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MARTIN MARIETTA

ANS Materials Databook

M. F. Marchbanks

August 1995

Advanced Neutron Source

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/M-4582

ADVANCED NEUTRON SOURCE MATERIALS DATABOOK

M. F. Marchbanks

August 1995

Prepared by
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
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LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

TABLE OF CONTENTS - MATERIALS

Selected properties are provided for the following materials. For a listing of the properties covered, see the TABLE OF CONTENTS - PROPERTIES at the beginning of each material section. The following list shows how the materials to be covered in the ANS Materials Information System are placed in the various designations (Part, Group, and Section) of the Chemical Code. Materials for which information is currently provided appear in **bold** type. Materials to be included in the future are in *italics*. The user may notice that there appear to be gaps in the chemical codes listed below. This is because the codes of this relatively limited number of materials are adapted from a much larger basic indexing system used by several different material property handbook and database projects covering a wide range of materials. It was found there are definite cost and accuracy benefits in using the Chemical Code notations from one "standard" system rather than developing a new list of codes for each project. See Appendix A of Volume 4 - Supporting Documentation, for a complete explanation of the Chemical Code indexing system.

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 1 - Material Property Summaries

CONTENTS

Page Revision 0.0

AMBK Update No. 0

Part-Group-Section Designations	Chemical Code	Manufacturing/ Process Code
6061-T6 Weldments	*BB01D*	*T6/WL*
2024	*BB02A*	
6063-T6	*BB03A*	*T6*
Group F - Iron Alloys	*BFxx*	
304 Stainless Steel	*BF01A*	
304L Stainless Steel	*BF01B*	
304LN Stainless Steel	*BF01C*	
304H Stainless Steel	*BF01D*	
304N Stainless Steel	*BF01E*	
302 Stainless Steel	*BF02A*	
316 Stainless Steel	*BF04A*	
316L Stainless Steel	*BF04B*	
316LN Stainless Steel	*BF04C*	
20% Cold-Worked 316SS	*BF04D*	*CW20*
321 Stainless Steel	*BF05A*	
A-286 Steel	*BF06A*	
17-4 PH Stainless Steel	*BF07A*	
410 Stainless Steel	*BF08A*	
Nitronic 60 Stainless Steel	*BF10A*	
Group I - Nickel Alloys	*BIxx*	
Alloy 600	*BI01*	
Alloy 625	*BI02*	
Alloy 718	*BI03*	
Generic Alloy X-750	*BI04*	

The *Advanced Neutron Source Materials Databook* (*AMBK*) is a multi-volume document compiled to meet the broad materials data needs of the designer, safety analyst, and materials engineer for the Advanced Neutron Source (ANS). The *AMBK* activity is sponsored by the U.S. Department of Energy's (DOE) Basic Energy Sciences Division of Energy Research (ER). Contributions to the *AMBK* contain information collected by and prepared by writing groups of experts approved by the ANS project. The intent is to provide urgently needed data on a quick-turnaround support basis for those design applications whose schedules demand immediate estimates of materials properties. Information in the document is classified into two levels: (a) "as-received" information that is presented in the form in which it was received, with no analysis or review having been performed, and (b) "draft" analysis and summary versions of the as-received information. The draft versions will be submitted to the ANS review and approval process in preparation for inclusion into the approved version of the *AMBK*, the *ANS Materials Handbook* (*AMHB*).

Pages are edited and published by Oak Ridge National Laboratory (ORNL), operated by Martin Marietta Energy Systems, Inc. Distribution is limited to DOE and DOE contractors and subcontractors, subject to DOE concurrence, who are engaged in ANS system activities. Distribution of the *AMBK* is controlled for the purpose of updating, since it is being revised continuously. Proposed additions, revisions, or comments and requests for copies should be forwarded to:

M. F. Marchbanks, Chairman
ANS Materials Information System Advisory Group
Oak Ridge National Laboratory
P. O. Box 2009
Oak Ridge, TN 37831-8051

The information in the *AMBK* is also provided in a computer database. Requests to access the database should also be directed to the above address.

PURPOSE

Technical development in the Advanced Neutron Source (ANS) project is dynamic, and a continuously updated information source is necessary to provide readily usable materials data to the designer, analyst, and materials engineer. The *Advanced Neutron Source Materials Databook* (*AMBK*) is being developed as a part of the Advanced Neutron Source Materials Information System (AMIS). Its purpose is to provide urgently needed data on a quick-turnaround support basis for those design applications whose schedules demand immediate estimates of material properties. In addition to the need for quick materials information, there is a need for consistent application of data throughout the ANS Program, especially where only limited data exist. The *AMBK* is being developed to fill this need as well. It is the forerunner to the *Advanced Neutron Source Materials Handbook* (*AMHB*). The *AMHB*, as reviewed and approved by the ANS review process, will serve as a common authoritative source of materials data in support of the ANS Project. It will furnish documented evidence of the materials data used in the design and construction of the ANS system and will serve as a quality record during any review process whose objective is to establish the safety level of the ANS complex.

The information in the *AMBK* and *AMHB* is also provided in electronic form in a dial-up computer database known as the ANS Materials Database (AMDB).

A single consensus source of materials information prepared and used by all national program participants has several advantages. Overlapping requirements and data needs of various sub-projects and subcontractors can be met by a single document which is continuously revised. Preliminary and final safety analysis reports, stress analysis reports, equipment specifications, materials service reports, and many other project-related documents can be substantially reduced in size and scope by appropriate reference to a single data source. The *AMBK* and *AMHB* will provide a broad base of materials data and process experience to support the ANS Program.

The procedures for preparing, maintaining, distributing, controlling, and storing the *AMBK* and *AMHB* are specified in the AMIS *General Operating Guide*. The *AMHB* will fully meet NQA-1 Basic Requirement #17, the requirements identified in NQA-1 Supplement 17S-1, and the requirements identified in NQA-3 Supplement 3SW-1.

