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SECTION III

Rules for Construction of Nuclear Facility Components

2015 ASME Boiler and Pressure Vessel Code

An International Code

Division 1 — Subsection NH

Class 1 Components in Elevated Temperature Service

ASME

SETTING THE STANDARD

AN INTERNATIONAL CODE

2015 ASME Boiler & Pressure Vessel Code

2015 Edition July 1, 2015

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 1 - Subsection NH

Class 1 Components in Elevated Temperature Service

ASME Boiler and Pressure Vessel Committee
on Nuclear Power

The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

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* The 2015 Edition of Section III is the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, will be published. The requirements located within Subsection NH have been moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.

INTERPRETATIONS

Interpretations of the Code have historically been posted in January and July at http://cstools.asme.org/interpretations.cfm. Interpretations issued during the previous two calendar years are included with the publication of the applicable Section of the Code in the 2015 Edition. Interpretations of Section III, Divisions 1 and 2 and Section III Appendices are included with Subsection NCA.

Following the 2015 Edition, interpretations will not be included in editions; they will be issued in real time in ASME's Interpretations Database at http://go.asme.org/Interpretations. Historical BPVC interpretations may also be found in the Database.

CODE CASES

The Boiler and Pressure Vessel Code committees meet regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases that have been adopted will appear in the appropriate 2015 Code Cases book: "Boilers and Pressure Vessels" or "Nuclear Components." Supplements will be sent or made available automatically to the purchasers of the Code Cases books up to the publication of the 2017 Code.

(**15**)

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) 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 only 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. 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. 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 pressure vessels. 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 judgement* 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 neither requires nor prohibits the use of computers for the design or analysis of components constructed to the

* 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 pressure relief.

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 an ASME 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.

STATEMENT OF POLICY ON THE USE OF THE 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 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 Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the 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 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 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 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 Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the Certification Mark. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

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 official Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the 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.

(15) SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL STANDARDS COMMITTEES

1 INTRODUCTION

(a) The following information provides guidance to Code users for submitting technical inquiries to the committees. See Guideline on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code in Section II, Parts C and D for additional requirements for requests involving adding new materials to the Code. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code Interpretations, as described below.

(1) Code Revisions. Code revisions are considered to accommodate technological developments, address administrative requirements, incorporate Code Cases, or to clarify Code intent.

(2) Code Cases. Code Cases represent alternatives or additions to existing Code rules. Code Cases are written as a question and reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all jurisdictions or owners automatically accept Code Cases. The most common applications for Code Cases are:

(-a) to permit early implementation of an approved Code revision based on an urgent need

(-b) to permit the use of a new material for Code construction

(-c) to gain experience with new materials or alternative rules prior to incorporation directly into the Code

(3) Code Interpretations. Code Interpretations provide clarification of the meaning of existing rules in the Code, and are also presented in question and reply format. Interpretations do not introduce new requirements. In cases where existing Code text does not fully convey the meaning that was intended, and revision of the rules is required to support an interpretation, an Intent Interpretation will be issued and the Code will be revised.

(b) The Code rules, Code Cases, and Code Interpretations established by the committees 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 rules.

(c) Inquiries that do not comply with these provisions or that do not provide sufficient information for a committee's full understanding may result in the request being returned to the inquirer with no action.

2 INQUIRY FORMAT

Submittals to a committee shall include:

(a) Purpose. Specify one of the following:

(1) revision of present Code rules

(2) new or additional Code rules

(3) Code Case

(4) Code Interpretation

(b) Background. Provide the information needed for the committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, edition, addenda (if applicable), paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) Presentations. The inquirer may desire or be asked to attend a meeting of the committee to make a formal presentation or to answer questions from the committee members with regard to the inquiry. Attendance at a committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the committee.

3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) Proposed Revisions or Additions. For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code, marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) Statement of Need. Provide a brief explanation of the need for the revision or addition.

(c) Background Information. Provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request that will allow the committee to adequately evaluate the proposed revision or addition. Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision or addition and identify paragraphs in the Code that reference the paragraphs that are to be revised or added.

4 CODE CASES

Requests for Code Cases shall provide a Statement of Need and Background Information similar to that defined in 3(b) and 3(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure, etc.) must be defined and it must be confirmed that the request is in connection with equipment that will bear the Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code editions and addenda (if applicable) to which the proposed Code Case applies.

5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations shall provide the following:

(1) Inquiry. Provide a condensed and precise question, omitting superfluous background information and, when possible, composed in such a way that a "yes" or a "no" *Reply,* with brief provisos if needed, is acceptable. The question should be technically and editorially correct.

(2) Reply. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no," with brief provisos if needed.

(3) Background Information. Provide any background information that will assist the committee in understanding the proposed *Inquiry* and *Reply.*

(b) Requests for Code Interpretations must be limited to an interpretation of a particular requirement in the Code or a Code Case. The committee cannot consider consulting type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements;

(2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation;

(3) a request seeking the rationale for Code requirements.

6 SUBMITTALS

Submittals to and responses from the committees shall meet the following:

(a) Submittal. Inquiries from Code users shall be in English and preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, fax number, and e-mail address, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Two Park Avenue
New York, NY 10016-5990

As an alternative, inquiries may be submitted via e-mail to: SecretaryBPV@asme.org or via our online tool at http://go.asme.org/InterpretationRequest.

(b) Response. The Secretary of the appropriate committee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the committee.

(15)

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January 1, 2015

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ORGANIZATION OF SECTION III

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, 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, and by the letter "H" for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, and 5.

- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NC — Class 2 Components
  - Subsection ND — Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
  - Subsection NH — Class 1 Components in Elevated Temperature Service*
- Division 2 — Code for Concrete Containments
  - Subsection CC — Concrete Containments
- Division 3 — Containments for Transportation and Storage of Spent Nuclear Fuel and High Level Radioactive Material and Waste
  - Subsection WA — General Requirements for Division 3
  - Subsection WB — Class TC Transportation Containments
  - Subsection WC — Class SC Storage Containments
- 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 A Metallic Core Support Structures
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HH — Class A Nonmetallic Core Support Structures
    - Subpart A — Graphite Materials
    - Subpart B — Composite Materials

2 SUBSECTIONS

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

* The 2015 Edition of Section III is the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, will be published. The requirements located within Subsection NH have been moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.

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 NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in subarticle NB-3200; reference to NB-3230 includes all paragraphs, NB-3231 through NB-3236.

(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-89-2003.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 Doral Boulevard, Suite 130, Doral, 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-2131. 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.

(**15**)

SPECIAL NOTICE

The 2015 Edition of Section III is the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, will be published. The requirements located within Subsection NH have been moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.

Beginning with the 2017 Edition of the ASME Boiler and Pressure Vessel Code, Subsection NH will no longer be published in Section III, Division 1.

This is being published to include a change from the 2013 edition that was approved by BPV III and some minor editorial revisions. The user is urged to consult Division 5 for the latest requirements after July 1, 2015.

SUMMARY OF CHANGES

After publication of the 2015 Edition, Errata to the BPV Code may be posted on the ASME Web site to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in the BPV Code. Such Errata shall be used on the date posted.

Information regarding Special Notices and Errata is published by ASME at http://go.asme.org/BPVCerrata.

Changes given below are identified on the pages by a margin note, **(15)**, placed next to the affected area.

The Record Numbers listed below are explained in more detail in "List of Changes in Record Number Order" following this Summary of Changes.

Page	*Location*	*Change (Record Number)*
vi	List of Sections	Revised
viii	Foreword	*(1)* Revised *(2)* New footnote added by errata *(13–860)*
xi	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	In last line of 6(a), URL revised
xiii	Personnel	Updated
xxx	Organization of Section III	*(1)* New footnote added *(2)* 9(d)(3) added *(13–1032)*
xxxiii	Special Notice	Added
6	NH-3112.2(a)	Revised *(11-1074)*
30	Figure NH-3352-1	Editorially revised

NOTE: Volume 63 of the Interpretations to Section III, Divisions 1 and 2 of the ASME Boiler and Pressure Vessel Code follows the last page of Subsection NCA.

LIST OF CHANGES IN RECORD NUMBER ORDER

Record Number	Change
13–860	In the Foreword, the subtitle has been deleted and replaced with an ANSI disclaimer as a footnote.
11-1074	Revised NH-3112.2(a) by changing “centigrade” to “Celsius.”

CROSS-REFERENCING AND STYLISTIC CHANGES IN THE BOILER AND PRESSURE VESSEL CODE

There have been structural and stylistic changes to BPVC, starting with the 2011 Addenda, that should be noted to aid navigating the contents. The following is an overview of the changes:

Subparagraph Breakdowns/Nested Lists Hierarchy

- First-level breakdowns are designated as (a), (b), (c), etc., as in the past.
- Second-level breakdowns are designated as (1), (2), (3), etc., as in the past.
- Third-level breakdowns are now designated as (-a), (-b), (-c), etc.
- Fourth-level breakdowns are now designated as (-1), (-2), (-3), etc.
- Fifth-level breakdowns are now designated as (+a), (+b), (+c), etc.
- Sixth-level breakdowns are now designated as (+1), (+2), etc.

Footnotes

With the exception of those included in the front matter (roman-numbered pages), all footnotes are treated as endnotes. The endnotes are referenced in numeric order and appear at the end of each BPVC section/subsection.

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees has been moved to the front matter. This information now appears in all Boiler Code Sections (except for Code Case books).

Cross-References

It is our intention to establish cross-reference link functionality in the current edition and moving forward. To facilitate this, cross-reference style has changed. Cross-references within a subsection or subarticle will not include the designator/identifier of that subsection/subarticle. Examples follow:

- *(Sub-)Paragraph Cross-References.* The cross-references to subparagraph breakdowns will follow the hierarchy of the designators under which the breakdown appears.
  - If subparagraph (-a) appears in X.1(c)(1) and is referenced in X.1(c)(1), it will be referenced as (-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(c)(2), it will be referenced as (1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).
- *Equation Cross-References.* The cross-references to equations will follow the same logic. For example, if eq. (1) appears in X.1(a)(1) but is referenced in X.1(b), it will be referenced as eq. (a)(1)(1). If eq. (1) appears in X.1(a)(1) but is referenced in a different subsection/subarticle/paragraph, it will be referenced as eq. X.1(a)(1)(1).

ARTICLE NH-1000 INTRODUCTION

NH-1100 SCOPE

NH-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NH contains rules for materials, design, fabrication, examination, testing, and overpressure relief of Class 1 components, parts, and appurtenances that are expected to function even when metal temperatures exceed those covered by the rules and stress limits of Subsection NB and Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(b) The rules of Subsection NH are applicable to Class 1 components independent of the type of contained fluid — water, steam, sodium, helium, or any other process fluid.

(c) The stress limits and design rules of Subsection NB are applicable only to service conditions where creep and relaxation effects are negligible. Consequently, the rules of 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 NH-3000 in Subsection NH, or alternatively, in compliance with the rules of Article NB-3000. In addition, the rules of Subsection NH extend specific rules of 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.

(d) 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

Brief guidelines are also provided in Subsection NH for the three modes of failure shown below:

(5) loss of function due to excessive deformation

(6) buckling due to short-term loadings

(7) creep buckling due to long-term loadings

(e) Design procedures and materials data not contained in Subsection NH 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 which 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.

NH-1120 TEMPERATURE AND SERVICE LIFE LIMITS

The rules of Subsection NH shall not be used for structural parts which 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 NH-I-14).

NH-1130 ORGANIZATION OF SUBSECTION NH RULES

In general, the numbering of rules in Subsection NH follows the numbering system used in Subsection NB. References to Appendices are to the Section III Appendices unless otherwise identified as Subsection NH Appendices.

ARTICLE NH-2000 MATERIAL

NH-2100

NH-2120 PRESSURE-RETAINING MATERIALS

NH-2121 Permitted Material Specifications

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

(b) In complying with (a) above, the base and weld material specifications of Tables NH-I-14.1(a) and NH-I-14.1(b), Tables NH-I-14.10A-1 through NH-I-14.10E-1, and Table NH-I-14.11 and the allowable stress intensities in Tables NH-I-14.3A through NH-I-14.3E, and Table NH-I-14.13C 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 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 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 NH-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 NH-3354.

(2) The attachment material and weld are of similar alloy composition to the pressure boundary material.[1]

NH-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 NH-2121(b). With the exception of attachment material covered by NH-2121(h), no material shall be used at metal and design temperatures above those for which values are given.

NH-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-3250), 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-3252 and NB-3124). When so specified, the check analysis shall be made in accordance with the base metal specification and in accordance with 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 NH-3225-2, are selected to correspond to the maximum wall-averaged temperature achieved during any Level A, B, or C Service Loading.

(2) For $2^1/_4$Cr-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, $(t_{\text{equiv}})_i$, corresponding to the temperature of the highest temperature interval, $T_{\max}$. The equivalent hours, $(t_{\text{equiv}})_i$, 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 NH-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 NH-I-14.3A through NH-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 NH-I-14.3A through NH-I-14.3E;

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

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

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

(-e) for $2^1/_4$Cr-1Mo and 9Cr-1Mo-V, the product of two-thirds of the yield strength at temperature (Table NH-I-14.5) and the yield strength reduction factor (Table NH-3225-2);

(-f) for 304 and 316 austenitic stainless steels and Alloy 800H, the product of 90% of the yield strength at temperature (Table NH-I-14.5) and the yield strength reduction factor (Table NH-3225-2).

NH-2400

NH-2430

NH-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.

NH-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 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 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).

NH-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 NB-2130 or NB-4120.

NH-2500

NH-2530

NH-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 NB-2539.1 through NB-2539.7 are met. The weld material used to make weld repairs shall meet the requirements of Table NH-I-14.1(b) and NB-2400. Additional requirements may be listed in the Design Specifications, as per 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.

NH-2800 FATIGUE ACCEPTANCE TEST

(a) For 304 and 316 austenitic stainless steel components intended for service where conditions for Level A, B, and C do not satisfy the limits of NH-T-1324(a) and NH-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 one-hour 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 1 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 NH-3000
DESIGN

NH-3100 GENERAL REQUIREMENTS FOR DESIGN

NH-3110 SCOPE, ACCEPTABILITY, AND LOADINGS

NH-3111 Scope

(a) Article NH-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 Article NB-3000 shall apply only where specifically called out by the rules of Subsection NH.

NH-3111.1 Acceptability. An acceptable design of a Class 1 Component for elevated temperature service is one which:

(a) is capable of meeting the functional requirements as specified in the Design Specifications (NCA-3250); and

(b) satisfies the requirements for a design by analysis, either in NH-3200 or in the Design Rules for components, while under the loadings described in NH-3111.2 and the Design Specifications; and

(c) satisfies the general design rules of NH-3130 and the applicable design rules for components that apply to a vessel (NH-3300), pump (NH-3400), valve (NH-3500), or piping (NH-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 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.

NH-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.

NH-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-3250): 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 NH-3113.

(c) The design parameter data stipulated in (1) and (2) below shall be specified in the Design Specifications (NCA-3250) 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 NH-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.

NH-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 NH-3200.

(c) All pressures referred to in this Article are to be taken as the value above atmospheric pressure unless otherwise stated.

NH-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 (NH-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 NH-3200.

(15) *(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 NH-3200.

NH-3112.3 Specified Mechanical Load Forces. The specified load forces for a given loading category (NH-3113) shall define all expected mechanical loadings that must be considered in design analysis computations made to show compliance with the limits of NH-3200.

NH-3113 Loading Categories

Loading categories used in this Subsection consist of Design Loading, Service Loadings (Levels A, B, C, and D), and Test Loadings.

NH-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 (NH-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 NH-3222.1.

NH-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-3250) 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 NH-3113.3, NH-3113.4, NH-3113.5, and NH-3113.6.

NH-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 shut-down, and excepting only those loadings covered by Level B, C, and D Service Loadings or Test Loading.

NH-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.

NH-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.

NH-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 operability of the nuclear energy system may be impaired to the extent that only considerations of public health and safety are involved.

NH-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.

NH-3114 Load Histogram

NH-3114.1 Level A and B Service Events. The Design Specifications (NCA-3250) 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 NH-3200.

NH-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 NH-3200. Level C Service events may be assumed as occurring between operational cycles (NH-3213.15) of Level A Service events unless otherwise specified in the Design Specifications (NCA-3250).

NH-3120 SPECIAL CONSIDERATIONS

NH-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.

NH-3122 Cladding

Cladding requirements are contained in NH-3227.8.

NH-3123 Welding

NH-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.

NH-3123.2 Fillet Welded Attachments. Fillet welded attachment requirements are contained in NH-3356.2.

NH-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.

NH-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.

NH-3130 GENERAL DESIGN RULES

NH-3131 Scope

Design rules generally applicable to all components are provided in NH-3130. The Design subarticle for the specific component provides rules applicable to that particular component. In case of conflict between NH-3130 and the design rules for a particular component, the component design rules shall govern.

NH-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.

NH-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 NH-3133-1 provides assistance in understanding where the limits are imposed.

NH-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-3250).

NH-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 NH-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 NH-3133-1
Size Restrictions on Connections

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
NH-3352(e), NH-3337.3	Creep	(As above)	Vessel	O.D. ≤ 1 in. (25 mm)
NB-3431, NH-3337.3, NB-3352.4(d)	Noncreep	Partial penetration piping connection weld	Pump	O.D. ≤ 2 in. (50 mm)
NH-3421.4, NH-3337.3, NH-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)
NH-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)
NH-3660(a), NH-3352(e), NH-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)
NH-3660(b)	Creep	(As above)	Pipe	O.D. ≤ 1 in. (25 mm)
NB-3671.3	Noncreep	Seal-welded threaded joints	Pipe	All
NH-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, NH-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)
NH-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
NH-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
NH-3352(d), NH-3660(c)	Creep	(As above)	All	O.D. ≤ 4 in. (100 mm)

NH-3136 Reinforcement for Openings

See NH-3330 and NH-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 NH-3330 shall apply unless otherwise specified in the Design Specifications.

NH-3137 Design Considerations Related to Other Articles of the Code

NH-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.

NH-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 1 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.

NH-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 NH-3250 will determine the acceptability of the design to guard against harmful consequences of elastic follow-up.

NH-3139 Welding

NH-3139.1 Abrupt Changes in Mechanical Properties at Weld and Compression Contact Junctions. In satisfying the requirements of Article NH-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.

NH-3139.2 Weld Design. All welds shall comply with the rules of NB-3350. Exceptions to this requirement are allowed only if a specific callout is made in either NH-3400, NH-3500, or NH-3600.

NH-3200 DESIGN BY ANALYSIS

NH-3210 DESIGN CRITERIA

NH-3211 Requirements for Acceptability

For a Class 1 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 NH-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,[2] then the experimental and analytical methods of Subsection NB shall be applicable. The other restrictions on temperature maxima that appear in Subsection NB [see NB-3228.5(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 NB-3000 may be used to satisfy (a) and (b) above. Alternatively, properties and allowable stress values from Subsection NB may be used in analyses to demonstrate compliance with the rules of NH-3200.

NH-3212 Basis for Determining Stress, Strain, and Deformation Quantities

(a) For elastic analysis allowed by Subsection NH, the maximum shear stress theory shall be used to determine stress intensities for multiaxial stress states (NB-3212).

(b) For inelastic analysis required by Subsection NH, 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.

NH-3213 Terms Relating to Analysis

In Subsection NH, 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:[3]

(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 NH relating to structural analysis are defined in the subparagraphs of NH-3213.

NH-3213.1 Stress Intensity.[4] 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.

NH-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.

NH-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.

NH-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.

NH-3213.5 Shear Stress. Shear stress is the component of stress tangent to the plane of reference.

NH-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.

NH-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.

NH-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 NH-3217-1 for examples of primary stress.

NH-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 NH-3213.13(a)];

(b) bending stress at a gross structural discontinuity.

Refer to Table NH-3217-1 for examples of secondary stress.

NH-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.

NH-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 NH-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.

NH-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 NH-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[5] 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 NH-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.

NH-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 NH-3113.

NH-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 NH-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.

NH-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.

NH-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.

NH-3213.20 Deformation. Deformation of a component part is an alteration of its shape or size.

NH-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.

NH-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.

NH-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.

NH-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.

NH-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.

NH-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.

NH-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*.

NH-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.

NH-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.

NH-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.

NH-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.

NH-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.

NH-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*.

NH-3213.34 Shakedown. Shakedown is the absence of significant progressive, cyclic, inelastic deformation, or ratcheting (NH-3213.33). A structure shakes down if, after a few cycles of load application, the deformation stabilizes.

NH-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.

NH-3213.36 Use-Fraction. Use-fraction is the material damage due to primary stresses expressed as a time ratio.

NH-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.

NH-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.)

NH-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.

NH-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 NH-3220 and NH-3230 is satisfied when the component is subjected to the loadings described in NH-3111. This detailed analysis shall become a part of the Design Report (NCA-3550).

NH-3214.1 Elastic Analysis. The analysis guidelines and methods in Article NB-3000 apply (NH-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.

NH-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 NH-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 NH-T are an exception; in NH-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.

NH-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, Mandatory Appendix NH-I-14 and in Nonmandatory Appendix NH-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.

NH-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (NH-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 NH-3213.11. Tables NH-3217-1 and NH-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 NH-3213.8

P_m, P_L = average primary stress components as defined in NH-3213.8 and NH-3213.10

Q = secondary stress components as defined in NH-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}.

NH-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 NH-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.

NH-3217 Classification of Stresses

Tables NH-3217-1 and NH-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 Article NB-3000.

NH-3220 DESIGN RULES AND LIMITS FOR LOAD-CONTROLLED STRESSES IN STRUCTURES OTHER THAN BOLTS

NH-3221 General Requirements

(a) The rules for design against failure from load-controlled stresses are illustrated in Figure NH-3221-1 and are explained in NH-3220. The allowable stress intensity values used in NH-3220 are listed in Section II, Part D, Subpart 1, Tables 2A and 2B and Tables NH-I-14.1(a) through NH-I-14.13C. Note that the strain, deformation, and fatigue limits of NH-3250 require analyses beyond those required by the rules of NH-3220.

(b) The stress intensity limits used in Figure NH-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 NH, the S_m values are extended to elevated temperatures by using the same criteria. As described in NH-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 NH-I-14.3A through NH-I-14.3E and in Tables NH-I-14.3A through NH-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 NH-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 NH-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 NH-I-14.3A through NH-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%;

Table NH-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. thru cross section)	P_m
			Bending (Av. thru width of lig., but gradient thru plate)	P_b
			Peak	F
	Isolated or atypical ligament	Pressure	Membrane	Q
			Bending	F
			Peak	F

Table NH-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 (NH-3227.5)	Within the limits of reinforcement defined by NH-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 NH-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 NH-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 NH-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 NH-3217-2
Classification of Stress Intensity in Piping, Typical Cases

Piping Component	Locations	Origin of Stresses	Classification [Note (1)]	Discontinuities Considered: Gross	Discontinuities Considered: 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 NH-T.
(2) See NH-3138 and NH-3213.8.
(3) Analysis is not required when reinforced in accordance with NH-3643.

(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 NH-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 NH-I-14.3A through NH-I-14.3E, or:

$$0.8\,S_r \times R$$

As described in NH-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.

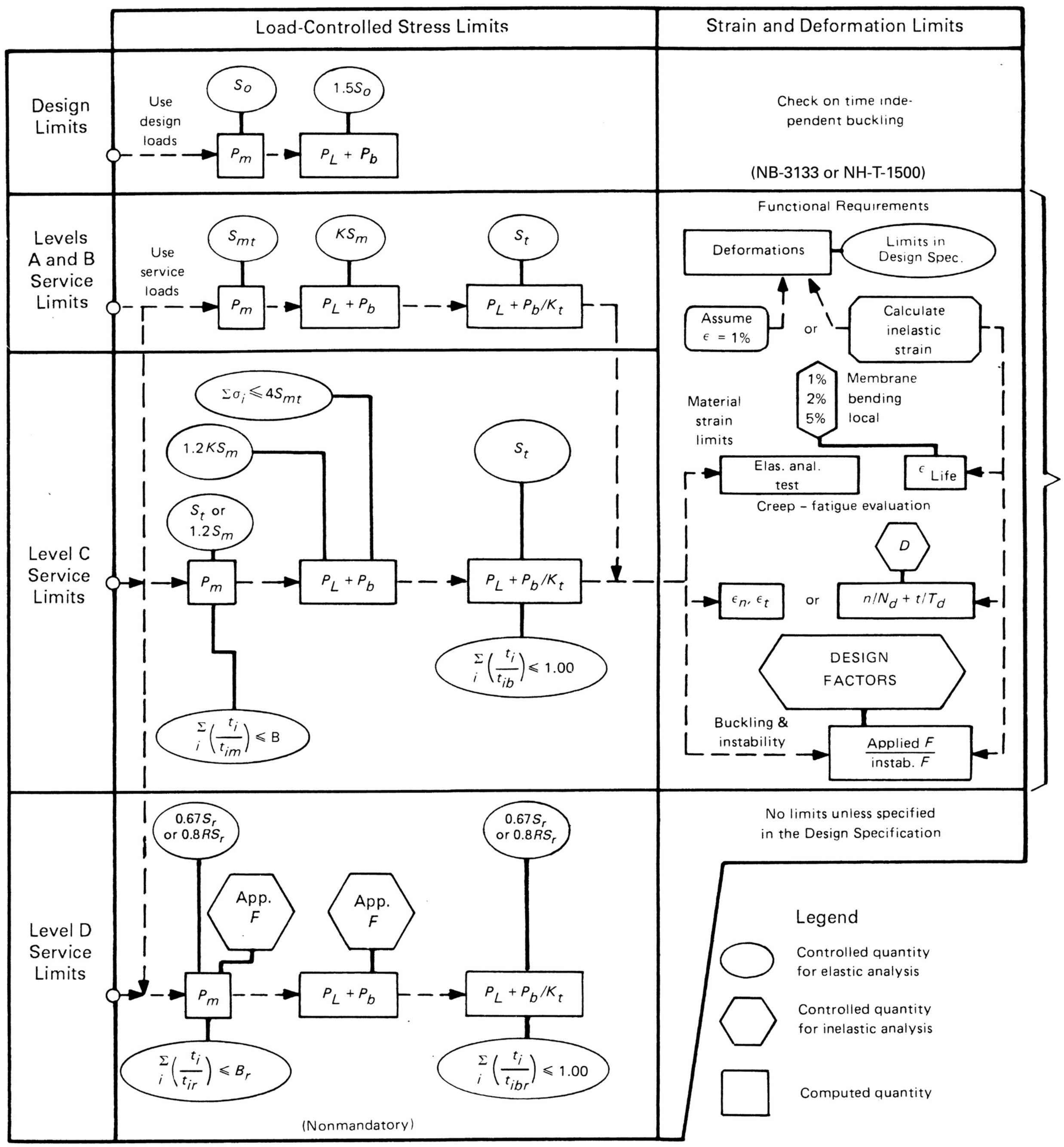
S_t = temperature and time-dependent stress intensity limit at a weldment, and shall be taken as the lower of the tabulated S_t values from Tables NH-I-14.4A through NH-I-14.4E, or:

$$0.8\,S_r \times R$$

where

R = the appropriate ratio of the weld metal creep rupture strength to the base metal creep rupture strength from Tables

Figure NH-3221-1
Flow Diagram for Elevated Temperature Analysis



NH-I-14.10A-1 through NH-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 NH-I-14.6A through NH-I-14.6F

NH-3222 Design and Service Limits

NH-3222.1 Design Limits. The stress calculations required for the analysis of Design Loadings (NH-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:[6]

$$P_m \le S_o \tag{1}$$

(b) The combined primary membrane plus bending stress intensity, derived from P_L and P_b, shall not exceed $1.5S_o$:

$$\left(P_L + P_b\right) \le \left(1.5\right) S_o \tag{2}$$

Note that the local primary membrane stress, P_L, includes the general primary membrane stress, P_m. As in 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 [NH-3215(b)].

(c) External pressure and other compression inducing loadings shall be investigated for adequate buckling strength, using the limits of NB-3133 or other limits and time-independent factors permitted under NH-3252.

NH-3222.2 Level A Service Limits. The stress intensity limits for Level A Service Limits (NH-3113.3) also apply to the stresses under both Level A and B Service Loadings. The limits for both are given in NH-3223.

NH-3223 Level A and B Service Limits

The stress calculations required for the analysis of Level A and B Service Loadings (NH-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}

$$P_m \le S_{mt} \tag{3}$$

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 NH-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:

$$P_L + P_b \le KS_m \tag{4}$$

$$P_L + P_b / K_t \le S_t \tag{5}$$

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 NH-3300 to NH-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 NH-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 NH-3250.

NH-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 $1.0S_t$

$$P_m \leq \begin{cases} 1.2\ S_m \\ 1.0\ S_t \end{cases} \tag{7}$$

(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:

$$\sum_i \left(\frac{t_i}{t_{im}} \right) \leq B \tag{8}$$

where

B = use-fraction factor and is equal to 1.0 [or less if so specified in the Design Specifications (NCA-3250)]

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 Subsection NB as explained in NH-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 NH-I-14.4A through NH-I-14.4E.)

The use of Figures NH-I-14.4A through NH-I-14.4E for determining t_{im} for two loading conditions at two different temperatures is shown schematically in Figure NH-3224-1. In Figure NH-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.

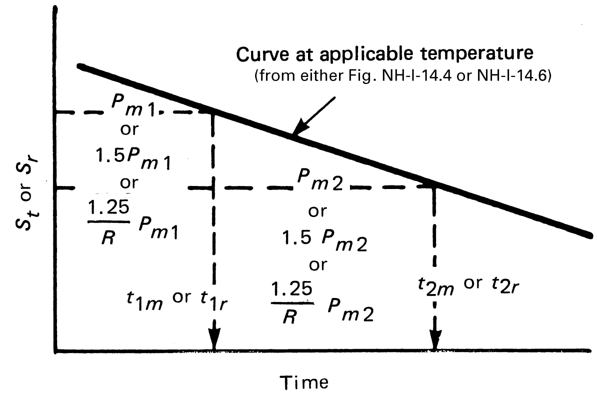
(c) The combined primary membrane plus bending stress intensities, derived from P_L and P_b for Level C Service Loadings, shall satisfy the following limits, with $1.0 < K \leq 1.5$:

$$P_L + P_b \leq 1.2KS_m \tag{9}$$

$$P_L + P_b / K_t \leq S_t \tag{10}$$

where K_t is defined as in NH-3223(c).

Figure NH-3224-1
Use-Fractions for Membrane Stress



(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:

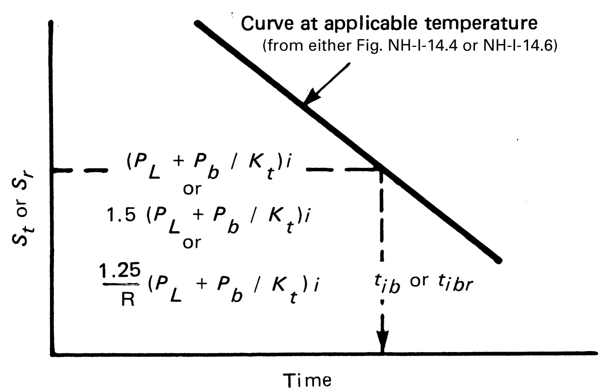
$$\sum_i \left(\frac{t_i}{t_{ib}} \right) \leq 1.00 \tag{11}$$

where

t_i = the total duration of the loading at temperature, T_i; and

t_{ib} = the time value determined by entering Figures NH-I-14.4A through NH-I-14.4E at a value of stress equal to $P_L + P_b / K_t$, as shown in Figure NH-3224-2.

Figure NH-3224-2
Use-Fractions for Membrane Plus Bending Stress



NH-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 NH-3225 (and in Section III Appendices, Nonmandatory Appendix F) 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-3250]. The type of analysis (elastic or inelastic) used by the system designer shall be indicated in the Design Specifications (see Section III Appendices, Nonmandatory Appendix F, F-1322.1).

(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, Nonmandatory Appendix F:

$$P_m \le \begin{cases} \text{Limit in Appendix F for } P_m \\ 0.67\, S_r \\ 0.8\, RS_r \end{cases} \qquad (12)$$

where

R = the appropriate ratio of the weld metal creep strength to the base metal strength from Tables NH-I-14.10A-1 through NH-I-14.10E-1

S_r = the expected minimum stress-to-rupture in time t taken from Figures NH-I-14.6A through NH-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-3250])

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 Subsection NB, as explained in NH-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 NH-I-14.6A through NH-I-14.6F).

The use of Figures NH-I-14.6A through NH-I-14.6F for determining t_{ir} for two loading conditions at two different temperatures is shown schematically in Figure NH-3224-1. In Figure NH-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, Nonmandatory Appendix F for $P_L + P_b$:

$$P_L + P_b / K_t \le \begin{cases} 0.67\, S_r \\ 0.8\, RS_r \end{cases} \qquad (13)$$

where K_t is defined in NH-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 NH-I-14.6A through NH-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 NH-3224-2

(f) For the purpose of Section III Appendices, Nonmandatory Appendix F 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 NH-I-14.5 and the strength reduction factor shown in Tables NH-3225-2, NH-3225-3A, and NH-3225-3B.

(2) Tensile strength values shall be the product of the value shown in Table NH-3225-1 and the strength reduction factor shown in Tables NH-3225-2, NH-3225-3A, NH-3225-3B, and NH-3225-4, 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.)

Table NH-3225-1
Tensile Strength Values, S_u

U.S. Customary Units, ksi

For Metal Temperature Not Exceeding, °F	304SS	316SS	Ni-Fe-Cr UNS N08810	$2^1/_4$Cr-1Mo	9Cr-1Mo-1V
	See Section II, Part D, Subpart 1, Table U for Values up to 1,000°F				
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	304SS	316SS	Ni-Fe-Cr UNS N08810	$2^1/_4$Cr–1Mo	9Cr-1Mo-1V
	See Section II, Part D, Subpart 1, Table U for Values up to 538°C				
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.

Table NH-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
304SS	≥ 900 (480)	1.00	0.80
316SS	≥ 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)	1.0	[Note (2)]

GENERAL NOTE: No reduction factor required for service below the indicated temperature.

NOTES:
(1) See Tables NH-3225-3A and NH-3225-3B are selected to correspond to the maximum wall-averaged temperature achieved during any Level A, B, or C Service Loading.
(2) See Table NH-3225-4.

Table NH-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 NH-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	...	...	...	...	...

NH-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 NH-3250.

NH-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 NH-3227 take precedence for the particular situations to which they apply.

NH-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.

Table NH-3225-4
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
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	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
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.93
1,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.93	0.90
1,050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.93	0.89	0.84
1,100	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.93	0.90	0.86	0.84
1,150	1.00	1.00	1.00	1.00	1.00	0.97	0.94	0.90	0.87	0.84	0.81
1,200	1.00	1.00	1.00	1.00	0.98	0.94	0.91	0.87	0.84	0.81	0.78

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
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	1.00
475	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	0.97	0.97
525	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.91
550	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.92	0.89
575	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.92	0.88	0.83
600	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.92	0.89	0.85	0.84
625	1.00	1.00	1.00	1.00	1.00	0.97	0.94	0.90	0.87	0.83	0.81
650	1.00	1.00	1.00	1.00	0.98	0.94	0.91	0.87	0.84	0.81	0.78

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.

NH-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 $0.8S_{mt}$.

NH-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.

NH-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}.

NH-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 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.

NH-3227.7 Requirements for Specially Designed Welded Seals.

(a) Welded seals, such as omega and canopy seals (NB-4360), shall be designed to meet the pressure-induced general primary membrane stress intensity limits specified in Subsection NH 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.

NH-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 NH-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.

NH-3230 STRESS LIMITS FOR LOAD-CONTROLLED STRESSES ON BOLTS

NH-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 Subsection NB (NB-3230 and Section III Appendices, Nonmandatory Appendix E).

(b) Bolts which are to experience elevated temperature service shall comply with the requirements of NH-3230.

NH-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 NH-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 NH-3233 are satisfied using the appropriate m and y factors for the test gasket.

NH-3233 Level A and B Service Limits for Bolts at Elevated Temperatures

NH-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 NH-I-14.13A through NH-I-14.13C. The rules of NH-3232 shall apply except for the S_{mt} values replacing S_o values.

NH-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 NH-I-14.13A through NH-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 NH-3224(b), with the use-fraction factor, B, set equal to 0.5.[7] 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.

NH-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 NH-I-14.13A through NH-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 NH-3224(d), but with the use-fraction set at 0.67 instead of 1.0.[7] 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.

NH-3233.4 Nonductile Fracture. The rules of NH-3241 shall apply to bolts.

NH-3234 Level C Service Limits

The limits of NH-3233 shall apply to primary loads in bolts.

NH-3235 Level D Service Limits

The rules of NH-3225 shall apply to primary loads in bolts.

NH-3240 SPECIAL REQUIREMENTS FOR ELEVATED TEMPERATURE COMPONENTS

NH-3241 Nonductile Fracture

(a) A portion of the Design Report (NCA-3550) 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 (NH-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.

NH-3250 LIMITS ON DEFORMATION-CONTROLLED QUANTITIES

NH-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-3550), what effects and conditions were considered in the final analysis procedures, the evaluation criteria, and the conclusions of the evaluation.

NH-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-3250). The acceptability criteria and material properties contained in Nonmandatory Appendix NH-T may be used. However, alternative criteria may be applied by the Manufacturer subject to approval by the Owner. The Owner's approval shall be indicated by incorporating the alternative criteria into the Design Specifications.

NH-3300 VESSEL DESIGNS

NH-3310 GENERAL REQUIREMENTS

NH-3311 Acceptability

(a) The requirements for acceptability of Class 1 vessel design are stated in NH-3111.1.

(b) In cases of conflict between this subarticle and the rules of NH-3100 and NH-3200, the requirements of NH-3300 shall govern.

NH-3330 OPENINGS AND REINFORCEMENT

NH-3331 General Requirements for Openings

(a) For vessels or parts thereof that meet the requirements of NH-3330, the analysis limits of NH-3220 related to load-controlled stresses need not be demonstrated in the vicinity of the openings. However, the deformation-controlled limits (NH-3250) shall be satisfied in the vicinity of any opening exposed to conditions where creep effects are significant [NH-3211(c)].

(b) Openings (for nozzle, branch, and piping connections) using deposited weld metal as reinforcement, as shown in 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 NH-3200 have been met for the structural material near an opening, then the rules of NH-3332 through NH-3339 are waived.

NH-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

The rules of 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.

NH-3333 Reinforcement Required for Openings in Flat Heads

The requirements of NB-3333 shall apply, with the t_r defined as in NH-3332.

NH-3334 Limits of Reinforcement

The requirements of NB-3334 shall apply.

NH-3335 Metal Available for Reinforcement

The requirements of 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 NH-3332) and is exclusive of corrosion allowance;

NH-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.

NH-3337 Attachment of Nozzles and Other Connections

NH-3337.1 General Requirements. Nozzles and other Category D connections (NH-3351) shall be attached to the shell or head of the vessel by one of the methods provided in NH-3352.

NH-3337.2 Full Penetration Welded Nozzles. Full penetration nozzle welds, as shown in Figs. 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 NH-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.

NH-3337.3 Partial Penetration Welded Nozzles.

(a) Partial penetration welds, as shown in Figs. 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 $d \le 1$ in. (25 mm)

(2) 0.020 in. (0.50 mm) for 1 in. (25 mm) $< d \le 4$ 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.

NH-3338 Evaluation of Strain and Creep-Fatigue Limits in Openings

NH-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 (NH-3338.2). This method covers only single, isolated openings. Stress indices may also be determined by analytical methods.

NH-3338.2 Stress Index Method. The stress indices and rules provided in 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 (NH-T-1320, NH-T-1330, and NH-T-1430).

NH-3339 Alternative Rules for Nozzle Design

Subject to the limitations stipulated in NB-3339.1, the requirements of NB-3339 constitute an acceptable alternative to the rules of NH-3332 through NH-3336 and NH-3338, provided t_r is as defined in NH-3332(b) and NH-3333.

NH-3339.1 Stress Indices. The stress indices and rules provided in 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 (NH-T-1320, NH-T-1330, NH-T-1430).

NH-3350 DESIGN OF WELDED CONSTRUCTION

NH-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 NH-3351-1 illustrates typical joint locations included in each category.

NH-3351.1 Category A. Category A comprises longitudinal welded joints within the main shell, communicating chambers,[8] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[9] 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.[8]

NH-3351.2 Category B. Category B comprises circumferential welded joints within the main shell, communicating chambers,[8] 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.[8]

NH-3351.3 Category C. Category C comprises welded joints connecting flanges, Van Stone laps, tube-sheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers[8] any welded joint connecting one side plate[9] to another side plate of a flat sided vessel.

NH-3351.4 Category D. Category D comprises welded joints connecting communicating chambers[8] 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.

NH-3352 Permissible Types of Welded Joints

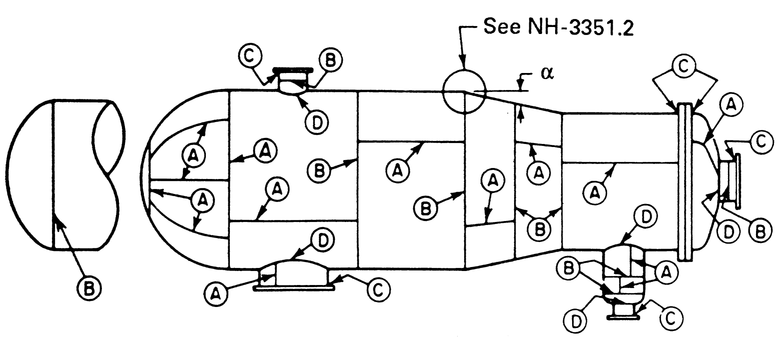
(a) The permissible types of welded joints and their dimensional requirements are described in the rules for fabrication of Class 1 components for elevated temperature service.

(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 NH-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 [NH-3211(c)]. For conditions where creep effects are significant, see NH-3353(b).

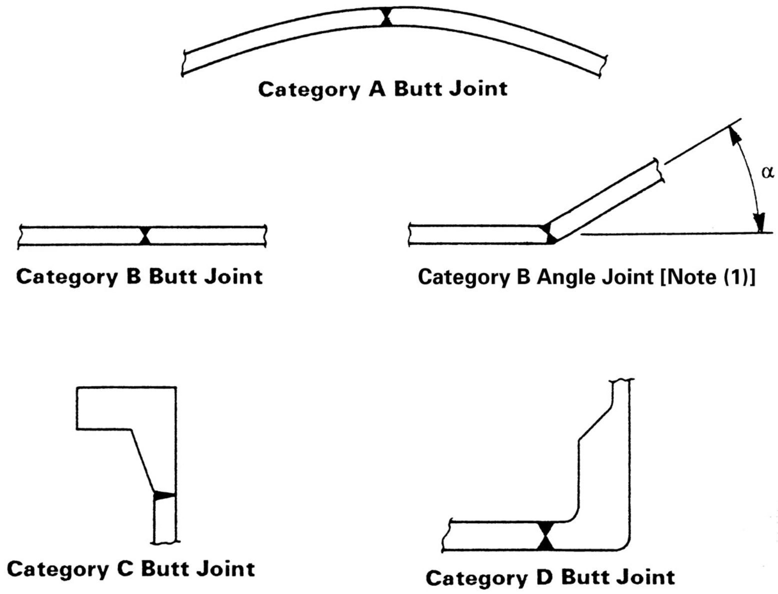
(d) The corners of the end of each nozzle neck extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half the thickness, t_n, of the nozzle neck, or $^3/_4$ in. (19 mm), whichever is smaller. The d is the outside diameter of the nozzle.

Figure NH-3351-1
Welded Joint Locations Typical of Categories A, B, C, and D



(15)

Figure NH-3352-1
Typical Butt Joints



NOTE:
(1) When α does not exceed 30 deg, joint meets requirements for butt joints.

(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 [NH-3211(c)]. For conditions where creep effects are significant, see NH-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.

(g) Non-full penetration welds, which are permitted by NH-3354 and NH-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 Figs. NB-4243-1 and NB-4244(b)-1, and defined as Categories 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.

NH-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 (NH-3211). The potential for reduced ductility often precludes locating welds in regions of high loading.

(b) For meeting the analysis requirements of NH-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.

NH-3354 Structural Attachment Welds

(a) Welds for structural attachments shall meet the requirements of NB-4430, NB-4240, and the rules of NH-3352(g).

(b) Those attachments using the exemption of NH-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 NB-3334 (see example in Figure NH-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 1 pressure boundary welds.

(3) Loads on the pressure boundary from all permanent attachments shall be considered in the analysis in the Design Report.

(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.

NH-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.

NH-3356 Fillet Welds

NH-3356.1 At Pressure Loaded Joints. Fillet welds are not permitted for pressure-retaining joints [see NH-3337.3 and NH-3352(g)].

NH-3356.2 At Structural Attachment Joints.

(a) Fillet welds conforming to Figure NB-4427-1 may be used for structural attachments to components, except as restricted and limited by the rules of NB-4433.

(b) Analysis limits for stress limits, strain limits, and damage limits shall be one-half of the allowable values under NH-3200 rules for the weaker of the two base materials being joined.

NH-3357 Thermal Treatment

All pressure vessels and pressure vessel parts shall be given the appropriate postweld heat treatment prescribed in NB-4620.

NH-3360 SPECIAL VESSEL REQUIREMENTS

NH-3361 Category A or B Joints Between Sections of Unequal Thickness

In general, a tapered transition section as shown in Figure NH-3361-1, which is a type of gross structural discontinuity (NH-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 NH-3200 for stress intensity limitations and other rules. The requirements of this paragraph do not apply to flange hubs.

Figure NH-3354-1
Permissible Attachment Weld Location

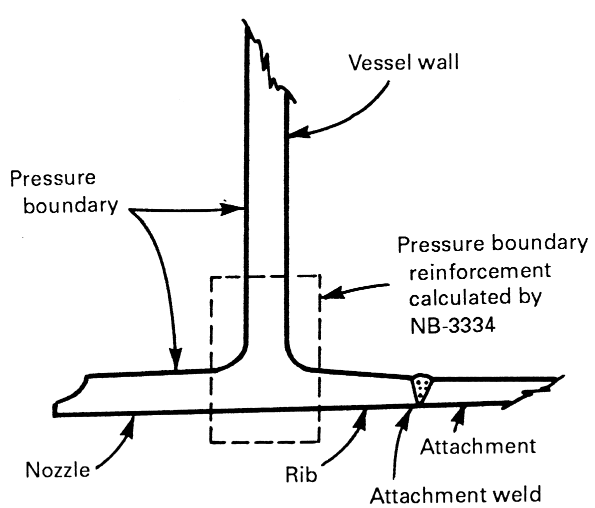
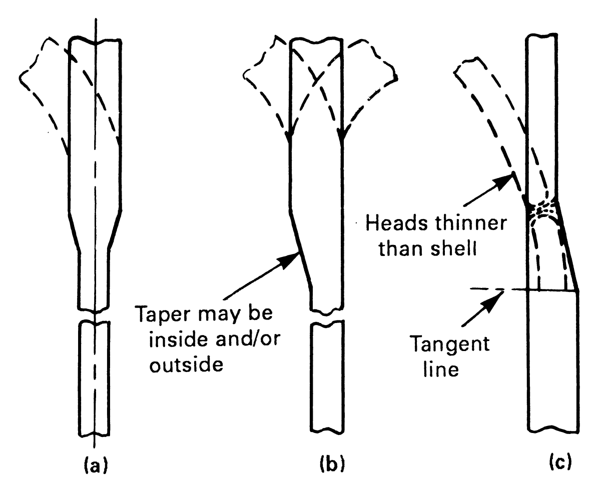


Figure NH-3361-1
Category A and B Joints Between Sections of Unequal Thickness



GENERAL NOTE: Length of taper may include the width of the weld.

NH-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.

NH-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.

NH-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 NH (NCA-3240 and Subsection NF).

NH-3400 DESIGN OF CLASS 1 PUMPS

NH-3410 GENERAL REQUIREMENTS

NH-3410.1 Scope. The rules of this subarticle constitute requirements for the design of Class 1 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.

NH-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 NH-3410.2-1 and NH-3410.2-2 show typical single and double volute casings, respectively.

NH-3411 Acceptability of Large Pumps

(a) The requirements for the design of a Class 1 pump having an inlet connection greater than NPS 4 (DN 100) are stated in NH-3111.1.

(b) In cases of conflict between this subarticle and the rules of NH-3100 and NH-3200, the requirements of NH-3400 shall govern.

NH-3412 Acceptability of Small Pumps

(a) The requirements for the design of a Class 1 pump having an inlet connection NPS 4 (DN 100) or smaller are stated in NH-3111.1.

(b) In cases of conflict between this subarticle and the rules of NH-3100 and NH-3200, the requirements of NH-3400 shall govern.

Figure NH-3410.2-1
Typical Single Volute Casing

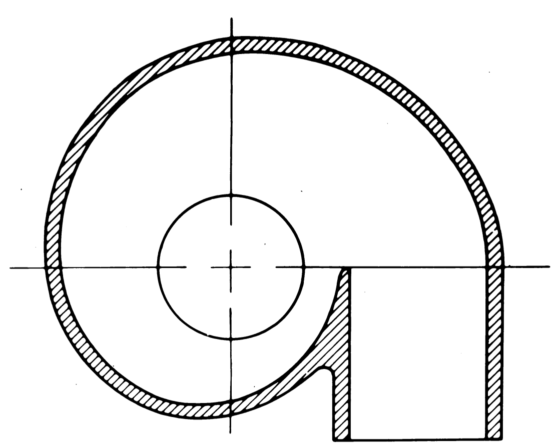
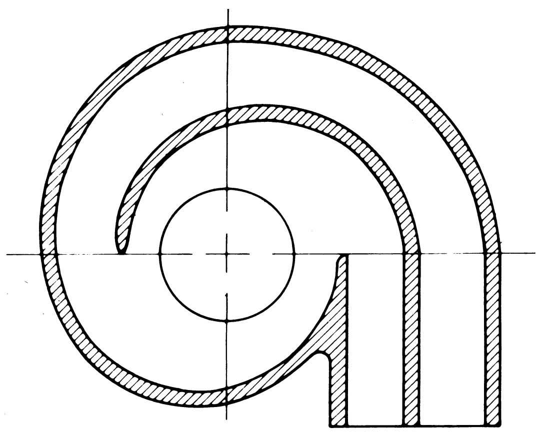


Figure NH-3410.2-2
Typical Double Volute Casing



NH-3413 Alternative Design Rules

For any size Class 1 pump, an experimental stress analysis may be used to determine elastic stresses and strains used with NH-3200 limits and/or Nonmandatory Appendix NH-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 NH-3421 design requirements are met.

NH-3420 DESIGN CONSIDERATIONS

NH-3421 Design Requirements

NH-3421.1 Loadings. Loadings, design and service conditions, special considerations, and general design rules are described in NH-3100.

NH-3421.2 Piping Under External Pressure. Piping located within the pressure-retaining boundary of the pump shall be designed in accordance with NH-3250.

NH-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 NH-3600.

NH-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 NH-3337.3 and NH-3352.

NH-3421.5 Bolting — Radially Split Configurations. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in NH-3230.

NH-3421.7 Supports. Pump supports shall be designed in accordance with the requirements of Subsection NF if negligible creep effects are present during the cycle. Otherwise, the supports shall comply with NH-3200.

NH-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 NH-3331 through NH-3336.

(b) To avoid stress concentrations, the outside radius r_2, Figure NB-3441.3-2, shall not be less than one-half the thickness of the inlets and outlets as reinforced.

NH-3421.9 Radially Oriented Inlets and Outlets. Reinforcement of radially oriented inlets and outlets is required. NH-3330 and NH-3421.11 shall apply.

NH-3421.10 Tangential Inlets and Outlets. Reinforcement of tangential inlets and outlets is required. NH-3330 and NH-3421.11 shall apply.

NH-3421.11 Stress Analysis, Nozzle Loads, and Reinforcement.

(a) Stress Analysis. The analysis methods in 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 NH-3250 when creep effects are insignificant [NH-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-3254.

(c) Reinforcement. The distance ℓ in Figure NH-3421.11-1 is the limit of reinforcement. The value of ℓ shall be determined from the relationship:

$$\ell = 0.5\sqrt{r_m t_m}$$

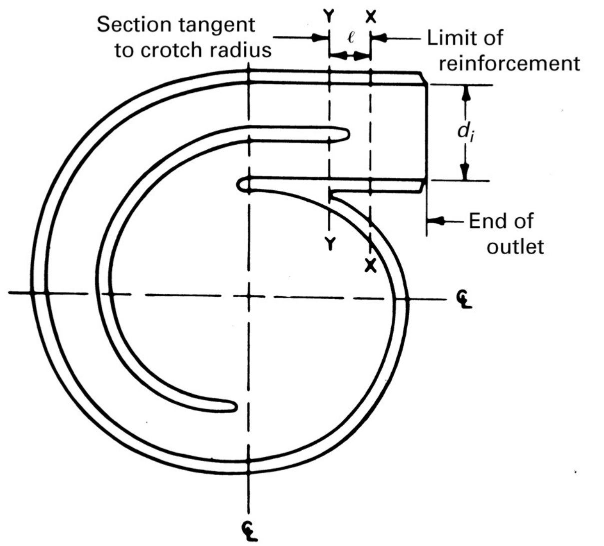
where

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

NH-3421.12 Earthquake Design Analysis. When earthquake loadings are specified in the Design Specification (NCA-3250), 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.

NH-3421.13 Attachments. Attachments are permitted when designed in accordance with NH-3135 and NB-4430.

