1/_2$Mo	4	1	Plate	SA-387	12	1	33/55 (230/380)	...	
1Cr–$^1/_2$Mo	4	1	Smls. tube	SA-213	T12	...	32/60 (220/415)	...	
1Cr–$^1/_2$Mo	4	1	Smls. pipe	SA-335	P12	...	32/60 (220/415)	...	
1Cr–$^1/_2$Mo	4	1	Forg. pipe	SA-369	FP12	...	32/60 (220/415)	...	
1Cr–$^1/_2$Mo	4	1	Plate	SA-387	12	2	40/65 (275/450)	...	
1Cr–$^1/_2$Mo	4	1	Forging	SA-182	F12	...	40/70 (275/485)	...	
1Cr–$^1/_2$Mo	4	1	Forging	SA-336	...	F12	40/70 (275/485)	...	
1$^1/_4$Cr–$^1/_2$Mo	4	1	Casting	SA-217	WC6	...	40/70 (275/485)	(2)(3)	
2$^1/_4$Cr–1Mo	5A	1	Forging	SA-182	F22	1	30/60 (205/415)	(10)(11)	
2$^1/_4$Cr–1Mo	5A	1	Fitting	SA-234	WP22, WP22W	1	30/60 (205/415)	(10)(12)	
2$^1/_4$Cr–1Mo	5A	1	Smls. tube	SA-213	T22	...	30/60 (205/415)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Smls. pipe	SA-335	P22	...	30/60 (205/415)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Forging	SA-336	F22	...	30/60 (205/415)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Forg. pipe	SA-369	FP22	...	30/60 (205/415)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	30/60 (205/415)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Wld. pipe	SA-691	2$^1/_4$CR	...	30/60 (205/415)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Casting	SA-217	WC9	...	40/70 (275/485)	(2)(3)(10)	
2$^1/_4$Cr–1Mo	5A	1	Forging	SA-182	F22	3	45/75 (310/515)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Forging	SA-336	F22	3	45/75 (310/515)	(10)	
2$^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	2	45/75 (310/515)	(4)(10)	
9Cr–1Mo	5B	1	Smls. tube	SA-213	T9	...	30/60 (205/415)	...	
9Cr–1Mo	5B	1	Smls. pipe	SA-335	P9	...	30/60 (205/415)	...	
9Cr–1Mo	5B	1	Forg. pipe	SA-369	FP9	...	30/60 (205/415)	...	

NOTES:

(1) The following are the abbreviations used for Product Form:
  - *(a)* Wld. — Welded
  - *(b)* Smls. — Seamless
  - *(c)* Forg. — Forged

(2) Statically and centrifugally cast products meeting the requirements of Division 1, NCD-2571.1(a) and NCD-2571.1(b), and cast pipe fittings, pumps, and valves with inlet piping connections of NPS 2 (DN 50) and less, shall receive a casting quality factor of 1.00. Other casting quality factors shall be in accordance with the following:

Method of Examination	Quality Factor
(a) Visual	0.80
(b) Magnetic particle	0.85

Table HCB-II-3000-1
Allowable Stress Values for Ferritic Steel Class B Components (Cont'd)

NOTES (CONT'D):

Method of Examination	Quality Factor
(c) Liquid penetrant	0.85
(d) Radiography	1.00
(e) Ultrasonic	1.00
(f) Magnetic particle or liquid penetrant — plus — Ultrasonic or radiography	1.00

(3) Normalized and Tempered, only.
(4) Normalized and Tempered.
(5) For external pressure charts, see Section II, Part D, Subpart 3.
(6) Note no longer used.
(7) For service temperatures above 850°F (454°C) for periods in excess of 1 hr, it is recommended that killed steels containing not less than 0.10% silicon by heat analysis be used. Killed steels that have been deoxidized with large amounts of aluminum and rimmed steels may have creep and stress rupture properties, in the temperature range above 850°F (454°C), which are somewhat less than those on which the values in the above table are based.
(8) If cumulative service times (i.e., sum of event times during the entire service life) are expected to exceed 1 hr with concurrent temperatures above 800°F (425°C), then the problems of corrosion and material transformation should be considered before selecting this alloy for the application. For example, the carbide phase of the carbon steel may be converted to graphite (graphitization).
(9) Note (8) above applies to this alloy, except that the range of temperatures of concern begins at 875°F (468°C) instead of 800°F (425°C).
(10) This material shall have a maximum specified room temperature ultimate strength of 85,000 psi (586 MPa) and a minimum specified carbon content of 0.07%.
(11) The tensile requirements shall meet those for F22A in Material Specification SA-336 instead of those for F22 in Specification SA-182.
(12) The material allowed under SA-234 shall correspond to one of the following:
(a) SA-335, Grade P22
(b) SA-387, Grade 22, Class 1
(c) SA-182, Grade F22 in compliance with Note (11).

Table HCB-II-3000-2
Allowable Stress Values for Class B Bolting

Nominal Composition	Minimum Tempering Temperature, °F (°C)	Diameter, in. (mm)	Spec. No.	Type	Grade or Class	Specified Minimum Strengths, S_y/S_u, ksi (MPa)	Notes	Allowable Stress Values
								See Section II, Part D, Subpart 1, Table 3, but disregard the Notes.
5Cr–$^1/_2$Mo	1,100 (595)	≤4 (≤100)	SA-193	B5	...	80/100 (550/690)	(1)	
1Cr–$^1/_5$Mo	1,100 (595)	≤2$^1/_2$ (≤64)	SA-193	B7	...	105/125 (720/860)	(1)	
1Cr–$^1/_5$Mo	1,100 (595)	2$^1/_2$ < D ≤ 4 (64 < D ≤ 100)	SA-193	B7	...	95/115 (655/795)	(1)	
1Cr–$^1/_5$Mo	1,100 (595)	4 < D ≤ 7 (100 < D ≤ 180)	SA-193	B7	...	75/100 (515/690)	(1)	
1Cr–$^1/_2$Mo–V	1,200 (650)	≤2$^1/_2$ (≤64)	SA-193	B16	...	105/125 (725/860)	(1)	
1Cr–$^1/_2$Mo–V	1,200 (650)	2$^1/_2$ < D ≤ 4 (64 < D ≤ 100)	SA-193	B16	...	95/110 (655/760)	(1)	
1Cr–$^1/_2$Mo–V	1,200 (650)	4 < D ≤ 7 (100 < D ≤ 180)	SA-193	B16	...	85/100 (585/690)	(1)	
18Cr–8Ni	Soln. treated @1,900°F (1 040°C)	...	SA-193	B8	1	30/75 (205/515)	(1)(2)(3)	
16Cr–12Ni–2Mo	Soln. treated @1,900°F (1 040°C)	...	SA-193	B8M	1	30/75 (205/515)	(1)(2)(3)	
18Cr–10Ni–Ti	Soln. treated @1,900°F (1 040°C)	...	SA-193	B8T	1	30/75 (205/515)	(1)(2)(3)	
19Cr–9Ni–Mo–W	1,200 (650)	≤3 (≤75)	SA-453	651	A	70/100 (485/690)	(1)	
19Cr–9Ni–Mo–W	1,200 (650)	>3 (>75)	SA-453	651	A	60/100 (415/690)	(1)	
19Cr–9Ni–Mo–W	1,350 (730)	≤3 (≤75)	SA-453	651	B	60/95 (415/655)	(1)	
19Cr–9Ni–Mo–W	1,350 (730)	>3 (>75)	SA-453	651	B	50/95 (345/655)	(1)	
25Ni–15Cr–2Ti	1,325 (715)	...	SA-453	660	A	85/130 (585/895)	(1)	
25Ni–15Cr–2Ti	1,325 (715)	...	SA-453	660	B	85/130 (585/895)	...	
53Ni–19Cr–19Fe–Cb–Mo (See Spec.)	1,150 (620)	≤6 (≤150)	SB-637	718	...	150/185 (1 034/1 275)	(4)	Use Table HCB-II-2000-2

NOTES:

(1) These 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 relative flexibility of the flanges and bolts and concomitant relaxation properties.

(2) For temperatures above 1,000°F (538°C), these stress values may be used only if the material is heat treated by heating it to a minimum temperature of 1,900°F (1 040°C) and quenching in water or rapidly cooling by other means.

(3) At temperatures above 1,000°F (538°C), these stress values apply only when the carbon content is 0.04% or higher.

(4) This material is solution treated and precipitation hardened. No welding is permitted.

Table HCB-II-3000-3
Allowable Stress Values for Austenitic Steel Class B Components

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u, ksi (MPa)	Notes	Allowable Stress Values [Note (2)]
									See Section II, Part D, Subpart 1, Table 1A, but disregard the Notes.
18Cr–8Ni	8	1	Casting	SA-351	CF8	...	30/70 (205/483)	(4)(5)(7)	
18Cr–8Ni	8	1	Forging	SA-182	F304	...	30/70 (205/483)	(5)(7)(8)	
					F304H	...	30/70 (205/483)	(5)	
18Cr–8Ni	8	1	Forging	SA-965	F304	...	30/70 (205/483)	(7)(8)	
					F304H	...	30/70 (205/483)	(7)(8)	
18Cr–8Ni	8	1	Forging	SA-182	F304	...	30/75 (205/515)	(7)(9)	
					F304H	...	30/75 (205/515)	(9)	
18Cr–8Ni	8	1	Smls. tube	SA-213	TP304	...	30/75 (205/515)	(5)(7)	
					TP304H	...	30/75 (205/515)	(5)	
18Cr–8Ni	8	1	Plate	SA-240	304	...	30/75 (205/515)	(5)(7)	
					304H	...	30/75 (205/515)	(5)	
18Cr–8N	8	1	Smls. pipe	SA-312	TP304	...	30/75 (205/515)	(3)(5)(7)	
					TP304H	...	30/75 (205/515)	(3)(5)	
18Cr–8Ni	8	1	Smls. pipe	SA-376	TP304	...	30/75 (205/515)	(5)(7)	
					TP304H	...	30/75 (205/515)	(5)	
18Cr–8Ni	8	1	Bar	SA-479	304	...	30/75 (205/515)	(7)(8)	
					304H	...	30/75 (205/515)	...	
18Cr–8Ni	8	1	Wld. tube	SA-249	TP304	...	30/75 (205/515)	(5)(7)(11)	
					TP304H	...	30/75 (205/515)	(5)(11)	
18Cr–8Ni	8	1	Wld. pipe	SA-312	TP304	...	30/75 (205/515)	(5)(7)(11)	
					TP304H	...	30/75 (205/515)	(5)(11)	
18Cr–8Ni	8	1	Fitting	SA-403	WP304	...	30/75 (205/515)	(7)(12)	
					WP304W	...	30/75 (205/515)	(3)(7)(12)	
					WP304H	...	30/75 (205/515)	(12)	
					WP304HW	...	30/75 (205/515)	(3)(12)	
18Cr–8Ni–N	8	1	Smls. tube	SA-213	TP304N	...	35/80 (240/550)	(7)	
18Cr–8Ni–N	8	1	Plate	SA-240	304N	...	35/80 (240/550)	(7)	
18Cr–8Ni–N	8	1	Smls. pipe	SA-312	TP304N	...	35/80 (240/550)	(7)	
18Cr–8Ni–N	8	1	Smls. pipe	SA-376	TP304N	...	35/80 (240/550)	(7)	
18Cr–8Ni–N	8	1	Wld. pipe	SA-312	TP304N	...	35/80 (240/550)	(3)(7)(11)	
18Cr–8Ni–N	8	1	Wld. pipe	SA-358	304N	1	35/80 (240/550)	(3)(7)(11)	
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316L	...	25/65 (170/450)	...	
16Cr–12Ni–2Mo	8	1	Plate	SA-240	316L	...	25/70 (170/485)	(5)	
16Cr–12Ni–2Mo	8	1	Smls. tube	SA-213	TP316L	...	25/70 (170/485)	(5)	
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-249	TP316L	...	25/70 (170/485)	(5)(11)	
16Cr–12Ni–2Mo	8	1	Wld. pipe	SA-312	TP316L	...	25/70 (170/485)	(5)(11)	
16Cr–12Ni–2Mo	8	1	Smls. pipe	SA-312	TP316L	...	25/70 (170/485)	(5)	
16Cr–12Ni–2Mo	8	1	Bar	SA-479	316L	...	25/70 (170/485)	...	
16Cr–12Ni–2Mo	8	1	Fitting	SA-403	WP316L	...	25/70 (170/485)	(12)	
16Cr–12Ni–2Mo	8	1	Fitting	SA-403	WP316LW	...	25/70 (170/485)	(3)(12)	
16Cr–12Ni–2Mo	8	1	Casting	SA-351	CF3M	...	30/70 (205/485)	(4)(10)	
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316	...	30/70 (205/485)	(7)	
					F316H	...	30/70 (205/485)	...	
16Cr–12Ni–2Mo	8	1	Forging	SA-965	F316	...	30/70 (205/485)	(7)(8)	
					F316H	...	30/70 (205/485)	(7)(8)	
16Cr–12Ni–2Mo	8	1	Casting	SA-351	CF8M	...	30/70 (205/485)	(4)(10)	
16Cr–12Ni–2Mo	8	1	Forging	SA-182	F316	...	30/75 (205/515)	(7)	

Table HCB-II-3000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u, ksi (MPa)	Notes	Allowable Stress Values [Note (2)]
									See Section II, Part D, Subpart 1, Table 1A, but disregard the Notes.
					F316H	...	30/75 (205/515)	...	
16Cr–12Ni–2Mo	8	1	Smls. tube	SA-213	TP316	...	30/75 (205/515)	(5)(7)	
					TP316H	...	30/75 (205/515)	(5)	
16Cr–12Ni–2Mo	8	1	Plate	SA-240	316	...	30/75 (205/515)	(5)(7)(8)	
					316H	...	30/75 (205/515)	(5)	
16Cr–12Ni–2Mo	8	1	Wld. tube	SA-249	TP316	...	30/75 (205/515)	(5)(7)(11)	
					TP316H	...	30/75 (205/515)	(5)(11)	
16Cr–12Ni–2Mo	8	1	Wld. pipe	SA-312	TP316	...	30/75 (205/515)	(5)(7)(11)	
					TP316H	...	30/75 (205/515)	(5)(11)	
16Cr–12Ni–2Mo	8	1	Smls. pipe	SA-312	TP316	...	30/75 (205/515)	(5)(7)	
					TP316H	...	30/75 (205/515)	(5)	
16Cr–12Ni–2Mo	8	1	Smls. pipe	SA-376	TP316	...	30/75 (205/515)	(5)(7)	
					TP316H	...	30/75 (205/515)	(5)	
16Cr–12Ni–2Mo	8	1	Bar	SA-479	316	...	30/75 (205/515)	(7)(8)	
					316H	...	30/75 (205/515)	...	
16Cr–12Ni–2Mo	8	1	Fitting	SA-403	WP316	...	30/75 (205/515)	(7)(8)(12)	
					WP316H	...	30/75 (205/515)	(12)	
					WP316W	...	30/75 (205/515)	(3)(7)(8)(12)	
					WP316HW	...	30/75 (205/515)	(3)(12)	
16Cr–12Ni–2Mo–N	8	1	Smls. tube	SA-213	TP316N	...	35/80 (240/550)	(7)	
16Cr–12Ni–2Mo–N	8	1	Plate	SA-240	316N	...	35/80 (240/550)	(7)	
16Cr–12Ni–2Mo–N	8	1	Wld. pipe	SA-312	TP316N	...	35/80 (240/550)	(7)(11)	
16Cr–12Ni–2Mo–N	8	1	Smls. pipe	SA-312	TP316N	...	35/80 (240/550)	(7)	
16Cr–12Ni–2Mo–N	8	1	Smls. pipe	SA-376	TP316N	...	35/80 (240/550)	(7)	
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321	...	30/70 (205/485)	(7)(9)	
18Cr–10Ni–Ti	8	1	Forging	SA-965	F321	...	30/70 (205/485)	(7)(8)	
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321	...	30/75 (205/515)	(7)(9)	
18Cr–10Ni–Ti	8	1	Smls. tube	SA-213	TP321	...	30/75 (205/515)	(5)(7)	
18Cr–10Ni–Ti	8	1	Plate	SA-240	321	...	30/75 (205/515)	(5)(7)(8)	
18Cr–10Ni–Ti	8	1	Wld. pipe	SA-312	TP321	...	30/75 (205/515)	(5)(7)(11)	
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-312	TP321	...	30/75 (205/515)	(5)(7)	
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-376	TP321	...	30/75 (205/515)	(5)(7)	
18Cr–10Ni–Ti	8	1	Fitting	SA-403	WP321	...	30/75 (205/515)	(7)(12)	
					WP321W	...	30/75 (205/515)	(3)(7)(12)	
18Cr–10Ni–Ti	8	1	Bar	SA-479	321	...	30/75 (205/515)	(7)(8)	
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321H	...	30/70 (205/485)	(9)	
18Cr–10Ni–Ti	8	1	Forging	SA-182	F321H	...	30/75 (205/515)	(9)	
18Cr–10Ni–Ti	8	1	Smls. tube	SA-213	TP321H	...	30/75 (205/515)	(5)	
18Cr–10Ni–Ti	8	1	Plate	SA-240	321H	...	30/75 (205/515)	(5)	
18Cr–10Ni–Ti	8	1	Wld. pipe	SA-312	TP321H	...	30/75 (205/515)	(5)(11)	
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-312	TP321H	...	30/75 (205/515)	(5)	
18Cr–10Ni–Ti	8	1	Smls. pipe	SA-376	TP321H	...	30/75 (205/515)	(5)	
18Cr–10Ni–Ti	8	1	Fitting	SA-403	WP321H	...	30/75 (205/515)	(12)	
					WP321HW	...	30/75 (205/515)	(3)(12)	
18Cr–10Ni–Ti	8	1	Bar	SA-479	321H	...	30/75 (205/515)	...	

NOTES:

(1) The following are the abbreviations used for Product Form:

Table HCB-II-3000-3
Allowable Stress Values for Austenitic Steel Class B Components (Cont'd)

NOTES (CONT'D):

(a) Wld. — Welded

(b) Smls. — Seamless

(2) At temperatures above 100°F (40°C), the allowable stress values may exceed $62^1/_2$% and may also reach 90% yield strength (0.2% offset) at temperature. This may result in a permanent strain of as much as 0.1%. When this amount of deformation is not acceptable, the designer shall reduce the design stress to obtain an acceptable deformation. Section II, Part D, Subpart 1, Table Y-2 lists multiplying factors that, when applied to the yield strength values shown in Section II, Part D, Subpart 1, Table Y-1 will give an allowable stress that will result in lower levels of permanent strain. These stress values are not recommended for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

(3) These *S* values do not include a weld efficiency factor. For materials welded without filler metal, ultrasonic examination or eddy current examination in accordance with Division 1, NCD-2550 shall provide a longitudinal weld efficiency factor of 1.00. Materials (welded with filler metal) meeting the requirements of Division 1, NCD-2560 shall receive a weld efficiency factor of 1.00. Other weld efficiency factors shall be in accordance with the following:

Type of Joint	**Efficiency Factor**
Single butt weld	0.80
Butt, without filler material	0.85
Double butt weld	0.90
Single or double butt weld with radiography	1.00

(4) For Class B, these *S* values do not include a casting quality factor. Statically and centrifugally cast products meeting the requirements of Division 1, NCD-2570 shall receive a casting quality factor of 1.00. Statically and centrifugally cast products meeting the requirements of Division 1, NCD-2571.1(a) and NCD-2571.1(b) and cast pipe, fittings, pumps, and valves with inlet piping connections of NPS 2 (DN 50) and less, shall receive a casting quality factor of 1.00. Other casting quality factors shall be in accordance with the following:

Method of Examination		Quality Factor
(a)	Visual	0.80
(b)	Magnetic particle	0.85
(c)	Liquid penetrant	0.85
(d)	Radiography	1.00
(e)	Ultrasonic	1.00
(f)	Magnetic particle or liquid penetrant — plus — Ultrasonic or Rdiography	1.00

(5) For external pressure chart references, see Section II, Part D, Subpart 3 or Division 1, Figure NCD-3133.8-1 as applicable.

(6) Note no longer used.

(7) At temperatures above 1,000°F (538°C), these stress values apply only when the carbon content is 0.04% or higher.

(8) For temperatures above 1,000°F (538°C), these stress values apply only if the material has been heat treated by heating it to a minimum temperature of 1,900°F (1 040°C) and quenching in water or rapidly cooling by other means.

(9) 5 in. (125 mm) and under.

(10) At temperatures above 800°F (425°C) these stress values apply only when the carbon content is 0.04% or higher.

(11) Stress values for Section VIII, Division 1 already apply the weld factors required by Note (3).

(12) When stress values are not listed under this SA specification in Section II, Part D, then the values for other specifications in the material grouping (i.e., same alloy, same tensile property requirements at room temperature) may be used.

Table HCB-II-3000-4
Allowable Stress Values for High-Nickel Alloy Class B Components

Nominal Composition	P-No.	Group No.	Product Form [Note (1)]	Spec. No.	Grade or Type	Class	Specified Minimum Strengths, S_y/S_u, ksi (MPa)	Notes	Allowable Stress Values
									See Table 1B in Section II, Part D, but disregard the Notes.
33Ni–42Fe–21Cr	45	...	Smls. tube	SB-163	800H	...	25/65 (170/450)	(2)(3)(4)(5)	
33Ni–42Fe–21Cr	45	...	Smls. pipe & tube	SB-407	800H	...	25/65 (170/450)	(2)(3)(4)(6)	
33Ni–42Fe–21Cr	45	...	Forging	SB-564	800H	...	25/65 (170/450)	(2)(3)(4)(5)	
33Ni–42Fe–21Cr	45	...	Bar	SB-408	800H	...	25/65 (170/450)	(2)(3)(4)(5)	
33Ni–42Fe–21Cr	45	...	Plate	SB-409	800H	...	25/65 (170/450)	(2)(3)(4)(5)	
33Ni–42Fe–21Cr	45	...	Smls. tube	SB-163	800	...	30/75 (205/515)	(2)(4)(9)	
33Ni–42Fe–21Cr	45	...	Smls. pipe & tube	SB-407	800	...	30/75 (205/515)	(2)(4)(9)	
33Ni–42Fe–21Cr	45	...	Bar	SB-408	800	...	30/75 (205/515)	(2)(4)(9)	
33Ni–42Fe–21Cr	45	...	Plate	SB-409	800	...	30/75 (205/515)	(2)(4)(9)	
33Ni–42Fe–21Cr	45	...	Forging	SB-564	800	...	30/75 (205/515)	(2)(4)(9)	
72Ni–15Cr-8Fe	43	...	Smls. tube	SB-163	600	...	35/80 (240/550)	(2)(4)(9)	
72Ni–15Cr-8Fe	43	...	Bar	SB-166	600	...	35/80 (240/550)	(2)(4)(9)	
72Ni–15Cr-8Fe	43	...	Smls. pipe & tube	SB-167	600	...	35/80 (240/550)	(2)(4)(7)(10)	
72Ni–15Cr-8Fe	43	...	Plate	SB-168	600	...	35/80 (240/550)	(2)(4)(9)	
72Ni–15Cr-8Fe	43	...	Forging	SB-564	600	...	35/80 (240/550)	(2)(4)	
72Ni–15Cr-8Fe	43	...	Smls. pipe & tube	SB-167	600	...	25/75 (170/515)	(2)(4)(6)(8)	
72Ni–15Cr-8Fe	43	...	Smls. pipe & tube	SB-167	600	...	30/80 (205/550)	(2)(4)(6)(7)	
47Ni-22Cr-9Mo-18Fe	43	...	Plate, sheet strip	SB-435	X	...	35/95 (240/655)	...	
47Ni-22Cr-9Mo-18Fe	43	...	Bar	SB-572	X	...	35/95 (240/655)	...	

NOTES:
(1) The following abbreviation is used for Product Form: Smls. — Seamless.
(2) Due to the relatively low yield strength of these materials, these higher stress values were established, at temperatures where the short-time tensile properties govern, to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed $66\frac{2}{3}$%, but not 90%, of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasket joints or other applications where a slight amount of distortion can cause leakage or malfunction.
(3) These materials shall have a total aluminum-plus-titanium content of at least 0.50% and shall have been heat treated at a temperature of 2,050°F (1 120°C) or higher.
(4) For external pressure charts, see Section II, Part D, Subpart 3.
(5) Solution treated/annealed.
(6) Hot finished/annealed.
(7) 5 in. (125 mm) nominal diameter and less.
(8) Nominal diameter > 5 in. (125 mm)
(9) Annealed.
(10) Cold drawn/annealed.

Table HCB-II-3000-5
Reduction Factors to Be Applied to Parent Metal Allowable Stresses for 304 SS Weldments

Temperature, °F (°C)	Weld Metal: SFA-5.22, E 308T & E 308LT SFA-5.4, E 308 & E 308L SFA-5.9, ER 308 & ER 308L	Weld Metal: SFA-5.22 EXXXT-G (16-8-2) SFA-5.4 E 16-8-2, SFA-5.9 ER 16-8-2	Weld Metal: SFA-5.22 E 316T & E 316LT-1, 2, 3 SFA-5.4 E 316 & E 316L SFA-5.9 ER 316 & ER 316L
850 (454)	1.0	1.0	1.0
900 (482)	1.0	1.0	1.0
950 (510)	1.0	1.0	1.0
1,000 (538)	0.91	1.0	0.89
1,050 (566)	0.91	1.0	0.89
1,100 (593)	0.89	1.0	0.89
1,150 (621)	0.81	1.0	0.83
1,200 (649)	0.71	...	0.79
1,250 (677)	0.57	...	0.72
1,300 (704)	...	...	0.65
1,350 (732)	...	...	0.59
1,400 (760)	...	...	0.51

Table HCB-II-3000-6
Reduction Factors to Be Applied to Parent Metal Allowable Stresses for 316 SS Weldments

Temperature, °F (°C)	Weld Metal: SFA-5.22, E 308T & E 308LT SFA-5.4, E 308 & E 308L SFA-5.9, ER 308 & ER 308L	Weld Metal: SFA-5.22 EXXXT-G (16-8-2) SFA-5.4 E 16-8-2, SFA-5.9 ER 16-8-2	Weld Metal: SFA-5.22 E 316T & E 316LT-1 and 2 SFA-5.4 E 316 & E 316L SFA-5.9 ER 316 & ER 316L
850 (454)	1.0	1.0	1.0
900 (482)	1.0	1.0	1.0
950 (510)	1.0	1.0	1.0
1,000 (538)	0.64	0.85	0.62
1,050 (566)	0.67	0.90	0.66
1,100 (593)	0.69	0.97	0.68
1,150 (621)	0.64	0.99	0.66
1,200 (649)	0.57	1.0	0.64
1,250 (677)	0.48	...	0.60
1,300 (704)	0.38	...	0.56
1,350 (732)	...	...	0.52
1,400 (760)	...	...	0.47

Table HCB-II-3000-7
Reduction Factors to Be Applied to Parent Metal Allowable Stresses for Alloy 800H Weldments

Temperature, °F (°C)	Weld Metal	
	SFA-5.11, ENiCrFe-2 (INCO A)	SFA-5.14 ERNiCr-3 (INCO 82)
850 (454)	1.0	1.0
900 (482)	1.0	1.0
950 (510)	1.0	1.0
1,000 (538)	1.0	1.0
1,050 (566)	1.0	1.0
1,100 (593)	1.0	1.0
1,150 (621)	0.77	0.83
1,200 (649)	0.75	0.83
1,250 (677)	0.73	0.82
1,300 (704)	0.71	0.82
1,350 (732)	0.68	0.77
1,400 (760)	0.65	0.62

Table HCB-II-3000-8
Reduction Factors to Be Applied to Parent Metal Allowable Stresses for $2\frac{1}{4}$Cr–1Mo Weldments

Temperature, °F (°C)	SFA-5.28 E 90C-B3; SFA-5.28 ER 90S-B3; SFA-5.5 E90XX-B3 (>0.05C); SFA-5.23 EB 3; SFA-5.23 ECB 3 (>0.05C); SFA-5.29 E90T1-B3 (>0.05C)
750 (399)	1.0
800 (427)	1.0
850 (454)	1.0
900 (482)	1.0
950 (510)	0.98
1,000 (538)	0.96
1,050 (566)	0.91
1,100 (593)	0.86
1,150 (621)	0.79
1,200 (649)	0.71

Table HCB-II-3000-9
Reduction Factors to Be Applied to Parent Metal Allowable Stresses for Modified 9Cr–1Mo Weldments

Temperature, °F (°C)	Standard 9Cr–1Mo Filler Wire and Modified 9Cr–1Mo Filler Wire GTA, SNA, and TA Welding Processes
850 (454)	1.0
900 (482)	1.0
950 (510)	1.0
1,000 (538)	1.0
1,050 (566)	0.88
1,100 (593)	0.85
1,150 (621)	0.81
1,200 (649)	0.76

MANDATORY APPENDIX HCB-III
TIME–TEMPERATURE LIMITS FOR CREEP AND STRESS-RUPTURE EFFECTS

ARTICLE HCB-III-1000
INTRODUCTION

When the requirements of HCB-III-1100 and HCB-III-1200 below are satisfied, creep and stress-rupture effects need not be directly considered during the evaluation of elevated temperature failure modes such as ratcheting, creep-buckling, and creep–fatigue.

HCB-III-1100 SERVICE LEVEL A AND B LOADINGS

At the point under consideration, Service Level A and B Loadings shall satisfy the equation below.[33]

$$\sum_i \left(\frac{t_i}{t_{id}} \right) \leq 0.9$$

where

t_i = total time duration (during the specified life) at the metal temperature, T_i

t_{id} = corresponding Allowable Time defined on Figure HCB-III-1000-1 by the intersection of T_i and the applicable curve for the alloy

For materials not listed in Figure HCB-III-1000-1, the Certificate Holder or its designee may use other curves, provided the Owner's approval is obtained.

HCB-III-1200 SERVICE LEVEL C EVENTS

The total number of specified Service Level C events shall not exceed 25. The combined history of all Level C events shall not involve more than 25 hr of service at elevated temperatures, and the temperatures shall not exceed the T_E limit listed in Table HCB-III-1000-1.[34]

Figure HCB-III-1000-1 Time–Temperature Limits for Service Level A and B Events

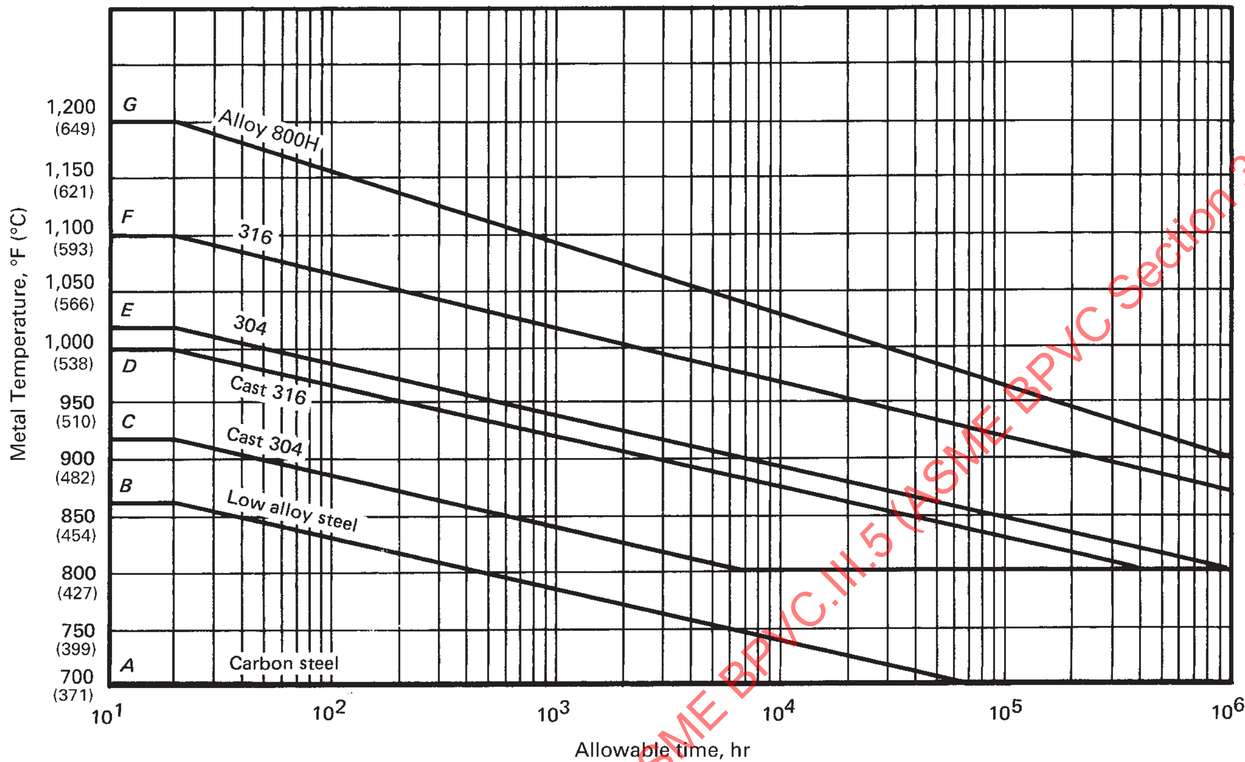


Table HCB-III-1000-1 Maximum Metal Temperatures During Level C Events

Material	Reference Peak Temperature, T_E, °F (°C)
Carbon steel	800 (427)
Low alloy steel	950 (510)
304 SS	1,150 (621)
Cast 304 SS	1,000 (538)
316 SS	1,250 (677)
Cast 316 SS	1,100 (593)
Alloy 800H	1,250 (677)

SUBSECTION HF
CLASS A AND CLASS B METALLIC SUPPORTS

SUBPART A
LOW TEMPERATURE SERVICE

ARTICLE HFA-1000
INTRODUCTION

HFA-1100 GENERAL

HFA-1110 SCOPE

The rules of this Subsection HF, Subpart A constitute the requirements associated with metallic component supports used in the construction of high temperature reactor systems and their supporting systems.

(a) Subsection HF provides rules for the material, design, fabrication, examination, installation, and preparation of certification documents (Certificate of Compliance and NS-1 Certificate of Conformance) of supports for components and piping that are intended to conform to the requirements for Class A and B construction as set forth in Subsections HB and HC, respectively, of this Division. These rules are intended to address supports that do not exceed the temperature limits established in Table HAA-1130-1 for the material under consideration.

(b) The rules of Subsection HF, Subpart A are contained in Division 1, Subsection NF, except for those paragraphs or subparagraphs (with numbered headers) replaced by corresponding numbered HFA paragraphs or subparagraphs in this Subpart or new numbered HFA paragraphs or subparagraphs added to this Subpart.

(c) Division 1 rules may use different terminology than Division 5 (e.g., Class 1 and Class 2 versus Class A and Class B, etc.) but the application of these rules is identical for Division 5 use.[35]

(d) Subsection HF rules *do not* cover deterioration that may occur in service as a result of corrosion, erosion, radiation effects, or metallurgical instability of the materials.

(e) Supports[35] for which the rules are specified in this Subsection are those metal elements that transmit loads between components (Divisions 1 and 2, NCA-1210), including piping systems, and intervening elements, and the building structure. However, the term *supports* does not encompass a structural element, the sole function of which is to carry dynamic loads caused by a postulated loss of pressure-retaining integrity.

(f) The Owner shall be responsible for ensuring the adequacy of the building structure and all intervening elements in the support load path in accordance with the requirements of Divisions 1 and 2, NCA-3211.18 and NCA-3211.19. To the extent necessary, the support designer shall consider the structural interaction with intervening elements and the building structure.

(g) Except for the requirements listed in (1) through (10) below, the requirements of Division 1, Subsection NF do not apply to bearings, bushings, gaskets, hydraulic fluids, seals, shims, slide plates, retaining rings, wear shoes, springs, washers, wire rope, compression spring end plates, thread locking devices, cotter pins, sight glass assemblies, spring hanger travel and hydro stops, nameplates, nameplate attachment devices, or for compression dynamic stops used as stops[36] for seismic and other dynamic loads that are designed primarily for compressive loading and are not connected to the support or pressure boundary.

(1) The material of the exempt items shall be selected to tolerate the environmental conditions to which they will be exposed, such as temperature, fluids, humidity, and irradiation.

(2) The exempt item shall be designed for the loading conditions and other requirements identified in the Design Specification.

(3) Design Output Documents (Divisions 1 and 2, NCA-3211.40) shall indicate items that are exempt.

(4) Materials, fabrication, and installation of the exempt items shall comply with Design Output Documents.

(5) Spring coils for Class A system mounted variable, constant, and sway brace standard supports shall be inspected in accordance with Division 1, NF-2520.

(6) Washers shall comply with the requirements of Division 1, NF-4700.

(7) Wire rope shall comply with the requirements of Division 1, NF-2530 and Article NF-3000.

(8) Compression spring end plates shall comply with the requirements of Division 1, Articles NF-3000, NF-4000, NF-5000, and NF-8000.

(9) Compression dynamic stops shall comply with the requirements of Division 1, Articles NF-3000, NF-4000, NF-5000, and NF-8000.

(10) Thread locking devices shall comply with the requirements of Division 1, NF-4725.1.

SUBSECTION HG CLASS SM METALLIC CORE SUPPORT STRUCTURES

SUBPART A LOW TEMPERATURE SERVICE

ARTICLE HGA-1000 INTRODUCTION

HGA-1100 GENERAL

HGA-1110 SCOPE

The rules of this Subsection HG, Subpart A constitute the requirements associated with Class SM metallic core support structures[37, 38] used in the construction of high temperature reactor systems when subjected to low temperature service.

(a) Subsection HG, Subpart A provides rules for the material, design, fabrication, examination, installation, marking, stamping, and preparation of reports by the Certificate Holder of metallic core support structures that are intended to conform to the requirements for Class SM construction for service when Service Loading temperatures do not exceed the appropriate temperature limits established in Table HAA-1130-1 for the material under consideration.

(b) The rules of Subsection HG, Subpart A are contained in Division 1, Subsection NG, except for those paragraphs or subparagraphs (with numbered headers) replaced by corresponding numbered HGA paragraphs or subparagraphs in this Subpart or new numbered HGA paragraphs or subparagraphs added to this Subpart.

(c) Division 1 rules may use different terminology than Division 5 (e.g., Class CS versus Class SM, etc.), but the application of these rules is identical for Division 5 use.

ARTICLE HGA-8000
NAMEPLATES, STAMPING WITH THE CERTIFICATION MARK, AND REPORTS

HGA-8100 REQUIREMENTS

The applicable requirements given in Article HAA-8000 shall apply to Class SM metallic core support structures.

SUBPART B
ELEVATED TEMPERATURE SERVICE

ARTICLE HGB-1000
INTRODUCTION

HGB-1100 GENERAL

HGB-1110 SCOPE

The rules of this Subsection HG, Subpart B constitute the requirements associated with Class SM metallic core support structures[37, 39] used in the construction of high temperature reactor systems when subjected to elevated temperature service.

(a) Subsection HG, Subpart B provides rules for the material, design, fabrication, examination, installation, marking, stamping, and preparation of reports by the Certificate Holder of metallic core support structures or portions of those core support structures that are intended to conform to the requirements for Class SM construction for service when Service Loading temperatures exceed the appropriate temperature limits established in Table HAA-1130-1 for the material under consideration. These zones of elevated temperature service shall have their finalized geometry descriptions and temperature profile details finalized in the Design Report prior to any fabrication and examination efforts.

(b) The rules of Subsection HG, Subpart B are contained in Division 1, Subsection NG, except for those paragraphs or subparagraphs (with numbered headers) replaced by corresponding numbered HGB paragraphs or subparagraphs in this Subpart or new numbered HGB paragraphs or subparagraphs added to this Subpart.

(c) Division 1 rules may use different terminology than Division 5 (e.g., Class CS versus Class SM, etc.), but the application of these rules is identical for Division 5 use.

(d) References to Appendices are to the Section III Appendices, unless otherwise identified as a Subsection HG, Subpart B Appendix, or other subsection-specific Appendix.

HGB-1111 Use of This Subpart

For low temperature service, Division 5 refers to Division 1, Subsection NG, which establishes rules for materials, design, fabrication, examination, and certification, required in the manufacture and installation of core support structures whose service metal temperatures (during the specified conditions of service) do not exceed those for which Section II, Part D, Subpart 1, Tables 2A and 2B provide allowable stress intensity values.

For elevated temperature service under Division 5, special rules are established in this Subpart that are required only for those zones of elevated temperature service of core support structures whose service metal temperatures (during the specified conditions of service) exceed those to which Section II, Part D, Subpart 1, Tables 2A and 2B apply. The interface, if any, between the low and elevated temperature portions (zones of elevated temperature service) of the core support structure shall be identified in the Design Report (Divisions 1 and 2, NCA-3211.40).

(a) At temperatures and loading conditions where creep effects are significant, the design analysis shall also consider the time-dependent material properties and structural behavior by guarding against the four modes of failure shown below

(1) ductile rupture from short-term loadings

(2) creep rupture from long-term loadings

(3) creep–fatigue failure

(4) gross distortion due to incremental collapse and ratcheting

(b) Brief guidelines are also provided in this Subpart for the three modes of failure shown below

(1) loss of function due to excessive deformation

(2) buckling due to short-term loadings

(3) creep buckling due to long-term loadings

The rules for construction of core support structures are found in the Articles of Subsection HG, Subpart B and Mandatory Appendix HGB-I where appropriate, where the time/temperature requirements of Mandatory Appendix HGB-IV are exceeded. These rules provide explicit consideration of creep and stress rupture at elevated temperature service. These rules for construction alter the rules of Division 1, Subsection NG to suitably account for creep and stress rupture effects. These rules may also be used when the time/temperature requirements of Mandatory Appendix HGB-IV are satisfied. References are made to paragraphs in Divisions 1 and 2, Subsection NCA and Division 1, Subsection NB without modifications or additions. References to specific rules in Subsection HB, Subpart B are also made. Note that rules referenced in Nonmandatory Appendix HBB-T that are not appropriate for Core Support Structures are identified in Mandatory Appendix HGB-I.