SCOPE

The *AMBK* includes property data for all materials used in the ANS systems. Sections on structural materials, fuel materials, absorber materials, shielding, non-metallics, and coolants will be included. Information in the *AMBK* is of two major types: (a) "as-received" information that is presented in the form in which it was received, with no analysis or review having been performed, and (b) a "draft" analysis and summary version of the as-received information. The draft versions will be submitted to the ANS review and approval process in preparation for inclusion into the *AMHB*.

The *AMBK* consists of four volumes having the following titles: Volume 1 - **Material Property Summaries,** Volume 2 - **Material Property Analyses,** Volume 3 - **Materials and Processes,** and Volume 4 - **Supporting Documentation**.

Volume 1 contains proposed "best-fit" property values represented by curves, equations, and tables for metallic and nonmetallic materials.

Volume 2 contains selected data, reference, notations, rationale, and method of analysis used in establishing the best-fit material properties in Volume 1. Since Volumes 1 and 2 are complementary they use a common indexing system. The "as-received" information mentioned above is contained primarily in Volume 2. Pages with as-received information are differentiated from the "draft" pages by the heading, **WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION**. In addition, they are printed on pink or rose colored paper and the Chemical Code (see Appendix B) at the top of the page is preceded by the characters "AR," indicating as-received information. These are temporary pages provided in this format in order to avoid the delay associated with preparing the analyzed draft pages in the usual *AMBK* format. *Note that these "as-received" pages have not been approved for use in final design. They are provided in this format so that urgently needed data may be available early-on as a convenience to the ANS designer.*

Volume 3 is designed primarily for the materials and manufacturing engineers. It contains manufacturing and process information. It will be a guideline document to aid the development of safe, reliable, and economic ANS systems, and will use experience gained from "lessons learned."

Volume 4 contains a bibliography and appendices. The bibliography section lists all sources used in Volumes 1 to 3 and also contains additional references considered to be of potential value.

The appendices contain special notes on data organization and presentation as well as other information applicable to Volumes 1 to 3. The information in Volumes 1 to 3 will subsequently be submitted for review and approval for input into the *AMHB*.

INTERFACES

The AMIS activity interfaces with national codes, standards, and other authoritative data sources. No attempt will be made to reproduce all of the material properties available for each material.

Reference will be made to other data sources when appropriate.
The choice of which properties to reproduce for the convenience of the user will be made by the ANS Advisory Group. In those cases where material properties developed for inclusion in the AMIS differ from those of the ASME Boiler and Pressure Vessel Code, the information will be properly qualified by appropriate notation. Efforts will be initiated to resolve the differences noted by appropriate interface with the responsible committee.

REVISION AND ADDITIONS

The *AMBK* is a "living" document. Users will be provided with copies of new and revised pages as they become available. These new pages will be distributed on approximately a quarterly basis, depending first upon urgency and, secondly, upon availability of a reasonable number of pages to comprise a print package. The sets of new and revised pages will be referred to as Update Packages and will be assigned consecutive numbers 1 through X. Each page in the *AMBK* shows the Update Package number in the shaded title box in the upper right-hand corner. This facilitates traceability when the databook is referenced.

ORGANIZATION

The *AMBK* uses an indexing scheme that will allow insertion of new pages without the necessity of renumbering pages already in the databook. This also makes it possible to keep pages treating identical or related subjects grouped together. In Volumes 1 and 2, materials are indexed by Parts, Groups, and Sections, with each division being identified by tabbed dividers. Properties are indexed in numerical order, according to a code number. A detailed explanation of the organization of the materials and properties is given in Appendix A.

PAGE NUMBERING

The page numbers in Volumes 1 and 2 run consecutively from 1.1-1X or 2.1-2.X, etc., for each Property Code. The integer portion of the page number is used to segregate minor differences such as average and minimum values under the same Property Code.

UPDATE PACKAGE NOTATION

Each page contains a special collation code on the lower right hand corner that includes the Update Package number followed by a slash ("/"), the volume number, and the page number within the Update Package. Use of this feature aids the printer and helps the user in the insertion of updates.

TABLE OF CONTENTS

There are two types of Tables of Contents in Volumes 1 and 2. The first lists the materials covered and is located in the front of each volume after the green tab labeled "CONTENTS." The second type of contents table lists the properties covered for each material. This table immediately follows each yellow tab.

REVISION CONTROL PAGE

FOREWORD

INTRODUCTION

TABLE OF CONTENTS - MATERIALS

Selected properties are provided for the following materials. For a listing of the properties covered, see the TABLE OF CONTENTS - PROPERTIES at the beginning of each material section. The following list shows how the materials to be covered in the ANS Materials Information System are placed in the various designations (Part, Group, and Section) of the Chemical Code. Materials for which information is currently provided appear in **bold type**. Materials to be included in the future are in *italics*. The user may notice that there appear to be gaps in the chemical codes listed below. This is because the codes of this relatively limited number of materials are adapted from a much larger basic indexing system used by several different material property handbook and database projects covering a wide range of materials. It was found there are definite cost and accuracy benefits in using the Chemical Code notations from one "standard" system rather than developing a new list of codes for each project. See Appendix A of Volume 4 - Supporting Documentation, for a complete explanation of the Chemical Code indexing system.

Part-Group-Section Designations	Chemical Code	Manufacturing/ Process Code
Part A - Elements	*Axxx*	
Group A - Metals	*AAxx*	
Group B - Metalloids	*ABxx*	
Group C - Non-Metals	*ACxx*	
Part B - Alloys	**Bxxx**	
Group A - Beryllium Alloys	*BAxx*	
Group B - Aluminum Alloys	**BBxx**	
Generic (All Aluminum Alloys)	**BB00**	
Generic 6061	**BB01**	
6061-T6	**BB01A**	**T6**
6061-T0	*BB01B*	*T0*
6061-T651	**BB01C**	**T651**

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 2 - Material Property Analyses

FOREWORD

Page Revision 0.0
AMBK Update No. 0

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Volume 2 contains selected data, reference, notations, rationale, and method of analysis used in establishing the best-fit material properties in Volume 1. The "as-received" information mentioned above is contained primarily in Volume 2. It is differentiated from the "draft" pages by the heading, **WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION**. These are temporary pages provided in this format in order to avoid the delay associated with preparing the analyzed draft pages in the usual *AMBK* format. *Note that these "as-received" pages have not been approved or recommended for use in final design. They are provided in this format so that urgently needed data may be available early-on as a convenience to the ANS designer.*

Volume 2 of the *AMBK* is organized in exactly the same manner as Volume 1. Rather that repeat a description of the method of organization, the reader is referred to Volume 1.