Figure NH-3421.11-1
Minimum Tangential Inlet and Outlet Wall Thickness



NH-3421.14 Appurtenances. Appurtenances as defined in NCA-1260 are permitted provided the requirements for documentation are fulfilled as described in NCA-1260.

NH-3421.15 Pump Covers. Pump covers shall be designed in accordance with NH-3200.

NH-3421.17 Cladding. The design of clad pressure-retaining parts shall be in accordance with NH-3227.8.

NH-3421.19 Cutwater Tip Stresses. It is recognized that localized high stresses can occur at the cutwater tip of volute casings (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 NH-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 NH-3250.

NH-3430 PUMP TYPES

Design requirements for specific pump types are listed in NB-3430.

NH-3500 DESIGN OF CLASS 1 VALVES

NH-3510 DESIGN REQUIREMENTS

NH-3511 Acceptability

(a) The requirements for acceptability of a Class 1 valve design are stated in NH-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 NH-3100 and NH-3200, the requirements of NH-3500 shall govern.

NH-3512 Stress Analysis

The analysis methods in 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 NH-3250 when creep effects are insignificant [NH-3211(c)].

NH-3520

NH-3524 Earthquake Design Analysis

(a) When earthquake loadings are specified in the Design Specifications (NCA-3250), 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.

NH-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 NH-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.

NH-3540

NH-3544 Body Shape Rules

The rules of 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.

NH-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 NH-I-14.1(a), NH-I-14.1(b), and NH-I-14.2 but allowed under the rules of 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 NH-3600 rules to govern the requirements for the extension.

NH-3550 CYCLIC LOADING REQUIREMENTS

When cyclic conditions exist, the rules for analysis are covered by NH-3250 and NH-3512.

NH-3600 PIPING DESIGN

NH-3610 GENERAL REQUIREMENTS

NH-3611 Acceptability

(a) The requirements for acceptability of a Class 1 piping system design are stated in NH-3111.1.

(b) In cases of conflict between this subarticle and the rules of NH-3100 and NH-3200, the requirements of NH-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.

NH-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.

NH-3620 DESIGN CONSIDERATIONS

NH-3622 Dynamic Effects

NH-3622.1 Impact. Impact forces caused by either external or internal conditions shall be considered in the piping design.

NH-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-3250). The stresses resulting from these earthquake effects must be included with weight, pressure, or other applied loads when making the required analysis.

NH-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.

NH-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.

NH-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.

NH-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.

NH-3627 Considerations for Liquid Metal Piping

NH-3627.1 Location. Routing of liquid metal piping in the vicinity of steam and water piping shall be avoided.

NH-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.

NH-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.

NH-3640 PRESSURE DESIGN OF COMPONENTS

NH-3641

NH-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 NH-3222.1.

NH-3642 Curved Segments of Pipe

NH-3642.1 Pipe Bends. The design of pipe bends shall provide that the completed bend will satisfy the analysis requirements of NH-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 NH-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 NH-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.

NH-3643 Intersections

The rules of NH-3643 may be satisfied by demonstrating, by analysis or experiment or both, that the component fully complies with the requirements of NH-3200.

NH-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 NB-3643.3 shall be met for the branch connections listed in NH-3643.2(b), NH-3643.2(c), and NH-3643.2(d), except that S_o and NH-3641.1 should be used instead of callouts (NB-3643.3) to S_m and NB-3641.1, respectively.

NH-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 NH-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 NH-4000;

(c) an extruded outlet at right angles to the run pipe;

(d) For conditions where creep effects are insignificant [NH-3211(c)], intersecting pipes may be joined by welding the branch pipe to the run pipe as shown in Figure NB-3643.3(a)-2. For such intersections, the intersection angle shall be not less than 60 nor greater than 120 deg.

NH-3644 Miters

Mitered joints may be used for elevated temperature service subject to meeting analysis requirements of NH-3200 and also complying with the requirements for fabrication. Maximum angles shall be $22\frac{1}{2}$ deg or less.

NH-3645 Attachments

The rules of NH-3135 apply.

NH-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 NH-3200.

(c) For closures not subjected to elevated temperatures, the rules of NB-3646 shall apply.

NH-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 NH-3200.

(d) Flanged joints not exposed to elevated temperatures shall meet the requirements of NB-3647.

NH-3648 Reducers

Reduced fittings shall be considered suitable for use subject to complying with the analysis requirements of NH-3200.

NH-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 NH. Pressure-retaining components not included in Table NCA-7100-1 may be used if they satisfy the requirements of NH-3200. The pressure design shall be based on an analysis consistent with the general design philosophy embodied in Subsection NH, or experimental stress analysis in accordance with NH-3649.1.

NH-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

NH-3650 ANALYSIS OF PIPING COMPONENTS

NH-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 NH-3200.

(b) The primary and secondary stress indices (B and C) and corresponding stress equations of NB-3600 may be used to determine stress intensities in satisfying the limits on load-controlled stresses (NH-3220) and strain limits using elastic analysis (NH-T-1320). Stress components determined from the stress indices given in 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 (NH-T-1320, NH-T-1330, NH-T-1430).

(c) Analytical methods such as finite element computer analyses may be used to provide detailed stress distributions.

NH-3660 DESIGN OF WELDS

(a) Weld designs shall comply with the requirements of NH-3350 and NH-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-3250). 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 NH-3643.2 and NH-3646, respectively.

NH-3670 SPECIAL PIPING REQUIREMENTS

NH-3671 Nonwelded Piping Joints

NH-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.

NH-3671.6 Brazed Joints. The rules of 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.

NH-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 NH-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-3250).

NH-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 NH-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.

NH-3674 Design of Piping Supports

Pipe supports shall be designed in accordance with applicable rules of Subsection NF, except for the stress analysis, which shall be in accordance with the rules of NH-3200.

ARTICLE NH-4000
FABRICATION AND INSTALLATION

NH-4100 GENERAL REQUIREMENTS

NH-4110 INTRODUCTION

(a) Those portions of the component which do not experience elevated temperature service (as defined by the rules of Article NH-3000) may use the 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 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.

NH-4200

NH-4210

NH-4212 Effects of Forming and Bending Processes

The rules of this paragraph shall supplement those of 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[10] do not exceed 5%,[11] 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 Levels 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 NH-4212-1. This option is also not permitted for any austenitic material that is subjected to greater than 20% strain.[10]

(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 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 NB-2211, the forming qualifications as required by 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 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.

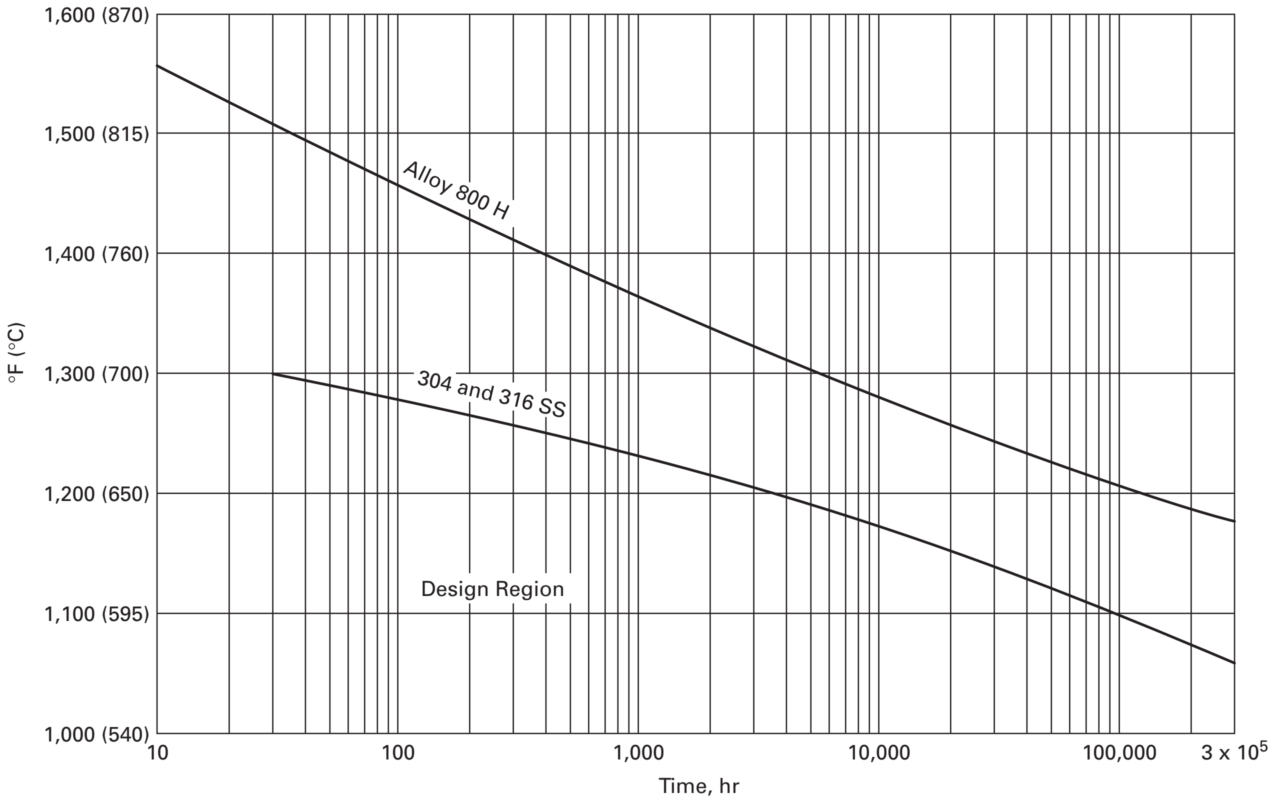
(2) For austenitic materials, the post fabrication heat treatment shall consist of the heat treatment specified in the base material specification except that Ni-Fe-Cr Alloy 800H shall be heat treated at 2,050°F (1 120°C) minimum.

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.

NH-4240 SPECIAL JOINTS AND FITTINGS — ADDED RULES FOR NB-4240

The rules of Article NH-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 verified either by radiographic examination or by following special written procedures (see the rules of Article NH-3000).

Figure NH-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.

NH-4400

NH-4420

NH-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 1 elevated temperature components.

ARTICLE NH-5000 EXAMINATION

NH-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NH-5110 GENERAL REQUIREMENTS

(a) Those portions of the component designated (in accordance with the rules of Article NH-3000) as not to experience elevated temperature service may use the 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 Article NB-5000.

(c) Those portions of the component which use option (a) above shall be identified during all steps of examination.

NH-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

The rules of this paragraph shall be substituted for the first sentence of 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.

NH-5200 REQUIRED EXAMINATION OF WELDS

NH-5210 CATEGORY A VESSEL WELDED JOINTS AND LONGITUDINAL WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of NB-5210.

All longitudinal butt welds of Category A, as defined in NB-3351.1, and all similar pressure boundary welds in other Class 1 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.

NH-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of 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 NB-3351.2, shall be examined in accordance with the requirements of NH-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 NH-5210(a).

NH-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of 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 NB-3351.3, shall be examined in accordance with the requirements of NH-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 NH-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 sketches (a), (b), and (c) of Figure NB-4243-1 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 NH-5210(a).

(d) For component regions with nominal diameter of 4 in. (100 mm) or less, all full penetration corner welds similar to sketches (d), (e), and (f) of Figure NB-4243-1 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.

NH-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 NB-5240. All welded joints of Category D, as defined in NB-3351.4, and similar pressure boundary welds in other components shall be examined in accordance with the requirements listed below.

NH-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 NH-5210. These welds shall be full penetration butt welds through either the component wall or the nozzle wall, as shown in 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 NH-5210(a).

NH-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 NH-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 sketch (f) of Figure NB-4244(b)-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 NH-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 sketches (a), (b), (c), (d), (e), and (g) of Figure NB-4244(b)-1 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.

NH-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 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 Figure NB-4244(c)-1.

(b) Full penetration attachment welds, similar to those shown in 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 NH-5210(a).

NH-5245 Partial Penetration Welds

Partial penetration welds shall be used only for the small diameter applications allowed by the rules of Article NH-3000. Partial penetration welds as shown in Figs. 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 NH-5210(a).

NH-5246 Full Penetration Category D Welds at Oblique Connections

(a) Full penetration welds shall be examined in accordance with the requirements of NH-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 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 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.

NH-5260 FILLET, SOCKET, AND ATTACHMENT WELDS

NH-5261 Fillet and Socket Welds

The rules of this paragraph shall be substituted for NB-5260. Fillet and socket welds shall be used only for the small diameter applications allowed by the rules of Article NH-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 NB-5112.

NH-5262 Permanent Structural Attachment Welds

The rules of this paragraph shall be substituted for NB-5262.

(a) Permanent structural attachment welds, as defined in 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.

NH-5263 Nonstructural and Temporary Attachments

All completed weld surfaces on welds of nonstructural and temporary attachments, as defined in NB-4435, shall be examined by either a liquid penetrant or magnetic particle method.

ARTICLE NH-6000
TESTING

NH-6100 GENERAL REQUIREMENTS

Testing of Section III, Division 1, Class 1 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.

NH-6110 SCOPE OF TESTING

NH-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.

NH-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, and gaskets are exempt from the rules of this Subsection.

(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 Manufacturer 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 Manufacturer's test records will be his authority to sign the report. This takes precedence over NCA-5280.

(d) Under the special conditions of NH-6117 and NH-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 NH-6113(a).

(f) The component or appurtenance pressure test, when conducted in accordance with the rules of NH-6221 or NH-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 NH-6221 or NH-6321. The Design Specifications may require further tests to demonstrate structural integrity under external pressure loading.

NH-6113 Pressure Testing of Systems

(a) Prior to initial operation, the installed Class 1 system shall be static pressure tested in the presence of the Inspector.

(b) Under the special restrictions of NH-6117 and NH-6118, a helium mass spectrometer leak test may replace the static pressure test in (a) above.

NH-6115 Time of Pressure Test and Stamping of Components and Appurtenances

(a) The pressure tests of components and appurtenances required by NH-6112(a) shall be performed prior to installation in the system as specified in NH-6221(a) or NH-6321(a).

(b) The pressure tests of components and appurtenances required by NH-6112(a) may be performed after installation if the system pressure test is used under the provisions of NH-6221(c) or NH-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 component Manufacturer has conducted the static pressure test.

(d) Specially designed welded seals,[12] that are identified on the Data Report Form as being welded by the Installer under the rules of NH-6118, need not be tested prior to the stamping of the component.

(e) Appurtenances containing brazed joints, pumps not designed by detailed analysis,[12] and valves shall be static pressure tested prior to installation in a system.

NH-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 1 components for elevated temperature service.

NH-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 NH-6112 and NH-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.

NH-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 NH-6112 and NH-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 NH-6112 and NH-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 Manufacturer, and the requirements appear in the Design Specifications and in the Installer's Data Report Forms.

NH-6120 PREPARATION FOR TESTING

NH-6121 Exposure of Joints

All mechanical and welded joints, including welds, shall be left uninsulated and exposed for examination during the test.

NH-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.

NH-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.

NH-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.

NH-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.

NH-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.

NH-6200 HYDROSTATIC TESTS

NH-6210 HYDROSTATIC TESTING PROCEDURE

NH-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.

NH-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 (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)], (NB-2331).

NH-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.

NH-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 NH-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.

NH-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

NH-6221 Minimum Required System Hydrostatic Test Pressure

(a) Except as may be otherwise required by material specifications and by the requirements of NH-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 1 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 NH-6117 and NH-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 NB-2500

(2) the component repair can be postweld heat treated, if required, and nondestructively examined in accordance with rules of 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

NH-6222 Maximum Permissible Hydrostatic Test Pressure

(a) The stress limits, contained in the rules of Article NH-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.

NH-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.

NH-6224 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained for a minimum total time of 10 minutes and for such additional time as may be necessary to conduct the examination for leakage required by NH-6215. When testing pumps, valves, and other components covered by NH-6223, the pressure shall be maintained a minimum of 15 minutes for each inch of design minimum wall thickness, but for not less than 10 minutes.

NH-6300 PNEUMATIC TESTS

NH-6310 PNEUMATIC TESTING PROCEDURES

NH-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of NH-6300 and NH-6112.

NH-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be nonflammable;

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (NB-2330). The test pressure shall not be applied until the component, appurtenance or system, and the pressurizing medium are approximately the same temperature.

NH-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.

NH-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 NH-6315.

NH-6315 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in NH-6324, examination of leakage in accordance with NH-6215 shall be made.

NH-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

NH-6321 Minimum Required System Pneumatic Test Pressure

(a) Except as may be otherwise required by material specifications and by the requirements of NH-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 1 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 NH-6117 and NH-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 NB-4400;

(2) the component repair can be postweld heat treated, if required, and nondestructively examined in accordance with the rules of 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.

NH-6322 Maximum Permissible Pneumatic Test Pressure

(a) The stress limits contained in the rules of Article NH-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.

NH-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.

NH-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 NH-6215.

NH-6400 PRESSURE TEST GAGES

The rules of NB-6400 shall apply.

ARTICLE NH-7000 OVERPRESSURE PROTECTION

NH-7100 GENERAL REQUIREMENTS

Overpressure protection for Section III, Class 1 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 Article NB-7000, except as modified by Subsection NH.

NH-7110 SCOPE

(a) Subsection NH provides Class 1 overpressure protection rules for those pressure boundary structures which, having been designated by the Owner (NCA-1140 and NCA-3230) as a group of items requiring such protection, are not covered by Article NB-7000 rules because some of the structures are expecting service temperatures above those currently allowed under the rules of Subsection NB.

(b) Whereas the rules of Article NB-7000 are oriented toward water and steam cooled reactor systems, the rules of Subsection NH encompass a wider variety of coolant fluids.

(c) The rules of Article NB-7000 shall govern unless paragraphs are specifically altered by the rules of Subsection NH. All references to other Article NB-7000 paragraphs are to be interpreted as referring to the Article NB-7000 paragraphs as modified by Subsection NH.

(d) As with 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 NH are covered by 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

NH-7130 VERIFICATION OF THE OPERATION OF PRESSURE RELIEF DEVICES

Revise 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.

NH-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

Revise title of NB-7173 to read:

Valve Types Permitted for Water Service

Revise NB-7174 to read:

NB-7174 Nonreclosing Devices

Rupture disk devices may be used in air, gas, or liquid metal service in accordance with NB-7600.

NH-7200 CONTENT OF OVERPRESSURE PROTECTION REPORT

Add to 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.

NH-7300 RELIEVING CAPACITY

Revise 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 NH-3000, are not exceeded for each of the components in the protected system.

NH-7600 NONRECLOSING PRESSURE RELIEF DEVICES

NH-7610 USE OF RUPTURE DISK DEVICES

Revise NB-7610 as shown below:

Rupture disk devices certified in accordance with NB-7720 may be used as sole protection against overpressure loadings. Rupture disks shall use materials of construction approved in Article NH-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 NB-7700 are met.

NH-7620

NH-7621 Provisions for Venting or Draining Near Rupture Disks

Revise 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.

MANDATORY APPENDIX NH-I-14
TABLES AND FIGURES

Table NH-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
$2^1/_4$Cr-1Mo [Note (5)]	SA-182	Forgings	F 22, Class 1
	SA-213	Smls. Tube	T 22
	SA-234	Piping Fittings	WP 22, WP 22W [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 $2^1/_4$ CR (SA-387, Gr. 22, Cl. 1)
9Cr-1Mo-V	SA-182	Forgings	F91
	SA-213	Smls. Tube	T91
	SA-335	Smls. Pipe	P91
	SA-387	Plate	91

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%.
(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 NH-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 (4).

Table NH-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-B9
	SFA-5.23	EB9
	SFA-5.28	ER90S-B9

Table NH-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	$2^1/_4$Cr-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	$2^1/_4$Cr-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 $2^1/_4$Cr-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 NH-I-14.3A
S_{mt} — Type 304 SS

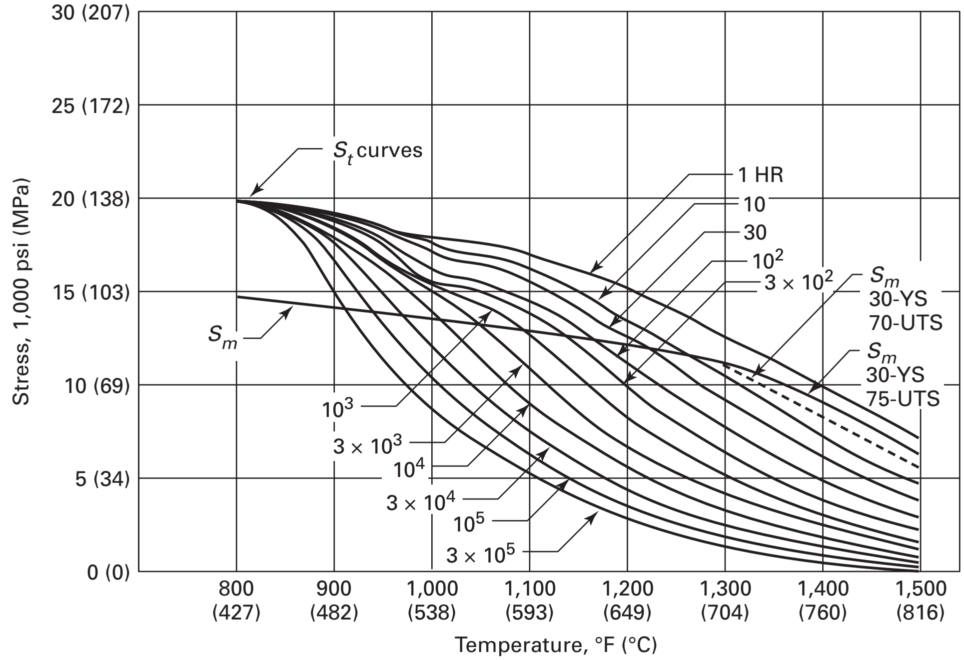


Table NH-I-14.3A
S_{mt} — Allowable Stress Intensity Values, 1,000 psi, Type 304 SS — 30-YS, 75-UTS (30-YS, 70-UTS)

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 NH-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 NH-I-14.3B
S_{mt} — Type 316 SS

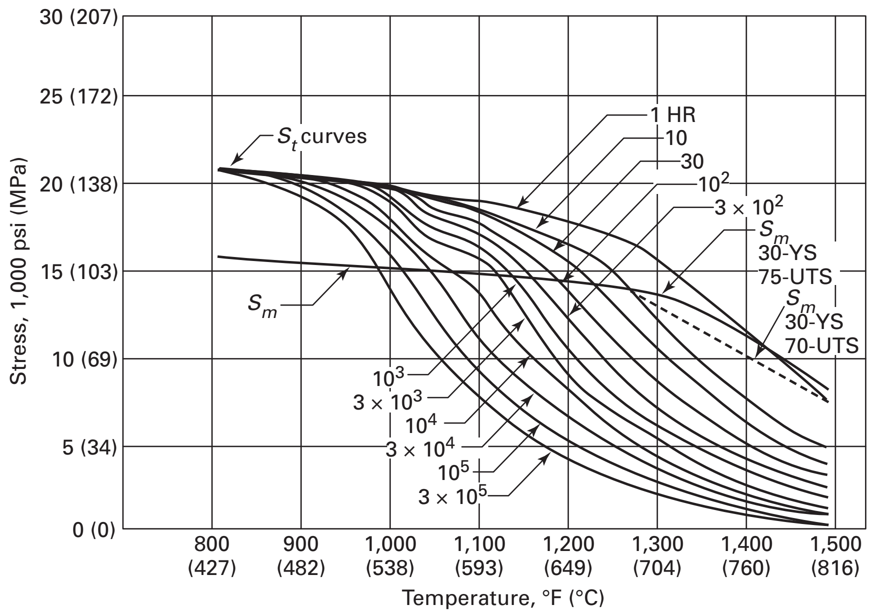


Table NH-I-14.3B
S_{mt} — Allowable Stress Intensity Values, 1,000 psi, Type 316 SS — 30-YS, 75-UTS (30-YS, 70-UTS)
S_{mt} — Allowable Stress Intensity Values, MPa, Type 316 SS — 207-YS, 518-UTS (207-YS, 483-UTS)

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 NH-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 NH-I-14.3C
S_{mt} — Ni-Fe-Cr (Alloy 800H)

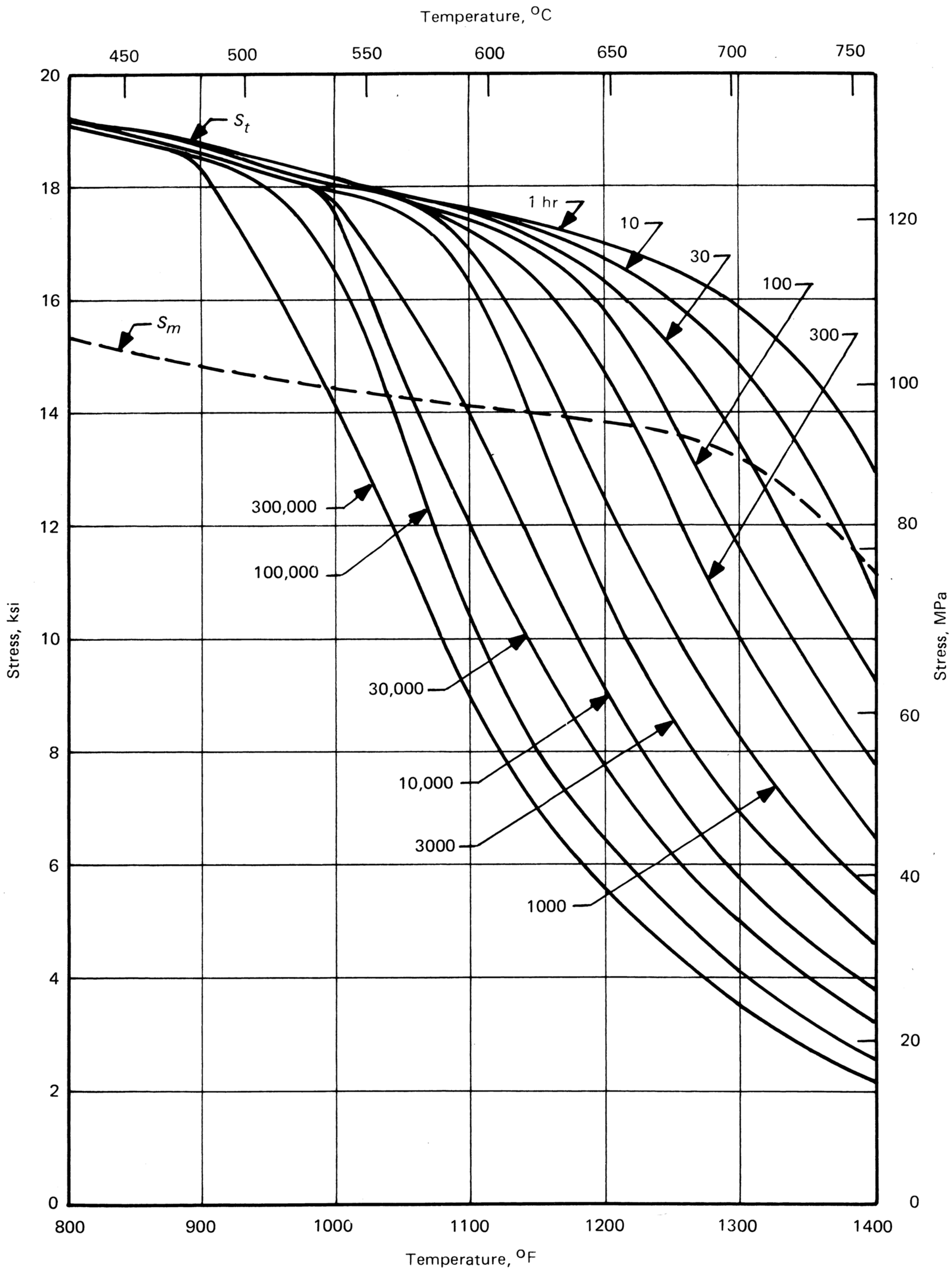


Table NH-I-14.3C
S_{mt} — Allowable Stress Intensity Values, ksi (MPa), Ni-Fe-Cr (Alloy 800H)

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 NH-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 NH-I-14.3D
S_{mt} — 2¼Cr-1Mo

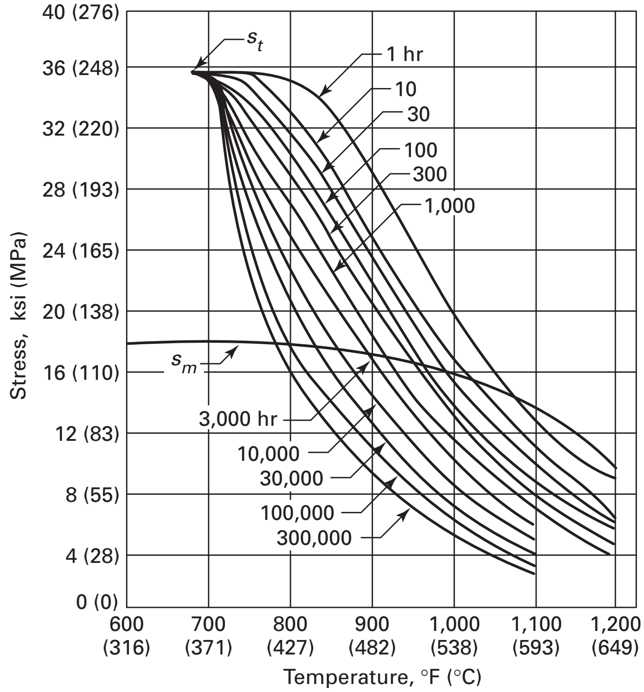


Table NH-I-14.3D
S_{mt} — Allowable Stress Intensity Values, ksi (MPa), 2¼Cr-1Mo

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 NH-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 NH-I-14.3E
S_{mt} — 9Cr-1Mo-V

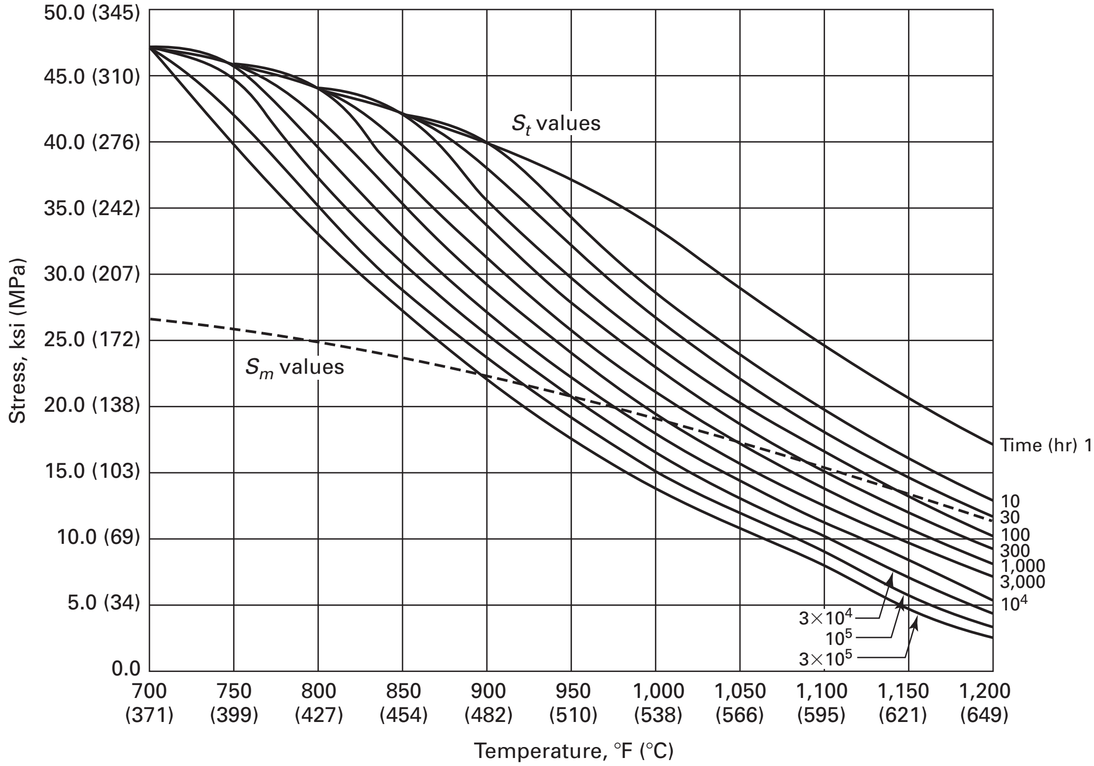


Table NH-I-14.3E
S_{mt} — Allowable Stress Intensity Values, ksi (MPa), 9Cr-1Mo-V

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
700	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
800	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
900	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	21.9
950	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.5	18.8	17.4
1,000	19.0	19.0	19.0	19.0	19.0	19.0	19.0	17.7	16.3	14.9	13.7
1,050	17.1	17.1	17.1	17.1	17.1	16.9	15.5	14.1	12.8	11.5	10.5
1,100	15.2	15.2	15.2	15.2	14.9	13.4	12.3	10.9	9.9	8.7	7.8
1,150	13.1	13.1	13.1	12.9	11.7	10.5	9.5	8.3	6.8	5.5	4.5
1,200	11.1	11.1	11.1	10.1	9.1	7.9	6.5	5.3	4.3	3.3	2.5

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
375	183	183	183	183	183	183	183	183	183	183	183
400	179	179	179	179	179	179	179	179	179	179	179
425	172	172	172	172	172	172	172	172	172	172	172
450	165	165	165	165	165	165	165	165	165	165	165
475	156	156	156	156	156	156	156	156	156	156	154
500	147	147	147	147	147	147	147	147	147	138	131
525	136	136	136	136	136	136	136	132	126	115	106
550	125	125	125	125	125	125	121	111	102	93	85
575	114	114	114	114	114	108	99	90	81	73	66
600	101	101	101	101	97	86	80	71	63	54	48
625	88	88	88	86	78	70	63	54	44	36	30
650	76	76	76	69	62	54	44	36	29	22	17

GENERAL NOTE: As described in NH-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 NH-I-14.4A
S_t — Type 304 SS

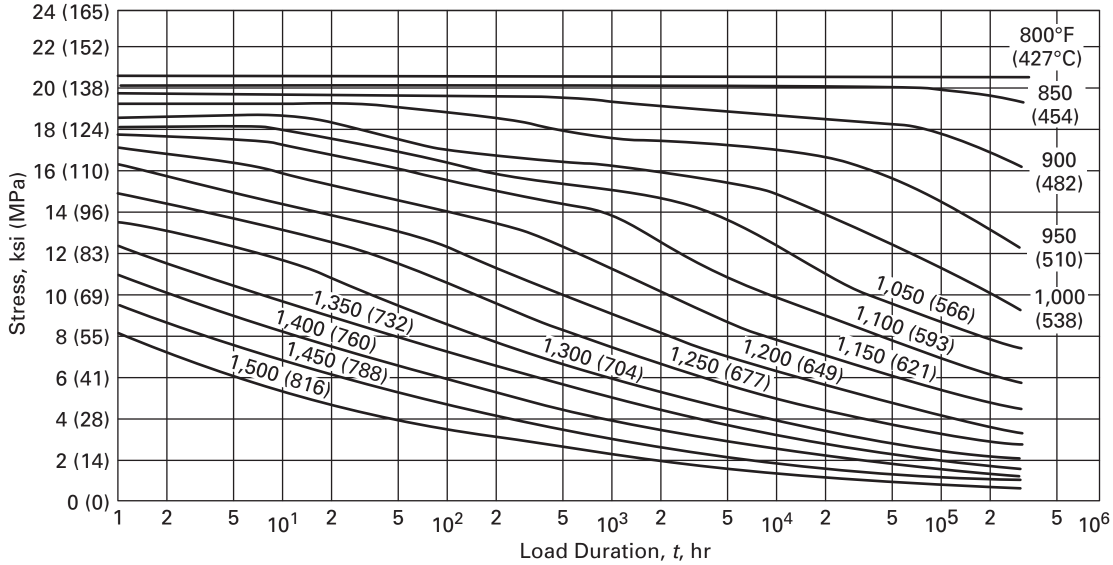


Table NH-I-14.4A
S_t — Allowable Stress Intensity Values, 1,000 psi (MPa), Type 304 SS

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	98	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 NH-I-14.4B
S_t — Type 316 SS

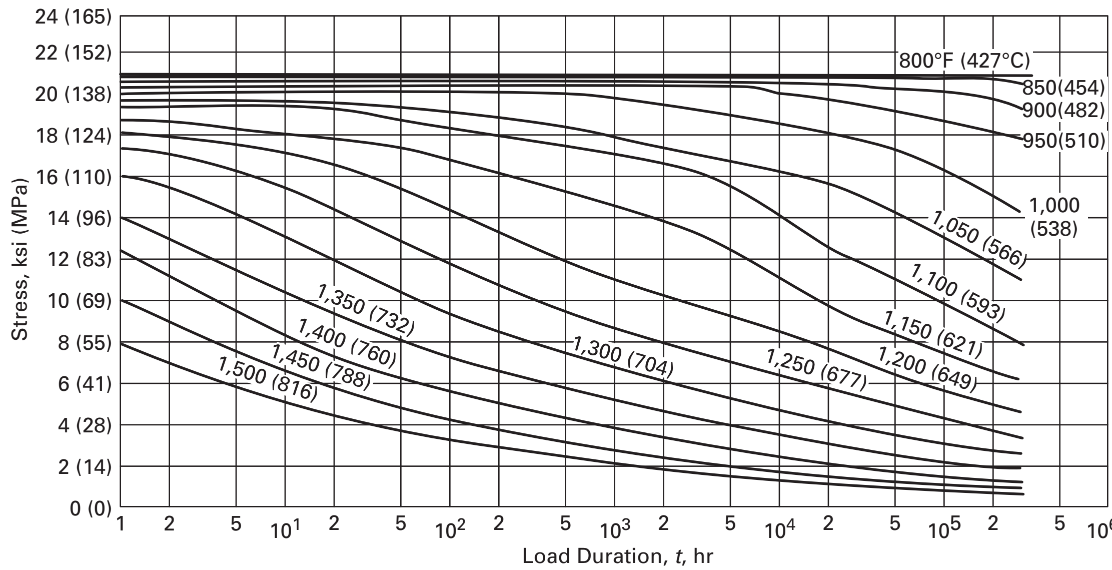


Table NH-I-14.4B
S_t — Allowable Stress Intensity Values, 1,000 psi (>MPa), Type 316 SS

U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	102 hr	3 × 102 hr	103 hr	3 × 103 hr	104 hr	3 × 104 hr	105 hr	3 × 105 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 NH-I-14.4C
S_t — Ni-Fe-Cr (Alloy 800H)

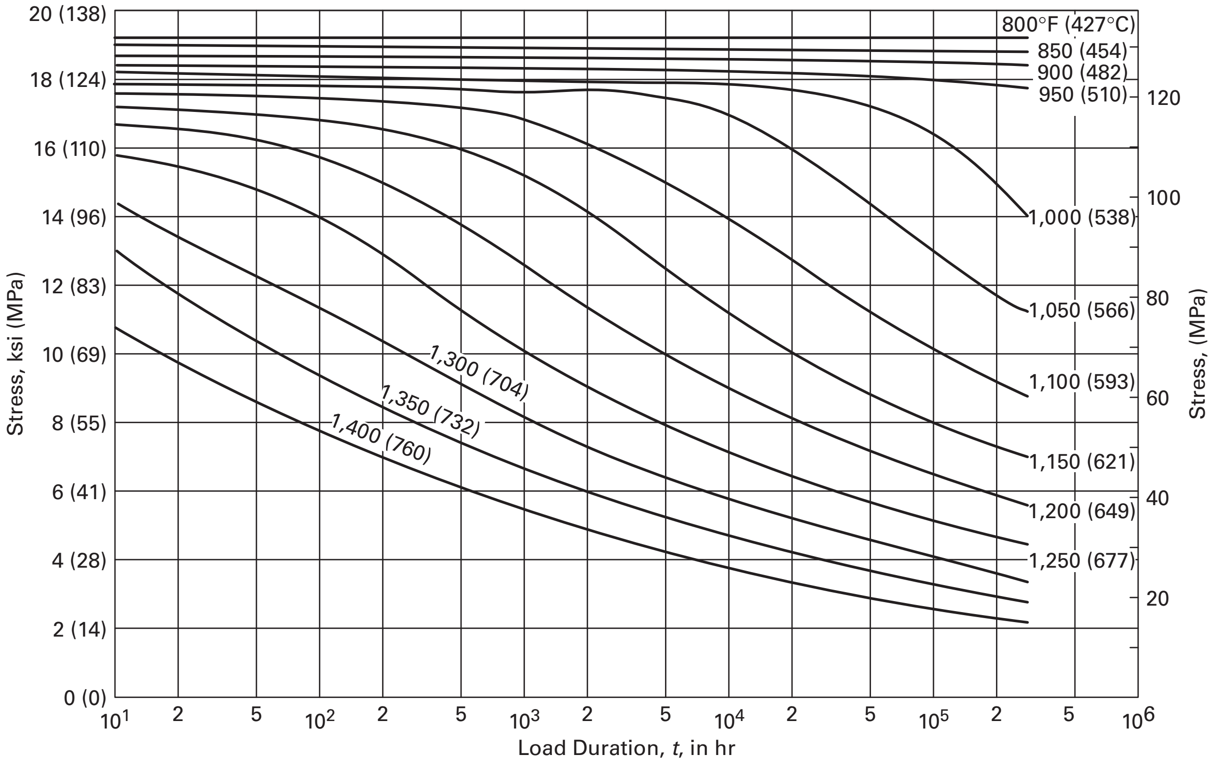


Table NH-I-14.4C
S_t — Allowable Stress Intensity Values, ksi (MPa), Ni-Fe-Cr (Alloy 800H)

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 NH-I-14.4D
S_t — 2¼Cr-1Mo

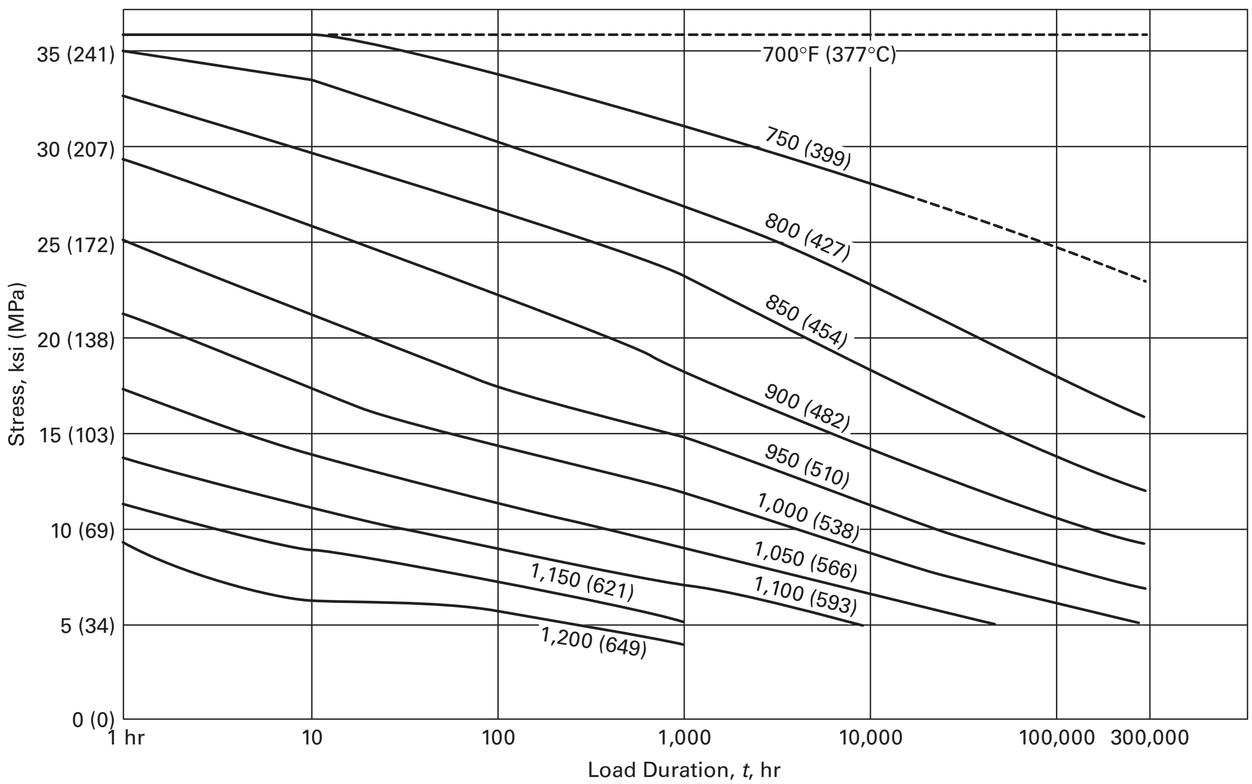


Table NH-I-14.4D
S_t — Allowable Stress Intensity Values, ksi (MPa), 2¼Cr-1Mo

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 NH-I-14.4E
S_t — 9Cr-1Mo-V

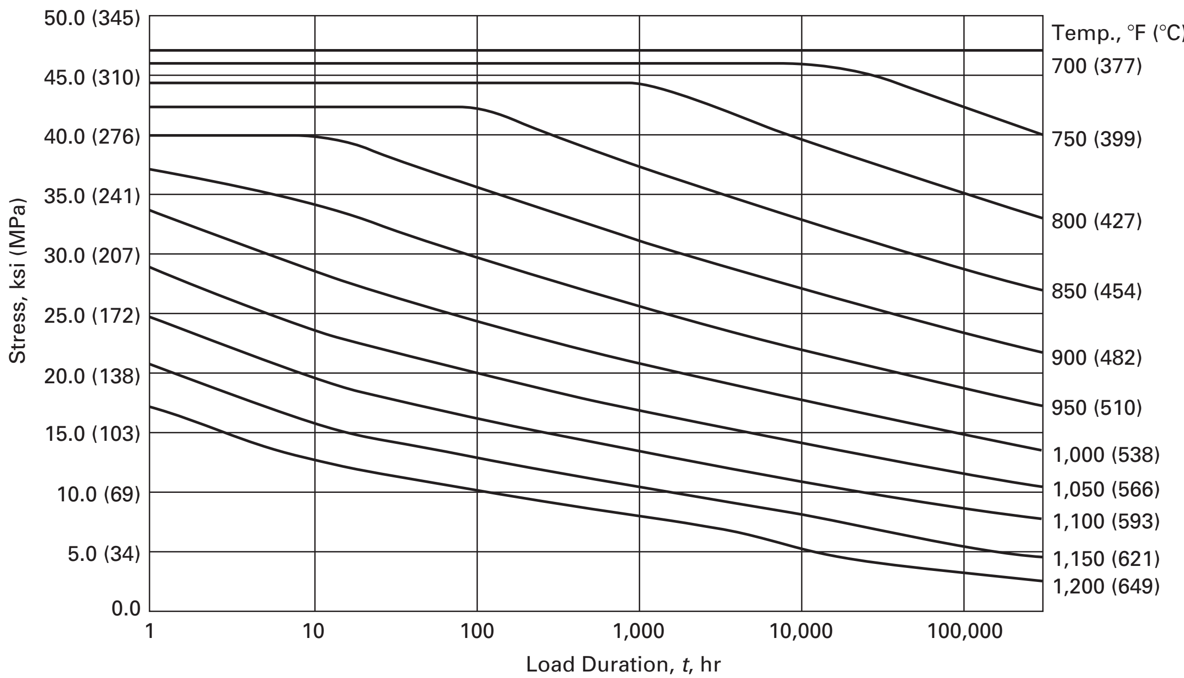


Table NH-I-14.4E
S_t — Allowable Stress Intensity Values, ksi (MPa), 9Cr-1Mo-V

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
700	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3
750	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	44.9	42.3	40.1
800	44.3	44.3	44.3	44.3	44.3	44.3	42.1	39.6	37.4	35.1	33.1
850	42.3	42.3	42.3	42.3	39.8	37.3	35.1	32.9	30.9	28.9	27.1
900	39.8	39.9	38.0	35.5	33.3	31.1	29.1	27.1	25.3	23.5	21.9
950	37.0	34.1	31.9	29.7	27.7	25.7	23.9	22.1	20.5	18.8	17.4
1000	33.5	28.5	26.6	24.5	22.7	20.9	19.3	17.7	16.3	14.9	13.7
1050	28.8	23.7	21.9	20.1	18.5	16.9	15.5	14.1	12.8	11.5	10.5
1100	24.6	19.5	17.9	16.3	14.9	13.4	12.2	10.9	9.9	8.7	7.8
1150	20.7	15.8	14.4	12.9	11.7	10.5	9.4	8.3	6.8	5.5	4.5
1200	17.1	12.7	11.4	10.1	9.1	7.9	7.0	5.3	4.3	3.3	2.5

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
375	325	325	325	325	325	325	325	325	325	325	325
400	317	317	317	317	317	317	316	316	307	290	275
425	307	307	307	307	307	307	292	276	262	246	232
450	294	294	294	294	279	264	249	234	220	206	193
475	275	275	271	256	241	225	211	197	184	171	160
500	262	249	235	219	205	191	178	165	153	141	131
525	242	214	200	185	172	163	148	136	126	115	106
550	217	182	170	156	144	132	119	111	102	93	85
575	189	154	142	130	119	108	99	90	81	73	66
600	164	126	115	107	97	86	79	71	63	54	48
625	139	106	96	86	78	70	62	54	44	36	30
650	117	87	78	69	62	54	47	36	29	22	17

Table NH-I-14.5
Yield Strength Values, S_y, Versus Temperature

U.S. Customary Units

	Stresses, ksi					
Temp., °F	**304SS**	**316SS**	**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 1000°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	**304SS**	**316SS**	**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	See Section II, Part D, Subpart 1, Table Y-1 for Values up to 538°C					937
350						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 NH-I-14.5
Yield Strength Values, S_y, Versus Temperature (Cont'd)

SI Units						
	Stresses, MPa					
Temp., °C	304SS	316SS	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 NH-I-14.6A
Minimum Stress-to-Rupture

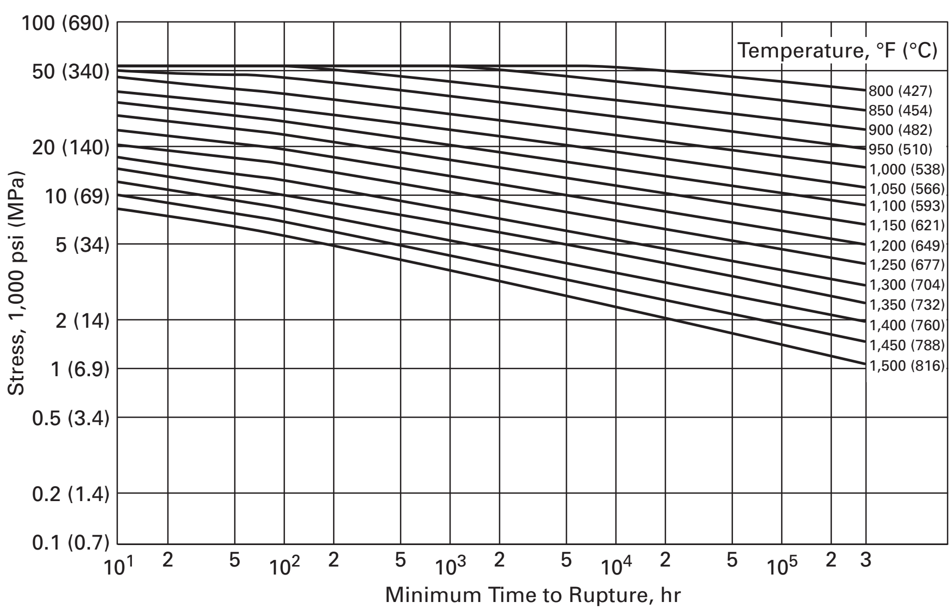


Table NH-I-14.6A
Expected Minimum Stress-to-Rupture Values, 1,000 psi (MPa), Type 304 SS

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 NH-I-14.6B
Minimum Stress-to-Rupture

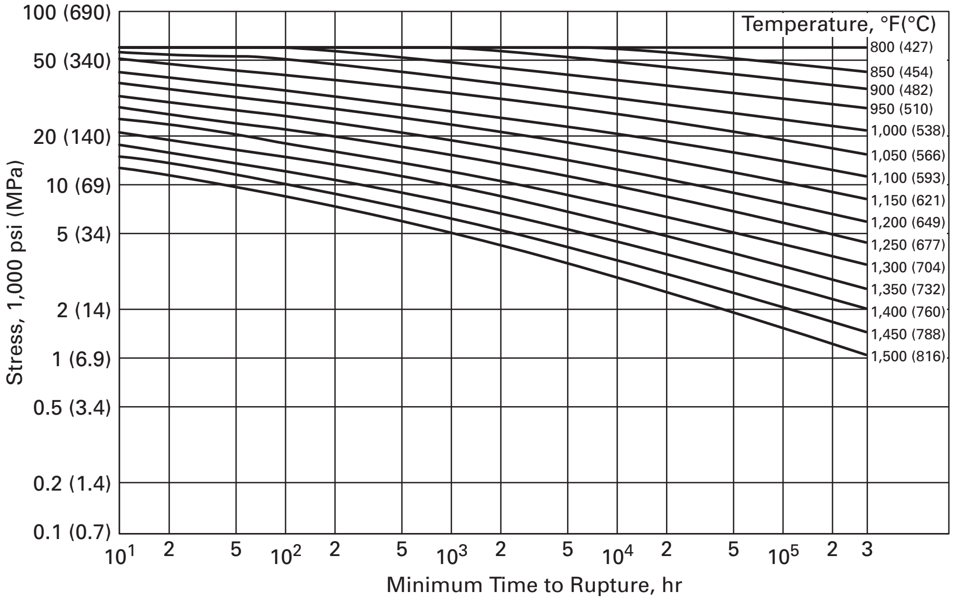


Table NH-I-14.6B
Expected Minimum Stress-to-Rupture Values, 1,000 psi (MPa), Type 316 SS

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 NH-I-14.6C
Minimum Stress-to-Rupture — Ni-Fe-Cr (Alloy 800H)

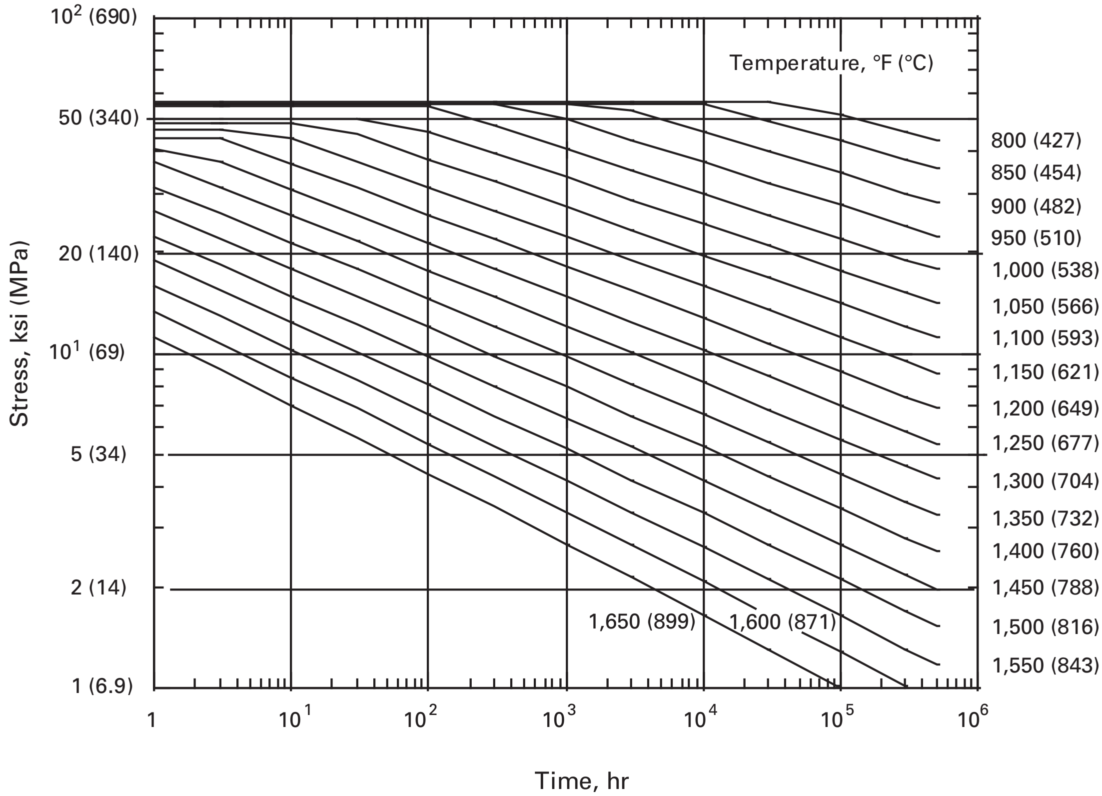


Table NH-I-14.6C
Expected Minimum Stress-to-Rupture Values, ksi (MPa), Ni-Fe-Cr (Alloy 800H)

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 NH-I-14.6D
2¼Cr-1Mo — 100% of the Minimum Stress-to-Rupture

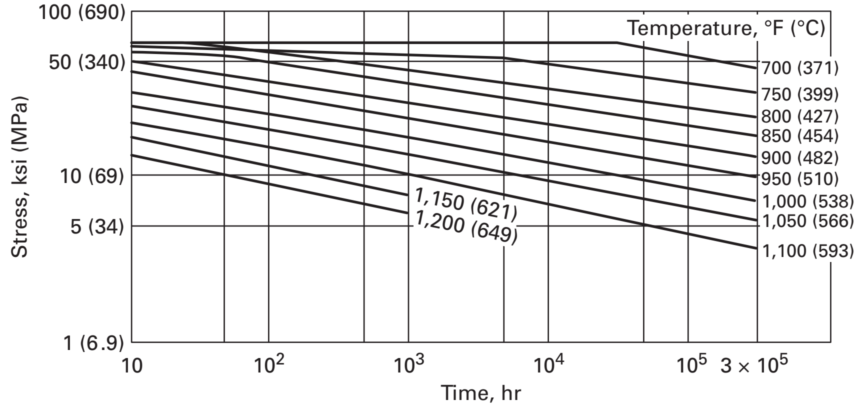


Table NH-I-14.6D
2¼Cr-1Mo — Expected Minimum Stress-to-Rupture Values, ksi (MPa)

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	391	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	48	52	...	...	...	...	...
650	92	76	62	51	43	...	...	...	...	...