For those situations where the core support structures experience limited elevated temperature service (where the time/temperature requirements of Mandatory Appendix HGB-IV are satisfied), Mandatory Appendix HGB-II and Mandatory Appendix HGB-III extend the construction rules of Division 1, Subsection NG to temperatures where creep and stress rupture effects may occur. However, the time-at-temperature limits of Mandatory Appendix HGB-IV restrict elevated temperature service such that explicit consideration of creep and stress rupture is not required.

Both evaluation options contain modifications and additions to Division 1, Subsection NG rules necessary for application at metal temperatures above the upper limits of Division 1, Subsection NG.

HGB-1120

HGB-1124 Temperature and Service Life Limits

The rules of this Subpart shall not be used for structural parts that will be subjected either to metal temperatures or to times greater than those values associated with the S_{mt} data for the specified material (see Tables HBB-I-14.3A through HBB-I-14.3E).

ARTICLE HGB-2000
MATERIAL

HGB-2100 GENERAL REQUIREMENTS FOR MATERIAL

All core support structure material and material welded thereto shall meet the requirements of Division 1, Article NG-2000, except as modified herein.

HGB-2120

(23) HGB-2121 Permitted Material Specifications

(a) Core support structural material, and material welded thereto, and threaded structural fasteners, with the exception of welding material (Division 1, NG-2430), hard surfacing material (Section IX, QW-251.4), cladding that is 10% or less of the thickness of the base material (Division 1, NG-3122), or the material excluded by Division 1, NG-4430, shall conform to the requirements of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A and 2B, including all applicable notes in the table, and to all of the special requirements of this Article (including material limitations) that apply to the product form in which the material is used. Materials used for zones of elevated temperature service of core support structures shall also conform to the material specifications identified in Table HBB-I-14.1(a) for base materials, and in Table HBB-I-14.11 for threaded structural fasteners, and in Table HBB-I-14.1(b) for weld materials. Nonmandatory Appendix HBB-U provides guidelines for restricted material specifications to improve performance in certain elevated temperature applications where creep effects are significant.

(b) The requirements of this Article apply to the internal structures (Division 1, NG-1122) only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the material used for the internal structures shall not adversely affect the integrity of the core support structure.

(c) Welding material used in the manufacture of items shall comply with an SFA Specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

HGB-2160 DETERIORATION OF MATERIAL IN SERVICE

(a) Consideration of deterioration of material caused by service is generally outside the scope of this Subpart. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (Divisions 1 and 2, NCA-3211.19), with specific attention being given to the effects of service conditions upon the properties of the material. Long-time, elevated temperature service may result in the reduction of the subsequent yield and ultimate tensile strengths. Refer to the rules of HBB-2160(d).

(b) The combination of fabrication-induced cold working and subsequent elevated temperature service may affect time-dependent material properties.

HGB-2400

HGB-2430

HGB-2433

HGB-2433.2 Acceptance Standards. For design temperatures up to and including 800°F (425°C), the minimum acceptable delta ferrite shall be 5 FN (Ferrite Number). For design temperatures exceeding 800°F (425°C), the delta ferrite shall be limited to the range 3 FN to 10 FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of Division 1, NG-2130 or NG-4120.

ARTICLE HGB-3000 DESIGN

HGB-3100 GENERAL DESIGN

All core support structure material and material welded thereto shall meet the requirements of Division 1, Article NG-3000, except as modified herein. HGB-3200 contained herein fully replaces the requirements of Division 1, NG-3200.

HGB-3110

HGB-3112 Design Parameters

(a) The design parameters are the pressure differences, temperatures, and mechanical load forces applicable to the design of nuclear power plant components. The simplest set of design parameters would consist of the temperature, pressure differences, and load forces that exist at some given time.

(b) To design a zone of elevated temperature service, two types of design parameter data are needed in the Design Specifications (Divisions 1 and 2, NCA-3211.19). First, an expected loading history that consists of how each design parameter varies as a function of time; and second, a list of events that occur under each loading category defined in HGB-3113.

(c) The design parameter data stipulated in (1) and (2) below shall be specified in the Design Specifications (Divisions 1 and 2, NCA-3211.19) for each component.

(1) the loading event history to be used in the structural analysis.

(2) the design parameters from which the designer will determine the most severe loading for each loading category defined in HGB-3113. (If fluid conditions are specified, the designer eventually must convert the data to metal temperatures and surface pressures.)

(d) It is permissible for the designer to establish the zone of elevated temperature service boundaries inside the component. However, the zone of elevated temperature service boundaries and applicable design parameters shall be fully described in the Design Report.

HGB-3112.1 Specified Pressure Difference.

(a) The specified internal and external pressure difference histories shall describe pressure difference values not less than the maximum pressure differences between the inside and outside of the core support structure. When the occurrence of different pressure differences during service can be predicted for different zones of elevated temperature service of a structure, the specified pressure difference histories of the different zones of elevated temperature service may be based on their predicted pressure difference.

(b) The specified pressure difference histories shall include allowances for pressure difference surges.

(c) The specified pressure difference histories shall be used in the computations made to show compliance with the limits of HGB-3200.

HGB-3112.2 Specified Temperature. The specified temperature history for the loading category shall enable the designer to describe a temperature value not less than the maximum local wall-averaged temperature that will exist in the structural metal in a given zone of elevated temperature service of the component. and for the particular analyses of Service Loadings (HGB-3113.2), the designer shall determine the history of the maximum local metal temperature in a given zone of elevated temperature service and shall use these metal temperature histories in the computations to show compliance with the limits of HGB-3200.

(a) All temperatures referred to in this Article are the metal temperatures expressed in degrees Fahrenheit (°F) or degrees Celsius (°C).

(b) Where a component is heated by trace heating, induction coils, jacketing, or by internal heat generation, the designer shall consider the effect of such heating in the establishment of the design temperature histories.

(c) Elevated temperature mechanical properties are extremely sensitive to temperature. The Design Specifications shall specify any inaccuracies in temperature measurement and prediction that are to be considered in the design analyses made to show compliance with the limits of HGB-3200.

HGB-3112.3 Specified Mechanical Load Forces. The specified load forces for a given loading category (HGB-3113) shall define all expected mechanical loadings that must be considered in design analysis computations made to show compliance with the limits of HGB-3200. The requirements of (a), (b), and (c) below shall also apply.

(a) Impact forces caused by either external or internal conditions shall be considered.

(b) The effects of earthquake shall be considered in the design of core support structures. The loadings, movements, and number of cycles to be used in the analysis

shall be part of the Design Specifications. The stresses resulting from these earthquake effects shall be included with pressure differences or other applied loads.

(c) Core support structures shall be arranged and supported so that vibration will be minimized to the extent practicable.

HGB-3112.4 Design Stress Intensity Values. Design stress intensity values for materials are listed in Section II, Part D, Subpart 1, Tables 2A and 2B. These stress intensity tables may be extended to higher metal temperatures using the values in Tables HBB-I-14.3A through HBB-I-14.3E. The material shall not be used at metal temperatures or Design Temperatures above those for which stress intensity values are listed. The values in the tables may be interpolated for intermediate temperatures.

HGB-3113 Loading Categories

Loading categories used in this Subpart consist of Design Loadings and Service Loadings (Levels A, B, C, and D).

HGB-3113.1 Design Loadings. The specified design parameters for the Design Loadings category shall equal or exceed those of the most severe combination of coincident pressure difference, temperature, and load forces specified under events that cause Level A Service Loadings (HGB-3113.3) for the same zone of elevated temperature service of the component. These specified design parameters for Design Loadings shall be called Design Temperature, Design Pressure Difference, and Design Mechanical Loads. These specified design parameters shall be used in computations to show compliance with the requirements on Design Limits in HGB-3222.

HGB-3113.2 Service Loadings. Each loading to which the component may be subjected shall be categorized in accordance with the following definitions and shall be described in the Design Specifications (Divisions 1 and 2, NCA-3211.19) in such detail as will provide a complete basis for construction in accordance with these rules. The Service Loading categories shall be as defined in the next four subparagraphs below.

HGB-3113.3 Level A Service Loadings. Level A Service Loadings are any loadings arising from system startup, operation in the design power range, hot standby, and system shutdown, and excepting only those loadings covered by Level B, C, and D Service Loadings.

HGB-3113.4 Level B Service Loadings (From Incidents of Moderate Frequency). These are deviations from Level A Service Loadings that are anticipated to occur often enough that design should include a capability to withstand the loadings without operational impairment. The events that cause Level B Service Loadings include those transients that result from any single operator error or control malfunction, transients caused by a fault in a system component requiring its isolation from the system, and transients due to loss of load or power. These events include any abnormal incidents not resulting in a forced outage and also forced outages for which the corrective action does not include any repair of mechanical damage. The estimated duration of a Level B Service Loading shall be included in the Design Specifications.

HGB-3113.5 Level C Service Loadings (From Infrequent Incidents). These are deviations from Level A Service Loadings that require shutdown for correction of the loadings or repair of damage in the system. The conditions have a low probability of occurrence but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events may not exceed 25. If more than 25 are expected, then some types of events must be evaluated by the more stringent requirements of the Level B Service Limits.

HGB-3113.6 Level D Service Loadings (From Limiting Faults). These are combinations of loadings associated with extremely low probability, postulated events whose consequences are such that the integrity and functionality of the nuclear energy system may be impaired to the extent that only considerations of public health and safety are involved.

HGB-3114 Load Histogram

HGB-3114.1 Level A and B Service Events. The Design Specifications (Divisions 1 and 2, NCA-3211.19) shall include an expected loading history or load histogram for all Service Loadings from Level A and B service events. These loads histograms shall give all expected mechanical load forces, pressure differences and temperatures for the various zones of elevated temperature service of the component throughout its service life. These histograms are then used in meeting the analysis requirements of HGB-3200.

HGB-3114.2 Level C Service Events. The Design Specifications shall include a time history of the design parameters during each type of Level C Service event. However, these events need not be specified as to time of occurrence during the service life of the component. The design parameter data shall be used in meeting the analysis requirements of HGB-3200. Level C Service events may be assumed as occurring between operational cycles (HGB-3213.15) of Level A Service events unless otherwise specified in the Design Specifications (Divisions 1 and 2, NCA-3211.19).

HGB-3120

HGB-3122 Cladding

The requirements of Division 1, NG-3122 shall not be used.

HGB-3124 Environmental Effects

Changes in material properties may occur due to environmental effects. In particular, fast (>1 MeV) neutron irradiation above a certain level may result in significant increase in the brittle fracture transition temperature and deterioration in the resistance to fracture at temperatures above the transition range (upper shelf energy). Therefore, structural discontinuities in ferritic structures should preferably not be placed in regions of high neutron flux. The combined effects of exposure to elevated temperature, contacting fluid, and nuclear radiation on material properties (including creep) shall also be considered.

HGB-3130

HGB-3132 Reinforcement for Openings

The rules of reinforcement for openings applicable to Class A vessels and piping may be used in the design of core support structures for internal pressure difference loadings, unless prohibited by the Design Specification. Analysis of other loadings to demonstrate satisfaction of the primary stress limits shall be performed using the methods of HGB-3200.

HGB-3133 External Pressure Difference

The requirements of Division 1, NG-3133 shall not be used.

HGB-3138 Elastic Follow-Up

When only a small portion of the structure undergoes inelastic strains while the major portion of the structural system behaves in an elastic manner, the calculations of load forces, stresses, and strains shall consider the behavior of the entire structural system. In these cases, certain areas may be subjected to strain concentrations due to the elastic follow-up of the rest of the connected structure. These abnormally large strain concentrations may result when structural parts of different flexibility are in series and the flexible portions are highly stressed. Examples include

(a) local reduction in size of a cross section or local use of a weaker material.

(b) in a piping system of uniform size, a configuration for which most of the system lies near the hypothetical straight line connecting the two anchors (stiffeners, flanges, or other stiff members), and with only a small portion departing from this line. Then the small portion absorbs most of the expansion strain.

If possible, the above conditions should be avoided in design. Where such conditions cannot be avoided, the analysis required in HGB-3250 will determine the acceptability of the design to guard against harmful consequences of elastic follow-up.

HGB-3139 Welding

HGB-3139.1 Abrupt Changes in Mechanical Properties at Weld and Compression Contact Junctions. In satisfying the requirements of Article HGB-3000, particular considerations shall be given to the design, analysis, and construction of welded and compression contact junctions between two materials that have different mechanical properties. Such properties at elevated temperatures include thermal expansion, creep rate, creep ductility, and fatigue life. Examples of such junctions are bimetallic welds, brazed joints, compression or shrink fits, bolted flanges, and other types of mechanical joints. When temperatures cycle between low temperatures and elevated temperatures, the inelastic strains can result in significant localized strain accumulation near an abrupt change in mechanical properties.

HGB-3139.2 Weld Design. All welds shall, as a minimum, comply with the rules of Division 1, NG-3350 and in addition to the other requirements delineated elsewhere in this Article.

HGB-3200 DESIGN BY ANALYSIS

HGB-3210 DESIGN CRITERIA

HGB-3211 Requirements for Acceptability

For a core support structure intended for elevated temperature service, the requirements for the acceptability of a design based on analysis shall be as stipulated in (a) through (d) below.

(a) The design shall be such that the calculated or experimentally determined stresses, strains, and deformations will not exceed the limits described in this subarticle.

(b) The design details shall conform to the rules of Division 1, NG-3100 and to those given in Division 1, NG-3350 as modified herein.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b) above, buckling shall be taken into account; see HGB-3250.

(d) Protection against nonductile fracture shall be provided per HGB-3241.

HGB-3212 Basis for Determining Stress, Strain, and Deformation Quantities

(a) For elastic analysis allowed by this Subpart, the maximum shear stress theory shall be used to determine stress intensities for multiaxial stress states. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

(b) For inelastic analysis required by this Subpart, appropriate multiaxial stress–strain relationships and associated flow rules shall be used to combine multiaxial stresses and strains.

(c) One of the materials of this Subpart, 9Cr–1Mo–V, has several unique characteristics that should be recognized and reflected in multiaxial stress–strain relationships. These include the following:

(1) There is not a clear distinction between time-independent elastic–plastic behavior and time-dependent creep behavior.

(2) Flow stresses are strongly strain-rate sensitive at elevated temperatures.

(3) The material exhibits cyclic softening over the entire elevated-temperature use range and significant flow softening at 1,000°F (540°C) and above.

(23) HGB-3213 Terms Relating to Analysis

In this Subpart, the stress and strain limits for design evaluation are related to the type of structural behavior under loading. The controlled quantities fall into two general categories as follows:[40]

(a) *Load-Controlled Quantities.* These quantities are stress intensities that are computed on the basis of equilibrium with the applied forces and moments during plant operation. Included in this category are general primary membrane, primary bending stresses, and secondary stresses with a large amount of elastic follow-up.

(b) *Deformation-Controlled Quantities.* These quantities are strains, cyclic strain ranges, or deformations that result from load deflection and/or strain compatibility.

Other terms used in this Subpart relating to structural analysis are defined in the subparagraphs of HGB-3213.

HGB-3213.1 Stress Intensity.[41] Stress intensity is defined as twice the maximum shear stress, which is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

HGB-3213.2 Gross Structural Discontinuity. Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire wall thickness. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

HGB-3213.3 Local Structural Discontinuity. Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

HGB-3213.4 Normal Stress. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components, one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.

HGB-3213.5 Shear Stress. Shear stress is the component of stress tangent to the plane of reference.

HGB-3213.6 Membrane Stress. Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

HGB-3213.7 Bending Stress. Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear.

HGB-3213.8 Primary Stress. Primary stress is any normal stress or shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stresses are

(a) general membrane stress in a circular cylindrical shell or a spherical shell due to internal pressure or to distributed loads

(b) bending stress in the central portion of a flat head due to pressure

(c) stresses in piping due to net cross section forces (normal or shear) arising from thermal expansion of structural material

Refer to Table HGB-3217-1 for examples of primary stress.

HGB-3213.9 Secondary Stress. Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stresses are

(a) general thermal stress [HGB-3213.13(a)]

(b) bending stress at a gross structural discontinuity

Refer to Table HGB-3217-1 for examples of secondary stress.

HGB-3213.11 Peak Stress. Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [see HGB-3213.13(b)] including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture, and, at elevated temperatures, as a possible source of localized rupture or creep–fatigue failure. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stresses are

(a) the thermal stress in the austenitic steel cladding of a carbon steel part

(b) certain thermal stresses that may cause fatigue but not distortion

(c) the stress at a local structural discontinuity

(d) surface stresses produced by thermal shock

HGB-3213.13 Thermal Stress. Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. Thermal stresses that are not classified as peak stresses fit in this category. Refer to HBB-T-1331(d) for further guidance on classification. Examples of general thermal stress are

(1) stress produced by an axial temperature distribution in a cylindrical shell

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached

(3) the equivalent linear stress[42] produced by the radial temperature distribution in a cylindrical shell

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in Table HGB-3217-1. Examples of local thermal stresses are

(1) the stress in a small hot spot in a vessel wall

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell

(3) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal

HGB-3213.14 Total Stress. Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

HGB-3213.15 Service Cycle. Service cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of service conditions that may occur are further defined in HGB-3113.

HGB-3213.16 Strain Cycle. Strain cycle is a condition in which the strain goes from an initial value, through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. In cases where creep or ratcheting is present in the cycle, there will not be a return to the initial strain value. Instead, the designer will have to examine the hysteresis loop for inelastic analysis and the stress history for elastic analysis to determine the end point of the cycle. See HBB-T-1413 for the method of combining cycles for fatigue analysis. A single service cycle may result in one or more strain cycles. Dynamic effects shall also be considered as strain cycles.

HGB-3213.17 Fatigue Strength Reduction Factor. Fatigue strength reduction factor is a stress intensification or a strain intensification factor that accounts for the effect of a local structural discontinuity (stress or strain concentration) on the fatigue strength. Factors currently exist only for cycles that do not involve significant creep effects.

HGB-3213.18 Free End Displacement. Free end displacement consists of the relative motions that would occur between a fixed attachment and connected piping if the two members were separated and permitted to move.

HGB-3213.20 Deformation. Deformation of a component part is an alteration of its shape or size.

HGB-3213.21 Inelasticity. Inelasticity is a general characteristic of material behavior in which the material does not return to its original shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

HGB-3213.22 Creep. Creep is the special case of inelasticity that relates to the stress-induced time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

HGB-3213.23 Plasticity. Plasticity is the special case of inelasticity in which the material undergoes time-independent nonrecoverable deformation. For 9Cr–1Mo–V, time-independent plasticity at higher temperatures occurs only in limiting cases where strain rates are high relative to creep rates.

HGB-3213.24 Plastic Analysis. Plastic analysis is that method that computes the structural behavior under given loads considering the plasticity characteristics of the materials, including strain hardening and the stress redistribution occurring in the structure. For 9Cr–1Mo–V, a plastic analysis must generally account for rate dependence and creep effects. A plastic analysis thus implies a full inelastic analysis.

HGB-3213.25 Plastic Analysis — Collapse Load. A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criteria for determination of the collapse load shall be used. A load-deflection or load-strain curve is plotted with load as the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load deflection or load strain curve makes with the ordinate is called θ. A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle $\varphi = \tan^{-1}(2\tan\theta)$ with the ordinate. The collapse load is the load at the intersection of the load-deflection or load-strain curve and the collapse limit line. If this method is used, particular care should be given to assuring that the strains or deflections that are used are indicative of the load-carrying capacity of the structure.

HGB-3213.26 Plastic Instability Load. The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbounded plastic deformation can occur without an increase in load. At the plastic-tensile instability load, the true stress in the material increases faster than strain hardening can accommodate.

HGB-3213.27 Limit Analysis. Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (non-strain hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods that are used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term *mechanism* is commonly used in lieu of *kinematically admissible velocity field.*

HGB-3213.28 Limit Analysis — Collapse Load. The methods of limit analysis are used to compute the maximum carrying load for a structure assumed to be made of ideally plastic material. If creep effects exist, then the influence of time-dependent deformations on the collapse load shall be considered.

HGB-3213.29 Calculated Collapse Load — Lower Bound. If, for a given load, any system of stresses can be found that everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis that permits calculations of a lower bound to the collapse load. If creep effects exist, then the influence of time-dependent deformations on the collapse load shall be considered.

HGB-3213.30 Plastic Hinge. A plastic hinge is an idealized concept used in Limit Analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells, a plastic hinge is formed where the generalized stresses lie on the yield surface.

HGB-3213.31 Strain Limiting Load. When a limit is placed upon a strain, the load associated with the strain limit is called the strain limiting load.

HGB-3213.33 Ratcheting. Ratcheting is a progressive cyclic inelastic deformation. Total inelastic strain per cycle may vary from cycle to cycle in the most general situation. Stable ratcheting occurs when the net inelastic strain from a given load cycle is constant for subsequent cycles.

(a) Progressive incremental inelastic deformation can occur in a component that is subjected to cyclic variations of mechanical secondary stress, thermal secondary stress; or both in the presence of a primary stress.

(b) Where creep effects are significant, creep ratcheting can occur, even in the absence of plastic yielding. At least two mechanisms are involved in creep ratcheting. First, creep can alter the residual stresses and thus affect the time-independent behavior. Secondly, the time-dependent deformation can be enhanced because of the nonlinear interaction of primary and secondary stresses. This latter effect is referred to as *enhanced creep.*

HGB-3213.34 Shakedown. Shakedown is the absence of significant progressive, cyclic, inelastic deformation, or ratcheting (HGB-3213.33). A structure shakes down if, after a few cycles of load application, the deformation stabilizes.

HGB-3213.36 Use-Fraction. Use-fraction is the material damage due to primary stresses expressed as a time ratio.

HGB-3213.37 Fatigue Damage. Fatigue damage is that part of the total material damage caused by cyclic deformation that is independent of time effects (e.g., stress hold time, strain hold time, frequency). The damage is expressed in terms of a cycle ratio.

HGB-3213.38 Creep Damage. Creep damage is that part of the total material damage caused by time exposure to steady and transient stresses at elevated temperatures, expressed as a time ratio. (Relaxation damage is a form of creep damage.)

HGB-3213.39 Creep–Fatigue Interaction. Creep–fatigue interaction is the effect of combined creep and fatigue on the total creep–fatigue damage accumulated at failure.

HGB-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each rule or limit of HGB-3220 and HGB-3230 is satisfied when the core support structure is subjected to the loadings described in Division 1, NG-3111. This detailed analysis shall become a part of the Design Report (Divisions 1 and 2, NCA-3211.40).

HGB-3214.1 Elastic Analysis. The analysis guidelines and methods in Article HGB-3000 apply (HGB-3211). As an aid to the evaluation of these elastic stresses, equations and methods for the solution of certain recurring problems have been placed in Section III Appendices, Nonmandatory Appendix A.

HGB-3214.2 Inelastic Analysis. When thermal and mechanical loadings are sufficiently severe to produce yielding and/or when thermal creep processes are active, inelastic design analysis may be required. The rules and limits of Nonmandatory Appendix HBB-T (referenced from Mandatory Appendix HGB-I) were established with the expectation that inelastic analyses would sometimes be required, and that such analyses would be sufficiently comprehensive to predict significant behavioral features. Generally, this requires analysis of combined time-independent elastic–plastic material behavior and time-dependent creep behavior capable of predicting stresses, strains, and deformations as functions of time for specific thermal-mechanical load histories.

The constitutive equations, which describe the inelastic behavior, should reflect the following features when they have a significant influence on structural response: the effects of plastic strain hardening including cyclic loading effects and the hardening or softening that can occur with high-temperature exposure; primary creep and the effects of creep strain hardening as well as softening (due to reverse loadings); and the effects of prior creep on subsequent plasticity, and vice versa.

The basis for choosing the selected methods and relations used shall be included in the Design Report.

Since the rules and limits incorporate design factors and margins to account for material property variations and uncertainties, it is generally appropriate to use average stress–strain and creep data in inelastic design analyses. The buckling and instability limits of Nonmandatory Appendix HBB-T are an exception; in HBB-T-1510(g) it is stated that the minimum expected stress–strain curve shall be used.

For 9Cr–1Mo–V, decoupling of plastic and creep strains in the classical constitutive framework is generally a poor representation of the true material behavior. Unified constitutive equations, which do not distinguish between rate-dependent plasticity and time-dependent creep, represent the rate dependence and softening that occur, particularly at higher temperatures.

HGB-3214.3 Mechanical Properties. The values of some mechanical and physical properties needed for analysis are listed in Section II, Part D, Subpart 2, Tables TM and TE; Mandatory Appendix HBB-I-14 and Nonmandatory Appendix HBB-T (referenced from Mandatory Appendix HGB-I). Properties covered include

(a) isochronous stress–strain curves

(b) yield strength

(c) stress-to-rupture

(d) modulus of elasticity

(e) instantaneous and mean coefficients of thermal expansion

Other mechanical and physical property relations used in the analysis shall be described and justified in the Design Report.

HGB-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (HGB-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities that are subject to the specified limits. The steps in the procedure are stipulated in the following subparagraphs.

(a) At the point on the component that is being investigated, choose an orthogonal set of coordinates such as tangential, longitudinal, and radial, and designate them by the subscripts, t, l, and r. The stress components in these directions are then designated σ_t, σ_l, and σ_r for direct stresses and τ_{lt}, τ_{llr}, and τ_{rt} for shearing stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:

F = peak stress components as defined in HGB-3213.11

P_b = primary bending stress components at a surface as defined in HGB-3213.8

P_m = primary membrane stress components as defined in HGB-3213.8

Q = secondary stress components as defined in HGB-3213.9

Table HGB-3217-1 provides assistance in the determination of the category to which a stress shall be assigned.

It should be noted that each of the symbols for the above stress categories represents six scalar quantities corresponding to the six stress components, σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, and τ_{rt}. In the particular case of the six membrane stress components, each component shall be averaged across the thickness of the structural section.

(c) For each category, calculate the algebraic sum of the σ_t's that result from the different types of loadings and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the t, l, and r directions into principal stresses, σ_1, σ_2, and σ_3. (In many pressure component calculations, the t, l, and r directions may be so chosen that the shearing stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r.)

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$S_{23} = \sigma_2 - \sigma_3$

$S_{31} = \sigma_3 - \sigma_1$

The stress intensity, S, is the largest absolute value of S_{12}, S_{23}, and S_{31}.

HGB-3216 Derivation of Stress Differences and Strain Differences

The ability of the component to withstand the specified cyclic operation without creep–fatigue failure shall be determined as in HGB-3250. The evaluation shall demonstrate, by evaluating the stresses and strains at selected points of the components, that the combined creep-fatigue damage is everywhere within design limits. Only the stress and strain differences due to the operational cycles as specified in the Design Specifications need be considered.

HGB-3217 Classification of Stresses

Table HGB-3217-1 provides assistance in the determination of the category to which a stress shall be assigned. For portions of the component not exposed to elevated temperature service, the classification or category may be selected as in Division 1, Article NG-3000.

HGB-3220 DESIGN RULES AND LIMITS FOR LOAD-CONTROLLED STRESSES IN STRUCTURES OTHER THAN THREADED STRUCTURAL FASTENERS

HGB-3221 General Requirements

(a) The rules for design against failure from load-controlled stresses are illustrated in Figure HBB-3221-1 (with P_L replaced with P_m) and are explained in HGB-3220. The allowable stress intensity values used in HGB-3220 are listed in Section II, Part D, Subpart 1, Tables 2A and 2B and in the tables of Mandatory Appendix HBB-I-14. Note that the strain, deformation, and fatigue limits of HGB-3250 require analyses beyond those required by the rules of HGB-3220.

(b) The stress intensity limits used in Figure HBB-3221-1 (with P_L replaced with P_m) and throughout this Subpart are defined for base metal and at weldments as follows:

(1) Base Metal

S_m = the lowest stress intensity value at a given temperature among the time-independent strength quantities that are defined in Section II, Part D, Subpart 1 as criteria for determining S_m; in this Subpart, the S_m values are extended to elevated temperatures by using the same criteria. As described in HBB-2160(d), it may be necessary to adjust the values of S_m to account for the effects of long-time service at elevated temperature.

S_{mt} = the allowable limit of primary membrane stress intensity to be used as a reference for stress calculations for the actual service life and under the Level A and B Service Loadings; the allowable values are shown in Figures HBB-I-14.3A through HBB-I-14.3E and in Tables HBB-I-14.3A through HBB-I-14.3E. The S_{mt} values are the lower of two stress intensity values, S_m (time independent) and S_t (time dependent). As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

S_o = the maximum allowable value of general primary membrane stress intensity to be used as a reference for stress calculations under Design Loadings. The allowable values are given in Table HBB-I-14.2. [The values correspond to the S values given in Section II, Part D, Subpart 1, Table 1A, except for a few cases at lower temperatures where values of S_{mt} (defined below and given in Tables HBB-I-14.3A through HBB-I-14.3E) at 300,000 hr exceed the S values. In those limited cases, S_o is equal to S_{mt} at 300,000 hr rather than S.]

S_t = a temperature and time-dependent stress intensity limit; the data considered in establishing these values are obtained from long-term, constant load, uniaxial tests. For each specific time, t, the S_t values shall be the lesser of

(a) 100% of the average stress required to obtain a total (elastic, plastic, primary, and secondary creep) strain of 1%;

(b) 80% of the minimum stress to cause initiation of tertiary creep; and

(c) 67% of the minimum stress to cause rupture.

(2) Weldments

S_{mt} = the allowable limit of primary membrane stress intensity, and shall be taken as the lower of the S_{mt} values from Tables HBB-I-14.3A through HBB-I-14.3E or:

$$0.8S_r \times R$$

As described in HBB-2160(d), it may be necessary to adjust the values of S_{mt} to account for the effects of long-time service at elevated temperature.

(23)

Table HGB-3217-1
Classification of Stress Intensity for Some Typical Cases

Core Support Structure	Location	Origin of Stress	Type of Stress	Classification	Discontinuity	
					Gross	Local
Cylindrical or spherical shell	Shell plate remote from discontinuities	Pressure difference	Membrane	P_m	No	No
			Gradient through plate thickness	Q	Yes	No
		Axial thermal gradient	Membrane	Q [Note (4)]	Yes	No
			Bending	Q	Yes	No
	Junction with head or flange	Pressure difference	Membrane	P_m [Note (6)]	Yes	No
			Bending	Q [Note (5)]	Yes	No
Any shell or head	Any section across entire shell	External load or moment, or pressure difference	Membrane averaged across full section. Stress component perpendicular to cross section	P_m	No	No
		External load or moment	Bending across full section. Stress component perpendicular to cross section	P_m	No	No
	Near nozzle or other opening	External load or moment, or pressure difference	Membrane	P_m [Note (6)]	Yes	No
			Bending	Q	Yes	No
			Peak (fillet or corner)	F	Yes	Yes
	Any location	Temp. difference between shell and head	Membrane	Q [Note (4)]	Yes	No
			Bending	Q	Yes	No
Dished head or conical	Crown	Pressure difference	Membrane	P_m	No	No
			Bending	P_b	No	No
	Knuckle or junction to shell	Pressure difference	Membrane	P_m [Note (1), (6)]	Yes	No
			Bending	Q	Yes	No
Flat head	Center region	Pressure difference	Membrane	P_m	No	No
			Bending	P_b	No	No
	Junction to shell	Pressure difference	Membrane	P_m [Note (6)]	Yes	No
			Bending	Q [Note (5)]	Yes	No
Perforated head or shell	Typical ligament in a uniform pattern	Pressure difference or external load	Membrane (average through cross section)	P_m	No	No
			Bending (average through width of ligament, but gradient through plate)	P_b	No	No
			Peak	F	No	Yes
	Isolated or atypical ligament	Pressure difference	Membrane	Q	Yes	No
			Bending	F	Yes	Yes
			Peak	F	Yes	Yes
Nozzle	Cross section perpendicular to nozzle axis	Pressure difference or external load or moment	Membrane average across full section. Stress component perpendicular to section.	P_m	No	No
	Nozzle wall	Pressure difference	Membrane	P_m	No	No
			Membrane	P_m [Note (6)]	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
	Any	Differential expansion	Membrane	Q [Note (4)]	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
Cladding	Any	Differential expansion	Membrane	F	Yes	Yes
			Bending	F	Yes	Yes

Table HGB-3217-1
Classification of Stress Intensity for Some Typical Cases (Cont'd)

Core Support Structure	Location	Origin of Stress	Type of Stress	Classification	Discontinuity Gross	Discontinuity Local
Any	Any	Radial thermal gradient through plate thickness [Note (2)]	Stress due to equivalent bending portion	Q [Note (3)]	Yes	No
			Stress due to nonlinear portion	F	Yes	Yes
Any	Any	Any	Stress concentration (notch effect)	F	Yes	Yes

NOTES:
(1) Consideration must also be given to the possibility of wrinkling and excessive deformation in shells with large diameter-to-thickness ratio.
(2) Consider possibility of thermal stress ratchet.
(3) Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.
(4) These classifications may be modified for purposes of certain criteria in Nonmandatory Appendix HBB-T (as referenced from Mandatory Appendix HGB-I).
(5) If the bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge bending is classified as P_b. Otherwise, it is classified as Q.
(6) This membrane stress is classified as Q in Section III Appendices, Mandatory Appendix XIII, Table XIII-2600-3.

S_t = temperature and time-dependent stress intensity limit at a weldment, and shall be taken as the lower of the tabulated S_t values from Tables HBB-I-14.4A through HBB-I-14.4E or:

$$0.8S_r \times R$$

where

R = is the appropriate ratio of the weld metal creep rupture strength to the base metal creep rupture strength from Tables HBB-I-14.10A-1 through HBB-I-14.10E-1. The lowest S_t value of the adjacent base metals shall be utilized for the weldment

S_r = the expected minimum stress-to-rupture strength given in Tables HBB-I-14.6A through HBB-I-14.6F

HGB-3222 Design Limits

The stress calculations required for the analysis of Design Loadings (HGB-3113.1) shall be based on a linearly elastic material model. The calculated stress intensity values shall satisfy the limits of (a) and (b) below.

(a) The general primary membrane stress intensity, derived from P_m, shall not exceed S_o[43]

$$P_m \leq S_o \tag{1}$$

(b) The combined primary membrane plus bending stress intensity, derived from P_m and P_b, shall not exceed $1.5S_o$:

$$(P_m + P_b) \leq (1.5)S_o \tag{2}$$

The left-hand side of eq. (2) does not represent a simple algebraic combination since P_m and P_b may each represent as many as six quantities [HGB-3215(b)].

(c) External pressure and other compression inducing loadings shall be investigated for adequate buckling strength, using the limits of HGB-3250.

HGB-3223 Level A and B Service Limits

The stress calculations required for the analysis of Level A and B Service Loadings (HGB-3113.3 and HGB-3113.4) are based on a linear elastic material model. The calculated stress intensity values shall satisfy the conditions of (a) through (f) below.

(a) The primary membrane stress intensity, derived from P_m for Level A and B Service Loadings, shall not exceed S_{mt}.

$$P_m \leq S_{mt} \tag{3}$$

where

S_{mt} = is determined for the time, t, corresponding to the total duration of the particular loading during the entire service life, and for temperature, T, corresponding to the maximum wall-averaged temperature that occurs during the particular loading event

(b) When time, t [in (a) above], is less than the total specified service life of the component, the cumulative effect of all the loadings shall be evaluated by the use-fraction sum in HGB-3224(b). In addition, it is permissible and often advantageous to subdivide a loading history into several load levels and into several temperatures at any given load level.

(c) The combined primary membrane plus bending stress intensities, derived from P_m and P_b for Level A and B Service Loadings, shall satisfy the following limits with

$$P_m + P_b \le K S_m \quad (4)$$

$$P_m + P_b/K_t \le S_t \quad (5)$$

The factor K_t accounts for the reduction in extreme fiber bending stress due to the effect of creep. The factor is given by the following:

$$K_t = (K + 1)/2 \quad (6)$$

The factor, K, is the section factor for the cross section being considered. It is the ratio of the load set producing a fully plastic section to a load set producing initial yielding of the extreme fiber of the cross section. In evaluating the initial yield and fully plastic section capabilities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified service load set.

(d) In evaluating across-the-wall bending of shell-type structures, K = 1.5 (for rectangular sections) shall be used. Thus, for across-the-wall shell bending, K_t = 1.25 in eq. (c)(6).

(e) In eq. (c)(5), the S_t value is determined for the time, t, corresponding to the total duration of the combined stress intensity derived from P_m and P_b/K_t and the maximum wall-averaged temperature, T, during the entire service life of the component.

(f) When t is less than the total service life of the component, the cumulative effect of all $[P_m + (P_b/K_t)]$loadings shall be evaluated by the use-fraction sum of HGB-3224(d). It is permissible and often advantageous to separate a loading history into several load levels and into several temperatures at any given load level.

(g) Under all conditions where a bending loading occurs across a section, the propensity for buckling of that part of the section in compression shall be investigated under the requirements of HGB-3250.

HGB-3224 Level C Service Limits

The stress calculations required for Level C Service Loadings analysis are based on a linear elastic material model. The calculated stress intensity values shall satisfy the conditions of (a) through (d) below.

(a) The primary membrane stress intensity, derived from P_m for Level C Service Loadings, shall not exceed the smaller of $1.2S_m$ and $1.0S_t$.

$$P_m \le \left\{ \begin{matrix} 1.2\,S_m \\ 1.0\,S_t \end{matrix} \right\} \quad (7)$$

(b) In addition, the use-fraction sum associated with the primary membrane stresses for all increments of primary loadings during Level A, B, and C Loadings shall satisfy the following requirements:

$$\sum_t \left(\frac{t_i}{t_{im}} \right) \le B \quad (8)$$

where

B = use-fraction factor and is equal to 1.0 [or less if so specified in the Design Specifications (Divisions 1 and 2, NCA-3211.19)].

t_i = the total duration of a specific loading, P_{mi}, at elevated temperature, T, during the entire service life of the component. Note that $\sum_i (t_i)$ is that part of the component service life at elevated temperatures (i.e., temperatures above values governed by the rules of Division 1, Subsection NG as explained in HGB-3211).

t_{im} = maximum allowed time under the load stress intensity, S_t, as determined from a graph of S_t–versus–time (see Figures HBB-I-14.4A through HBB-I-14.4E).

The use of Figures HBB-I-14.4A through HBB-I-14.4E for determining t_{im} for two loading conditions at two different temperatures is shown schematically in Figure HGB-3224-1. In Figure HGB-3224-1, P_{mi} (i = 1, 2, 3, etc.) represents the calculated membrane stress intensity for the loading condition and temperature in question; and T_i represents the maximum local wall-averaged temperature during t_i. Note that it may be desirable to consider that a given stress intensity, P_{mi}, acts during several time periods, t_i, in order to take credit for the fact that the temperature varies with time.

(c) The combined primary membrane plus bending stress intensities, derived from P_m and P_b for Level C Service Loadings, shall satisfy the following limits, with $1.0 < K \le 1.5$:

$$P_m + P_b \le 1.2KS_m \quad (9)$$

$$P_m + P_b/K_t \le S_t \quad (10)$$

where K_t is defined as in HGB-3223(c).

(d) In addition, the sum of the use-fractions associated with the primary membrane plus bending stresses for all increments of primary loadings during Level A, B, and C Service Loadings shall not exceed the value 1.00.

$$\sum_i \left(\frac{t_i}{t_{ib}} \right) \le 1.00 \quad (11)$$

where t_i is the total duration of the loading at temperature, T_i, and t_{ib} is the time value determined by entering Figures HBB-I-14.4A through HBB-I-14.4E at a value of stress equal to $P_m + P_b/K_t$, as shown in Figure

HGB-3224-2. Note that it is permissible to extrapolate the allowable stress intensity at temperature curve (Figures HBB-I-14.3A through HBB-I-14.3E and Figures HBB-I-14.4A through HBB-I-14.4E) to determine time value (t_{ib}) when computing use-fractions. Any such extrapolation and the method used shall be reported in the Design Report [Divisions 1 and 2, NCA-3211.40(b)].

HGB-3225 Level D Service Limits

The rules of this paragraph may be used in the evaluation of components subjected to loads specified as Level D Service Loadings.

(a) The rules in HGB-3225 (and in Section III Appendices, Mandatory Appendix XXVII) shall be applied in all instances unless alternative or supplementary criteria, as required by public health safety considerations for specific components or systems, are defined in, and made applicable by the Owner's Design Specifications (Divisions 1 and 2, NCA-3211.19). The type of analysis (elastic or inelastic) used by the system designer shall be indicated in the Design Specifications (see Section III Appendices, Mandatory Appendix XXVII, XXVII-2000).

(b) The primary membrane stress intensity, derived from P_m for the Level D Service Loadings, shall not exceed the smaller of $0.67S_r$, $0.8S_rR$, and one of the Level D Service Limits in Section III Appendices, Mandatory Appendix XXVII.

$$P_m \le \begin{cases} \text{Limit in Appendix XXVII for } P_m \\ 0.67S_r \\ 0.8S_rR \end{cases} \tag{12}$$

where S_r is the expected minimum stress-to-rupture in time t taken from Figures HBB-I-14.6A through HBB-I-14.6F and R is the appropriate ratio of the weld metal creep–fatigue strength to the base metal strength from Tables HBB-I-14.10A-1 through HBB-I-14.10E-1.