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Advanced Neutron Source

Vol 2 - Material Property Analyses

Aluminum Alloys
Poisson's Ratio
Page Revision 0.0
AMBK Update No. 0

****AS-RECEIVED INFORMATION *****

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TABLE NF-1
TYPICAL MECHANICAL
PROPERTIES OF MATERIALS

Material	Poisson's Ratio
Aluminum	0.33

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Advanced Neutron Source

Vol 2 - Material Property Analyses

**AS-RECEIVED INFORMATION **

WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCE NO. 12

TABLE NF-1
TYPICAL MECHANICAL
PROPERTIES OF MATERIALS

Material	Modulus of Rigidity, psi
Aluminum	3,800,000

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****AS-RECEIVED INFORMATION ****

Aluminum Alloys
Thermal Emissivity
Page Revision 0.0
AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION DIRECTLY TRANSFERRED FROM AMIS REFERENCE NO. 20

2.9. Normal Total Emittance

For 298 K $\leq$ T $\leq$ 933.45 K,

$$\varepsilon = 0.0294 + 4.878 \times 10^{-5}\, T$$

The recommended equation is that derived by Sienicki[24] to represent the experimental data in the temperature range from 311 to 780 K gathered by Touloukian and DeWitt.[25] The measured values show little variation with temperature. The variation with type and condition of the aluminum is illustrated by the range in experimental results at a single temperature. At 311 K, measured emittances range from 0.34 to 0.10 in 15 separate studies.

Measurements of the normal total emittance were made on cleaned, polished, and oxidized aluminum, embossed, bright, and roughened aluminum foil, polished sheet, and commercial aluminum sheet. Touloukian and DeWitt also included in their tabulation and graphs the results of measurements of the emittance of white painted aluminum but these differ greatly from values obtained for pure aluminum and were not included in the data set from which the above equation was derived.

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Advanced Neutron Source

Vol 2 - Material Property Analyses

AS-RECEIVED INFORMATION

TABLE OF CONTENTS

- PROPERTIES -

Page Revision 0.0

AMBK Update No. 0

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Advanced Neutron Source

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**AS-RECEIVED INFORMATION **

Aluminum Alloy 6061
Chemical Composition
Page Revision 0.0
AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION DIRECTLY TRANSFERRED FROM ANS REFERENCE NO. 13

Table 3. Chemical composition of 6061 aluminum by weight percent

Element	Specification SB-209	ANS Special Chemistry
Silicon	0.4-0.8	0.4-0.5
Iron	0-0.7	0-0.1
Copper	0.15-0.40	0.15-0.40
Mananese	0-0.15	0-0.15
Magnesium	0.8-1.2	0.8-1.2
Chromium	0.04-0.35	0.04-0.06
Zinc	0-0.25	0.002-0.004
Titanium	0-0.15	0-0.15
Zirconium	0-0.05*	0-0.05*
Carbon	0-0.05*	0-0.05*
Hydrogen	0-0.05*	0-0.05*
Oxygen	0-0.05*	0-0.05*
Nickel	0-0.05*	0-0.05*
Lead	0-0.05*	0-0.05*
Tin	0-0.05*	0-0.05*
Aluminum	Remainder	Remainder

*Total of other elements including these elements can't exceed 0.15 percent.

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Advanced Neutron Source

Vol 2 - Material Property Analyses

****AS-RECEIVED INFORMATION ****

Aluminum Alloy 6061
Young's Modulus
Page Revision 0.0
AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCE NO. 12

TABLE TM-2
MODULI OF ELASTICITY *E* OF ALUMINUM AND ALUMINUM ALLOYS
FOR GIVEN TEMPERATURES

Material	Modulus of Elasticity E = Value Given × 10^6 psi, for Temp., °F, of							
	−325	−200	−100	70	200	300	400	500
A96061 (6061)	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 2 - Material Property Analyses

****AS-RECEIVED INFORMATION *****

Aluminum Alloy 6061
Melting Point
Page Revision 0.0
AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED , UNREVIEWED SUMMARY INFORMATION FROM AMIS REFERENCE NO. 12

PART D — PROPERTIES

TABLE NF-2
TYPICAL PHYSICAL PROPERTIES OF MATERIALS

Material	Approx. Melting Range, °F
6061	1080–1205

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 2 - Material Property Analyses

AS-RECEIVED INFORMATION

Aluminum Alloy 6061
Specific Heat
Page Revision 0.0
AMBK Update No. 0

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PART D — PROPERTIES

TABLE NF-2
TYPICAL PHYSICAL PROPERTIES OF MATERIALS

Material	Specific Heat, Btu/lb/°F at 212°F
6061	0.23

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Advanced Neutron Source

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****AS-RECEIVED INFORMATION ****

Aluminum Alloy 6061
Thermal Diffusivity
Page Revision 0.0
AMBK Update No. 0

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NOMINAL COEFFICIENTS OF THERMAL DIFFUSIVITY (TD)

6061 Alloy

Deg F	TD
70	2.66
100	2.66
150	2.65
200	2.65
250	2.64
300	2.63
350	2.62
400	2.62

GENERAL NOTE:

TC is the thermal conductivity, Btu/hr-ft-F, and TD is the thermal diffusivity, ft^2/hr:

$$TD = \frac{TC\ (Btu/hr-ft-F)}{Density\ (lb/ft^3) \times Specific\ Heat\ (Btu/lb-F)}$$

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 2 - Material Property Analyses