Figure NH-I-14.6E
Minimum Stress-to-Rupture, Alloy 718

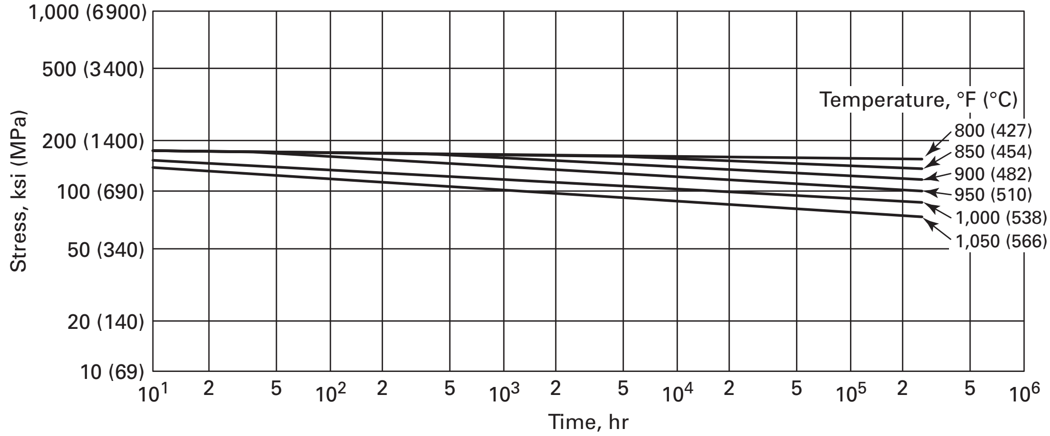


Table NH-I-14.6E
Expected Minimum Stress-to-Rupture Values, ksi (MPa), Ni-Cr-Fe-Mo-Cb (Alloy 718)

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 NH-I-14.6F
9Cr-1Mo-V — Expected Minimum Stress-to-Rupture, ksi (MPa)

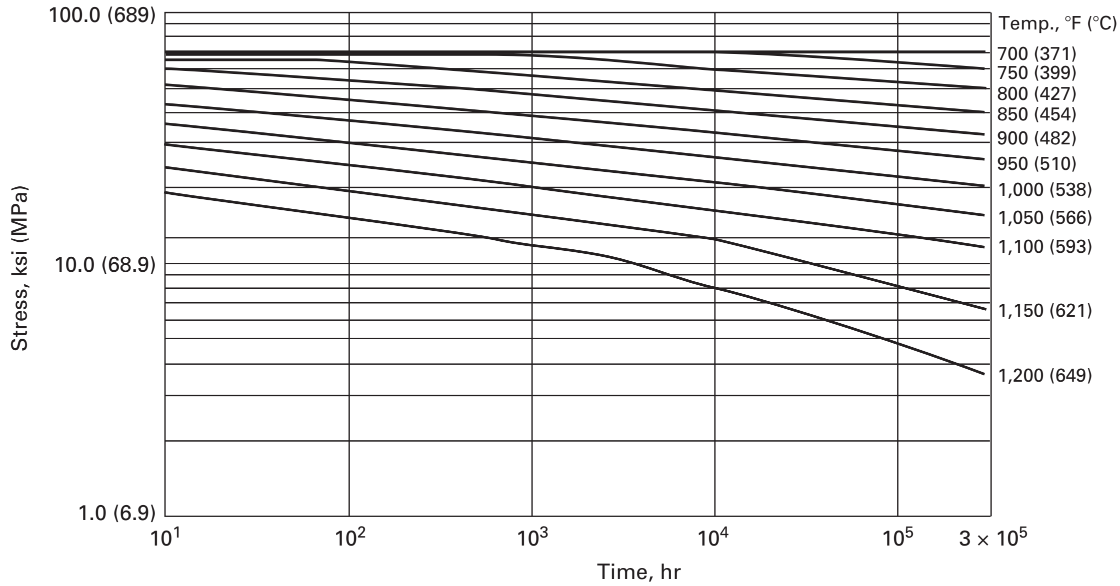


Table NH-I-14.6F
9Cr-1Mo-V, S_r, — Expected Minimum Stress-to-Rupture Values, ksi (MPa)

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
700	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0
750	69.0	69.0	69.0	69.0	69.0	69.0	69.0	67.3	63.5	60.2
800	66.5	66.5	66.5	66.5	66.5	63.1	59.4	56.1	52.7	49.6
850	63.4	63.4	63.4	59.7	56.0	52.7	49.3	46.3	43.3	40.6
900	59.8	57.0	53.3	50.0	46.6	43.7	40.6	37.9	35.2	32.8
950	51.2	47.9	44.5	41.5	38.5	35.8	33.1	30.7	28.2	26.1
1,000	42.8	39.9	36.8	34.1	31.4	29.0	26.6	24.5	22.3	20.5
1,050	35.6	32.9	30.1	27.7	25.3	23.2	21.1	19.2	17.3	15.7
1,100	29.2	26.8	24.4	22.3	20.1	18.3	16.4	14.8	13.1	11.7
1,150	23.7	21.6	19.4	17.6	15.7	14.1	12.4	10.2	8.2	6.7
1,200	19.0	17.1	15.2	13.6	11.9	10.5	8.0	6.5	4.9	3.7

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
375	487	487	487	487	487	487	487	487	487	487
400	475	475	475	475	475	475	475	461	435	412
425	459	459	459	459	459	436	412	390	366	345
450	440	440	440	418	396	374	350	329	308	289
475	419	404	385	361	338	317	295	276	257	240
500	374	353	329	307	285	266	247	229	212	196
525	322	301	278	259	239	222	204	189	173	159
550	274	251	234	216	198	178	166	153	139	127
575	231	213	194	179	163	149	135	122	110	99
600	192	176	160	146	132	118	106	94	82	72
625	159	145	130	117	105	94	81	67	53	42
650	130	117	104	93	81	72	54	44	33	25

Table NH-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 NH-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 NH-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 NH-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 NH-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 NH-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 NH-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 NH-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 NH-I-14.10D-1
Stress Rupture Factors for 2¼Cr-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

Table NH-I-14.10E-1
Stress Rupture Factors for 9Cr-1Mo-V Welded With SFA-5.28 ER 90S-B9; SFA-5.5 E90XX-B9; SFA-5.23 EB9

U.S. Customary Units		SI Units	
Temp., °F	Ratio	Temp., °C	Ratio
800	1.0	425	1.0
850	0.94	450	0.95
900	0.93	475	0.93
950	0.92	500	0.92
1,000	0.90	525	0.91
1,050	0.88	550	0.89
1,100	0.85	575	0.87
1,150	0.81	600	0.84
1,200	0.76	625	0.80
		650	0.76

Table NH-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 NH-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 NH-I-14.13A
S_{mt} — Allowable Stress Intensity, Type 304 SS, Bolting

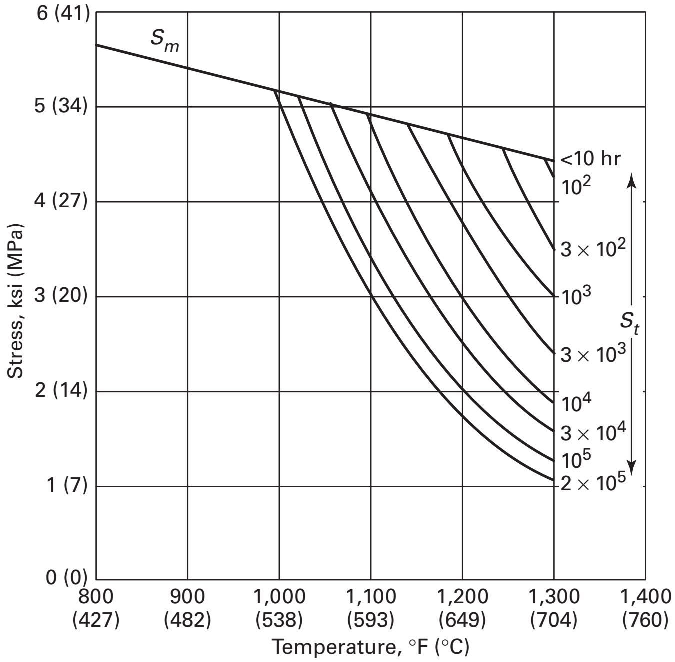


Figure NH-I-14.13B
S_{mt} — Allowable Stress Intensity, Type 316 SS, Bolting

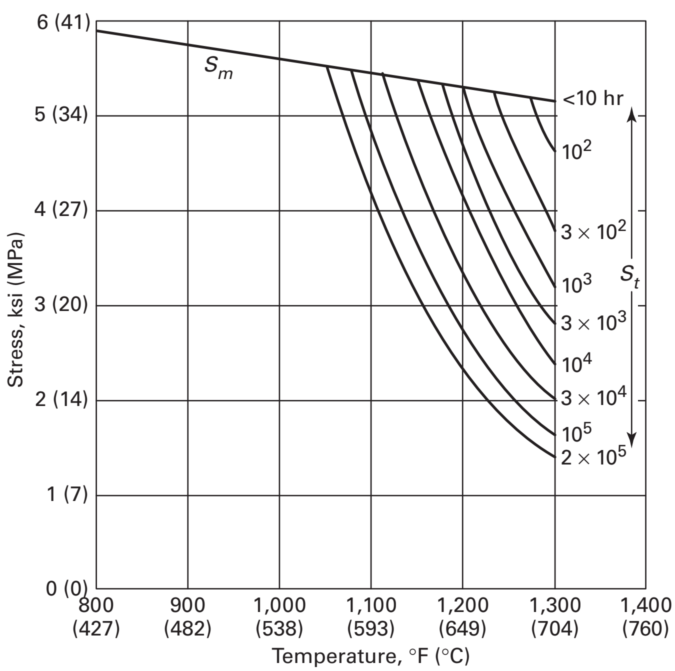


Figure NH-I-14.13C
S_{mt} — Allowable Stress, Alloy 718, Bolting

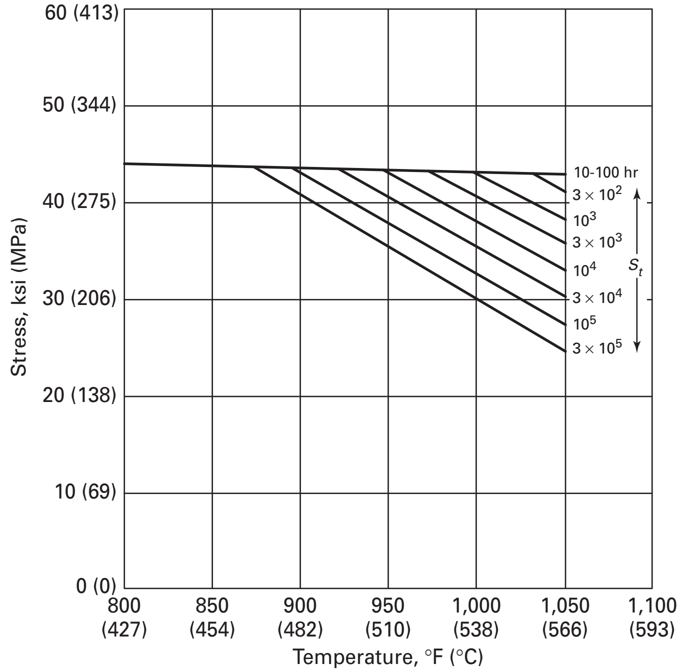


Table NH-I-14.13C
S_{mt} — Allowable Stress Values, ksi (MPa), Alloy 718, Bolting

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

NONMANDATORY APPENDIX NH-T RULES FOR STRAIN, DEFORMATION, AND FATIGUE LIMITS AT ELEVATED TEMPERATURES

NH-T-1100 INTRODUCTION

NH-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 NH.

NH-T-1120 GENERAL REQUIREMENTS

NH-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.

NH-T-1122 Analysis Required

The rules for design against gross distortion and fatigue are illustrated in Figure NH-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 NH-T. Regions not expecting any service time under elevated temperatures may use the secondary stress and fatigue limits of NB-3222.2 and NB-3222.4 in place of the rules in NH-T-1300, NH-T-1400, and NH-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.

NH-T-1200 DEFORMATION LIMITS FOR FUNCTIONAL REQUIREMENTS

NH-T-1210 STATEMENT IN DESIGN SPECIFICATION

Deformation limits to ensure proper component functioning shall be specified in the Design Specification (NCA-3250) 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 NH-3220.

NH-T-1220 ELASTIC ANALYSIS METHOD

The limitations on loads from the rules and the other limits contained in NH-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.

NH-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 NH-T-1220 has demonstrated compliance.

NH-T-1300 DEFORMATION AND STRAIN LIMITS FOR STRUCTURAL INTEGRITY

NH-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.

NH-T-1320 SATISFACTION OF STRAIN LIMITS USING ELASTIC ANALYSIS

NH-T-1321 General Requirements

The strain limits of NH-T-1310 are considered to have been satisfied if the limits of any one of NH-T-1322, NH-T-1323, or NH-T-1324 are satisfied. The guidelines of (a) through (d) below should be used in establishing the appropriate cycle to be evaluated in NH-T-1322 and NH-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 eq. NH-3223(c)(6).

(c) Any number of cycles can be grouped together and evaluated according to the conditions of NH-T-1322 or NH-T-1323, whichever is applicable.

(d) The following definitions apply to NH-T-1322 and NH-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

NH-T-1322 Test No. A-1

For Test Number A-1:

$$X + Y \leq S_a / S_y \quad (1)$$

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

NH-T-1323 Test No. A-2

For Test Number A-2:

$$X + Y \leq 1 \quad (2)$$

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 NH-T-1323.

NH-T-1324 Test No. A-3

For Test Number A-3, the limits of NB-3222.2, NB-3222.3, and NB-3222.5 shall be met and, in addition, the requirements of (a) through (c) below shall be satisfied.

Table NH-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)
$2^1/_4$Cr-1Mo	801 (427)
9Cr-1Mo-V	940 (504)

(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 NH-I-14.6A through NH-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 NH-T-1324. If $s(S_y|T_i)$ is above the stress values provided in Figures NH-I-14.6A through NH-I-14.6F, this test cannot be satisfied. When $s(S_y|T_i)$ is below the lowest stress value provided in Figures NH-I-14.6A through NH-I-14.6F, the constant temperature line may be extrapolated to larger t_{id} values using the steepest slope on Figures NH-I-14.6A through NH-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:

$$\sum_i t_i \Big| T_i \geq \text{service lifetime}$$

(c) For the $3S_m$ limit in NB-3222.2 and NB-3222.3, 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 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 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 2¼Cr-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 2¼Cr-1Mo and 9Cr-1Mo-V].

Table NH-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
2¼Cr-1Mo	1.0	1.5
9Cr-1Mo-V	0.1	1.0

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 2¼Cr-1Mo and 9Cr-1Mo-V].

NH-T-1325 Special Requirements for Piping Components

(a) Piping evaluations using the provisions of NH-3651(b) to satisfy the limits of NH-T-1322, NH-T-1323, or NH-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 NB-3650.

(b) For purposes of applying the limits of NH-T-1324 to piping components, satisfaction of the NB-3650 requirements may be used in lieu of meeting NB-3222.2, NB-3222.3, and NB-3222.5, provided that S_m is replaced by $\bar{S}_m$ and the ratchet check of 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 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 NH-T-1324(c).

NH-T-1330 SATISFACTION OF STRAIN LIMITS USING SIMPLIFIED INELASTIC ANALYSIS

NH-T-1331 General Requirements

The strain limits of NH-T-1310 are considered to have been satisfied if the limits of NH-T-1332 are satisfied in addition to (a) through (h) below.

(a) NH-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 NH-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 NH-T-1332, the inelastic strains due to any number of selected operational cycles may be evaluated separately by NH-T-1333 or using detailed inelastic analysis. The resulting sum of the inelastic strains must satisfy the limits of NH-T-1310. NH-T-1333 is applicable only to axisymmetric structures subjected to axisymmetric loadings and away from local structural discontinuities.

(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 NH-T-1332 and NH-T-1333, the sum being limited to the values of NH-T-1310. If the latter is done, stresses with elastic follow-up should be treated as secondary in the σ_c evaluation as defined in NH-T-1332(a).

(e) The time used in NH-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 NH-T-1332, the definitions of X and Y in NH-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) For NH-T-1333, the definitions of X and Y in NH-T-1321(d) apply, but X_L, Y_L, X_H, and Y_H are calculated for the cold and hot ends using S_{yL} and S_{yH}, respectively.

(h) When applying the procedures of NH-T-1332 (Test No. B-1) and NH-T-1333, wall membrane forces from overall bending of a pipe section or vessel can be conservatively included as axisymmetrical forces.

NH-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 NH-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 NH-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 NH-T-1332-1 for Test No. B-1 and in Figure NH-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 NH-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 $^1/_2$% 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 NH-T-1332-1, and:

$$Z = X \cdot Y \tag{3}$$

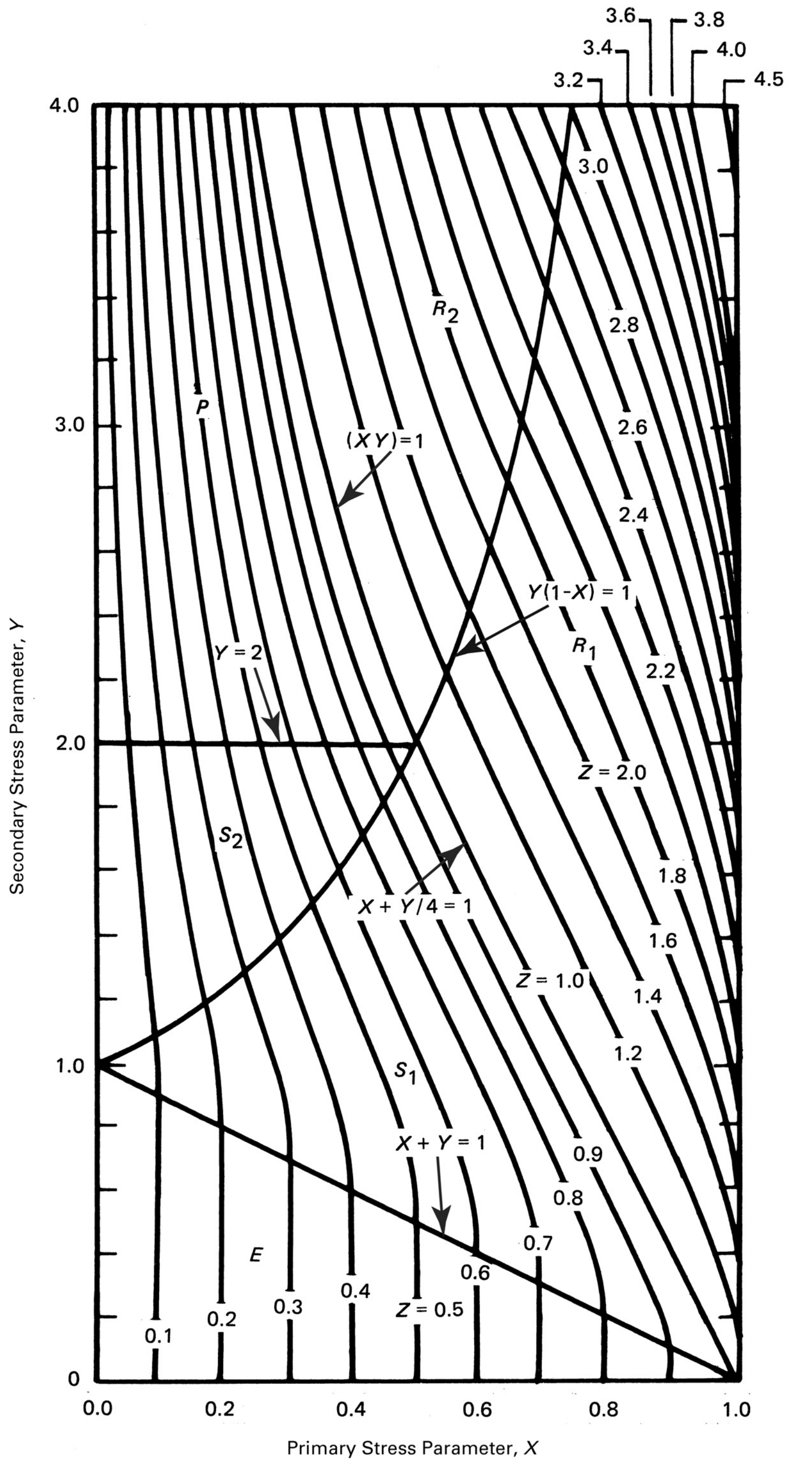
in regimes S_2 and P, and:

$$Z = Y + 1 - 2\sqrt{(1 - X)Y} \tag{4}$$

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 NH-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).

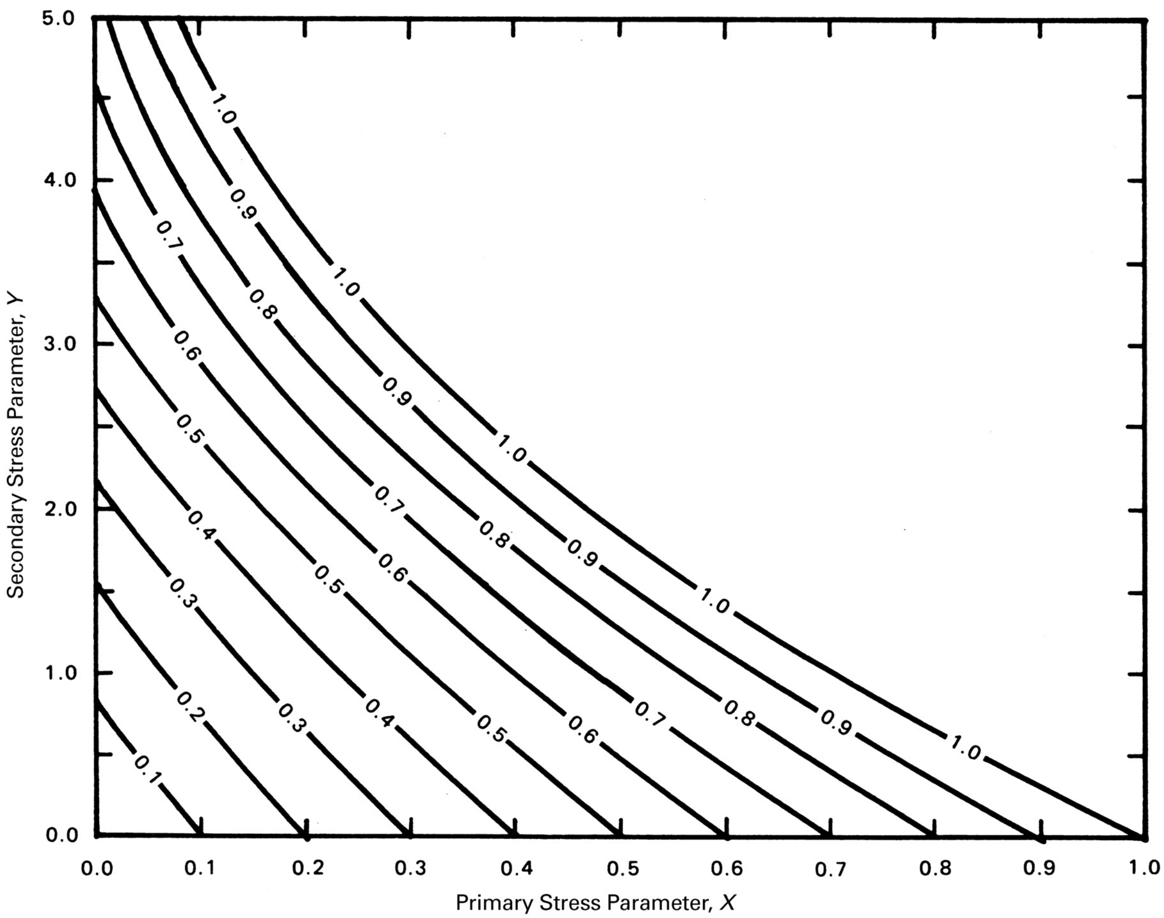
(d) For Test No. B-2, the effective creep stress σ_c shall be obtained from Figure NH-T-1332-2.

Figure NH-T-1332-1
Effective Creep Stress Parameter *Z* for Simplified Inelastic Analysis Using Test Nos. B-1 and B-3



GENERAL NOTE: For use only when the restrictions of NH-T-1331(a) for Test No. B-1 are met.

Figure NH-T-1332-2
Effective Creep Stress Parameter *Z* for Simplified Inelastic Analysis Using Test No. B-2



GENERAL NOTE: Applicable to general structures.

NH-T-1333 Test No. B-3

(a) The procedure of NH-T-1333 may be used for cycles in regimes R_1 and R_2. This procedure may also be applied to cycles in the S_1, S_2, and P regimes in order to minimize the conservatism in the calculated strains when there are a few relatively severe cycles. For cycles evaluated using NH-T-1333, the resulting plastic ratchet strains and the enhanced creep strains due to creep relaxation within these cycles must be added to strains bounded by NH-T-1332, Test No. B-1. The total inelastic strains accumulated in the lifetime of the component are given by:

$$\Sigma\epsilon = \Sigma\nu + \Sigma\eta + \Sigma\delta \qquad (5)$$

where

$\Sigma\delta$ = the enhanced creep strain increments due to relaxation of the $[\sigma_c]$ stresses, obtained as explained in (c)

$\Sigma\eta$ = the plastic ratchet strain increments for cycles in regimes S_1, S_2, P, R_1, and R_2, obtained as explained in (b)

$\Sigma\nu$ = the inelastic strains obtained from the isochronous curves as in Test No. B-1 of NH-T-1332, ignoring the increase of σ_c stress for cycles evaluated using NH-T-1333 and detailed inelastic analyses

(b) Plastic ratcheting occurs in cycles when $[\sigma_{cL}] \geq S_{yH}$. The increment of plastic ratchet strain within this cycle is bounded by:

$$\eta_{(n)} = \frac{1}{E_H}\left[\left(\left[\sigma_{cL}\right] - S_{yH}\right) + \left(\left[\sigma_{cH}\right] - S_{yL}\right)\right] \qquad (6)$$

(hot extreme only in regimes S_1, S_2, and P) for $Z_L \leq 1.0$, or:

$$\eta_{(n)} = \frac{1}{E_L}\left(\left[\sigma_{cL}\right] - S_{yL}\right) + \frac{1}{E_H}\left(\left[\sigma_{cH}\right] - S_{yH}\right) \qquad (7)$$

(both extremes in regimes R_1 and R_2) for $Z_L > 1.0$. $[\sigma_{cL}]$ and $[\sigma_{cH}]$ are the effective stresses for the cold and hot extremes of the cycles as given by $[\sigma_{cL}] = Z_L S_{yL}$ and $[\sigma_{cH}] = Z_H S_{yH}$, respectively.

The effective creep stress parameter Z is obtained from eq. NH-T-1332(c)(3) for regimes S_2, P, and R_2. Equation NH-T-1332(c)(4) is for regimes S_1 and R_1. Curves resulting from eqs. NH-T-1332(c)(3) and NH-T-1332(c)(4) are shown in Figure NH-T-1332-1. Note that braces indicate $[\sigma_c]$ stress calculated for NH-T-1333 evaluations. E_L and E_H are the elastic moduli at the cold and hot ends of the cycle.

Note that all values in eqs. (6) and (7) are related to the load cycle (n).

(c) For cycles where $[\sigma_{cL}] \geq S_{yH}$, the enhanced creep strain increment due to stress relaxation is given by:

$$\delta_{(n)} = \frac{1}{E_H}\,\frac{S_{yH}^2 - \sigma_c^2}{\sigma_c} \qquad (8)$$

For cycles where $[\sigma_{cL}] < S_{yH}$, the enhanced creep strain increment due to $[\sigma_{cL}]$ stress relaxation is given by:

$$\delta_{(n)} = \frac{1}{E_H}\,\frac{\left[\sigma_{cL}\right]^2 - \sigma_c^2}{\sigma_c} \qquad (9)$$

σ_c is the effective creep stress from NH-T-1332 for the next cycle when sequence of loading is specified. Otherwise, the lowest σ_c stress used in the NH-T-1332 evaluation should be used in eqs. (8) and (9).

Note that all values in eqs. (8) and (9) are related to the load cycle (n). Only positive $\delta_{(n)}$ increments should be considered.

NH-T-1400 CREEP-FATIGUE EVALUATION

NH-T-1410 GENERAL REQUIREMENTS

NH-T-1411 Damage Equation

The combination of Levels 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:

$$\sum_{j=1}^{p}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_k \leq D \qquad (10)$$

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 NH-T-1420-1A through NH-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 NH-I-14.6A through NH-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 NH-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 NH-I-14.6A through NH-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 NH-T-1411-1).

$(n)_j$ = number of applied repetitions 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.

NH-T-1412 Exemption From Fatigue Analysis

The rules in NB-3222.4(d) that permit exemption from fatigue analysis do not apply to temperatures above the limits of Subsection NB, except where the service loadings have been qualified as not introducing significant time-dependent effects under the procedure of NH-3211(c).

NH-T-1413 Equivalent Strain Range

An equivalent strain range is used to evaluate the fatigue damage sum for both elastic and inelastic analysis. When the Design Specification contains a histogram delineating a specific loading sequence, the strain range shall be calculated for the cycles described by the histogram. If the sequence of loading is not defined by the Design Specification, then the method of combining cycles described in NB-3222.4(e)(5) shall be applied. The equivalent strain range is 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 NH-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.

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.

$$\Delta\epsilon_{xi} = \epsilon_{xi} - \epsilon_{xo}$$
$$\Delta\epsilon_{yi} = \epsilon_{yi} - \epsilon_{yo}$$
etc;

Step 4. Calculate the equivalent strain range for each point in time as:

$$\Delta\epsilon_{\text{equiv},i} = \frac{\sqrt{2}}{2(1+\nu^*)}\left[\begin{array}{l}\left(\Delta\epsilon_{xi} - \Delta\epsilon_{yi}\right)^2 + \left(\Delta\epsilon_{yi} - \Delta\epsilon_{zi}\right)^2 \\ + \left(\Delta\epsilon_{zi} - \Delta\epsilon_{xi}\right)^2 \\ + \frac{3}{2}\left(\Delta\gamma_{xyi}^2 + \Delta\gamma_{yzi}^2 + \Delta\gamma_{zxi}^2\right)\end{array}\right]^{1/2} \quad (11)$$

where

ν^* = 0.5 when using the rules of NH-T-1420
ν^* = 0.3 when using the rules of NH-T-1430

Table NH-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	0.9	0.67

Step 5. Define $\Delta\epsilon_{max}$ as the maximum value of the above calculated equivalent strain ranges, $\Delta\epsilon_{equiv.i}$.

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 NH-T-1414.

NH-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 NH-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.

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:

$$\Delta(\epsilon_1 - \epsilon_2)_i = (\epsilon_1 - \epsilon_2)_i - (\epsilon_1 - \epsilon_2)_o$$

$$\Delta(\epsilon_2 - \epsilon_3)_i = (\epsilon_2 - \epsilon_3)_i - (\epsilon_2 - \epsilon_3)_o$$

$$\Delta(\epsilon_3 - \epsilon_1)_i = (\epsilon_3 - \epsilon_1)_i - (\epsilon_3 - \epsilon_1)_o$$

Step 6. For each time point, i, calculate the equivalent strain range as:

$$\Delta\varepsilon_{equiv.\,i} = \frac{\sqrt{2}}{2(1 + \nu^*)}\left\{\left[\Delta(\varepsilon_1 - \varepsilon_2)_i\right]^2 + \left[\Delta(\varepsilon_2 - \varepsilon_3)_i\right]^2 + \left[\Delta(\varepsilon_3 - \varepsilon_1)_i\right]^2\right\}^{1/2}$$

where ν^* is defined as in NH-T-1413.

Step 7. Define $\Delta\epsilon_{max}$ as the maximum value of the above calculated equivalent strain ranges, $\Delta\epsilon_{equiv.i}$.

NH-T-1420 LIMITS USING INELASTIC ANALYSIS

When inelastic analysis is used to satisfy the requirements of NH-T-1411, the rules of (a), (b), and (c) below apply.

(a) The creep damage term of eq. NH-T-1411(10) may also be calculated by using the integral form:

$$\int_o^t \frac{dt}{T_d}$$

(b) The fatigue damage term of eq. NH-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 NH-T-1413 or NH-T-1414. The appropriate design fatigue curve is selected from Figures NH-T-1420-1A through NH-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 NH-T-1420-2.

NH-T-1430 LIMITS USING ELASTIC ANALYSIS

NH-T-1431 General Requirements

(a) The elastic analysis rules in this paragraph may be used only when:

(1) the elastic ratcheting rules of NH-T-1320 or NH-T-1330 with Z less than, or equal to, 1.0 have been satisfied;

(2) the $3S_m$ limit in NB-3222.2 is met using for $3S_m$ the lesser of $3S_m$ and $3\bar{S}_m$ as defined in NH-T-1324; and

(3) pressure-induced membrane and bending stresses and thermal induced membrane stresses are classified as primary (load-controlled) stresses.

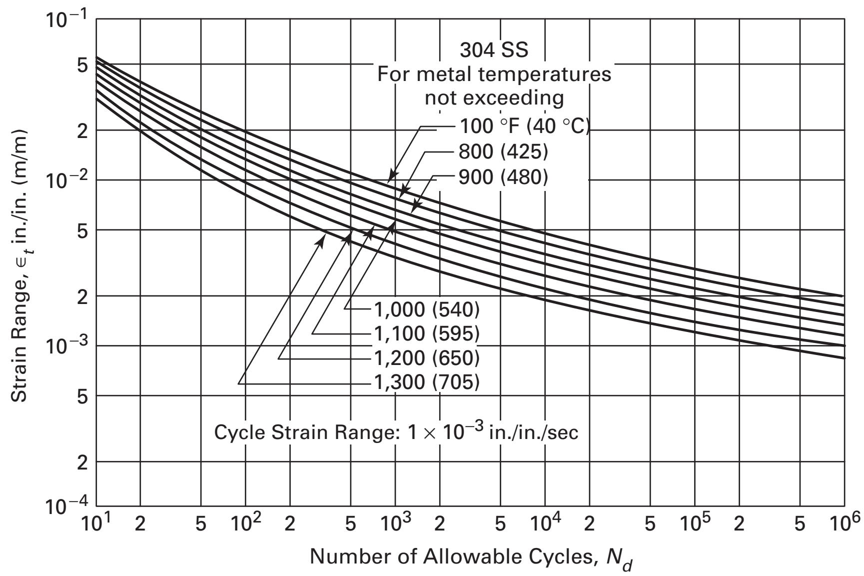
The secondary stress range due to radial thermal gradients may be excluded from $(Q_R)_{max}$ in either NH-T-1322 or NH-T-1323 in determining the applicability of elastic creep-fatigue rules.

(b) Linearly elastic analysis methods may significantly underestimate the actual strain range incurred during plastic or creep deformation. The method of NH-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. NH-T-1411(10). The appropriate design fatigue curve is selected from Figures NH-T-1420-1A through NH-T-1420-1E and corresponds to the maximum metal temperature occurring during the cycle.

(c) The creep damage term of eq. NH-T-1411(10) is evaluated using the procedure of NH-T-1433.

(d) The total damage, D, shall not exceed the creep-fatigue damage envelope of Figure NH-T-1420-2.

Figure NH-T-1420-1A
Design Fatigue Strain Range, ϵ_t, for 304 SS



N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (in./in.) at Temperature — U.S. Customary Units						
	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

N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (m/m) at Temperature — SI Units						
	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

Figure NH-T-1420-1A
Design Fatigue Strain Range, ϵ_t, for 304 SS (Cont'd)

Table continued

N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (m/m) at Temperature SI Units						
	40°C	425°C	480°C	540°C	595°C	650°C	705°C
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).

NH-T-1432 Strain Range Determination

(a) Calculate $\Delta\epsilon_{max}$ using NH-T-1413 or NH-T-1414. The strain components to be used in NH-T-1413 or NH-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 NB-3216. 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 $2S_{alt}/E$, where E equals the modulus of elasticity at the maximum metal temperature experienced during the cycle.

(b) Calculate the modified maximum equivalent strain range, $\Delta\epsilon_{mod}$, using the procedure specified in any one of (c), (d), or (e).

(c) The modified maximum equivalent strain range, $\Delta\epsilon_{mod}$, may be calculated as:

$$\Delta\epsilon_{mod} = \left(\frac{S^*}{\bar{S}}\right)K^2\Delta\epsilon_{max} \qquad (12)$$

where (see Figure NH-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 NH-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 NH-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)

$\Delta\epsilon_{mod}$ = 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 NH-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') from Figures NH-T-1800-A-1 through NH-T-1800-E-11. The appropriate curve of Figures NH-T-1800-A-1 through NH-T-1800-E-11 corresponds to the maximum metal temperature occurring during the cycle.

O = origin of the composite isochronous stress-strain curve (Figure NH-T-1432-1) used in this analysis

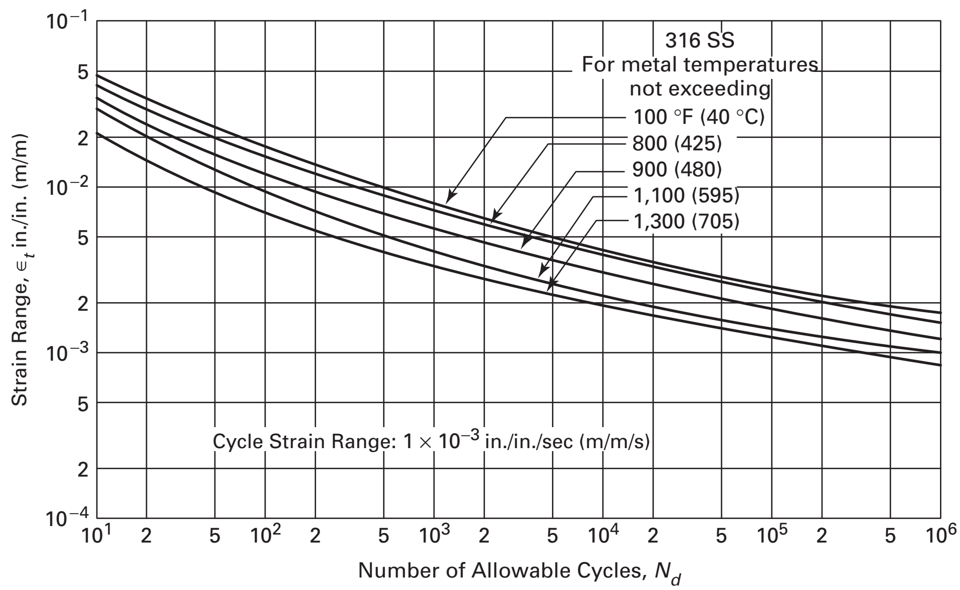
O' = origin of the time-independent isochronous stress-strain curve of Figures NH-T-1800-A-1 through NH-T-1800-E-11

S_{rH} = a relaxation strength defined in NH-T-1324

ϵ' = strain abscissa of the time-independent isochronous stress-strain curve of Figures NH-T-1800-A-1 through NH-T-1800-E-11

σ' = stress ordinate of the time-independent isochronous stress-strain curve of Figures NH-T-1800-A-1 through NH-T-1800-E-11

Figure NH-T-1420-1B
Design Fatigue Strain Range, ϵ_t, for 316 SS



N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (in./in.) at Temperature — U.S. Customary Units 100°F	800°F	900°F	1,000-1,200°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

N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (m/m) at Temperature — SI Units 40°C	425°C	480°C	540-650°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

Figure NH-T-1420-1B
Design Fatigue Strain Range, ϵ_t, for 316 SS (Cont'd)

Table continued

N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (m/m) at Temperature				
	SI Units				
	40°C	425°C	480°C	540-650°C	705°C
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).

(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):

$$\Delta\epsilon_{mod} = \frac{K^2 S^* \Delta\epsilon_{max}}{\Delta\sigma_{mod}} \tag{13}$$

where (see Figure NH-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 NH-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:

$$\Delta\epsilon_{mod} = K_e K \Delta\epsilon_{max} \tag{14}$$

where $\Delta\epsilon_{mod}$, K, and $\Delta\epsilon_{max}$ are defined in (c) above, and

$K_e = 1$ if $K\Delta\epsilon_{max} \leq 3\bar{S}_m / E$

$K_e = K\Delta\epsilon_{max} E / 3\bar{S}_m$ for $K\Delta\epsilon_{max} > 3\bar{S}_m / E$

(f) Determine the multiaxial plasticity and Poisson ratio adjustment factor, K_ν, defined in eq. (15):

$$K_\nu = 1.0 + f(K_\nu' - 1.0), \text{ but not less than } 1.0 \tag{15}$$

where

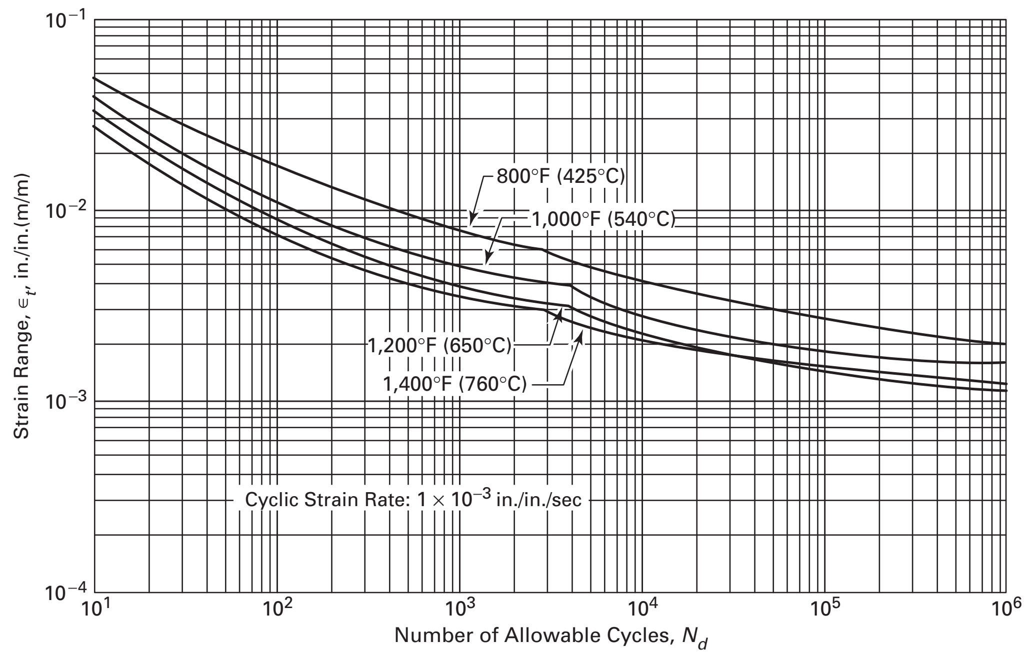
f = factor determined by entering Figure NH-T-1432-2 at the Triaxiality Factor, T.F., for the stress state at each of the two extremes of the stress cycle. The larger magnitude of f shall be used in eq. (15).

K_ν' = plastic Poisson ratio adjustment factor determined by entering Figure NH-T-1432-3 at the ratio of $K_e K \Delta\epsilon_{max} E / 3\bar{S}_m$ with the terms as defined in eq. (e)(14)

(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 $\sigma_c = Z \cdot S_y$ as defined in NH-T-1332. The rules of NH-T-1321, NH-T-1331, and NH-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 NH-T-1323 relative to Table NH-T-1323 does not apply to determining $\Delta\epsilon_c$. Enter the isochronous stress-strain curve (Figures NH-T-1800-A-1 through NH-T-1800-E-11) 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 NH-T-1320 and the NH-T-1431(a) rules, the $\Delta\epsilon_c$ value used need not exceed 1% divided by the total number of stress cycles:

$$\sum_{j=1}^{P} (n)_j$$

Figure NH-T-1420-1C
Design Fatigue Strain Range, ϵ_t, for Ni-Fe-Cr Alloy 800H



N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (in./in.) at Temperature, U.S. Customary Units 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	0.0027	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

N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (m/m) at Temperature, SI Units 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	0.0027	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

Figure NH-T-1420-1C
Design Fatigue Strain Range, ϵ_t, for Ni-Fe-Cr Alloy 800H (Cont'd)

Table continued

N_d Number of Cycles [Note (1)]	ϵ_t, Strain Range (m/m) at Temperature, SI Units			
	425°C	540°C	650°C	760°C
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).

(h) The total strain range, ϵ_t, that is used to enter one of the design fatigue curves of Figures NH-T-1420-1A through NH-T-1420-1E, is calculated as:

$$\epsilon_t = K_v \Delta\epsilon_{mod} + K \Delta\epsilon_c \tag{16}$$

where

K = local geometric concentration factor determined above in (c), (d), or (e)

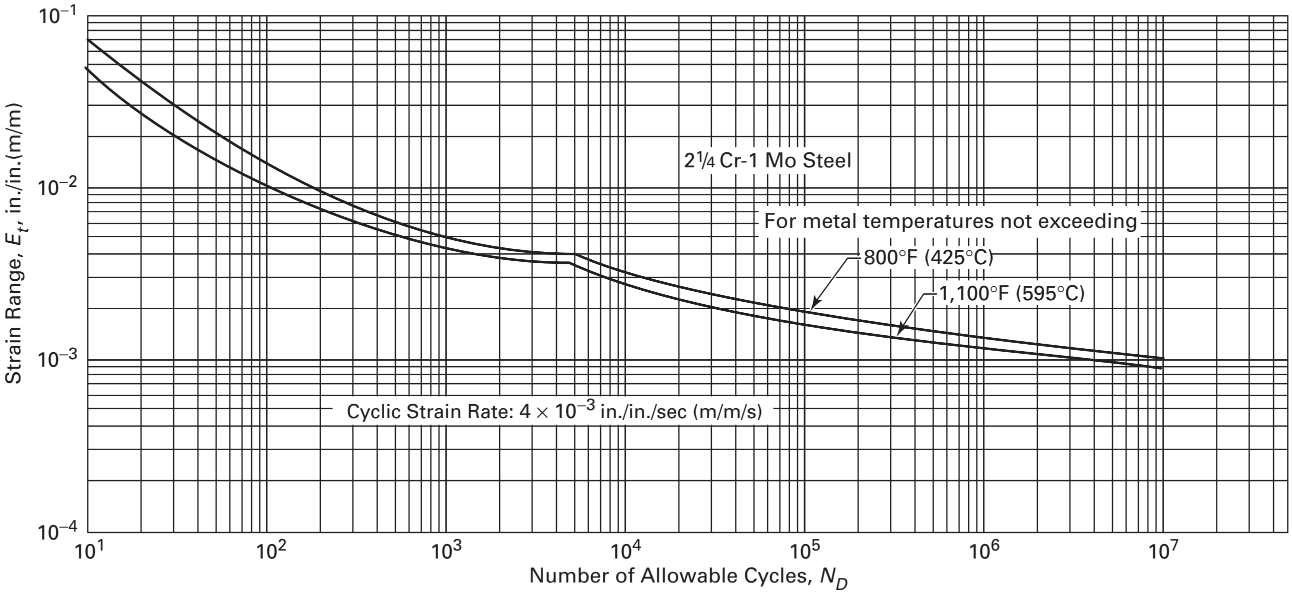
K_v = the multiaxial plasticity and Poisson ratio adjustment factor determined above in (f)

$\Delta\epsilon_c$ = the creep strain increment as determined above in (g)

$\Delta\epsilon_{mod}$ = the modified maximum equivalent strain range as determined above in any one of (c), (d), or (e)

ϵ_t = the total strain range that is used to enter one of the design fatigue curves of Figures NH-T-1420-1A through NH-T-1420-1E to determine the allowable number of cycles, N_d

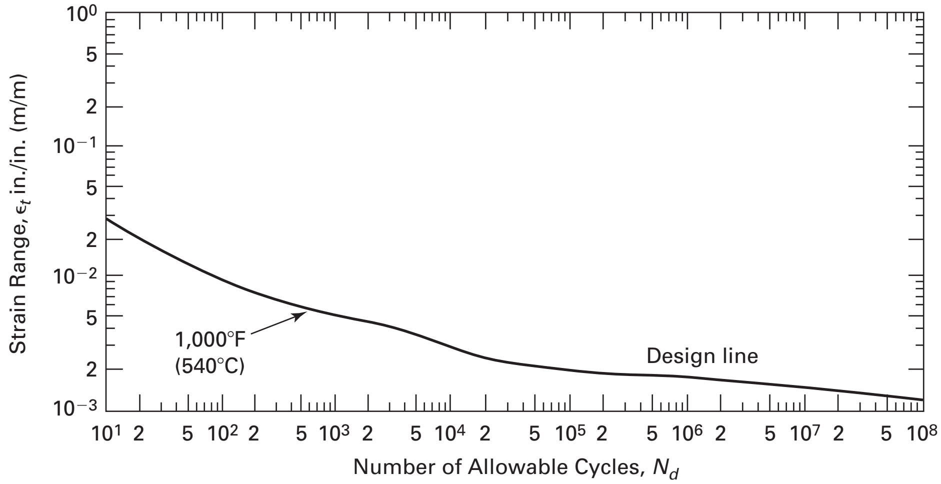
Figure NH-T-1420-1D
Design Fatigue Strain Range, ϵ_t, for 2¼Cr-1Mo Steel



N_d, Number of Cycles [Note (1)]	ϵ_t, Strain Range (in./in.) (m/m) at Temperature	
	800°F (425°C)	900–1,000°F (480–595°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).