Figure HGB-3224-1
Use-Fractions for Membrane Stress

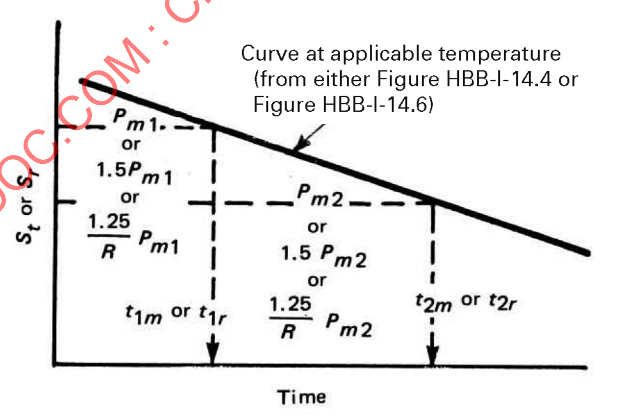
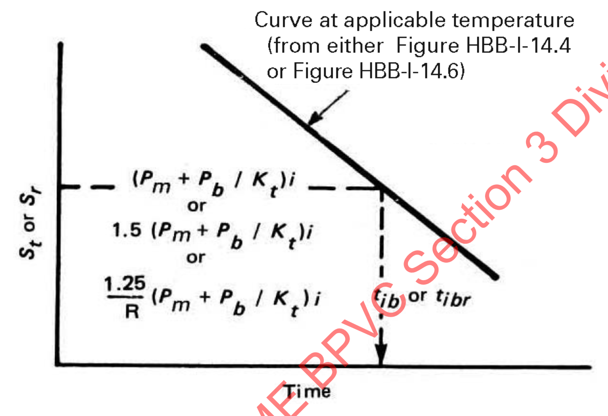


Figure HGB-3224-2
Use-Fractions for Membrane Plus Bending Stress



(c) In addition, the use-fraction sum associated with the primary membrane stresses that arise from all Service Loadings, shall satisfy the requirement

$$\sum_i \left(\frac{t_i}{t_{ir}}\right) \le B_r$$

where

B_r = use-fraction factor and is equal to 1.0 [or less if so specified in the Design Specifications (Divisions 1 and 2, NCA-3211.19)]

t_i = the total duration of a specific loading, P_{mi}, at elevated temperature, T_i, during the entire service life of the component. Note that $\sum_i (t_i)$ is that part of the component service life at elevated temperatures (i.e., temperatures above values governed by the rules of Division 1, Subsection NG, as explained in HGB-3211).

t_{ir} = maximum allowed time under the load stress intensity $1.5P_{mi}$ for base metal or weldments, the higher of $1.5P_{mi}$ or $(1.25/R)P_{mi}$. The allowable time under load is determined from the graph of minimum stress-to-rupture vs. time (see Figures HBB-I-14.6A through HBB-I-14.6F).

The use of Figures HBB-I-14.6A through HBB-I-14.6F for determining t_{ir} for two loading conditions at two different temperatures is shown schematically in Figure HGB-3224-1. In Figure HGB-3224-1, $1.5P_{mi}$ (i = 1, 2, 3, etc.) represents 1.5 times the calculated membrane stress intensity for the loading condition and temperature in question; and T_i represents the maximum local wall-averaged temperature during t_i. Note that it may be desirable to consider that a given stress intensity acts during several time periods, t_i, in order to take credit for the variation of temperature with time.

(d) The combined primary membrane plus bending stress intensities, derived from P_m and P_b, shall satisfy the following limits, with $1.0 < K \leq 1.5$, and Level D Service Limits in Section III Appendices, Mandatory Appendix XXVII for $P_m + P_b$.

$$P_m + P_b/K_t \leq \begin{cases} 0.67S_r \\ 0.8S_r \times R \end{cases}$$

where K_t is defined in HGB-3223(c).

(e) In addition, the sum of the use-fractions associated with the primary membrane plus bending stresses that arise from all Service Loadings, shall not exceed the value of 1.00.

$$\sum_i \left(\frac{t_i}{t_{ibr}}\right) \leq 1.00$$

where t_i is the total duration of loading at temperature, T_i, and t_{ibr} is the time value determined by entering Figures HBB-I-14.6A through HBB-I-14.6F at a value of stress equal to $1.5(P_m + P_b/K_t)$ for base metal or the higher of $1.5(P_m + P_b/K_t)$ or $1.25(P_m + P_b/K_t)/R$ for weldments as shown in Figure HGB-3224-2. For the purpose of Section III Appendices, Mandatory Appendix XXVII calculations, the yield strength and tensile strength values shall be defined as follows:

(1) Yield strength values shall be the product of the value shown in Table HBB-I-14.5 and the strength reduction factor shown in Tables HBB-3225-2 and HBB-3225-3A.

(2) Tensile strength values shall be the product of the value shown in Table HBB-3225-1 and the strength reduction factor shown in Tables HBB-3225-2 and HBB-3225-3B, where the strength reduction factor is selected as a function of the accumulated time-temperature history to which the component has been exposed prior to the event under analysis. Where a component has been exposed to a varying temperature history, the reduction factor employed shall be determined by assuming that the component has operated at the maximum temperature throughout its prior operational life (exclusive of Level D Service Conditions.)

HGB-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special operating conditions or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of HGB-3227 take precedence for the particular situations to which they apply.

HGB-3227.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of load categories other than Level D Service Loading, shall be considered.

The average bearing stress for Service Levels A, B, and C shall be limited to the lesser of the following:

(1) the tabulated yield strength at the Service Temperature; or

(2) the stress at 0.2% offset strain as obtained from the isochronous stress–strain curve for the temperature of service and for the time duration equal to the total service life the component is expected to spend at temperatures greater than those listed in the tables of Mandatory Appendix HBB-I-14.

(b) For clad surfaces, the properties of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(c) When bearing loads are applied near free edges, such as at a protruding edge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to $0.6S_{mt}$ in the case of load-controlled stresses. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

HGB-3227.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear (for example, keys, shear rings), experienced as a result of any loading categories other than Level D Service Loadings, shall be limited to $0.6S_{mt}$.

(b) The maximum primary shear stress, experienced as a result of any loading categories other than Level D Service Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_{mt}$.

HGB-3227.3 Progressive Distortion of Nonintegral Connections. Screwed-on caps, screwed-in plugs, shear-ring closures, and breech-lock closures are examples of nonintegral connections that are subject to failure by bell-mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operational cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that inter-locking parts, such as threads, can eventually lose engagement. Such nonintegral connections shall not be used where service temperatures are expected to exceed those associated with allowable stress intensity values for the specific materials as shown in Section II, Part D, Subpart 1, Tables 2A and 2B.

HGB-3227.4 Triaxial Stresses. The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_{mt}.

HGB-3227.5 Nozzle Piping Transition. The P_m classification of stresses resulting from pressure difference, external loads, and moments is applicable for that length of nozzle that lies within the limits of reinforcement given by HGB-3132, whether or not nozzle reinforcement is provided. Beyond the limits of reinforcement, a P_m classification shall be applied to the primary membrane stress intensity averaged across the section (not thickness) resulting from combined pressure difference and external mechanical loads; a $P_m + P_b$ classification shall be applied to primary membrane plus bending stress intensities that result from design pressure difference and external mechanical loads; and a $P_m + P_b + Q$ classification shall be applied to primary plus secondary stress intensities resulting from all loads including external load or moment attributable to restrained free end displacement of the attached pipe.

HGB-3227.8 Cladding. The rules of (a) through (d) below apply to the analysis of clad components constructed of material under this Subpart.

(a) Load-Controlled Stresses. No structural strength shall be attributed to the cladding in satisfying the load-controlled stress limits in HGB-3200.

(b) Design Dimensions. The dimensions stipulated in (1) and (2) below shall be used in the design of the component.

(1) For components subjected to internal pressure difference, the inside diameter shall be taken at the nominal inner face of the cladding.

(2) For components subjected to external pressure difference, the outside diameter shall be taken at the outer face of the base metal.

(c) Deformation-Controlled Quantities. No structural strength shall be attributed to the cladding in satisfying requirements on buckling instability. However, the cladding shall be considered in all other calculations related to satisfying limits on deformation-controlled quantities.

(d) Bearing Stresses. In satisfying (a), the presence of cladding shall be included.

HGB-3230 STRESS LIMITS FOR LOAD-CONTROLLED STRESSES IN THREADED STRUCTURAL FASTENERS

HGB-3231 General Requirements

(a) The rules of this paragraph apply to mechanical connections joining parts in core support structures located within a pressure-retaining boundary. Devices that are used to assemble structural elements of core support structures are referred to as threaded structural fasteners. The design stress intensity values S_{mt} for threaded structural fasteners shall be the values given in Tables HBB-I-14.3A through HBB-I-14.3E.

(b) The special stress limits of HGB-3227 do not apply to threaded structural fasteners.

(c) For connections joining parts of pressure-retaining boundaries, the rules for Class A components in elevated temperature service (Subsection HB, Subpart B) shall apply.

HGB-3232 Design and Level A Service Limits

The number and cross-sectional area of threaded structural fasteners shall be such that the stress intensity limits of this paragraph are satisfied for the Design Loadings and for the Service Loadings for which Level A Limits are designated in the Design Specifications. Any deformation limit prescribed in the Design Specifications shall be considered. The total axial load transferred through the fastener threads shall not go to or through zero during the specified Service Loadings.

HGB-3232.1 Average Stress. Elastic analysis of specified conditions shall show the following:

(a) The maximum value of the primary membrane stress due to internal pressure difference and other mechanical loads (excluding stresses from preload), averaged across either the area of the fastener shank or the tensile area of the threads, shall be no greater than either:

(1) $0.5S_m$;[44] or

(2) S_{mt},[44] provided the strains and deformations, including the effects of ratcheting, creep, and eventual retightening, are evaluated and shown to be acceptable per HGB-3250, and;

(b) The maximum value of the primary plus secondary membrane stress including stress from preload meets the requirements of (1) and (2) below.

(1) The maximum value of the membrane stress averaged across either the area of the fastener shank or the stress area of the threads, and neglecting stress concentrations, shall be no greater than S_{mt}, for the design life at the maximum service temperature, unless the design lifetime is divided into two or more loading periods and the possibility of creep rupture due to membrane stresses is guarded against by satisfying the use-fraction rule described in HGB-3224(b) with the use-fraction

factor, B, set equal to 0.5.[45] Stress intensity, rather than maximum stress, shall be limited to this value when threaded structural fasteners are

(-a) tightened by devices that result in residual torsion stresses (residual torsion stresses are minimized by devices such as heaters and stretchers)

(-b) loaded in transverse shear, or

(-c) both

(2) If a tight joint is required, the stress due to preload shall be shown to remain greater than that due to primary and secondary membrane stress excluding preload, throughout the design life of the joint.

HGB-3232.2 Maximum Stress. The maximum value of the primary membrane and bending plus secondary membrane and bending stresses produced by the combination of all primary loads and secondary loads but excluding effects of stress concentrations shall not exceed the lesser of $1.5S_{mt}$ or K_tS_t for the design life at the maximum service temperature, unless the design lifetime is divided into two or more loading periods and the possibility of creep rupture due to bending stresses is guarded against by satisfying the use-fraction rule described in HGB-3224(d) but with the use-fraction set at 0.67 instead of 1.0.[44] Stress intensity, rather than maximum stress, shall be limited to this value when threaded structural fasteners are

(a) tightened by devices that result in residual torsion stresses (residual torsion stresses are minimized by devices such as heaters and stretchers)

(b) loaded in transverse shear, or

(c) both

HGB-3232.3 Nonductile Fracture. The rules of HGB-3241 shall apply to threaded structural fasteners.

HGB-3233 Level B Service Limits

Level A Service Limits (HGB-3232) apply.

HGB-3234 Level C Service Limits for Threaded Structural Fasteners

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of HGB-3224 are satisfied for the Service Loadings for which Level C Limits are designated in the Design Specifications. Any deformation limit prescribed in the Design Specifications shall be considered.

HGB-3235 Level D Service Limits for Threaded Structural Fasteners

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of HGB-3225 are satisfied for the Service Loadings for which Level D Limits are designated [Divisions 1 and 2, NCA-2142.4(b)(4)] in the Design Specifications. Any deformation limit prescribed in the Design Specifications shall be considered.

HGB-3240 SPECIAL REQUIREMENTS FOR ELEVATED TEMPERATURE COMPONENTS

HGB-3241 Nonductile Fracture

(a) The Design Report (Divisions 1 and 2, NCA-3211.40) shall justify the ability of the component to withstand the expected service conditions without undergoing nonductile fracture. Even though components are not expected to fail by nonductile fracture while at elevated temperatures, the stress relaxation occurring under elevated temperature conditions will often lead to high residual stresses during the portion of the operational cycle with lowest temperatures. For loading times, stresses and temperatures where creep effects are not significant, an acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G for ferritic materials. When Section III Appendices, Nonmandatory Appendix G is not applicable, the fracture analysis shall consider the anticipated stress level and flaw size and compare these conditions with the fracture toughness of the material in the flaw region and at the appropriate temperature.

(b) The above justification requirements do not apply to Type 304 SS, Type 316 SS, or Alloy 800H, unless the fabrication effects substantially alter the fracture characteristics of these materials in such a manner that nonductile fracture becomes a plausible failure mode. The Design Specifications shall state when and how environmental effects shall be considered for nonductile fracture behavior in these materials.

HGB-3250 LIMITS ON DEFORMATION-CONTROLLED QUANTITIES

HGB-3251 General Requirements

The strains and deformation resulting from the specified operating conditions shall be evaluated. This evaluation shall include the effects of ratcheting, the interaction of creep and fatigue, and the possibility of buckling and structural instability. The N Certificate Holder shall document, as a portion of the Design Report (Divisions 1 and 2, NCA-3211.40), what effects and conditions were considered, the final analysis procedures, the evaluation criteria, and the conclusions of the evaluation.

HGB-3252 Criteria

It is the responsibility of the Owner to define the acceptability criteria to be applied as buckling, strain, deformation, and fatigue limits in the Design Specifications (Divisions 1 and 2, NCA-3211.19). The acceptability criteria and material properties contained in Nonmandatory Appendix HBB-T (referenced from Mandatory Appendix HGB-I) may be used. However, alternative criteria may be applied by the Certificate Holder subject to the approval by the Owner. The Owner's approval shall be indicated by incorporating the alternative criteria into the Design Specifications.

HGB-3300

HGB-3350

HGB-3352 Permissible Types of Welded Joints

Subject to the limitations given in Division 1, NG-3351, core support structures may use any of the types of joints described in the following subparagraphs, providing the quality factor, n, and fatigue factor, f, used in the analysis meet the requirements of Division 1, Table NG-3352-1 for the method of examinations employed. The allowable stress limits of HGB-3220, the strain limits of HGB-3250, and the damage limits of both HGB-3220 and HGB-3250 shall be multiplied by the quality factor, n, to evaluate the design of welded joints. The fatigue factor, f, shall be used as a stress concentration factor for the creep–fatigue analysis required by HGB-3250, unless a larger stress concentration factor is obtained per HGB-3353(b).

HGB-3352.2 Type II Joints. Full penetration welds between plates or other elements meet the intent of this subparagraph when made either according to Division 1, NG-3352.1 or with edges of the joint prepared with opposing lips to form an integral backing strip, or with metal backing strips that are not later removed, except that the suitability for cyclic operation shall be analyzed as required by HGB-3250.

HGB-3353 Design of Welded Construction at Elevated Temperatures

(a) Because of the potential for limited ductility of weld metal at elevated temperatures and the potential for high strain concentrations (both metallurgical and geometric) in the heat-affected zones of weldments, the analysis requirements of this paragraph shall be satisfied for the design and location of all pressure-retaining and other primary structural welds subjected to metal temperatures where creep effects are significant. The potential for reduced ductility often precludes locating welds in regions of high loading.

(b) For meeting the analysis requirements of HGB-3251 at elevated temperature weld regions, the assumed weld surface shall model the most severe strain concentrations expected in the actual weld placed in service. This geometry may be prescribed on a drawing or may be recorded by prior observation. Prior observations of weld surface geometry can be visual, remote visual (e.g., using a borescope device or making a surface replica), ultrasonic, based on a weld mockup test in which the same weld procedures are used on the same nominal diameter and wall thickness, or, based on a radiographic technique that is suitable for inspection of internal surfaces. The assumed strain concentration shall not be smaller than the applicable fatigue factor from Division 1, Table NG-3352-1.

ARTICLE HGB-4000
FABRICATION AND INSTALLATION

HGB-4100 GENERAL REQUIREMENTS

All core support structure material and material welded thereto shall meet the requirements of Division 1, Article NG-4000, except as modified herein.

HGB-4200

HGB-4210

HGB-4212 Forming and Bending Processes

Any process may be used to form or bend core support structure materials, including weld metal, provided that the requirement of the subparagraph below are met.

(a) Post-fabrication heat treatment [in accordance with (b) below] of materials that have been formed during fabrication, shall be required unless one of the following conditions are met:

(1) Maximum fabrication-induced local strains[28] do not exceed 5%,[29] regardless of the service temperature.

(2) Written technical justification shall be provided in the Design Report for not performing heat treatment, subsequent to straining, or for the use of an alternate heat treatment procedure, to that specified in (b) below, for fabrication-induced strains greater than 5%. The justification shall provide assurance that the resultant material property capabilities are adequate for the intended service (fatigue, creep rupture, impact toughness, etc.) and shall include consideration of property variability through the material section. This option is not permitted for certain materials if the components are subjected during Level A, B, and C service conditions, or for Design conditions when only Design conditions are specified, to short time high temperature excursions that result in accumulated temperature exposures exceeding the maximum permissible values shown in Figure HBB-4212-1. This option is also not permitted for any austenitic material that is subjected to greater than 20% strain.[28]

(3) The roll-threaded portion of threaded structural fastener material is exempt from the heat treatment requirement.

(b) When required, the post-fabrication heat treatment shall be in accordance with the following:

(1) For ferritic materials, the post-fabrication heat treatment shall consist of heating to temperatures listed in Division 1, Table NG-4622.1-1 for the appropriate alloy P-Number. Holding times shall also be in accordance with this table based on the material thickness at the point of maximum strain. This heat treatment shall be included in material certification per Division 1, NG-2211, the forming qualifications as required by Division 1, NG-4213, and applicable weld procedure qualifications. Alternatively, the base material and weld may be reheat treated and recertified in accordance with the applicable material specification and requirements in Division 1, NG-2400 (except as modified in HGB-2433.2). Reheat treatment may entail appropriate cooling from hot working temperatures above the upper critical temperature of the respective material provided required material property levels are recertified.

(2) For austenitic materials, the post-fabrication heat treatment shall consist of the heat treatment specified in the base material specification except that Alloy 800H shall be heat treated at 2,050°F (1 120°C) minimum.

Following reheat treatment, the final grain size of Alloy 800H shall be verified as being not finer than ASTM 5. If reheat treatment is employed, the designer shall be alerted to the possibility for material yield strength reductions, and the effect on buckling analysis must be accommodated as dictated by design rules.

HGB-4230

HGB-4233 Alignment Requirements When Component Inside Surface Is Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with Division 1, NG-4232, alignment of sections shall meet the requirements of (1) and (2) below:

(1) See (-a) and (-b) below.

(-a) For circumferential joints, the inside diameters shall match each other within $^{1}/_{16}$ in. (1.5 mm). When the items are aligned concentrically, a uniform mismatch of $^{1}/_{32}$ in. (0.8 mm) all around the joint can result as shown in Division 1, Figure NB-4233(a)-1, sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $^{3}/_{32}$ in. (2.5 mm) as shown in Division 1, Figure NB-4233(a)-1, sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations that do not meet these limits, the inside

diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of Division 1, NB-4250 are met.

(-b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints, the misalignment of inside surfaces shall not exceed $^{3}/_{32}$ in. (2.5 mm) and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single-welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of Division 1, NG-4232.

HGB-4400

HGB-4420

HGB-4424 Surfaces of Welds

As-welded surfaces are permitted provided that the surface geometry is considered in the stress analysis in accordance with the rules for design of core support structures in elevated temperature service. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the following requirements:

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and any other required nondestructive examinations of the welds. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with Division 1, NG-4426.

(c) Undercuts shall not exceed $^{1}/_{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of Article HGB-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

ARTICLE HGB-5000 EXAMINATION

HGB-5100 GENERAL REQUIREMENTS FOR EXAMINATION

All core support structure material and material welded thereto shall meet the requirements of Division 1, Article NG-5000, except as modified herein.

HGB-5200

HGB-5220 REQUIREMENTS FOR RADIOGRAPHY OR ULTRASONIC AND LIQUID PENETRANT OR MAGNETIC PARTICLE EXAMINATION

When radiography is required by the Certificate Holder (Division 1, Table NG-3352-1), welds shall be examined in accordance with the requirements of HGB-5221, HGB-5222, HGB-5223, HGB-5224, or HGB-5225, as applicable, and the external and accessible internal weld surfaces and adjacent base metal for at least $^1/_2$ in. (13 mm) on each side of the weld examined by either the magnetic particle or liquid penetrant method. Per Division 1, Table NG-3352-1, ultrasonic examination may be substituted for radiography except for those materials and welds that have coarse grains or configurations that do not yield meaningful results by ultrasonic methods.

HGB-5221 Category A Welded Joints

Longitudinal butt welds of Category A, as defined in Division 1, NG-3351.1, shall be examined in accordance with the requirements below.

Weld metal and adjacent base material for at least $^1/_2$ in. (13 mm) outside the edges of each weld shall be volumetrically examined by an appropriate method from the three listed as follows:

(a) radiography plus ultrasonic examination, where the radiography may be performed prior to any intermediate or required postweld heat treatment, provided ultrasonic examination is performed after the final postweld heat treatment

(b) radiography plus eddy current examination, provided the portion of the weld being examined is less than $^1/_4$ in. (6 mm) thick

(c) radiography at two different angles; one angle within 15 deg of perpendicular to the surface, the other at some angle appropriate for revealing any lack of fusion and cracking defects at the weld metal/base material interface near the root pass

HGB-5222 Category B Welded Joints

(a) For component regions with nominal diameter greater than 4 in. (100 mm), circumferential butt welds similar to Category B, as defined in Division 1, NG-3351.2, shall be examined in accordance with the requirements of HGB-5221.

(b) For component regions with nominal diameter of 2 in. (50 mm) or less, circumferential butt welds similar to Category B, along with adjacent base material for at least $^1/_8$ in. (3 mm) outside the edges of the completed weld, shall be radiographed. For component regions with a nominal diameter over 2 in. (50 mm) but not exceeding 4 in. (100 mm), circumferential butt welds similar to Category B welds shall be radiographed. The adjacent base material for a distance outside the edges of the completed weld equal to the greater of $^1/_8$ in. (3 mm) or t, but not to exceed $^1/_2$ in. (13 mm) where t is the thickness of the weld, shall also be radiographed.

HGB-5223 Category C Welded Joints

(a) For component regions with nominal diameter greater than 4 in. (100 mm), full penetration welds similar to Category C, as defined in Division 1, NG-3351.3, shall be examined in accordance with the requirements of HGB-5221.

(b) For component regions with nominal diameter of 4 in. (100 mm) or less, full penetration welds similar to Category C, along with adjacent base material for at least $^1/_2$ in. (13 mm), outside the edges of the completed weld, shall be radiographed. For full penetration corner welds, the requirements of (c) and (d) below shall replace the requirements of this paragraph.

(c) For component regions with nominal diameter of 4 in. (100 mm) or less, full penetration corner welds similar to Figure HGB-5223-1, sketches (a), (b), and (c) shall be radiographed: this radiography may require special techniques such as the use of multiple exposures.

(d) For component regions with nominal diameter of 4 in. (100 mm) or less, full penetration corner welds similar to Figure HGB-5223-1, sketches (d), (e), and (f) shall be examined in accordance with the requirements of (c) above. In addition, the fusion zone and the parent metal beneath the attachment surface shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects.

HGB-5224 Category D Welded Joints

Welded joints of Category D, as defined in Division 1, NG-3351.4, shall be examined in accordance with the requirements listed below.

HGB-5224.1 Butt-Welded Nozzles.

(a) Butt-welded attachment welds for nozzles with nominal diameter greater than 4 in. (100 mm) shall be examined in accordance with the requirements of HGB-5221. These welds shall be full penetration butt welds through either the component wall or the nozzle wall.

(b) Butt-welded attachment welds for nozzles with nominal diameter of 4 in. (100 mm) or less shall be examined by radiography. The examination shall cover the weld metal and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld.

HGB-5224.2 Full Penetration Corner-Welded Nozzles.

(a) Full penetration corner-welded attachment welds for nozzles with nominal diameter greater than 4 in. (100 mm) shall be examined in accordance with the requirements of HGB-5221.

(b) For nozzles with nominal diameter of 4 in. (100 mm) or less, full penetration corner-welded attachment welds similar to Figure HGB-5224.2-1, sketch (f) shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. The examination shall cover the weld metal and the adjacent base metal for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld.

(c) For nozzles with nominal diameter of 4 in. (100 mm) or less, full penetration corner-welded attachment welds similar to Figure HGB-5224.2-1, sketches (a), (b), (c), (d), (e), and (g) shall be examined in accordance with the requirements of (b) above. In addition, the fusion zone and the parent material beneath the attachment surface shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects.

HGB-5224.3 Deposited Weld Metal as Reinforcement for Openings and Attachment of Nozzles.

(a) Weld buildup deposits may be made to a surface as shown in Step 1 of Figure HGB-5224.3-1 for nozzles. When such weld deposits are made, the fusion zone and the parent metal beneath the weld shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects. Nozzles may then be attached as shown in Step 2 of Figure HGB-5224.3-1.

(b) Full penetration attachment welds, similar to those shown in Figure HGB-5224.3-1 shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. The examination shall cover the weld metal and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld.

HGB-5224.4 Full Penetration Welds at Oblique Connections.

(a) Full penetration welds shall be examined in accordance with the requirements of HGB-5221. Prior to examination, backing rings shall be removed and the nozzle bore surface finish shall be suitable for the type of examination.

(b) The radiographic examination in (a) above may be replaced with meeting all the conditions listed below.

(1) The weld is made as per Figure HGB-5224.4-1, Step 1. After attachment [Step 1, sketch (a) of figure] or after cladding [Step 1, sketch (b) or (c) of figure] the weld, weld fusion zone, and base metal under the attachment shall have been ultrasonically examined.

(2) The weld is made as per Figure HGB-5224.4-1, Step 2, and the magnetic particle or liquid penetrant method shall have been used to progressively examine the weld at the lesser of one-half the thickness of the weld joint, or each $\frac{1}{2}$ in. (13 mm) of weld thickness.

(3) A surface examination using the magnetic particle or liquid penetrant method shall have been made on the root pass weld.

(4) The angle that the nozzle axis makes with the component wall at the point of attachment is not smaller than 40 deg.

HGB-5225 Category E Welded Joints

Welds of Category E, as defined in Division 1, NG-3351.5, shall be examined in accordance with the requirements of HGB-5221.

Figure HGB-5223-1
Full Penetration Corner Weld Details for Category C Joints

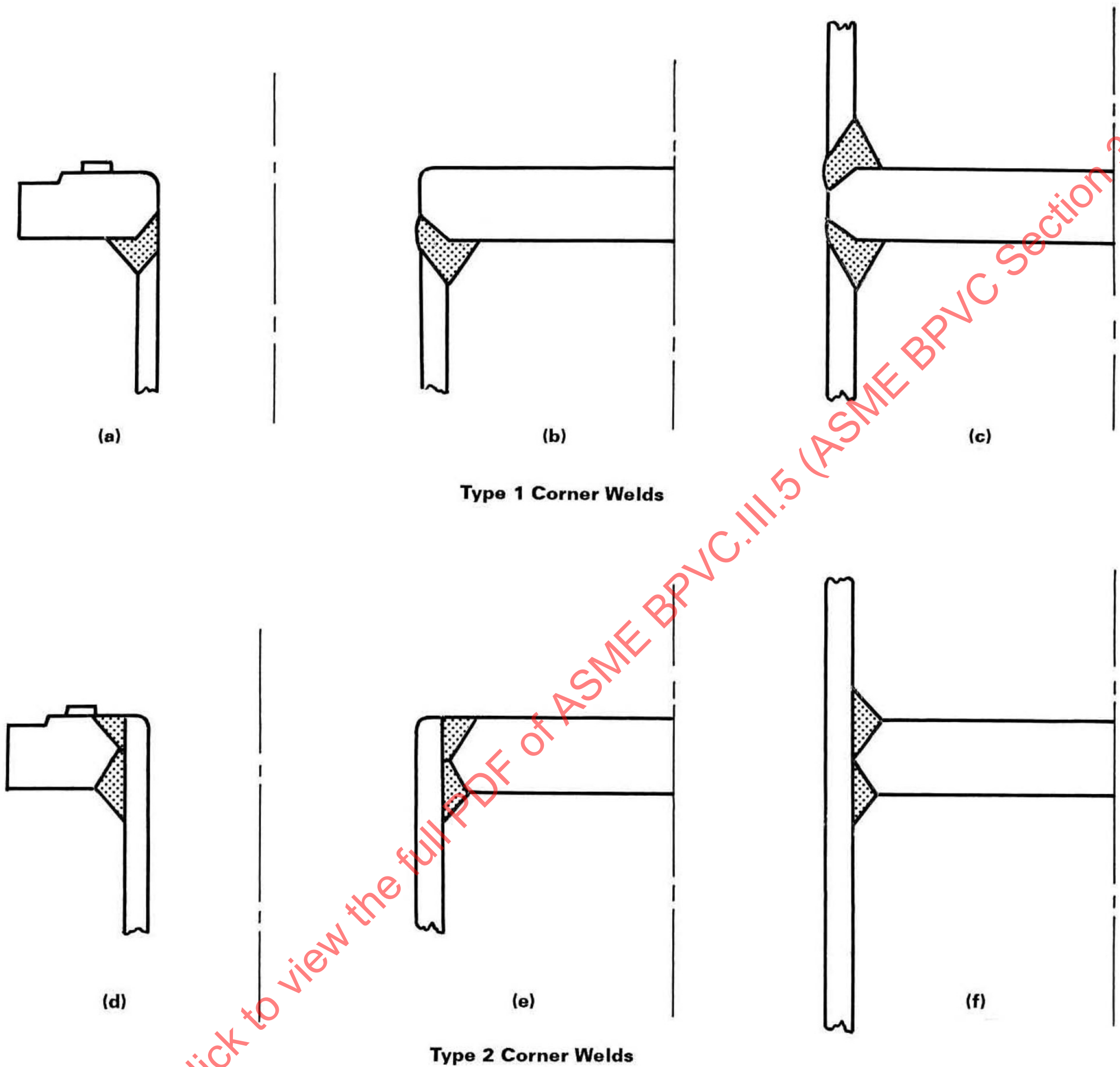


Figure HGB-5224.2-1
Nozzles Joined by Full Penetration Corner Welds

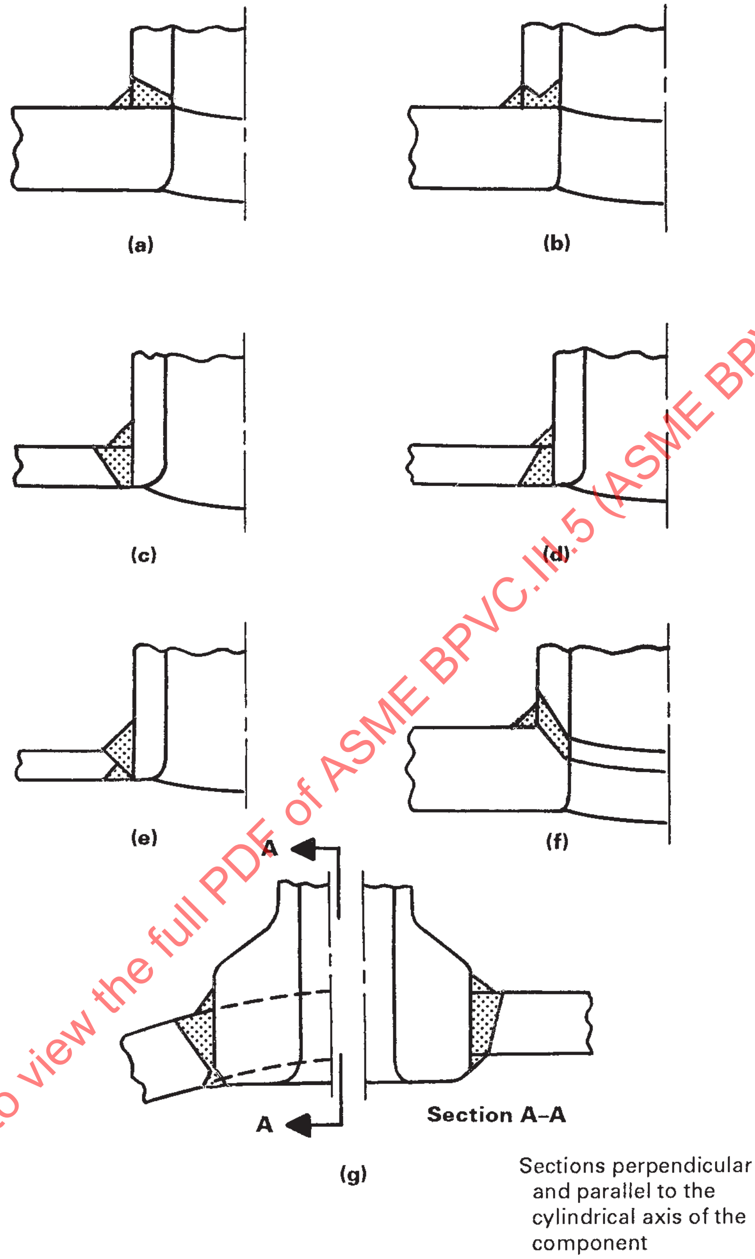


Figure HGB-5224.3-1
Deposited Weld Metal Used as Reinforcement of Openings for Nozzles

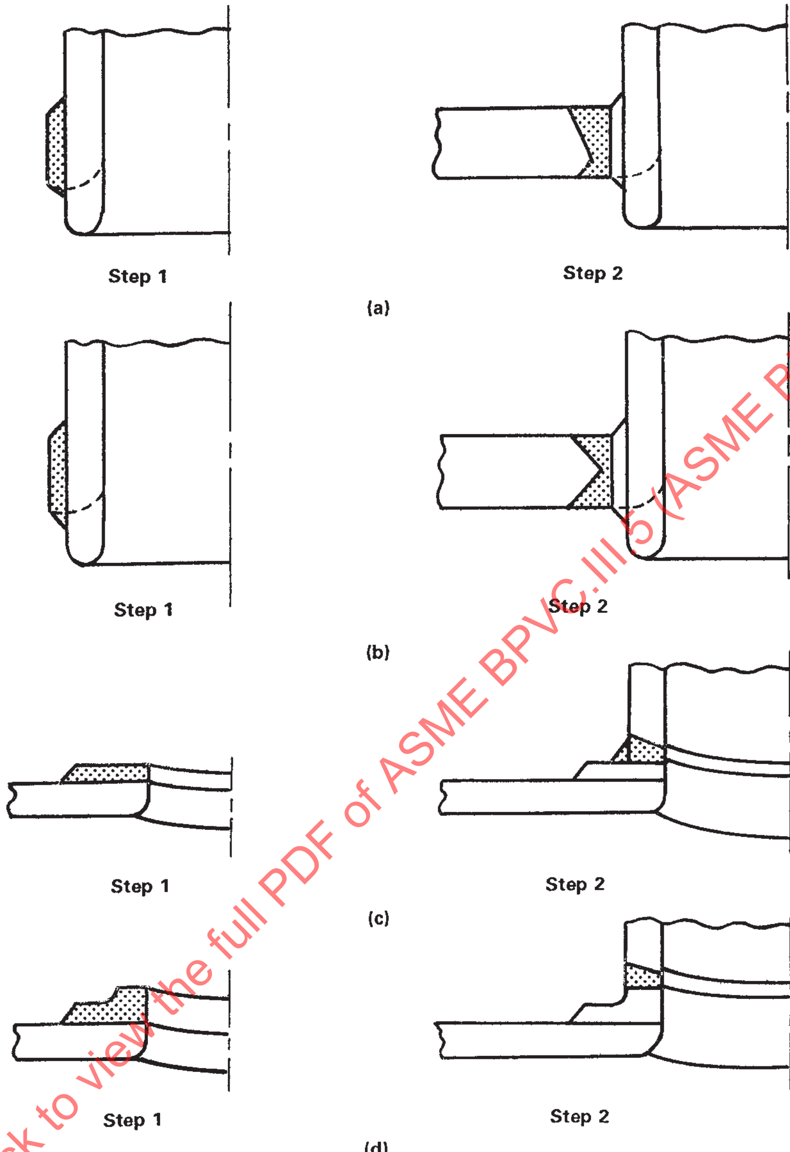
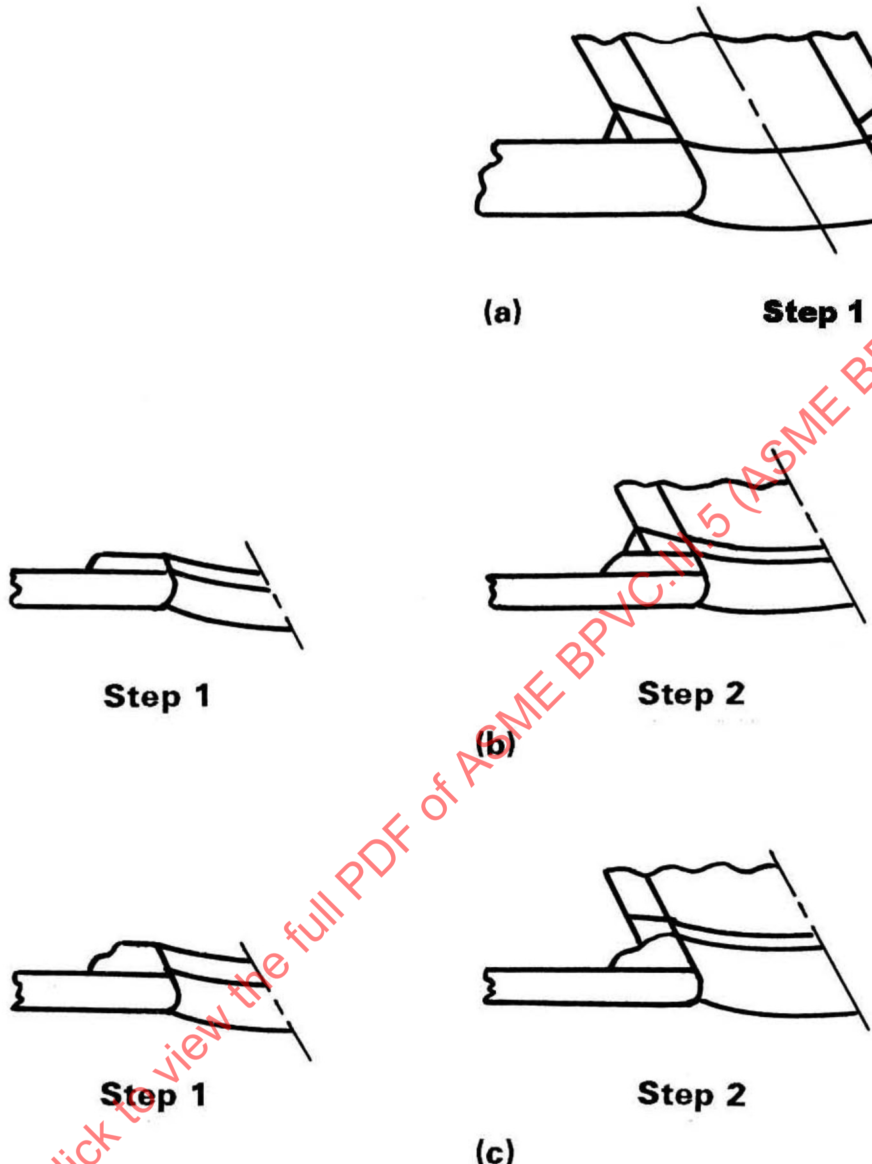


Figure HGB-5224.4-1
Oblique Connections



GENERAL NOTE: Step 1 examination required before assembly.

ARTICLE HGB-8000
NAMEPLATES, STAMPING WITH THE CERTIFICATION MARK, AND REPORTS

HGB-8100 REQUIREMENTS

The applicable requirements given in Article HAA-8000 shall apply to Class SM metallic core support structures.

MANDATORY APPENDIX HGB-I RULES FOR STRAIN, DEFORMATION, AND FATIGUE LIMITS AT ELEVATED TEMPERATURES

ARTICLE HGB-I-1000 INTRODUCTION

(23)

The objective of this Appendix is to provide rules that may be used by Owners and N Certificate Holders with respect to evaluation by analysis of strain, deformation, and fatigue limits for components whose load-controlled stresses are evaluated by the rules of Subsection HG, Subpart B.

These evaluation rules are contained in Nonmandatory Appendix HBB-T with the following clarifications needing to be applied in order to comply with Subsection HG, Subpart B.

(a) Local primary membrane stress, P_L, is not used in Subsection HG, Subpart B. Hence, all P_L references in Nonmandatory Appendix HBB-T shall become general primary membrane stress, P_m.

(b) All Division 1, Subsection NB and Subsection HB, Subpart B references made in Nonmandatory Appendix HBB-T shall remain as referenced.

(c) HBB-T-1325 and HBB-T-1434 shall not apply to core support structures evaluations per Subsection HG, Subpart B.

(d) In HBB-T-1435, Division 1, NB-3653.6 reference shall not be applicable to core support structures.

(e) In HBB-T-1714, a last sentence shall be added that states, "The assumed concentration factors shall not be smaller than the applicable fatigue factors from Division 1, Table NG-3352-1."

(f) Since there is no Article NG-6000 in Division 1, Subsection NG, references to Test Loadings in Nonmandatory Appendix HBB-T shall not be applicable to core support structures evaluations.

MANDATORY APPENDIX HGB-II RULES FOR CONSTRUCTION OF CORE SUPPORT STRUCTURES, EXTENDED FOR RESTRICTED SERVICE AT ELEVATED TEMPERATURE, WITHOUT EXPLICIT CONSIDERATION OF CREEP AND STRESS-RUPTURE

ARTICLE HGB-II-1000 INTRODUCTION

HGB-II-1100 GENERAL

The rules of Division 1, Article NG-1000 apply except as modified below.

HGB-II-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

Division 1, Subsection NG establishes rules for materials, design, fabrication, examination, and certification required in the manufacture and installation of core support structures whose service metal temperatures (during the specified conditions of service) do not exceed those for which Section II, Part D, Subpart 1, Tables 2A and 2B provide design stress intensity values.

For elevated temperature service, special rules are established in this Appendix that are required only for those zones of elevated temperature service of core support structures whose service metal temperatures (during the specified conditions of service) exceed those to which Section II, Part D, Subpart 1, Tables 2A and 2B apply, provided the time and temperature requirements of Mandatory Appendix HGB-IV are satisfied. The interface, if any, between low temperature portions and elevated temperature portions (zones of elevated temperature service) of the core support structure shall be identified in the Design Report (Divisions 1 and 2, NCA-3211.40).