**AS-RECEIVED INFORMATION **

Aluminum Alloy 6061
Thermal Conductivity
Page Revision 0.0
AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCE NO. 12

NOMINAL COEFFICIENTS OF THERMAL CONDUCTIVITY (TC)

6061 Alloy

Deg F	TD
79	96.1
100	96.9
150	98.0
200	99.0
250	99.8
300	100.6
350	101.3
400	101.9

GENERAL NOTE:

TC is the thermal conductivity, Btu/hr-ft-F, and TD is the thermal diffusivity, ft^2/hr:

$$TD = \frac{TC\ (Btu/hr-ft-F)}{Density\ (lb/ft^3) \times Specific\ Heat\ (Btu/lb-F)}$$

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**AS-RECEIVED INFORMATION **

Aluminum Alloy 6061
Coefficient of Thermal Expansion
Page Revision 0.0
AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED, UNREVIEWED SUMMARY INFORMATION FROM AMIS REFERENCE NO. 12

Table TE-2 1992 SECTION II

TABLE TE-2
NOMINAL COEFFICIENTS OF THERMAL EXPANSION FOR ALUMINUM ALLOYS

Materials	Coef-ficient	Temperature, °F 70	100	150	200	250	300	350	400
6061	A	12.52	12.70	13.01	13.31	13.62	13.92	14.22	14.53
	B	...	12.60	12.76	12.91	13.07	13.22	13.37	13.52
	C	0	0.0045	0.0122	0.0201	0.0282	0.0365	0.0449	0.0535

GENERAL NOTE:
Coefficient A is the instantaneous coefficient of thermal expansion × 10^{-6} (in./in./°F). Coefficient B is the mean coefficient of thermal expansion × 10^{-6} (in./in./°F) in going from 70°F to indicated temperature. Coefficient C is the linear thermal expansion (in./ft) in going from 70°F to indicated temperature.

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AS-RECEIVED INFORMATION

Aluminum Alloy 6061
Density
Page Revision 0.0
AMBK Update No. 0

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Density
lb/cu inch
0.098

Advanced Neutron Source

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****AS-RECEIVED INFORMATION *****

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- PROPERTIES -

Page Revision 0.0

AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCE NO. 15

TABLE 1. SPECIFICATIONS

SB-209	Sheet and Plate
SB-210	Drawn Seamless Tube
SB-241/SB-241M	Seamless Pipe and Seamless Extruded Tube
SB-221	Extruded Bar, Rod, and Shape
SB-247	Die and Hand Forgings
SB-211	Bar, Rod, and Wire
SB-234	Drawn Seamless Tubes for Condensers and Heat Exchangers
SB-308/SB-308M	Standard Structural Shapes

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 2 - Material Property Analyses

**AS-RECEIVED INFORMATION **

Aluminum Alloy 6061-T6
Design Stress Intensity Values, S_m
Page Revision 0.0
AMBK Update No. 0

WARNING - THIS IS AS-RECEIVED , UNREVIEWED INFORMATION DIRECTLY TRANSFERRED FROM ANS REFERENCE NO. 15

TABLE 3. DESIGN STRESS INTENSITY VALUES, S_m, FOR 6061-T6 ALUMINUM

Spec. No.	Temper	Size or thickness (in)	Specified Min. Tensile Strength (ksi)	Specified Min. Yield Strength (ksi)	Notes	Allowable Stress, ksi, for Metal Temp., °F, Not Exceeding 100	150	200	250	300
Sheet and Plate										
SB-209	T6	0.051-0.249	42	35	(1)(2)	14.0	14.0	14.0	13.4	11.3
	T6,T651 Wld.	All	24		(1)	8.0	8.0	8.0	7.9	7.3
Rod, Bar, and Shape										
SB-221	T6	All	38	35	(1)(2)	12.7	12.7	12.7	12.3	10.5
	T6 Wld.	All	24		(1)	8.0	8.0	8.0	7.9	7.3
Drawn Seamless Tube										
SB-210	T6	0.025-0.500	42	35	(1)(2)	14.0	14.0	14.0	13.4	11.3
	T6 Wld.	All	24		(1)	8.0	8.0	8.0	7.9	7.3
Seamless Pipe										
SB-241	T6	<1	42	35	(1)(2)	14.0	14.0	14.0	13.4	11.3
	T6	≥1	38	35	(1)(2)	12.7	12.7	12.7	12.3	10.5
	T6 Wld.	All	24		(1)	8.0	8.0	8.0	7.9	7.3
Seamless Extruded Tube										
SB-241	T6	All	38	35	(1)(2)	12.7	12.7	12.7	12.3	10.5
	T6 Wld.	All	24		(1)	8.0	8.0	8.0	7.9	7.3
Die and Hand Forgings										
SB-247	Die T6	Up thru 4.000	38	35	(1)(2)	12.7	12.7	12.7	12.1	10.5
	Hand T6	Up thru 4.000	37	33	(1)(2)	12.3	12.3	12.3	11.7	10.3
	Hand T6	4.000-8.000	35	32	(1)(2)	11.7	11.7	11.7	11.2	9.9
	T6 Wld.	Up thru 8.000	24		(1)	8.0	8.0	8.0	7.9	7.3

Notes:
1. Design stress intensity values for 100°F may be used at temperatures down to -452°F without additional specification requirements.
2. The stress values given for this material are not applicable when either welding or thermal cutting is employed.