Figure NH-T-1420-1E
Design Fatigue Strain Range, ϵ_t, for 9Cr-1Mo-V Steel



N_d, Number of Cycles [Note (1)]	ϵ_t, Strain Range in./in. (m/m) at Temperature, 1,000°F (540°C)
10	0.028
20	0.019
40	0.0138
10^2	0.0095
2×10^2	0.0075
4×10^2	0.0062
10^3	0.0050
2×10^3	0.0044
4×10^3	0.0039
10^4	0.0029
2×10^4	0.0024
4×10^4	0.0021
10^5	0.0019
2×10^5	0.00176
4×10^5	0.0017
10^6	0.00163
2×10^6	0.00155
4×10^6	0.00148
10^7	0.00140
2×10^7	0.00132
4×10^7	0.00125
10^8	0.00120

NOTE:
(1) Cycle strain rate: 4×10^{-3} in./in./sec (m/m/s).

Figure NH-T-1420-2
Creep-Fatigue Damage Envelope

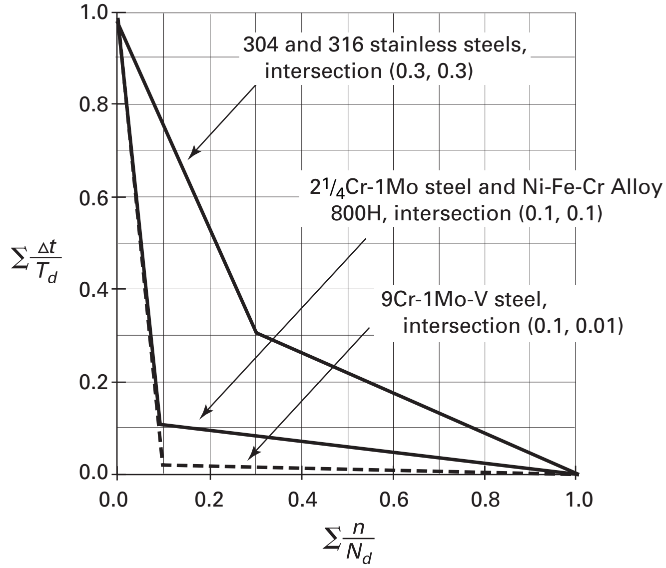


Figure NH-T-1432-1
Stress-Strain Relationship

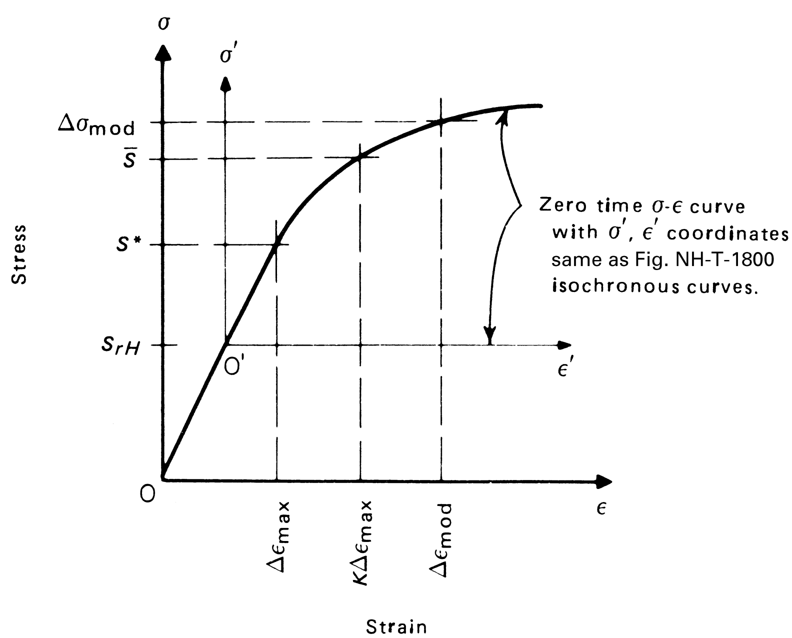
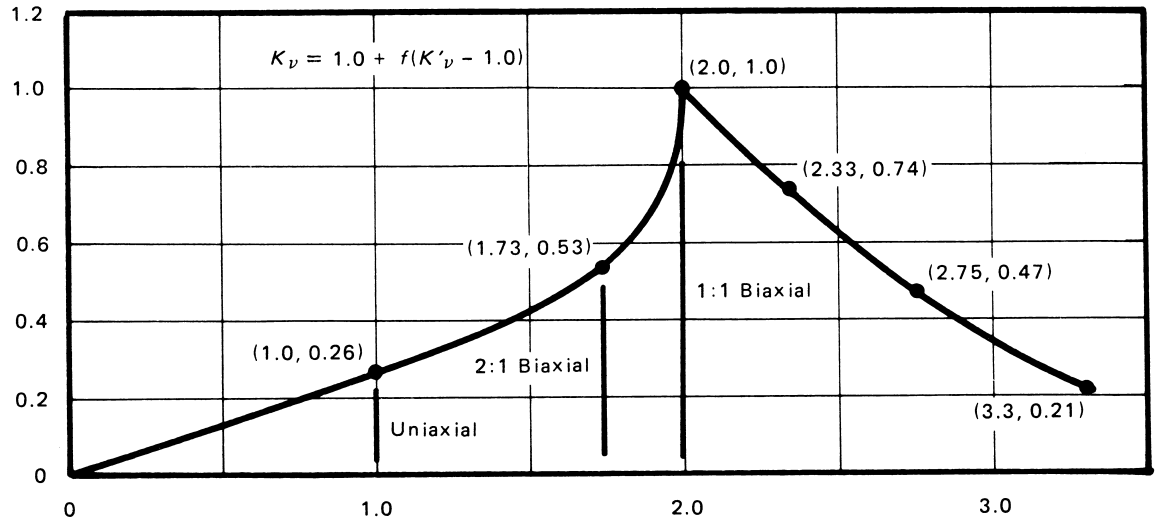


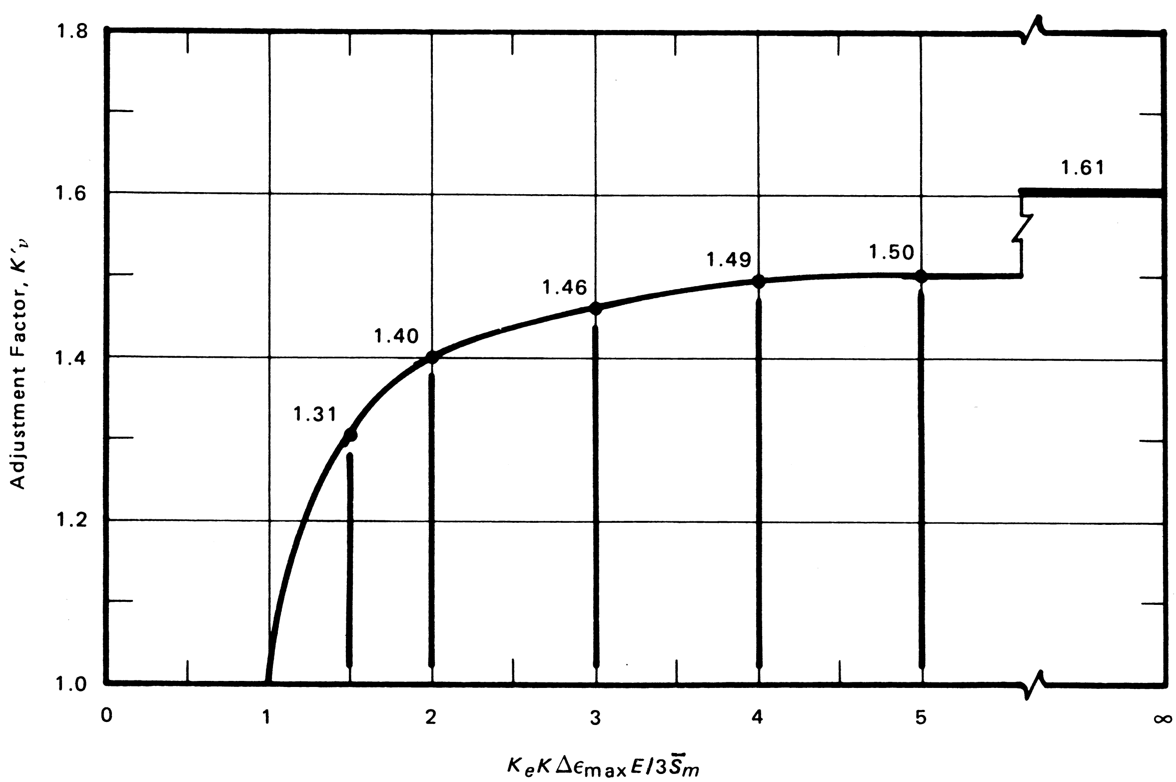
Figure NH-T-1432-2
Inelastic Multiaxial Adjustments



$$\text{T.F.} = \frac{|\sigma_1 + \sigma_2 + \sigma_3|}{\frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{1/2}}$$

σ's are principal stresses at extreme of stress cycle.

Figure NH-T-1432-3
Adjustment for Inelastic Biaxial Poisson's Ratio



NH-T-1433 Creep Damage Evaluation

The creep damage term of eq. NH-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 NH-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. NH-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 NH-T-1432. Recall that j extends from 1 to P as defined in NH-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 2¹⁄₄Cr-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 from Figures NH-T-1800-A-1 through NH-T-1800-E-11 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 NH-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 NH-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

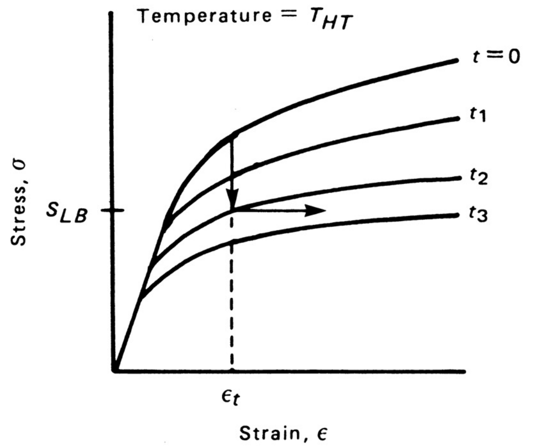
S_r = relaxed stress level at time t adjusted for the multiaxial stress state

$\bar{S}_r$ = relaxed stress level at time t based on a uniaxial relaxation model

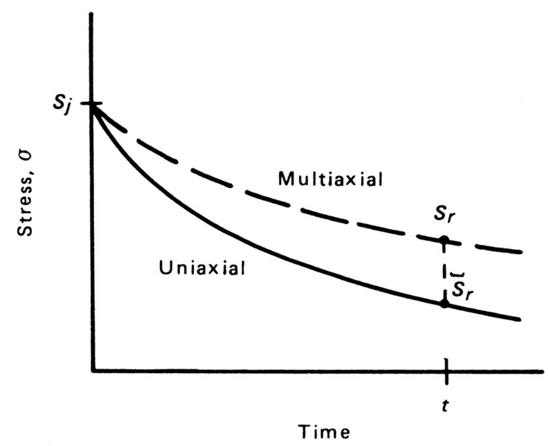
or

(b) by entering the appropriate isochronous stress-strain curves of Figures NH-T-1800-A-1 through NH-T-1800-E-11 at a strain level equal to ϵ_t and determining corresponding stress levels at varying times (see Figure NH-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 NH-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 NH-T-1433-2.

Figure NH-T-1433-1
Methods of Determining Relaxation

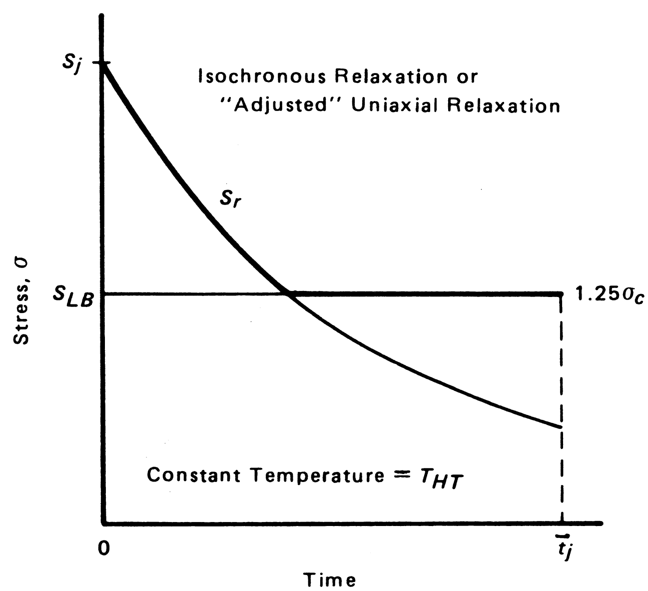


(a) Stress Relaxation From Isochronous Stress–Strain Curves



(b) Multiaxial Relaxation, S_r, Calculated From Uniaxial Relaxation, $\overline{S}_r$

Figure NH-T-1433-2
Stress-Relaxation Limits for Creep Damage



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 $(t_{TRAN})_j$. Determine the time point, during the transient conditions, for which the load-controlled stresses are at maximum conditions. Define $(S_{TRAN})_j$ to be equal to the load-controlled stress intensity at that time point. Indicate both $(t_{TRAN})_j$ and $(S_{TRAN})_j$ on the stress-time history (determined in Step 5 above) as shown in Figure NH-T-1433-3 sketch (a). If $(S_{TRAN})_j$ does not exceed the stress-time history within the time duration $(t_{TRAN})_j$ [as is illustrated in Figure NH-T-1433-3 sketch (a)], then no further modification of the stress-time history is required. If $(S_{TRAN})_j$ exceeds the stress-time history within the time duration $(t_{TRAN})_j$, then the stress-time history must be modified by a simple translation in time, as shown in Figure NH-T-1433-3 sketch (b).

Step 7. Define the cycle transient temperature, $(T_{TRAN})_j$, to be equal to the maximum metal temperature that occurs during cycle type j. In no case shall $(T_{TRAN})_j$ be defined as less than the hold time temperature, T_{HT}. Note that the temperature $(T_{TRAN})_j$ 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 $(t_{TRAN})_j$.

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 NH-T-1433-4.

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. NH-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. NH-T-1411(10) is obtained from the expected minimum stress-to-rupture curve of Figures NH-I-14.6A through NH-I-14.6F. The appropriate temperature is $(T)_k$ and the appropriate stress is $(S)_k/K'$, where K' is selected from Table NH-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 NH-T-1432(h)] is less than or equal to $3\bar{S}_m / E$ for all specified cycle types, j, considered in NH-T-1432. The stress-time history for this single relaxation curve is to

Figure NH-T-1433-3
Stress-Relaxation Limits for Creep Damage

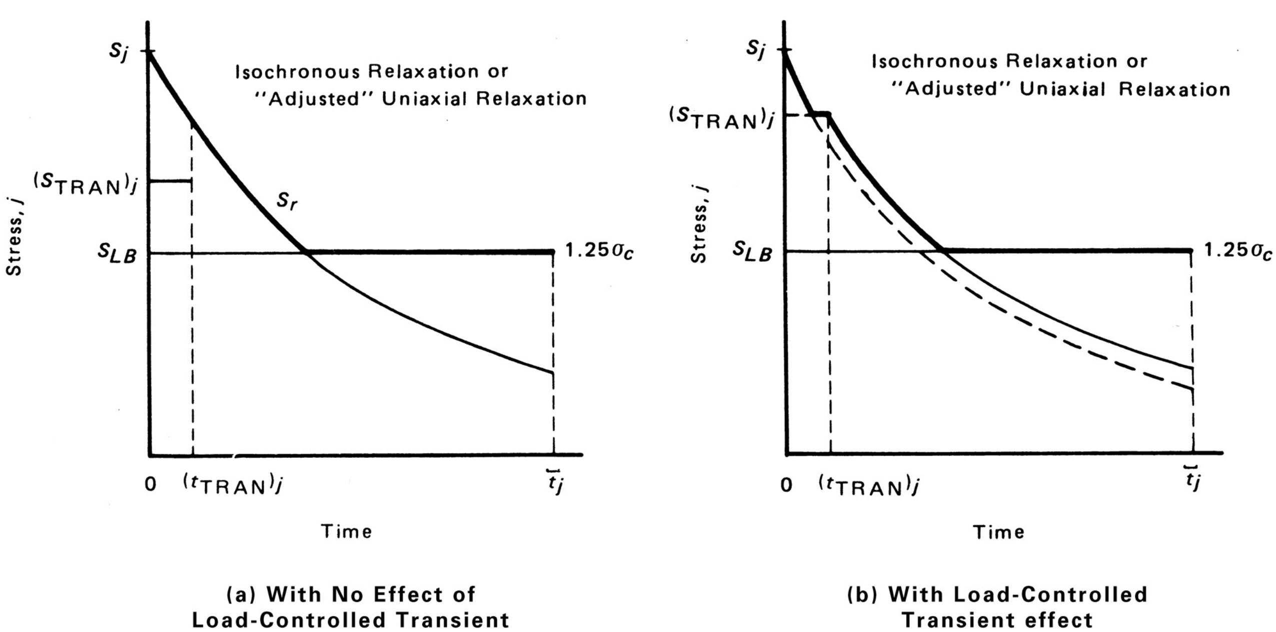
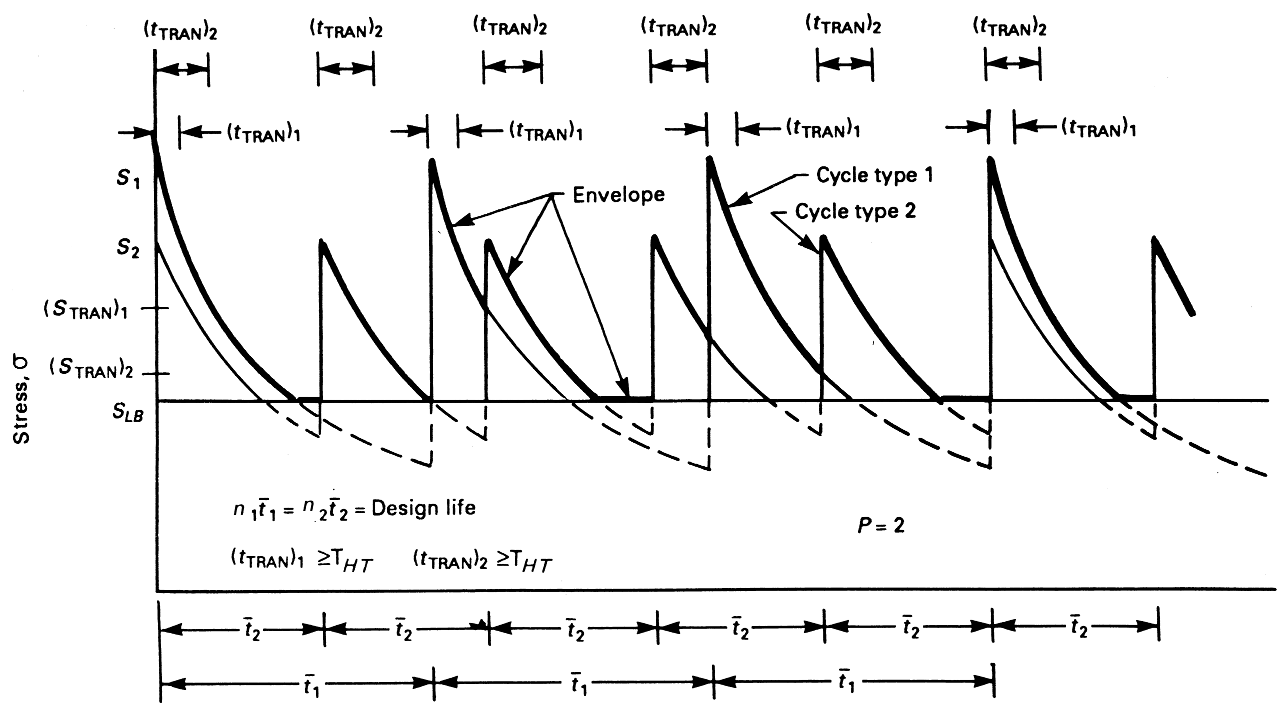


Figure NH-T-1433-4
Envelope Stress-Time History for Creep Damage Assessment



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 NH-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 NH-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. NH-T-1411(10) is obtained from the expected minimum stress-to-rupture curve of Figures NH-I-14.6A through NH-I-14.6F. The appropriate temperature is $(T)_k$ and the appropriate stress is $(S)_k/K'$; where K' is selected from Table NH-T-1411-1.

NH-T-1434 Calculation of Strain Range for Piping

When simplified elastic rules are used for piping analysis utilizing the stress indices of Table NB-3681(a)-1, the equivalent strain range may be calculated directly from eq. NH-T-1432(c)(12) or eq. NH-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 NH-T-1430. The follow-up analysis shall be disclosed and justified in the Design Report.

NH-T-1435 Alternate Creep-Fatigue Evaluation

Providing the limits of NH-T-1324 are satisfied, the rules of NH-T-1431, NH-T-1432, and NH-T-1433 may be replaced by NB-3222.4, except:

(a) The reference to Section III Appendices, Mandatory Appendix I may be replaced by Figures NH-T-1420-1A through NH-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 NB-3228.5 and 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 NH-T-1412.

NH-T-1500 BUCKLING AND INSTABILITY

NH-T-1510 GENERAL REQUIREMENTS

(a) The stability limits in NB-3133 of Section III pertain only to specific geometrical configurations under specific loading conditions. For example, column mode buckling is not evaluated by 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 NH-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 NH-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 NH-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 NH-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 NH-T-1200 and NH-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 of Figures NH-T-1800-A-1 through NH-T-1800-E-11 to the tabulated yield strength given in Table NH-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 NH-T-1520.

(h) The limits of both NH-T-1521 and NH-T-1522 shall be satisfied for the specified Design and Service Loadings.

NH-T-1520 BUCKLING LIMITS

NH-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 NH-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 NB-3133 may be applied.

NH-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 NH-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 NH-T-1522-1, Figure NH-T-1522-2, or Figure NH-T-1522-3, the design limits of NB-3133 or of NH-T-1521 may be applied without consideration of creep effects. The temperature limits of Figures NH-T-1522-1 and NH-T-1522-2 are given in terms of design life and are applicable for any radius-to-thickness ratio. The temperature limits of Figure NH-T-1522-3 are given in terms of radius-to-thickness ratio and are applicable for any design life.

Table NH-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 NH-3113.7.

NH-T-1700 SPECIAL REQUIREMENTS

NH-T-1710 SPECIAL STRAIN REQUIREMENTS AT WELDS

NH-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 NH-3211). The potential for reduced ductility often precludes locating welds in regions of high loading.

Table NH-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

NH-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.

NH-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 NH-T-1310).

NH-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-3550). The worst surface geometry for a given weld shall be determined by the methods described in NH-3353.

NH-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 NH-T-1400 shall utilize reduced values of the allowable number of design cycles N_d and the allowable time duration T_d in eq. NH-T-1411(10). The N_d value shall be one-half the value permitted for the parent material (Figures NH-T-1420-1A through NH-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 NH-I-14.6A through NH-I-14.6F) by the weld strength reduction factors given in Tables NH-I-14.10A-1 through NH-I-14.10E-1, and defined in NH-3220. The factor K' (Table NH-T-1411-1) must still be applied in this determination of T_d.

NH-T-1720 STRAIN REQUIREMENTS FOR BOLTING

NH-T-1721 Strain Limits

The limits of NH-T-1300 shall apply.

NH-T-1722 Creep-Fatigue Damage Accumulation

The fatigue analysis exemptions in NB-3222.4(d) of Section III shall not apply. Creep and fatigue damage shall be assessed using eq. NH-T-1411(10). The total damage factor, D, shall be set at the appropriate value determined from Figure NH-T-1420-2. Additional requirements are given in (a) and (b) below.

Figure NH-T-1522-1
Time-Temperature Limits for Application of Section II External Pressure Charts

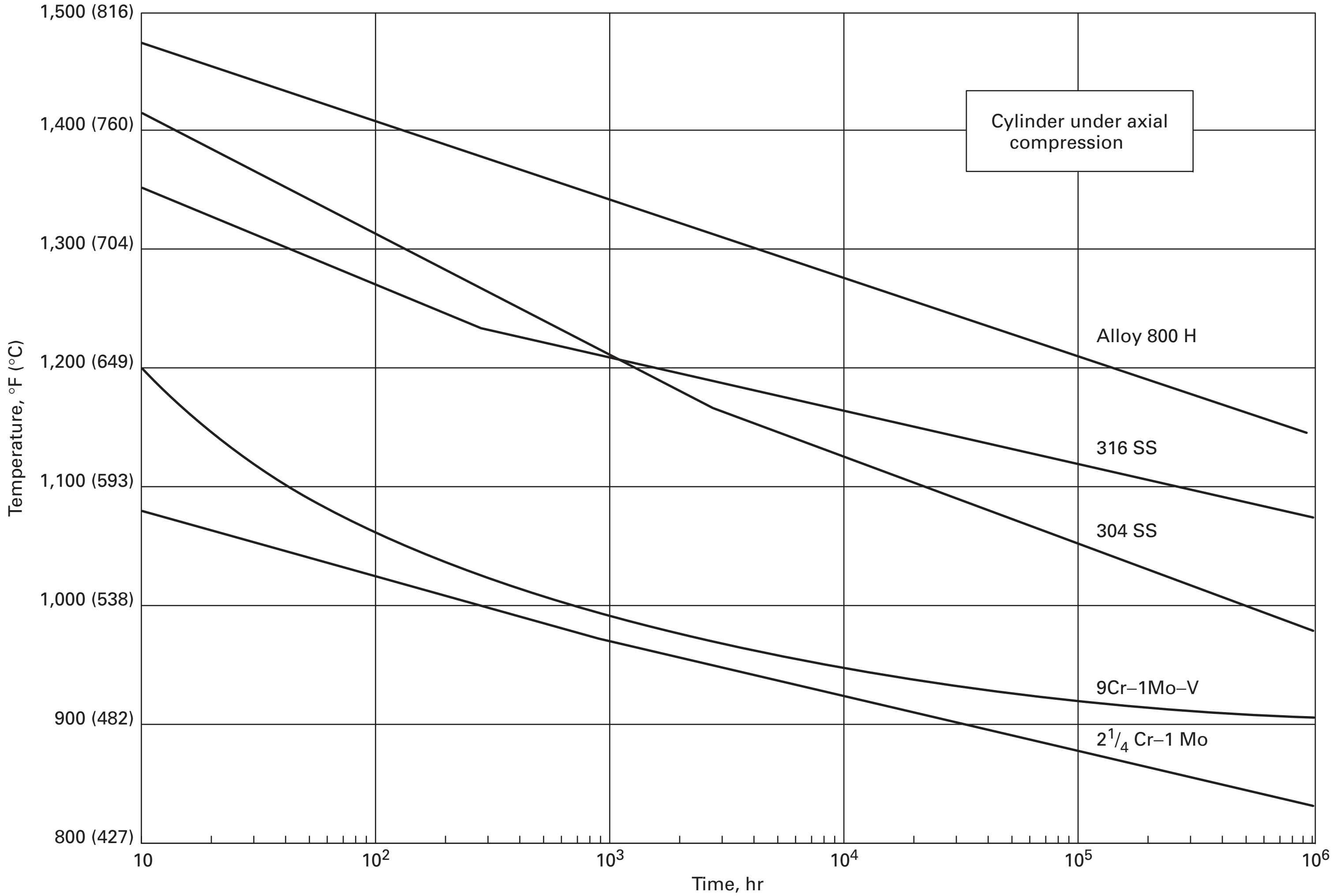


Figure NH-T-1522-2
Time-Temperature Limits for Application of Section II External Pressure Charts

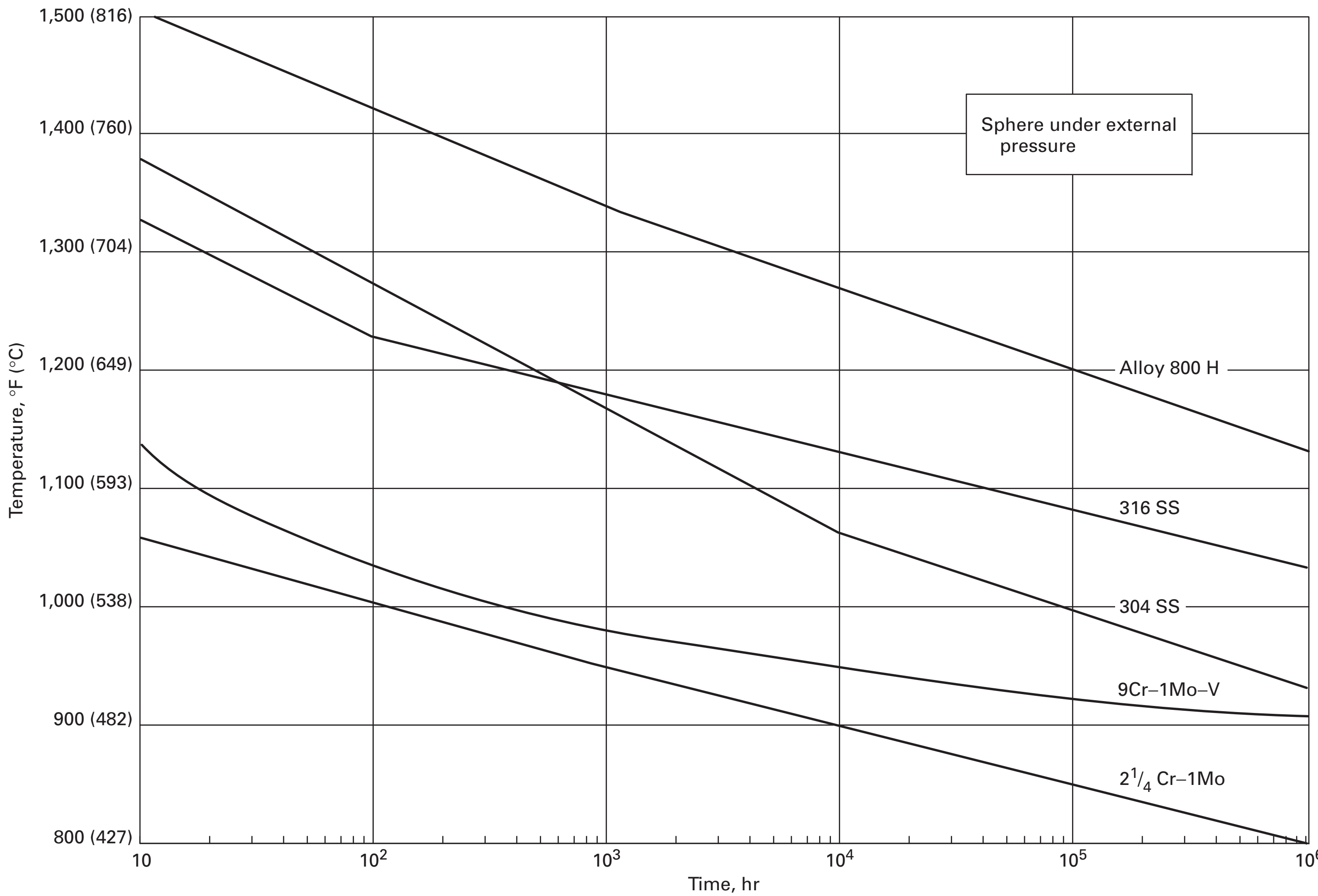
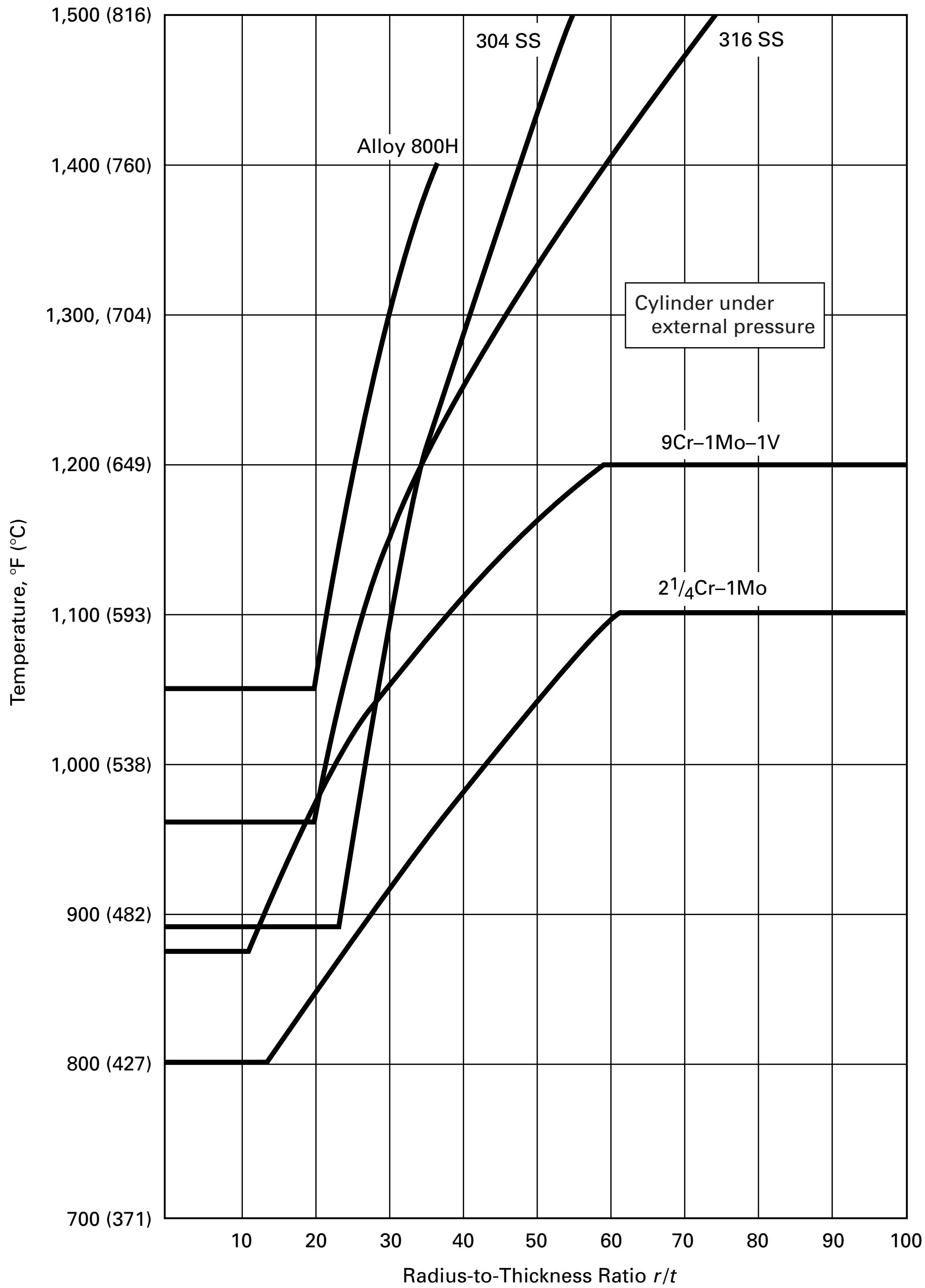


Figure NH-T-1522-3
Temperature Limits for Application of Section II External Pressure Charts



(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 NB-3232.3(b)(2) and NB-3232.3(b)(3) shall apply.

NH-T-1800 ISOCHRONOUS STRESS-STRAIN RELATIONS

NH-T-1810 OBJECTIVE

Figures NH-T-1800-A-1 through NH-T-1800-E-11 of this subarticle provide graphs giving isochronous stress-strain curves, each graph being for a specific material at a specific temperature. The graphs are intended to provide the designer with information regarding the total strain caused by stress under elevated temperature conditions, assuming average material properties.

NH-T-1820 MATERIALS AND TEMPERATURE LIMITS

Table NH-T-1820-1 gives the alloys and temperatures covered by the isochronous stress-strain curves of this Appendix.

Table NH-T-1820-1

	Material	Maximum Temp., °F (°C)	Temperature Increment, °F (°C)
A.	304 SS	1,500 (816)	50 (28)
B.	316 SS	1,500 (816)	50 (28)
C.	Ni-Fe-Cr, (Alloy 800H)	1,400 (760)	50 (28)
D.	$2^1/_4$Cr-1Mo	1,200 (649)	50 (28)
E.	9Cr-1Mo-V	1,200 (649)	50 (28)