The rules of this Appendix are contained in Division 1, Subsection NG, except for those paragraphs or subparagraphs (with numbered headings) replaced by corresponding numbered HGB-II paragraphs or subparagraphs in this Appendix or newly numbered HGB-II paragraphs or subparagraphs added to this Appendix.

ARTICLE HGB-II-2000 MATERIALS

HGB-II-2100

The rules of Division 1, Article NG-2000 apply except as modified below.

HGB-II-2120

(23) **HGB-II-2121 Permitted Material Specifications**

(a) Core support structural material, and material welded thereto, and threaded structural fasteners, with the exception of welding material (Division 1, NG-2430), hard surfacing material (Section IX, QW-251.4), cladding that is 10% or less of the thickness of the base material (Division 1, NG-3122), or the material excluded by Division 1, NG-4430, shall conform to the requirements of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A and 2B, including all applicable notes in the table, and to all of the special requirements of this Article that apply to the product form in which the material is used. Materials used for zones of elevated temperature service of core support structures shall also conform to the material specifications identified in Tables HGB-II-2121-1 and HGB-II-2121-2 or Tables HGB-II-2121-3 and HGB-II-2121-4 of this Appendix.

(b) The requirements of this Article apply to the internal structures (Division 1, NG-1122) only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the material used for the internal structures shall not adversely affect the integrity of the core support structure.

(c) Welding material used in the manufacture of items shall comply with an SFA Specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

HGB-II-2400

HGB-II-2430

HGB-II-2433

HGB-II-2433.2 Acceptance Standards. For Design Temperatures up to and including 800°F (425°C), the minimum acceptable delta ferrite shall be 5 FN (Ferrite Number). For design temperatures exceeding 800°F (425°C), the delta ferrite shall be limited to the range 3 FN to 10 FN. The results of the delta ferrite determination shall be included in the Certified Material Report of Division 1, NG-2130 or NG-4120.

Table HGB-II-2121-1
Design Stress Intensity Values, S_m, for Ferritic Steels at Elevated Temperatures in Core Support Structure Applications

U.S. Customary Units, ksi

Nominal Composition	P-No.	Group No.	Product Form	Spec. No.	Grade or Type	Class	Minimum Strengths, S_y/S_u, ksi	Notes	Applicable Line in Figure HGB-IV-1000-1	Stress Values, ksi, for Metal Temperatures, °F, Not to Exceed: 750	800	850	900	950	1,000	1,050	1,100
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Forgings	SA-182	F11	2	40/70	...	B	19.7	19.2	18.7	18.1	...	...	...	...
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Plate	SA-387	11	2	45/75	...	B	22.2	...	...	...	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Wld. pipe	SA-691	$2^1/_4$CR	...	30/60	(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$ Cr–1Mo	5A	1	Smls. tube	SA-213	T22	...	30/60	(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Smls. pipe	SA-335	P22	...	30/60	(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-336	F22	1	30/60	(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Forg. pipe	SA-369	FP22	...	30/60	(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-182	F22	1	30/60	(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Fittings	SA-234	WP22	1	30/60	(1)(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Wld. fittings	SA-234	WP22	1/W	30/60	(1)(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	30/60	(2)	B	17.9	17.9	17.6	17.2	16.7	15.9	14.9	13.9
$2^1/_4$Cr–1Mo	5A	1	Cast pipe	SA-426	CP22	...	40/70	(3)	B	21.6	21.0	20.0	18.9	17.6	16.0	14.5	12.7

Table HGB-II-2121-1
Design Stress Intensity Values, S_m, for Ferritic Steels at Elevated Temperatures in Core Support Structure Applications (Cont'd)

SI Units, MPa

Nominal Composition	P-No.	Group No.	Product Form	Spec. No.	Grade or Type	Class	Minimum Strengths, S_y/S_u, MPa	Notes	Applicable Line in Figure HGB-IV-1000-1	Stress Values, MPa, for Metal Temperatures, °C, Not to Exceed: 400	425	450	475	500	525	550	575	600
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Forgings	SA-182	F11	2	275/485	...	B	136	133	129	126	...	...	...	...	...
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Plate	SA-387	11	2	310/515	...	B	153	...	...	...	...	...	...	...	...
$2^1/_4$Cr–1Mo	5A	1	Wld. pipe	SA-691	$2^1/_4$CR	...	205/415	(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Smls. tube	SA-213	T22	...	205/415	(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Smls. pipe	SA-335	P22	...	205/415	(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-336	F22	1	205/415	(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Forg. pipe	SA-369	FP22	...	205/415	(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-182	F22	1	205/415	(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Fittings	SA-234	WP22	1	205/415	(1)(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Wld. fittings	SA-234	WP22	1/W	205/415	(1)(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	205/415	(2)	B	123	123	122	119	116	112	107	100	94
$2^1/_4$Cr–1Mo	5A	1	Cast pipe	SA-426	CP22	...	275/485	(3)	B	149	145	139	132	125	115	106	96	85

GENERAL NOTES:
(a) Not applicable for threaded structural fasteners.
(b) The following are the abbreviations used for Product Form:
   (1) Wld. — Welded
   (2) Forg. — Forged
   (3) Smls. — Seamless

NOTES:
(1) The material allowed under SA-234 shall correspond to one of the following:
   (a) SA-335, Grade P22
   (b) SA-387, Grade 22, Class 1
   (c) SA-182, Grade F22, Class 1
(2) This material shall have a minimum specified room temperature yield strength of 30,000 psi (205 MPa), a minimum specified room temperature ultimate strength of 60,000 psi (415 MPa), a maximum specified room temperature ultimate tensile strength of 85,000 psi (585 MPa), and a minimum specified carbon content of 0.07%.
(3) This material shall have a maximum specified room temperature ultimate tensile strength of 85,000 psi (585 MPa).

Table HGB-II-2121-2
Design Stress Intensity Values, S_m, for Ferritic Steels at Elevated Temperatures in Threaded Structural Fastener Applications

U.S. Customary Units, ksi

Nominal Composition	Spec. No.	Grade or Type	Class	Minimum Tempering Temperature, °F	Size/ Thickness, in.	Specified Minimum Strengths, S_y/S_u, ksi	Notes	Applicable Line in Figure HGB-IV-1000-1	Stress Values, ksi, for Metal Temperatures, °F, Not to Exceed: 750	800	850	900	950	1,000	1,050	1,100
1Cr–$^1/_2$Mo–V	SA-540	B21	5	850	$2 < t \le 8$	100/115	(1)	B	24.1	22.8	21.1	19.4	17.1	14.9	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	2	850	≤ 4	140/155	(1)	B	33.8	31.9	29.5	27.1	23.9	20.8	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	3	850	≤ 6	130/145	(1)	B	31.4	29.6	27.4	25.2	22.2	19.3	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	4	850	≤ 6	120/135	(1)	B	29.0	27.4	25.3	23.2	20.5	17.8	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	5	850	≤ 2	105/120	(1)	B	25.3	23.9	22.1	20.3	18.0	15.6	...	...
1Cr–$^1/_2$Mo–V	SA-193	B16	...	1,200	$\le 2^1/_2$	105/125	...	B	25.3	23.9	22.1	20.3	18.0	15.6	...	...
1Cr–$^1/_2$Mo–V	SA-193	B16	...	1,200	$2^1/_2 < t \le 4$	95/110	...	B	22.9	21.7	20.0	18.4	16.2	14.1	...	...
1Cr–$^1/_2$Mo–V	SA-193	B16	...	1,200	$4 < t \le 7$	85/100	...	B	20.5	19.4	17.9	16.5	14.5	12.6	...	...
2$^1/_4$Cr–1Mo	SA-336	F22	1	...	...	30/60	(2)	B	17.9	17.9	17.6	17.2	...	...	...	...

Table HGB-II-2121-2
Design Stress Intensity Values, S_m, for Ferritic Steels at Elevated Temperatures in Threaded Structural Fastener Applications (Cont'd)

SI Units, MPa																		
Nominal Composition	Spec. No.	Grade or Type	Class	Minimum Tempering Temperature, °C	Size / Thickness, mm	Specified Minimum Strengths, S_y/S_u, MPa	Notes	Applicable Line in Figure HGB-IV-1000-1	Stress Values, MPa, for Metal Temperatures, °C, Not to Exceed 400	425	450	475	500	525	550	575	600
1Cr–$^1/_2$ Mo–V	SA-540	B21	5	455	50 < t ≤ 200	690/795	(1)	B	166	158	147	137	124	110	...	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	2	455	≤ 100	965/1070	(1)	B	233	221	206	191	173	153	...	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	3	455	≤ 150	895/1000	(1)	B	216	205	191	178	161	142	...	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	4	455	≤ 150	825/930	(1)	B	200	190	177	164	148	131	...	...	...
1Cr–$^1/_2$Mo–V	SA-540	B21	5	455	≤ 50	725/825	(1)	B	174	165	154	143	130	115	...	...	...
1Cr–$^1/_2$Mo–V	SA-193	B16	...	650	≤ 64	725/860	...	B	174	165	154	143	130	115	...	...	...
1Cr–$^1/_2$Mo–V	SA-193	B16	...	650	64 < t ≤ 100	655/760	...	B	158	150	140	130	117	104	...	...	...
1Cr–$^1/_2$Mo–V	SA-193	B16	...	650	100 < t ≤ 175	585/690	...	B	141	134	125	116	105	93	...	...	...
2$^1/_4$Cr–1Mo	SA-336	F22	1	...	...	205/415	(2)	B	123	123	122	119	...	...	...	...	...

NOTES:

(1) These stress values may result in relaxation of the threaded structural fastener materials after prolonged service at temperature. The designer shall investigate the effect of this relaxation upon the application.

(2) This material shall have a minimum carbon content of 0.07%.

Table HGB-II-2121-3
Design Stress Intensity Values, S_m, for Austenitic and High Nickel Alloys at Elevated Temperatures in Core Support Structure Applications

U.S. Customary Units, ksi

Spec. No.	Nominal Composition	P-No.	Gr. No.	Product Form	Type/Grade/Class/Condition	Notes	Applicable Line in Figure HGB-IV-1000-1	Ext. Press. Chart	Minimum Values at Room Temperature S_y, ksi	Minimum Values at Room Temperature S_u, ksi	Design Stress Intensity Values, ksi, for Temperature, °F 850	900	950	1,000	1,050	1,100	1,150	1,200
Type 304 SS																		
SA-182	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(4)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-213	18Cr–8Ni	8	1	Seamless tube	TP304 & TP304H	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-240	18Cr–8Ni	8	1	Plate	304 & 304H	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-249	18Cr–8Ni	8	1	Welded tube	TP304 & TP304H	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-312	18Cr–8Ni	8	1	Welded & seamless pipe	TP304 & TP304H	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-358	18Cr–8Ni	8	1	Welded pipe	304 & 304H/1	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-376	18Cr–8Ni	8	1	Seamless pipe	TP304 & TP304H	(2)(3)(5)	E	HA-1	30	70	14.8	14.6	14.3	14.0	...	...	...	...
SA-403	18Cr–8Ni	8	1	Fittings	304 & 304H	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-403	18Cr–8Ni	8	1	Welded fittings	304 & 304H/WP-W	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-479	18Cr–8Ni	8	1	Bar	304 & 304H	(2)(3)(5)	E	HA-1	30	75	14.8	14.6	14.3	14.0	...	...	...	...
SA-965	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(5)	E	HA-1	30	70	14.8	14.6	14.3	14.0	...	...	...	...
Type 316 SS [Note (1)]																		
SA-182	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(4)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-213	16Cr–12Ni–2Mo	8	1	Seamless tube	TP316 & TP316H	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-240	16Cr–12Ni–2Mo	8	1	Plate	316 & 316H	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-249	16Cr–12Ni–2Mo	8	1	Welded tube	TP316 & TP316H	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-312	16Cr–12Ni–2Mo	8	1	Welded & seamless pipe	TP316 & TP316H	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-358	16Cr–12Ni–2Mo	8	1	Welded pipe	316 & 316H/1	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-376	16Cr–12Ni–2Mo	8	1	Seamless pipe	TP316 & TP316H	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-403	16Cr–12Ni–2Mo	8	1	Fittings	316 & 316H	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-403	16Cr–12Ni–2Mo	8	1	Welded fittings	316 & 316H/WP-W	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-479	16Cr–12Ni–2Mo	8	1	Bar	316 & 316H	(2)(3)(5)	F	HA-2	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-965	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(5)	F	HA-2	30	70	15.7	15.6	15.5	15.4	15.1	14.8	...	...
Alloy 800H																		
SB-163	42Fe–33Ni–21Cr	45	...	Seamless tube	Annealed	(3)	G	NFN-9	25	65	15.1	14.8	14.6	14.4	14.3	14.1	13.9	13.8
SB-407	42Fe–33Ni–21Cr	45	...	Seamless pipe & tube	Annealed	(3)	G	NFN-9	25	65	15.1	14.8	14.6	14.4	14.3	14.1	13.9	13.8
SB-408	42Fe–33Ni–21Cr	45	...	Bar, rod	Annealed	(3)	G	NFN-9	25	65	15.1	14.8	14.6	14.4	14.3	14.1	13.9	13.8
SB-409	42Fe–33Ni–21Cr	45	...	Plate	Annealed	(3)	G	NFN-9	25	65	15.1	14.8	14.6	14.4	14.3	14.1	13.9	13.8
SB-564	42Fe–33Ni–21Cr	45	...	Forgings	Annealed	(3)	G	NFN-9	25	65	15.1	14.8	14.6	14.4	14.3	14.1	13.9	13.8

Table HGB-II-2121-3
Design Stress Intensity Values, S_m, for Austenitic and High Nickel Alloys at Elevated Temperatures in Core Support Structure Applications (Cont'd)

SI Units, MPa

Spec. No.	Nominal Composition	P-No.	Gr. No.	Product Form	Type/Grade/ Class/ Condition	Notes	Applicable Line in Figure HGB-IV-1000-1	Ext. Press. Chart	Minimum Values at Room Temperature S_y, MPa	Minimum Values at Room Temperature S_u, MPa	Design Stress Intensity Values, MPa, for Temperature, °C 450	475	500	525	550	575	600	625	650
Type 304 SS																			
SA-182	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(4)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-213	18Cr–8Ni	8	1	Seamless tube	TP304 & TP304H	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-240	18Cr–8Ni	8	1	Plate	304 & 304H	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-249	18Cr–8Ni	8	1	Welded tube	TP304 & TP304H	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-312	18Cr–8Ni	8	1	Welded & seamless pipe	TP304 & TP304H	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-358	18Cr–8Ni	8	1	Welded pipe	304 & 304H/1	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-376	18Cr–8Ni	8	1	Seamless pipe	TP304 & TP304H	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-403	18Cr–8Ni	8	1	Fittings	304 & 304H	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-403	18Cr–8Ni	8	1	Welded fittings	304 & 304H/WP-W	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-479	18Cr–8Ni	8	1	Bar	304 & 304H	(2)(3)(5)	E	HA-1	205	515	102	101	99	97	...	...	...	...	...
SA-965	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(5)	E	HA-1	205	485	102	101	99	97	...	...	...	...	...
Type 316 SS [Note (1)]																			
SA-182	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(4)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-213	16Cr–12Ni–2Mo	8	1	Seamless tube	TP316 & TP316H	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-240	16Cr–12Ni–2Mo	8	1	Plate	316 & 316H	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-249	16Cr–12Ni–2Mo	8	1	Welded tube	TP316 & TP316H	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-312	16Cr–12Ni–2Mo	8	1	Welded & seamless pipe	TP316 & TP316H	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-358	16Cr–12Ni–2Mo	8	1	Welded pipe	316 & 316H/1	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-376	16Cr–12Ni–2Mo	8	1	Seamless pipe	TP316 & TP316H	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-403	16Cr–12Ni–2Mo	8	1	Fittings	316 & 316H	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-403	16Cr–12Ni–2Mo	8	1	Welded fittings	316 & 316H/WP-W	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-479	16Cr–12Ni–2Mo	8	1	Bar	316 & 316H	(2)(3)(5)	F	HA-2	205	515	108	108	107	107	105	103	...	...	...
SA-965	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(5)	F	HA-2	205	485	108	108	107	107	105	103	...	...	...
Alloy 800H																			
SB-163	42Fe–33Ni–21Cr	45	...	Seamless tube	Annealed	(3)	G	NFN-9	170	450	104	103	101	100	99	98	97	96	95
SB-407	42Fe–33Ni–21Cr	45	...	Seamless pipe & tube	Annealed	(3)	G	NFN-9	170	450	104	103	101	100	99	98	97	96	95
SB-408	42Fe–33Ni–21Cr	45	...	Bar, rod	Annealed	(3)	G	NFN-9	170	450	104	103	101	100	99	98	97	96	95
SB-409	42Fe–33Ni–21Cr	45	...	Plate	Annealed	(3)	G	NFN-9	170	450	104	103	101	100	99	98	97	96	95
SB-564	42Fe–33Ni–21Cr	45	...	Forgings	Annealed	(3)	G	NFN-9	170	450	104	103	101	100	99	98	97	96	95

Table HGB-II-2121-3
Design Stress Intensity Values, S_m, for Austenitic and High Nickel Alloys at Elevated Temperatures in Core Support Structure Applications (Cont'd)

GENERAL NOTES:
(a) Except for threaded structural fasteners, see Table HGB-II-2121-4.
(b) For deformation-sensitive structures, see HGB-3250 of this Subsection HG, Subpart B.

NOTES:
(1) These materials may be used at temperatures above 1,000°F (540°C) only if heat treated by heating to a minimum temperature of 1,900°F (1 040°C) and quenching in water, or rapidly cooling by other means.
(2) These materials shall have a minimum carbon content of 0.4%.
(3) At temperatures above 100°F (40°C), the design stress intensity values may exceed $66\frac{2}{3}\%$ and may reach 90% yield strength (0.2% offset) at temperature. This may result in a permanent strain of 0.1%. When small amounts of deformation are not acceptable, the designer shall reduce the design stress to obtain an acceptable deformation. Section II, Part D, Subpart 1, Table Y-2 lists multiplying factors that, when applied to the yield strength values shown on Table HGB-II-3229-3 of this Appendix, will give a design stress intensity that will result in lower levels of permanent strain.
(4) 5 in. (125 mm) and under.
(5) Solution annealed.

Table HGB-II-2121-4
Design Stress Intensity Values, S_m, for Austenitic and High Nickel Alloys at Elevated Temperatures in Threaded Structural Fastener Applications

U.S. Customary Units, ksi

Spec. No.	Nominal Composition	P-No.	Gr. No.	Product Form	Type/Grade/Class/ Condition	Notes	Applicable Line in Figure HGB-IV-1000-1	Minimum Values at Room Temperature S_y, ksi	Minimum Values at Room Temperature S_u, ksi	Design Stress Intensity Values, ksi, for Temperature, °F 850	900	950	1,000	1,050	1,100	1,150	1,200
Type 304 SS [Note (1)]																	
SA-182	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(4)	E	30	75	14.8	14.6	14.3	14.0	13.6	...	...	...
SA-193	18Cr–8Ni	8	1	Bolting	B8	(2)(3)(4)	E	30	75	14.8	14.6	14.3	14.0	13.6	...	...	...
SA-479	18Cr–8Ni	8	1	Bar	304 & 304H	(2)(3)(4)	E	30	75	14.8	14.6	14.3	14.0	13.6	...	...	...
SA-965	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(4)	E	30	70	14.8	14.6	14.3	14.0	13.6	...	...	...
Type 316 SS [Note (1)]																	
SA-182	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(4)	F	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-193	16Cr–12Ni–2Mo	8	1	Bolting	B8M	(2)(3)(4)	F	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-479	16Cr–12Ni–2Mo	8	1	Bar	316 & 316H	(2)(3)(4)	F	30	75	15.7	15.6	15.5	15.4	15.1	14.8	...	...
SA-965	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(4)	F	30	70	15.7	15.6	15.5	15.4	15.1	14.8	...	...
Alloy 800H																	
SB-408	42Fe–33Ni–21Cr	45	...	Bar	Annealed	(4)	G	25	65	15.1	14.8	14.6	14.4	14.3	14.1	13.9	13.8

SI Units, MPa

Spec. No.	Nominal Composition	P-No.	Gr. No.	Product Form	Type/Grade/Class/ Condition	Notes	Applicable Line in Figure HGB-IV-1000-1	Minimum Values at Room Temperature S_y, MPa	Minimum Values at Room Temperature S_u, MPa	Design Stress Intensity Values, MPa, for Temperature, °C 450	475	500	525	550	575	600	625	650
Type 304 SS [Note (1)]																		
SA-182	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(4)	E	205	515	102	101	99	96	...	...	...	...	...
SA-193	18Cr–8Ni	8	1	Bolting	B8	(2)(3)(4)	E	205	515	102	101	99	96	...	...	...	...	...
SA-479	18Cr–8Ni	8	1	Bar	304 & 304H	(2)(3)(4)	E	205	515	102	101	99	96	...	...	...	...	...
SA-965	18Cr–8Ni	8	1	Forgings	F304 & F304H	(2)(3)(4)	E	205	485	102	101	99	96	...	...	...	...	...
Type 316 SS [Note (1)]																		
SA-182	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(4)	F	205	515	108	108	107	107	105	103	102	...	...
SA-193	16Cr–12Ni–2Mo	8	1	Bolting	B8M	(2)(3)(4)	F	205	515	108	108	107	107	105	103	102	...	...
SA-479	16Cr–12Ni–2Mo	8	1	Bar	316 & 316H	(2)(3)(4)	F	205	515	108	108	107	107	105	103	102	...	...
SA-965	16Cr–12Ni–2Mo	8	1	Forgings	F316 & F316H	(2)(3)(4)	F	205	485	108	108	107	107	105	103	102	...	...
Alloy 800H																		
SB-408	42Fe–33Ni–21Cr	45	...	Bar	Annealed	(4)	G	170	450	104	103	101	100	99	98	97	96	95

GENERAL NOTES:
(a) Applies only to threaded structural fasteners.
(b) For deformation-sensitive structures, see HGB-3250.

Table HGB-II-2121-4
Design Stress Intensity Values, S_m, for Austenitic and High Nickel Alloys at Elevated Temperatures in Threaded Structural Fastener Applications (Cont'd)

NOTES:

(1) These materials may be used at temperatures above 1,000°F (540°C) only if heat treated by heating to a minimum temperature of 1,900°F (1 040°C) and quenching in water, or rapidly cooling by other means.

(2) Solution annealed.

(3) These materials shall have a minimum carbon content of 0.4%.

(4) At temperatures above 100°F (40°C), the design stress intensity values may exceed $66\frac{2}{3}$% and may reach 90% yield strength (0.2% offset) at temperature. This may result in a permanent strain of 0.1%. When small amounts of deformation are not acceptable, the designer shall reduce the design stress to obtain an acceptable deformation. Section II, Part D, Subpart 1, Table Y-2 lists multiplying factors that, when applied to the yield strength values shown on Table HGB-II-3229-3 of this Appendix, will give a design stress intensity that will result in lower levels of permanent strain.

ARTICLE HGB-II-3000 DESIGN

HGB-II-3100

The rules of Division 1, Article NG-3000 apply except as modified below.

HGB-II-3110

HGB-II-3112

HGB-II-3112.4 Design Stress Intensity Values. Design stress intensity values for materials are listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The stress intensity tables of Section II, Part D, Subpart 1 may be extended to higher metal temperatures using the values in Tables HGB-II-2121-1 through HGB-II-2121-4 of this Appendix only when the time and temperature requirements of Mandatory Appendix HGB-IV are satisfied. The material shall not be used at metal temperatures and Design Temperatures that exceed the temperature limit for which stress intensity values are listed. The values in the Tables may be interpolated for intermediate temperatures.

HGB-II-3130

HGB-II-3132 Reinforcement for Openings

The rules for reinforcing applicable to Class A vessels and piping may be used in the design of core support structures if stipulated in the Design Specifications. The area replacement rules for Class A components may only be used for internal pressure loadings. Additional engineering analysis shall be used to demonstrate satisfaction of the primary stress limits due to other loadings.

HGB-II-3133 External Pressure Difference

The requirements of Division 1, NG-3133 shall be satisfied for all zones of elevated temperature service of core support structures. The requirements of HGB-II-3133.7 (of this Appendix) shall be satisfied whenever the rules of Division 1, NG-3133.1 through NG-3133.6 are not applicable due to the nature of the load or the geometry. When the rules of Division 1, NG-3133.1 through NG-3133.6 are used, the forming tolerance requirements applicable to Class A components shall be satisfied.

HGB-II-3133.7 Alternate Rules for Buckling Loadings Due to External Pressure. The design factors of Mandatory Appendix HGB-III may be used to demonstrate compliance with the requirements of Division 1, NG-3133.1 through NG-3133.6.

HGB-II-3200

HGB-II-3210

HGB-II-3211 Requirements for Acceptability

The requirements for the acceptability of a design by analysis are those set forth in (a) through (d) below.

(a) The design shall be such that stress intensities will not exceed the limits of Division 1, NG-3200 using the design stress intensity values, S_m, as tabulated in Tables HGB-II-2121-1 through HGB-II-2121-4 of this Appendix, and considering the effects of the service environment (Division 1, NG-2160). If austenitic materials are solution annealed during fabrication and may experience elevated temperatures above the limit of Division 1, Subsection NG during service, then the limits of Division 1, NG-3200 shall also address the requirements of Division 1, NG-2190.

(b) The design details shall conform to the rules given in Division 1, NG-3100 and NG-3350.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b), the critical buckling stress shall be taken into account; see Division 1, NG-3133. (For the special case of external pressure difference, see Division 1, NG-3133.1. Where dynamic pressure differences are involved, the permissible external pressure difference shall satisfy the requirements of Division 1, NG-3133 or be limited to 25% of the dynamic instability pressure difference for normal service conditions.)

(d) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G.

HGB-II-3220 (23)

The rules of Section III Appendices, Mandatory Appendix XIII, XIII-3000 for core support structures apply except as modified below.

For Section III Appendices, Mandatory Appendix XIII, Figure XIII-II-2, add the following phrase to the end of Note (5): "For elevated temperature applications, the S_a values are obtained from Tables HGB-II-3222.4-1 through HGB-II-3222.4-4 of this Appendix."

HGB-II-3222

(23) **HGB-II-3222.4 Analysis for Cyclic Operation.**

(a) Suitability for Cyclic Condition. The suitability of a structure for specified Service Loadings involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength threaded structural fasteners shall be determined by the methods of Section III Appendices, Mandatory Appendix XIII, XIII-X230(b) and the possibility of thermal stress ratchet shall be investigated in accordance with Section III Appendices, Mandatory Appendix XIII, XIII-3430. If the specified Service Loadings of the structure meet all of the conditions of (d) below, no analysis for cyclic service is required, and it may be assumed that the peak stress limit discussed in (b) below has been satisfied by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Appendix. If the Service Loadings do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with Section III Appendices, Mandatory Appendix II, II-1500.

(b) Peak Stress Intensity. This stress intensity is derived from the highest value at any point across the thickness of a section of all primary, secondary, and peak stresses produced by specified service pressure differences and other mechanical loads, and by general and local thermal effects associated with normal Service Conditions and including the effects of gross and local structural discontinuities.

(c) Conditions and Procedures. The conditions and procedures of Section III Appendices, Mandatory Appendix XIII, XIII-3500 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Section III Appendices, Mandatory Appendix I. These curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The design fatigue curves in Section III Appendices, Mandatory Appendix I are derived from both strain-controlled test data and load-controlled fatigue data. When strain-controlled test data are used, the fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. The curves have been adjusted, where necessary, to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero. As a consequence of this procedure, it is essential that the requirements of (b) above be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(5) below. Section III Appendices, Mandatory Appendix I may be extended to elevated temperatures using Tables HGB-II-3222.4-1 through HGB-II-3222.4-4 of this Appendix. The elevated temperature design fatigue curves are based on the observed total strain range versus cycles to failure relationships from controlled strain cycling tests in an air environment, and on the maximum effect of hold times.

(d) Components Not Requiring Analysis for Cyclic Service. An analysis for cyclic service is not required, and it may be assumed that the peak stress limit discussed in (b) above has been satisfied for a structure by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Appendix, provided the specified Service[46] Loadings of the structure or portion thereof meets all the conditions stipulated in (1) through (4) below.

(1) Temperature Difference — Startup and Shutdown. The temperature difference in °F (°C) between any two adjacent points[47] of the structure during normal service does not exceed $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curves for the specified number of startup–shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Table TE, and E is taken from Section II, Part D, Subpart 2, Table TM at the mean value of the temperature at the two points.

(2) Temperature Difference — Normal Service. The temperature difference in °F (°C) between any two adjacent points[47] does not change[48] during normal service by more than the quantity $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I (and the extended fatigue curve from Tables HGB-II-3222.4-1 through HGB-II-3222.4-4) for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows:

(-a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(3) Temperature Difference — Dissimilar Materials. For structures fabricated from materials of differing moduli of elasticity and coefficients of thermal expansion or both, the total algebraic range of temperature fluctuation in °F (°C) experienced by the component during normal service does not exceed the magnitude

$S_a/2\ (E_1\alpha_1 - E_2\alpha_2)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction (Section II, Part D, Subpart 2, Tables TE and TM). A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2\ (E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows:

(-a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph.

(4) Mechanical Loads. The specified full range of mechanical loads, including pipe reactions and pressure differences, does not result in load stresses whose range exceeds the S_a value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I (and the extended fatigue curve from Tables HGB-II-3222.4-1 through HGB-II-3222.4-4) for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds 10^6, the S_a value at $N = 10^6$ may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the value of S_a where S is defined as follows:

(-a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) Procedure for Analysis for Cyclic Loading. If the specified service loadings for the structure do not meet the conditions of (d) above, the ability of the structure to withstand the specified cyclic service without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point and the allowable stress cycles shall be adequate for the specified Service Loadings at every point. Only the stresses due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the structure is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Service Loadings is also dependent on meeting the general stress limits of Section III Appendices, Mandatory Appendix XIII, XIII-3100 and XIII-3400 and any applicable special stress limits of Division 1, NG-3210(a).

(1) Stress Differences. For each condition of normal service, determine the stress differences and the alternating stress intensity S_{alt} in accordance with Section III Appendices, Mandatory Appendix XIII, XIII-2400.

(2) Local Structural Discontinuities. These effects shall be evaluated by the use of theoretical stress concentration factors for all conditions, except that experimentally determined fatigue strength reduction factors may be used when stated herein or when determined in accordance with the procedures of Section III Appendices, Mandatory Appendix II, II-1600. Except for the case of crack-like defects and specific piping geometries for which specific values are given in Division 1, NB-3680, no fatigue strength reduction factor greater than five need be used.

(3) Design Fatigue Curves. Section III Appendices, Mandatory Appendix I (and the extended fatigue curves from Tables HGB-II-3222.4-1 through HGB-II-3222.4-4) contain the applicable fatigue design curves for the materials permitted by this Appendix. When more than one curve is presented for a given material, the applicability of each curve to material of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein, the strength level is the specified minimum room temperature value.

(4) Effect of Elastic Modulus. Multiply S_{alt} (see Section III Appendices, Mandatory Appendix XIII, XIII-2410 or XIII-2420) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I (and the extended fatigue curve from Tables HGB-II-3222.4-1 through HGB-II-3222.4-4) at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one that produces significant fluctuating stresses, this is the allowable number of cycles.

(5) Cumulative Damage. If there are two or more types of stress cycle that produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

Step 1. Designate the specified number of times each type of stress cycle of types 1, 2, 3, etc., will be repeated during the life of the component as n_1, n_2, n_3, ..., n_n, respectively.

NOTE: In determining n_1, n_2, n_3, ..., n_n, consideration shall be given to the superposition of cycles of various origins that produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to −50,000 psi, the two types of cycle to be considered are defined by the following parameters:

(a) Type 1 cycle: n_1 = 1,000, S_{alt1} = (60,000 + 50,000)/2 = 55,000 psi

(b) Type 2 cycle: n_2 = 9,000, S_{alt2} = (50,000 + 0)/2 = 25,000 psi

Step 2. For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of Section III Appendices, Mandatory Appendix XIII, XIII-2410 or XIII-2420. Call these quantities S_{alt1}, S_{alt2}, S_{alt3}, ..., S_{altn}.

Step 3. For each value S_{alt1}, S_{alt2}, S_{alt3}, ..., $S_{alt\ n}$, use the applicable design fatigue curve to determine the maximum number of repetitions that would be allowable if this type of cycle were the only one acting. Call these values N_1, N_2, N_3, ..., N_n.

Step 4. For each type of stress cycle, calculate the usage factors U_1, U_2, U_3, ..., U_n from $U_1 = n_1/N_1$, $U_2 = n_2/N_2$, $U_3 = n_3/N_3$, ..., $U_n = n_n/N_n$.

Step 5. Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + ... + U_n$.

Step 6. The cumulative usage factor U shall not exceed 1.0.

(23) **HGB-II-3224**

For elevated temperature service, the applicable rules of Section III Appendices, Mandatory Appendix XIII, XIII-3100 for core support structures are modified as follows:

For Section III Appendices, Mandatory Appendix XIII, Figure XIII-II-3, add Note (2) to "Membrane + Bending": "For elevated temperature applications, the S_u values are obtained from Tables HGB-II-3229-4 through HGB-II-3229-6 of this Appendix."

(23) **HGB-II-3224.1 Stress Intensity Limits.**

(a) Elastic Analysis Method

(1) The general primary membrane stress intensity [see Section III Appendices, Mandatory Appendix XIII, XIII-1300(p), XIII-1300(y), and XIII-3110] shall not exceed 1.5 times the allowable stress intensity S_m as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(2) The primary membrane plus primary bending stress intensity [see Section III Appendices, Mandatory Appendix XIII, XIII-1300(a), XIII-1300(y), and XIII-3130] shall not exceed 2.25 times the allowable stress intensity S_m as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) Limit Load Analysis. Instead of the elastic analysis of (a), a limit load analysis may be performed as set forth below.

(1) The lower bound collapse load is determined with material yield point equal to 1.5 times the allowable stress intensity S_m at temperatures where S_m is given in Section II, Part D, Subpart 1, Tables 2A and 2B. The lower bound collapse load [see Section III Appendices, Mandatory Appendix XIII, XIII-1300(b)] is that load, determined from the analysis [see Section III Appendices, Mandatory Appendix XIII, XIII-1300(l)] of an ideally plastic (nonstrain-hardening) material, which produces increasing deformations with no further increase in applied load. The lower bound collapse load is one in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength, using either the maximum shear stress theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.

(2) For Service Loadings for which Level C Limits are designated, the general primary membrane stress intensity shall not exceed the lower bound collapse load.

(3) For Service Loadings for which Level C Limits are designated, the general primary membrane plus primary bending stress intensities shall not exceed the lower bound collapse load.

(c) Plastic Analysis. Instead of the elastic analysis of (a), a plastic analysis may be performed as set forth in (1) and (2) below.

(1) For Service Loadings for which Level C Limits are designated, general primary membrane stress intensity values shall not exceed 1.5 times the allowable stress intensity S_m at temperatures where S_m is given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(2) For Service Loadings for which Level C Limits are designated, the general primary membrane plus primary bending stress intensities shall not exceed the greater of either one-half of the ultimate strength values at temperature or 2.25 times the allowable stress intensity values S_m at temperature as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(d) Stress Ratio Analysis. Instead of the elastic analysis of (a), a stress ratio analysis may be performed, in which event the limits of (1) and (2) below shall be met.

(1) Service loads producing primary membrane stresses shall not result in stress intensities exceeding S_E where $S_E \le 2.0\ S_m$.

(2) The stress intensity limits for other stress fields shall be as specified in Section III Appendices, Nonmandatory Appendix A, Article A-9000. For example, for bending:

$$P_B \le S_E[1 - (P_m/S_E)^2]$$

for rectangular sections, where

$$n = 2 \text{ or } P_B \le \sqrt{K^2 S_E(S_E - P_m)}$$

where K is the Section Factor for n = 1 as determined by the method of Section III Appendices, Nonmandatory Appendix A, Article A-9000.

The application of this method of analysis to applications where all of the following conditions exist may produce an invalid and unconservative result:

(-a) a low yield-strength-to-ultimate-tensile-strength ratio

(-b) a high uniform elongation value

(-c) a cross section that can distort under load in a manner that reduces the moment of inertia or that increases the loading on the structure

(e) Prototype or Model Tests. For Service Loadings for which Level C Limits are designated, the limits of (a) need not be satisfied if it can be shown from the test of a prototype or model that the specified loads (dynamic or static equivalent) do not exceed 60% of L_e, where L_e is the ultimate load or the maximum load or load combination used in the test. In using this method, account shall be taken of the size effect and dimensional tolerances that exist between the actual part and the test part or parts, as well as differences that may exist in the ultimate strength or other governing material properties of the actual part and the tested parts, to assure that the loads obtained from the test are a conservative representation of the load-carrying capability of the actual structure under postulated Service Loadings for which Level C Limits are designated.

HGB-II-3228

(23) **HGB-II-3228.3 Simplified Elastic–Plastic Analysis.** The $3S_m$ limit on the range of primary plus secondary stress intensity (see Section III Appendices, Mandatory Appendix XIII, XIII-3420) may be exceeded, provided that the requirements of (a) through (e) below are met.

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be ≤ $3S_m$.

(b) The value of S_{alt} used for entering the design fatigue curve is multiplied by the factor K_e where

$$
\begin{aligned}
K_e &= 1.0 \text{ for } S_n \leq 3S_m \\
&= 1.0 + [(1 - n)/n(m - 1)][(S_n/3S_m) - 1] \\
&\quad \text{for } 3S_m < S_n < 3mS_m \\
&= 1/n \text{ for } S_n \geq 3mS_m \\
S_n &= \text{range of primary plus secondary stress intensity}
\end{aligned}
$$

The values of the material parameters m and n for the various classes of permitted materials are as follows:

Material	Condition	Applicable Line in Figure HGB-IV-1000-1	m	n
$1^1/_4$Cr–$^1/_2$Mo–Si	...	B	2.0	0.2
$2^1/_4$Cr–1Mo	...	B	2.0	2.0
18Cr–8Ni	Solution treated	E	1.7	0.3
16Cr–12Ni–2Mo	Solution treated	F	1.7	0.3
42Fe–33Ni–21Cr (Alloy 800H)	...	G	1.7	0.3

(c) The rest of the fatigue evaluation stays the same as required in HGB-II-3222.4 of this Appendix, except that the procedure of Section III Appendices, Mandatory Appendix XIII, XIII-2500 need not be used.

(d) The structure meets the thermal ratcheting requirement of Section III Appendices, Mandatory Appendix XIII, XIII-3430.

(e) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

HGB-II-3229 Design Stress Values (23)

The design stress intensity values, S_m, are given in Section II, Part D, Subpart 1, Tables 2A and 2B for core support structure material. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Section II, Part D, Subpart 1, Table Y-1. Values of the coefficient of thermal expansion are in Section II, Part D, Subpart 2, Table TE, and values of the modulus of elasticity are in Section II, Part D, Subpart 2, Table TM. The basis for establishing stress intensity values is given in Section II, Part D, Mandatory Appendix 2. The design fatigue curves used in conjunction with Section III Appendices, Mandatory Appendix XIII, XIII-3500 are those of Section III Appendices, Mandatory Appendix I (and the extended fatigue curves from Tables HGB-II-3222.4-1 through HGB-II-3222.4-4).

The design stress intensity values in Section II, Part D, Subpart 1, Tables 2A and 2B may be extended to elevated temperatures using the values in Tables HGB-II-2121-1 and HGB-II-2121-3 of this Appendix, provided the time–temperature requirements of Mandatory Appendix HGB-IV are satisfied, and the materials of construction meet the requirements of the specifications given in Tables HGB-II-2121-1 and HGB-II-2121-3 of this Appendix. The yield strength values of Section II, Part D, Subpart 1, Table Y-1 may be extended to elevated temperatures using the values in Tables HGB-II-3229-1 and HGB-II-3229-3 of this Appendix. In evaluating the functional adequacy of the core support structure, the N Certificate Holder shall account for the plastic strain that is associated with the S_m limits for materials to which Note (3) of Table HGB-II-2121-3 applies. For elevated temperature applications, the extended elevated temperature S_u values are obtained from Tables HGB-II-3229-4 and HGB-II-3229-6 of this Appendix.

HGB-II-3230

HGB-II-3231 Design Conditions (23)

(a) The rules of this paragraph apply to mechanical connections joining parts in core support structures located within a pressure-retaining boundary. Devices that are used to assemble structural elements of core support structures are referred to as threaded structural fasteners. The design stress intensity values, S_m, and yield strength values, S_y, for threaded structural fasteners shall be the values given in Section II, Part D, Subpart 1, Tables 2A and 2B and in Section II, Part D, Subpart 1, Table Y-1, respectively. Section II, Part D, Subpart 1, Tables 2A, 2B, and Y-1 shall be extended to elevated temperatures using Tables HGB-II-2121-2, HGB-II-2121-4, HGB-II-3229-2, and HGB-II-3229-3 of this Appendix when the material

meets the requirements of the specifications in Tables HGB-II-2121-2 and HGB-II-2121-4, and, in addition, the requirements of Mandatory Appendix HGB-IV are satisfied. For elevated temperature applications, the extended elevated temperature S_u values are obtained from Tables HGB-II-3229-5 and HGB-II-3229-6 of this Appendix.

(b) The special stress limits of Division 1, NG-3210(a) do not apply to threaded structural fasteners. For connections joining parts of pressure-retaining boundaries, see Section III Appendices, Mandatory Appendix XIII, XIII-4000.

(c) In evaluating the functional adequacy of threaded structural fasteners, the N Certificate Holder shall account for the plastic strain that is associated with the S_m limits for materials to which Note (4) of Table HGB-II-2121-4 applies.