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 2 - Material Property Analyses

**AS-RECEIVED INFORMATION **

Aluminum Alloy 6061-T6
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TABLE 5. TENSILE STRENGTH VALUES, S_u, FOR 6061-T6 ALUMINUM

Spec. No.	Temper	Size or thickness (in)	Specified Min. Tensile Strength (ksi)	Tensile Strength, ksi, for Metal Temp., °F, Not Exceeding 100	150	200	250	300
Sheet and Plate								
SB-209	T6	0.051-0.249	42	42.0	42.0	42.0	40.2	33.9
	T6,T651 Wld.	All	24	24.0	24.0	24.0	23.7	21.9
Rod, Bar, and Shape								
SB-221	T6	All	38	38.0	38.0	38.0	36.9	31.5
	T6 Wld.	All	24	24.0	24.0	24.0	23.7	21.9
Drawn Seamless Tube								
SB-210	T6	0.025-0.500	42	42.0	42.0	42.0	40.2	33.9
	T6 Wld.	All	24	24.0	24.0	24.0	23.7	21.9
Seamless Pipe								
SB-241	T6	<1	42	42.0	42.0	42.0	40.2	33.9
	T6	≥1	38	38.0	38.0	38.0	36.9	31.5
	T6 Wld.	All	24	24.0	24.0	24.0	23.7	21.9
Seamless Extruded Tube								
SB-241	T6	All	38	38.0	38.0	38.0	36.3	31.5
	T6 Wld.	All	24	24.0	24.0	24.0	23.7	21.9
Die and Hand Forgings								
SB-247	Die T6	Up thru 4.000	38	38.0	38.0	38.0	36.3	31.5
	Hand T6	Up thru 4.000	37	37.0	37.0	37.0	35.1	30.9
	Hand T6	4.000-8.000	35	35.0	35.0	35.0	33.6	29.7
	T6 Wld.	Up thru 8.000	24	24.0	24.0	24.0	23.7	21.9

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TABLE 4. VALUES OF YIELD STRENGTH S_y FOR 6061-T6 ALUMINUM

Spec. No.	Temper	Thickness, in.	Notes	Yield Strength, ksi (Multiply by 1000 to Obtain psi), for Metal Temp., °F, Not Exceeding						
				100	150	200	250	300	350	400
Sheet and Plate SB-209	T6	0.051-0.249	...	35.0	34.6	33.7	32.4	27.4	20.0	13.3
Rod, Bar, and Shape SB-221	T6	All	(1)	35.0	34.6	33.7	32.4	27.4	20.0	13.3
Drawn Seamless Tube SB-210	T6	0.025-0.500	...	35.0	34.6	33.7	32.4	27.4	20.0	13.3
Seamless Pipe SB-241	T6	All	(2)	35.0	34.6	33.7	32.4	27.4	20.0	13.3
Seamless Extruded Tube SB-241	T6	All	(1)	35.0	34.6	33.7	32.4	27.4	20.0	13.3
Die and Hand Forgings SB-247	Die-T6	≤4.000		35.0	34.6	33.7	32.4	27.4	20.0	13.3
	Hand-T6	≤4.000		33.0	32.6	31.8	30.5	25.8	18.9	12.5
	Hand-T6	4.001-8.000		32.0	31.6	30.8	29.6	25.1	18.3	12.2
Welds		≤0.375		20.0	19.8	19.3	18.5	15.7	11.4	7.6
		≥0.375		15.0	14.8	14.4	13.9	11.7	8.6	5.7

Notes:

(1) For stress-relieved temper (T-651), stress values for material in the basic temper shall be used.

(2) All standard pipe sizes.

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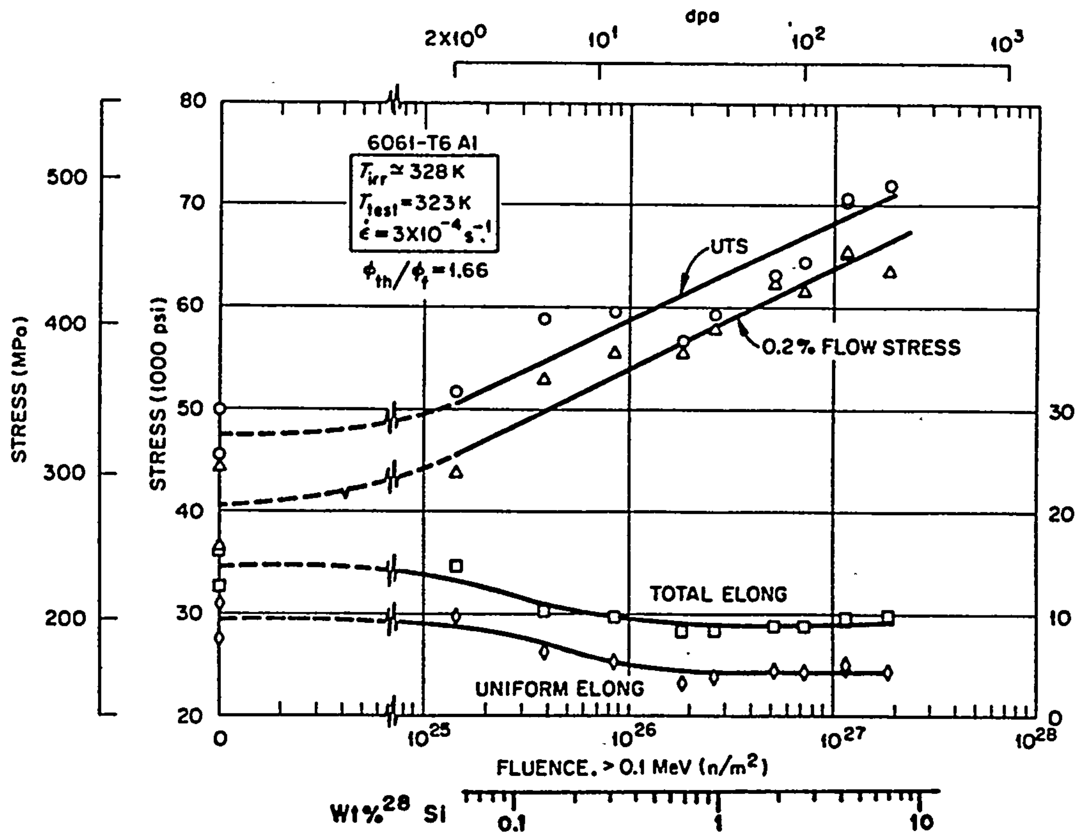