Figure NH-T-1800-A-1
Average Isochronous Stress–Strain Curves

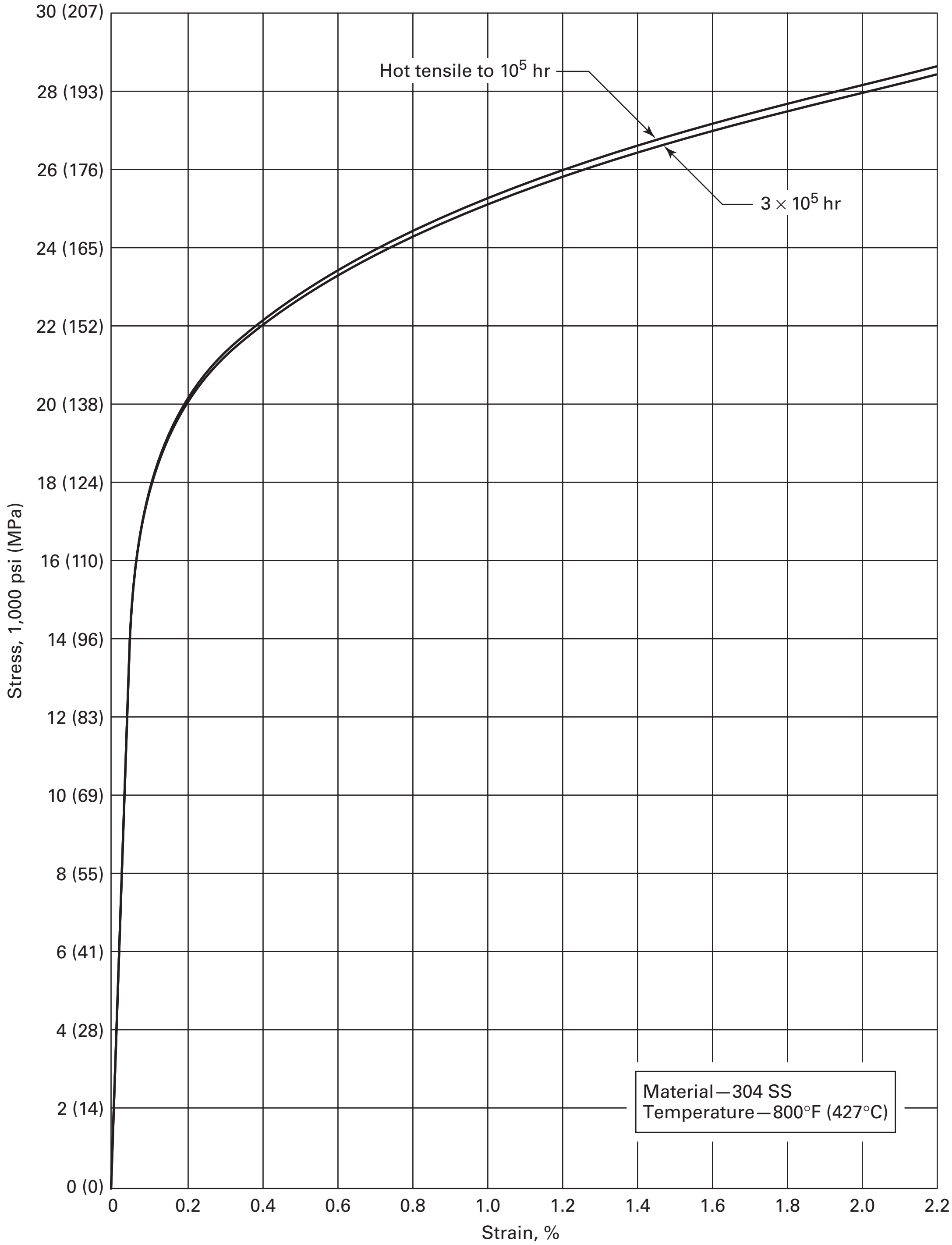


Figure NH-T-1800-A-2
Average Isochronous Stress–Strain Curves

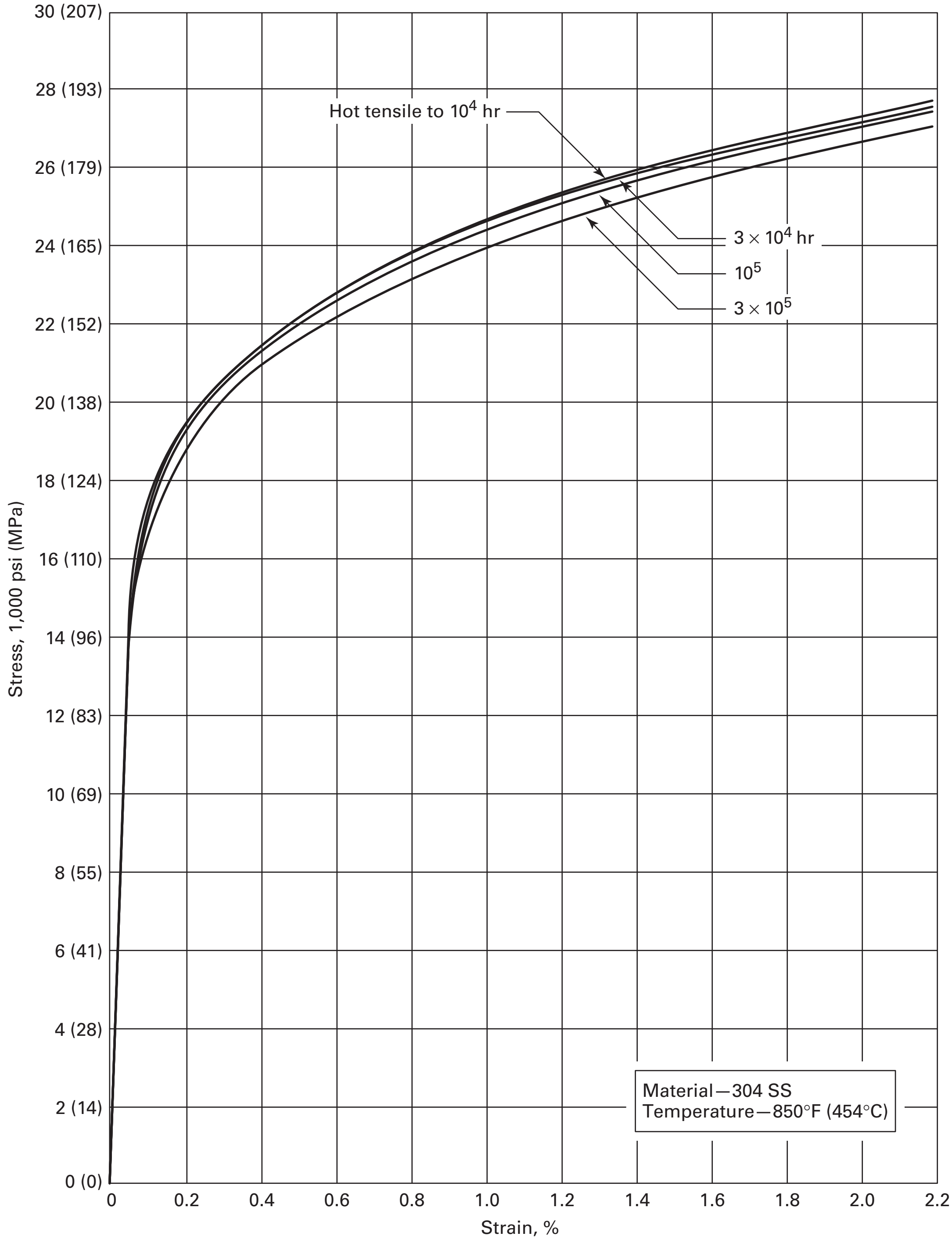


Figure NH-T-1800-A-3
Average Isochronous Stress–Strain Curves

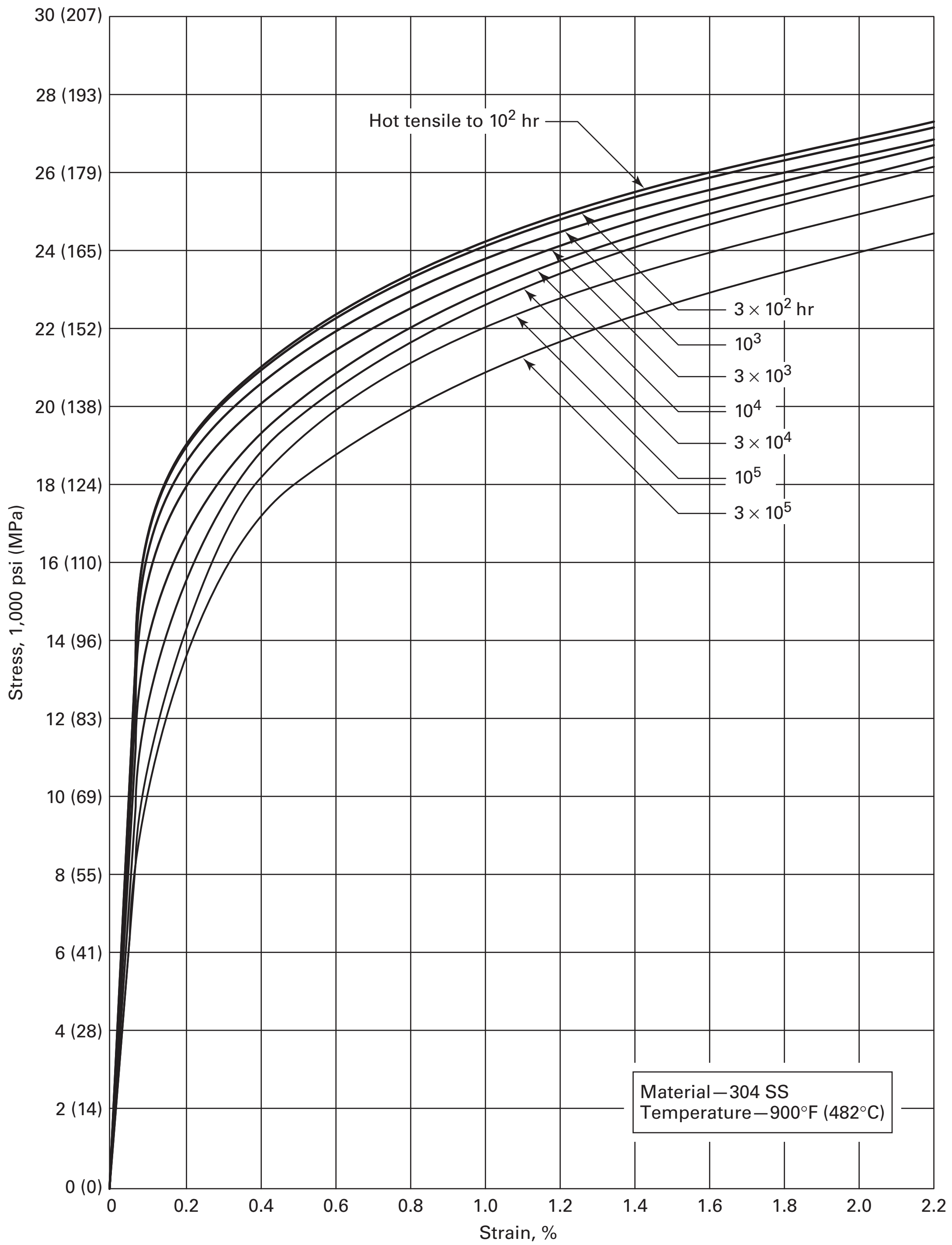


Figure NH-T-1800-A-4
Average Isochronous Stress–Strain Curves

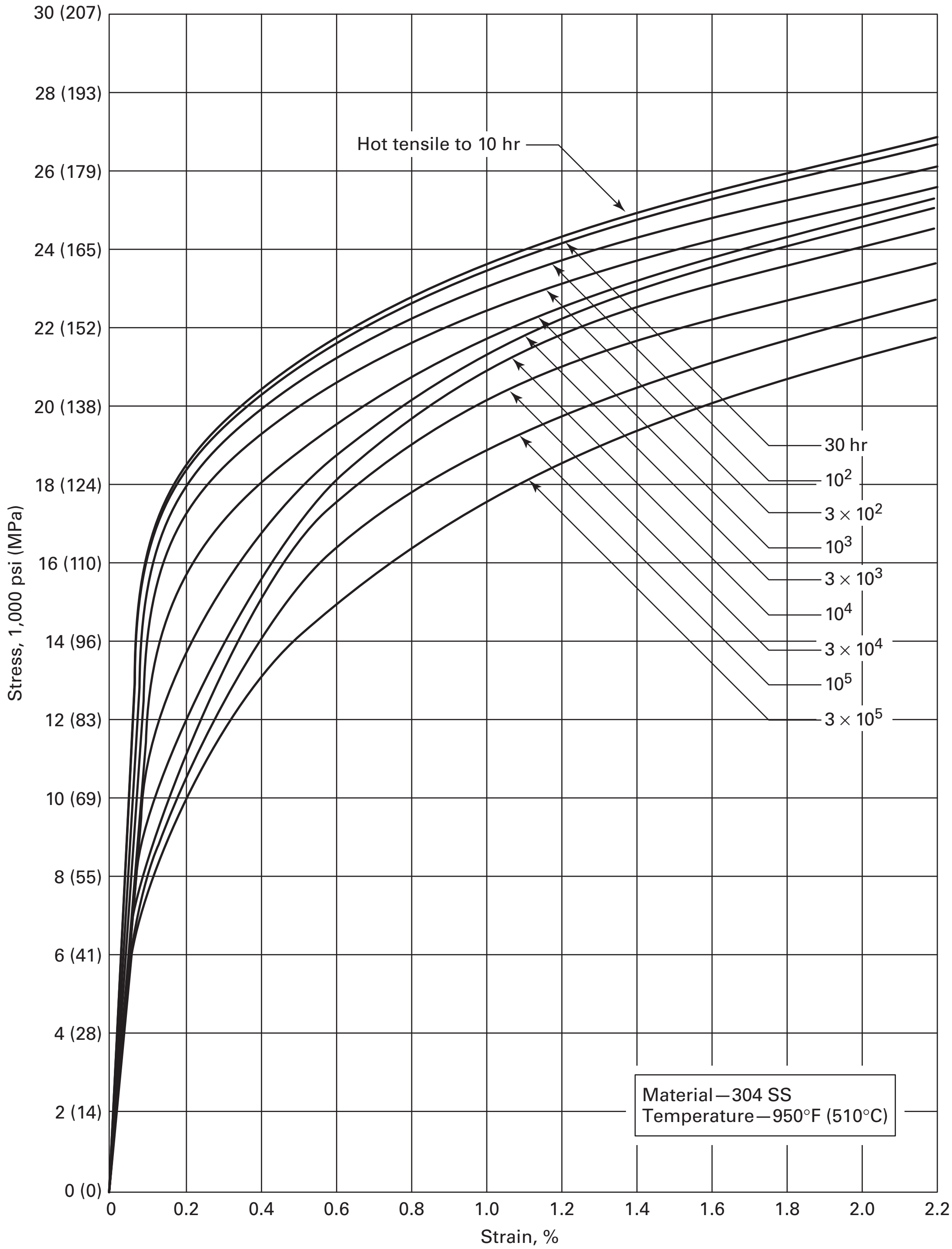


Figure NH-T-1800-A-5
Average Isochronous Stress–Strain Curves

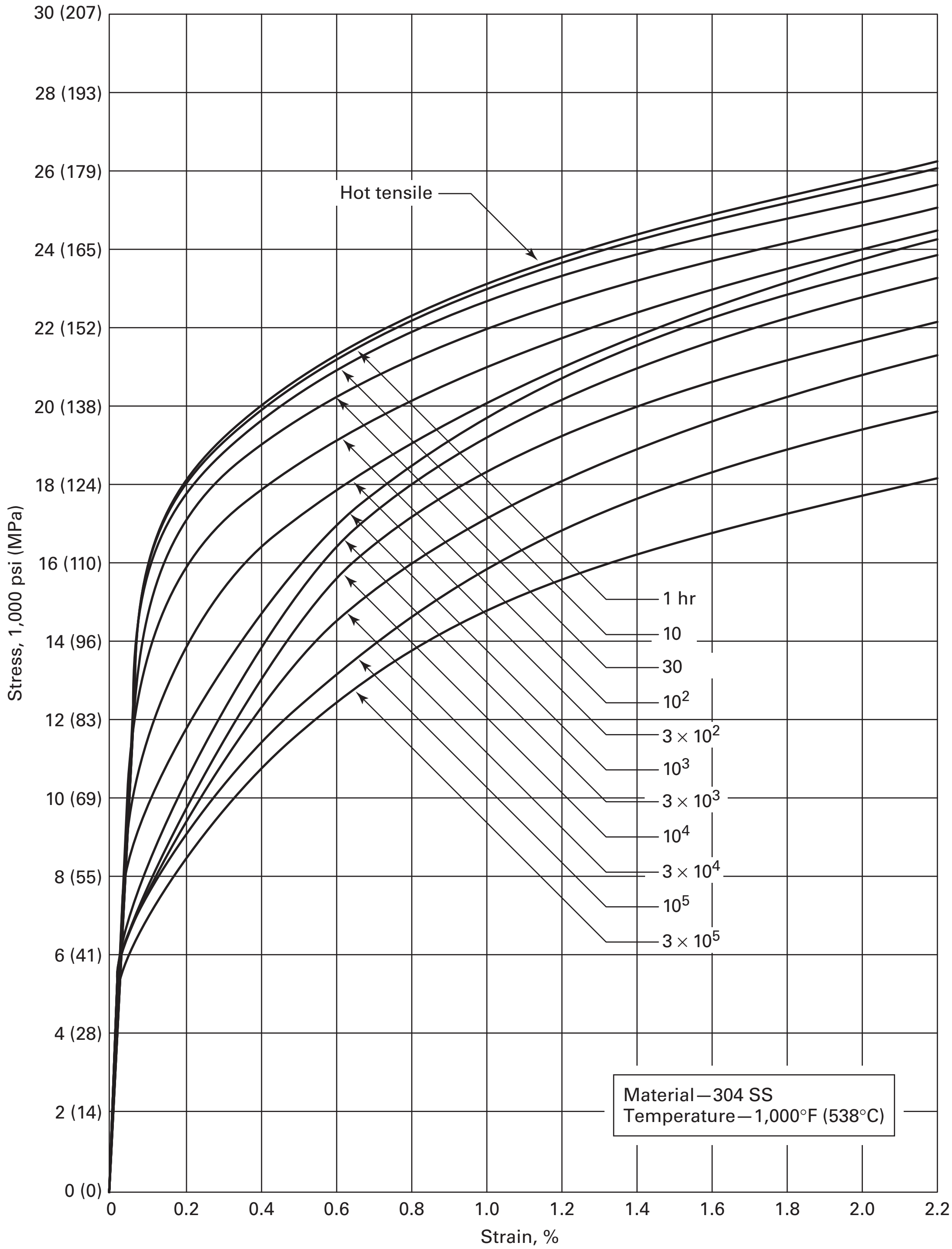


Figure NH-T-1800-A-6
Average Isochronous Stress–Strain Curves

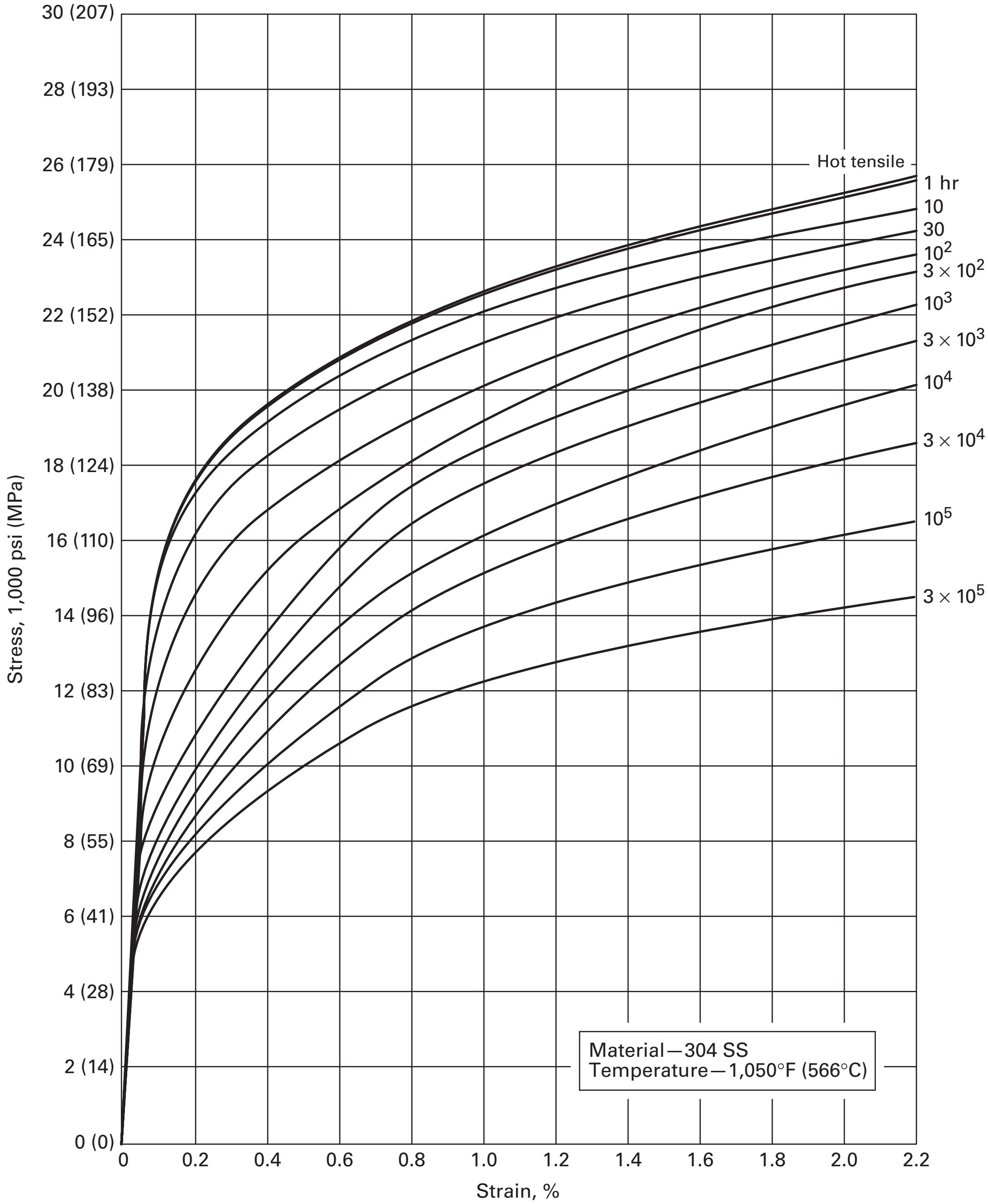


Figure NH-T-1800-A-7
Average Isochronous Stress–Strain Curves

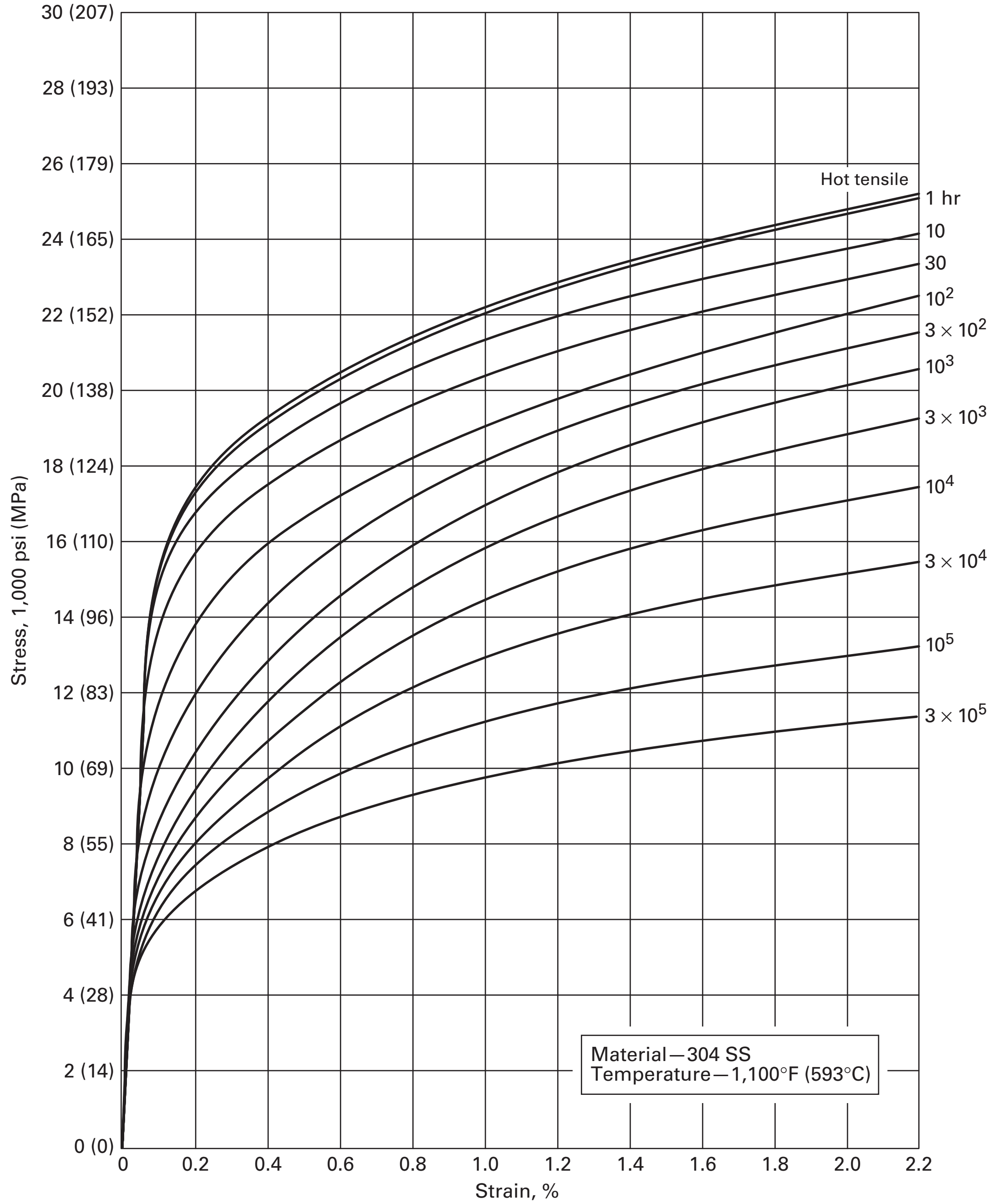


Figure NH-T-1800-A-8
Average Isochronous Stress–Strain Curves

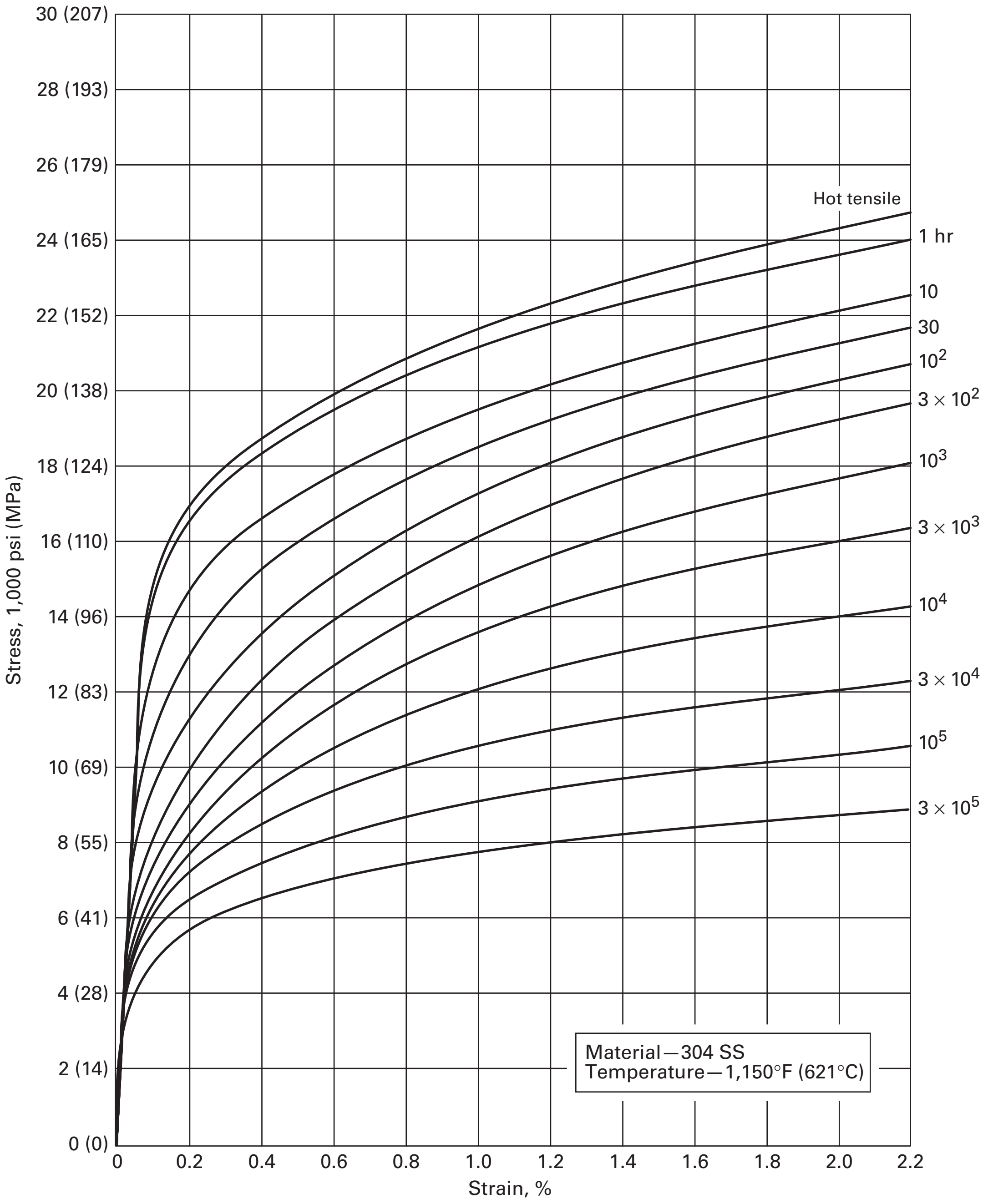


Figure NH-T-1800-A-9
Average Isochronous Stress–Strain Curves

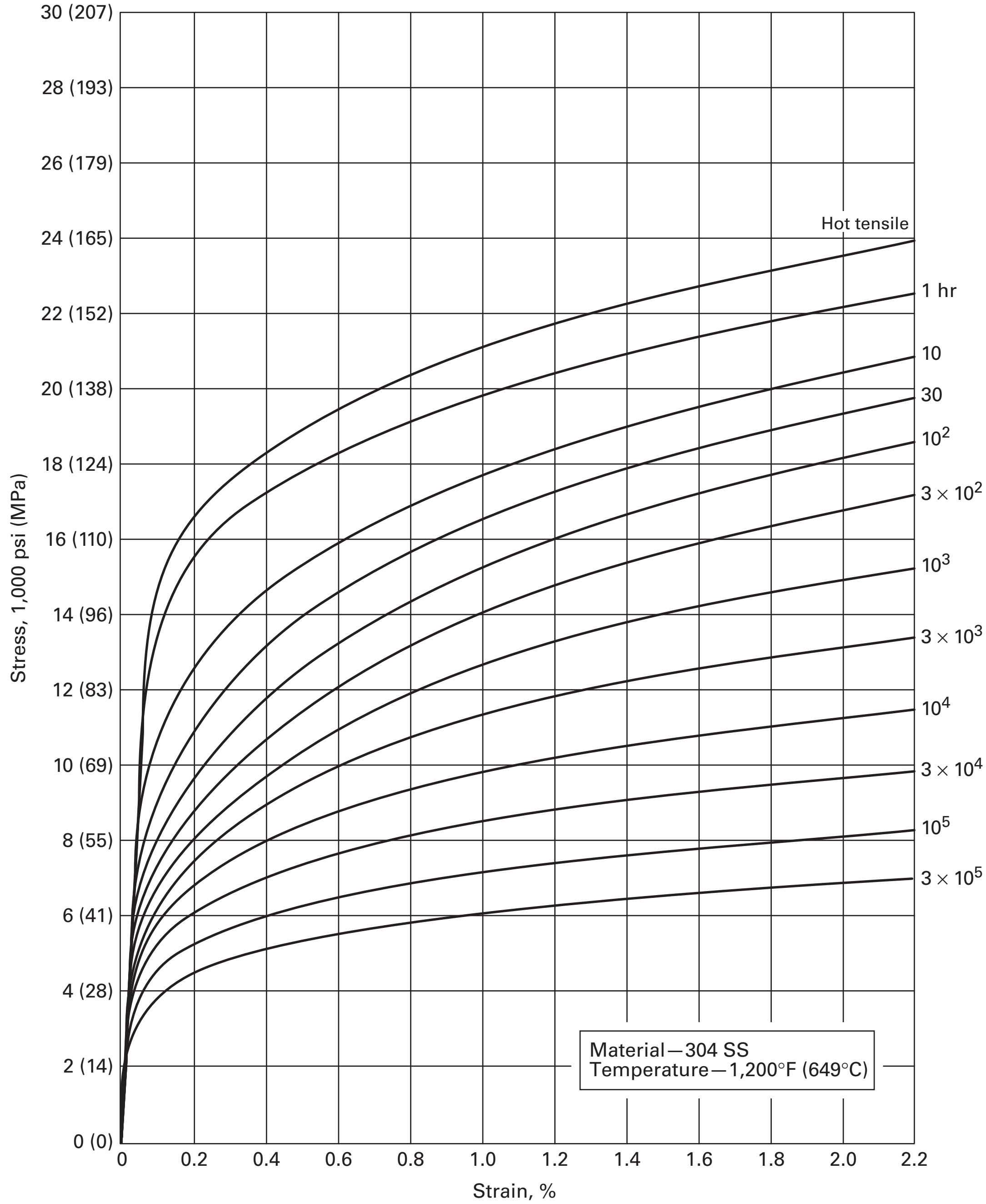


Figure NH-T-1800-A-10
Average Isochronous Stress–Strain Curves

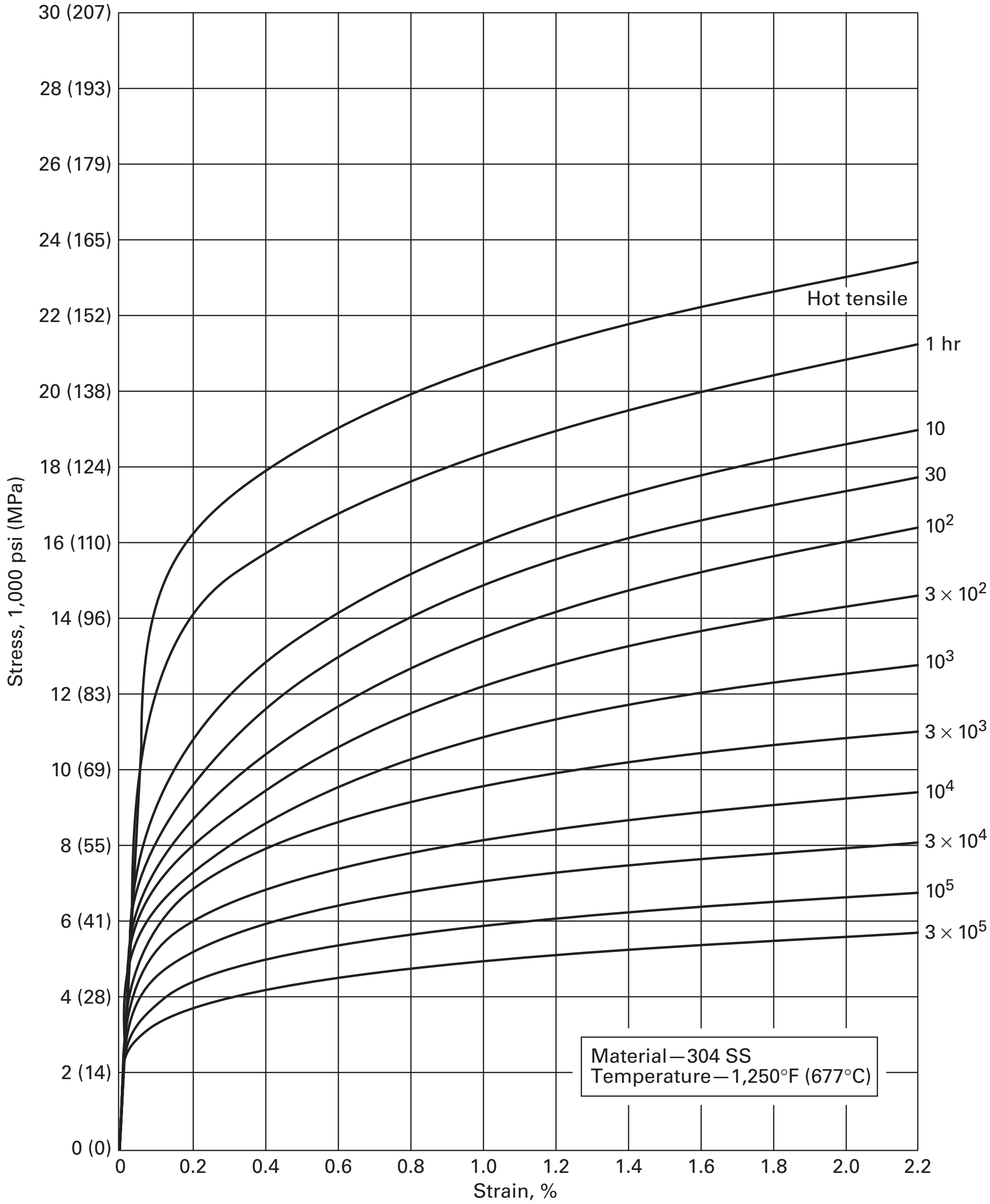


Figure NH-T-1800-A-11
Average Isochronous Stress–Strain Curves

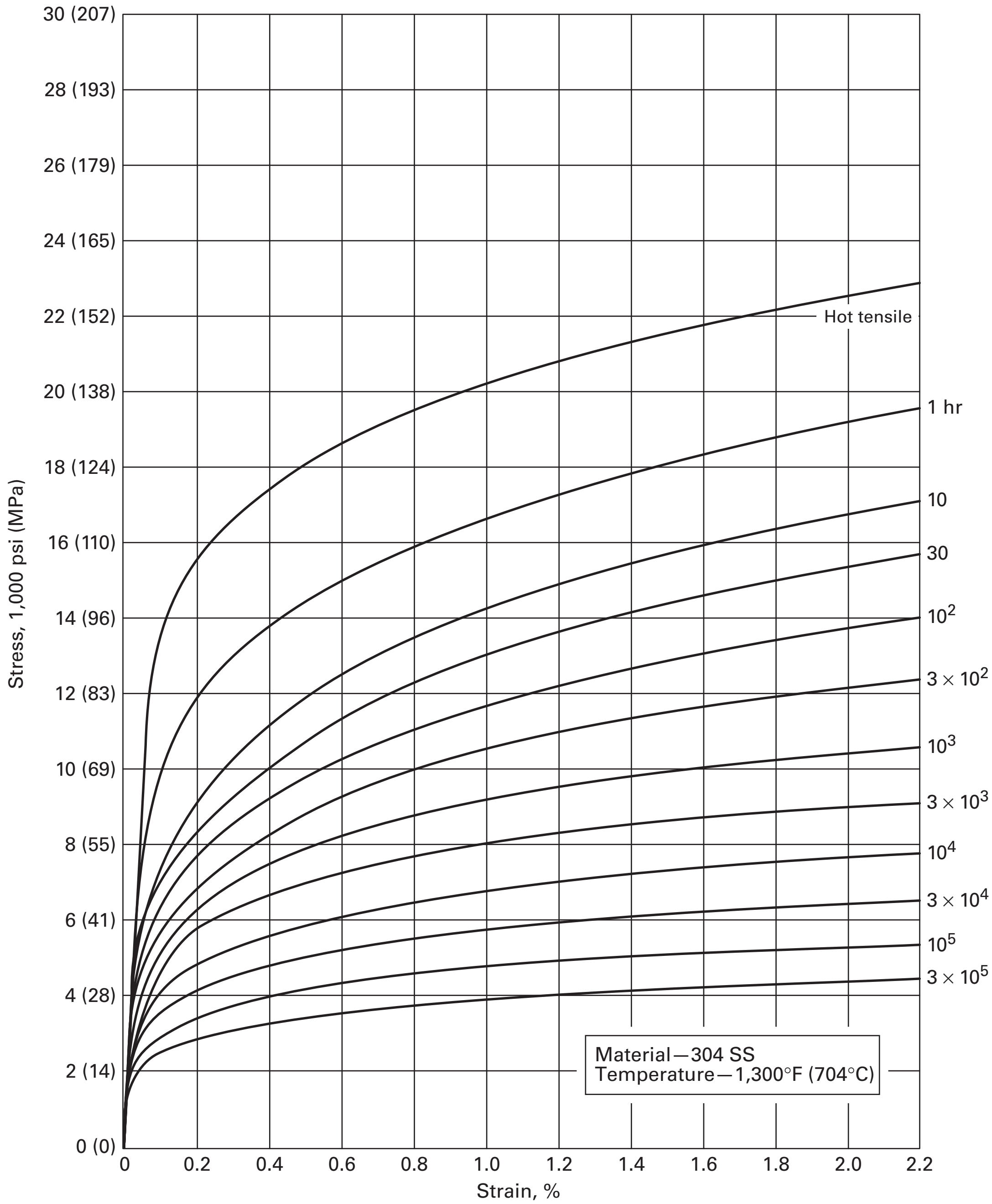


Figure NH-T-1800-A-12
Average Isochronous Stress–Strain Curves

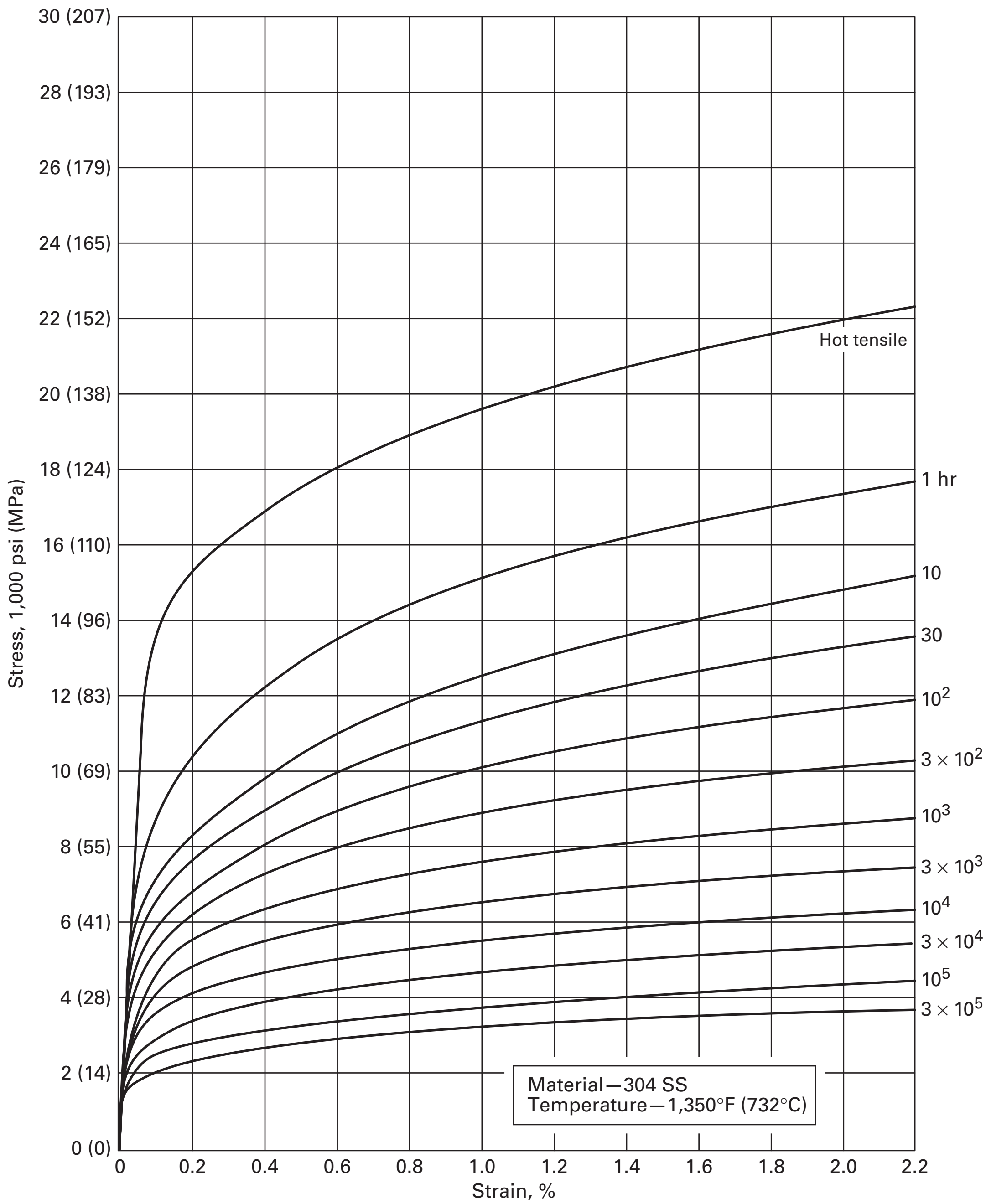


Figure NH-T-1800-A-13
Average Isochronous Stress–Strain Curves

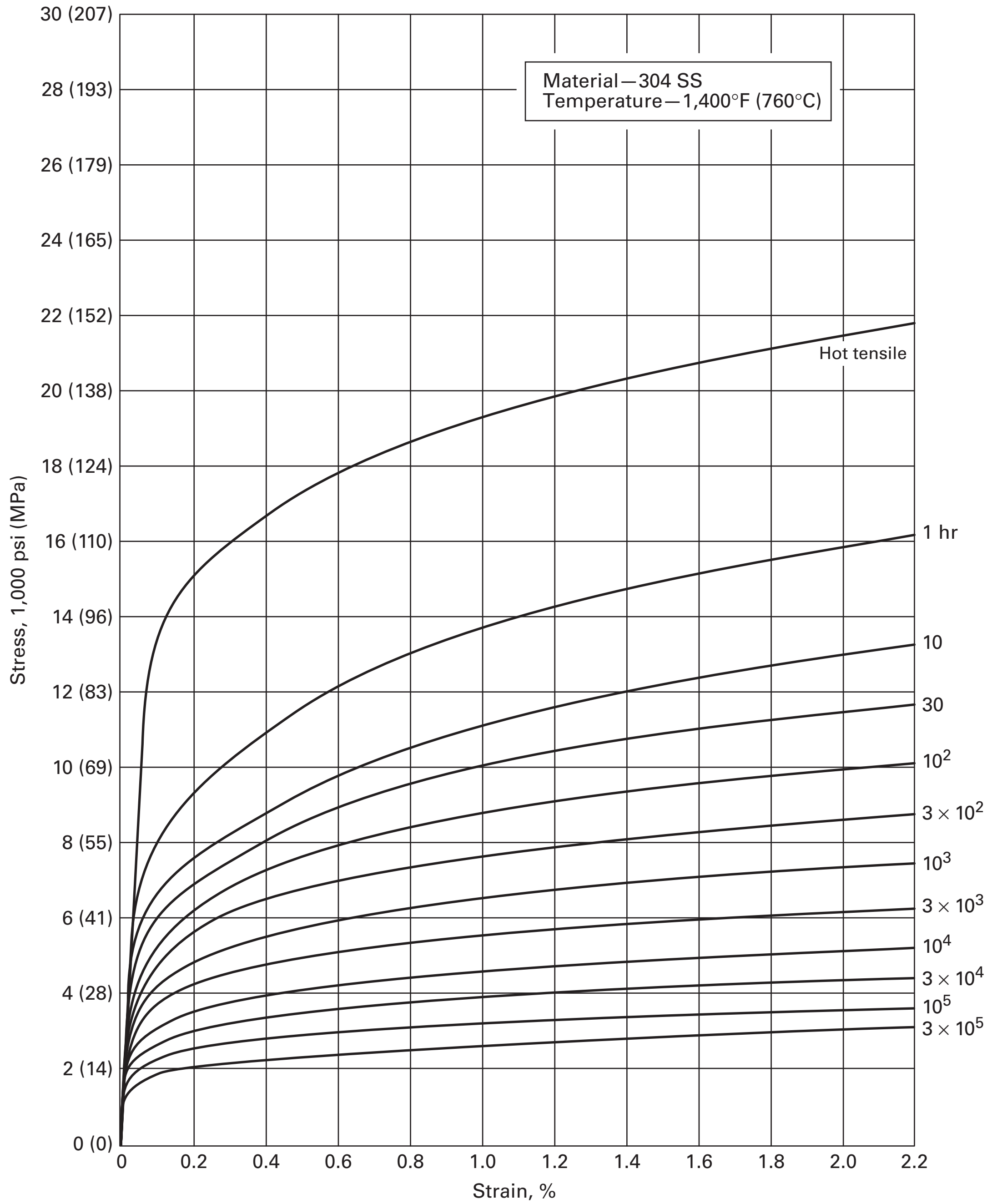


Figure NH-T-1800-A-14
Average Isochronous Stress–Strain Curves

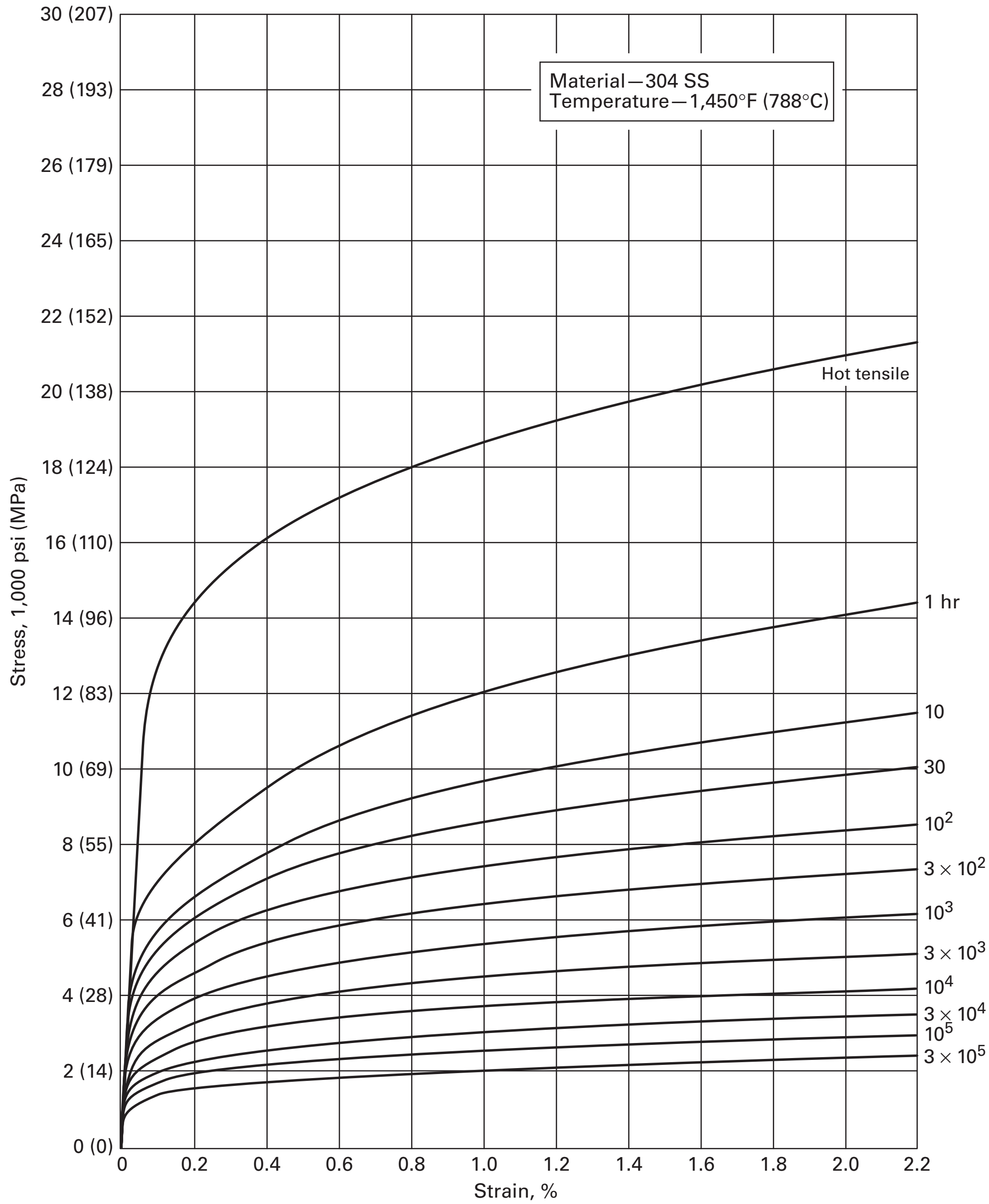


Figure NH-T-1800-A-15
Average Isochronous Stress–Strain Curves

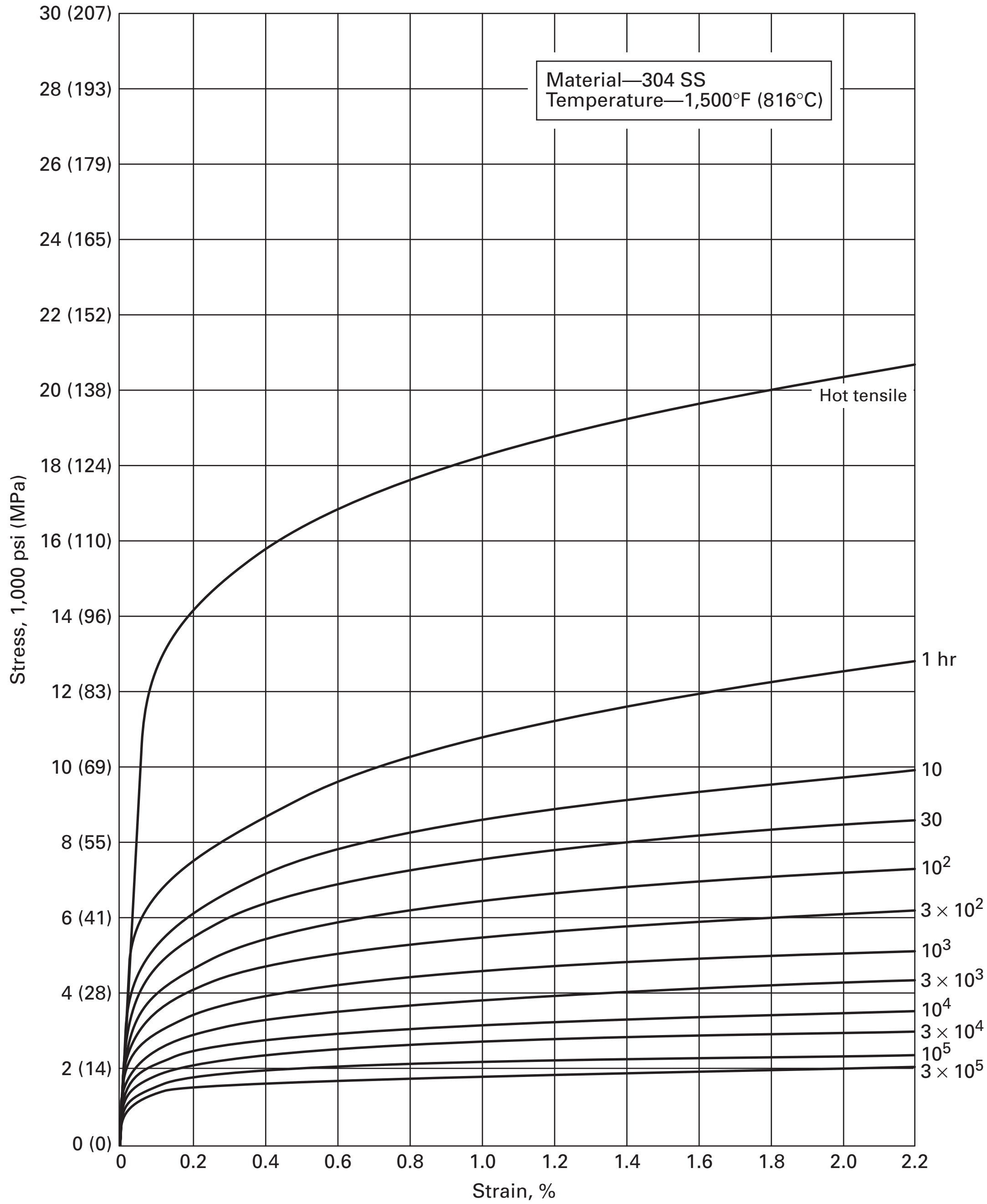
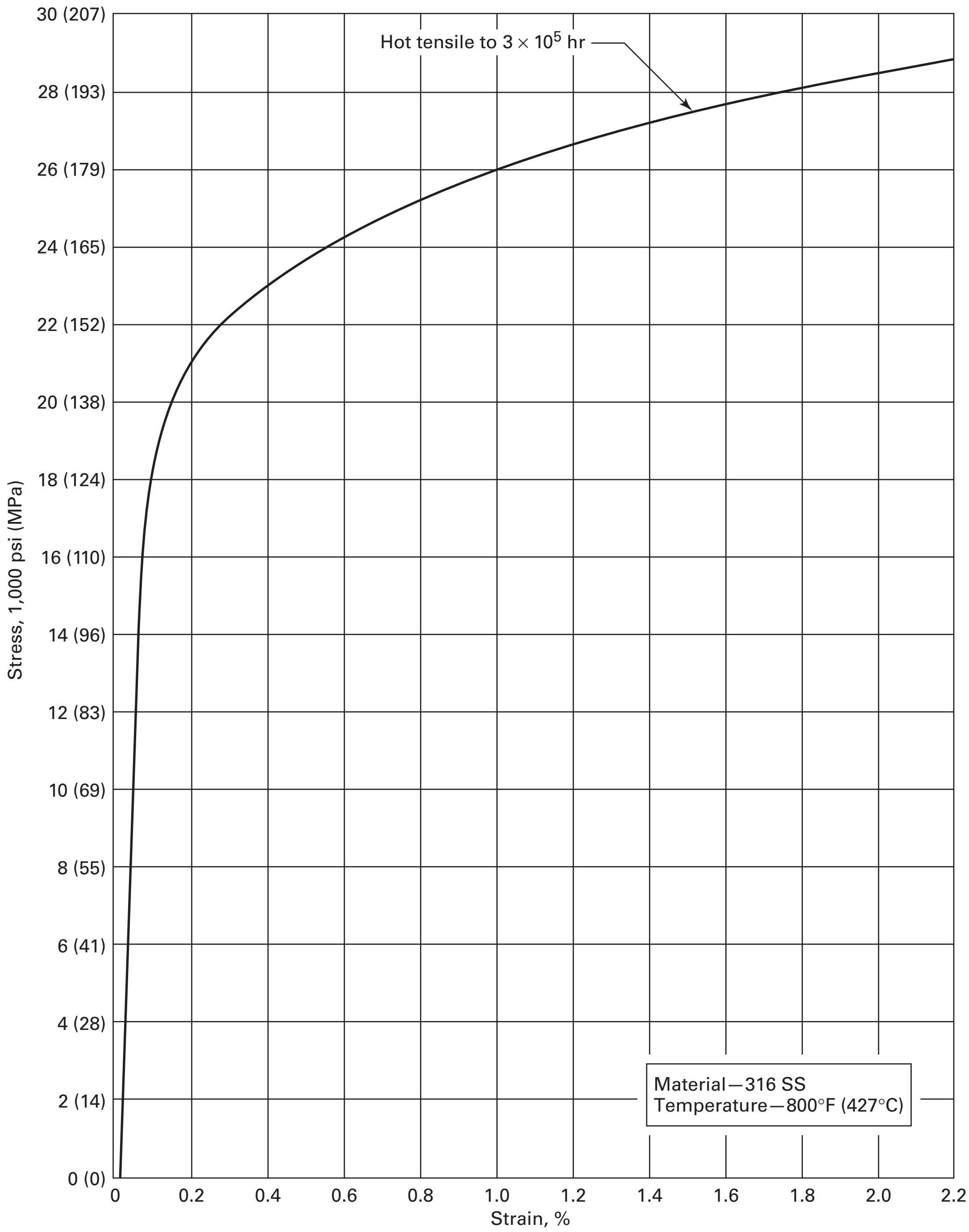


Figure NH-T-1800-B-1
Average Isochronous Stress–Strain Curves



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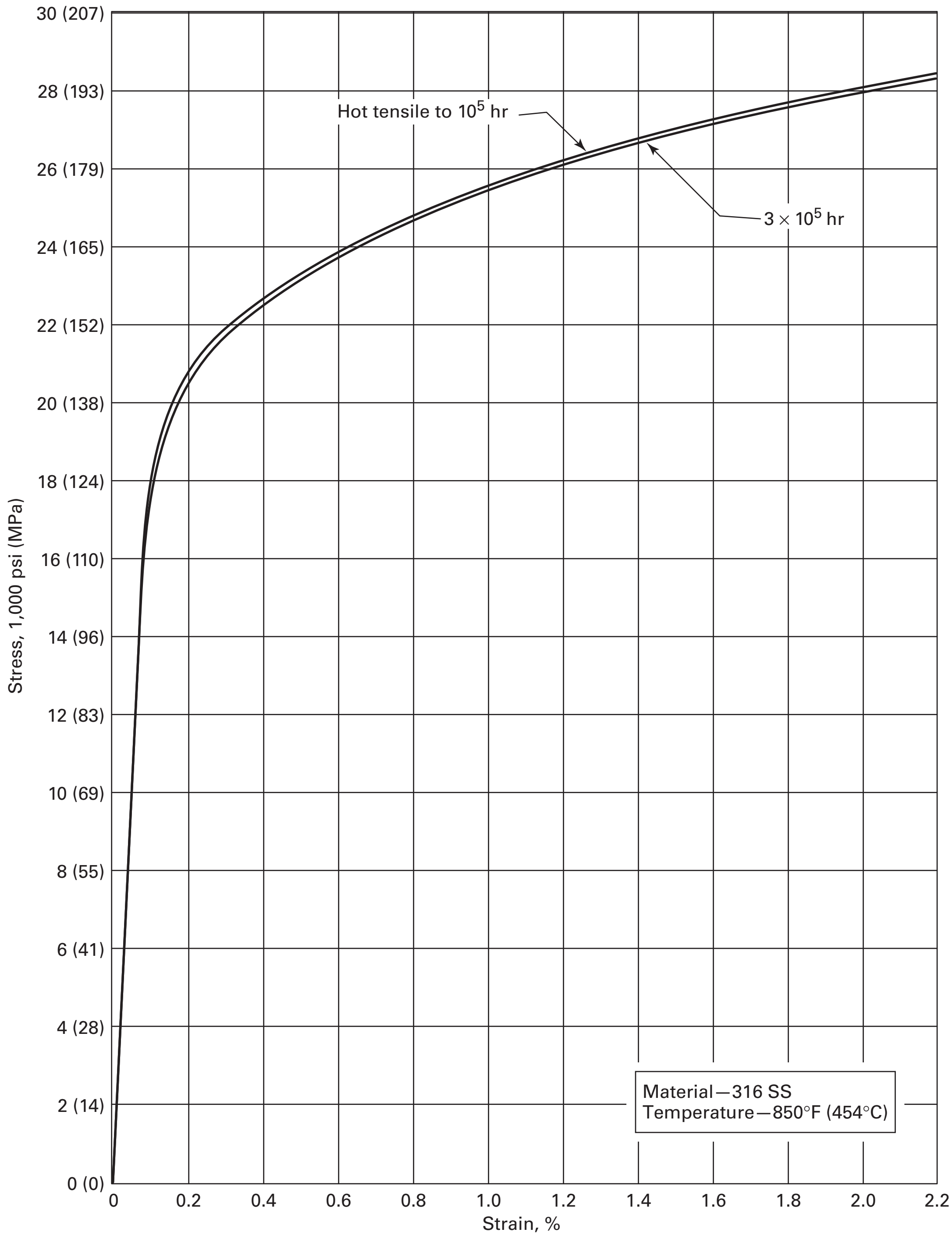
Average Isochronous Stress–Strain Curves



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Average Isochronous Stress–Strain Curves