Table HGB-II-3222.4-1
Design Fatigue Limits for Solution Annealed Type 304 SS

U.S. Customary Units

Number of Cycles, N_d	Allowable Stress Amplitude, S_a, ksi						
	100°F	800°F	900°F	1,000°F	1,100°F	1,200°F	1,300°F
10^1	663	650	605	553	497	436	386
2×10^1	468	449	410	369	325	282	242
4×10^1	342	320	289	256	221	190	160
10^2	234	213	190	166	143	121	100
2×10^2	185	163	143	125	107	89.7	74.1
4×10^2	147	125	110	95.6	81.9	68.3	57.6
10^3	110	94.3	81.9	71.5	61.1	50.1	43.3
2×10^3	87.1	76.7	66.3	58.5	49.4	41.0	35.9
4×10^3	70.9	63.1	54.6	48.5	41.6	34.2	29.9
10^4	55.9	50.1	43.6	38.7	33.8	28.0	24.1
2×10^4	48.1	42.9	37.7	33.3	29.4	24.3	20.5
4×10^4	41.6	37.3	33.0	29.1	25.6	21.1	17.9
10^5	35.4	31.5	27.7	24.4	21.3	18.2	15.2
2×10^5	31.2	28.0	24.7	21.7	18.9	16.0	13.7
4×10^5	28.0	25.0	22.1	19.5	16.9	14.3	12.2
10^6	22.0	22.0	19.4	16.9	14.6	12.7	10.9

SI Units

Number of Cycles, N_d	Allowable Stress Amplitude, S_a, MPa						
	40°C	425°C	480°C	540°C	595°C	650°C	705°C
10^1	4 571	4 482	4 168	3 809	3 424	3 003	2 662
2×10^1	3 227	3 092	2 824	2 546	2 241	1 945	1 667
4×10^1	2 357	2 205	1 990	1 766	1 524	1 309	1 103
10^2	1 613	1 470	1 309	1 147	986	834	690
2×10^2	1 273	1 120	986	860	735	618	511
4×10^2	1 013	865	757	659	565	471	397
10^3	757	650	565	493	421	345	298
2×10^3	601	529	457	403	341	282	247
4×10^3	489	435	376	334	287	236	206
10^4	385	345	300	267	233	193	166
2×10^4	332	296	260	229	203	168	142
4×10^4	287	257	228	201	177	145	124
10^5	244	217	191	169	147	125	105
2×10^5	215	193	170	150	130	110	94.1
4×10^5	193	172	152	134	117	98.6	84.3
10^6	151	151	134	117	100	87.8	75.3

GENERAL NOTE: $E = 26 \times 10^6$ psi (178×10^3 MPa)

Table HGB-II-3222.4-2
Design Fatigue Limits for Solution Annealed Type 316 SS

U.S. Customary Units

Number of Cycles, N_d	Allowable Stress Amplitude, S_a, ksi				
	100°F	800°F	900°F	1,000°F Through 1,200°F	1,300°F
10^1	659	569	491	413	278
2×10^1	464	413	326	270	194
4×10^1	338	303	235	192	137
10^2	230	207	160	127	92.4
2×10^2	181	163	125	96.7	71.6
4×10^2	143	124	98.9	74.6	56.0
10^3	106	93.1	74.2	55.1	42.6
2×10^3	83.6	75.5	60.6	44.1	34.8
4×10^3	67.3	61.9	49.5	36.3	29.4
10^4	52.4	48.9	39.1	28.7	24.2
2×10^4	44.6	41.1	33.3	24.2	21.1
4×10^4	38.1	35.5	28.7	20.9	18.7
10^5	31.9	29.4	23.7	17.7	15.7
2×10^5	27.7	25.5	20.7	15.7	14.0
4×10^5	24.4	22.5	18.1	14.2	12.4
10^6	21.2	19.6	15.3	12.5	10.8

SI Units

Number of Cycles, N_d	Allowable Stress Amplitude, S_a, MPa				
	40°C	425°C	480°C	540°C Through 650°C	705°C
10^1	4 544	3 926	3 388	2 850	1 918
2×10^1	3 200	2 850	2 250	1 864	1 336
4×10^1	2 331	2 088	1 622	1 327	941
10^2	1 587	1 425	1 103	873	637
2×10^2	1 246	1 120	861	667	494
4×10^2	986	857	682	515	386
10^3	733	642	512	380	294
2×10^3	576	521	418	304	240
4×10^3	464	427	342	250	203
10^4	361	337	270	198	167
2×10^4	307	283	229	167	145
4×10^4	263	245	198	144	129
10^5	220	203	163	122	108
2×10^5	191	176	143	108	96.8
4×10^5	169	155	125	97.7	85.5
10^6	146	135	106	86.3	74.8

GENERAL NOTE: $E = 26 \times 10^6$ psi (178×10^3 MPa)

Table HGB-II-3222.4-3
Design Fatigue Limits for Ni–Cr–Fe Alloy 800H

U.S. Customary Units

Number of Cycles, N_d	Allowable Stress Amplitude, S_a, ksi			
	800°F	1,000°F	1,200°F	1,400°F
10^1	650	551	444	369
2×10^1	471	356	286	238
4×10^1	351	240	193	160
10^2	239	151	121	101
2×10^2	185	110	88.1	73.1
4×10^2	147	85.8	69.3	61.0
10^3	109	67.0	54.2	50.4
2×10^3	89.1	59.0	47.6	45.4
3×10^3	83.7	56.3	45.1	40.2
4×10^3	74.4	53.2	42.5	35.1
10^4	58.8	38.1	30.4	27.6
2×10^4	51.0	31.6	25.6	23.8
4×10^4	44.6	27.6	22.8	21.3
10^5	37.4	25.2	20.2	19.4
2×10^5	33.0	24.2	19.1	18.2
4×10^5	29.8	23.1	18.2	17.2
10^6	26.0	22.0	17.0	15.9

SI Units

Number of Cycles, N_d	Allowable Stress Amplitude, S_a, MPa			
	425°C	540°C	650°C	760°C
10^1	4 482	3 801	3 060	2 547
2×10^1	3 245	2 452	1 971	1 639
4×10^1	2 420	1 657	1 329	1 105
10^2	1 649	1 043	835	694
2×10^2	1 273	761	608	504
4×10^2	1 013	592	478	420
10^3	754	462	374	348
2×10^3	614	407	328	313
3×10^3	577	388	311	277
4×10^3	513	367	293	242
10^4	405	263	210	190
2×10^4	351	218	177	164
4×10^4	307	190	157	147
10^5	258	174	139	134
2×10^5	228	167	132	125
4×10^5	205	160	125	118
10^6	179	151	117	109

GENERAL NOTE: $E = 26 \times 10^6$ psi (178×10^3 MPa)

Table HGB-II-3222.4-4
Design Fatigue Limits for 2¼Cr–1Mo Steel

U.S. Customary Units

Number of Cycles, N_d [Note (1)]	Allowable Stress Amplitude, S_a, ksi	
	800°F	900°F Through 1,100°F
10^1	728	520
4×10^1	299	212
10^2	169	126
2×10^2	122	91.0
4×10^2	91.0	72.8
10^3	67.6	54.6
2×10^3	57.2	50.7
4×10^3	52.0	45.5
10^4	41.6	34.5
2×10^4	33.8	28.0
4×10^4	29.9	23.7
10^5	25.4	20.5
2×10^5	22.5	18.5
4×10^5	20.2	16.9
10^6	17.8	15.3

SI Units

Number of Cycles, N_d [Note (1)]	Allowable Stress Amplitude, S_a, MPa	
	425°C	480°C Through 595°C
10^1	5 020	3 585
4×10^1	2 062	1 461
10^2	1 165	869
2×10^2	843	627
4×10^2	627	502
10^3	466	376
2×10^3	394	350
4×10^3	359	314
10^4	287	238
2×10^4	233	193
4×10^4	206	163
10^5	175	142
2×10^5	155	127
4×10^5	139	117
10^6	123	106

GENERAL NOTE: $E = 26 \times 10^6$ psi (178×10^3 MPa)

NOTE:
(1) Cycle strain rate: 4×10^{-3} in./in./sec (m/m/s).

Table HGB-II-3229-1
Yield Strength Values, S_y, for Ferritic Steels at Elevated Temperatures in Core Support Structure Applications

U.S. Customary Units, ksi

Material	P-No.	Gr. No.	Product Form	Spec. No.	Type	Class	RT S_y/S_u, ksi	Temperature, °F 750	800	850	900	950	1,000	1,050	1,100
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Forgings	SA-182	F11	2	40/70	(See Section II, Part D, Subpart 1, Table Y-1)						...	...
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Plate	SA-387	11	2	45/75	(See Section II, Part D, Subpart 1, Table Y-1)						...	...
$2^1/_4$Cr–1Mo	5A	1	Wld. P.	SA-691	$2^1/_4$CR	...	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Smls. T.	SA-213	T22	...	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Smls. P.	SA-335	P22	...	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-336	F22	1	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Forg. P.	SA-369	FP22	...	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-182	F22	1	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Fittings	SA-234	WP22	1	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Wld. F.	SA-234	WP22	1/W	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	30/60	(See Section II, Part D, Subpart 1, Table Y-1)						22.4	20.6
$2^1/_4$Cr–1Mo	5A	1	Cast. P.	SA-426	CP22	...	40/70	(See Section II, Part D, Subpart 1, Table Y-1)						25.6	23.0

Table HGB-II-3229-1
Yield Strength Values, S_y, for Ferritic Steels at Elevated Temperatures in Core Support Structure Applications (Cont'd)

SI Units, MPa

Material	P-No.	Gr. No.	Product Form	Spec. No.	Type	Class	RT S_y/S_u, MPa	400	425	450	475	500	525	550	575	600
								Temperature, °C								
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Forgings	SA-182	F11	2	275/485	(See Section II, Part D, Subpart 1, Table Y-1)						...	...	...
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Plate	SA-387	11	2	310/515	(See Section II, Part D, Subpart 1, Table Y-1)						...	...	...
$2^1/_4$Cr–1Mo	5A	1	Wld. P.	SA-691	$2^1/_4$CR	...	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Smls. T.	SA-213	T22	...	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Smls. P.	SA-335	P22	...	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-336	F22	1	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Forg. P.	SA-369	FP22	...	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-182	F22	1	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Fittings	SA-234	WP22	1	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Wld. F.	SA-234	WP22	1/W	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	205/415	(See Section II, Part D, Subpart 1, Table Y-1)						159	150	139
$2^1/_4$Cr–1Mo	5A	1	Cast. P.	SA-426	CP22	...	275/485	(See Section II, Part D, Subpart 1, Table Y-1)						184	170	154

GENERAL NOTES:

(a) The tabulated values of tensile strength and yield strength are those that the Committee believes are suitable for use in design calculations required by this Appendix. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value that may be as much as 10% above the tensile strength adjusted to the minimum specified room temperature strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either "average" or "minimum," as these terms are applied to a statistical treatment of a homogeneous set of data.

(b) Neither the ASME Material Specifications nor the rules of this Appendix require elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that the results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means shall be considered.

(c) The following are the abbreviations used for Product Form:

(1) Wld. P – Welded Pipe
(2) Forg. P. – Forged Pipe
(3) Cast P. – Cast Pipe
(4) Smls. P. – Seamless Pipe
(5) Smls. T. – Seamless Tube
(6) Wld. F. – Welded Fitting

Table HGB-II-3229-2
Yield Strength Values, S_y, for Ferritic Steels at Elevated Temperatures in Threaded Structural Fastener Applications

U.S. Customary Units, ksi

Material	Specification	Notes	Type	Class	Size/Thickness, in.	RT S_y, ksi	Temperature, °F 750	800	850	900	950	1,000	1,050
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	$4 < t \le 7$	85	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	$2½ < t \le 4$	95	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	≤ 2½	105	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	$2 < t \le 8$	100	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	≤ 2	105	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	4	≤ 6	120	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	3	≤ 6	130	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	2	≤ 4	140	(See Section II, Part D, Subpart 1, Table Y-1)						...
2$^1/_4$Cr–1Mo	SA-336	...	F22	1	...	30	(See Section II, Part D, Subpart 1, Table Y-1)						...

Table HGB-II-3229-2
Yield Strength Values, S_y, for Ferritic Steels at Elevated Temperatures in Threaded Structural Fastener Applications (Cont'd)

SI Units, MPa													
							Temperature, °C						
Material	Specification	Notes	Type	Class	Size / Thickness, mm	RT S_y, MPa	400	425	450	475	500	525	550
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	100 < t ≤ 175	585	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	64 < t ≤ 100	655	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	≤ 64	725	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	50 < t ≤ 200	690	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	≤ 50	725	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	4	≤ 150	825	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	3	≤ 150	895	(See Section II, Part D, Subpart 1, Table Y-1)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	2	≤ 100	965	(See Section II, Part D, Subpart 1, Table Y-1)						...
2$^1/_4$Cr–1Mo	SA-336	...	F22	1	...	205	(See Section II, Part D, Subpart 1, Table Y-1)						...

GENERAL NOTES:

(a) The tabulated values of tensile strength and yield strength are those that the Committee believes are suitable for use in design calculations required by this Appendix. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value that may be as much as 10% above the tensile strength adjusted to the minimum specified room temperature strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either "average" or "minimum," as these terms are applied to a statistical treatment of a homogeneous set of data.

(b) Neither the ASME Material Specifications nor the rules of this Appendix require elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that the results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means shall be considered.

NOTES:

(1) The minimum tempering or aging temperature is 1,200°F (650°C).

(2) The minimum tempering or aging temperature is 850°F (455°C).

Table HGB-II-3229-3
Yield Strength Values, S_y, for Austenitic and High Nickel Alloys at Elevated Temperatures in Core Support Structure and Threaded Structural Fastener Applications

U.S. Customary Units, ksi

Material	Product Form	RT S_y, ksi	Temperature, °F 850	900	950	1,000	1,050	1,100	1,150	1,200
304 SS	Wrought	30	(See Section II, Part D, Subpart 1, Table Y-1)				…	…	…	…
316 SS	Wrought	30	(See Section II, Part D, Subpart 1, Table Y-1)				16.7	16.5	…	…
Alloy 800H	Wrought	25	(See Section II, Part D, Subpart 1, Table Y-1)				15.8	15.6	15.5	15.3

SI Units, MPa

Material	Product Form	RT S_y, MPa	Temperature, °C 450	475	500	525	550	575	600	625	650
304 SS	Wrought	205	(See Section II, Part D, Subpart 1, Table Y-1)				…	…	…	…	…
316 SS	Wrought	205	(See Section II, Part D, Subpart 1, Table Y-1)				117	114	…	…	…
Alloy 800H	Wrought	170	(See Section II, Part D, Subpart 1, Table Y-1)				110	108	107	107	106

GENERAL NOTES:

(a) The tabulated values of tensile strength and yield strength are those that the Committee believes are suitable for use in design calculations required by this Appendix. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value that may be as much as 10% above the tensile strength trend curve adjusted to the minimum specified room temperature tensile strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either "average" or "minimum," as these terms are applied to a statistical treatment of a homogeneous set of data.

(b) Neither the ASME Material Specifications nor the rules of this Appendix require elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that the results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means shall be considered.

Table HGB-II-3229-4
Tensile Strength Values, S_u, for Ferritic Steels at Elevated Temperatures in Core Support Structure Applications

U.S. Customary Units, ksi

Material	P-No.	Gr. No.	Product Form	Spec. No.	Type	Class	RT S_y/S_u, ksi	Temperature, °F 750	800	850	900	950	1,000	1,050
$1^1/_4$Cr-$^1/_2$Mo-Si	4	1	Forgings	SA-182	F11	2	40/70	(See Section II, Part D, Subpart 1, Table U)						...
$1^1/_4$Cr-$^1/_2$Mo-Si	4	1	Plate	SA-387	11	2	45/75	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Wld. P.	SA-691	$2^1/_4$CR	...	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Smls. T.	SA-213	T22	...	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Smls. P.	SA-335	P22	...	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Forgings	SA-336	F22	1	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Forg. P.	SA-369	FP22	...	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Forgings	SA-182	F22	1	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Fittings	SA-234	WP22	1	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Wld. F.	SA-234	WP22	1/W	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Plate	SA-387	22	1	30/60	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr-1Mo	5A	1	Cast P.	SA-426	CP22	...	40/70	(See Section II, Part D, Subpart 1, Table U)						...

Table HGB-II-3229-4
Tensile Strength Values, S_u, for Ferritic Steels at Elevated Temperatures in Core Support Structure Applications (Cont'd)

SI Units, MPa

Material	P-No.	Gr. No.	Product Form	Spec. No.	Type	Class	RT S_y/S_u, MPa	Temperature, °C 400	425	450	475	500	525	550
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Forgings	SA-182	F11	2	275/485	(See Section II, Part D, Subpart 1, Table U)						...
$1^1/_4$Cr–$^1/_2$Mo–Si	4	1	Plate	SA-387	11	2	310/515	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Wld. P.	SA-691	$2^1/_4$CR	...	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Smls. T.	SA-213	T22	...	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Smls. P.	SA-335	P22	...	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-336	F22	1	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Forg. P.	SA-369	FP22	...	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Forgings	SA-182	F22	1	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Fittings	SA-234	WP22	1	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Wld. F.	SA-234	WP22	1/W	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Plate	SA-387	22	1	205/415	(See Section II, Part D, Subpart 1, Table U)						...
$2^1/_4$Cr–1Mo	5A	1	Cast P.	SA-426	CP22	...	275/485	(See Section II, Part D, Subpart 1, Table U)						...

GENERAL NOTES:

(a) The tabulated values of tensile strength and yield strength are those that the Committee believes are suitable for use in design calculations required by this Appendix. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value that may be as much as 10% above the tensile strength adjusted to the minimum specified room temperature strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either "average" or "minimum," as these terms are applied to a statistical treatment of a homogeneous set of data.

(b) Neither the ASME Material Specifications nor the rules of this Appendix require elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that the results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means shall be considered.

(c) The following are the abbreviations used for Product Form:

(1) Wld. P – Welded Pipe
(2) Forg. P. – Forged Pipe
(3) Cast P. – Cast Pipe
(4) Smls. P. – Seamless Pipe
(5) Smls. T. – Seamless Tube
(6) Wld. F. – Welded Fitting

Table HGB-II-3229-5
Tensile Strength Values, S_u, for Ferritic Steels at Elevated Temperatures in Threaded Structural Fastener Applications

U.S. Customary Units, ksi

Material	Specification	Notes	Type	Class	Size/Thickness, in.	RT S_u, ksi	Temperature, °F 750	800	850	900	950	1,000	1,050
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	$4 < t \le 7$	100	(See Section II, Part D, Subpart 1, Table U)						...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	$2^1/_2 < t \le 4$	110	(See Section II, Part D, Subpart 1, Table U)						...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	$\le 2^1/_2$	125	(See Section II, Part D, Subpart 1, Table U)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	$2 < t \le 8$	115	(See Section II, Part D, Subpart 1, Table U)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	≤ 2	120	(See Section II, Part D, Subpart 1, Table U)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	4	≤ 6	135	(See Section II, Part D, Subpart 1, Table U)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	3	≤ 6	145	(See Section II, Part D, Subpart 1, Table U)						...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	2	≤ 4	155	(See Section II, Part D, Subpart 1, Table U)						...
2$^1/_4$Cr–1Mo	SA-336	...	F22	1	...	60	(See Section II, Part D, Subpart 1, Table U)						...

SI Units, MPa

Material	Specification	Notes	Type	Class	Size/Thickness, mm	RT S_u, MPa	Temperature, °C 400	425	450	475	500	525	550	575
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	$100 < t \le 175$	690	(See Section II, Part D, Subpart 1, Table U)						...	...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	$64 < t \le 100$	760	(See Section II, Part D, Subpart 1, Table U)						...	...
1Cr–$^1/_2$Mo–V	SA-193	(1)	B16	...	≤ 64	860	(See Section II, Part D, Subpart 1, Table U)						...	...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	$50 < t \le 200$	795	(See Section II, Part D, Subpart 1, Table U)						...	...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	5	≤ 50	825	(See Section II, Part D, Subpart 1, Table U)						...	...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	4	≤ 150	930	(See Section II, Part D, Subpart 1, Table U)						...	...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	3	≤ 150	1000	(See Section II, Part D, Subpart 1, Table U)						...	...
1Cr–$^1/_2$Mo–V	SA-540	(2)	B21	2	≤ 100	1070	(See Section II, Part D, Subpart 1, Table U)						...	...
2$^1/_4$Cr–1Mo	SA-336	...	F22	1	...	415	(See Section II, Part D, Subpart 1, Table U)						...	...

GENERAL NOTES:

(a) The tabulated values of tensile strength and yield strength are those that the Committee believes are suitable for use in design calculations required by this Appendix. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value that may be as much as 10% above the tensile strength adjusted to the minimum specified room temperature strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either "average" or "minimum," as these terms are applied to a statistical treatment of a homogeneous set of data.

(b) Neither the ASME Material Specifications nor the rules of this Appendix require elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that the results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means shall be considered.

NOTES:

(1) The minimum tempering or aging temperature is 1,200°F (650°C).

(2) The minimum tempering or aging temperature is 850°F (455°C).

Table HGB-II-3229-6
Tensile Strength Values, S_u, for Austenitic and High Nickel Alloys at Elevated Temperatures in Core Support Structure and Threaded Structural Fastener Applications

U.S. Customary Units, ksi

Material	RT S_u, ksi	850	900	950	1,000	1,050	1,100	1,150	1,200
		Temperature, °F							
304 SS	70	(See Section II, Part D, Subpart 1, Table U)				...	...	...	...
304 SS	75	(See Section II, Part D, Subpart 1, Table U)				...	...	...	...
316 SS	70	(See Section II, Part D, Subpart 1, Table U)				57.0	54.7	...	...
316 SS	75	(See Section II, Part D, Subpart 1, Table U)				61.1	58.6	...	...
Alloy 800H	65	(See Section II, Part D, Subpart 1, Table U)				59.0	58.6	54.0	50.4

SI Units, MPa

Material	RT S_u, MPa	450	475	500	525	550	575	600	625	650
		Temperature, °C								
304 SS	485	(See Section II, Part D, Subpart 1, Table U)				...	...	...	...	...
304 SS	515	(See Section II, Part D, Subpart 1, Table U)				...	...	...	...	...
316 SS	485	(See Section II, Part D, Subpart 1, Table U)				422	397	...	...	...
316 SS	515	(See Section II, Part D, Subpart 1, Table U)				452	426	...	...	...
Alloy 800H	450	(See Section II, Part D, Subpart 1, Table U)				424	412	400	389	382

GENERAL NOTE: The general notes to Table HGB-II-3229-3 also apply to Table HGB-II-3229-6.

ARTICLE HGB-II-4000
FABRICATION AND INSTALLATION REQUIREMENTS

HGB-II-4100

The rules of Division 1, Article NG-4000 apply except as modified below.

HGB-II-4200

HGB-II-4230

HGB-II-4233 Alignment Requirements When Component Inside Surface Is Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with Division 1, NG-4232, alignment of sections shall meet the requirements of (1) and (2) below

(1) See (-a) and (-b) below.

(-a) For circumferential joints, the inside diameters shall match each other within $^{1}/_{16}$ in. (1.5 mm). When the items are aligned concentrically, a uniform mismatch of $^{1}/_{32}$ in. (0.8 mm) all around the joint can result as shown in Division 1, Figure NB-4233(a)-1, sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $^{3}/_{32}$ in. (2.5 mm) as shown in Division 1, Figure NB-4233(a)-1, sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations that do not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits provided the requirements of Division 1, NB-4250 are met.

(-b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints, the misalignment of inside surfaces shall not exceed $^{3}/_{32}$ in. (2.5 mm), and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single-welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of Division 1, NG-4232.

ARTICLE HGB-II-5000
EXAMINATION REQUIREMENTS

The requirements of Division 1, Article NG-5000 shall apply.

MANDATORY APPENDIX HGB-III BUCKLING AND INSTABILITY

ARTICLE HGB-III-1000 GENERAL REQUIREMENTS

(a) The stability limits in Division 1, NG-3133 pertain only to specified geometrical configurations under specific loading conditions. Those limits include the effects of initial geometrical imperfections permitted by fabrication tolerances. However, those limits do not consider the effects of other loads or other geometries or cases where the fabrication tolerances are not satisfied. The rules of this Appendix provide additional limits that are applicable to general configurations and loading conditions that may cause buckling or instability due to time-independent behavior of the material. These additional limits are applicable to all specified Design and Service Loadings.

(b) For the limits specified in Article HGB-III-2000, distinction is made between load-controlled buckling and strain-controlled buckling. Load-controlled buckling is characterized by continued application of an applied load in the post-buckling regime, leading to failure (e.g, collapse of a tube under external pressure). Strain-controlled buckling is characterized by the immediate reduction of strain-induced load upon initiation of buckling, and by the self-limiting nature of the resulting deformations. Even though it is self-limiting, strain-controlled buckling must be avoided to guard against failure of fatigue, excessive strain, and interaction with load-controlled instability.

(c) For conditions under which strain-controlled and load-controlled buckling may interact, the Load Factors applicable to load-controlled buckling shall be used for the combination of load-controlled and strain-controlled loads to guard against buckling in the interactive mode.

(d) For conditions where significant elastic follow-up may occur, the Load Factors applicable to load-controlled buckling shall also be used for strain-controlled buckling.

(e) For load-controlled buckling, the effects of initial geometrical imperfections and tolerances shall be considered in the calculation of the instability load.

(f) For purely strain-controlled buckling, the effects of initial geometrical imperfections and tolerances need not be considered in the calculation of the instability strain.

(g) The expected minimum stress–strain curve for the material at the specified temperatures shall be used.

(h) The limits of either Article HGB-III-2000 or Article HGB-III-3000 shall be satisfied for the specified Design and Service Loadings.

ARTICLE HGB-III-2000
BUCKLING LIMITS: TIME-INDEPENDENT BUCKLING

For load-controlled buckling, the Load Factor, and for strain-controlled buckling, the Strain Factor, shall equal or exceed the values given in Table HGB-III-2000-1 for the specified Design and Service Loadings to guard against time-independent (instantaneous) buckling.

Table HGB-III-2000-1
Time-Independent Buckling Limits

	Load Factor [Note (1)]	Strain Factor [Notes (1), (2), (3)]
Design Limits	3.00	1.67
Service Level Limits		
A	3.00	1.67
B	3.00	1.67
C	2.00	1.40
D	1.25	1.10

NOTES:

(1)
$$\left(\begin{array}{l}\text{Load (or}\\\text{strain)}\\\text{factor}\end{array}\right)=\left(\begin{array}{l}\text{Load (or strain [Note (4)]) that}\\\text{would cause instant}\\\text{instability at the actual}\\\text{design or service}\\\text{temperature}\end{array}\right)\div\left(\begin{array}{l}\text{Design or}\\\text{expected load}\\\text{(or strain [Note (4)])}\end{array}\right)$$

(2) Changes in configuration induced by service need not be considered in calculating the buckling load.

(3) For thermally induced strain-controlled buckling, the Strain Factor is applied to loads induced by thermal strain. To determine the buckling strain, it may be necessary to artificially induce high strains concurrent with the use of realistic stiffness properties. The use of an "adjusted" thermal expansion coefficient is one technique for enhancing the applied strains without affecting the associated stiffness characteristics.

(4) In this case, the strain represents the average membrane strain through the thickness.

ARTICLE HGB-III-3000
ALTERNATIVE PROCEDURES

In lieu of meeting the requirements of Article HGB-III-2000, an evaluation of the stresses, strains, and deformations resulting from buckling may be used to demonstrate that the component has remained structurally and functionally integral. In that evaluation, the specified loads shall be multiplied by the applicable Load Factor of Table HGB-III-2000-1. Nonlinear, plastic, and initial imperfection effects shall be included, if relevant, in the analyses used to determine the structural response to the enhanced load.

MANDATORY APPENDIX HGB-IV TIME–TEMPERATURE LIMITS

ARTICLE HGB-IV-1000 TIME–TEMPERATURE LIMITS

When this Appendix is invoked, the temperature-dependent time-use fraction shall not exceed unity when summed over the entire specified design lifetime

$$\sum_i \left(\frac{t_i}{t_{ai}} \right) \leq 1.00$$

t_{ai} = the maximum allowable time that can be spent at temperature $(T)_i$ without explicitly acknowledging creep and stress rupture. The value of t_{ai} is obtained from the appropriate line on Figure HGB-IV-1000-1. In computing use-fractions, it is permissible to extrapolate the time at elevated temperature $(T)_i$ in Figure HGB-IV-1000-1.

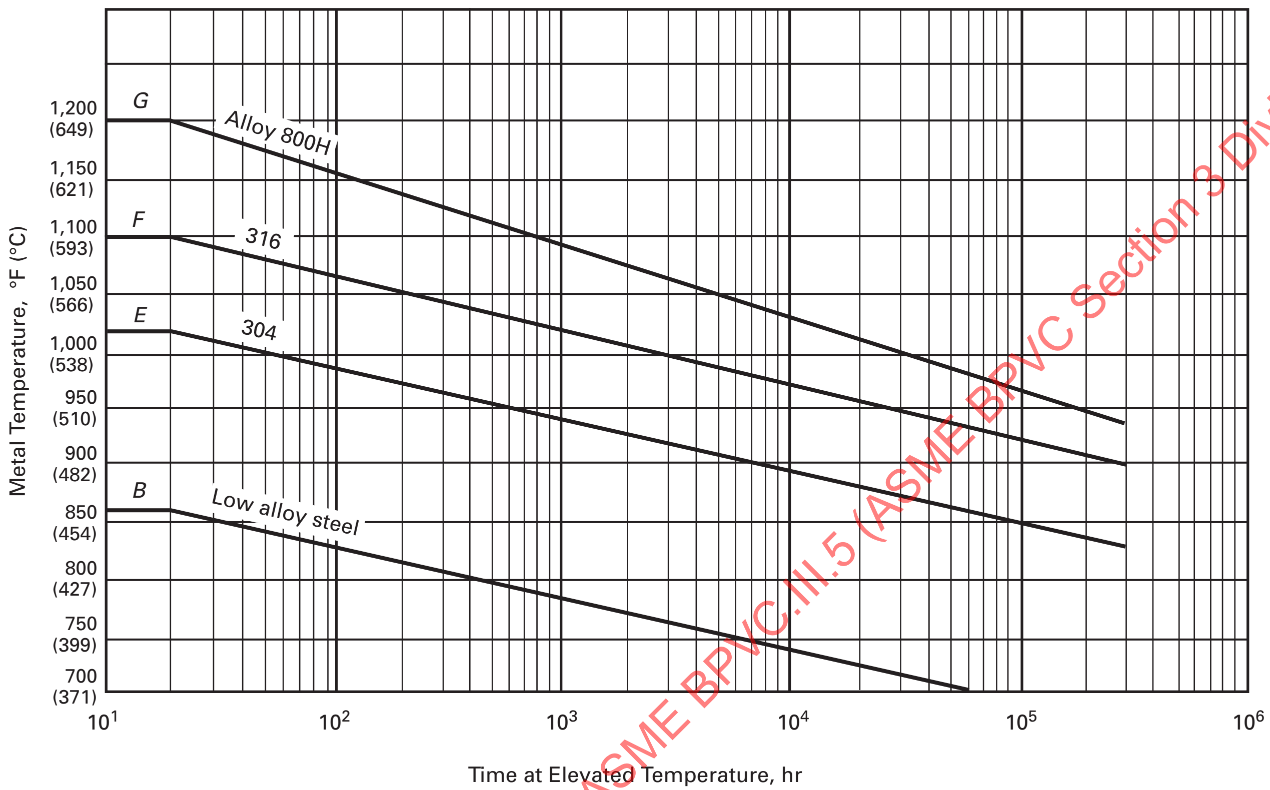
t_i = the total time in the design lifetime spent at the metal temperature, $(T)_i$

Note that the summation over i must encompass the entire design lifetime. Thus $\sum_i t_i$ = specified design lifetime.

This Appendix shall not be used if the specified design lifetime exceeds 300,000 hr.

The criteria for t_{ai} is defined in HBB-T-1324(a) and HBB-T-1324(b).

Figure HGB-IV-1000-1
Time at Elevated Temperature, hr



SUBSECTION HH CLASS SN NONMETALLIC CORE COMPONENTS

SUBPART A GRAPHITE MATERIALS

ARTICLE HHA-1000 INTRODUCTION

HHA-1100 SCOPE

HHA-1110 ASPECTS COVERED

This Subpart establishes rules for Graphite Core Components and Graphite Core Assemblies, where Graphite Core Components are defined as components manufactured from graphite that are installed to form a Graphite Core Assembly within the reactor pressure vessel of a high temperature, graphite moderated fission reactor. The rules cover the following:

(a) materials selection and qualification (see Article HHA-2000)

(b) Graphite Core Component and Graphite Core Assembly design (see Article HHA-3000)

(c) Graphite Core Component machining, examination, and testing (see Article HHA-4000)

(d) Graphite Core Component installation and Graphite Core Assembly examination (see Article HHA-5000)

(e) the preparation of reports (see Article HHA-8000)

The application of these rules is given in HHA-1300. The rules are directed at the integrity and functionality of the individual Graphite Core Components and of the Graphite Core Assembly, and due account shall be taken of the degradation in integrity and functionality as a result of the effects of fast neutron irradiation and oxidation (see HHA-1120). The rules are not intended to ensure sealing against coolant leakage since the Graphite Core Components are not pressure-retaining parts, and need not remain leak tight to perform their function. The same applies to the Graphite Core Assembly.

HHA-1120 ENVIRONMENTAL EFFECTS AND LIMITS

Over the life of the plant, the Graphite Core Components that form the moderator and reflector regions of the Graphite Core Assembly are subject to high fast neutron irradiation fluxes, high temperatures, and a limited amount of oxidation. Nuclear grade graphites are generally tolerant of relatively high fast neutron fluences and of temperatures well in excess of most metallic materials, but the tolerance to oxidation (in terms of strength reduction) is more limited. Appropriate design data for the graphite(s) used shall be available (HHA-1220). For reactor systems where the graphite is in contact with coolants other than gas, the requirements for consideration of coolant interaction with graphite shall be included in the Design Specification.

HHA-1200 REQUIREMENTS

HHA-1210 GENERAL

The general requirements to be satisfied in fulfilling this Subpart are given in Subsection HA, Subpart B.

HHA-1220 MATERIALS

The requirements for the selection and qualification of graphite materials are given in Article HHA-2000. This includes material identification and certification, material properties for design, and material property deterioration during service (due to fast neutron irradiation and oxidation).

HHA-1230 DESIGN

The requirements for the design of Graphite Core Components and Graphite Core Assemblies are given in Article HHA-3000. For the design of Graphite Core Components, the within-billet and billet-to-billet variability in material properties shall be taken into account. Due account shall also be taken of the effects of fast neutron irradiation, irradiation temperature, and oxidation on the appropriate mechanical and thermal properties, and on dimensional change behavior, as well as the design and service loadings. Both probabilistic and deterministic design methodologies are acceptable and therefore covered. In addition, for the design of the Graphite Core Assembly, account shall be taken of the fast neutron irradiation-induced changes in component geometries, which could significantly affect its stability and geometry. These in turn could significantly affect the coolant flow paths, the freedom of movement of fuel and control devices, and the interaction with interfacing metallic components or structures.

HHA-1240 GRAPHITE CORE COMPONENT MACHINING

The requirements for the machining of Graphite Core Components are given in Article HHA-4000. These include requirements for material and Graphite Core Component machining, examination, testing, part acceptance criteria, and the qualification of personnel.

HHA-1250 INSTALLATION

The requirements for the installation of Graphite Core Components to form the Graphite Core Assembly are given in Article HHA-5000. These include requirements for Graphite Core Component storage, unpacking and examination, construction procedures and reporting, examination during installation and post-installation, and the qualification of personnel.

HHA-1260 RESPONSIBILITIES

Responsibilities are defined in Article HAB-3000.

HHA-1300 APPLICATION OF THESE RULES

(a) The rules shall apply to Graphite Core Components utilized in a high temperature, graphite moderated fission reactor. Graphite Core Components include fuel blocks, reflector blocks, shielding blocks, and any keys or dowels used to interconnect them.

(b) The rules shall also apply to the arrangement of Graphite Core Components that form the Graphite Core Assembly.

(c) The rules shall not apply to fuel compacts, bushings, bearings, seals, blanket materials, instrumentation, or components internal to the reactor other than those defined above.

HHA-1400 BOUNDARIES OF JURISDICTION

Figures HHA-1400-1 and HHA-1400-2 are provided as an aid in defining the boundaries of jurisdiction for this Subpart.

HHA-1410 BOUNDARY BETWEEN GRAPHITE CORE COMPONENTS AND CORE SUPPORT STRUCTURES

(a) The jurisdictional boundary between a Graphite Core Component and the metallic core support structure or the metallic/ceramic core restraints (see Figures HHA-1400-1 and HHA-1400-2) shall be the surface of the Graphite Core Component.

(b) Mechanical fasteners (excluding graphite dowels or keys) used to connect a Graphite Core Component to a metallic core support structure or the metallic core restraint cylinder shall be deemed as part of the metallic core support structure or the metallic core restraint cylinder, respectively.

HHA-1420 BOUNDARY BETWEEN GRAPHITE CORE COMPONENTS AND FUEL PEBBLES OR COMPACTS

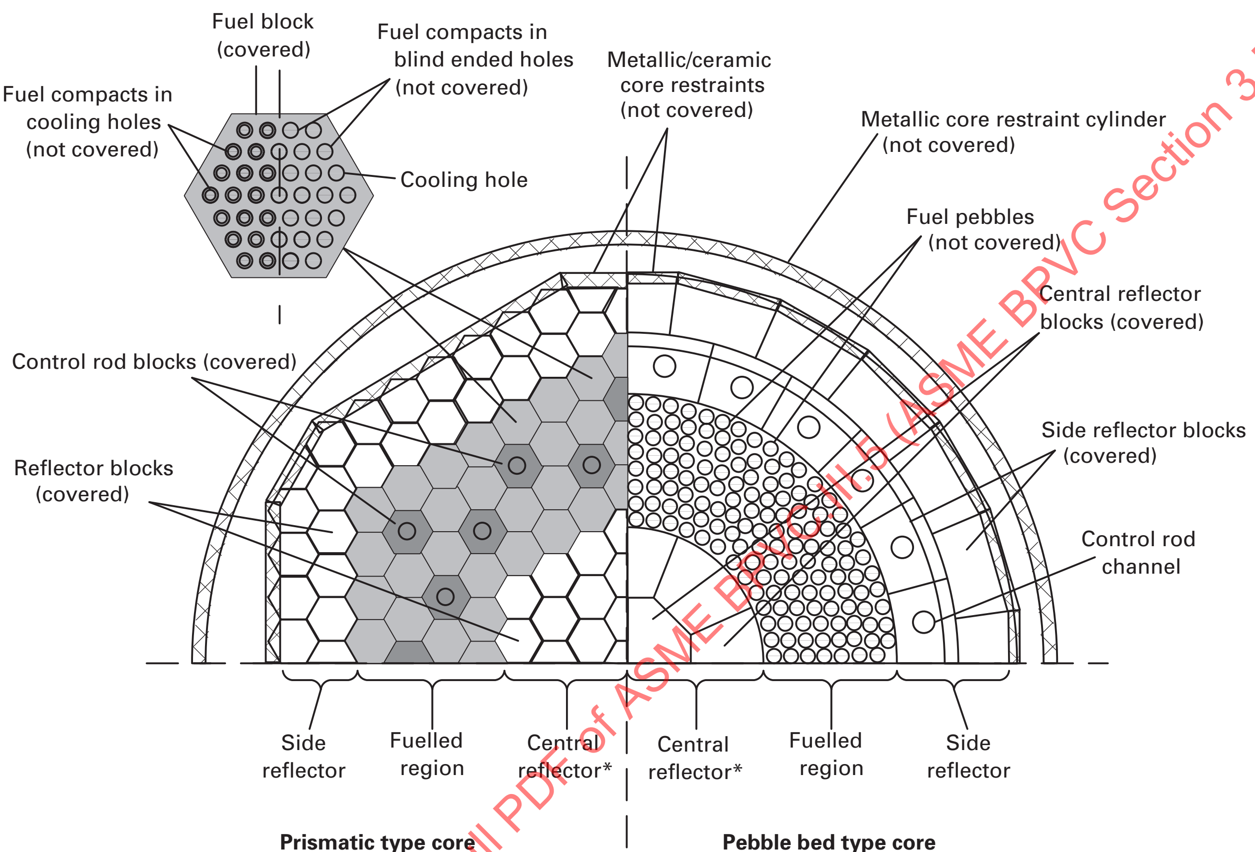
(a) Fuel pebbles and compacts may bear on or be constrained by Graphite Core Components. The surfaces of the Graphite Core Components shall be considered the jurisdictional boundary of this Subpart.

(b) Mechanical fasteners (excluding graphite dowels or keys) used to secure fuel compacts to the Graphite Core Components shall be considered as part of the fuel compacts and as such are outside the jurisdictional boundary of this Subpart.