FIG. 2—*Fluence dependence of tensile properties of 6061-T6 at 323 K.*

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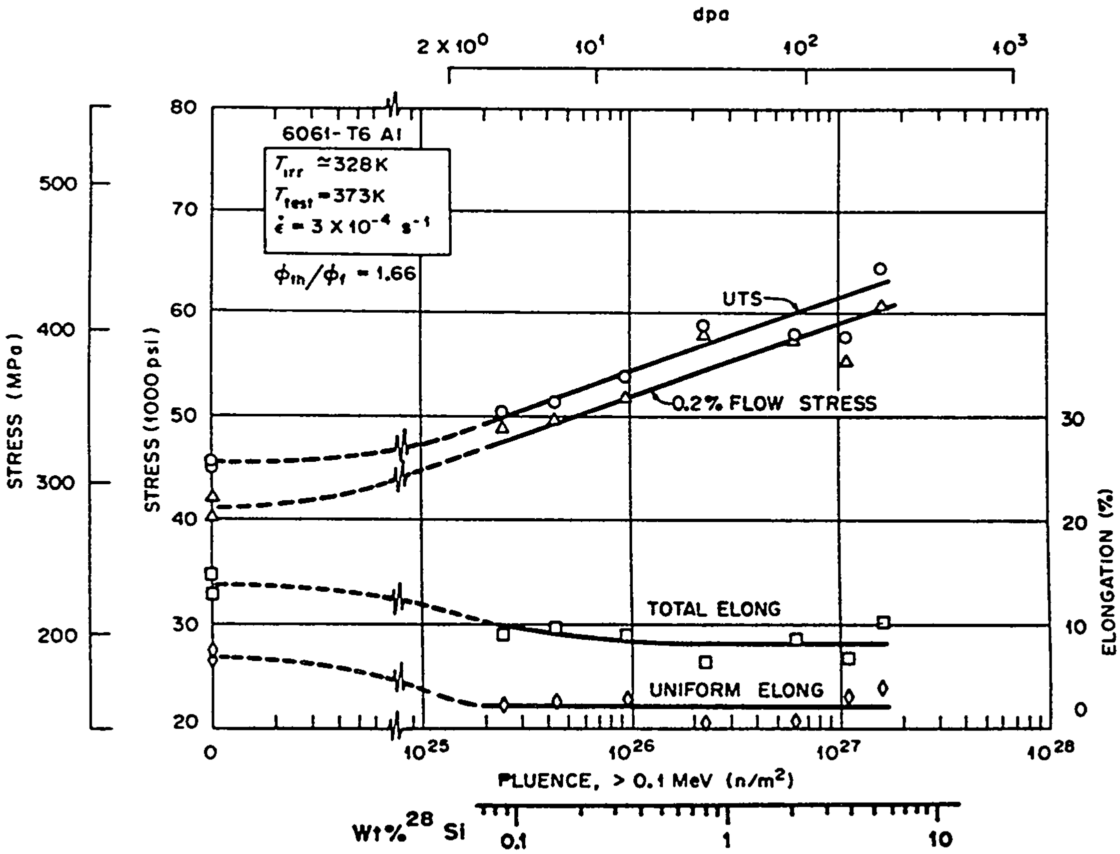

FIG. 3—*Fluence dependence of tensile properties of 6061-T6 at 373 K.*

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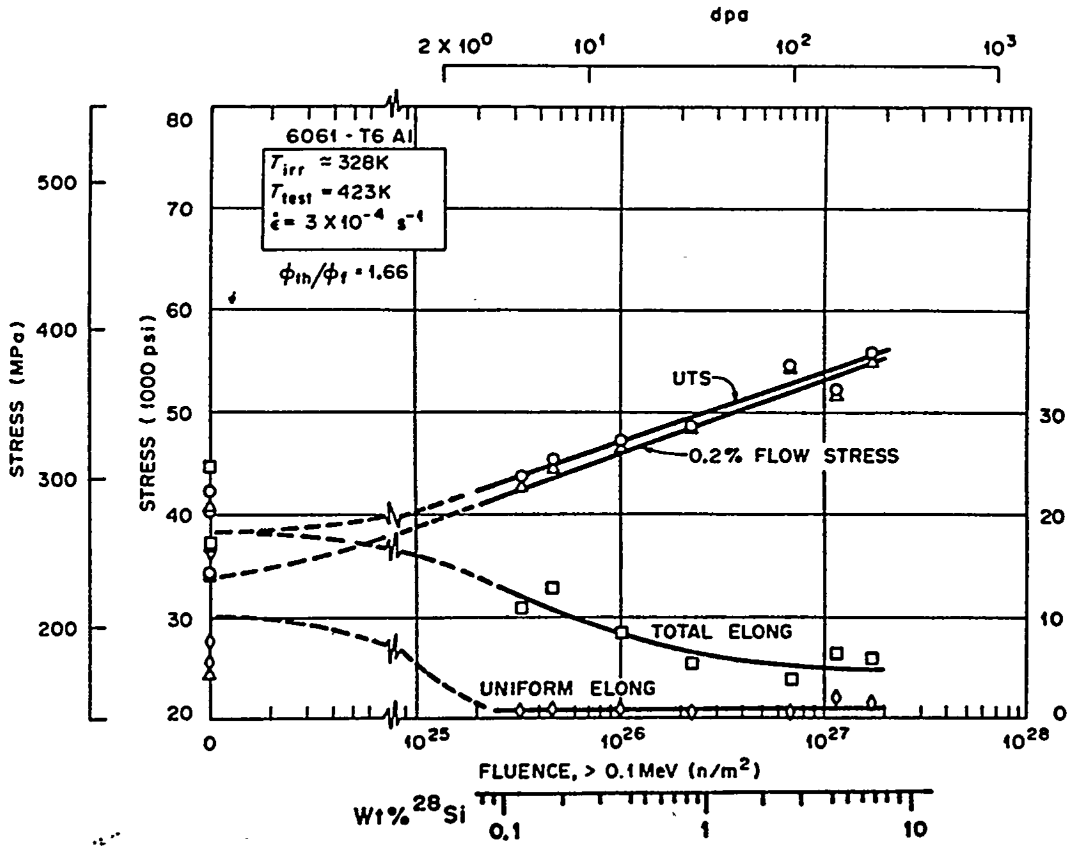