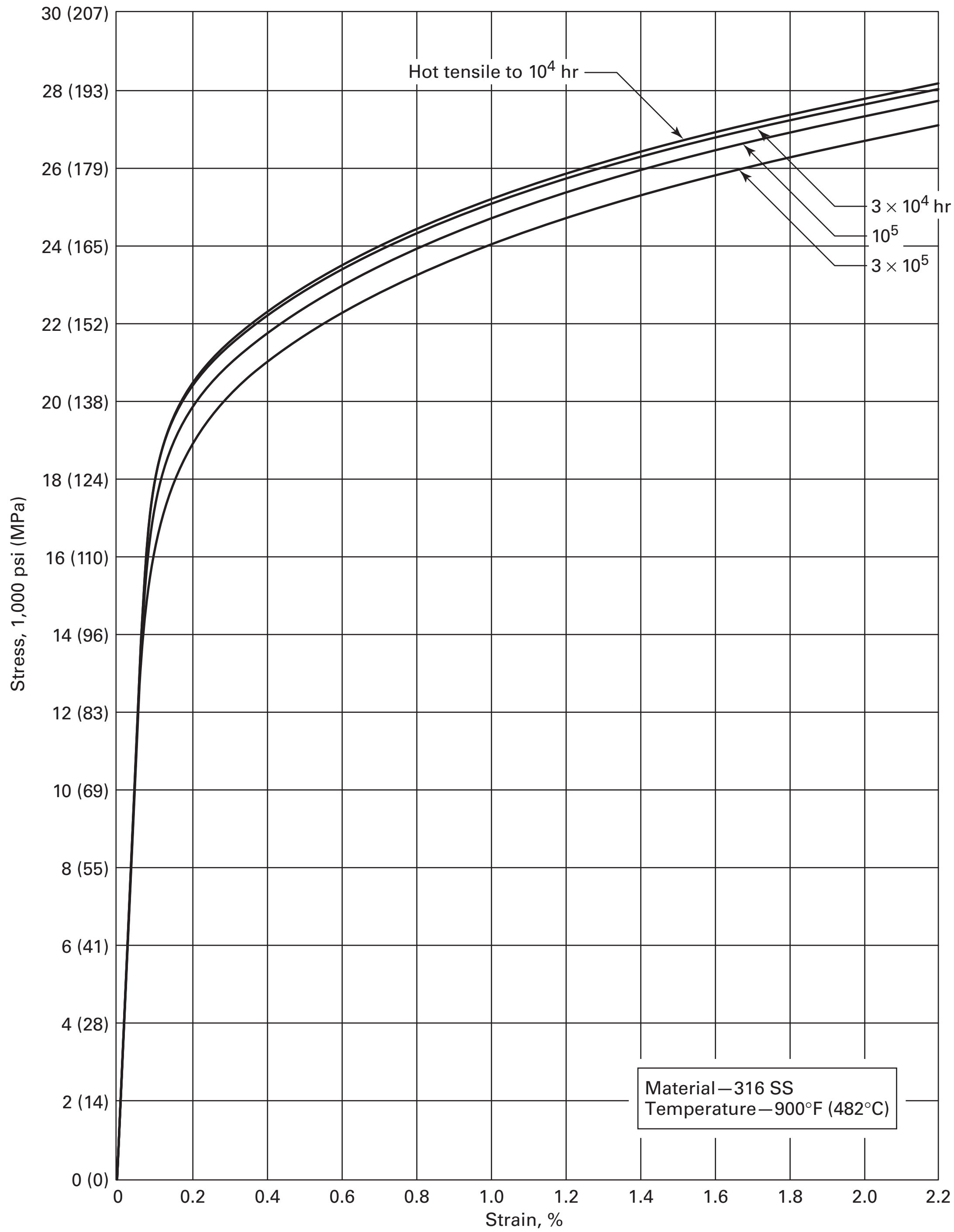

Figure NH-T-1800-B-4
Average Isochronous Stress–Strain Curves

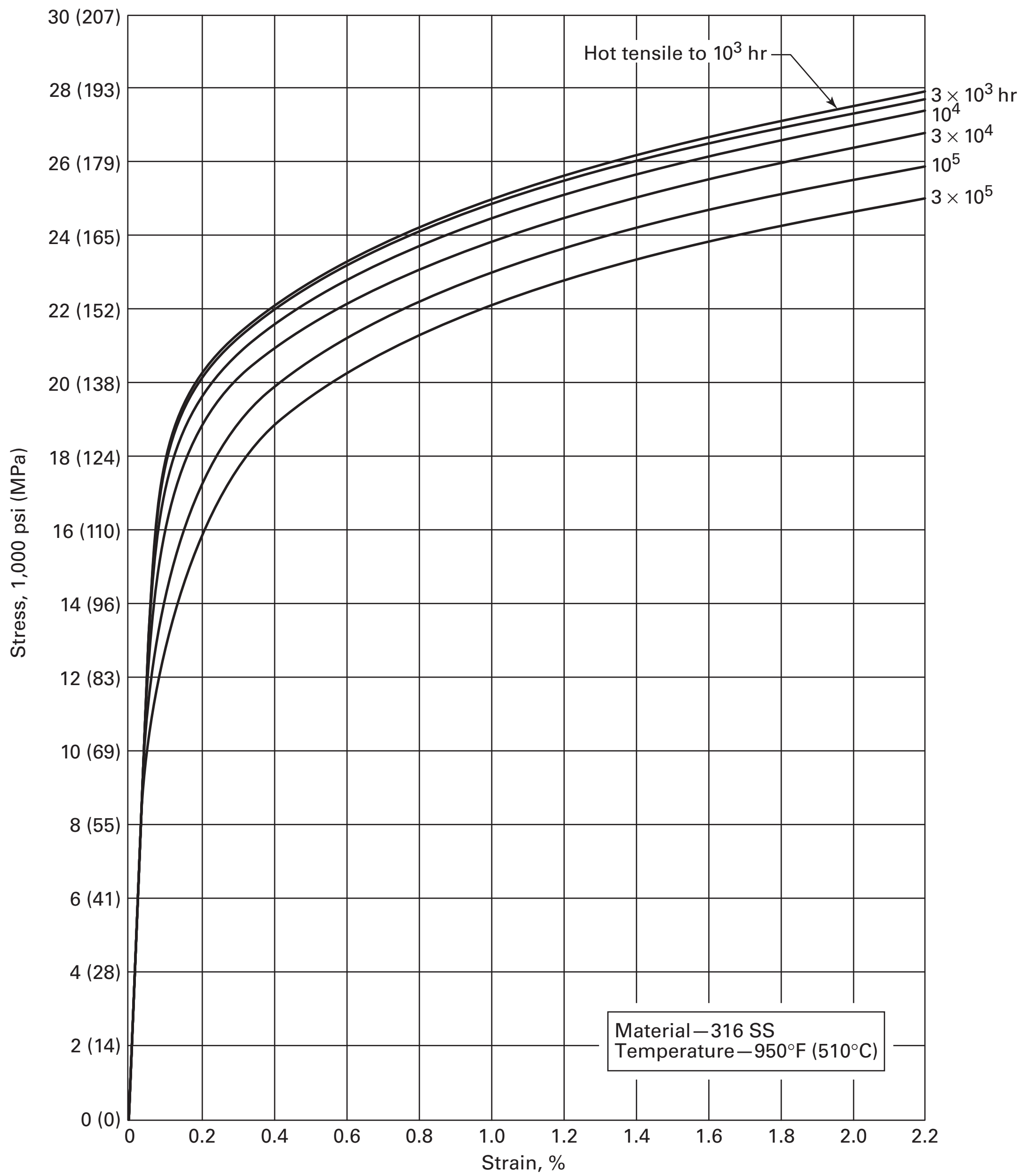

Figure NH-T-1800-B-5
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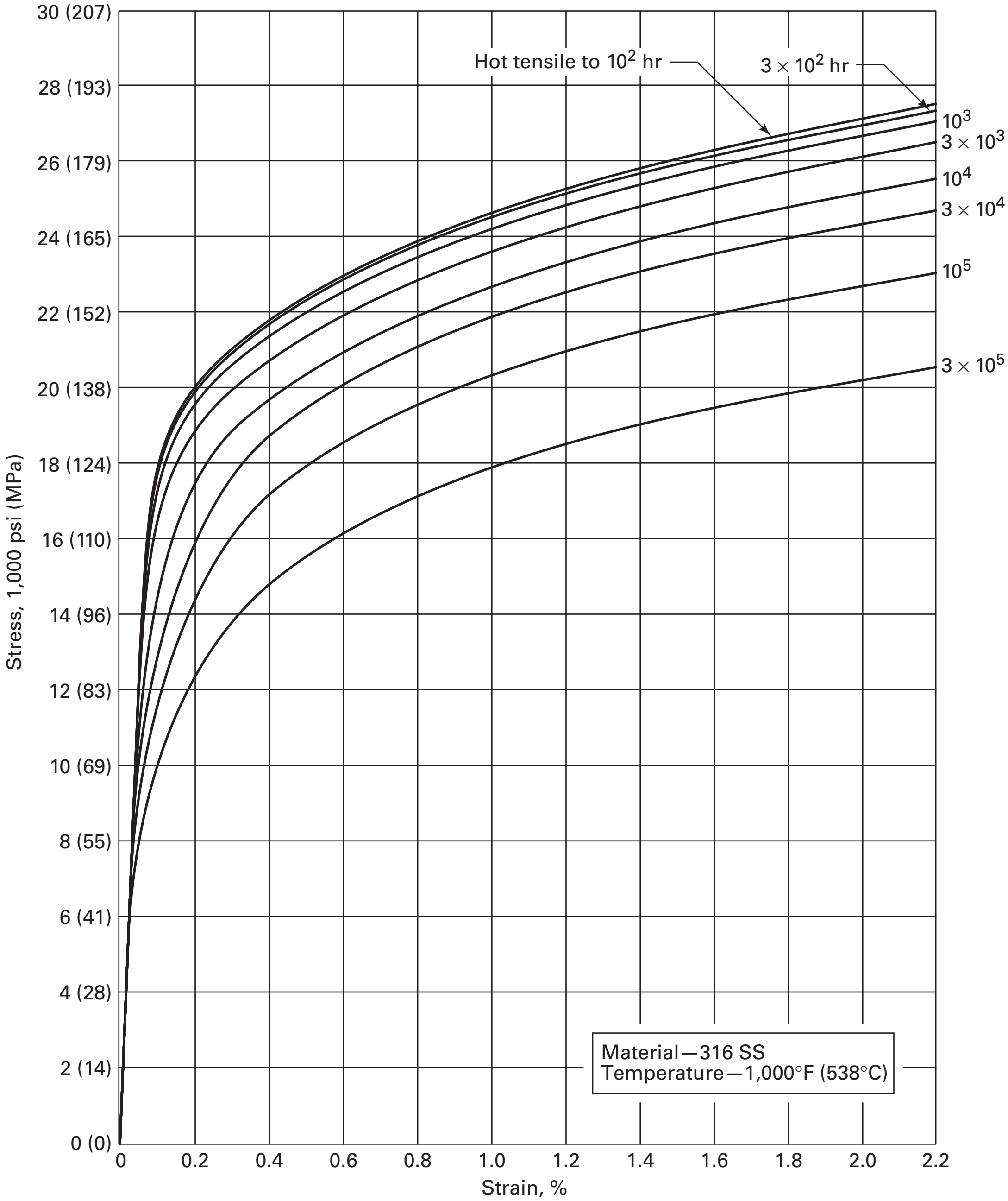

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Average Isochronous Stress–Strain Curves

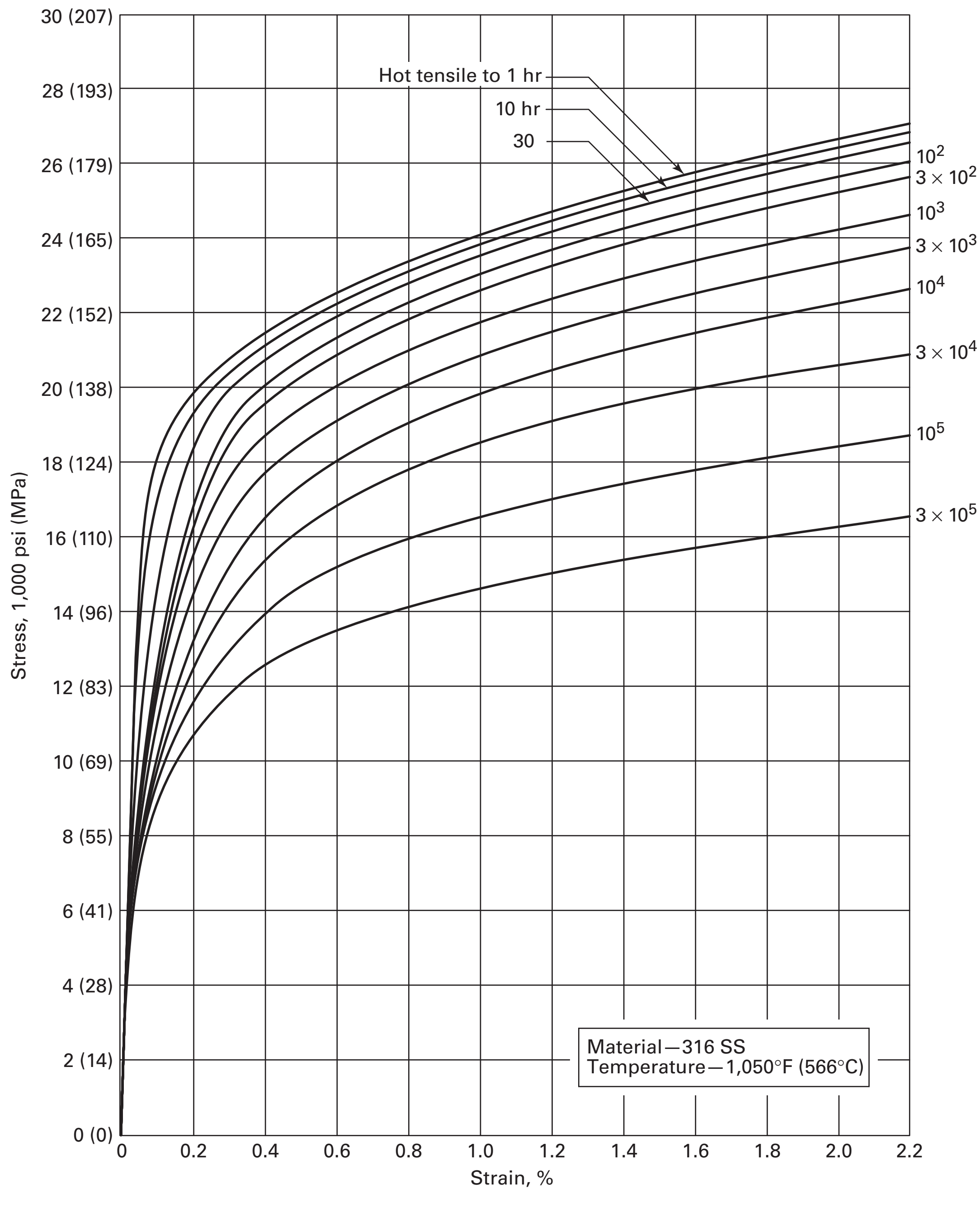

Figure NH-T-1800-B-7
Average Isochronous Stress–Strain Curves

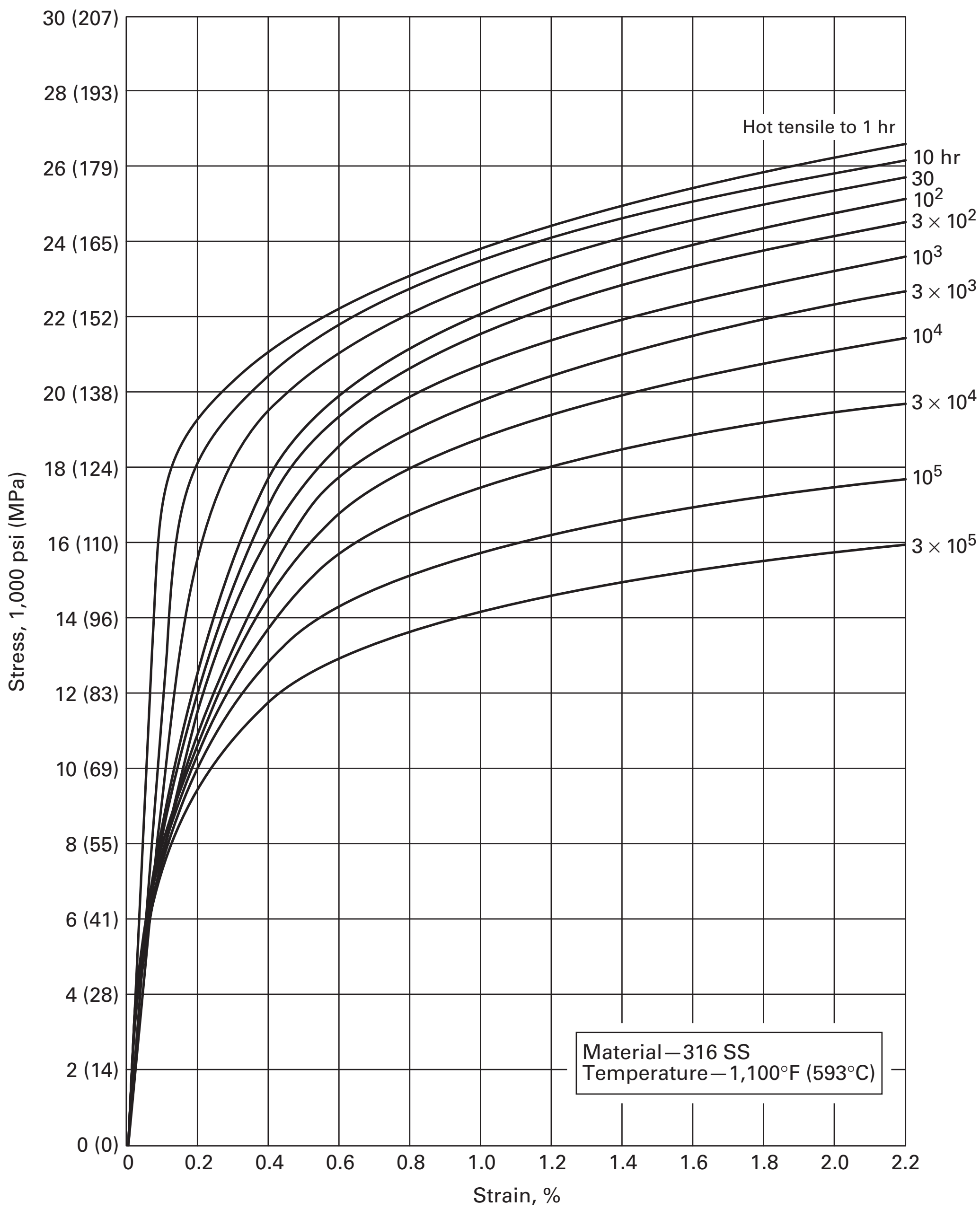

Figure NH-T-1800-B-8
Average Isochronous Stress–Strain Curves

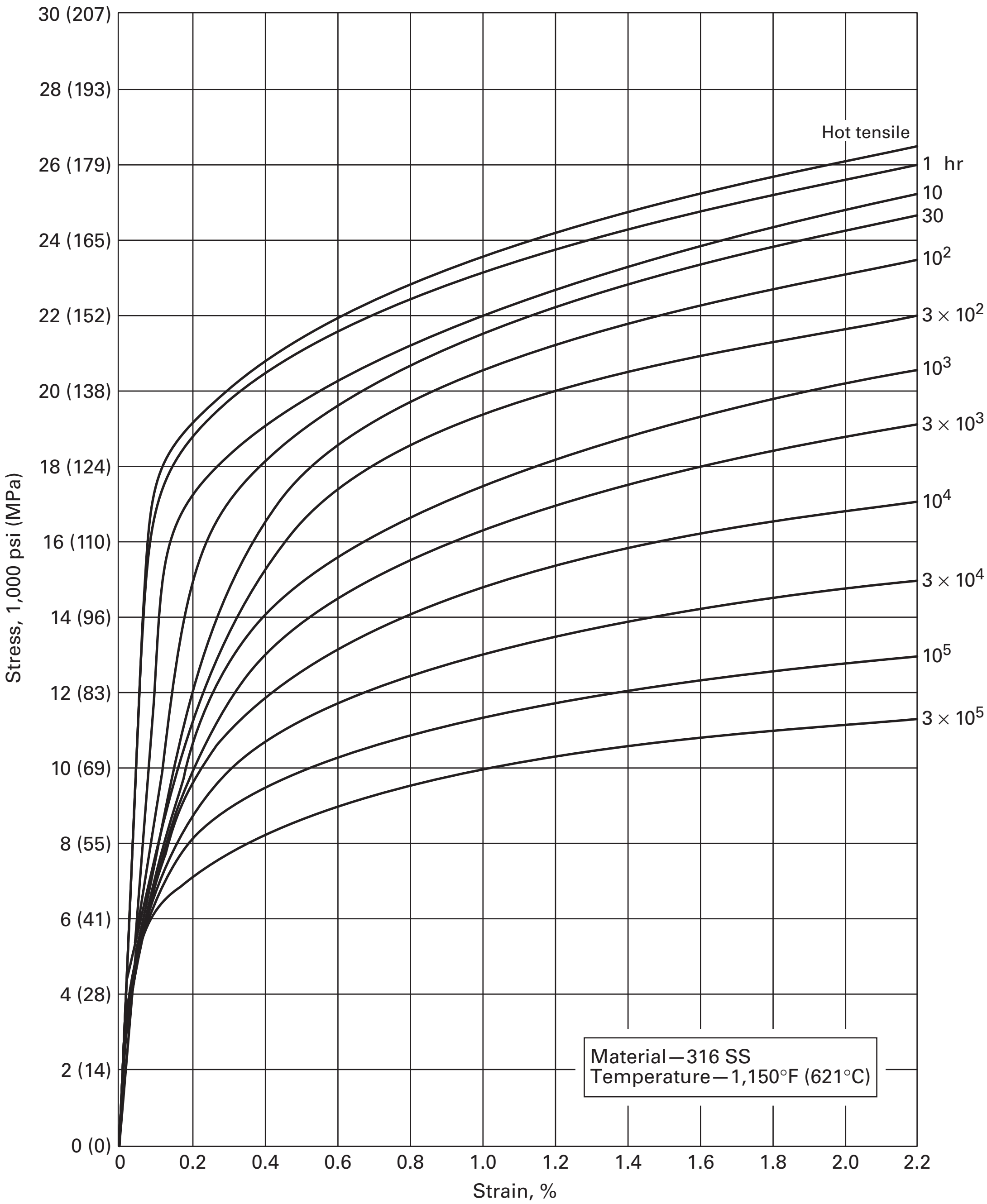

Figure NH-T-1800-B-9
Average Isochronous Stress–Strain Curves

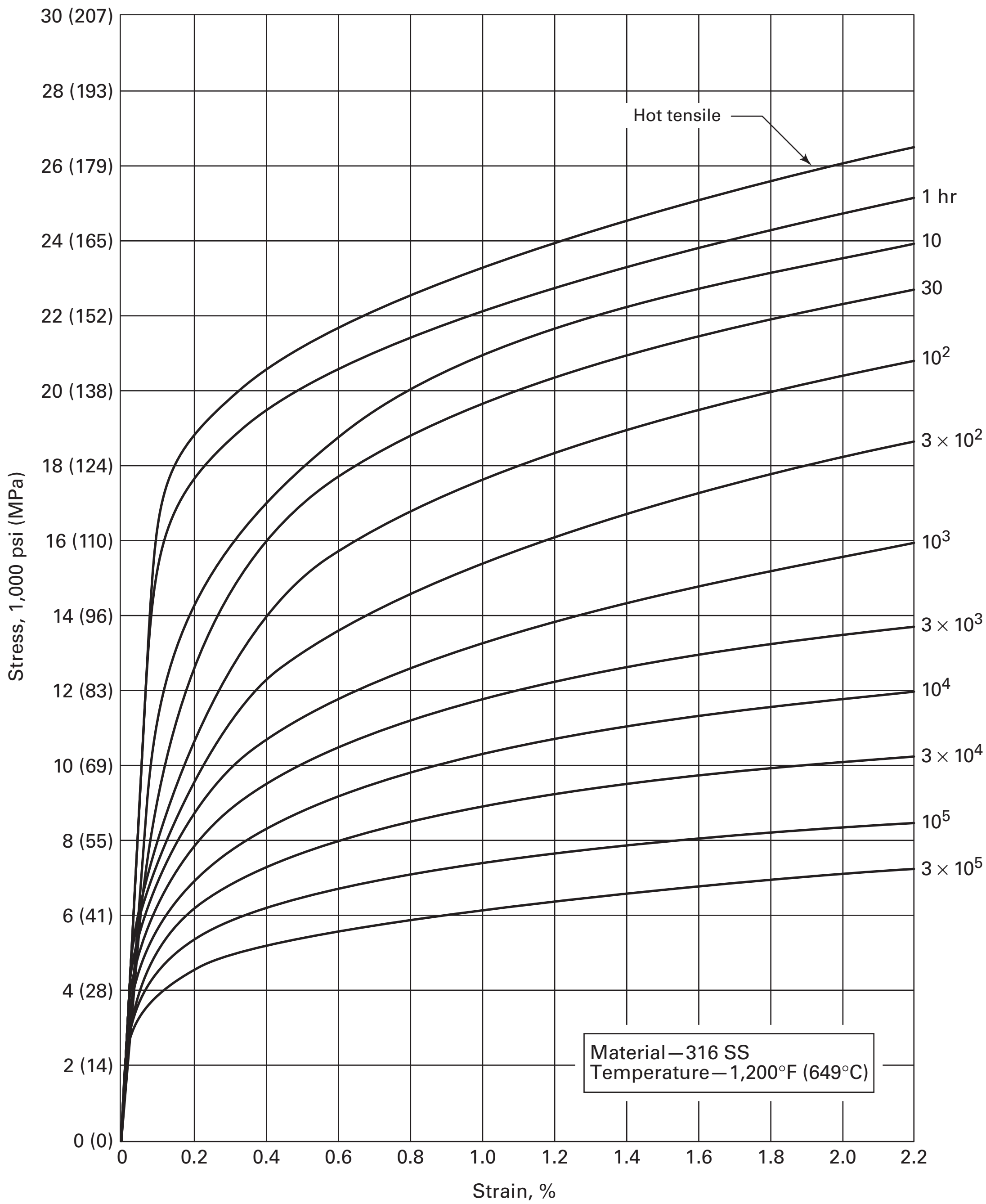

Figure NH-T-1800-B-10
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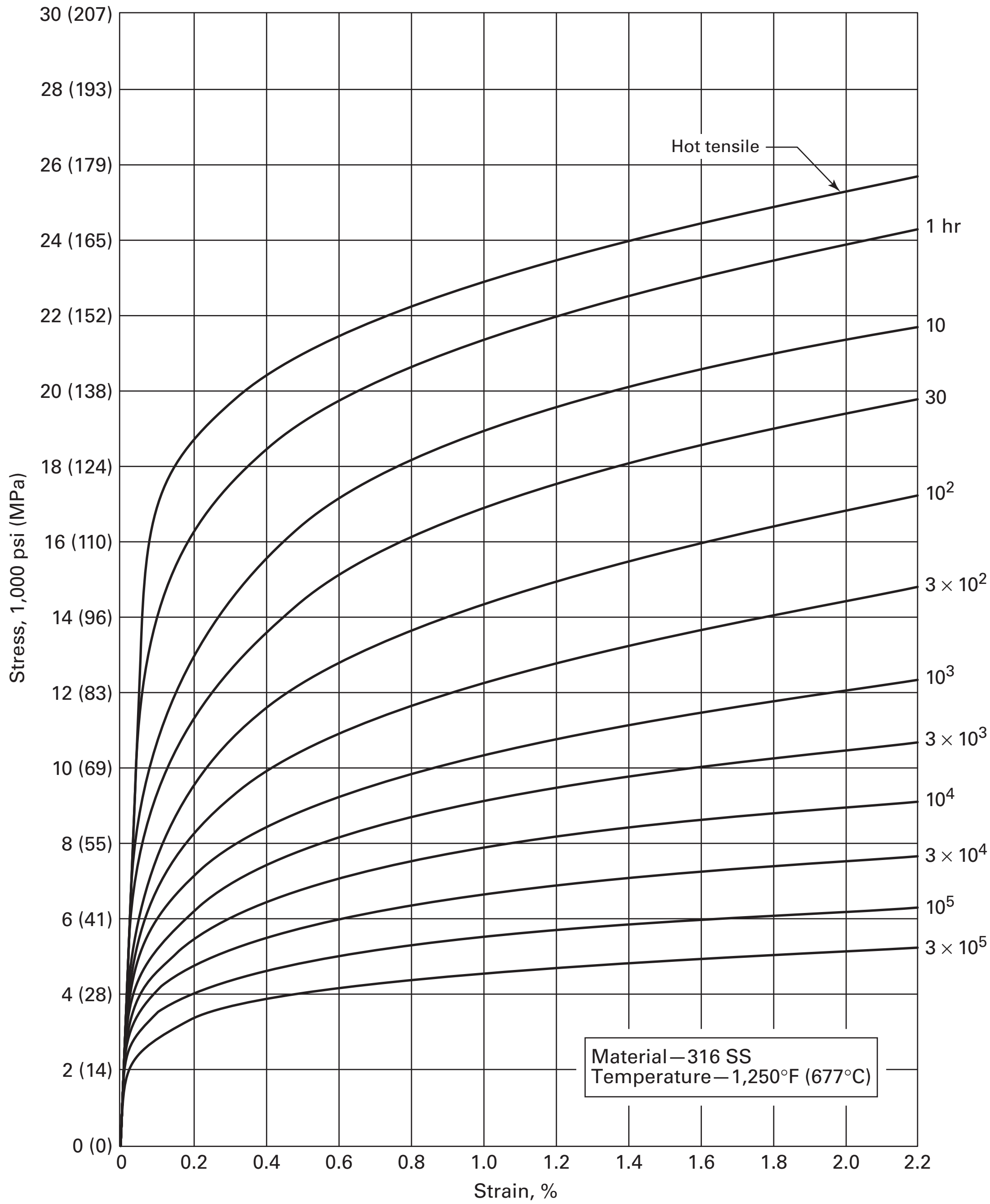