HHA-1430 OTHER BOUNDARIES

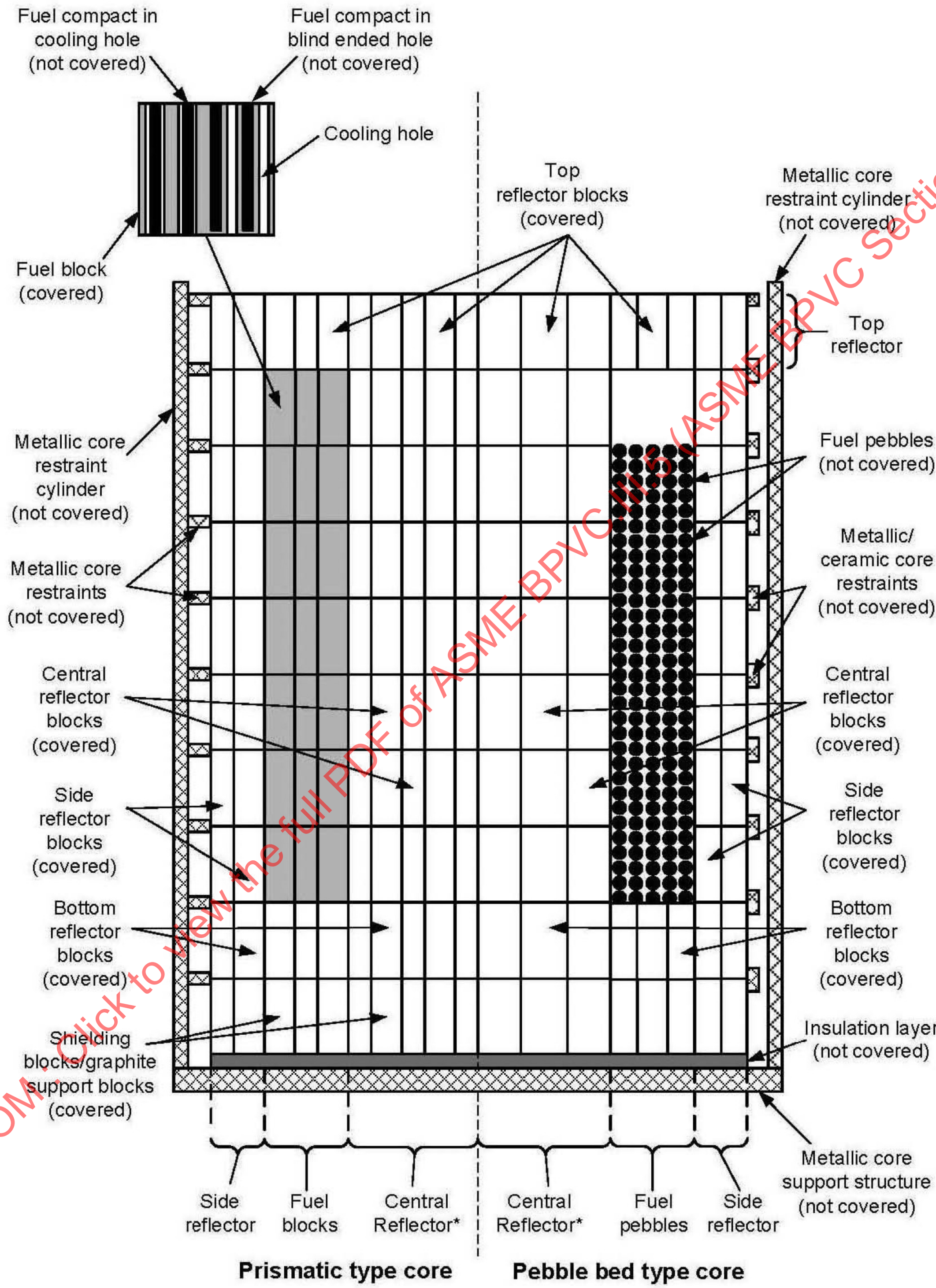
Other boundaries shall be defined in the Design Specification (see HAB-3250).

Figure HHA-1400-1
Jurisdictional Boundary for Graphite Core Components and Assemblies — Circumferential Section View



* Some designs may not have a central reflector i.e., the fuelled region extends to the core centerline

Figure HHA-1400-2
Jurisdictional Boundary for Graphite Core Components and Assemblies — Longitudinal Section View



*Some designs may not have a central reflector (i.e., the fuelled region extends to the core centerline).

ARTICLE HHA-2000 MATERIALS

HHA-2100 GENERAL REQUIREMENTS

HHA-2110 MATERIAL FOR GRAPHITE CORE COMPONENTS

HHA-2111 Permitted Material Specifications

(a) Graphite Core Component material shall conform to the requirements of the material specification(s) given in Mandatory Appendix HHA-I, including all applicable notes in the table of Mandatory Appendix HHA-I, and to all of the special requirements of this Article that apply to the product form in which the material is used.

(b) The specifications in Mandatory Appendix HHA-I provide the minimum requirements.

(c) The Designer may define supplementary requirements in addition to those in the material specification that are transmitted to the Material Manufacturer in the purchasing documents.

HHA-2112 Special Requirements Conflicting With Permitted Specifications

The special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever these special requirements conflict with the material specification requirements. Where the special requirements include an examination, inspection, test, or treatment that is also required by the material specification, the examination, test, or treatment need be performed only once. Nondestructive examinations shall be performed for each product form in accordance with HHA-2500.

HHA-2120 CERTIFICATION OF MATERIAL

All material used in the construction or installation of Graphite Core Assemblies or Graphite Core Components shall be certified in accordance with HAB-3862 and HAB-3861. Certified Material Test Reports (CMTRs) are required for Graphite Core Assemblies or Graphite Core Components material except as provided by HAB-3862. Copies of all Certified Material Test Reports applicable to material used in a Graphite Core Assemblies or Graphite Core Components shall be furnished with the material.

HHA-2121 Application of the Rules of This Subpart

The Material Manufacturer's Certified Material Test Reports shall certify that all requirements of the material specification and all special requirements of this Article that are to be fulfilled by the Material Manufacturer have been met. The Material Manufacturer's Certified Material Test Reports shall include

(a) identification data, including material grade, charge and content of charge, identification, and dimensions of billets in the charge.

(b) certified reports of the actual results of all specified chemical analyses, physical tests, mechanical tests, examinations, and other tests.

(c) a statement giving the manner in which the material is identified, including specific marking.

(d) a statement confirming compliance with all special requirements of this Subpart. A Certified Material Test Report is to be issued for each graphitization charge of graphite material produced.

HHA-2122 Exclusion of Small Products

No graphite components shall be excluded from certification (HHA-2120).

HHA-2130 DETERIORATION OF MATERIALS DURING SERVICE

Materials provided to meet the plant operating conditions specified in the Design Specification shall be evaluated for their adequacy, including deterioration factors that modify the physical and mechanical properties of the material (for example, the effect of neutron irradiation and oxidation).

Refer to Nonmandatory Appendix HHA-B for more information on the effects of fast neutron irradiation on graphite.

Refer to Nonmandatory Appendix HHA-B for more information on the effects of oxidation on graphite.

HHA-2131 Design Specification

The Design Specification shall define the requirements for material qualification. This specification shall include the anticipated ranges (qualification envelope) of

(a) irradiation conditions including damage dose (in dpa) and temperatures

(b) temperatures during all plant operating conditions

(c) oxidative environment (coolant impurity content and temperature) and anticipated maximum weight loss

HHA-2132 Qualification of Materials

Qualification of the materials shall be in accordance with HHA-2200.

HHA-2140 MATERIAL IDENTIFICATION

HHA-2141 Billet Marking

Each graphite billet produced as part of a charge shall be clearly marked so that the graphite grade, production lot, and serial number can be determined. The marking shall indicate the axis of forming.

HHA-2142 Method of Marking

Graphite billets shall be marked by any method that will not result in harmful contamination, functional degradation, or sharp discontinuities and will identify the material, at least until the Graphite Core Component is machined. The use of vibroetching and laser engraving is permitted.

HHA-2143 Transfer of Marking When Materials Are Cut or Machined

Billet markings must be transferred to finished Graphite Core Components and billet sections using one of the prescribed methods identified in HHA-2142.

HHA-2200 MATERIAL PROPERTIES FOR DESIGN

(a) Graphite properties used for design shall be determined by the Designer and published in the Material Data Sheet. The Material Data Sheet contains the data required for design in accordance with this Subpart. Additional property data may be generated by the Designer as required. One Material Data Sheet is to be generated for each graphite grade used in the design.

(b) The Material Data Sheet shall define the material properties in the as-manufactured, irradiated, and oxidized conditions.

Requirements for the Material Data Sheet are defined in HHA-2210, HHA-2220, and HHA-2230. Material of the selected grade that complies with the material specification shall be tested to provide data for the Materials Data Sheet. The testing of the material shall be as defined in Mandatory Appendix HHA-III.

The Designer shall be responsible for the generation and validation of the Material Data Sheet. The requirements for generation of the Material Data Sheet from the test data shall be as specified in Mandatory Appendix HHA-II.

HHA-2210 AS-MANUFACTURED MATERIAL PROPERTIES

(a) The Material Data Sheet shall include the properties defined in Mandatory Appendix HHA-II.

(b) The temperature range for the property measurements shall envelope the temperature range as defined in HHA-2131(b), or as required for the application of the graphite grade in the Graphite Core Assembly.

HHA-2220 IRRADIATED MATERIAL PROPERTIES

(a) The Material Data Sheet shall include the properties specified in Mandatory Appendix HHA-II. Fast neutron irradiation effects on the following properties shall be required for compliance with this Subpart:

(1) dimensional change

(2) creep coefficient

(3) coefficient of thermal expansion

(4) strength

(5) thermal conductivity

(6) elastic modulus

(b) The magnitude of the material property change depends on the damage dose and irradiation temperature. The damage dose and temperature range for the measurements shall cover the qualification envelope range of HHA-2131(a), or as required for the application of the graphite grade in the Graphite Core Assembly.

HHA-2230 OXIDIZED MATERIAL PROPERTIES (23)

The Material Data Sheet shall include the properties defined in Mandatory Appendix HHA-II. The effects of thermal oxidation on the following properties shall be required for compliance with this Subpart:

(a) strength — tensile

(b) elastic modulus (dynamic)

(c) thermal conductivity

The magnitude of the material property change depends on the level of oxidation (normally expressed as a percentage weight loss). The weight loss range for the measurements shall cover the qualification envelope range of HHA-2131(c), or as required for the application of the graphite grade in the Graphite Core Assembly. The changes in thermal conductivity shall be accounted for in the calculation of component temperature and the change in elastic modulus shall be accounted for in the stress analysis.

HHA-2300 SAMPLING

HHA-2310 GENERAL REQUIREMENTS

The Material Manufacturer shall sample in accordance with the material specification.

HHA-2400 MATERIAL MANUFACTURER'S QUALITY SYSTEM PROGRAM

The Material Manufacturer's Quality System program shall be in accordance with HAB-3800.

HHA-2500 EXAMINATION AND REPAIR OF GRAPHITE CORE COMPONENT MATERIAL

HHA-2510 EXAMINATION

Examination shall be in accordance with the material specification.

HHA-2520 REPAIR

(a) Graphite billets that fail the purity or electrical resistivity requirements as defined in the material specification may only be used if repaired by repurification or re-graphitization. This repair shall be documented in the Certified Material Test Report.

(b) Undamaged portions of billets damaged or cracked in the production process may be used for Graphite Core Component manufacture provided that all other requirements of the material specification are met.

HHA-2600 PACKAGING, TRANSPORTATION, AND STORAGE

(a) Requirements for packaging, transportation, and storage shall be included in the Construction Specification.

(b) The Construction Specification shall address, as a minimum, the following:

(1) appropriateness of packaging to prevent contamination (by moisture, dust, oil, grease, etc.) and to protect against mechanical damage

(2) the use of gloves or other suitable precautions to prevent contamination during handling

(3) provision of shock monitors during transportation

(c) The billet identification shall be repeated on the packaging.

ARTICLE HHA-3000 DESIGN

HHA-3100 GENERAL DESIGN

Rules for the design of Graphite Core Components and Graphite Core Assemblies are described in this Article.

Design of Graphite Core Components is addressed in HHA-3200. Provisions are made for three alternative approaches to the design. These are

(a) Design of Graphite Core Components to meet the reliability targets based on stress limits derived from the material reliability curve (HHA-3220). This is referred to as a simplified assessment.

(b) Design of Graphite Core Components to meet the reliability targets based on calculated reliability values derived from the distribution of stress in the Graphite Core Component and the material reliability curve (HHA-3230). This is referred to as a full assessment.

(c) Design of Graphite Core Components to meet the reliability targets based on experimental proof of Graphite Core Component performance with margins derived from the material reliability curve (HHA-3240). This is referred to as design by test.

HHA-3300 provides requirements for the design of the Graphite Core Assembly.

The design approach selected is semiprobabilistic, based on the variability in the strength data of the graphite grade. Due to the nature of the material, it is not possible to ensure absolute reliability, expressed as an absence of cracks, of Graphite Core Components. This is reflected in the setting of Probability of Failure (POF) targets. Also note that due to the complex nature of the loadings of graphite components in a reactor combined with the possibility of disparate failures of material due to undetectable manufacturing defects, the Probability of Failure values used as design targets may not be precisely accurate predictions of the rate of cracking of components in service. The Designer is required to evaluate the effects of cracking of individual Graphite Core Components in the course of the design of the Graphite Core Assembly and ensure that the assembly is damage tolerant.

HHA-3110 GRAPHITE CORE COMPONENTS

HHA-3111 Classification of Graphite Core Components

Graphite Core Components shall be assigned to one of the following Structural Reliability Classes in the Design Specification:

(a) SRC-1: The Structural Reliability of components in this class is important to safety. These parts may be subject to environmental degradation.

(b) SRC-2: The Structural Reliability of components in this class is not important to safety. These parts are subject to environmental degradation during life.

(c) SRC-3: The Structural Reliability of components in this class is not important to safety. These parts are not subject to environmental degradation during life.

The Structural Reliability Class defines the graded level of reliability that the Graphite Core Component is designed to meet. Generally, a lower class (SRC-3) signifies a lower mechanical reliability than a higher class (SRC-1).

The allocation of Graphite Core Components to these Structural Reliability Classes is the responsibility of the Owner and shall be justified in the system safety criteria for the nuclear power system. The classes are to be indicated in the Design Specification. Interfaces between components of different classes shall be designed to ensure that any failure in a component classified in a lower class will not propagate to a component in a higher class.

HHA-3112 Enveloping Graphite Core Components

A Graphite Core Assembly may consist of many hundreds of Graphite Core Components. These Graphite Core Components may have minor geometric differences and be exposed to variations in loading. It is acceptable to subdivide the Graphite Core Assembly into groups of components and then to assess Graphite Core Components that see the highest utilization. The grouping of components shall be based on similar function, geometry, and environmental conditions.

Design analyses are to be completed for the Graphite Core Components of each group subject to the highest utilization (which is defined as the ratio of applied loads, both internal and external, to the load to failure). The Designer shall show the acceptability of the Graphite Core Components subject to highest utilization with respect to the requirements in this Subpart. The responsibility for identifying and justifying the enveloping Graphite Core Components is allocated to the Designer.

HHA-3120 LOADING CRITERIA

HHA-3121 General

The Design Specification provides the basis for the design, construction, and examination of the Graphite Core Components.

The specific loads or load combinations (from HHA-3124) to which these components may be subjected shall be established in the Design Specification.

HHA-3122 Loadings

The loadings that shall be taken into account in designing the Graphite Core Components include, but are not limited to, those in (a) to (n) below. Note that some of the loadings below may be loadings on the Graphite Core Assembly that shall be reduced to loads on the individual Graphite Core Components.

(a) pressure differences due to coolant flow

(b) weight of the core components and fuel

(c) superimposed loads such as those due to other structures, the reactor core, flow distributors and baffles, thermal shields, and safety equipment

(d) earthquake loads or other loads that result from motion of the reactor vessel

(e) reactions from supports, restraints, or both

(f) loads due to temperature effects, thermal gradients and differential expansion of the Graphite Core Assembly, or any combination thereof

(g) loads resulting from the impingement or flow of reactor coolant, or other contained or surrounding fluids or gases

(h) transient pressure difference loads, such as those that result from rupture of the main coolant pipe

(i) vibratory loads

(j) loads resulting from operation of machinery such as snubbing of control rods

(k) handling loads experienced in preparation for or during refueling or inservice inspection

(l) internal loads such as those resulting from thermal stresses or irradiation-induced stresses resulting from temperature and flux/fluence distribution within a Graphite Core Component

(m) loading due to instabilities caused by component distortion (such as bowing of graphite columns)

(n) assembly loads and loading during construction

HHA-3123 Design Loadings

The Design Loadings are the distributions of pressure, temperature, fast neutron flux or damage dose rate, and various forces applicable to Graphite Core Components as defined in HHA-3123.1 through HHA-3123.4.

These are defined as the enveloping Service Level A Loadings for the Graphite Core Component in the core. Note that instances of a single Graphite Core Component may be positioned in many locations. The various positions where the Graphite Core Component is used shall be considered when selecting the Design Loading for the Graphite Core Component.

HHA-3123.1 Design Fast Flux Distribution. The Design Fast Flux Distribution is the enveloping fast neutron flux experienced by the Graphite Core Component in all locations that it is installed in the Graphite Core Assembly. This shall be multiplied by the design life to determine the enveloping fast neutron fluence that the Graphite Core Component is exposed to.

HHA-3123.2 Design Temperature Distribution. The Design Temperature shall be the normal operating temperature field that the Graphite Core Component is exposed to that, in combination with the Design Fast Flux, results in the highest utilization of the Graphite Core Component. The Design Temperature shall be used with the Design Fast Flux and Design Mechanical Load for the completion of the design life assessment calculation.

Nonlocal heating (due to gamma and neutron interaction) shall be considered in the assessment of the temperature distribution within the Graphite Core Assembly.

HHA-3123.3 Design Mechanical Load. The specific combinations and values of mechanical loadings (such as dead weight and loads transferred from adjacent components) that shall be considered in conjunction with the Design Fast Flux Distribution and Design Temperature Distribution in evaluating the requirements of this Subpart shall be those identified in the Design Specifications (HAB-3250). The actual mechanical loads shall be used in the computations made to show compliance with the stress limits of HHA-3220 or the Probability of Failure Limits of HHA-3230. Only loadings that are sustained or occur for prolonged periods over the design life are considered. Short duration loadings (such as impact or seismic) are excluded from the Design Mechanical Loads.

HHA-3123.4 Design Pressure Distribution. The Graphite Core Assembly is not pressure retaining. Notwithstanding this, loads on the Graphite Core Components due to sustained pressure differences during normal operation are to be included in the Design Loads.

HHA-3124 Service Loadings

Each Service Loading to which the Graphite Core Assembly or Graphite Core Component may be subjected shall be classified in accordance with HAB-2142 and Service Limits [HAB-2142.4(b)] designated in the Design Specifications in such detail as to provide a complete basis for design, construction, and examination in accordance with these rules.

HHA-3130 NOMENCLATURE (23)

The following nomenclature is used in this Subpart:

C_b = combined bending stress
C_m = combined membrane stress
F = peak stresses

K_{Ic} = critical or reference stress intensity factor for mode I (as defined in the Material Data Sheet, HHA-2200)
L = probability of survival of the component
L_e = the ultimate load or the maximum load or load combination used in the test
L_I = probability of survival of a group
L, D = length and equivalent diameter of member under compression (buckling), HHA-3145
$m'_{0.05}$ = Weibull modulus; three-parameter distribution material reliability curve (from Material Data Sheet, HHA-2200)
$m_{0.05}$ = Weibull modulus of the material reliability curve (from Material Data Sheet, HHA-2200)
POF = Probability of Failure
R_{tc}, R_{tf} = ratio of mean compressive to mean tensile strength and the ratio of the mean flexural to mean tensile strength (from Material Data Sheet, HHA-2200)
t, l, r = tangential, longitudinal, radial coordinate directions
$S_{c_{0.05}}$ = characteristic stress of the material reliability curve (from Material Data Sheet, HHA-2200)
$S'_{c_{0.05}}$ = characteristic stress; three-parameter distribution material reliability curve (from Material Data Sheet, HHA-2200)
S_g = design equivalent stress. This is an allowable stress that is dependent on the target Probability of Failure and the variability in strength of the graphite grade selected for the design.
S' = threshold stress; three-parameter distribution of the material reliability curve (from Material Data Sheet, HHA-2200)
S'' = the modified threshold stress
V_I = group volume
V_m = process zone volume based on critical stress intensity factor and mean tensile strength (from the Material Data Sheet, HHA-2200)
V = Poisson's ratio
x, y, z = coordinate system directions (alternative to t, l, r)
σ_1, σ_2, σ_3 = principal stresses
σ_d = design critical stress (buckling), HHA-3145
σ_m = mean tensile strength (from the Material Data Sheet, HHA-2200)
σ_t, σ_l, σ_r = direct stress components in the tangential, longitudinal, and radial directions
σ_v = equivalent stress
τ_{rl}, τ_{lt}, τ_{tr} = shear stress components in the tangential, longitudinal, and radial directions
σ_x, σ_y, σ_z = direct stress components in Cartesian coordinate system
τ_{xy}, τ_{yz}, τ_{zx} = shear stress components in Cartesian coordinate system
Δ = stress range parameter

HHA-3140 SPECIAL CONSIDERATIONS (23)

Assessment of Graphite Core Components comprising the Graphite Core Assembly shall include consideration of the effects of thermal oxidation, irradiation, abrasion and erosion, fatigue, and buckling. The rules for oxidation in HHA-3141 and abrasion and erosion in HHA-3143 are specific to high temperature gas-cooled reactors.

HHA-3141 Oxidation (23)

Graphite Core Components may be oxidized by moisture, oxygen, or carbon dioxide in the coolant. The corroding gas mixtures diffuse into the porous structure of the graphite. The local weight loss in the Graphite Core Component varies depending on the conditions at which the oxidation occurs and the distance from the surface exposed to the gas flow. Subsurface weight loss (or density) profiles provide a means to estimate oxidation gradients versus distance from the exposed surface. The local weight loss decays exponentially from the surface down to the maximum penetration depth, which depends on temperature. At equal overall weight loss, oxidation at lower temperatures penetrates deeper under the surface than at higher temperatures.

Oxidation analysis shall be carried out in detail to estimate the weight loss profiles of graphite structures, since reaction rates depend on the temperature, reactants, and graphite grade. Assessment of oxidized Graphite Core Components shall comply with (a) through (d) below.

(a) Material is considered oxidized if the weight loss is greater than 1%.

(b) Strength Reduction. The strength (both tensile and compressive) decreases as a function of weight loss as shown by the example in Nonmandatory Appendix HHA-B, Figure HHA-B-3000-1. For other grades, unless historical data are available (see Mandatory Appendix HHA-III, Article HHA-III-5000), the strength versus weight loss relationship shall be determined by tests on uniformly oxidized specimens and reported in the Material Data Sheet per HHA-2200. The stress evaluation shall be made according to these data. The region where strength decreases to less than 50% shall not be credited in the stress evaluation.

(c) Geometry Reduction. The region where the amount of weight loss exceeds 10% is in general associated with 50% loss of strength from the unoxidized graphite strength. Using strength versus weight loss information from Material Data Sheet per HHA-2200, the designer shall determine the threshold of weight loss, such that any region that experiences weight loss above this amount needs to be considered as completely removed

from the structure and justification must be made to ensure that the limit is adequate for design-specific oxidation analysis.

(d) Combinations of weight loss and irradiation where the resulting strength is lower than the nonirradiated strength are excluded from the scope of these code requirements. Oxidation to high weight loss (>1%) occurring simultaneously with significant irradiation (>0.25 dpa) is excluded from the scope of these code requirements. Note that large-scale oxidation resulting from accidental air or water ingress occurs over a short time scale without significant irradiation of the material and thus still falls within the scope of these rules.

(23) ## HHA-3142 Irradiation Effects

HHA-3142.1 Irradiation Damage Dose Limits. Graphite components in a core are classified according to their cumulative fast neutron irradiation fluence.

(a) For damage dose (at any point in the component) <0.001 dpa, the effects of neutron irradiation are negligible and may be ignored.

(b) For damage dose (at any point in the component) >0.001 dpa, the effect of neutron irradiation on thermal conductivity shall be taken into account.

(c) For damage dose (at any point in the component) greater than 0.25 dpa, all effects of neutron irradiation (described in HHA-2200) shall be considered and a viscoelastic analysis applied. For the purpose of Code assessment, these Graphite Core Components are considered irradiated. For the purpose of this Subpart, material in this range is referred to as irradiated graphite.

Use of materials within the core shall be limited by the range of temperature and fast neutron damage dose over which the material is characterized (refer to HHA-2220).

HHA-3142.2 Stored (Wigner) Energy. Should graphite be irradiated to significant damage dose [>0.25 dpa] at a temperature <200°C, the effect of stored (Wigner) energy buildup shall be accounted for when evaluating reactor thermal transients.

HHA-3142.3 Internal Stresses Due to Irradiation. The internal stresses in irradiated Graphite Core Components [that exceed the dose limits described in HHA-3142.1(c)] shall be calculated. This calculation shall be completed by viscoelastic modeling of the material behavior.

(a) Irradiation-induced dimensional change, creep, and changes in properties (elastic modulus, coefficient of thermal expansion, thermal conductivity) shall be accounted for in this analysis. The interaction between irradiation-induced creep and the coefficient of thermal expansion shall be included in this assessment.

(b) The analysis shall account for stress concentrations resulting from the Graphite Core Component geometry.

(c) The stress analysis shall account for superposition of the stresses resulting from all of the loads that a Graphite Core Component is exposed to simultaneously.

HHA-3142.4 Graphite Cohesive Life Limit. A temperature-dependent cohesive life limit fluence is to be defined for the graphite grade used for Graphite Core Components. Material that exceeds this fluence limit is considered to provide no contribution to the structural performance (stiffness and strength) of the Graphite Core Component. This fluence limit shall be set to the fluence at which the material experiences a +10% linear dimensional change in the with-grain direction. For full assessment (HHA-3230), this material shall not be included in the volume of the Graphite Core Component assessed.

HHA-3143 Abrasion and Erosion

(a) Abrasion shall be evaluated if there is relative motion between Graphite Core Components, Graphite Core Components and interfacing components, or Graphite Core Components and the fuel of a pebble bed reactor.

(b) Erosion shall be evaluated in areas where the mean gas flow velocity in the cross section of the channel exceeds 330 ft/sec (100 m/s).

HHA-3144 Graphite Fatigue

In the course of preparation.

HHA-3145 Compressive Loading

(a) Graphite Core Components loaded in compressive loading shall be assessed against buckling failure.

(b) The design critical stress is

$$\sigma_d = \frac{0.9 \times R_{tc} \times S_g(10^{-2})}{1 + 0.00448\left(\frac{L}{D}\right)^2}$$

(c) The design stress limit to be applied is modified depending on the Design and Service Level as follows:

- Design, Level A and Level B: $<0.25\sigma_d$
- Level C: $<0.5\sigma_d$
- Level D: $<0.6\sigma_d$

(d) Noncircular Cross Sections. Replace diameter with twice the minimum radius of gyration.

HHA-3200 DESIGN BY ANALYSIS — GRAPHITE CORE COMPONENTS

HHA-3210 DESIGN CRITERIA FOR GRAPHITE CORE COMPONENTS

HHA-3211 Requirements for Acceptability

The requirements for acceptability of a design by analysis are those set forth in (a) through (f) below.

(a) The design shall be such that the SRC specific requirements of HHA-3200 are met. This is accomplished by either meeting the requirements for a simplified assessment (HHA-3220) or a full assessment (HHA-3230).

(b) The design details of the Graphite Core Assembly and the Graphite Core Components shall conform to the rules given in HHA-3300 and HHA-3200, respectively.

(c) For configurations where compressive loading occurs in addition to the requirements of (a) and (b) above, the allowable buckling limits of HHA-3145 shall not be exceeded.

(d) Protection against fatigue failure shall be provided by meeting the requirements of HHA-3144.

(e) As an alternative to (a), (c), or (d) above, the design shall be qualified by test in accordance with the requirements of HHA-3240.

(f) *Deformation Limits.* Any deformation limits prescribed in the Design Specifications shall be satisfied.

HHA-3212 General Design Requirements for the Graphite Core Components

The individual Graphite Core Components are to be designed such that

(a) all mechanical loads that occur shall be transferred to the adjacent load-carrying or supporting structures within allowable limits.

(b) displacement or deformation of adjacent Graphite Core Component in opposing directions do not cause constraint and thus hinder expansion or shrinkage due to temperature or irradiation.

(c) changes in the shape of a Graphite Core Component due to irradiation do not adversely affect the stability or functionality of the core assembly.

(d) the compensation of the differential strains inside the Graphite Core Assembly and in the surrounding structures does not lead to stresses exceeding the HHA-3211 limits in the Graphite Core Components.

(e) movement of blocks and the accumulation of gaps inside the Graphite Core Assembly are within allowable limits.

(f) changes in shape of the Graphite Core Component due to radiation and temperature effects are within allowable limits and do not affect the function and stability of the core assembly.

(g) design channels for the gas flow through Graphite Core Components are such that the shielding effect of the graphite internals is within allowable limits.

(h) grooves, keyways, dowel holes, and other recesses in the blocks are to be blended. The minimum fillet radius shall be five times the maximum grain size as documented in the Mandatory Appendix HHA-II Material Data Sheet.

(i) external edges of Graphite Core Components shall be chamfered.

HHA-3213 Basis for Determining Stresses

The theory of failure used in the rules of this Article for combining stresses is the maximum deformation energy theory. This allows for an arbitrary stress state at a point to be converted to an equivalent stress that shall be compared directly to the results of a uniaxial strength test. The equivalent stress, σ_v, at a point within a graphite structure shall be calculated as follows:

$$\sigma_v = \sqrt{\bar{\sigma}_1^2 + \bar{\sigma}_2^2 + \bar{\sigma}_3^2 - 2 \cdot \nu \cdot \left(\bar{\sigma}_1 \cdot \bar{\sigma}_2 + \bar{\sigma}_1 \cdot \bar{\sigma}_3 + \bar{\sigma}_2 \cdot \bar{\sigma}_3\right)}$$

with

$$\bar{\sigma}_i = f \cdot \sigma_i$$

and

$f = 1$ if σ_i (i=1,2,3) is a tensile stress and $f = (\frac{1}{R_{tc}})$ if σ_i is a compressive stress, where

R_{tc} = the ratio of the mean compressive to mean tensile strength for the specific grade of graphite [from the Material Data Sheet (HHA-2200)]

ν = 0.15

HHA-3214 Terms Relating to Stress Analysis

Terms used in this Subpart relating to stress analysis are defined in the following subparagraphs.

HHA-3214.1 Equivalent Stress. The assessment of Graphite Core Components is based on an equivalent stress. This equivalent stress is computed using a Maximum Deformation Energy Criterion as described in HHA-3213.

HHA-3214.2 Peak Equivalent Stress. The peak equivalent stress in a Graphite Core Component is the highest equivalent stress computed from the total stress in the Graphite Core Component in accordance with the provisions of HHA-3215.

This stress shall be calculated for the case where all of the loads in a load case are superimposed. The peak equivalent stress for a Service Level is the most severe peak equivalent stress for all of the loadings or combinations of loadings comprising the Service Level.

HHA-3214.3 Normal Stress. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a Graphite Core Component. This stress is considered to be made up of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness under consideration, and the other of which varies from this average value with the location across the thickness.

HHA-3214.4 Shear Stress. Shear stress is the component of stress tangent to the plane of reference.

HHA-3214.5 Membrane Stress. Membrane stress is the component of normal stress (HHA-3214.3) that is uniformly distributed and equal to the average of stress across the thickness of the section under consideration.

HHA-3214.6 Bending Stress. Bending stress is the variable component of normal stress described in HHA-3214.3. The variation may or may not be linear across the thickness.

HHA-3214.7 Combined Stress. The combined stress is the sum of all of the components of stress at a point. In design, it is customary to distinguish between primary and secondary stresses. These are defined as follows:

(a) Primary stress is any normal stress or a shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the material strength will result in failure. A thermal stress is not classified as a primary stress.

(b) Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions may satisfy the conditions that cause the stress to occur.

Due to the brittle nature of graphite, no distinction is made between primary and secondary stresses for the purpose of assessment to these rules. Combined stress is thus the combination of primary and secondary stress.

HHA-3214.9 Peak Stress. Peak stress is that increment of stress that is additive to the combined stresses by reason of local discontinuities or local thermal stress. This includes the effect of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture.

Due to the brittle nature of graphite, it is important that peak stresses are considered explicitly when assessing the compliance of a Graphite Core Component to these rules. Stress analysis requirements are included in HHA-3215 to ensure this.

HHA-3214.10 Load Stress. Load stress is the stress resulting from the application of a load, such as pressure difference or the effects of gravity as distinguished from internal stress.

HHA-3214.11 Internal Stress. An internal stress may be a thermal stress or an irradiation-induced stress.

(a) Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing coefficients of thermal expansion.

(b) Irradiation-induced stress is a self-balancing stress produced by a nonuniform distribution of irradiation-induced shrinkage or swelling in the material, or irradiation-induced change in properties in the material. Note that for an irradiated Graphite Core Component, the changes in thermal conductivity throughout the Graphite Core Component's volume resulting from a nonuniform flux field over the Graphite Core Component may lead to thermal stresses even when the Graphite Core Component is at a uniform temperature.

Internal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should.

HHA-3214.12 Total Stress. Total stress is the sum of the combined and peak stress contributions. As graphite is a brittle material, the total stress is limited, irrespective of the contributions of the different components.

HHA-3214.13 Operational Cycle. Operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of plant operating conditions that may occur are further defined in HHA-3124.

HHA-3214.14 Probability of Failure. The probability of failure is the estimated probability of the Graphite Core Component failing under a given load case (see HHA-3217).

HHA-3215 Stress Analysis

A detailed stress analysis that addresses all Graphite Core Components shall be prepared in sufficient detail to show that each of the stress limitations of HHA-3220 or the Probability of Failure limits of HHA-3230 are satisfied when the Graphite Core Component is subjected to the loadings of HHA-3120. It is necessary that the distribution of total stress due to all the superimposed loads be determined throughout the volume of the Graphite Core Component for each load case. This implies that the stress analysis is normally completed by making use of a three-dimensional finite element model or equivalent. This is especially necessary for the full assessment (HHA-3230). For simplified assessment (HHA-3220), only the peak equivalent stress need be known, thus simplifications to the stress analysis commensurate with achieving this objective are acceptable.

The general requirements of HHA-3215.1 relate to all stress analyses.

Graphite Core Components classed as irradiated according to HHA-3142.1(c) shall be analyzed in accordance with the requirements of HHA-3215.3; otherwise, the Graphite Core Components shall be analyzed in accordance with HHA-3215.2. Where Graphite Core Components are classified as oxidized (HHA-3141), the additional requirements of HHA-3215.4 apply.

All loads or effects on the Graphite Core Components that cause loads or deformations shall be evaluated. Loads that act on a Graphite Core Component simultaneously need to be applied simultaneously in the stress analysis model. Special attention to the boundary conditions applied to the model to ensure that the stresses are accurate through the entire volume of the Graphite Core Component and the stress concentrations (local areas of high stress) are to be adequately represented.

The Designer shall consider that the precision of the determined stress values depends on the quality of the geometric idealization of the Graphite Core Component, the accuracy of the assumptions made about loads, the boundary conditions and the material properties, as well as the suitability of the chosen method of analysis. The uncertainty of the calculated results shall be assessed as part of the analysis.

HHA-3215.1 General. The determination of stresses for assessment shall, as a minimum, include the following:

(a) stresses resulting from all loads acting simultaneously shall be considered. No differentiation among primary, secondary, and peak stress is permissible.

(b) stress concentration effects shall be accurately taken into account in the stress analysis.

(c) linear elastic material properties are to be used in the stress analysis (modified by the viscoelastic properties for the irradiated Graphite Core Components per HHA-3215.3).

(d) dynamic elastic modulus of the material is to be used for the stress analysis.

(23) **HHA-3215.2 Stress Analysis of Nonirradiated Graphite Core Components.** For nonirradiated Graphite Core Components [HHA-3142.1(a) and HHA-3142.1(b)], an elastic analysis shall be completed. This analysis need not take account of the effects of irradiation damage on the properties of graphite, with the exception of thermal conductivity. Thermal stress prediction shall include the effect of neutron irradiation on thermal conductivity on the temperature field applied to the Graphite Core Component in the case where the dose exceeds 0.001 dpa in the Graphite Core Component.

HHA-3215.3 Stress Analysis of Irradiated Graphite Core Components. For irradiated Graphite Core Components [HHA-3142.1(c)], a viscoelastic analysis that takes into account the effects of irradiation damage on the properties of the graphite and on the development of stresses in the components shall be completed. This analysis shall account for irradiation-induced dimensional change and creep as well. The Designer is responsible for the accuracy and acceptability of the analysis methods used.

HHA-3215.4 Stress Analysis of Oxidized Graphite Core Components. For oxidized Graphite Core Components (HHA-3141), the effect of oxidation on the dimensions of the Graphite Core Component and the distribution of material properties in the Graphite Core Component shall be considered in the completion of the stress analysis.

HHA-3216 Derivation of Equivalent Stress

One requirement for the acceptability of a design (HHA-3210) is that the calculated equivalent stress shall not exceed specified allowable limits. This paragraph describes a procedure for the calculation of the equivalent stress values that are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the component that is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t, l, and r. The stress components in these directions are then designated σ_t, σ_l, and σ_r for direct stresses, and τ_{rl}, τ_{lt}, and τ_{tr} for shear stresses.

(b) Subdivide the component into integration volumes, represented by points (integration points). This may be achieved by making use of a numeric calculation by the Finite Element Method.

(c) For each Service Loading or combination of loadings, calculate the algebraic sum of the values of σ_t, which result from the different types of loadings, and repeat for the other five stress components.

(d) Translate the stress components for the t, l, and r directions into principal stresses σ_1, σ_2, and σ_3. In many component calculations, the t, l, and r directions may be chosen such that the shear stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r.

(e) Calculate the equivalent stress resulting from the three principal stresses using the equation in HHA-3213.

(f) If this is the highest equivalent stress in the Graphite Core Component, it is identified as the peak equivalent stress (HHA-3214.2).

HHA-3217 Calculation of Probability of Failure (23)

One requirement for the acceptability of a design (HHA-3210) is that the calculated Probability of Failure shall not exceed specified allowable limits. This paragraph describes the procedure for the calculation of the Probability of Failure. The procedure is completed in the following steps:

(a) Over the entire component that is being investigated, choose an orthogonal set of coordinates and designate them by the subscripts x, y, and z. The stress components in these directions are then designated σ_x, σ_y, and σ_z for direct stresses, and τ_{xy}, τ_{yz}, and τ_{xz} for shear stresses.

(b) Subdivide the component into integration volumes, represented by points (integration points). This may be achieved by making use of a numerical calculation by the Finite Element Method.

(c) For each integration point, i (with volume v_i), calculate the stress components for each loading to which the Graphite Core Component will be subjected. This is typically the output of a three-dimensional finite element calculation of the stresses in the Graphite Core Component.

(d) For each load case, calculate the algebraic sum of the values of σ_x at each integration point, which result from the different types of loadings, and similarly for the other five stress components. Load combinations within a Service Level as identified in the Design Specification shall also be considered.

(e) For each integration point, translate the stress components for the x, y, and z directions calculated in (d), into principal stresses σ_1, σ_2, and σ_3.

(f) For each integration point, calculate the equivalent stress resulting from the three principal stresses using the equation in HHA-3213. This is designated σ_{vi}, the point equivalent stress.

(g) The following stress-volume integral is to be completed over the Graphite Core Component:

(1) Rank the integration volumes in decreasing order of the point equivalent stress (σ_{vi}).

(2) Moving Threshold Value. If the maximum equivalent stress is greater than $S'_{c0.05}$, then S'' remains unchanged.

$$S'' = S'$$

If the maximum equivalent stress is less than the value of $S'_{c0.05}$, then S'' is recalculated as follows:

$$S'' = \frac{\sigma_{\max}}{S'_{c0.05}} S'$$

where $\sigma_{\max}$ is the highest equivalent stress occurring in the component.

Truncate the list of integration points to those where the point equivalent stress is greater than the threshold stress (S'_0).

(3) For the integration point, calculate and store

$$X_i = \left[\frac{\sigma_{vi} - S''}{S'_{c0.05} - S''}\right]^{m'_{0.05}}$$

(4) Group the integration volumes into groups (designated by the index I, II, III,...), starting with the point of highest stress. The allocation to groups is based on the following two conditions:

- Condition 1: group volume $V_{\mathrm{I,\,II,\,III,\ldots}} > V_m$.
- Condition 2: group stress range as follows:

$$\frac{\max.\left(X_{\mathrm{I,II,III}\ldots}\right) - \min.\left(X_{\mathrm{I,II,III}\ldots}\right)}{\min.\left(X_{\mathrm{I,II,III}\ldots}\right)} \geq \Delta$$

where

V_m = a process zone volume, which is calculated from the following equation:

$$V_m = \left[\frac{\pi}{2} \times \left(\frac{K_{IC}}{\sigma_m}\right)^2\right]^3$$

Δ = the stress range parameter, 20%

(5) For each group, compute a Probability of Survival by summing over the integration volumes within each group as follows:

$$L_I = \exp\left[-\left(\sum_i X_i \times \frac{v_i}{V_I}\right)\right]$$

(6) Calculate the Probability of Survival of the Graphite Core Component by multiplying the Probability of Survival of the groups.

$$L = \prod_I L_I$$

(7) Calculate and report the Probability of Failure

$$\mathrm{POF} = 1 - L$$

HHA-3220 STRESS LIMITS FOR GRAPHITE CORE COMPONENT — SIMPLIFIED ASSESSMENT

As a simplified assessment, the peak equivalent stress (see HHA-3214.2) calculated for the Graphite Core Component shall be compared directly to an allowable stress value (calculated in accordance with HHA-3226). The allowable stress value depends on the target Probability of Failure derived from the Structural Reliability Class (SRC) of the Graphite Core Component and the Service Level of the load. The SRC is defined in HHA-3110. The Design Loadings are as defined in HHA-3123, and the Service Level Loadings are as defined in HHA-3124. The allowable stress values are retrieved from the Material Data Sheet (see HHA-2200) for the specific graphite grade.

This assessment is conservative, and not meeting the prescribed limit does not mean that the Graphite Core Component is not acceptable. A full assessment (HHA-3230) or design by test (HHA-3240) may be completed to accept the Graphite Core Component.

HHA-3221 Design Limits

The equivalent stress limits that shall be satisfied for the Design Loadings (HHA-3123) stated in the Design Specifications are the two limits of this paragraph and the special stress limits of HHA-3226. The Design Allowable Stress values, S_g, as a function of the required Probability of Failure, are defined in HHA-3227. These limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3221.1 Combined Membrane Stress. This equivalent stress is derived from the average value across the thickness of a ligament or other section of the combined stresses (see HHA-3214.7) produced by all Design Loadings. Averaging is to be applied to the stress components prior to determination of the equivalent stress values. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as recorded in the Material Data Sheet (see HHA-2200). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the S_g value, derived to a Probability of Failure of 10^{-4} [$S_g(10^{-4})$].