FIG. 4—*Fluence dependence of tensile properties of 6061-T6 at 423 K.*

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Alloy Designation: 6061 Data Sheet No.: 4
Heat Treatment: T6 Form: 3/4-in. Dia. rod

Chemical Analysis % by Wt.												
Al	Bal.	Cu	0.23	Zn	0.05	Cr	0.22	Bi		Th	
Mg	0.88	Fe	0.38	Ni	0.03	Zr		Pb		Be	
Si	0.59	Mn	0.04	Ti	0.07	Ca		Misch Metal			

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Elastic Modulus 10^6 psi	Tensile Strength 1000 psi
		Room		44.3
212	1/2	Room		44.7
212	1/2	Room		44.3
212	1/2	Room		44.2
212	100	Room		44.4
212	100	Room		44.1
212	1000	Room		45.2
212	1000	Room		45.0
212	5000	Room		45.1
212	10000	Room		45.0
300	1/2	Room		44.8
300	1/2	Room		44.1
300	1/2	Room		44.3
300	4	Room		44.0
300	16	Room		44.2
300	100	Room		44.4
300	1000	Room		43.2
300	5000	Room		41.0
300	10000	Room		40.4
400	1/12	Room		42.4
400	1/6	Room		42.8
400	1/3	Room		43.1
400	1/2	Room		43.0
400	1/2	Room		42.9
400	4	Room		41.8
400	16	Room		39.7
400	20	Room		39.1
400	100	Room		37.1
400	1000	Room		31.4
400	5000	Room		26.7
400	10000	Room		26.1
500	1/2	Room		40.7
500	4	Room		32.3
500	100	Room		25.2
500	1000	Room		22.4
500	5000	Room		18.5
500	10000	Room		17.9
600	1/2	Room		25.9
600	4	Room		24.9
600	20	Room		22.5
600	100	Room		19.9
600	500	Room		18.7
600	1000	Room		18.5
600	10000	Room		17.8

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Elastic Modulus 10^6 psi	Tensile Strength 1000 psi
700	1/2	Room		23.4
700	1/2	Room		21.9
700	4	Room		20.6
700	20	Room		19.3
700	100	Room		18.9
800	1/2	Room		21.6
900	1/2	Room		22.7
1000	1/2	Room		22.8
212	1/2	212		40.3
212	100	212		40.2
300	1/2	300		36.0
300	4	300		36.1
300	16	300		36.1
300	100	300		37.0
300	200	300		36.4
300	1000	300		35.9
300	5000	300		34.0
300	10000	300		33.5
400	1/2	400		31.3
400	4	400		30.5
400	16	400		28.3
400	20	400		27.9
400	100	400		25.7
400	200	400		24.9
400	1000	400		20.5
400	5000	400		17.5
400	10000	400		17.3
500	1/2	500		20.6
500	4	500		16.8
500	100	500		13.2
500	1000	500		10.7
500	5000	500		7.9
500	10000	500		7.7
600	1/2	600		9.9
600	4	600		9.4
600	20	600		7.9
600	100	600		6.2
600	500	600		5.5
600	1000	600		5.3
600	10000	600		5.4
700	1/2	700		5.5
700	4	700		4.4
700	20	700		4.3
700	100	700		4.2
800	1/2	800		3.5
900	1/2	900		2.6
1000	1/2	1000		1.9

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

Contributor: Alcoa Research Laboratories
Comments: Rod rolled plus drawn.

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Test Temp Deg C	Strength MPa	Comments	AMIS Ref No
27	310	Average of 8 tests.	8
27	311		31
27	311		31
27	321	Annealed 1/2 h at 100°C	31
27	315	Annealed 1/2 h at 100°C	31
27	295	Annealed 1/2 h at 200°C	31
27	296	Annealed 1/2 h at 200°C	31
24	319	Tested after 50-day thermal aging @ 24°C	31
24	314	Tested after 50-day thermal aging @ 24°C	31
24	325	Tested after 50-day thermal aging @ 149°C	31
24	323	Tested after 50-day thermal aging @ 149°C	31
24	228	Tested after 50-day thermal aging @ 204°C	31
24	151	Tested after 50-day thermal aging @ 260°C	31
24	129	Tested after 50-day thermal aging @ 316°C	31
24	126	Tested after 50-day thermal aging @ 371°C	31
24	314	Tested after thermal aging at Test Temp	31
204	152	Tested after thermal aging at Test Temp	31
316	36.7	Tested after thermal aging at Test Temp	31
<100	325		32
60-65	365	Tested* at 55°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	362	Tested* at 55°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33
60-65	330	Tested* at 100°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	243	Tested* at 150°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	220	Tested* at 200°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	247	Tested* at 200°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33

* Tests were conducted on curved specimens.

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Test Temp Deg C	Strength MPa	Comments	AMIS Ref No
60-65	313		34
60-65	344		34
60-65	329		41
60-65	330		41
60-65	320		41
27	320		35
27	347		35
149	255		35
177	256		35
27	330 ± 4		36
-253	446	Tested in the Longitudinal Direction	40
-253	423	NOTCHED SPECIMEN. Tested in the Longitudinal Direction.	40
23	316 ± 27	NOTCHED SPECIMEN.	37