Figure NH-T-1800-B-11
Average Isochronous Stress–Strain Curves

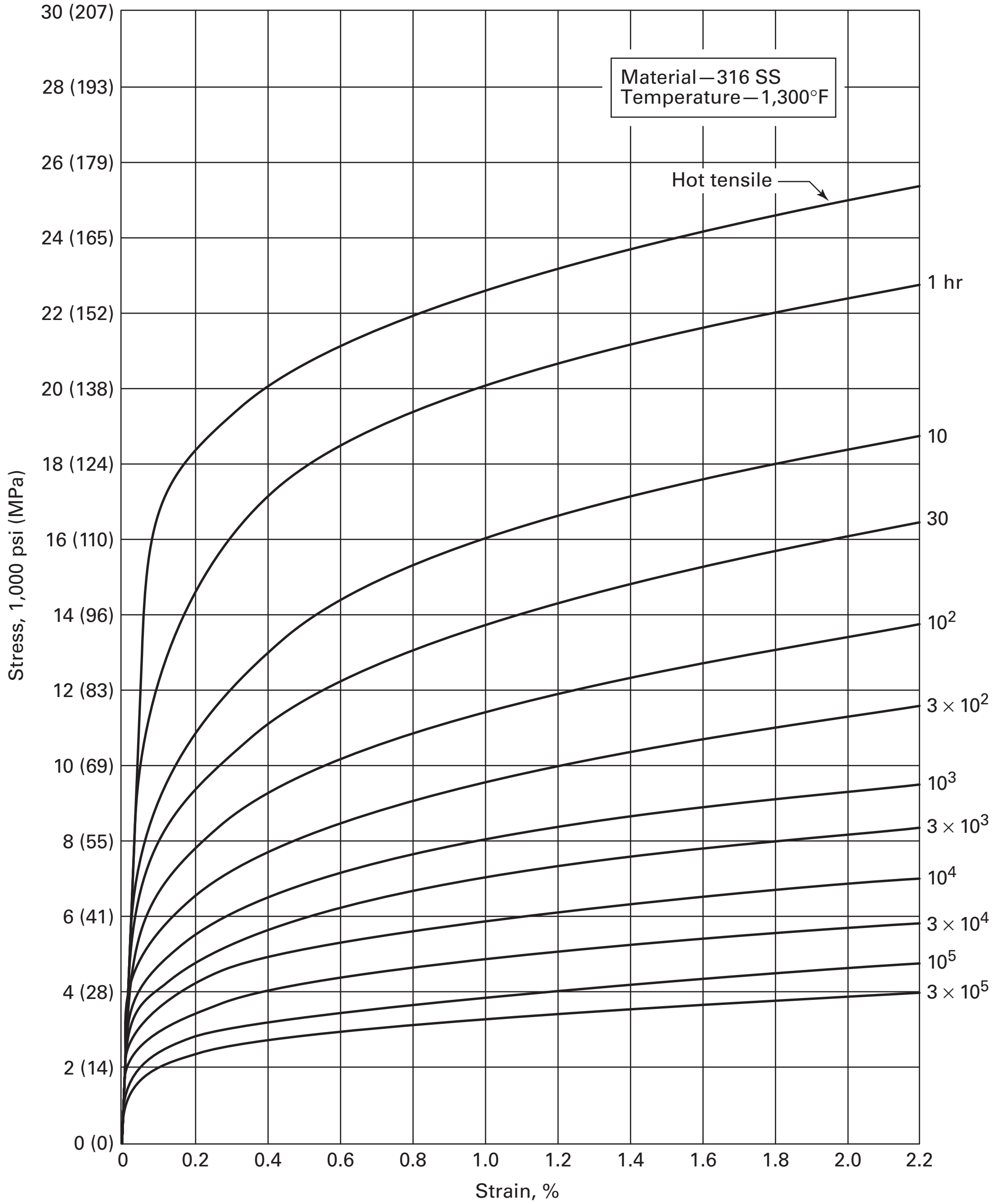


Figure NH-T-1800-B-12
Average Isochronous Stress–Strain Curves

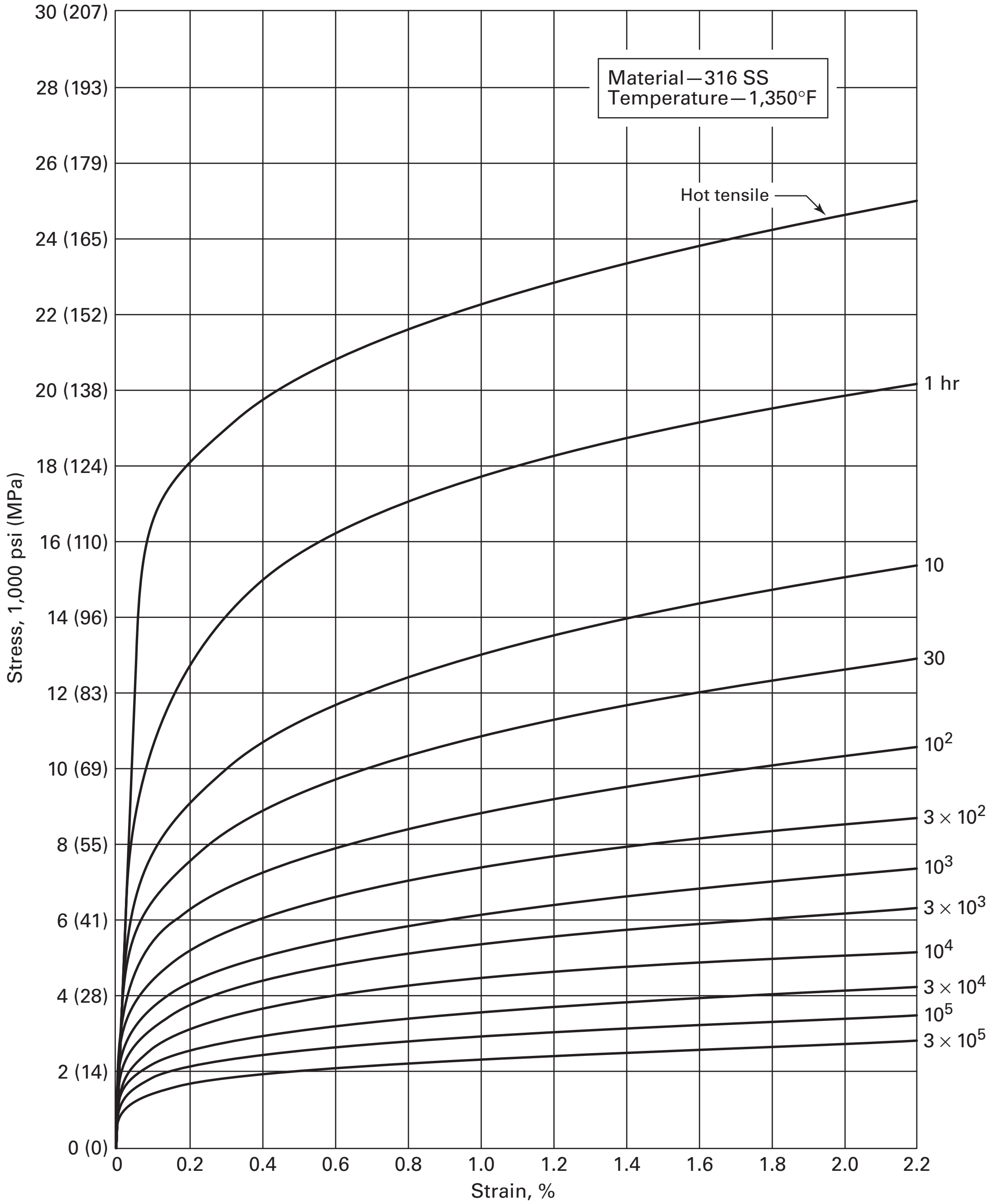


Figure NH-T-1800-B-13
Average Isochronous Stress–Strain Curves

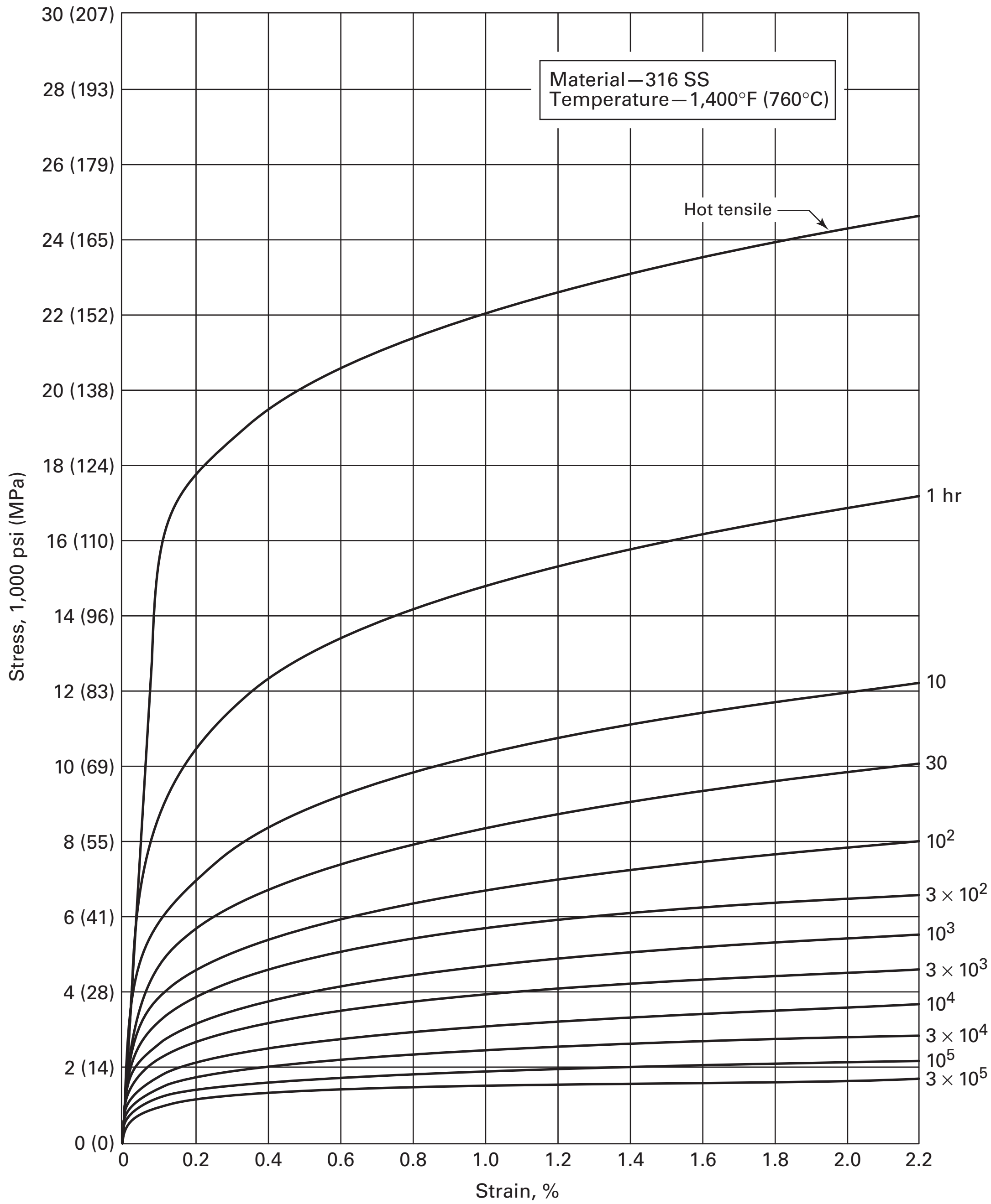


Figure NH-T-1800-B-14
Average Isochronous Stress–Strain Curves

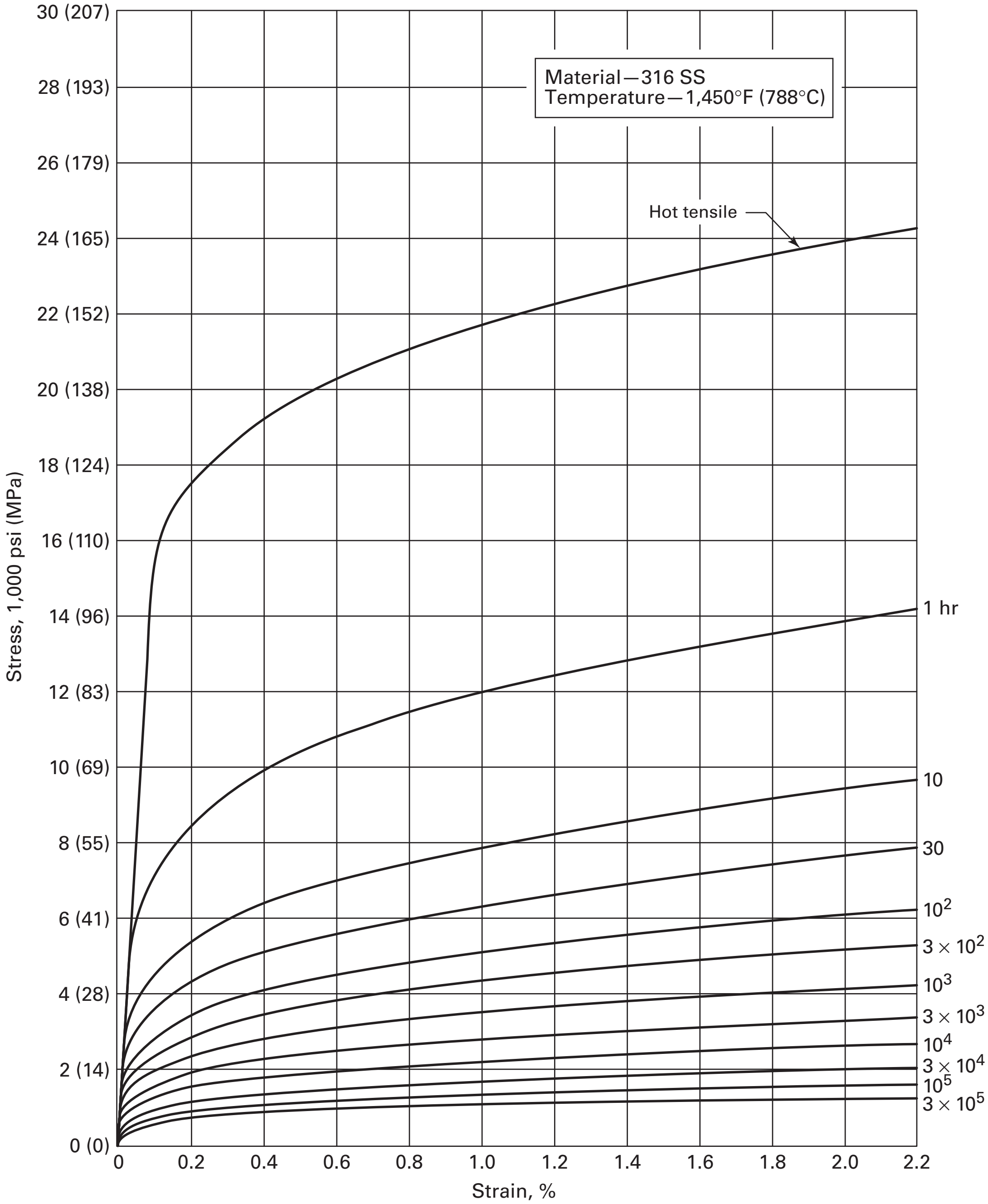


Figure NH-T-1800-B-15
Average Isochronous Stress–Strain Curves

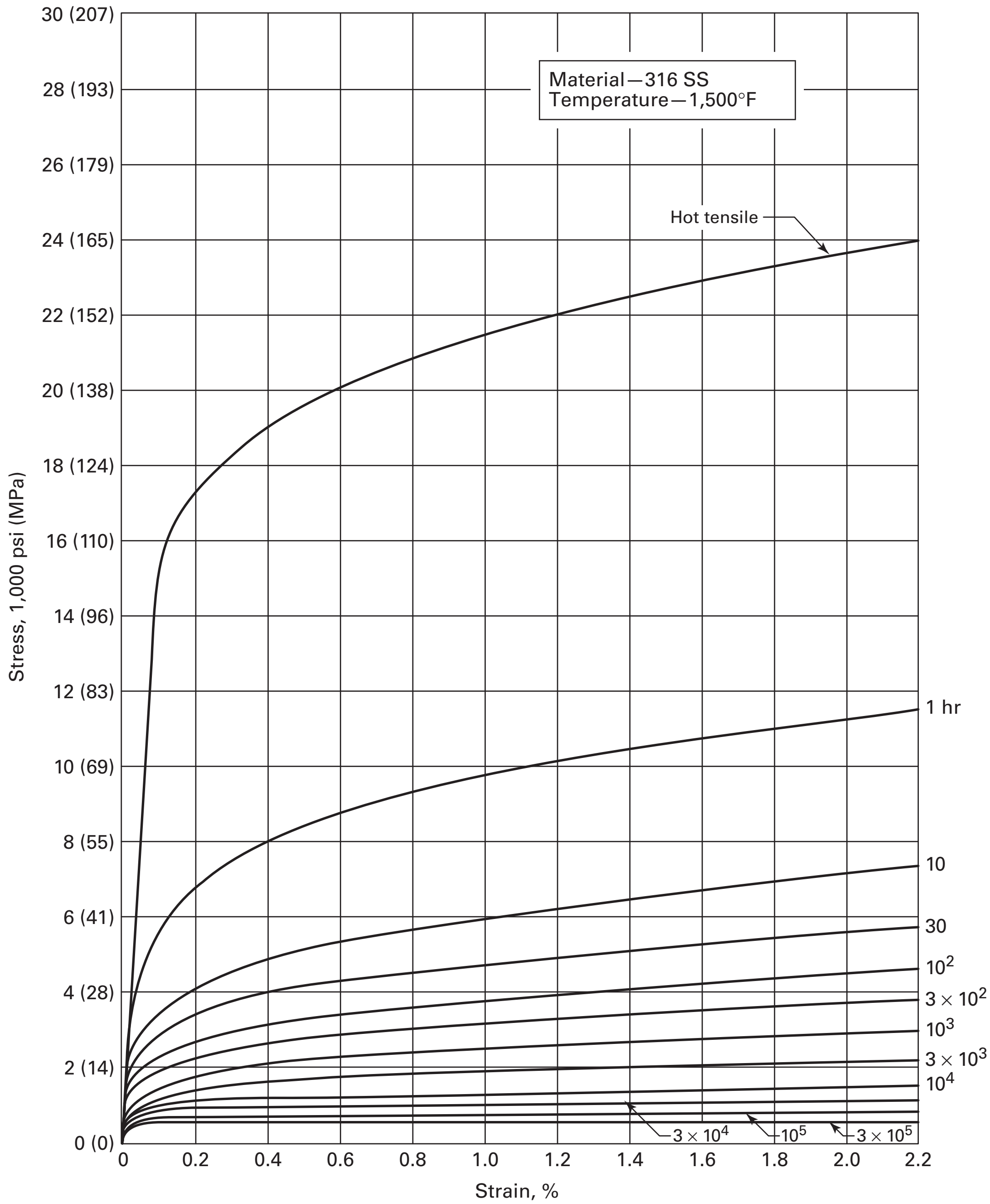


Figure NH-T-1800-C-1
Average Isochronous Stress–Strain Curves

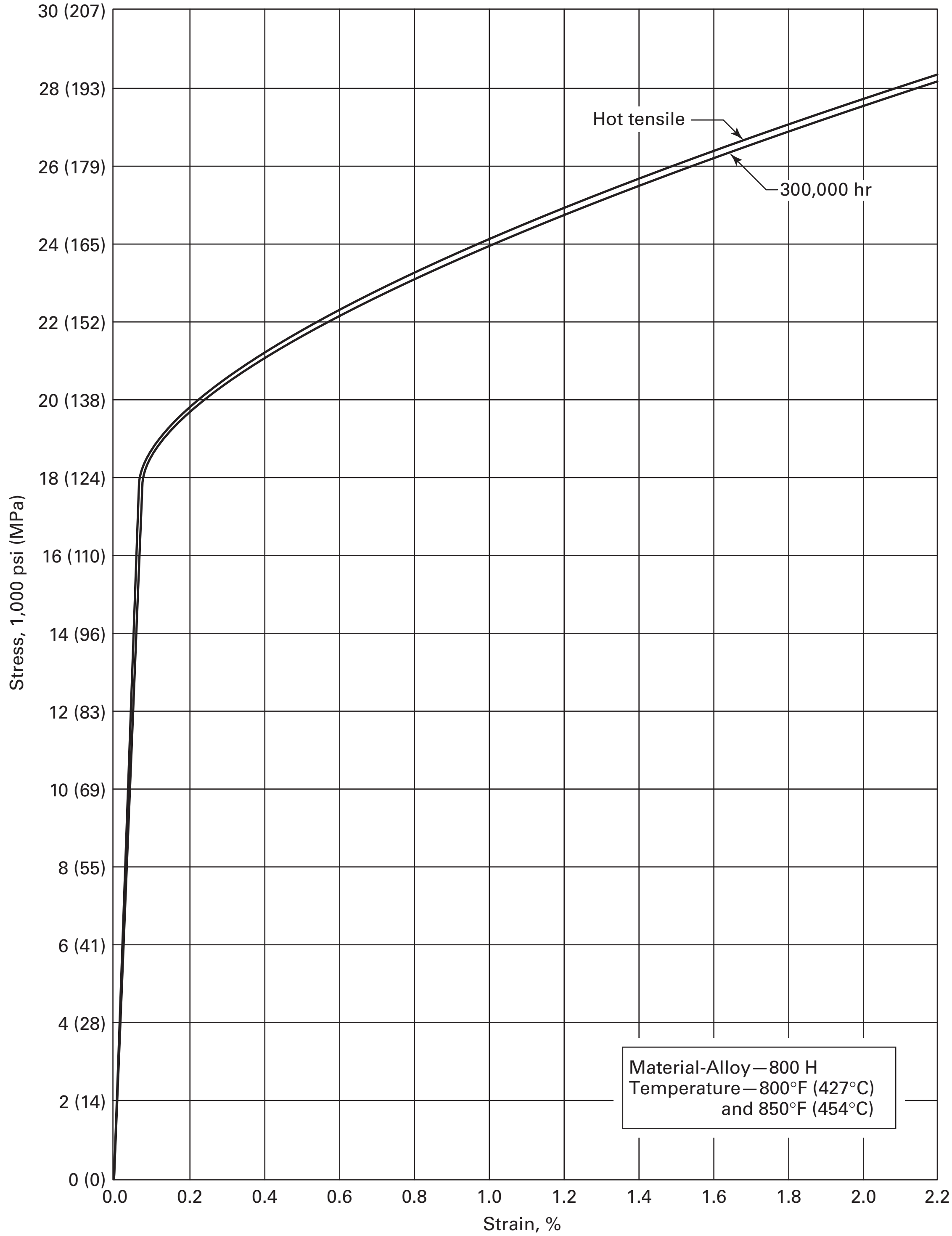


Figure NH-T-1800-C-2
Average Isochronous Stress–Strain Curves

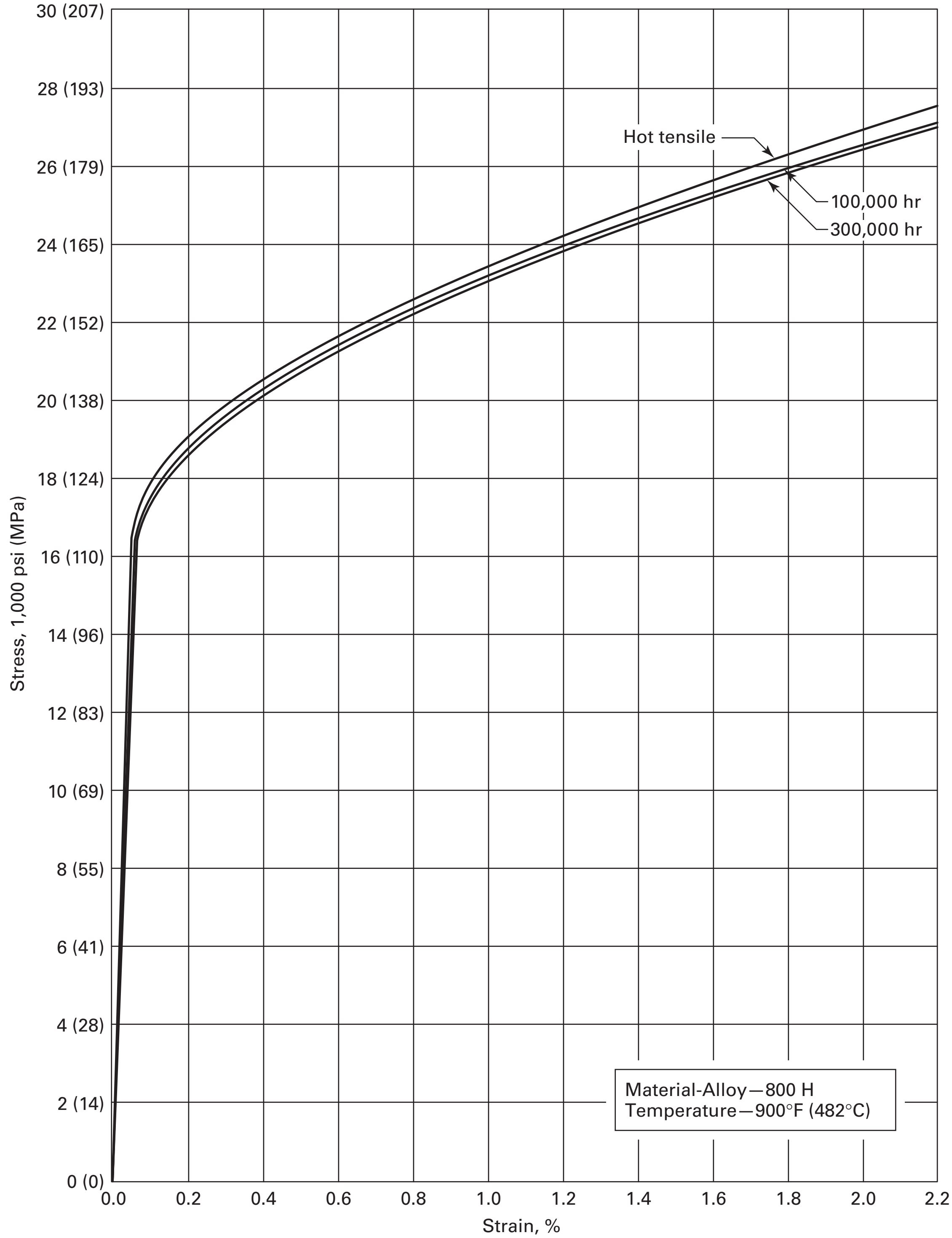


Figure NH-T-1800-C-3
Average Isochronous Stress–Strain Curves

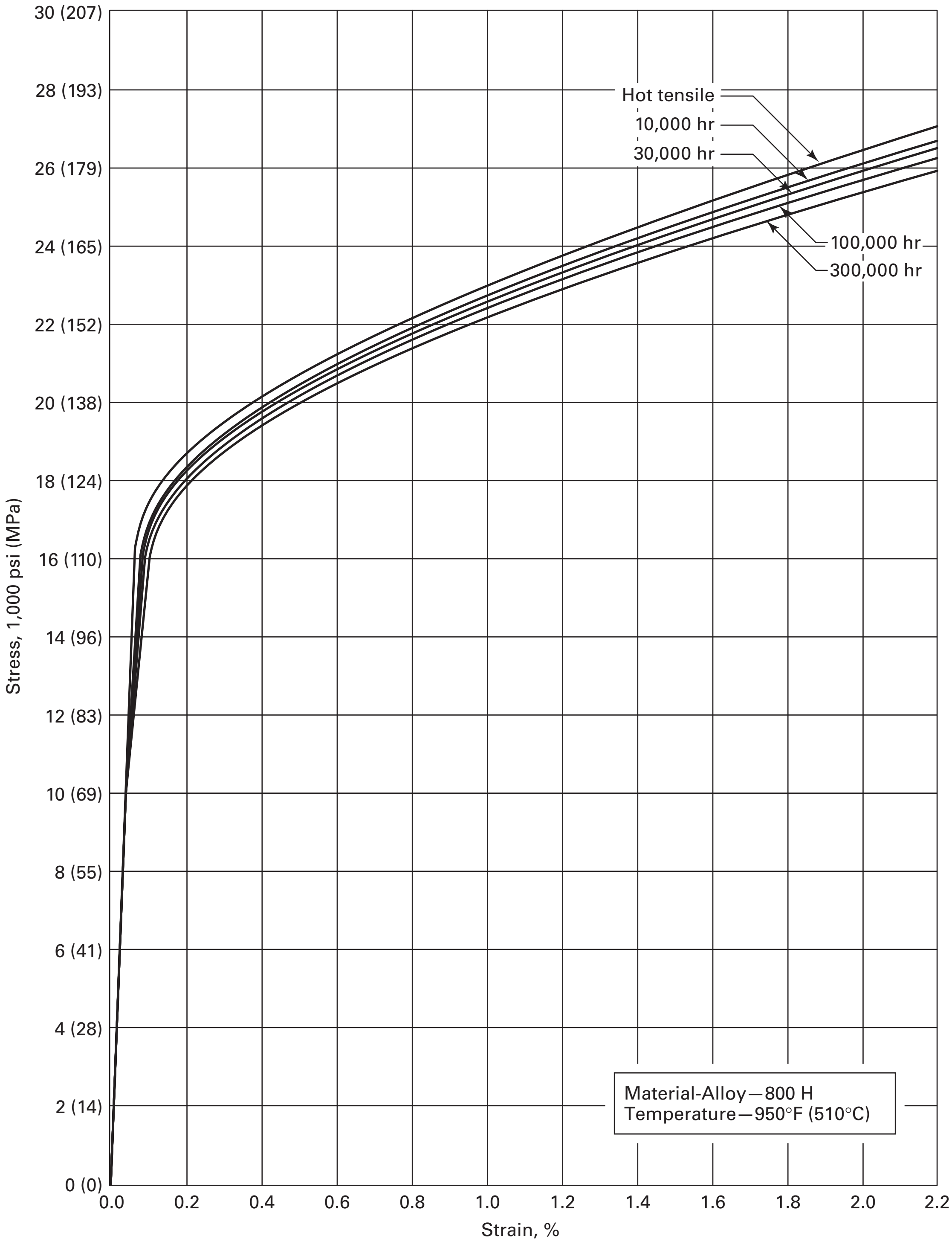


Figure NH-T-1800-C-4
Average Isochronous Stress–Strain Curves

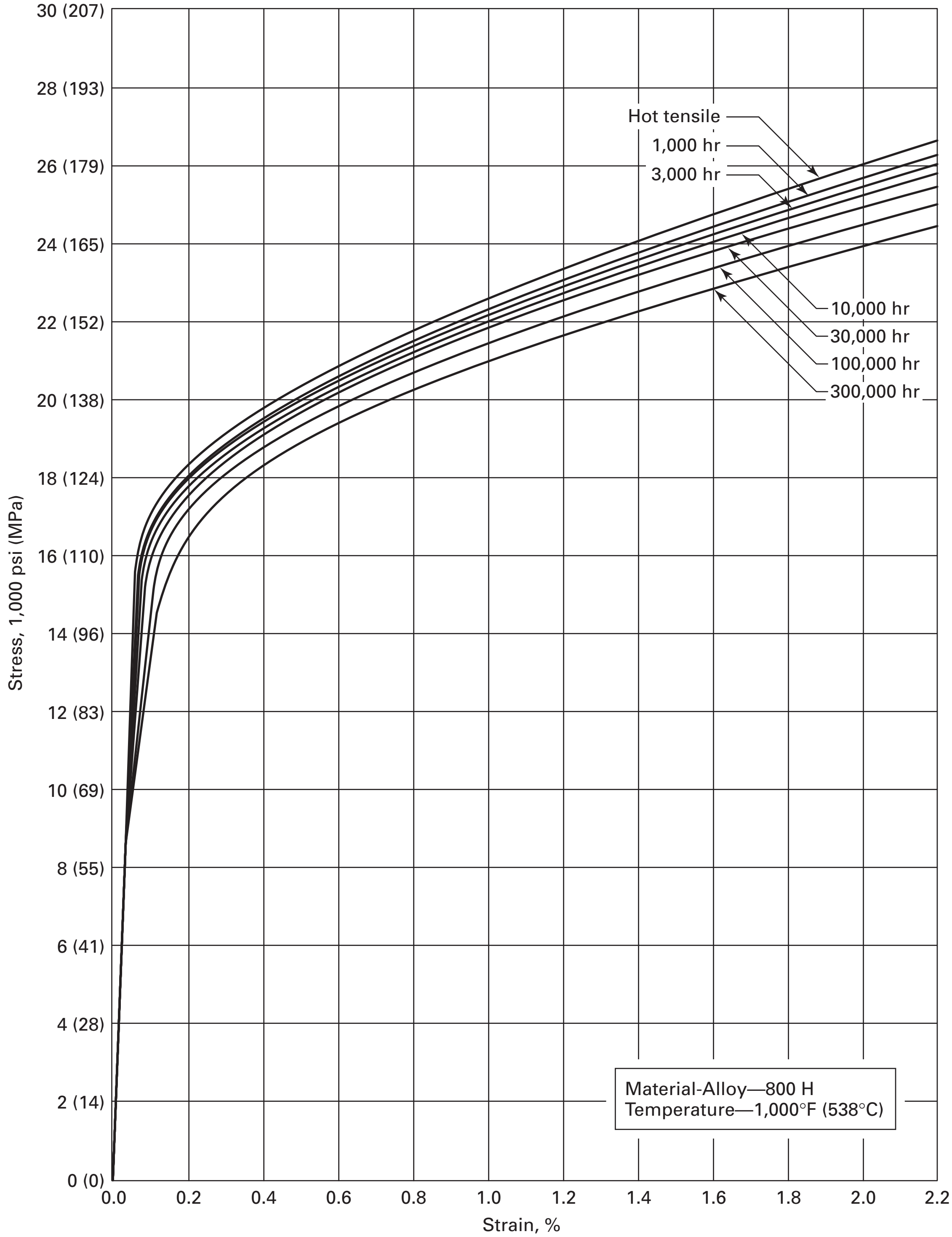


Figure NH-T-1800-C-5
Average Isochronous Stress–Strain Curves

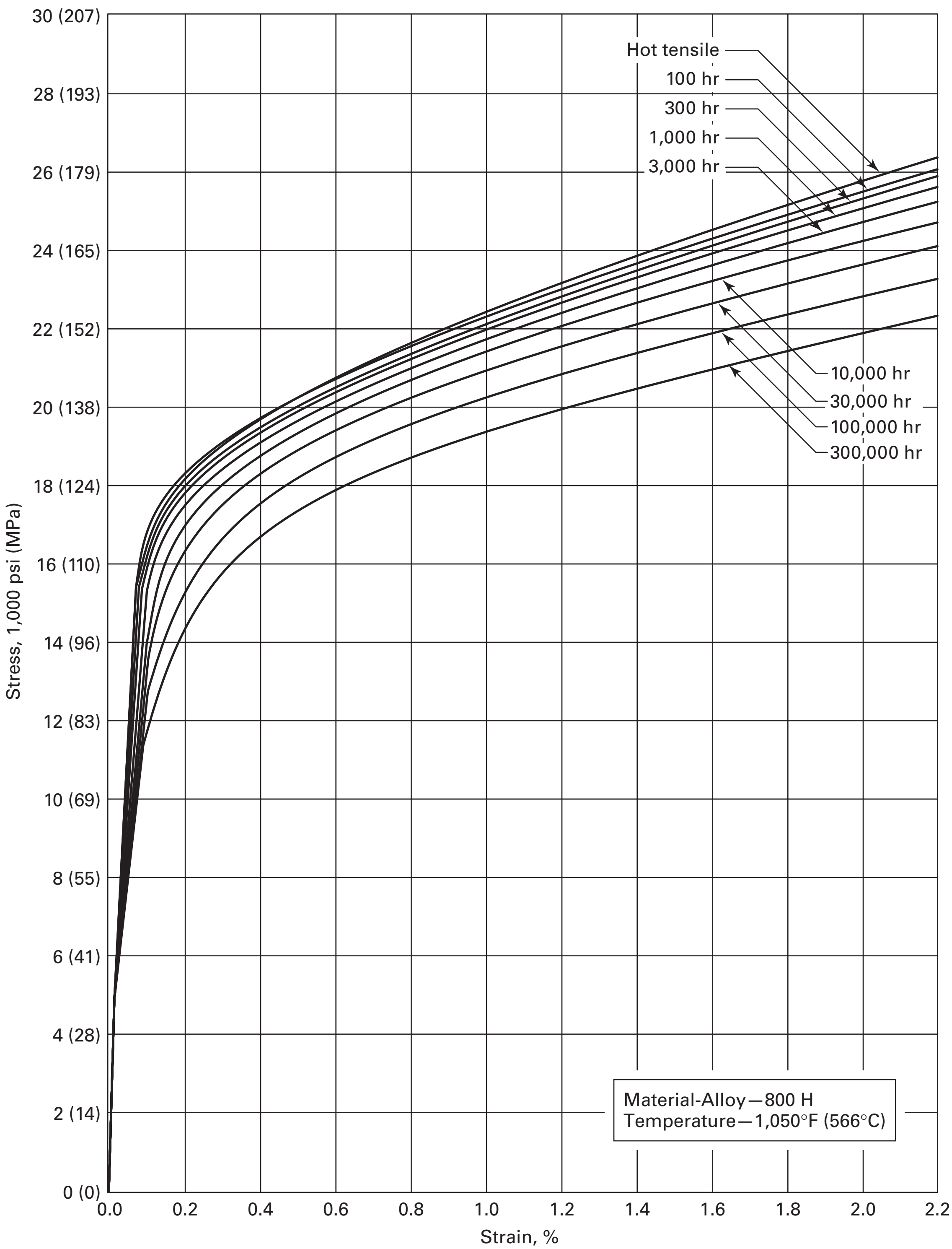


Figure NH-T-1800-C-6
Average Isochronous Stress–Strain Curves

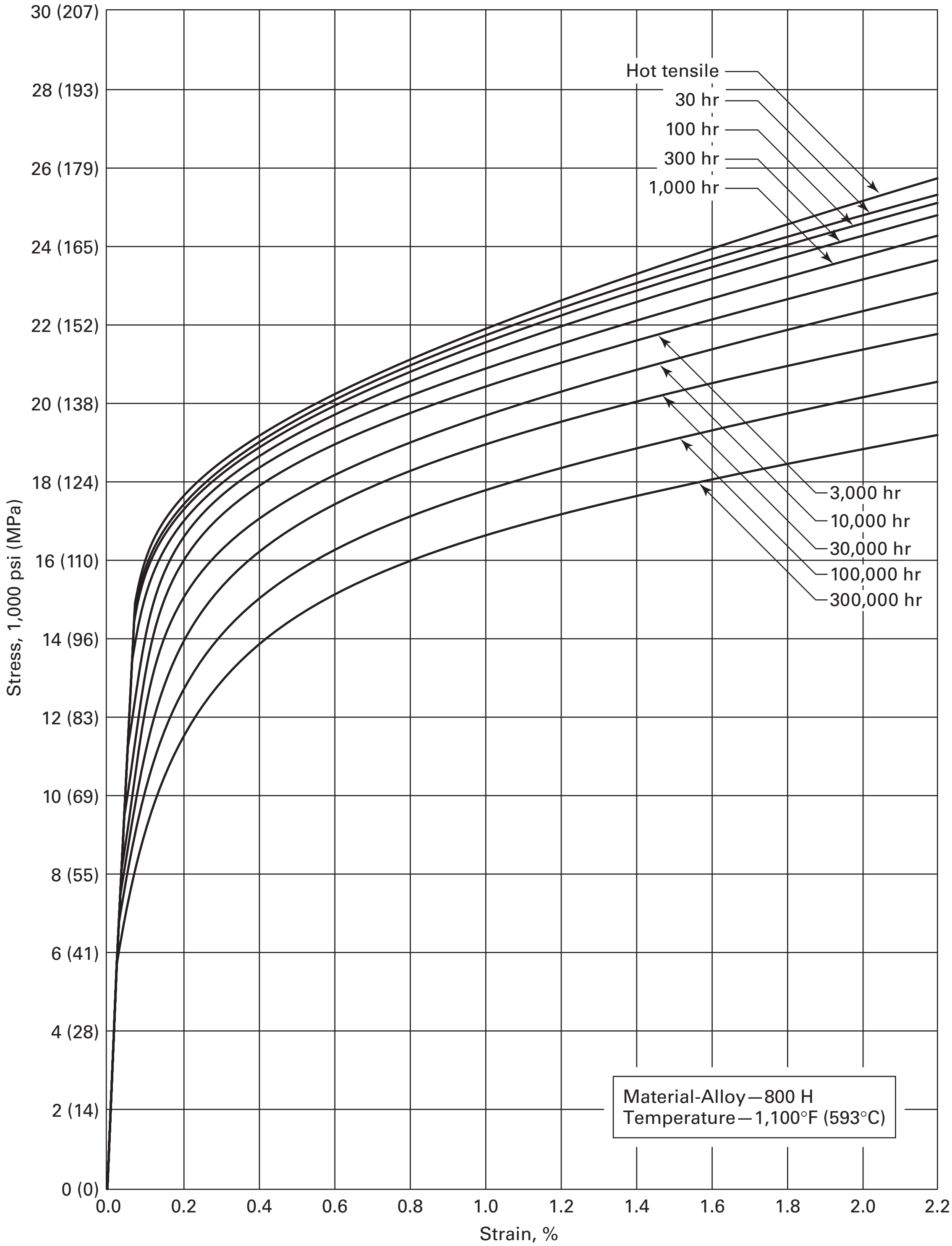


Figure NH-T-1800-C-7
Average Isochronous Stress–Strain Curves

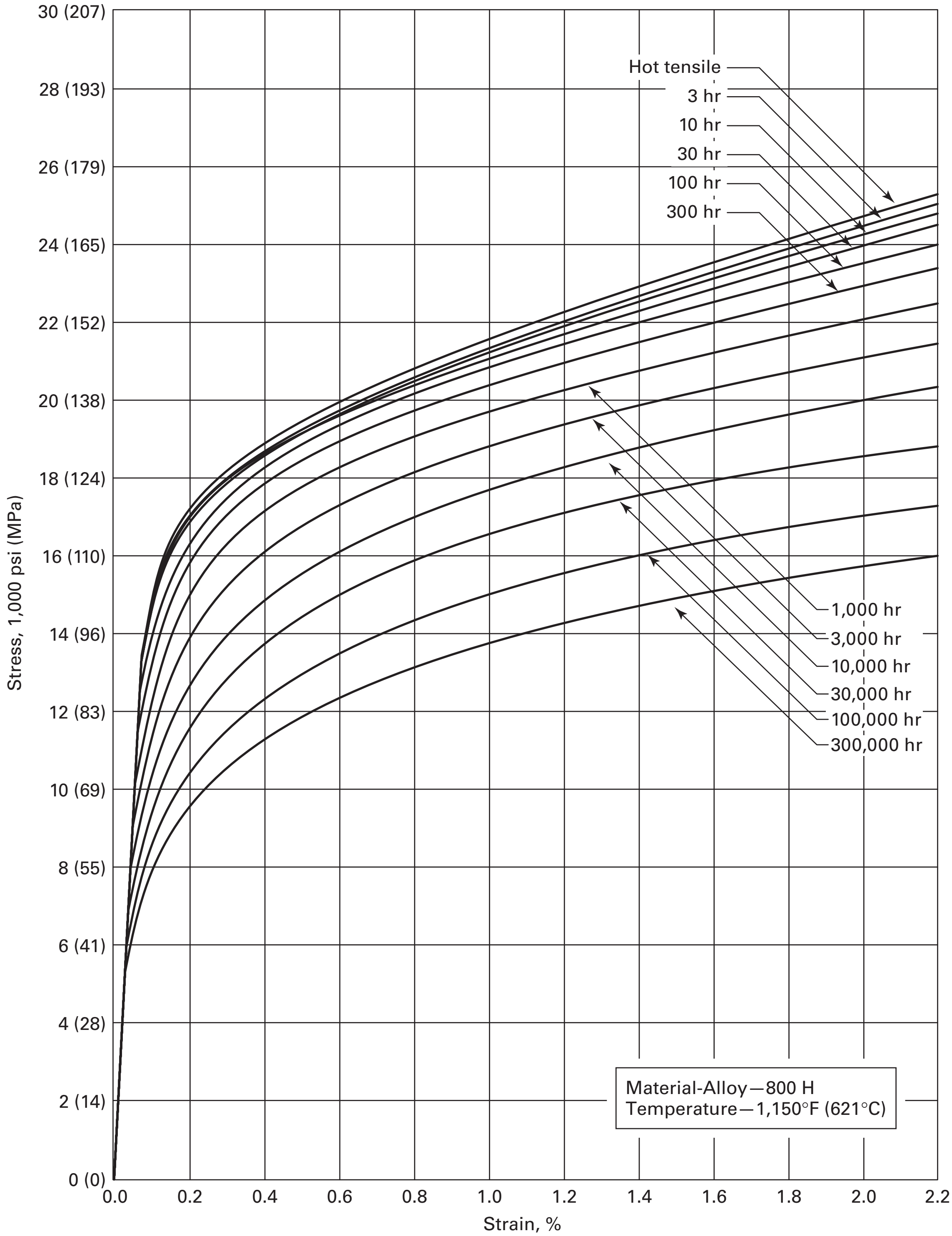


Figure NH-T-1800-C-8
Average Isochronous Stress–Strain Curves

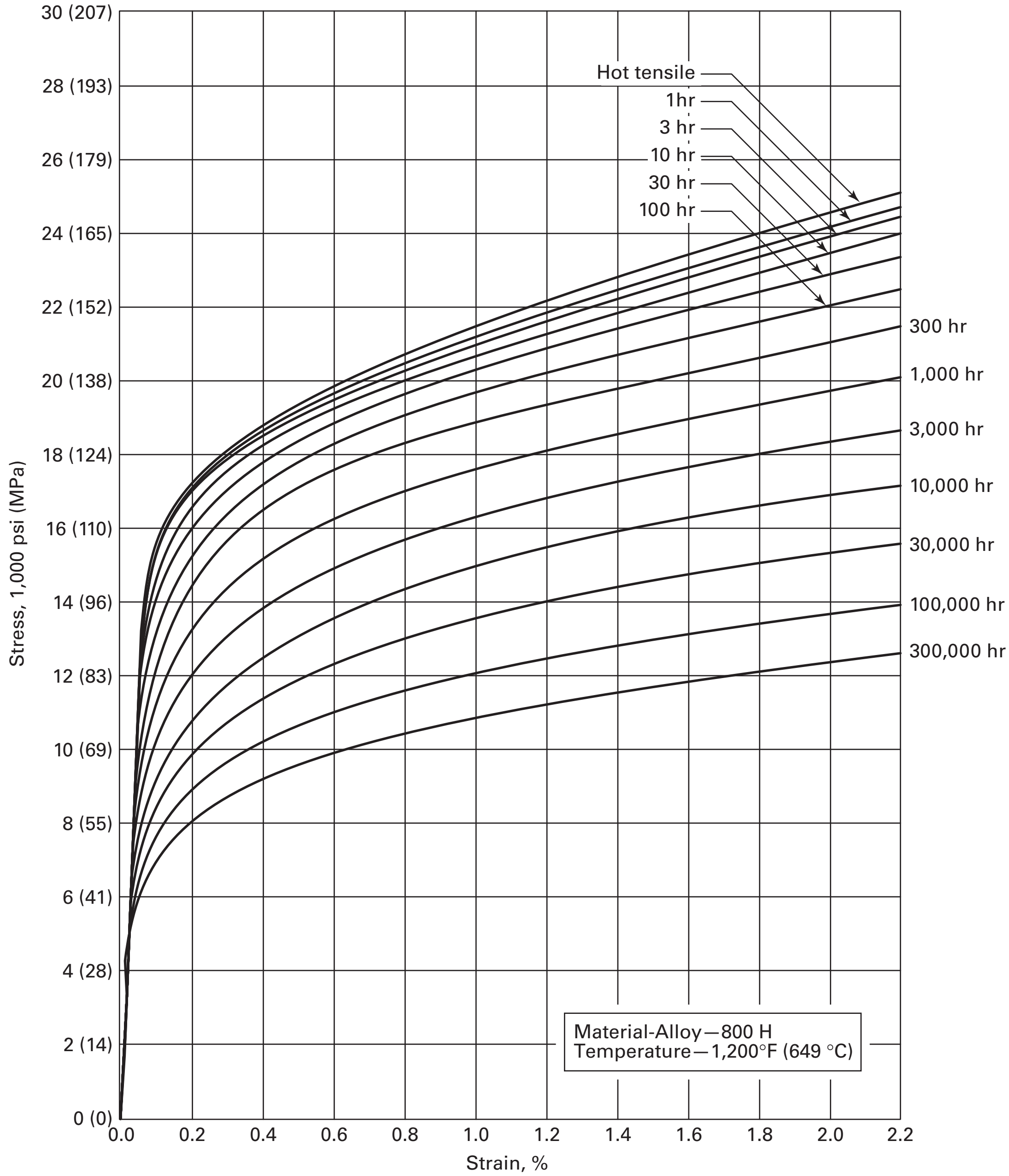


Figure NH-T-1800-C-9
Average Isochronous Stress–Strain Curves

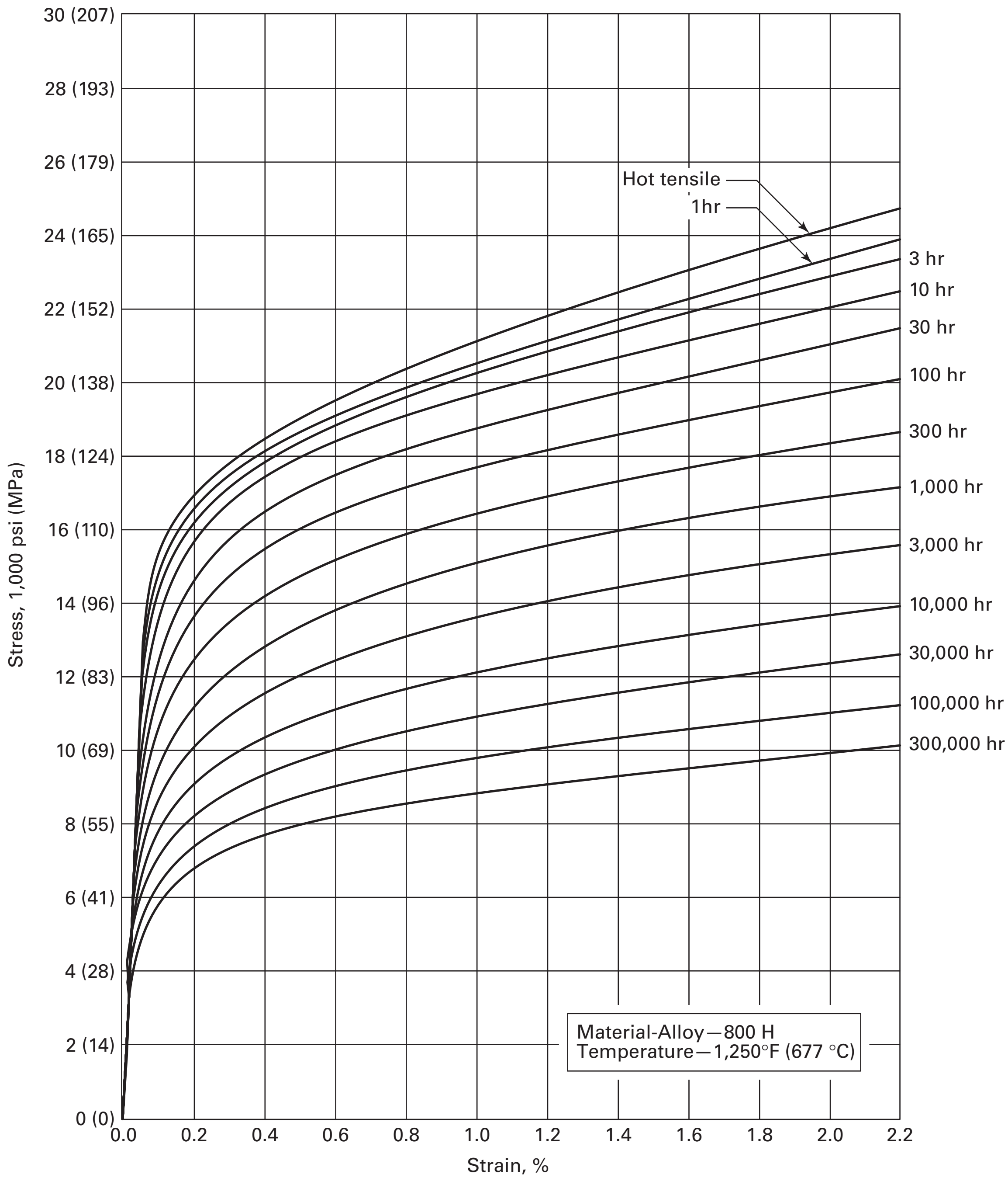


Figure NH-T-1800-C-10
Average Isochronous Stress–Strain Curves

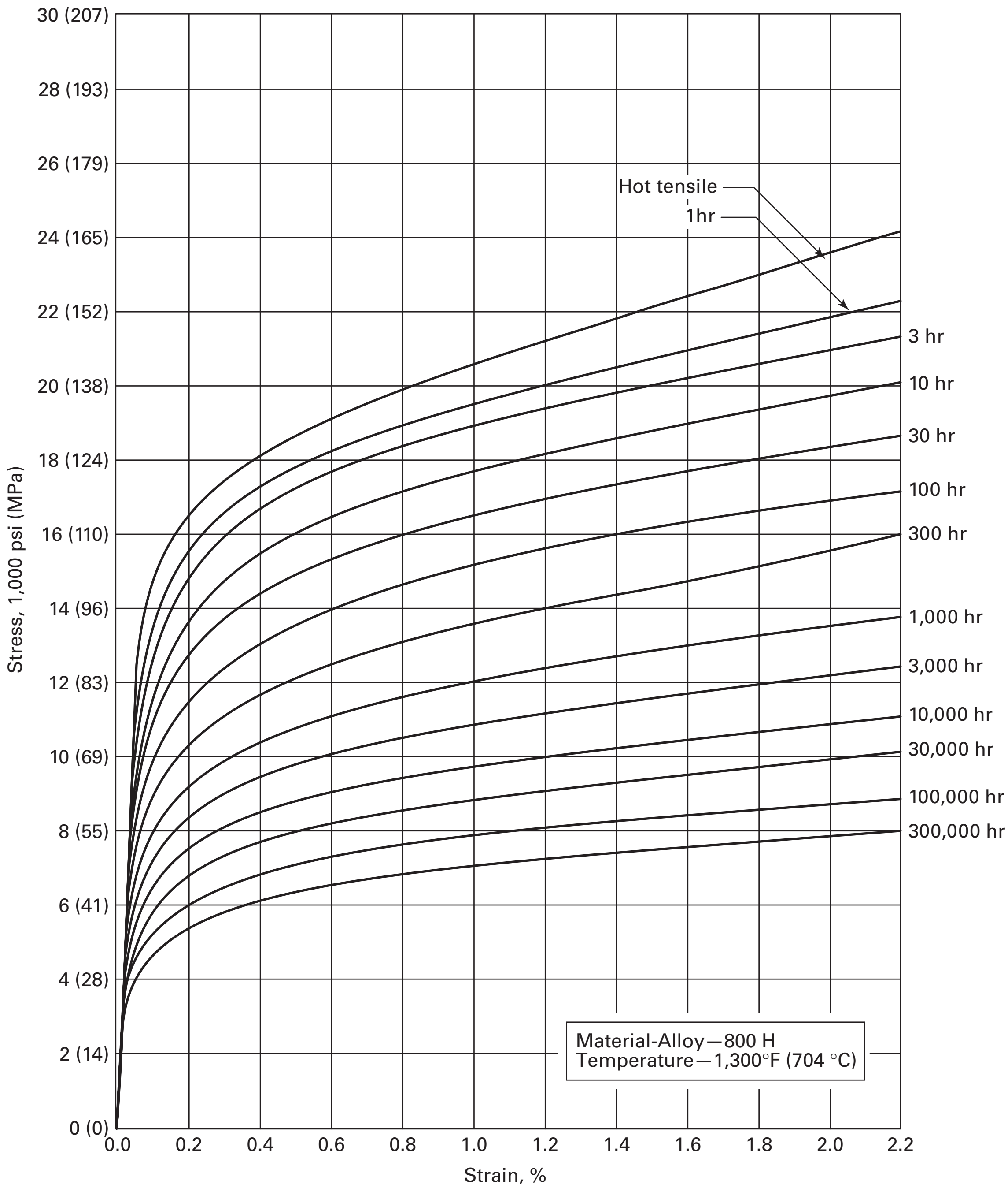


Figure NH-T-1800-C-11
Average Isochronous Stress–Strain Curves

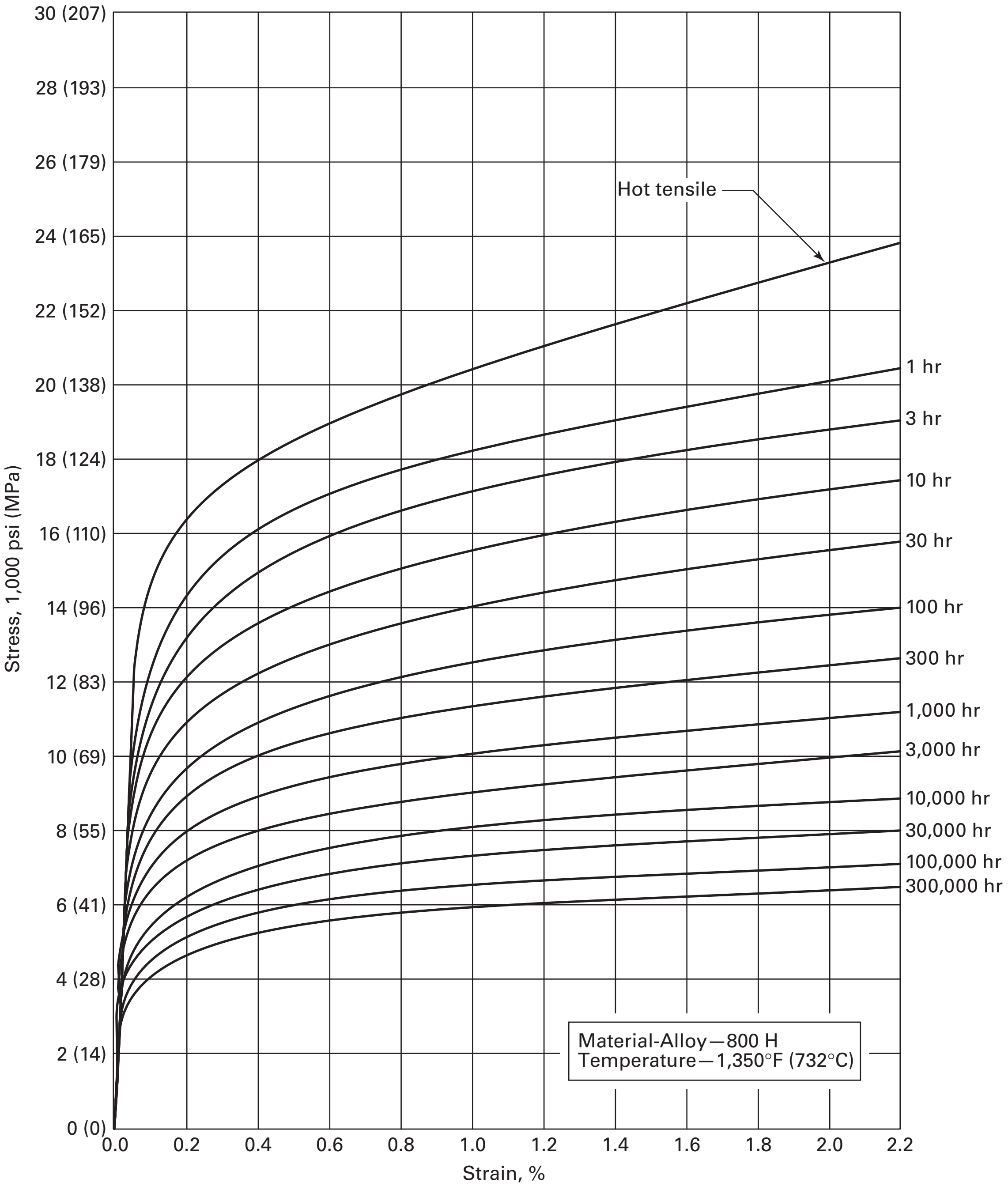


Figure NH-T-1800-C-12
Average Isochronous Stress–Strain Curves

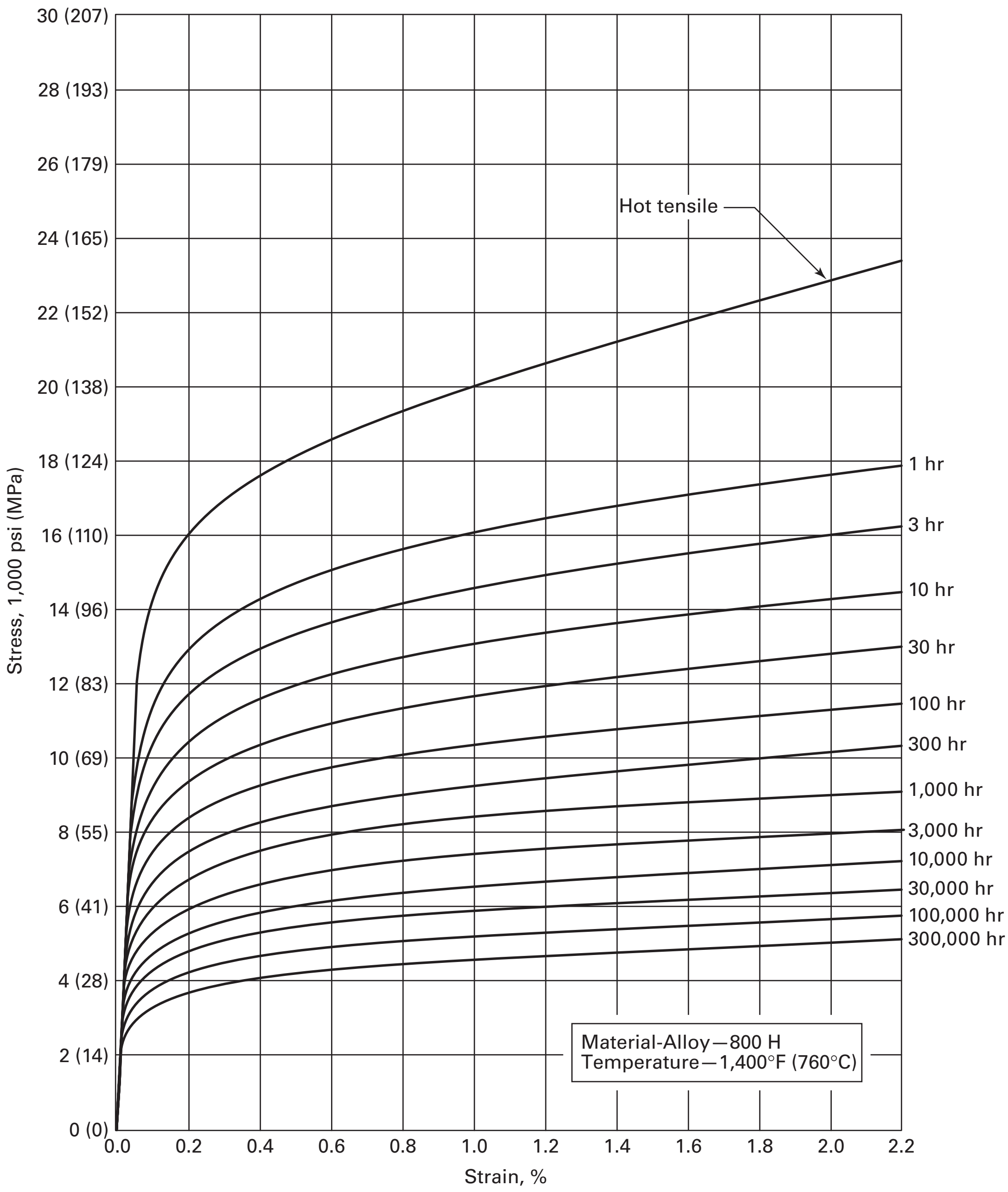


Figure NH-T-1800-D-1
Average Isochronous Stress–Strain Curves

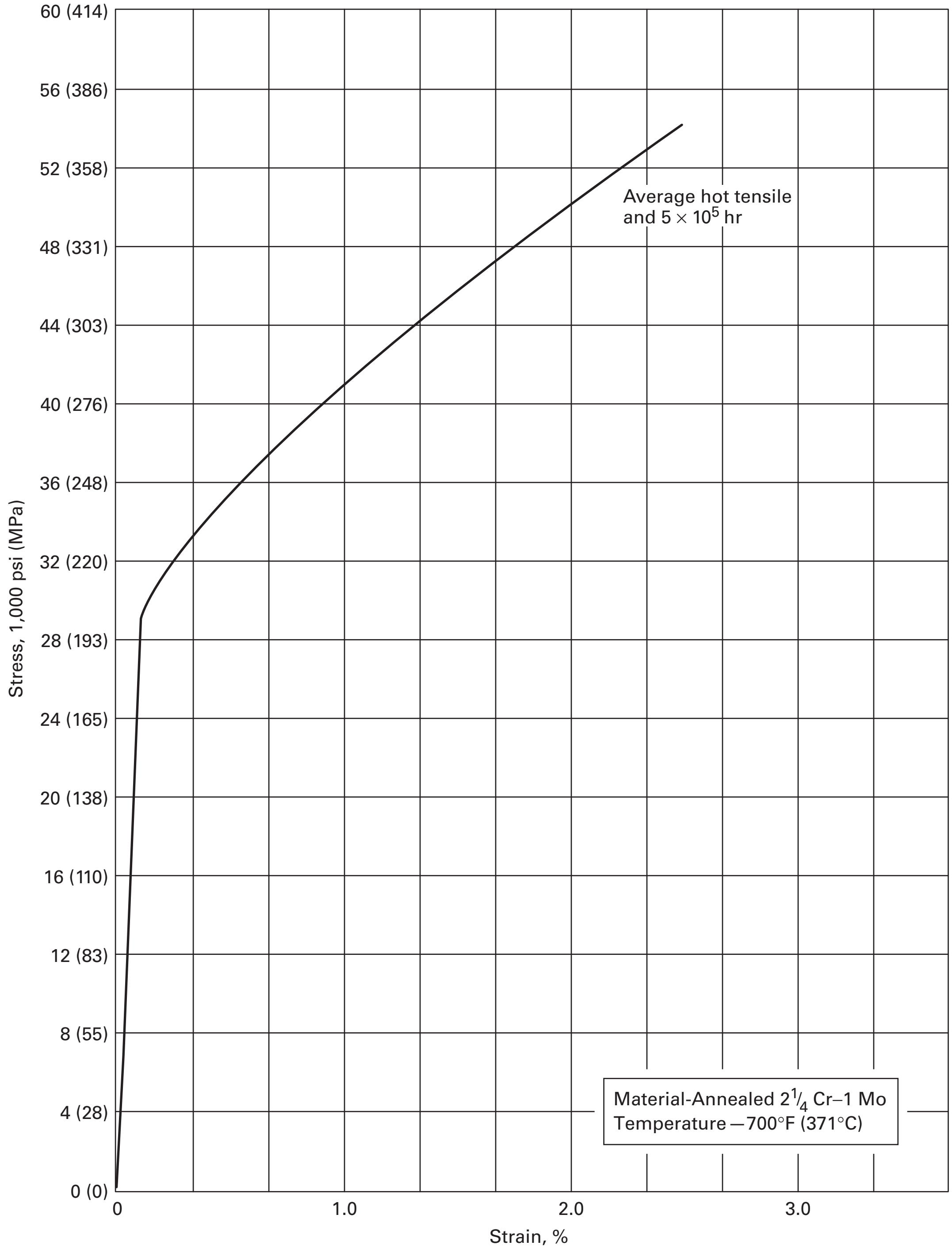


Figure NH-T-1800-D-2
Average Isochronous Stress–Strain Curves

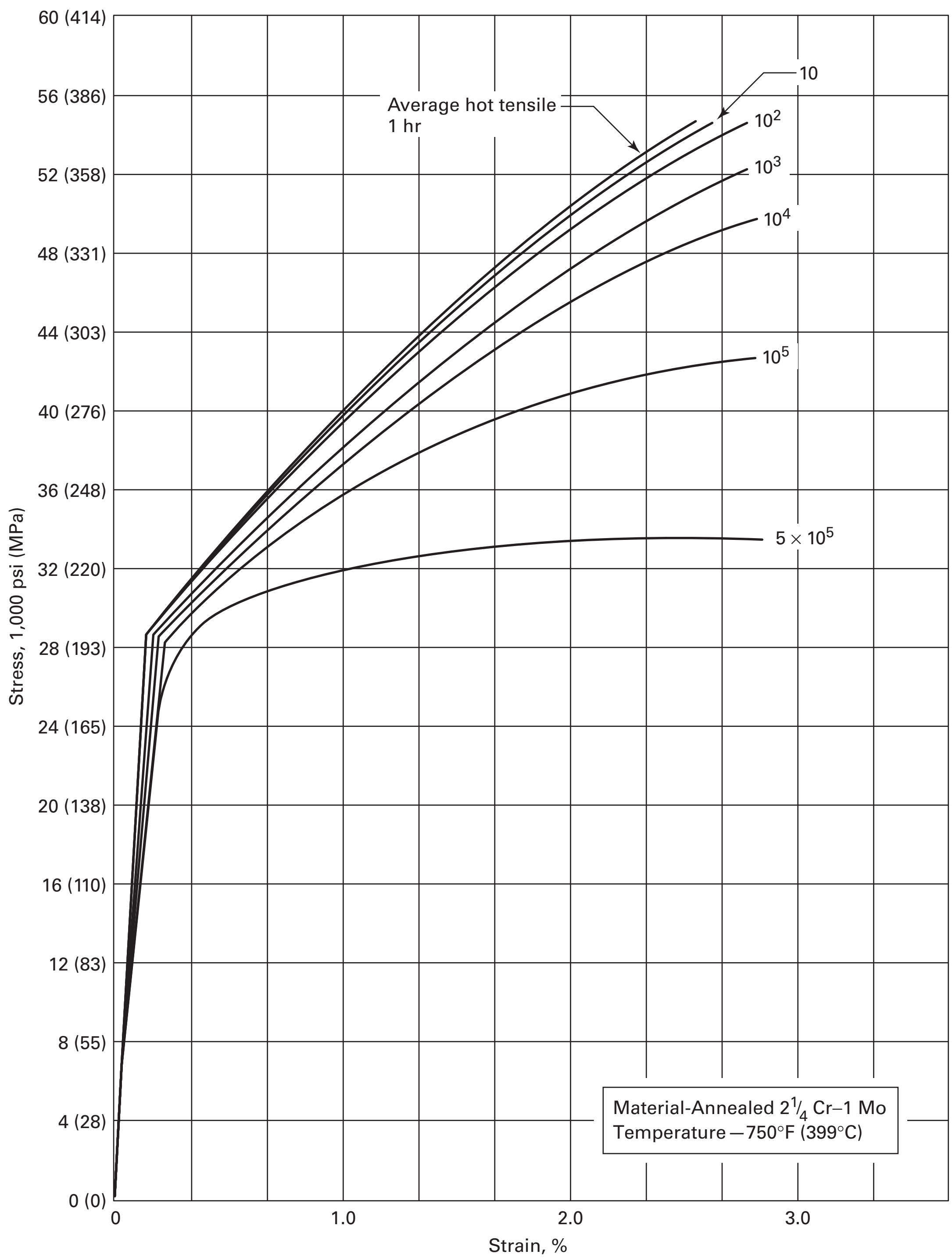


Figure NH-T-1800-D-3
Average Isochronous Stress–Strain Curves

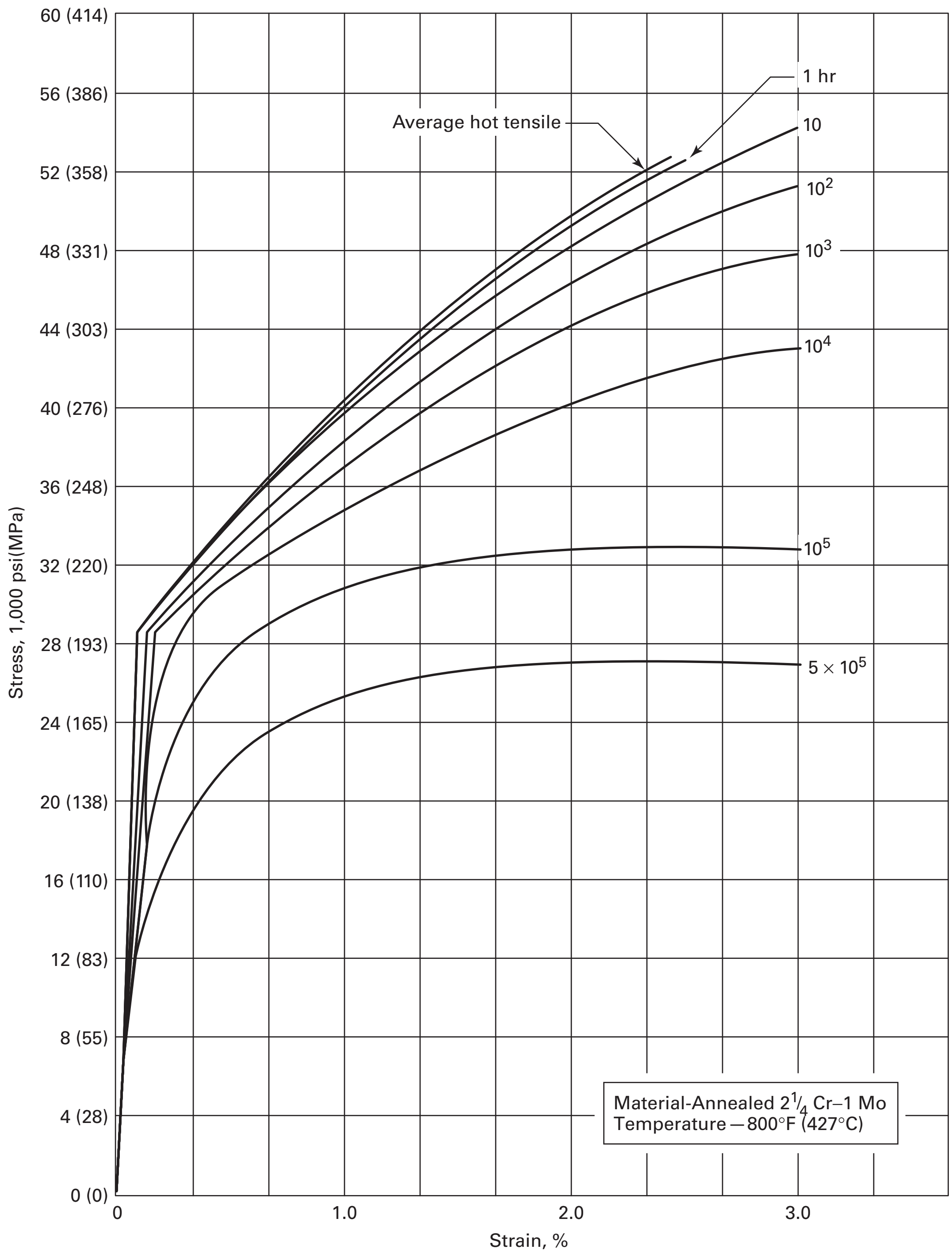


Figure NH-T-1800-D-4
Average Isochronous Stress–Strain Curves

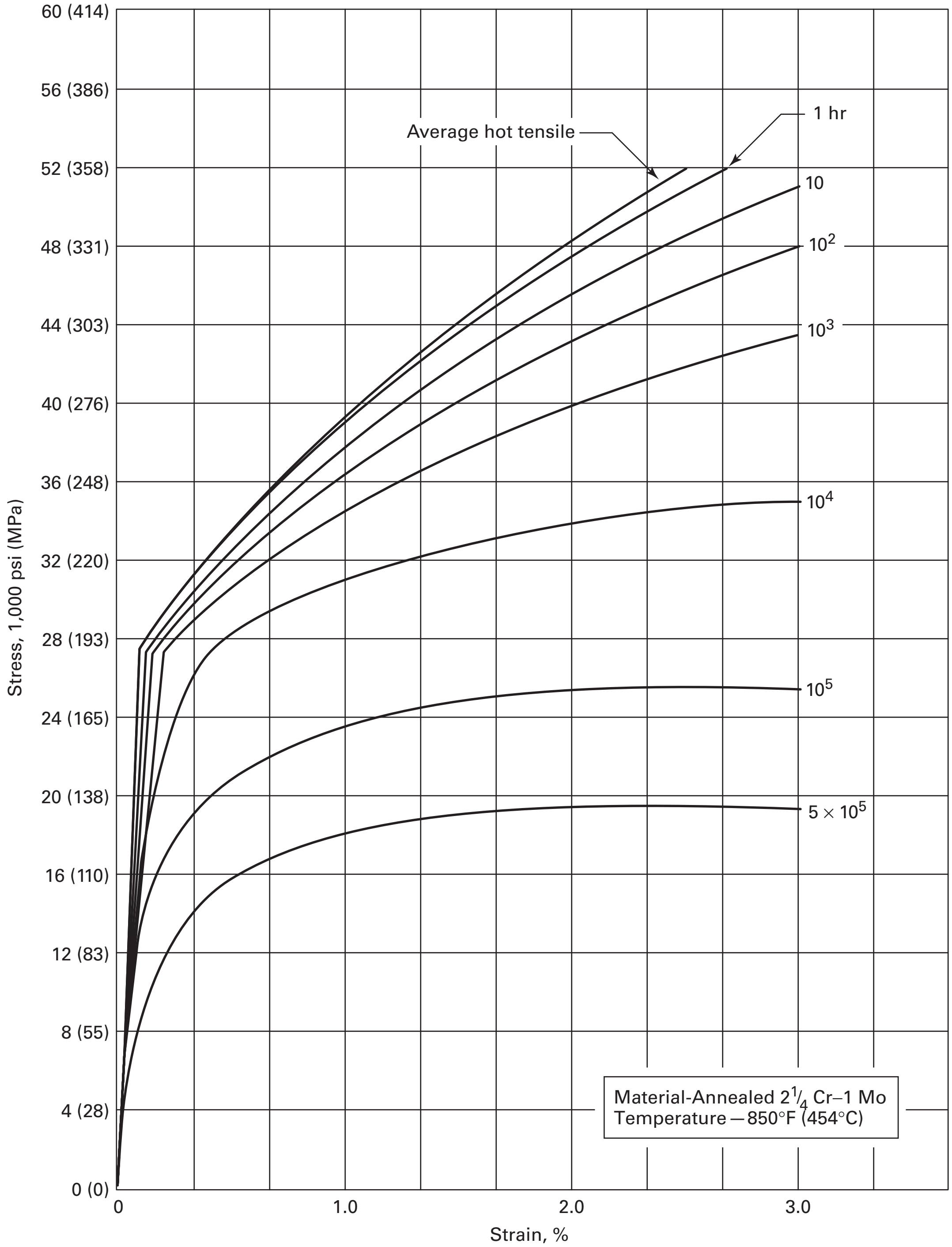


Figure NH-T-1800-D-5
Average Isochronous Stress–Strain Curves

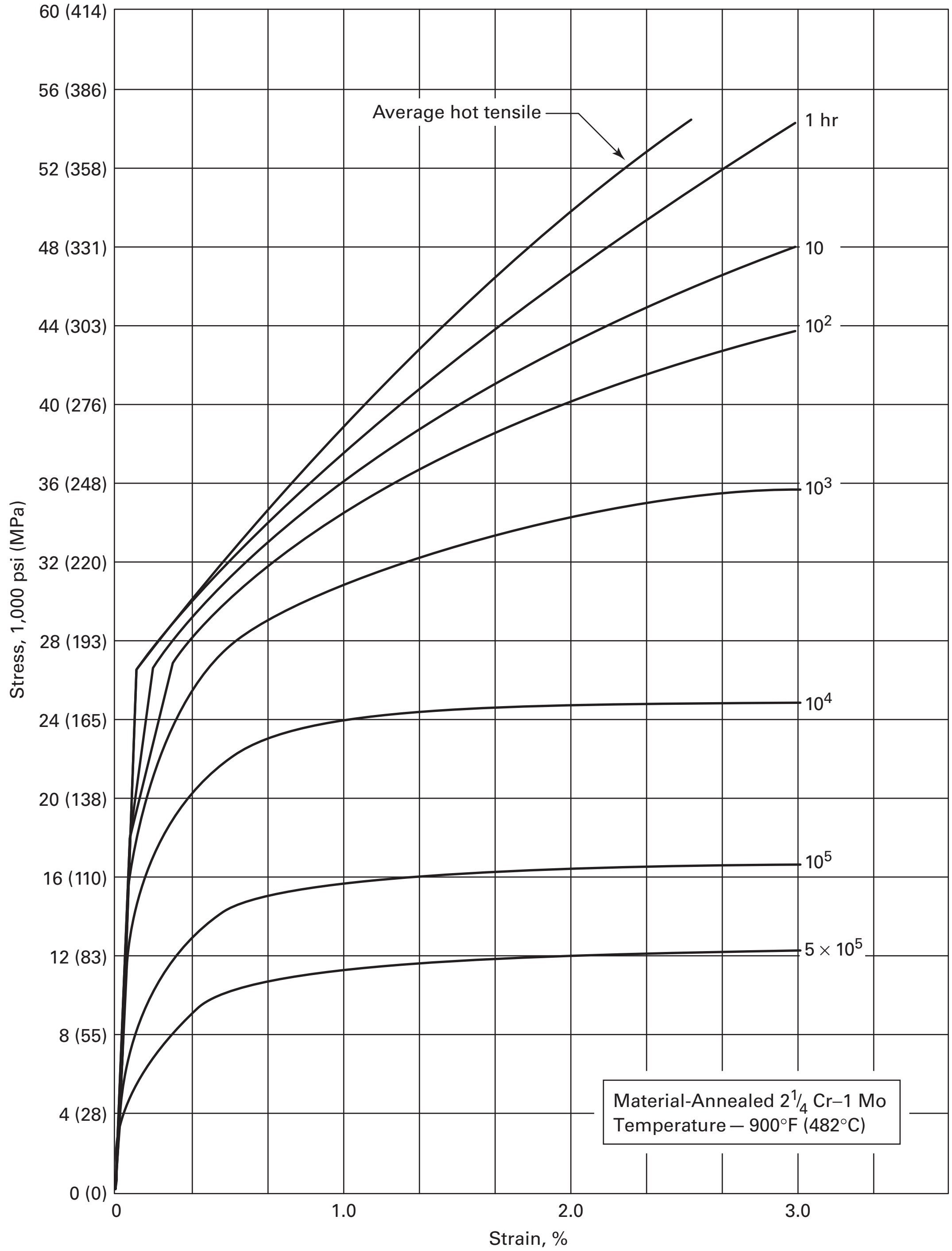


Figure NH-T-1800-D-6
Average Isochronous Stress–Strain Curves

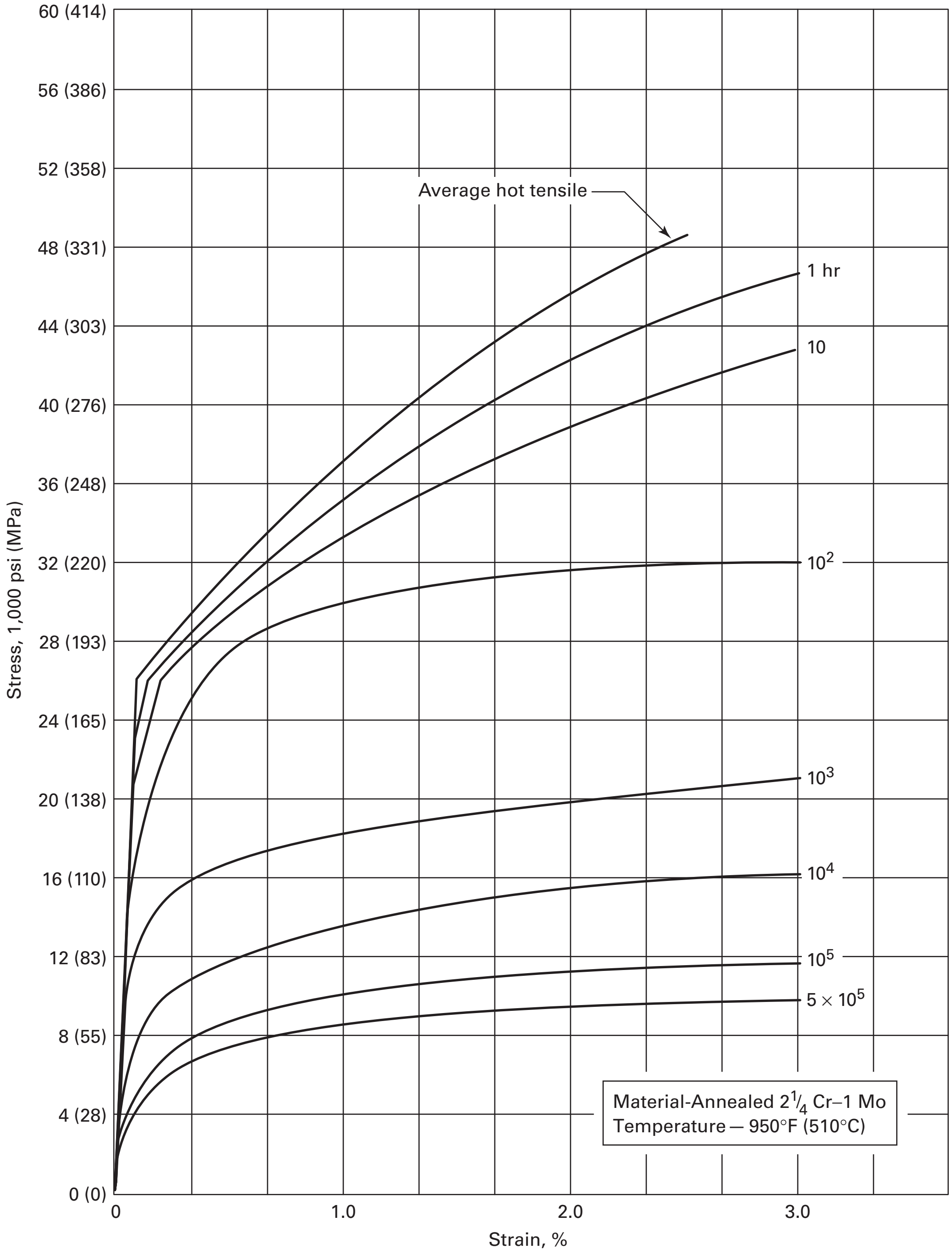


Figure NH-T-1800-D-7
Average Isochronous Stress–Strain Curves

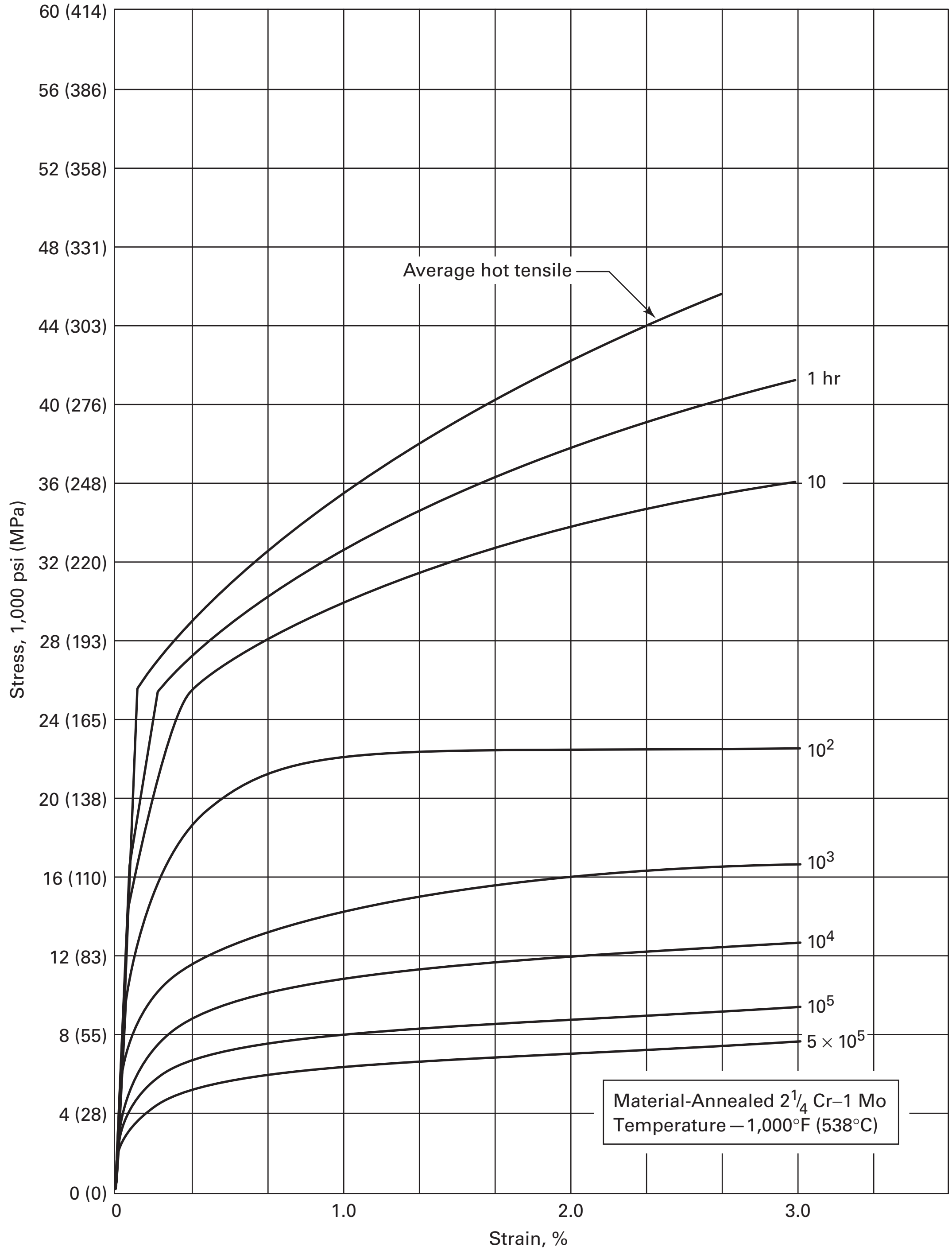


Figure NH-T-1800-D-8
Average Isochronous Stress–Strain Curves

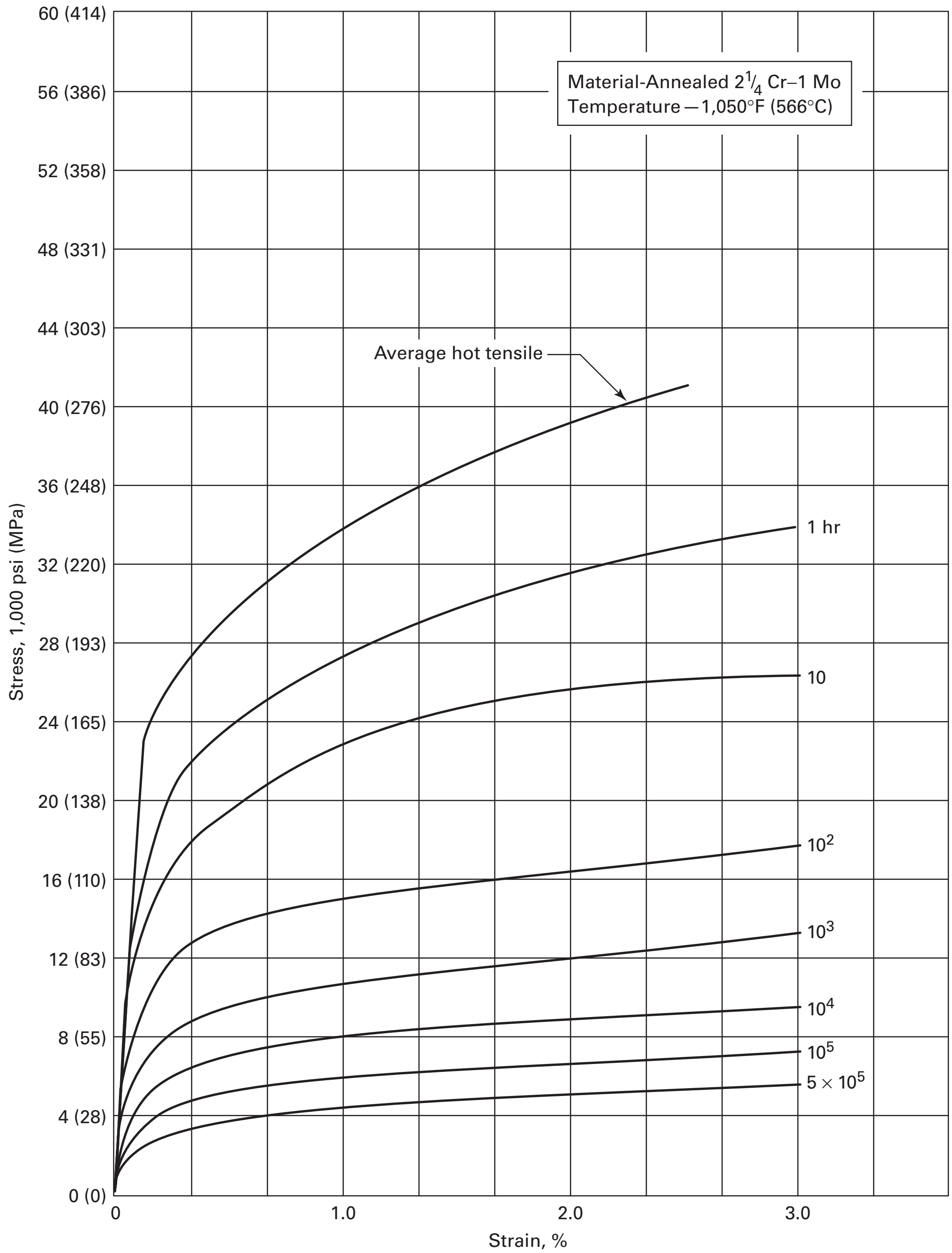


Figure NH-T-1800-D-9
Average Isochronous Stress–Strain Curves

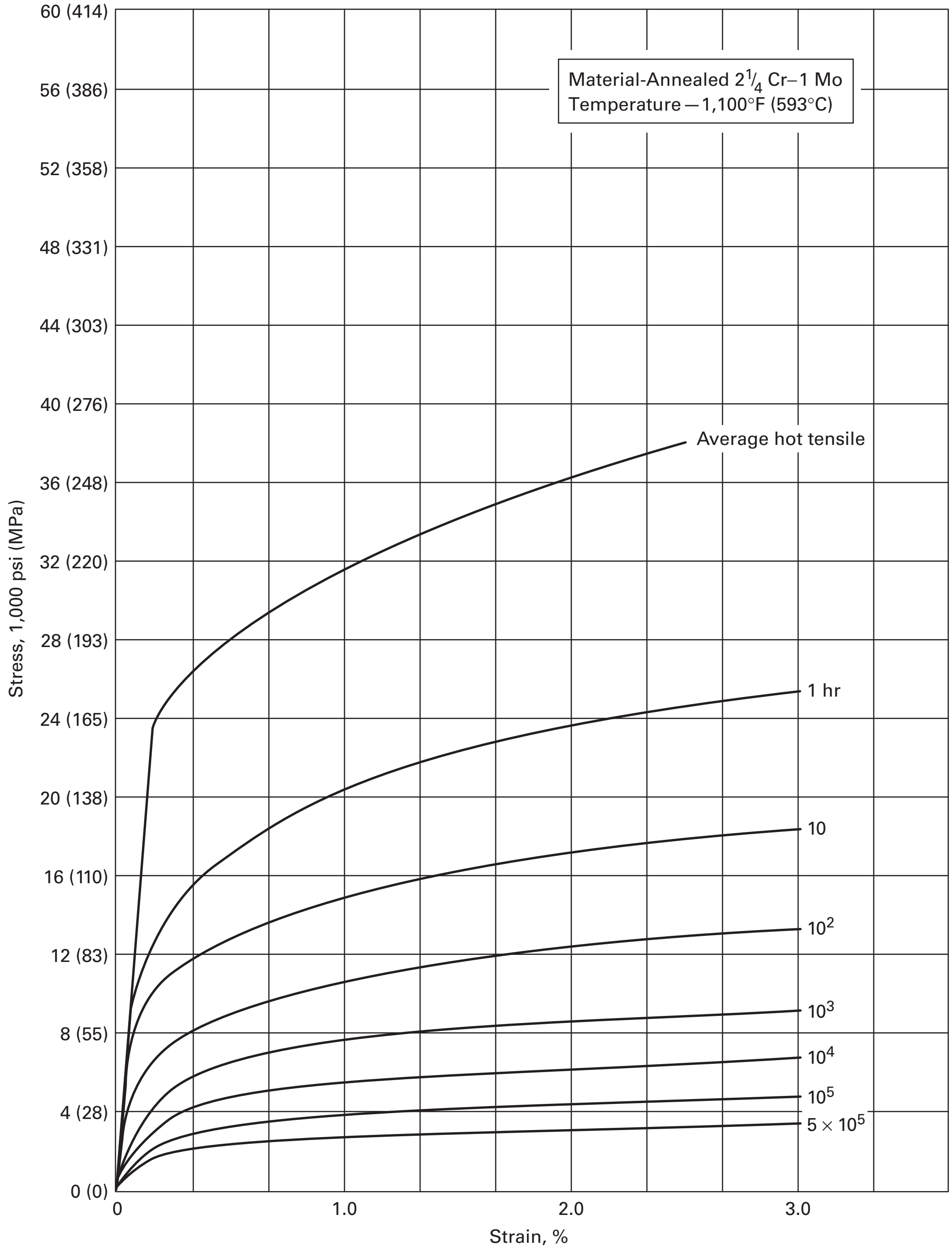


Figure NH-T-1800-D-10
Average Isochronous Stress–Strain Curves

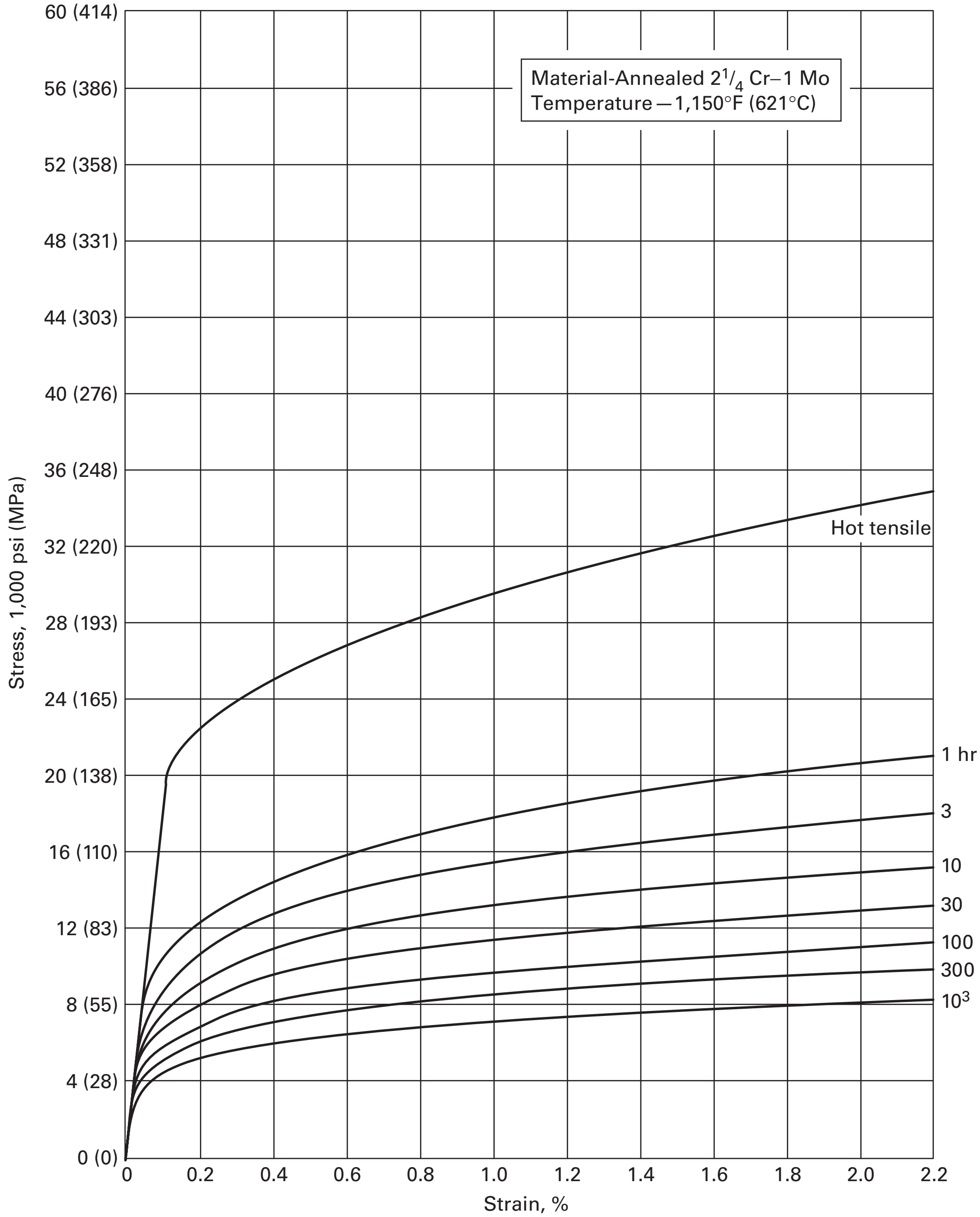


Figure NH-T-1800-D-11
Average Isochronous Stress–Strain Curves

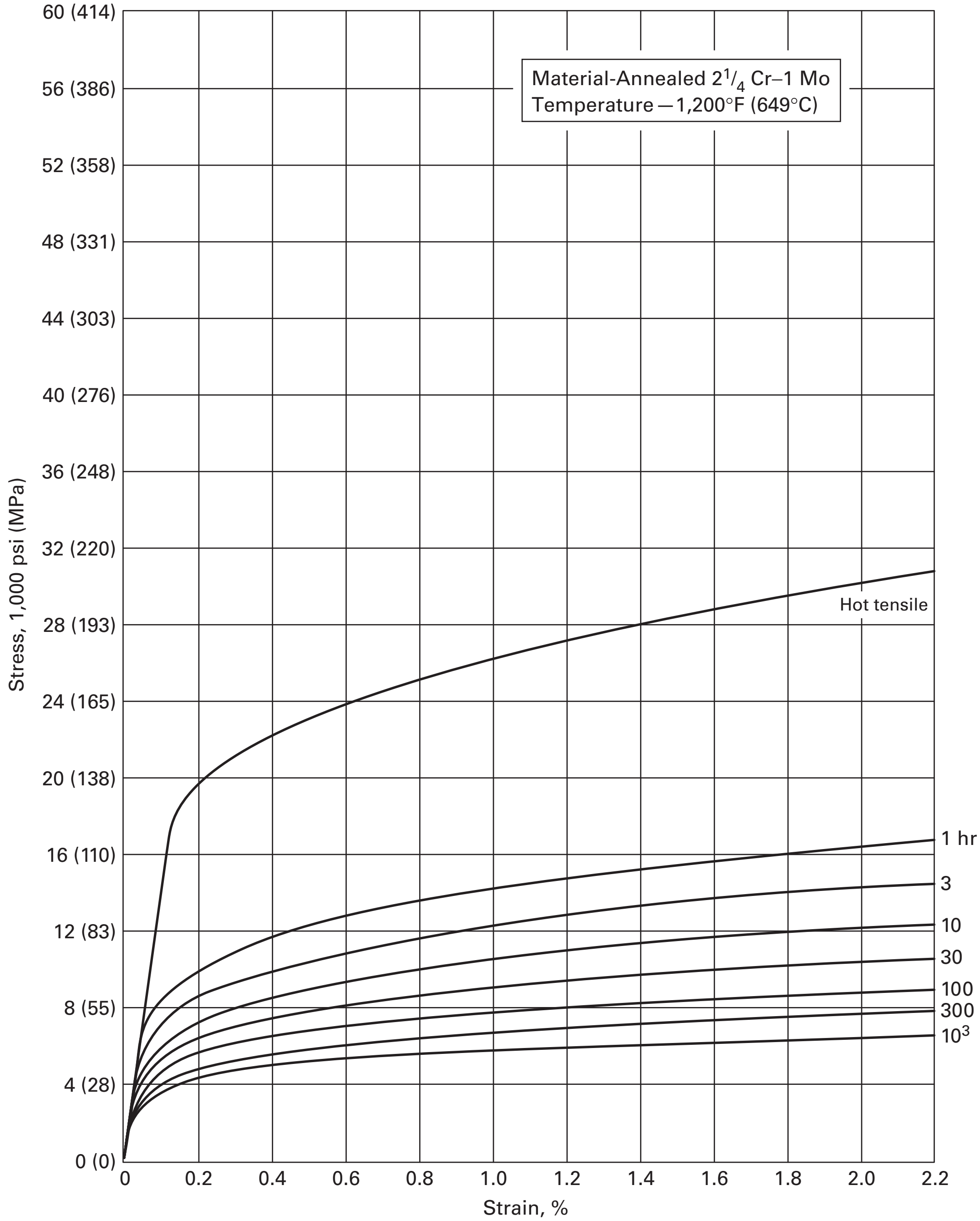


Figure NH-T-1800-E-1
Average Isochronous Stress–Strain Curves

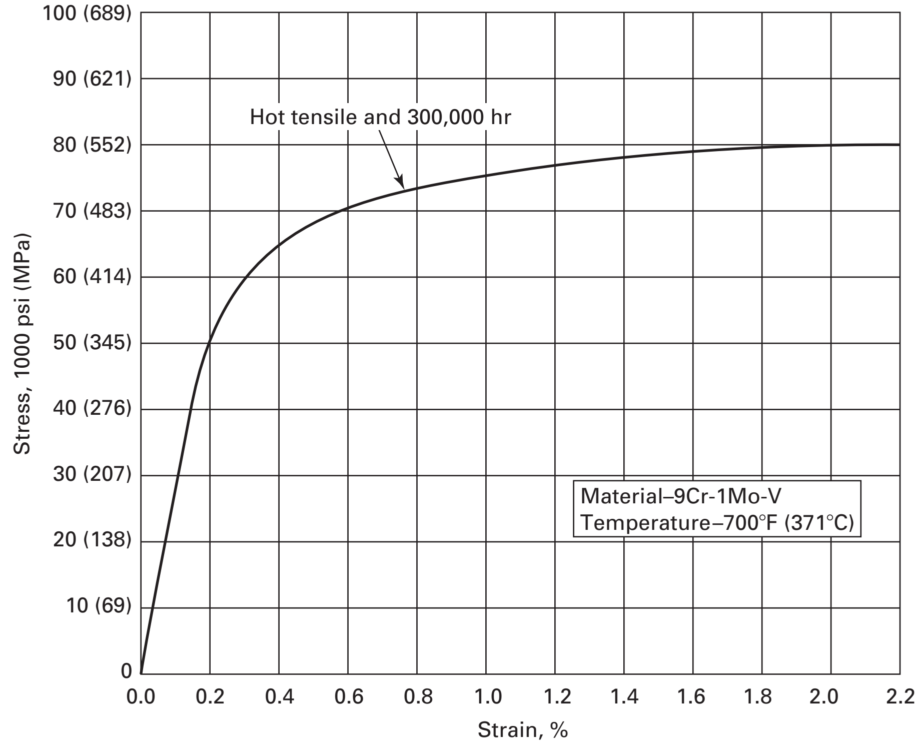


Figure NH-T-1800-E-2
Average Isochronous Stress–Strain Curves

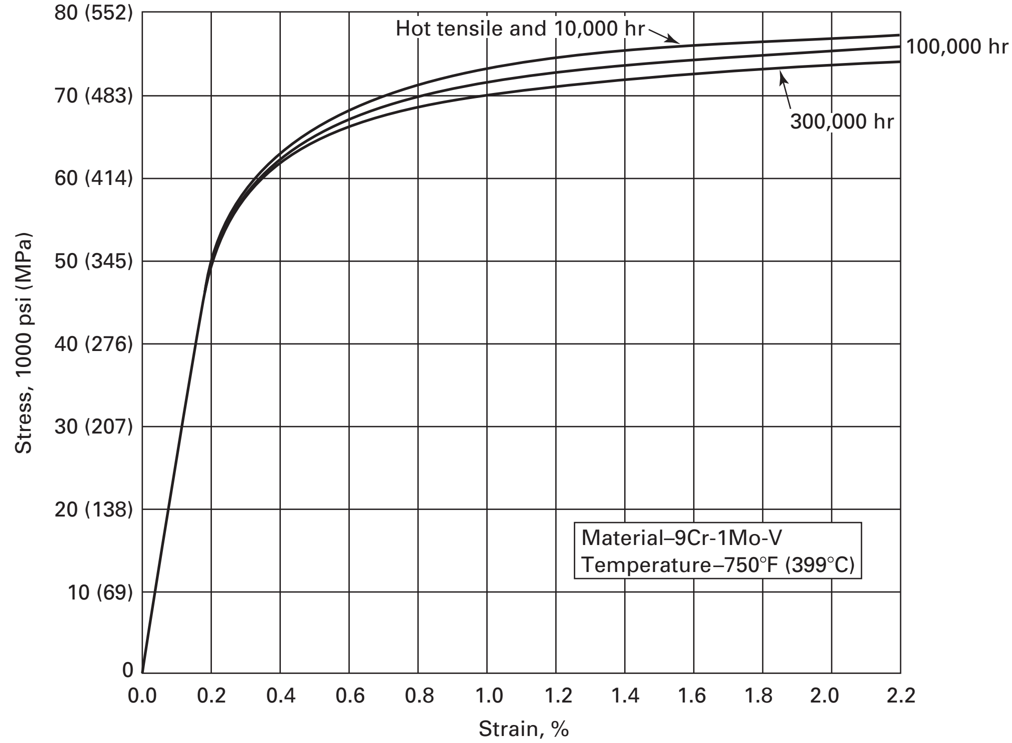


Figure NH-T-1800-E-3
Average Isochronous Stress–Strain Curves

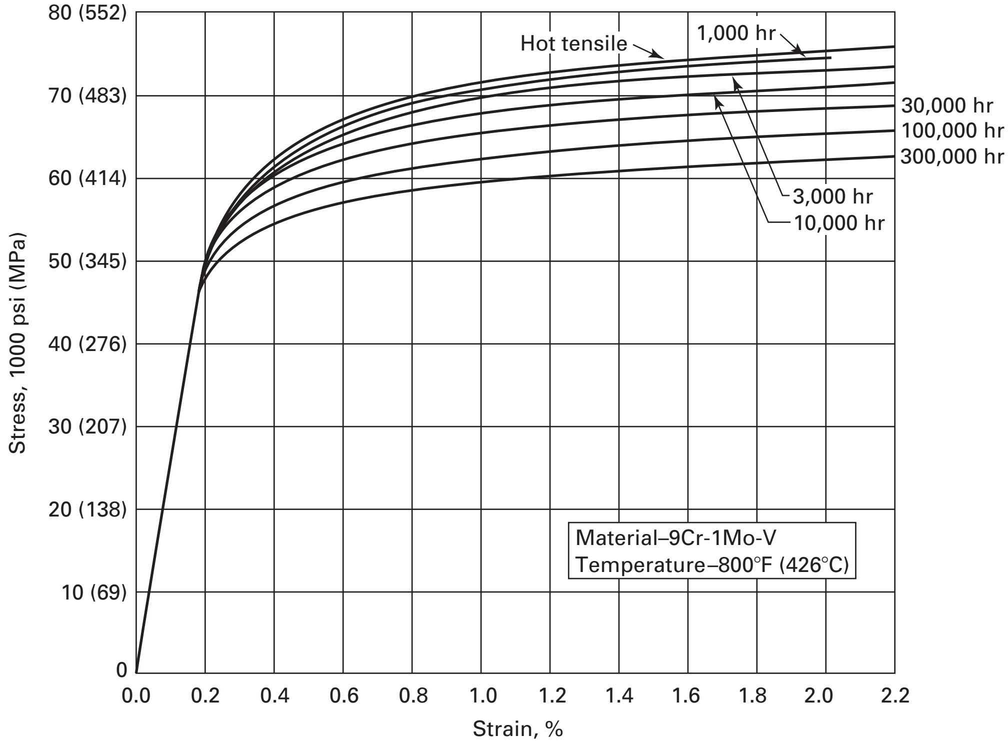


Figure NH-T-1800-E-4
Average Isochronous Stress–Strain Curves