(b) For SRC-2, the allowable value is both of the following:

(1) the S_g value, derived to a Probability of Failure of 10^{-4} [$S_g(10^{-4})$] prior to the inclusion of any internal stress due to irradiation

(2) the S_g value, derived to a Probability of Failure of 10^{-2}[$S_g(10^{-2})$] when including any internal stress due to irradiation at the design lifetime

(c) For SRC-3, the allowable value is the S_g value, derived to a Probability of Failure of 10^{-2} [$S_g(10^{-2})$].

HHA-3221.2 Peak Equivalent Stress. The Peak Equivalent Stress (HHA-3214.2) produced by the Design Loadings, including all combined and peak stresses, is evaluated. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as published in the Material Data Sheet (see HHA-2200), multiplied by the ratio of flexural to tensile strength (R_{tf}). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-4} [$R_{tf} \times S_g(10^{-4})$].

(b) For SRC-2, the allowable value is both of the following:

(1) $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-4} [$R_{tf} \times S_g(10^{-4})$] prior to the inclusion of any internal stress due to irradiation

(2) $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-2} [$R_{tf} \times S_g(10^{-2})$] when including any internal stress due to irradiation at the design lifetime

(c) For SRC-3, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-2} [$R_{tf} \times S_g$ (10^{-2})].

HHA-3222 Level A Service Limits

The Level A Service Limits shall be satisfied for the Service Level A Loadings (HHA-3124) for which these limits are designated in the Design Specifications and are the three limits of this paragraph and HHA-3226. The Design Allowable Stress values, S_g, as a function of the required Probability of Failure, are defined in HHA-3227. These limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3222.1 Combined Membrane Stress. This equivalent stress is derived from the average value across the thickness of a ligament or other section of the combined stresses (see HHA-3214.7) produced by all Level A Service Loadings. Averaging is to be applied to the stress components prior to determination of the equivalent stress values. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as recorded in the Material Data Sheet (see HHA-2200). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the S_g value, derived to a Probability of Failure of 10^{-4} [$S_g(10^{-4})$].

(b) For SRC-2, the allowable value is both of the following:

(1) the S_g value, derived to a Probability of Failure of 10^{-4} [$S_g(10^{-4})$] prior to the inclusion of any internal stress due to irradiation

(2) the S_g value, derived to a Probability of Failure of 10^{-2} [$S_g(10^{-2})$] when including any internal stress due to irradiation at the design lifetime

(c) for SRC-3, the allowable value is the S_g value, derived to a Probability of Failure of 10^{-2} [$S_g(10^{-2})$].

HHA-3222.2 Peak Equivalent Stress. The Peak Equivalent Stress (HHA-3214.2) produced by the Level A Service Loadings including all combined and peak stresses is evaluated. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as recorded in the Material Data Sheet (see HHA-2200), multiplied by the ratio of flexural to tensile strength (R_{tf}). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-4} [$R_{tf} \times S_g(10^{-4})$].

(b) For SRC-2, the allowable value is both of the following:

(1) $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-4} [$R_{tf} \times S_g(10^{-4})$] prior to the inclusion of any internal stress due to irradiation

(2) $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-2} [$R_{tf} \times S_g$ (10^{-2})] when including any internal stress due to irradiation at the design lifetime

(c) For SRC-3, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-2} [$R_{tf} \times S_g(10^{-2})$].

HHA-3222.3 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be met.

HHA-3223 Level B Service Limits

For Graphite Core Components, the requirements of (a) and (b) below apply.

(a) The values of Level A Service Limits (HHA-3222) shall apply for Level B Service Loadings (HHA-3124).

(b) Deformation or other limits in the Design Specifications shall be met.

HHA-3224 Level C Service Limits

The Level C Service Limits shall be satisfied for Level C Service Loadings (HHA-3124) for which these limits are designated in the Design Specifications and are the three limits of this paragraph and HHA-3226. The Design

Allowable Stress values, S_g, as a function of the required Probability of Failure, are defined in HHA-3227. These limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3224.1 Combined Membrane Stress. This equivalent stress is derived from the average value across the thickness of a ligament or other section of the combined stresses (see HHA-3214.7) produced by all Level C Service Loadings. Averaging is to be applied to the stress components prior to determination of the equivalent stress values. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as recorded in the Material Data Sheet (see HHA-2200). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the S_g value, derived to a Probability of Failure of 10^{-4} [$S_g(10^{-4})$].

(b) For SRC-2, the allowable value is the S_g value, derived to a Probability of Failure of 5×10^{-2} [$S_g(5 \times 10^{-2})$] when including any internal stress due to irradiation at the design lifetime.

(c) For SRC-3, the allowable value is the S_g value, derived to a Probability of Failure of 5×10^{-2} [$S_g(5 \times 10^{-2})$].

HHA-3224.2 Peak Equivalent Stress. The Peak Equivalent Stress (HHA-3214.2) produced by the Level C Service Loadings including all combined and peak stresses is evaluated. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as recorded in the Material Data Sheet (see HHA-2200), multiplied by the ratio of flexural to tensile strength (R_{tf}). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-4} [$R_{tf} \times S_g(10^{-4})$].

(b) For SRC-2, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 5×10^{-2} [$R_{tf} \times S_g(10^{-2})$] when including any internal stress due to irradiation at the design lifetime.

(c) For SRC-3, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 5×10^{-2} [$R_{tf} \times S_g(10^{-2})$].

HHA-3224.3 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be met.

HHA-3225 Level D Service Limits

The Level D Service Limits shall be satisfied for Service Level D Loadings (HHA-3124) for which these limits are designated in the Design Specifications and are the three limits of this paragraph and HHA-3226. In addition, when the special stress limits of HHA-3226 are applicable for Level D Service Limits, the calculated stresses shall not exceed twice the stress limits given in HHA-3226 as applied for Level A Service Limits. The Design Allowable Stress values, S_g, as a function of the required Probability of Failure, are defined in HHA-3227. These limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3225.1 Combined Membrane Stress. This equivalent stress is derived from the average value across the thickness of a ligament of the combined stresses (see HHA-3214.7) produced by all Service Level D Loadings. Averaging is to be applied to the stress components prior to determination of the equivalent stress values. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as recorded in the Material Data Sheet (see HHA-2200). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the S_g value, derived to a Probability of Failure of 10^{-3} [$S_g(10^{-3})$].

(b) For SRC-2, the allowable value is the S_g value, derived to a Probability of Failure of 5×10^{-2} [$S_g(5 \times 10^{-2}\ S_g)$] when including any internal stress due to irradiation at the design lifetime.

(c) For SRC-3, the allowable value is the S_g value, derived to a Probability of Failure of 5×10^{-2} [$S_g(5 \times 10^{-2})$].

HHA-3225.2 Peak Equivalent Stress. The Peak Equivalent Stress (HHA-3214.2) produced by the Service Level D Loadings including all combined and peak stresses is evaluated. The criteria for acceptability are based on the S_g values derived from a Probability of Failure as recorded in the Material Data Sheet (see HHA-2200), multiplied by the ratio of flexural to tensile strength (R_{tf}). These allowable stresses depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 10^{-3} [$R_{tf} \times S_g(10^{-3})$].

(b) For SRC-2, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 5×10^{-2} [$R_{tf} \times S_g\ (5 \times 10^{-2})$] when including any internal stress due to irradiation at the design lifetime.

(c) For SRC-3, the allowable value is the $R_{tf} \times S_g$ value, derived to a Probability of Failure of 5×10^{-2} [$R_{tf} \times S_g\ (5 \times 10^{-2})$].

HHA-3225.3 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be met.

HHA-3226 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Design or Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of HHA-3226 take precedence for the particular situations to which they apply.

HHA-3226.1 Bearing Stresses. The average bearing stress over the contact area shall be less than the applicable S_g value multiplied by the ratio of compressive to tensile strength (R_{tc}). The S_g values in HHA-3222.1, HHA-3224.1, and HHA-3225.1 shall apply. The value for R_{tc} documented in the Material Data Sheet (HHA-2200) shall apply.

HHA-3227 Design Equivalent Stress Values and Material Properties

The design equivalent stress values S_g, derived from the material reliability curve, are given in the Material Data Sheets per HHA-2200. The Material Data Sheet contains all of the other graphite material properties used for design.

HHA-3230 PROBABILITY OF FAILURE LIMITS FOR GRAPHITE CORE COMPONENTS — FULL ASSESSMENT

A full assessment Probability of Failure (see HHA-3214.14) calculated for the Graphite Core Component shall be compared directly to an allowable value. The target Probability of Failure values are derived from the SRC of the Graphite Core Component and the Design or Service Level of the Loading. The SRC is defined in HHA-3110. The Design Loadings are as defined in HHA-3123, and the Service Loadings are as defined in HHA-3124. The material values are calculated from the Material Data Sheet (see HHA-2200) generated for the specific graphite grade.

HHA-3231 Design Limits

The Probability of Failure limits that shall be satisfied for the Design Loadings (HHA-3123) stated in the Design Specifications are the limits of this paragraph and the special stress limits of HHA-3236. These Probability of Failure limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3231.1 Probability of Failure Resulting From Combined Stress. This Probability of Failure derived from the combined equivalent stress throughout the entire Graphite Core Component, including peak stress, shall be calculated. The procedure for this calculation is described in HHA-3217. The stress is produced by all Design Loadings, over the design life of the Graphite Core Component. The criteria for acceptability are based on the Probability of Failure (POF). These allowable Probability of Failures depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is a Probability of Failure of 10^{-4}.

(b) For SRC-2, the allowable value is both of the following:

(1) the Probability of Failure of 10^{-4} prior to the inclusion of any internal stress due to irradiation

(2) the Probability of Failure of 10^{-2} when including any internal stress due to irradiation at the design lifetime

(c) For SRC-3, the allowable value is a Probability of Failure of 10^{-2}.

HHA-3232 Level A Service Limits

The Level A Service Limits shall be satisfied for the Level A Service Loadings (HHA-3124) for which these limits are designated in the Design Specifications and are the limits of this paragraph and HHA-3236. These Probability of Failure limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3232.1 Probability of Failure Resulting From Combined Stress. This Probability of Failure derived from the combined equivalent stress, including peak stress, throughout the entire Graphite Core Component shall be calculated. The procedure for this calculation is described in HHA-3217. The stress is produced by all Level A Service Loadings, over the design life of the Graphite Core Component. The criteria for acceptability are based on the Probability of Failure (POF). These allowable Probability of Failures depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is a Probability of Failure of 10^{-4}.

(b) For SRC-2, the allowable value is both of the following:

(1) the Probability of Failure of 10^{-4} prior to the inclusion of any internal stress due to irradiation

(2) the Probability of Failure of 10^{-2} when including any internal stress due to irradiation at the design lifetime

(c) For SRC-3, the allowable value is a Probability of Failure of 10^{-2}.

HHA-3232.2 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be met.

HHA-3233 Level B Service Limits

For Graphite Core Components, the requirements of (a) and (b) below apply.

(a) The values of Level A Service Limits (HHA-3232) shall apply for Level B Service Loadings (HHA-3124).

(b) Deformation or other limits in the Design Specifications shall be met.

HHA-3234 Level C Service Limits

The Level C Service Limits shall be satisfied for Service Level C Loadings (HHA-3124) for which these limits are designated in the Design Specifications and are the two limits of this paragraph and HHA-3236. These Probability of Failure limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3234.1 Probability of Failure Resulting From Combined Stress. This Probability of Failure derived from the combined equivalent stress, including peak stress, throughout the entire Graphite Core Component shall be calculated. The procedure for this calculation is described in HHA-3217. The stress is produced by all Level C Service Loadings, over the design life of the Graphite Core Component. The criteria for acceptability are based on the Probability of Failure (POF). These allowable Probability of Failures depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is a Probability of Failure of 10^{-4}.

(b) For SRC-2, the allowable value is a Probability of Failure of 5×10^{-2} including any internal stress due to irradiation at the design lifetime.

(c) For SRC-3, the allowable value is a Probability of Failure of 5×10^{-2}.

HHA-3234.2 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be met.

HHA-3235 Level D Service Limits

The Level D Service Limits shall be satisfied for Level D Service Loadings (HHA-3124) for which these limits are designated in the Design Specifications and are the limits of this paragraph and HHA-3236. In addition, when the special stress limits of HHA-3236 are applicable for Level D Service Limits, the calculated stresses shall not exceed twice the stress limits given in HHA-3236 as applied for Level A Service Limits. These Probability of Failure limits are summarized in Figure HHA-3221-1 and Table HHA-3221-1.

HHA-3235.1 Probability of Failure Resulting From Combined Stress. This Probability of Failure derived from the combined equivalent stress throughout the entire Graphite Core Component shall be calculated. The procedure for this calculation is described in HHA-3217. The stress is produced by all Level D Service Loadings, over the design life of the Graphite Core Component. The criteria for acceptability are based on the Probability of Failure (POF). These allowable Probability of Failures depend on the Structural Reliability Class of the Graphite Core Component, as follows:

(a) For SRC-1, the allowable value is a Probability of Failure of 10^{-3}.

(b) For SRC-2, the allowable value is a Probability of Failure of 5×10^{-2} including any internal stress due to irradiation at the design lifetime.

(c) For SRC-3, the allowable value is a Probability of Failure of 5×10^{-2}.

HHA-3235.2 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be met.

HHA-3236 Special Stress Limits

See HHA-3226.

HHA-3237 Design Stress Values and Material Properties (23)

The Probability of Failure calculation is based on the statistical material parameters describing the material reliability curve: Characteristic Strength, $S'_{c0.05}$; Weibull Modulus, $m'_{0.05}$; and threshold stress value, S', as given in the Material Data Sheets per HHA-2200. The Material Data Sheet contains all of the other graphite material properties used for design.

HHA-3240 EXPERIMENTAL LIMITS — DESIGN-BY-TEST

It is permissible to declare a design in compliance to the requirements of this Article based on component testing. This is referred to as design-by-test. Design-by-test either demonstrates the Probability of Failure of the Graphite Core Component subjected to an enveloping loading meets the requirements of this Article or establishes a Service Load Rating for the component consistent with the limits provided in this Article. These Probability of Failure limits are summarized in Table HHA-3221-1.

NOTES:

(1) Not all parts and loadings may be suitable to design-by-test as complex loadings, and environmental effects may not be adequately reproducible in a test.

(2) Design-by-test may be used to demonstrate compliance to the special stress limits (HHA-3226); however, specific requirements and guidance on how to do this are not provided.

HHA-3241 General

(a) The Designer shall specify the tests to be completed to demonstrate compliance to this Article and the Design Specification. The test shall be designed to ensure that the loads determined from the tests conservatively represent the load-carrying capacity of the actual Graphite Core Component for the specified loadings.

(b) The test design shall consider the following essential features of the test:

(1) Where a scale model test is used, the influence of the scale of model shall be evaluated, specifically the possibility of size effects in the material that can influence the results.

(2) The effect of dimensional tolerances, both of the Graphite Core Component and between the Graphite Core Component and the test equipment, on the results of the test shall be evaluated. This is especially important for scaled tests.

(c) It is preferable that the design-by-test should be completed on the graphite grade that will be used for construction. Should a substitute graphite grade be used, differences in strength, elastic modulus, and other appropriate material properties between the tested

material grade and the material grade used for construction shall be addressed in the evaluation of the results of the test.

(d) To ensure similitude between the Graphite Core Components used for the testing and the components to be used in the reactor, the following requirements must be met for every component used for design-by-test:

(1) The geometry shall either be nominally the same as the final component and shall satisfy all tolerance requirements defined in Article HHA-4000, the Design Specification, and the Construction Specification, or, where scaled geometry is used, the effects of geometric tolerances shall be considered.

(2) The requirements of this subpart shall apply to all aspects of the manufacture of the components under test.

HHA-3242 Experimental Proof of Strength and Demonstration of Probability of Failure

(a) When using design-by-test for Probability of Failure, it shall be demonstrated that the Probability of Failure of a Graphite Core Component under the specified Design and Service Loadings as defined in the Design Specification is less than the allowable Probability of Failure defined in this Article.

(b) It is permissible to extrapolate to the required Probability of Failure values by using statistical analysis of the test results. This statistical analysis of the test results shall provide values with a 95% certainty as represented by a single sided confidence interval. The number of test items used for the demonstration of the Probability of Failure shall be considered in the assessment of the Probability of Failure.

(c) The test loading shall represent or envelope all appropriate Design and Service Loadings.

HHA-3242.1 Design Limits, Level A and Level B Service Limits. The Probability of Failure limits to be met by the test for Design, Level A and Level B Service Loadings are as defined in HHA-3232.

HHA-3242.2 Level C and Level D Service Limits.

(a) The Probability of Failure limits to be met by the test for Level C and Level D Service Loadings are as defined in HHA-3234 and HHA-3235, respectively.

(b) Alternatively, for Service Loadings for which Level C and D Limits are designated, the limits of (a) above need not be satisfied if it can be shown from the test of a prototype or model that the specified loads do not exceed 60% of L_e, where L_e is the ultimate load or the maximum load or load combination used in the test. Static equivalent loads may be used in lieu of dynamic loads.

HHA-3243 Experimental Proof of Strength, Service Load Rating

When using design-by-test for Service Load Rating (SLR), the SLR of the component shall be demonstrated. This SLR shall be greater than the enveloping Service Load for the Service Level under consideration.

The SLR is defined by the following equation:

$$\mathrm{SLR} = LT \times \frac{S_g(P)}{S_{ut}} \times \frac{2N}{2N + 1}$$

where

LT = the mean test load at which the test specimens fail

N = the number of test samples

$S_g(P)$ = the design equivalent stress. This is an allowable stress that is dependent on the target Probability of Failure, P, and the variability in strength of the graphite grade selected for the design. The Probability of Failure depends on the Structural Reliability Class of the component and the Service Level. The S_g values in HHA-3222.1, HHA-3224.1, and HHA-3225.1 shall apply.

S_{ut} = the mean tensile strength as described in the Material Data Sheet (HHA-2200)

HHA-3300 REQUIREMENTS FOR DESIGN OF THE GRAPHITE CORE ASSEMBLY

This subarticle defines requirements for the design of a Graphite Core Assembly, comprised of Graphite Core Components. This is not a full set of requirements but provides an extension to the requirements in the Design Specification. Functional requirements placed on the Graphite Core Assembly shall be documented in the Design Specification and assessed as part of the design process.

HHA-3310 GENERAL REQUIREMENTS

The design shall be such that the Graphite Core Components that comprise the Graphite Core Assembly meet the requirements of HHA-3100 and HHA-3200.

HHA-3320 DESIGN CONSIDERATIONS

HHA-3321 Design and Service Loadings

The provisions of HHA-3120 apply.

HHA-3322 Special Considerations

The provisions of HHA-3140 apply.

HHA-3323 General Design Rules

The provisions of HHA-3212 apply, except when they conflict with the rules of this subarticle. In case of conflict, this subarticle governs in the design of the Graphite Core Assembly.

HHA-3330 DESIGN OF THE GRAPHITE CORE ASSEMBLY

The design and construction of the Graphite Core Assembly shall

(a) arrange the Graphite Core Components comprising the Graphite Core Assembly so that the external mechanical loads imposed on the Graphite Core Assembly do not result in tensile load in the Graphite Core Components

(b) arrange the Graphite Core Components comprising the Graphite Core Assembly so that cracking of individual Graphite Core Components does not detrimentally affect the connections between the Graphite Core Components and thus impede the functionality of the Graphite Core Assembly

(c) provide clearances between Graphite Core Components to preclude constraint in the Graphite Core Assembly against movement, and thermal or irradiation expansion, or accumulation of tolerances

(d) arrange and support the Graphite Core Assembly so that vibration will be minimized

(e) connect Graphite Core Components with dowels and keys so that they are always positively located in the required position

(f) use only mechanical means (such as dowels, spigots, and keys) to join and fix Graphite Core Components

(g) allow for access to performing inservice inspection. If necessary, inservice inspection may be replaced by operational monitoring

(h) allow for repair or replacement of Graphite Core Components if required

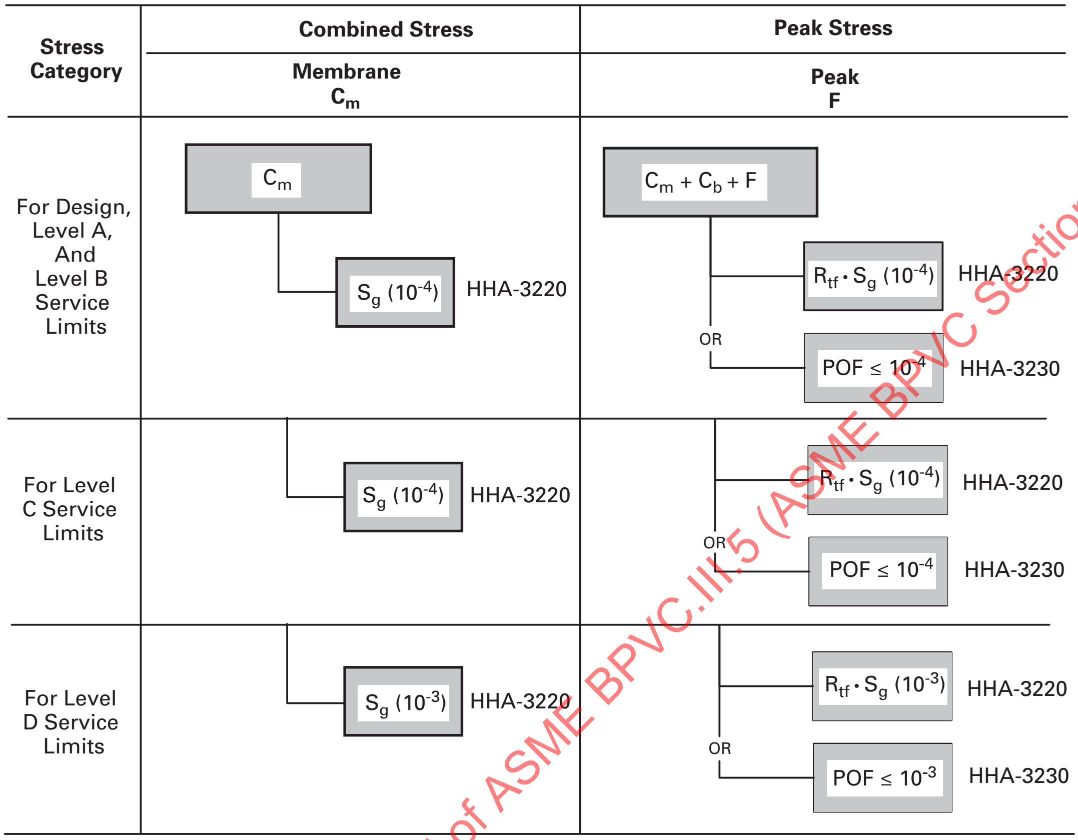
(i) allow for removal of the Graphite Core Components after final shutdown of the reactor in line with the overall decommissioning plan for the power plant

Table HHA-3221-1
Design Allowable Probability of Failure

		Service Limit			
SRC	**Design**	**Level A**	**Level B**	**Level C**	**Level D**
SRC-1	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10^{-3}
SRC-2 [Note (1)]	10^{-4} (10^{-2})	10^{-4} (10^{-2})	10^{-4} (10^{-2})	5×10^{-2}	5×10^{-2}
SRC-3	10^{-2}	10^{-2}	10^{-2}	5×10^{-2}	5×10^{-2}

NOTE:
(1) This applies to the SRC-2 Design as well as Service Level A and B limits. The change in limits is to indicate that this Article allows for the degradation of Graphite Core Components (or increase in stresses) caused by irradiation during service. The difference between the initial allowable stress value and the allowable stress value in parentheses makes sure that there is margin for material degradation or increase of stresses in service.

Figure HHA-3221-1
Design Allowable Stresses Flowchart for SRC-1 Graphite Core Component



GENERAL NOTE: This only defines the allowables for SRC-1 components

ARTICLE HHA-4000
MACHINING, EXAMINATION, AND TESTING

This Article covers the certification of materials prior to Graphite Core Component machining, and the machining, examination, testing, and packaging of Graphite Core Components.

HHA-4100 GENERAL REQUIREMENTS

(23) HHA-4110 INTRODUCTION

Graphite Core Components shall be machined, examined, and tested in accordance with the requirements of this Article and those described in the Construction Specification and shop drawings by the party responsible for Graphite Core Component machining, who is either a Certificate Holder or a Material Organization, as described in Article HAB-3000.

HHA-4120 CERTIFICATION OF MATERIALS AND MACHINING BY THE GRAPHITE CORE COMPONENT MANUFACTURER

HHA-4121 Means of Certification

The Graphite Core Component manufacturer shall certify, by completion of the G-2 Data Report (in accordance with Article HAB-8000), that the materials used comply with the requirements of the materials specification and that the machining, examination, and testing of all Graphite Core Components comply with the requirements of this Article, the Construction Specification, and the shop drawings. The G-2 Data Report will form part of the G-1 Data Report (in accordance with Article HAB-8000).

HHA-4122 Certification of Examinations and Tests

When the Graphite Core Component manufacturer performs examinations or tests, certified reports for all such examinations or tests shall be prepared and distributed as shown in Table HAB-3255-1.

HHA-4123 Identification of Materials and Machined Graphite Core Components

HHA-4123.1 Materials. Any material not clearly marked in accordance with HHA-2140 shall be rejected.

HHA-4123.2 Machined Graphite Core Components.

(a) All machined Graphite Core Components [with the exception of those identified in (e) below] shall be marked with an identification number that is traceable to material grade, charge, and billet number, and quality records generated during the manufacture of the material. The use of vibroetching and laser engraving is permitted.

(b) All machined Graphite Core Components shall also be marked with the component type or part number to assist installation (see Article HHA-5000).

(c) Marking on the final product shall be kept as far away as practical from corners and edges.

(d) Location(s) for marking of Graphite Core Components shall be defined by the Designer in the shop drawings.

(e) Standard Graphite Core Components such as dowels and keys need not be marked but must be traceable, by a batch number, to the material grade, charge, and billet number of the billet from which they were manufactured.

HHA-4130 JOINING

Graphite items that require joining shall only be done so mechanically.

HHA-4200 MACHINING, EXAMINATION, AND TESTING

HHA-4210 PROCEDURES, QUALIFICATION, AND EVALUATION

HHA-4211 General Requirements

Nondestructive examinations shall be performed by personnel who have been qualified as required in this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards defined in this Article.

HHA-4212 Nondestructive Examination Procedures

All nondestructive examinations performed under this Article shall be executed in accordance with detailed written procedures. Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Graphite Inspector upon request. At least one copy of each procedure shall be readily available to all applicable examination personnel for reference and use.

Measures shall be put in place to ensure that the Graphite Core Component is not contaminated during examination.

HHA-4213 Qualifications of Examination Personnel

All personnel performing nondestructive examination operations under this Article shall be competent and knowledgeable of the applicable examination requirements and procedures. All examinations required by this Article shall be performed and the results evaluated by qualified examination personnel. All nondestructive examination personnel shall be qualified on the basis of education, experience, training, and examination in accordance with the organization's Quality System Program.

HHA-4220 GRAPHITE CORE COMPONENT MACHINING

HHA-4221 General

All Graphite Core Components shall be machined and finished according to the shop drawings and documented procedures.

Graphite Core Components shall be protected during and after machining from contaminants such as liquids, dust, oil, and grease. Gloves or other suitable precautions shall be used to prevent contamination during handling.

Care must be taken when handling graphite components to avoid causing mechanical damage such as chips.

HHA-4222 Machining Facilities and Tools

(a) Any area where a graphite billet is unpacked or stored outside of its packaging shall be clean to limit contamination of the materials.

(b) Material not individually marked should be stored only with material of the same type and from the same billet to ensure traceability is maintained.

(c) Only graphite or other carbon materials shall be machined on the manufacturing equipment.

(d) Machine tools (cutting edges and beds) shall be maintained free of contamination.

(e) The machining facilities to be used for the machining of the Graphite Core Components shall be cleaned immediately prior to machining.

(f) Measures shall be taken to protect the Graphite Core Components from contamination with incompatible materials such as oil and grease during processing.

(g) Measures shall be put in place to ensure that prohibited substances (as listed in Table HHA-4222-1) are not used or introduced into the graphite during machining.

(h) In addition, the use of controlled substances (as listed in Table HHA-4222-1) shall be minimized in the processing of the materials to limit any contamination.

HHA-4223 Receiving Inspection

Receiving inspection shall verify that any material used is of the correct grade and that the material meets the requirements of Article HHA-2000 prior to release of the material for Graphite Core Component machining. This shall be checked again prior to machining.

HHA-4224 Other Processing Steps

Procedures shall detail measures in place to ensure that material traceability is maintained during the machining of Graphite Core Components. This will require the transfer of individual markings from the unmachined material to the finished Graphite Core Component, as described in HHA-2143. The transfer of markings shall also be undertaken if a machining stage results in the removal of the existing marking.

HHA-4230 GRAPHITE CORE COMPONENT EXAMINATION

HHA-4231 General (23)

Machined Graphite Core Components shall be examined in accordance with the rules established in this Article. These cover dimensional checks and visual examinations for material defects/flaws and damage. Appropriate nondestructive examination techniques, as described in the Construction Specification, may be used for detecting subsurface defects/flaws. The examinations required by this Article shall be performed by the Certificate Holder or a Material Organization (responsible for Graphite Core Component machining).

HHA-4232 Dimensional Examination

The dimensions of all machined and finished Graphite Core Components shall be examined using accepted measurement techniques using calibrated equipment to ensure conformity with the shop drawings and Construction Specification. Any Graphite Core Component with one or more dimension that is out-of-tolerance shall be rejected unless further machining can be carried out to bring the dimension(s) within tolerance. Following remachining, the dimension(s) shall be verified to show that they now conform to the shop drawing before the Graphite Core Component can be accepted.

HHA-4233 Examination for Material Defects and Damage

HHA-4233.1 Requirements. As a minimum, each Graphite Core Component shall be visually examined following machining for material defects/flaws and for damage sustained during handling. Each Graphite Core Component may also be examined using appropriate nondestructive examination techniques, as described in the Construction Specification.

HHA-4233.2 Material Defects/Flaws. Material defects/flaws are classified as either

(a) cracks, notches, or inclusions, or

(b) excessive voidage.

Observed defects/flaws shall be compared against the appropriate acceptance criteria (HHA-4233.4). Guidance on defects/flaws in graphite and their acceptability is provided in Nonmandatory Appendix HHA-D (in course of preparation).

HHA-4233.3 Damage. Due to the brittle nature of graphite, damage, in the form of cracks and chips, can be experienced during handling. Any such damage arising shall be compared against the appropriate acceptance criteria (HHA-4233.4).

HHA-4233.4 Acceptance Criteria. The acceptance criteria for material defects, and damage incurred during handling, shall be defined by the Designer in the Construction Specification. These may differ for SRC-1, SRC-2, and SRC-3 Graphite Core Components and also for different material grades.

For surface cracks, this will be in terms of a length for a single crack or a total length in terms of multiple cracks. For other surface defects/flaws or damage, these will have a limit on individual area or volume, and also on total area or volume, over the visible surface. The location and orientation of a defect/flaw, or its distance from a particular feature may also be subject to a limit. For subsurface defects/flaws, different criteria may apply, and these shall also be defined in the Construction Specification.

Surface or subsurface defects/flaws or damage of a particular type, which are individually, or collectively outside the limits specified in the Construction Specification, shall be cause for rejection of the material unless the material can be brought into compliance by repair (HHA-4233.5).

HHA-4233.5 Repair of Defects and Flaws. Only cracks that are visible at the surface shall be the subject of repair. A crack shall be dressed to a depth not exceeding 0.079 in. (2.0 mm). If all or part of the crack is still visible, the material shall be rejected.

HHA-4240 GRAPHITE CORE COMPONENT TESTING

(23) HHA-4241 General

The Designer shall identify in the Construction Specification all necessary requirements to carry out load testing of machined Graphite Core Components prior to final acceptance. This shall be a proof load test or an internal pressure test and shall be performed by the Certificate Holder or a Material Organization (responsible for Graphite Core Component machining).

HHA-4242 Graphite Core Component Testing

Graphite Core Components requiring testing either individually or as part of a subassembly shall be defined in the Construction Specification. The Construction Specification shall specify the modes of loading to be applied (e.g., axial compressive, internal pressure), together with the maximum test load or pressure to be applied separately or in combination.

HHA-4243 Post-Test Examination of Graphite Core Components (23)

The Certificate Holder shall examine all Graphite Core Components for the purpose of finding damage that resulted from the test. Acceptability of damage shall be determined from criteria given in the Construction Specification. The Construction Specification shall contain specific allowable sizes and locations of damaged areas of the Graphite Core Component to quantify acceptable damage. The Construction Specification shall also specify examination techniques to be used along with a complete examination procedure.

HHA-4244 Trial Assembly

The Designer shall define the requirement for trial assembly of portions of the Graphite Core Assembly in the Construction Specification. This definition shall include the sections of the Graphite Core Assembly to be assembled, any applicable acceptance criteria, and requirements for results reporting. The results shall be captured in the Construction Report.

HHA-4250 GRAPHITE CORE COMPONENT PACKAGING (23)

Detailed packaging and storage procedures shall be agreed upon between the Designer and the Certificate Holder (with construction scope) in the Construction Specification. As a minimum

(a) the larger Graphite Core Components shall be packaged in containers that will prevent damage occurring during transportation and subsequent storage at site.

(b) the machined Graphite Core Components shall be wrapped with an impermeable barrier to prevent contamination.

(c) smaller Graphite Core Components, such as keys and dowels, may be packaged in appropriate quantities in containers that also prevent contamination and damage during transportation.

(d) the packages shall be appropriately marked with information regarding the contents.

(e) each package shall contain the G-2 data report for the Graphite Core Component(s) within, which specifies the material, Graphite Core Component type(s), and any existing damage/defects.

Table HHA-4222-1
Prohibited and Controlled Substances

Prohibited Substances	Controlled Substances
Aluminum	Arsenic
Antimony	Beryllium
Bismuth	Cesium
Boron	Chromium
Cadmium	Cobalt
Gold	Copper
Halogens	Hafnium
Indium	Iron
Lead	Manganese
Lithium	Molybdenum
Magnesium	Nickel
Mercury	Phosphorus
Potassium	Platinum
Silver (solder)	Rare earth metals
Sodium	Selenium
Tin	Sulfur
Rhenium	Tantalum
Rhodium	Titanium
Thorium	Tungsten
Uranium	Vanadium
Zinc	

ARTICLE HHA-5000 INSTALLATION AND EXAMINATION

This Article covers the storage of Graphite Core Components at site, the unpackaging and examination of Graphite Core Components, the installation of Graphite Core Components to form the Graphite Core Assembly, and the examination requirements during installation and post-installation of the Graphite Core Assembly.

HHA-5100 GENERAL REQUIREMENTS

(23) HHA-5110 INTRODUCTION

Graphite Core Components shall have been machined in accordance with the requirements of Article HHA-4000 by a Certificate Holder or a Material Organization, and subsequently packaged, transported to site, and stored in suitable facilities. The Graphite Core Components shall be unpackaged, examined, and installed to form the Graphite Core Assembly in accordance with the requirements of this Article and those described in the Construction Specification. These activities shall be carried out by the party responsible for installing the Graphite Core Assembly, who is a Certificate Holder or a Material Organization, as described in Article HAB-3000.

HHA-5200 STORAGE, UNPACKAGING, AND EXAMINATION

(23) HHA-5210 STORAGE AND UNPACKAGING

Minimum requirements for the packaging and storage of Graphite Core Components prior to transportation to the site are given in HHA-4250. Detailed storage, unpackaging, and examination procedures at the site shall be agreed upon between the Designer and the Graphite Core Assembly Installer in the Construction Specification. As a minimum

(a) the packages shall be stored in a weatherproof building.

(b) the packages may be stacked, but only to a safe level that does not overload packages underneath or lead to instability.

(c) it is advisable to segregate packages into component types to facilitate marshalling prior to installation.

(d) the individual Graphite Core Components shall be unpackaged in a suitably clean area prior to installation.

(e) each Graphite Core Component shall be verified against the G-2 data report to ascertain that it is indeed the right material/component and examined to determine that no additional damage/defects have arisen during transportation/storage (see HHA-5220).

(f) if there are any discrepancies, the Graphite Core Component shall be quarantined in a separate segregated area for examination by the appropriate personnel, specifically the Certificate Holder with overall responsibility to fill in the G-1 data report and the Designer. The Graphite Core Component may be subsequently accepted or rejected by the Certificate Holder.

HHA-5220 EXAMINATION OF GRAPHITE CORE COMPONENTS

HHA-5221 General Requirements

The examination of Graphite Core Components after unpackaging shall be performed by personnel who have been qualified as required in this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards defined in this Article.

HHA-5222 Examination Procedures

All examinations performed under this Article shall be executed in accordance with detailed written procedures. Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Graphite Inspector upon request. At least one copy of each procedure shall be readily available to all applicable examination personnel for reference and use.

Measures shall be put in place to ensure that the Graphite Core Component is not contaminated during examination.

HHA-5223 Qualifications of Examination Personnel

All personnel performing examinations under this Article shall be competent and knowledgeable of the applicable examination requirements and procedures. All examinations required by this Article shall be performed and the results evaluated by qualified examination personnel. All examination personnel shall be qualified on the basis of education, experience, training, and examination in accordance with the organization's Quality System Program.

HHA-5300 INSTALLATION

HHA-5310 DOCUMENTATION

HHA-5311 Construction Procedures

The construction procedure(s) (HAB-3451) shall include the following:

(a) how the Graphite Core Components shall be stored, handled, unpackaged, checked, and installed

(b) field drawings, which identify all Graphite Core Components and their locations/orientations in the Graphite Core Assembly

(c) the installation sequence for all the Graphite Core Components

(d) the method(s) for lifting, moving, and placing Graphite Core Components

(e) the method for installing the lateral core restraints

(f) the positional, and any other, tolerances to be achieved during installation

(g) the method of measuring, and test equipment required, for setting each layer within specified tolerances

(h) the method for checking each layer to ensure that it has been installed correctly

(i) the methods of recording the location of Graphite Core Components in a completed layer

(j) the methods of verifying that the completed Graphite Core Assembly has been installed correctly and is within the specified tolerances

(k) the methods for assessing and accepting/rejecting Graphite Core Components damaged during installation

HHA-5400 EXAMINATION DURING INSTALLATION (23)

During installation, examinations shall be completed by the Certificate Holder after the completion of each layer to ensure that the Graphite Core Components have been installed in the specified locations/orientations and the Graphite Core Assembly remains within the specified tolerances according to the construction procedures pertaining to the field drawings.

HHA-5500 EXAMINATION POST-INSTALLATION (23)

After the Graphite Core Assembly and any interfacing metallic items/structures have been installed, examinations shall be completed by the Certificate Holder to ensure that it has been correctly installed according to the construction procedures and field drawings, it is within the specified tolerances, and there are no foreign bodies present. These should include at least the following:

(a) a visual examination of channels to ensure that

(1) they are clear (i.e., no foreign bodies are present)

(2) that no disengagement of components has occurred giving rise to discontinuities

(3) there are no damaged items that do not meet the acceptance criteria

(b) a measurement of individual channel verticality/straightness

The results of these examinations shall also be recorded in the Construction Report (see HAB-3454). The Authorized Nuclear Inspector for Graphite shall verify the accuracy of the Construction Report.

ARTICLE HHA-8000
NAMEPLATES, STAMPING, AND REPORTS

HHA-8100 REQUIREMENTS

The applicable requirements given in Article HAB-8000 shall apply to Graphite Core Components and the Graphite Core Assembly.

MANDATORY APPENDIX HHA-I GRAPHITE MATERIAL SPECIFICATIONS

ARTICLE HHA-I-1000 INTRODUCTION

HHA-I-1100 SCOPE

This Mandatory Appendix defines the material specifications that are to be used for manufacture of material used in this Subpart.

HHA-I-1110 MATERIAL SPECIFICATIONS

The following material specifications are accepted:

(a) ASTM D7219-08: Standard Specification for Isotropic and Near-isotropic Nuclear Graphites

(b) ASTM D7301-08: Standard Specification for Nuclear Graphite Suitable for Components Subjected to Low Neutron Irradiation Dose

MANDATORY APPENDIX HHA-II REQUIREMENTS FOR PREPARATION OF A MATERIAL DATA SHEET

ARTICLE HHA-II-1000 INTRODUCTION

(a) This Appendix defines the requirements for the development of data to be obtained by testing in accordance with the requirements in Mandatory Appendix HHA-III to prepare these data for use as design input data (HHA-2200).

(b) This Appendix defines the requirements for

(1) calculation of design input values from material test data

(2) documentation of the design input values

(c) HHA-2210 defines the requirement to prepare a Material Data Sheet. The Material Data Sheet is to include as-manufactured, irradiated, and oxidized material properties as well as an assessment of the uncertainties in the properties.

(d) Material testing required to prepare the Material Data Sheet shall comply with the standards specified in Mandatory Appendix HHA-III.

(e) The Designer is responsible for the derivation of data and documenting and filing the Material Data Sheet (as described in Article HAB-3000).

(f) Mandatory Appendix HHA-III defines the requirements for material testing that is to be completed to provide input data to the Material Data Sheet. When material test data is referred to in this Appendix, this refers to material test data generated in accordance with the requirements of Mandatory Appendix HHA-III.

(g) Only the data required to complete a design to the requirements of this Subpart are mandated in the Material Data Sheet. Additional data shall be included as the Designer requires or as specified in the Design Specification.

(h) The nomenclature of HHA-3130 applies.

ARTICLE HHA-II-2000 MATERIAL DATA SHEET FORMS

(23)

Material Data Sheet Form MDS-1 for SI units or Form MDS-2 for U.S. Customary units shall be completed for each graphite grade used to construct the Graphite Core Assembly. The completed form shall be filed with the Design Report. Graphite has increasing strength with increasing temperature. If the Designer takes credit for increased strength values due to elevated temperatures, Form MDS-1 or Form MDS-2 shall be completed with demonstrated strength results at elevated temperatures.

FORM MDS-1 MATERIAL DATA SHEET (SI UNITS)

Grade Designation

Material Grade ______ (1) ______ Material spec. ID ______ (2) ______ ASTM spec. ______ (3) ______

Max. grain size (mm) ______ (4) ______ Designation ______ (5) ______

Temperature-Dependent Parameters

Property	Units	Orientation	20°C	200°C	400°C	600°C	800°C	1 000°C [Note (1)]
Bulk density (6)	kg•m^{-3}	…						
Strength – tensile (7)	MPa	WG, AG						
Strength – flexural (8) (4-point)	MPa	WG, AG						
Strength – compressive (9)	MPa	WG, AG						
Elastic modulus (10) (dynamic)	GPa	WG, AG						
Elastic modulus (static) (11)	GPa	WG, AG						
Coefficient of thermal (12) expansion	°C^{-1}	WG, AG						
Thermal conductivity (13)	W/m•k	WG, AG						

Temperature-Independent Parameters

Poisson's ratio ______ (14) ______ Anisotropy factor ______ (15) ______ Critical stress intensity factor K_{IC} MPa•m$^{1/2}$ ______ (16) ______

Design Strength and Material Reliability Curve Values

Ratio of compressive to tensile strength (R_{tc}) ______ (17) ______ Ratio of flexural to tensile strength (R_{tf}) ______ (18) ______ $S_{c_{0.05}}$ MPa ______ (19) ______ $m_{0.05}$ ______ (20) ______

S'MPa ______ (21) ______ $S_c'{}_{0.05}$ MPa ______ (22) ______ $m'_{0.05}$ ______ (23) ______

S_g(10^{-4}) MPa ______ (24) ______ S_g (10^{-3}) MPa ______ (25) ______ S_g(10^{-2}) MPa ______ (26) ______ S_g(5×10^{-2}) MPa ______ (27) ______

Property Degradation Versus Weight Loss % in Uniformly Oxidized Graphite

Property	Units	2%	4%	6%	8%	10%
Strength [.] (28)						
Elastic modulus (dynamic) [.] (29)						
Thermal conductivity [.] (30)						

Irradiated Graphite

Property	Units	WG	AG
Dimensional change [.] (31)			
Creep coefficient [.] (32)			
Coefficient of thermal expansion [.] (33)			
Strength [.] (34)			
Elastic modulus [.] (35)			
Thermal conductivity [.] (36)			

GENERAL NOTES:
(a) WG, AG refers to the with- and against-grain direction of the material.
(b) [.] indicates a dimensionless quantity.

NOTE:
(1) If the maximum intended use temperature exceeds 1 000°C, then the temperature dependent data shall be extended to cover the property values at the maximum intended use temperature.

(07/23)

FORM MDS-2 MATERIAL DATA SHEET (U.S. CUSTOMARY UNITS)

Grade Designation

Material Grade ___ 1 ___ Material spec. ID ___ 2 ___ ASTM spec. ___ 3 ___

Max. grain size (in.) ___ 4 ___ Designation ___ 5 ___

Temperature-Dependent Parameters

Property	Units	Orientation	68°F	392°F	752°F	1,112°F	1,472°F	1,832°F [Note (1)]
Bulk density 6	lb•ft^{-3}	WG, AG						
Strength – tensile 7	ksi	WG, AG						
Strength – flexural 8 (4-point)	ksi	WG, AG						
Strength – compressive 9	ksi	WG, AG						
Elastic modulus 10 (dynamic)	ksi	WG, AG						
Elastic modulus (static) 11	ksi	WG, AG						
Coefficient of thermal 12 expansion	°F^{-1}	WG, AG						
Thermal conductivity 13	Btu/(hr•ft•°F)	WG, AG						

Temperature-Independent Parameters

Poisson's ratio ___ 14 ___ Anisotropy factor ___ 15 ___ Critical stress intensity factor K_{IC} ksi•in$^{1/2}$ ___ 16 ___

Design Strength and Material Reliability Curve Values

Ratio of compressive to tensile strength (R_{tc}) ___ 17 ___ Ratio of flexural to tensile strength (R_{tf}) ___ 18 ___ $S_{c_{0.05}}$ ksi ___ 19 ___ $m_{0.05}$ ___ 20 ___

S' MPa ___ 21 ___ $S_c{}'_{0.05}$ ksi ___ 22 ___ $m'_{0.05}$ ___ 23 ___

$S_g(10^{-4})$ ksi ___ 24 ___ $S_g(10^{-3})$ MPa ___ 25 ___ $S_g(10^{-2})$ ksi ___ 26 ___ $S_g(5 \times 10^{-2})$ ksi ___ 27 ___

Property Degradation Versus Weight Loss % in Uniformly Oxidized Graphite

Property	Units	2%	4%	6%	8%	10%
Strength [.] 28						
Elastic modulus (dynamic) [.] 29						
Thermal conductivity [.] 30						

Irradiated Graphite

Property	Units	WG	AG
Dimensional change [.] 31			
Creep coefficient [.] 32			
Coefficient of thermal expansion [.] 33			
Strength [.] 34			
Elastic modulus [.] 35			
Thermal conductivity [.] 36			

GENERAL NOTES:
(a) WG, AG refers to the with- and against-grain direction of the material.
(b) [.] indicates a dimensionless quantity.

NOTE:
(1) If the maximum intended use temperature exceeds 1,832°F, then the temperature dependent data shall be extended to cover the property values at the maximum intended use temperature.

(07/23)

Table HHA-II-2000-1
Notes on Material Data Sheet, Forms MDS-1 and MDS-2

Reference to Circled Numbers in the Form	Description
(1)	Material Grade: The manufacturer's grade designation that complies to the requirements of the Mandatory Appendix HHA-I material specification.
(2)	Material spec ID: Identify the construction specification for the graphite grade applicable to this Material Data Sheet.
(3)	ASTM spec: The Mandatory Appendix HHA-I material specification (ASTM) number that applies to the manufacture of the material.
(4)	Maximum grain size: The maximum filler particle grain size that is used in the mix formulation. (For isostatically pressed graphite, report mean grain size.)
(5)	Designation: Material designation as defined in the Mandatory Appendix HHA-I material specification.
(6)	Bulk density: The material bulk density. Mean and standard deviation of material test specimen results.
(7)	Strength, tensile: Mean and standard deviation of material test specimen results. Note that the temperature dependence of only one strength parameter need be determined; the others can be assumed to change by the same relative amount. Note that the elevated temperature strength needs only be measured should the Designer desire to take account of the strength increase.
(8)	Strength, flexural (4-point): Mean and standard deviation of material test specimen results. Note that the temperature dependence of only one strength parameter need be determined; the others can be assumed to change by the same relative amount. Note that the elevated temperature strength needs only be measured should the Designer desire to take account of the strength increase.
(9)	Strength, compressive: Mean and standard deviation of material test specimen results. Note that the temperature dependence of only one strength parameter need be determined; the others can be assumed to change by the same relative amount. Note that the elevated temperature strength needs only be measured should the Designer desire to take account of the strength increase.
(10)	Elastic modulus (dynamic): Mean and standard deviation of material test specimen results.
(11)	Elastic modulus (static): Mean and standard deviation. Use either a measured value of the dynamic elastic modulus (10) scaled by the ratio between static and dynamic. Note that the dynamic and static modulus are related. Only one need be measured and the other can be computed from these measurements and scaling over with the ratio between the two values.
(12)	Coefficient of thermal expansion: Mean and standard deviation of material test specimen results. This property's temperature dependence shall be determined.
(13)	Thermal conductivity: Mean and standard deviation of material test specimen results.
(14)	Poisson's ratio: Mean and standard deviation of material test specimen results. As an alternative, a published historical value may be used.
(15)	Anisotropy factor: Mean and standard deviation for the charges as described in the graphite specification (Mandatory Appendix HHA-I). The average of the charges is then given in the Material Data Sheet.
(16)	Critical stress intensity factor (K_{IC}): The average and standard deviation of the material test specimen results.
(17)	Ratio of compressive to tensile strength (R_{tc}): Computed from the mean tensile and mean compressive strengths as published in (7) and (9) above. R_{tc} = Compressive Strength (9) ÷ Tensile Strength (7). This quantity is defined as positive.
(18)	Ratio of flexural to tensile strength (R_{tf}): Computed from the mean tensile and mean flexural strengths as published in (7) and (8) above. R_{tf} = Flexural Strength (8) ÷ Tensile Strength (7). This quantity is defined as positive.
(19)	$S_{c_{0.05}}$: The computed 95% single side confidence interval value for the Weibull characteristic strength that defines the material reliability curve. This is calculated in accordance with HHA-II-3100, based on the tensile strength measurements.
(20)	$m_{0.05}$: The computed 95% single side confidence interval value for the Weibull modulus that defines the material reliability curve. This is calculated in accordance with HHA-II-3100, based on the tensile strength measurements.
(21)	S': The computed value for the threshold stress based on the three-parameter distribution that defines the material reliability curve. This is calculated in accordance with HHA-II-3200, based on the tensile strength measurements.
(22)	$S'_{c_{0.05}}$: The computed 95% single side confidence interval value for the characteristic stress based on the three-parameter distribution that defines the material reliability curve. This is calculated in accordance with HHA-II-3200, based on the tensile strength measurements.
(23)	$m'_{0.05}$: The computed 95% single side confidence interval value for the Weibull modulus based on the three-parameter distribution that defines the material reliability curve. This is calculated in accordance with HHA-II-3200, based on the tensile strength measurements.
(24)	$S_g(10^{-4})$: The design allowable stress value corresponding to the Probability of Failure of 10^{-4}, computed in accordance with HHA-II-3300 based on $S_{c0.05}$ and $m'_{0.05}$ [(19) and (20) above].
(25)	$S_g(10^{-3})$: The design allowable stress value corresponding to the Probability of Failure of 10^{-3}, computed in accordance with HHA-II-3300 based on $S_{c0.05}$ and $m'_{0.05}$ [(19) and (20) above].
(26)	$S_g(10^{-2})$: The design allowable stress value corresponding to the Probability of Failure of 10^{-2}, computed in accordance with HHA-II-3300 based on $S_{c0.05}$ and $m'_{0.05}$ [(19) and (20) above].
(27)	$S_g(5 \times 10^{-2})$: The design allowable stress value corresponding to the Probability of Failure of 5×10^{-2}, computed in accordance with HHA-II-3300 based on $S_{c0.05}$ and $m'_{0.05}$ [(19) and (20) above].

Table HHA-II-2000-1
Notes on Material Data Sheet, Forms MDS-1 and MDS-2 (Cont'd)

Reference to Circled Numbers in the Form	Description
(28)	Oxidation change in strength: Either as a chart or curve that describes the mean behavior of the relative property change as a percentage of weight loss in uniformly oxidized graphite. This is expressed as a value normalized to the as-manufactured value and may be based on a strength parameter selected by the Designer. The strength parameter used should be justified and recorded in an attachment to the Material Data Sheet.
(29)	Oxidation change in elastic modulus (dynamic): Either as a chart or curve that describes the mean behavior of the relative property change as a function of weight loss in uniformly oxidized graphite. This is expressed as a value normalized to the as-manufactured value.
(30)	Oxidation change in thermal conductivity: Either as a chart or curve that describes the mean behavior of the relative property change as a function of weight loss in uniformly oxidized graphite. This is expressed as a value normalized to the as-manufactured value.
(31)	Irradiation-induced dimensional change: This is the change in length, normalized to the initial length expressed as a percentage. The data shall be expressed as either a table of data or as a mathematical fit, appended to the data sheet. Range of applicability to be identified and checked as part of the design assessment.
(32)	Irradiation-induced creep coefficient: Shall be expressed as either a table of data or as a mathematical fit, appended to the data sheet. Range of applicability to be identified and checked as part of the design assessment. The creep coefficient to be used is to be the coefficient (or set of coefficients) required for the irradiation creep model proposed for use by the Designer. The model shall be recorded in an attachment to the Material Data Sheet.
(33)	Irradiation-induced change in coefficient of thermal expansion: Shall be expressed as either a table of data or as a mathematical fit, appended to the data sheet. Range of applicability to be identified and checked as part of the design assessment. This is expressed as a value normalized to the as-manufactured value. The temperature dependence of this property shall be determined.
(34)	Irradiation-induced change in strength: Shall be expressed as either a table of data or as a mathematical fit, appended to the data sheet. Range of applicability to be identified and checked as part of the design assessment. This is expressed as a value normalized to the as-manufactured value and shall be based on a strength parameter selected by the Designer. The strength parameter used shall be recorded in an attachment to the Material Data Sheet. Note that irradiation-induced change in strength need only be measured should the Designer desire to take account of the strength increase at low or intermediate damage doses.
(35)	Irradiation-induced change in elastic modulus: This is expressed as a value normalized to the as-manufactured value.
(36)	Irradiation-induced change in thermal conductivity: This is expressed as a value normalized to the as-manufactured value. The temperature dependence of this property shall be determined.

GENERAL NOTE: These notes provide a definition of the parameters in the Material Data Sheet and how they are to be determined. The information in this table shall be defined for each cell in the Material Data Sheet: mean, standard deviation, and number of specimens. The data may either be included on the form or as attachments. Attachments, where used, shall be filed with the form.

(23)

ARTICLE HHA-II-3000
DETAILED REQUIREMENTS FOR DERIVATION OF THE MATERIAL DATA SHEET — AS-MANUFACTURED PROPERTIES

HHA-II-3100 MATERIAL RELIABILITY CURVE PARAMETERS (TWO PARAMETER FOR SIMPLE ASSESSMENT)

(a) The probability density function, $f(x)$, of the strength distribution is to be determined from the measured strength values using the following two-parameter Weibull distribution:

$$f(x) = \left(\frac{x}{S_c}\right)^{m-1} \cdot \frac{m}{S_c} \cdot \exp\left[-\left(\frac{x}{S_c}\right)^m\right];\ x > 0 \tag{1}$$

The distribution function

$$p(x) = \int_0^x f(x') \cdot dx' = 1 - \exp\left[-\left(\frac{x}{S_c}\right)^m\right];\ x > 0 \tag{2}$$

is designated as the failure probability. The survival probability is defined as

$$L(x) = 1 - p(x) = \exp\left[-\left(\frac{x}{S_c}\right)^m\right];\ x > 0 \tag{3}$$

(b) The following Weibull parameters:

(1) m = shape parameter

(2) S_c = characteristic strength value

are to be determined using the method of least squares from the linearized relationship

$$\ln\left\{-\ln\left[L(x)\right]\right\} = m \cdot \ln(x) - m \cdot \ln(S_c) \tag{4}$$

corresponding to the straight line equation

$$y(x) = a \cdot x + b$$

(c) The measured values are to be arranged in a monotonically increasing order. Everyone of the n measured strength values is to be allocated its probability of survival in accordance with the following equation:

$$L_k = 1 - \frac{k}{n+1};\ k = 1, \cdots, n \tag{5}$$

Applying the straight line, one obtains estimated values of m^* and S_c^* from the measured values (strength values) for the true Weibull parameters m and S_c. These estimated values are approximations whose precision depends on the scope of test samples examined.

(d) The lower limits of the one-sided 95% confidence interval for the Weibull parameters ($m_{0.05}$ and $S_{c0.05}$) are used for the stress evaluation. The lower limits of the Weibull parameters are found using the upper limits of the pivotal quantities [$t(n; 0.95)$ and $t'(n; 0.95)$] associated with the appropriate sample size, n. The pivotal quantities are to be determined using eqs. (8) and (9) (up to n = 1,000) or Table HHA-II-3100-1 (up to n = 120). Figures HHA-II-3100-1 and HHA-II-3100-2 display trends seen in eqs. (8) and (9).

$$m_{0.05} = \frac{m^*}{t(n; 0.95)} \tag{6}$$

$$S_{c0.05} = S_c^* \times \exp[-t'(n; 0.95)/m^*] \tag{7}$$

$$t\left(n; 0.95\right) = \exp\left[-0.59669 + 0.040572 \times \ln\left(n\right) + \frac{2.532271}{\ln(n)}\right] \tag{8}$$

$$t'\left(n; 0.95\right) = \left[0.86483 + 0.565442 \times n^{0.5} + \frac{-0.95568}{n^{0.5}}\right]^{-1} \tag{9}$$

(e) The characteristic strength value $S_{c_{0.05}}$ depends on the fluence of fast neutrons. In the case of a neutron-irradiated material, therefore, the $S_{c_{0.05}}$ value determined for a nonirradiated material is multiplied by a factor that considers the strength increase or decrease due to the irradiation.

HHA-II-3200 MATERIAL RELIABILITY CURVE PARAMETERS (THREE PARAMETER FOR FULL ASSESSMENT)

The Probability Density Function (PDF) and the Cumulative Distribution Function (CDF) of the three-parameter Weibull distribution are given by

$$f(x|\alpha,\beta,\mu) = \frac{\alpha}{\beta^{\alpha}}(x-\mu)^{\alpha-1}e^{-\left(\frac{x-\mu}{\beta}\right)^{\alpha}} \tag{10}$$

and

$$F(x|\alpha,\beta,\mu) = 1 - e^{-\left(\frac{x-\mu}{\beta}\right)^{\alpha}} \tag{11}$$

respectively, where $x > \mu$, $-\infty < \mu < \infty$, $\alpha > 0$, and $\beta > 0$. The parameter α is called the shape parameter, β is called the scale parameter and μ is called the threshold parameter.

Given a sample of independent and identically distributed observations $X_1, X_2, ..., X_n$ having a common PDF [eq. (10)], the maximum likelihood estimates $\hat{\alpha}$, $\hat{\beta}$, and $\hat{\mu}$ of the parameters α, β, and μ satisfy the following three equations:

$$\hat{\beta} = \left(\frac{1}{n}\sum_{i=1}^{n}(X_i - \hat{\mu})^{\hat{\alpha}}\right)^{\frac{1}{\hat{\alpha}}} \tag{12}$$

$$\hat{\alpha} = \left[\frac{\left(\sum_{i=1}^{n}(X_i-\mu)^{\hat{\alpha}}\ln(X_i-\hat{\mu})\right)}{\left(\sum_{i=1}^{n}(X_i-\hat{\mu})^{\hat{\alpha}}\right) - \left(\frac{1}{n}\sum_{i=1}^{n}\ln(X_i-\hat{\mu})\right)}\right]^{-1} \tag{13}$$

$$(\hat{\alpha}-1)\sum_{i=1}^{n}(X_i-\hat{\mu})^{-1} = \frac{\hat{\alpha}}{\hat{\beta}^{\hat{\alpha}}}\sum_{i=1}^{n}(X_i-\hat{\mu})^{\hat{\alpha}-1} \tag{14}$$

Let ξ denote the population 100th percentile point $(0 < c < 1)$ of the three-parameter Weibull distribution, i.e., let

$$c = F(x|\alpha,\beta,\mu) = 1 - e^{-\left(\frac{\xi-\mu}{\beta}\right)} \tag{15}$$

Then ξ_c can be obtained as:

$$\xi_c = \mu + \beta\{-\ln(1-c)\}^{\frac{1}{\alpha}} \tag{16}$$

It follows from the invariance property of maximum likelihood estimators that the maximum likelihood estimates, of ξ_c is given by:

$$\hat{\xi}_c = \hat{\mu} + \hat{\beta}\{-\ln(1-c)\}^{\frac{1}{\hat{\alpha}}} \tag{17}$$

An approximate two-sided $(1 - \gamma)$ 100% confidence interval for ξ_c is given by L (lower limit) and U (upper limit) where:

$$L = e^{(\ln\hat{\xi}_c - k_\gamma \mathrm{var}(\hat{\xi}_c)/\hat{\xi})_c} \text{ and } U = e^{(\ln\hat{\xi}_c - k_\gamma \mathrm{var}(\hat{\xi}_c)/\hat{\xi})_c} \tag{18}$$

and where $k\gamma$ is the $(1 - \gamma)/\ 2$ percentile of the standard normal distribution.

A reparameterization of the three-parameter Weibull distribution, using eqs. (10) and (11), is given by:

$$h(x\,|\,S', S_c, m) = \left(\frac{x-S'}{S_c-S'}\right)^{m-1}\frac{m}{S_c-S'}e^{-\left(\frac{x-S'}{S_c-S'}\right)^{m}} \tag{19}$$

and

$$H\left(x\,|\,S', S_c, m\right) = 1 - e^{-\left(\frac{x-S'}{S_c-S'}\right)^{m}} \tag{20}$$

where x is the value of the individual data point. The correspondence between the parameters α, β, and μ in eqs. (10) and (11) and the parameters S', S_c, and m in eqs. (19) and (20), is obtained by comparing eqs. (11) and (20), i.e.

$$\mu = S' \quad \alpha = m \quad \beta = S_c - S' \tag{21}$$

Given the maximum likelihood estimates (MLEs) $\hat{\alpha}$, $\hat{\beta}$, and $\hat{\mu}$ and using the invariance property of MLEs, the MLE of $\hat{S}_c$, $\hat{S}'$, and $\hat{m}$ of the parameters S', S_c, and m follows from eq. (21) and is given by

$$S' = \mu \quad m'_{0.05} = \hat{\alpha}\ ,\ S'_{c_{0.05}} = \hat{\beta} + S' = \hat{\beta} + \hat{\mu} \tag{22}$$

HHA-II-3300 DESIGN ALLOWABLE STRESS VALUE

(a) Using the determined values of $m_{0.05}$ and $S'_{c_{0.05}}$, the stress values $S_g(p)$ are to be ascertained [from eq. (23)] for failure probabilities POF corresponding to 10^{-4}, 10^{-3}, 10^{-2}, and 5×10^{-2}. The allowable stress values S_g (POF) depend on the Structural Reliability Class and the Design or Service Level Loading (refer to HHA-3220). In the case of simple stress distributions, these values are used for the evaluation of component stresses.

$$S_g(\mathrm{POF}) = S'_{c_{0.05}}\left(-\ln(1-\mathrm{POF})\right)^{\frac{1}{m_{0.05}}} \tag{23}$$

The allowable stress values for tensile stresses, compressive stresses, and bending stresses are to be determined from the measured tensile, compressive, and bending strengths, respectively.

Figure HHA-II-3100-1
Pivotal Quantity $t(n;0.95)$ of the Shape Parameter of the Two Parameter $m_{0.05}$ Weibull Distribution

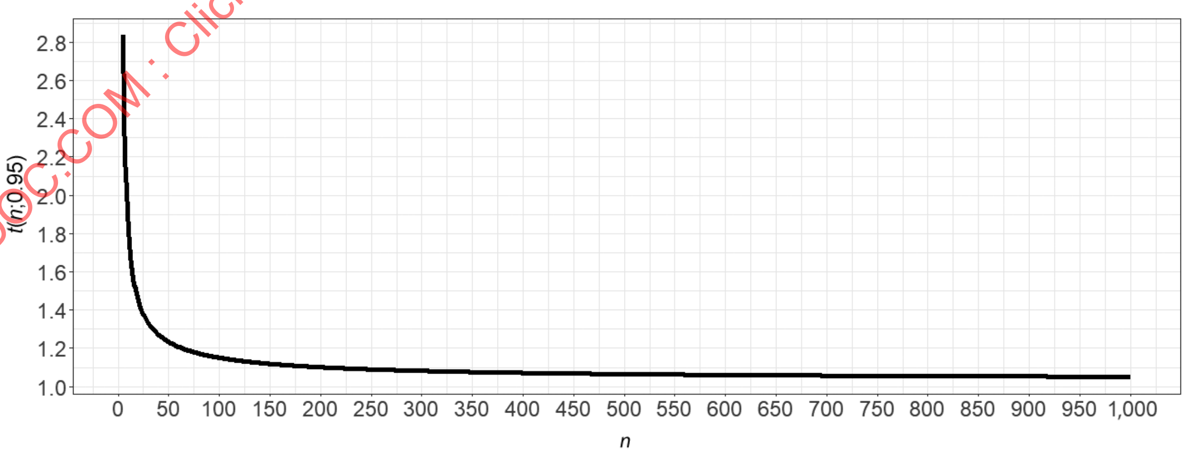


Figure HHA-II-3100-2
Pivotal Quantity $t'(n;0.95)$ of the Characteristic Stress Parameter $S_{c0.05}$ of the Two Parameter Weibull Distribution

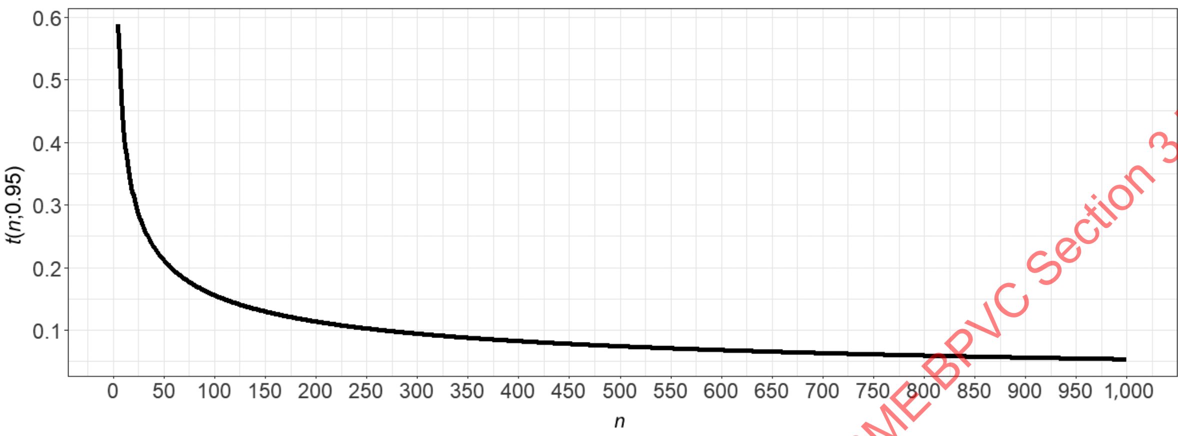


Table HHA-II-3100-1
Normalized Upper Bounds on the Shape and Characteristic Stress Pivotal Quantities, Samples Sizes 5-120

Number of Specimans, n	$t(n; 0.95)$	$t'(n; 0.95)$
5	2.779	1.107
6	2.436	0.939
7	2.183	0.829
8	2.015	0.751
9	1.896	0.691
10	1.807	0.644
11	1.738	0.605
12	1.682	0.572
13	1.636	0.544
14	1.597	0.52
15	1.564	0.499
16	1.535	0.48
17	1.51	0.463
18	1.487	0.447
19	1.467	0.433
20	1.449	0.421
22	1.418	0.398
24	1.392	0.379
26	1.37	0.362
28	1.351	0.347
30	1.334	0.334
32	1.319	0.323
34	1.306	0.312
36	1.294	0.302
38	1.283	0.293
40	1.273	0.285
42	1.265	0.278
44	1.256	0.271
46	1.249	0.264
48	1.242	0.258
50	1.235	0.253
52	1.229	0.247
54	1.224	0.243
56	1.218	0.238
58	1.213	0.233
60	1.208	0.229
62	1.204	0.225
64	1.2	0.221
66	1.196	0.218
68	1.192	0.214
70	1.188	0.211
72	1.185	0.208
74	1.182	0.205
76	1.179	0.202
78	1.176	0.199
80	1.173	0.197
85	1.166	0.19
90	1.16	0.185
95	1.155	0.179
100	1.15	0.175
110	1.141	0.166
120	1.133	0.159

ARTICLE HHA-II-4000
DETAILED REQUIREMENTS FOR DERIVATION OF THE MATERIAL DATA SHEET — IRRADIATED MATERIAL PROPERTIES

HHA-II-4100 GENERAL

(a) The changes in these properties with neutron irradiation shall be determined at sufficient intervals over the design fluence and temperature range. Temperature and fluence intervals shall be selected so as to provide adequate confidence in the accuracy of the interpolations. Limited extrapolations are permitted, but such extrapolations shall be justified.

(b) Property changes (such as strength, thermal conductivity, the linear coefficient of thermal expansion, and the elastic modulus) are to be reported in the form of the relative change with regard to value before irradiation as a function of the fluence over the relevant operating temperature range. When reporting fractional change of these properties, for near-isotropic graphite grades, distinction with respect to the preferred grain orientation is not required.

(c) The creep coefficient (creep model parameters) is to be given for those temperatures that occur in the irradiated components, in accordance with HHA-3142.1(c).

(d) The effect of creep strain on coefficient of thermal expansion and elastic modulus shall be determined and included in the Material Data Sheet.

(e) The irradiation-induced relative linear dimensional changes are to be given for the design service temperature range for the irradiated components. The relative linear dimensional changes are to be given separately for both grain orientations. For isotropic graphite, where the difference between dimensional change curves is insignificant, only one curve is necessary.

MANDATORY APPENDIX HHA-III REQUIREMENTS FOR GENERATION OF DESIGN DATA FOR GRAPHITE GRADES

ARTICLE HHA-III-1000 SCOPE

This Appendix defines the requirements for the generation of graphite design data to be used for the design of Graphite Core Components and the Graphite Core Assembly in accordance with the rules in this Subpart. The properties data required to qualify a grade for use in this Subpart are defined herein.

It is the policy of the ASME Boiler and Pressure Vessel Committee to adopt for inclusion only such specifications adopted by the American Society for Testing and Materials (ASTM) and by other recognized national or international organizations. Mandatory Appendix HHA-I contains two ASTM material specifications for nuclear grade graphites.

Changes to a graphite grade (specifically the coke or processing route) will require the generation of new design data.

ARTICLE HHA-III-2000 GENERAL REQUIREMENTS

Design data, generated for use in this Subpart, shall comply with the following requirements:

(a) Material that is tested shall satisfy the applicable requirements of Article HHA-2000. The material shall be manufactured and the data generated under a Quality Assurance Program that complies with the requirements of Article HAB-4000 or HAB-3800. The scope of the program shall include material testing.

(b) The specimen data generated shall be traceable to the billet number, location within the billet, and orientation of the specimen within the billet.

(c) The measuring and test equipment shall be calibrated and calibration records shall be maintained.

ARTICLE HHA-III-3000
PROPERTIES TO BE DETERMINED

Together with the specifications for the material (Mandatory Appendix HHA-I), the Designer shall generate adequate data as basis for design values to be used for the Material Data Sheet. The Designer shall record the product cutting and sampling plan from which the specimens and various properties were taken, as well as all supporting test records. The heterogeneity of the graphite and statistical nature of the data shall be considered. Where property means and standard deviations are reported, the size of the sample population shall be reported as well.

(a) The test standards specified in ASTM C781 shall be used.

(b) Where a test standard does not exist or has to be customized for application, the test procedure used for the completion of the tests shall be filed with the material test data.

HHA-III-3100 AS-MANUFACTURED GRAPHITE

For as-manufactured graphite [HHA-3142.1(a)] the following properties shall be determined:

(a) strength — tensile, temperature dependent

(b) strength — compressive, temperature dependent

(c) strength — flexural, temperature dependent

(d) elastic modulus (dynamic), temperature dependent

(e) elastic modulus (static)

(f) Poisson's ratio

(g) coefficient of thermal expansion, temperature dependent

(h) critical stress intensity factor (K_{IC})

(i) density

(j) thermal conductivity, temperature dependent

Temperature-dependent properties are to be measured at a maximum of 360°F (200°C) increments, from room temperature to at least the maximum intended use temperature. The temperature dependence of only one strength parameter shall be determined; the others may be assumed to change by the same relative fraction.

(23) HHA-III-3200 OXIDIZED GRAPHITE

For oxidized graphite (HHA-3141) the following properties shall be determined:

(a) strength versus oxidative weight loss in uniformly oxidized graphite

(b) dynamic modulus versus oxidative weight loss in uniformly oxidized graphite

(c) thermal conductivity versus oxidative weight loss in uniformly oxidized graphite

Test data shall represent and envelope the oxidative conditions in service (i.e., they shall mimic reactor coolant chemistry and thermal operating histories).

HHA-III-3300 IRRADIATED GRAPHITE

For irradiated graphite [HHA-3142.1(b) and HHA-3142.1(c)] the following properties shall be determined:

(a) thermal conductivity – temperature dependent

(b) dimensional change [HHA-3142.1(c) only]

(c) creep coefficient(s) [HHA-3142.1(c) only]

(d) coefficient of thermal expansion – temperature dependent [HHA-3142.1(c) only]

(e) strength [HHA-3142.1(c) only]

(f) elastic modulus [HHA-3142.1(c) only]

Test data shall represent and envelope the irradiation conditions in service, i.e., they shall mimic reactor neutron fluence and temperature ranges. Data shall be reported in accordance with ASTM C625.

The temperature range of material in operation in the reactor for all service levels shall be enveloped by the temperature range of the data. The irradiation response of properties shall be determined over the enveloping fluence and temperature range as defined in the qualification envelope (HHA-2131). Maximum temperature increments of 360°F (200°C) shall be used.

Temperature-dependent properties shall be measured at a maximum of 360°F (200°C) intervals. The range of the temperature at which the property shall be measured is to be determined from the qualification envelope (HHA-2131). Measurements that do not envelope the maximum use temperature are permissible as this may be necessary to measure changes in properties with irradiation without partially annealing the irradiation-induced damage.

Note that the irradiation-induced change in strength shall only be measured if the Designer desires to take account of strength increase at low or intermediate damage doses.

ARTICLE HHA-III-4000 REQUIREMENT FOR REPRESENTATIVE DATA

HHA-III-4100 AS-MANUFACTURED GRAPHITE

As-manufactured material property data shall be obtained from at least three charges, consisting of a minimum of four billets per charge, of material meeting all of the requirements of the material specification (see Mandatory Appendix HHA-I). Moreover, property data (including the effects of temperature on properties) shall be obtained from billets whose dimensions are comparable to the production billets for which a Material Data Sheet is to be prepared. Specimen sampling plans and billet selections shall reflect the anticipated heterogeneity of the product form. The requirements for sampling are based on the material forming method as follows:

(a) For Extruded Material: Measure two specimens in both the with-grain and against-grain direction from both the center and periphery of a slice taken from the billet. The slices shall be taken from the top, middle, and bottom of the billet relative to the orientation of the billet during first bake. Slices shall be selected so that there are approximately equal numbers of slices from the top, middle, and bottom over all of the billets that are measured for the Material Data Sheet.

(b) For Molded Material: Measure two specimens in both the with-grain and against-grain direction from both the center and periphery of a slice taken from the billet. The slices shall be taken from the top, middle, and bottom of the billet relative to the orientation of the billet during first bake. Slices shall be selected so that there are approximately equal numbers of slices from the top, middle, and bottom over all of the billets that are measured for the Material Data Sheet.

(c) For Isomolded Material: Measure two specimens in both the with-grain and against-grain direction from both the center and periphery of a slice taken from the billet. The slices shall be taken from the top, middle, and bottom of the billet relative to the orientation of the billet during first bake. Slices shall be selected so that there are approximately equal numbers of slices from the top, middle, and bottom over all of the billets that are measured for the Material Data Sheet.

The measurements described in (a) through (c) above are minimum values. More specimens may be measured. It is not permissible to replace additional specimen measurements against numbers of billets or slices sampled.

HHA-III-4200 IRRADIATED OR OXIDIZED GRAPHITE

Irradiated or oxidized material property data shall be obtained from material that is representative of the material used for the generation of the irradiated or oxidized material design data.

The Designer is responsible for the determination and justification of the representative data.

ARTICLE HHA-III-5000
USE OF HISTORICAL DATA

This Appendix does not require new testing if the required test data are already generated. The historical data shall meet the requirements of this Appendix and be on the same graphite grade. If credit is taken from previous qualification programs, then testing shall also demonstrate that the historic data is applicable to the current production material.

NONMANDATORY APPENDIX HHA-A GRAPHITE AS A STRUCTURAL MATERIAL

ARTICLE HHA-A-1000 INTRODUCTION

This Appendix has been written to familiarize the Designer with graphite. Graphite as a structural material has properties that are very different from metals. It is brittle and porous and has much higher compressive strength than tensile strength. As temperature increases, the strength increases. In addition, components are usually three-dimensional solids, rather than two-dimensional, shell-type structures; therefore, three-dimensional stress analysis or its equivalent is required.

HHA-A-1100 MANUFACTURE

Manufactured graphites are relatively pure carbon. Manufactured graphite, known also as artificial or electrographite, is produced by heating carbon to high temperatures in electric furnaces. The manufacture of graphite is worldwide, although the industry is less than 100 yr.

Manufactured graphite is not a single well-defined material, but rather a family of materials. Each is essentially pure carbon, but each varies in such ways as the orientation of crystallites, size and number of pore spaces, and degree of graphitization. These variations are due to the raw material and processing variables. Artificial graphites are composed of individual coke graphite particles cemented together by a carbon binder that is later converted into graphite. The manufacturing process involves the following major operations: raw material preparation, mixing and forming, baking and impregnating, graphitizing, and finishing, as shown in the typical flowchart in Figure HHA-A-1100-1.

Figure HHA-A-1100-1

petroleum coke ⟶ calcining ⟶ sizing ⟶ mixing with binder ⟶ extrusion or molding ⟶ baking ⟶ impregnating ⟶ graphitizing ⟶ finishing

This process requires considerable time because "green" stock is a poor thermal conductor, evolves large quantities of gases, and is sensitive to thermal shock. Baking cycles may range from 20 days to 70 days, and graphitization cycles may run 10 days to 30 days. The finished graphite products may vary widely in physical and mechanical properties, depending upon the raw materials used, the sizing of the filler materials, the forming method, baking, impregnating, and graphitization.

HHA-A-1110 RAW MATERIAL PREPARATION

Although artificial graphites can be made from almost any organic material that leaves a high carbon residue on heating, the principal raw materials for commercial products are petroleum coke (the solid residue formed during the distillation of petroleum) and coal tar pitch. Other materials may be used, such as lampblack, natural graphite, anthracite, coal, and petroleum pitch. Raw materials contain latent crystallinity, which is developed by heat treatment affecting the final product properties. The purity of the finished product is also influenced by the choice of raw materials. The particle sizes selected are partially determined by the product to be made, and particle size affects the physical properties of the finished product.

HHA-A-1120 MIXING AND FORMING

Forming is another variable that affects final product properties. If the sized filler materials tend to possess one dimension larger than the other two, these long axes tend to take on a preferred orientation during forming, either with the direction of extrusion or perpendicular to the molding direction. Thus, the anisotropy of a formed graphite piece reflects both the effects of the forming process and the anisotropy of the raw materials. The final graphite product retains this same grain orientation.

HHA-A-1130 BAKING AND IMPREGNATION

In the baking process, the binder is coked to develop an infusible carbon bond by heating the "green" stock in a kiln. The stock must be carefully spaced and surrounded by a supportive material, since the binder liquefies in the early stages of the baking cycle and the stock becomes plastic. Since very large furnaces are commonly used for commercial processing, some variations in properties from piece to piece and within a piece may occur.

During baking of the formed piece, approximately one-third of the binder is driven off through destructive distillation. This results in a loss of apparent density and the development of porosity and permeability to liquids and gases. These characteristics, as well as mechanical strength, can be improved by impregnation prior to graphitization so that additional bond coke is formed during heat treatment.

HHA-A-1140 GRAPHITIZATION

In the graphitization step, the incipient crystalline short range order in the baked carbon piece grows into an ordered pattern of stacked parallel planes. There is an abrupt change in the physical properties of the stock as it is transformed from carbon to graphite in the 4,000°F to 5,540°F (2 200°C to 3 000°C) temperature range.

HHA-A-1150 FINISHING (PURIFICATION)

Where purity is important, increased graphitization temperatures may be used. Chemical reagents may be added to the carbon stock to react with impurities to form volatile products. An atmosphere of pure reactive gases may be used to achieve the same high purity.

HHA-A-1160 GRAIN ORIENTATION

Because of the grain orientation of most graphite products and the possibility of piece-to-piece variations within a piece, sampling becomes very important. Sampling procedures should identify the orientation of the product, and the selection of samples should recognize possible distribution patterns occurring in chemistry and physical and mechanical properties. The preferred orientations of graphite are shown below.

(a) Extrusion. As shown in Figure HHA-1160-1, *X* and *Y* are equivalent directions and are termed the "against-grain" or "perpendicular" directions. Properties will be symmetric about the *Z* axis, termed the "with-grain" or "parallel" direction. The *Z* axis is parallel to the direction of the applied force.

(b) Molding. As shown in Figure HHA-1160-2, *Z* is the axis of symmetry and is "parallel" to the direction of the applied force. The grain orientation is such that the *Z* axis is the "against-grain" or "perpendicular" direction. All vectors in the molding plane have equivalent properties and are "with-grain" or "parallel" properties.

HHA-A-1170 RECENT LITERATURE

Graphite has been used as a nuclear structural material for more than 70 yr. A vast body of literature has been generated in that time. More recent literature can be found in the references ([1], [2]).

HHA-A-1180 REFERENCES

[1] Ball, D. R. STP-NU-009, Graphite for High Temperature Gas-Cooled Nuclear Reactors, ASME Standards Technology, LLC, 2008.

[2] Burchell, T. D. Graphite: Properties and Characteristics. In: Konings, R. J. M. (ed.) *Comprehensive Nuclear Materials*, Vol. 2, pp. 285-305, Amsterdam: Elsevier, 2012.

Figure HHA-1160-1
Extrusion

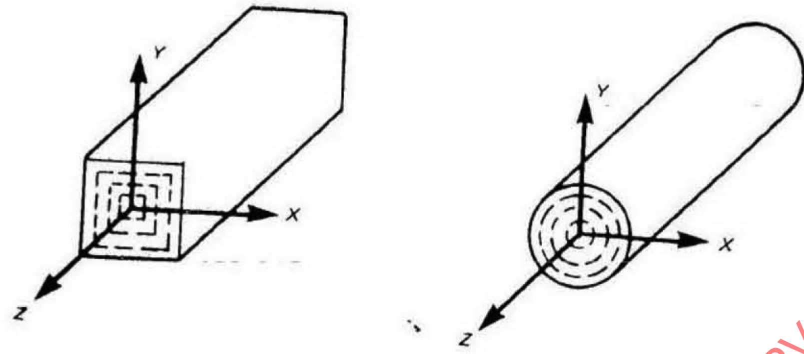


Figure HHA-1160-2
Molding