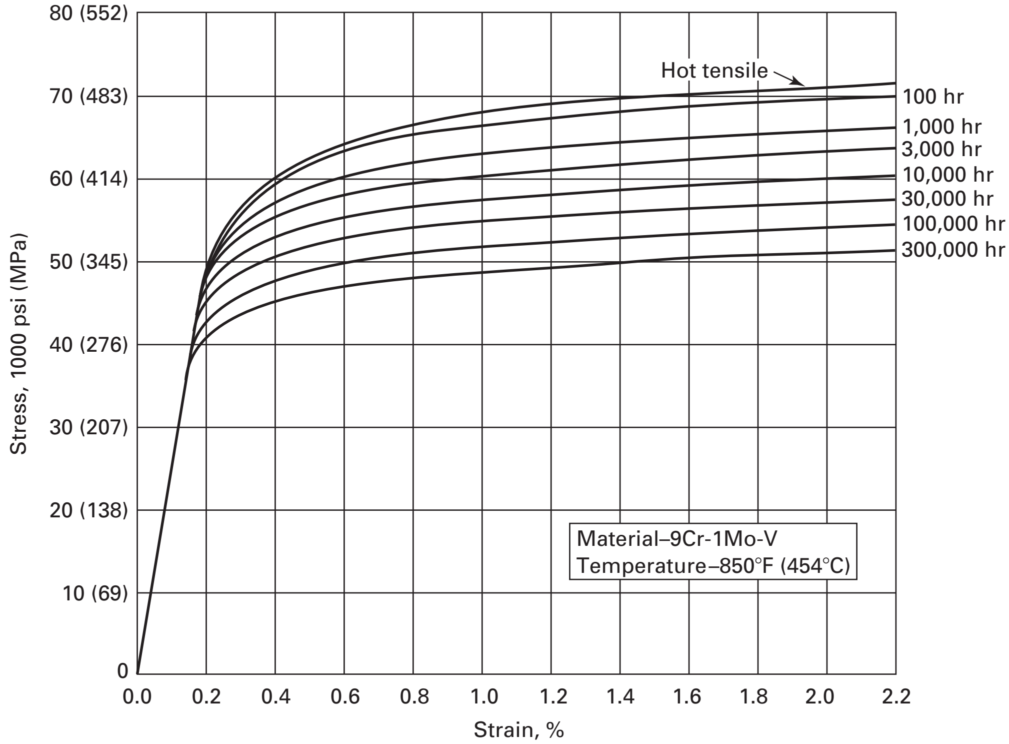


Figure NH-T-1800-E-5
Average Isochronous Stress–Strain Curves

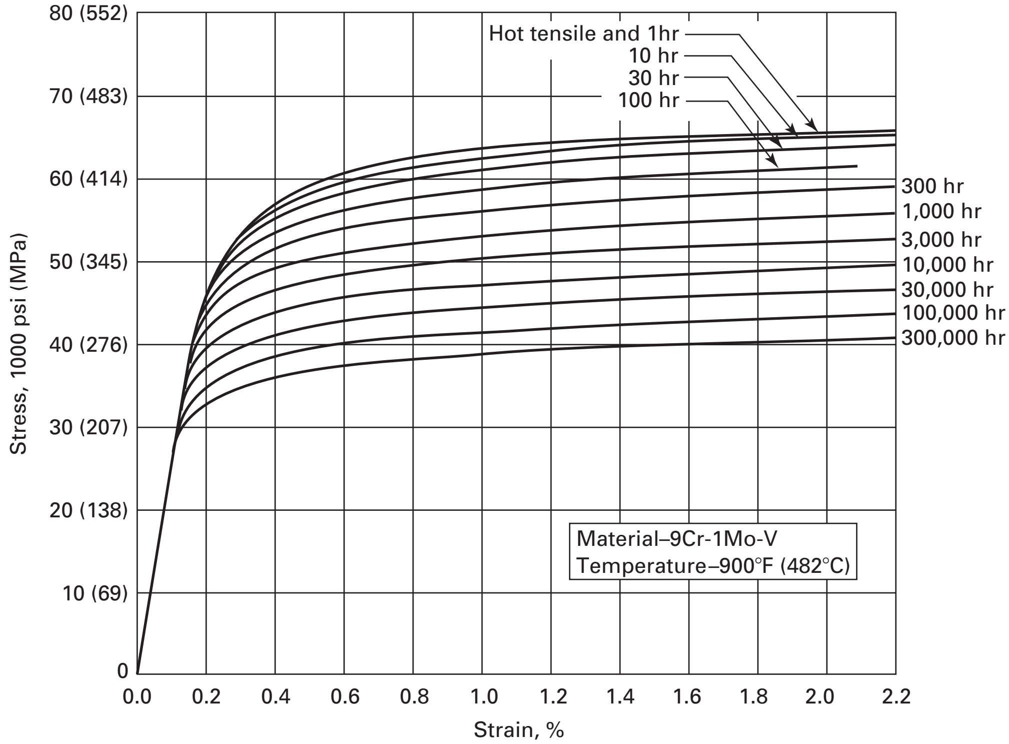


Figure NH-T-1800-E-6
Average Isochronous Stress–Strain Curves

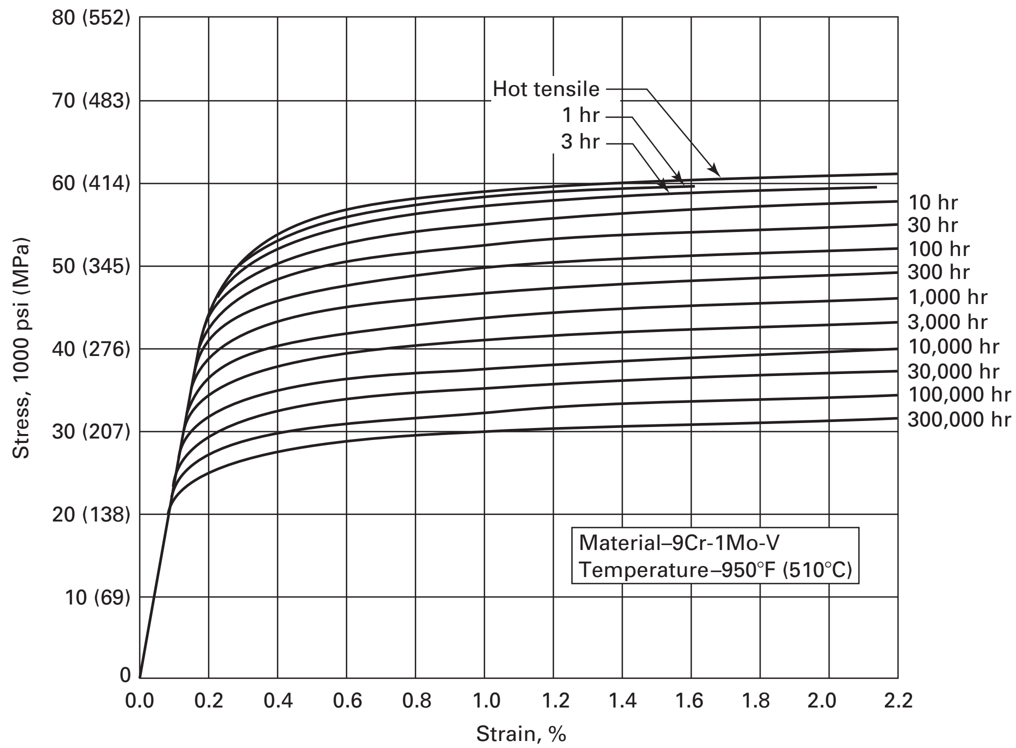


Figure NH-T-1800-E-7
Average Isochronous Stress–Strain Curves

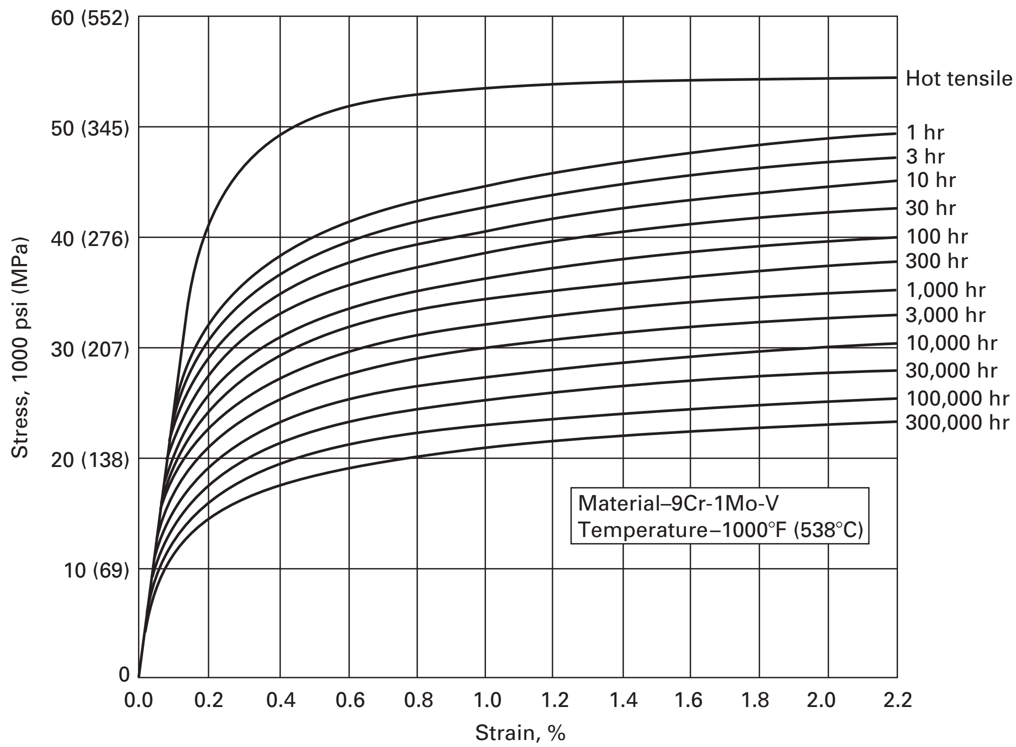


Figure NH-T-1800-E-8
Average Isochronous Stress–Strain Curves

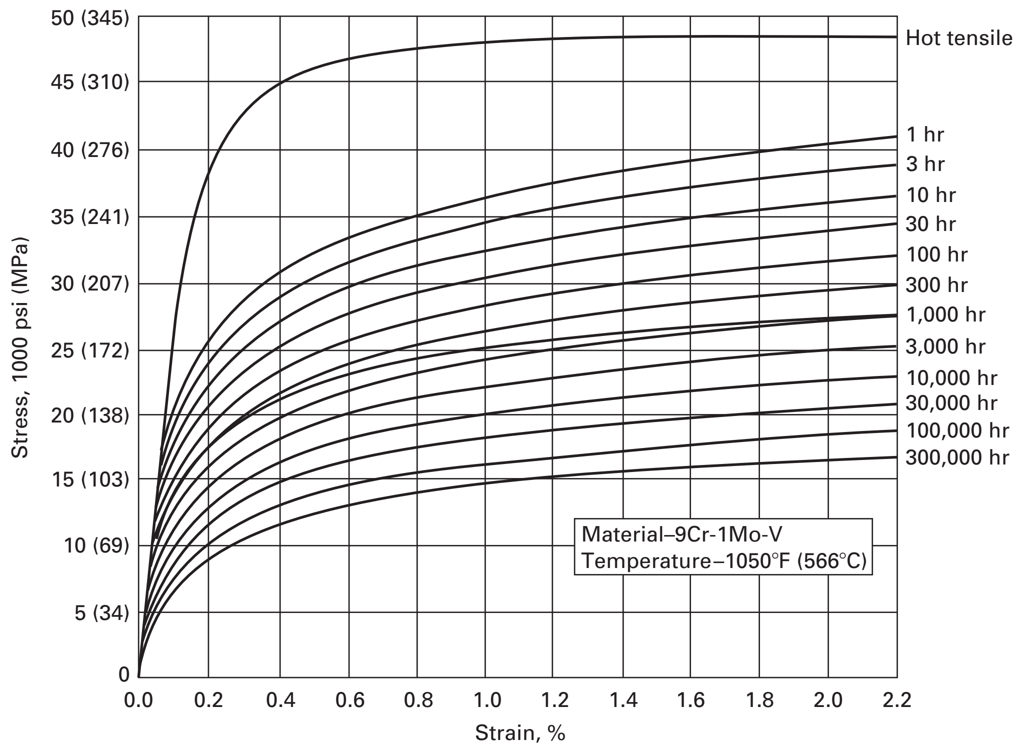


Figure NH-T-1800-E-9
Average Isochronous Stress–Strain Curves

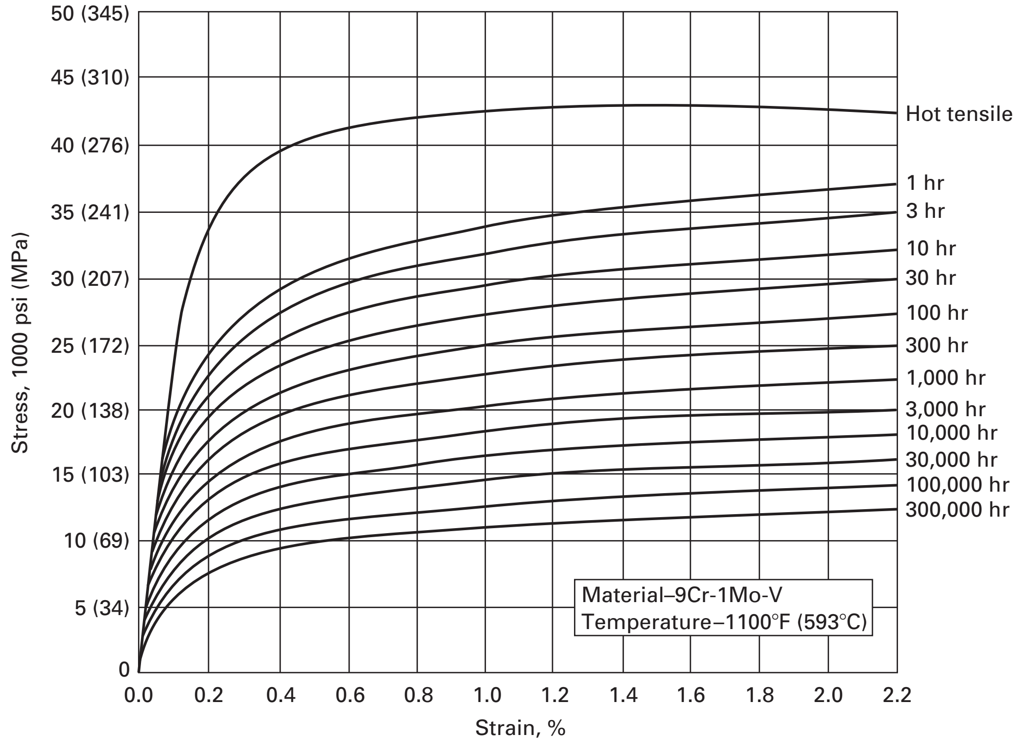


Figure NH-T-1800-E-10
Average Isochronous Stress–Strain Curves

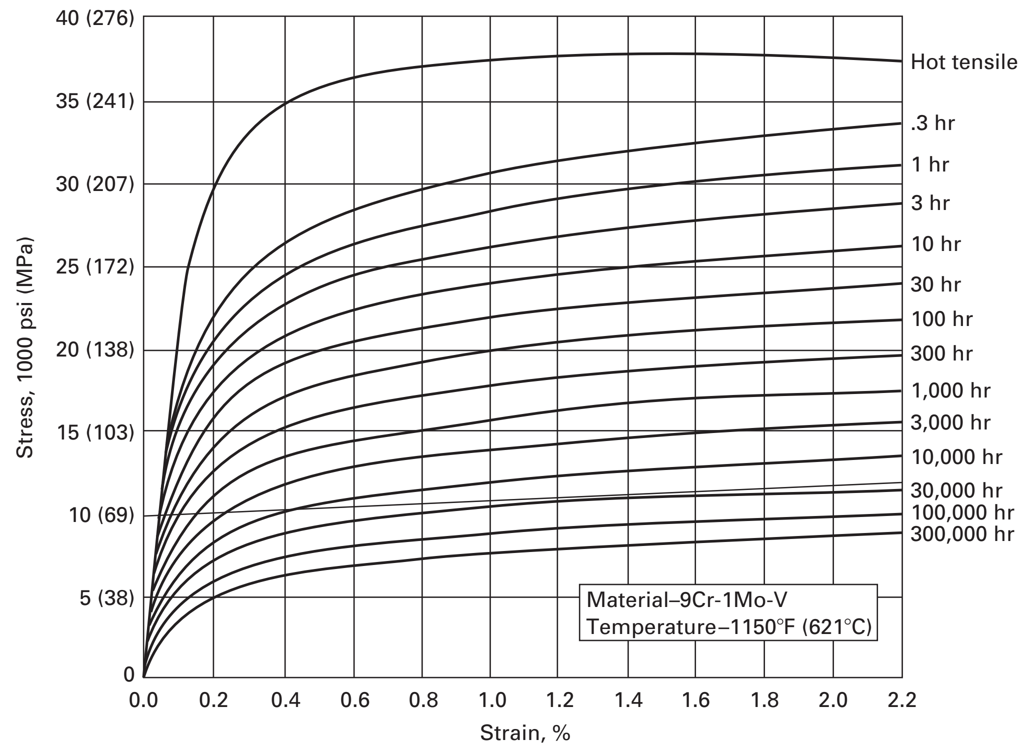
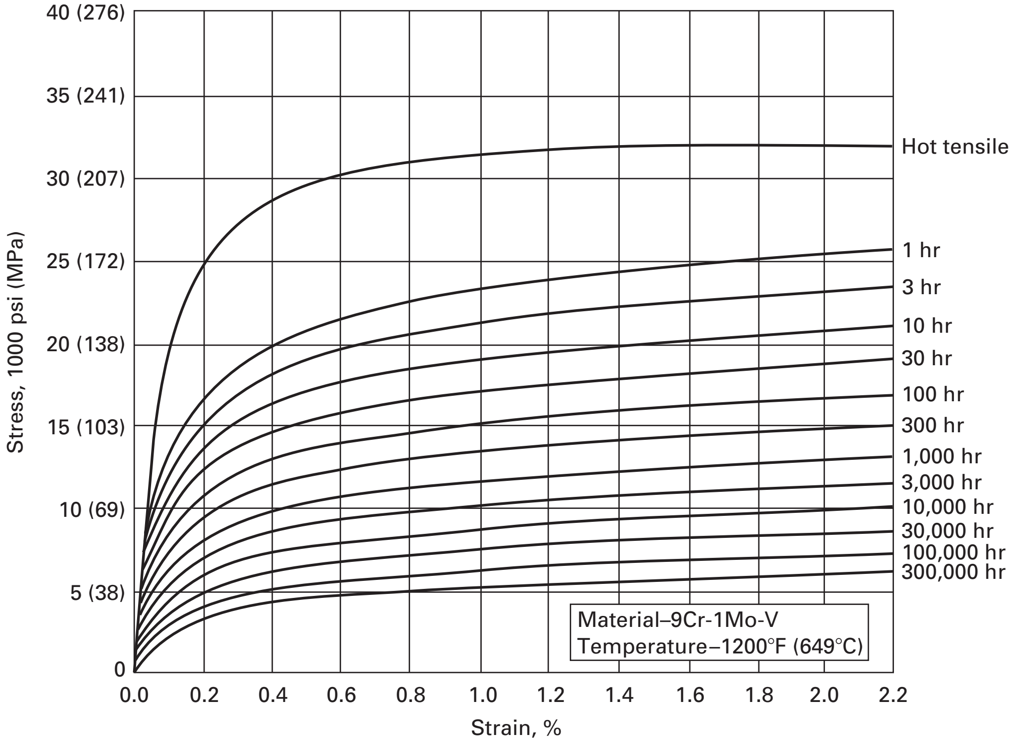


Figure NH-T-1800-E-11
Average Isochronous Stress–Strain Curves



NONMANDATORY APPENDIX NH-U GUIDELINES FOR RESTRICTED MATERIAL SPECIFICATIONS TO IMPROVE PERFORMANCE IN CERTAIN SERVICE APPLICATIONS

NH-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 NH-I-14.1(a) and its notes.

NH-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.

NH-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.

NH-U-1300 RECOMMENDED RESTRICTIONS

The recommended restrictions are shown in Table NH-U-1.

Table NH-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.

ENDNOTES

1 Different product forms, such as castings, are acceptable for the attachment.

2 A report documenting the experimental data or calculations based on experimental data or both shall demonstrate that the elevated temperature service does not introduce creep effects. This document shall be incorporated into the Design Report (NCA-3550) and shall be approved by the Owner by means of a certified revision to the Design Specifications (NCA-3250).

3 Note that the expansion stress (P_e) defined in NB-3222.3 is deleted for Subsection NH. Stresses resulting from the constraint of *free end displacement* and the effects of anchor motion shall be assigned to either primary or secondary stress categories [see NH-3213(a), NH-3213(b), and NH-3217].

4 This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

5 Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.

6 To satisfy eq. NH-3222.1(a)(1) for straight cylindrical shapes, the minimum wall thickness may be calculated by the equations in PG-27 of Section I, Power Boilers, using S_o in place of S.

7 S_t values to be used are twice those given in Figures NH-I-14.13A through NH-I-14.13C.

8 Communicating chambers are defined as appurtenances to the vessel that intersect the shell or heads of a vessel and form an integral part of the pressure-retaining closure, e.g., sumps.

9 Side plates of a flat-sided vessel are defined as any of the flat plates forming an integral part of the pressure-retaining enclosure.

10 Strain is defined as the maximum local fiber elongation or contraction per unit length; and where more than one strain increment occurs (e.g., biaxiality or reversed bending), it shall be the sum of the absolute values of all the strain increments.

11 Strain resulting from final straightening operations performed on materials furnished in the solution annealed or heat treated condition need not be included in the computation of strain.

12 Definitions are contained in the rules governing the design of Class 1 components in elevated temperature service.

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