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal[2]	MPa		
65	27	~2×10^{24}	~6×10^{24}	349	Average of 23 tests. Irradiated in MTS to total fluence of 1.26×10^{25} n/m^2 with fast fluence (assumed >1 MeV) of ~1×10^{24} n/m^2. Thermal fluence is estimated.	8
43	27	2×10^{23}	7.4×10^{23} *	320		31
43	27	2×10^{23}	7.4×10^{23}	318		31
43	27	2×10^{23}	7.4×10^{23} *	312	Annealed 1/2 h at 73°C	31
43	27	2×10^{23}	7.4×10^{23}	296	Annealed 1/2 h at 103°C	31
43	27	2×10^{23}	7.4×10^{23}	312	Annealed 1/2 h at 130°C	31
43	27	2×10^{23}	7.4×10^{23}	309	Annealed 1/2 h at 150°C	31
43	27	2×10^{23}	7.4×10^{23}	309	Annealed 1/2 h at 180°C	31
43	27	2×10^{23}	7.4×10^{23}	305	Annealed 1/2 h at 200°C	31
116	24	2.8×10^{23} to 2×10^{24} *	8×10^{23} to 3×10^{24} *	294		31
129	24	"	"	312		31
146	24	"	"	306		31
199	24	"	"	223		31
212	24	"	"	144		31
216	24	"	"	191		31
244	24	"	"	134		31
253	24	"	"	128		31
254	24	"	"	141		31
271	24	"	"	139		31
316	24	"	"	158		31
321	24	"	"	118		31

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
338	24	2.8×10^{23} to 2×10^{24} *	8×10^{23} to 3×10^{24} *	122		31
356	24	"	"	166		31
404	24	"	"	123		31
135	135	2.8×10^{23} to 2.4×10^{24} *	"	272		31
199	199	"	"	204		31
216	216	"	"	129		31
244	244	"	"	88.9		31
253	253	"	"	64.2		31
271	271	"	"	71.7		31
304	304	"	"	42		31
316	316	"	"	31.9		31
348	348	"	"	30		31
348	348	"	"	29.6		31
356	356	"	"	26.5		31
404	404	"	"	21.8		31
418	418	"	"	22.2		31
434	434	"	"	18.7		31
467	467	"	"	16.7		31
485	485	"	"	12.8		31
<100		1×10^{25} *	1.3×10^{25}	346	Flux > 1MeV was 0.5 to 4 H 10^{18} n/m^2/s. Thermal flux is quoted as being 2 to 3 times larger than fast flux > 1 MeV.	32
<100		2.3×10^{25}	2.9×10^{25}	358	Flux > 1MeV was 0.5 to 4 $\times$ 10^{18} n/m^2/s	32
<100		9.5×10^{25}	1.2×10^{25}	398	Flux > 1MeV was 0.5 to 4 $\times$ 10^{18} n/m^2/s	32

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Irradiation Temp	Test Temp	Fluence (n/m²)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
<100		1.8×10^{26}	2.3×10^{26}	478	Flux > 1MeV was 0.5 to 4 × 10^{18} n/m²/s	32
<100	150	3.3×10^{26}	4.1×10^{26}	411		32
<100	150	3.3×10^{26}	4.1×10^{26}	363		32
60-65	55	4.1×10^{26}	1.2×10^{27}	462	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	507	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	528	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	55	4.1×10^{26}	1.2×10^{27}	514	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	506	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	589	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	100	7.1×10^{26}	1.8×10^{27}	396	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	100	1.0×10^{27}	2.5×10^{27}	416	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	150	7.1×10^{26}	1.8×10^{27}	393	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33

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Deg C	Deg C	Fast	Thermal	MPa		
60-65	150	1.0×10^{27}	2.5×10^{27}	400	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	342	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	330	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	314	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	412	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65		1.43×10^{25}	3.1×10^{25}	355		34
60-65		3.9×10^{25}	6.4×10^{25}	406		34
60-65		8.5×10^{25}	1.4×10^{26}	410		34
60-65		1.9×10^{26}	3.1×10^{26}	391		34
60-65		2.6×10^{26}	4.4×10^{26}	409		34
60-65		5.1×10^{26}	8.5×10^{26}	434		34
60-65		7.2×10^{26}	1.2×10^{27}	449		34
60-65		1.1×10^{27}	1.9×10^{27}	488		34
60-65		1.1×10^{27}	1.9×10^{27}	488		34
60-65		1.8×10^{27}	3.0×10^{27}	497		34
60-65		1.8×10^{20}	5×10^{20}	314		41
60-65		1.8×10^{20}	5×10^{20}	303		41
60-65		5.5×10^{21}	1.5×10^{22}	327		41
60-65		5.5×10^{21}	1.5×10^{22}	323		41

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Deg C	Deg C	Fast	Thermal	MPa		
60-65		1.7×10^{22}	4.8×10^{22}	320		41
60-65		1.7×10^{22}	4.8×10^{22}	315		41
60-65		5.5×10^{22}	1.5×10^{23}	334		41
60-65		5.5×10^{22}	1.5×10^{23}	327		41
60-65		1.2×10^{23}	3.4×10^{23}	328		41
60-65		1.2×10^{23}	3.4×10^{23}	329		41
60-65		3.6×10^{23}	1×10^{24}	318		41
60-65		3.6×10^{23}	1×10^{24}	316		41
60-65		1.2×10^{24}	3.4×10^{24}	337		41
60-65		1.2×10^{24}	3.4×10^{24}	340		41
60-65		7.4×10^{24}	2.1×10^{25}	360		41
60-65		7.4×10^{24}	2.1×10^{25}	362		41
60-65		9.9×10^{24}	3.1×10^{25}	366		41
60-65		9.9×10^{24}	3.1×10^{25}	369		41
71	27	1×10^{24} *	4.7×10^{24} *	320		35
71	27	1×10^{24} *	4.7×10^{24} *	345		35
71	27	4×10^{24}	1.9×10^{25}	350		35
71	27	4×10^{24}	1.9×10^{25}	345		35
71	27	2.4×10^{25}	1.1×10^{26}	441		35
71	27	2.4×10^{25}	1.1×10^{26}	400		35
149	27	1×10^{24} *	4.7×10^{24} *	336		35
149	27	1×10^{24} *	4.7×10^{24} *	326		35
149	27	4×10^{24}	1.9×10^{25}	295		35
149	27	2.4×10^{25}	1.1×10^{26}	369		35
149	27	2.4×10^{25}	1.1×10^{26}	387		35

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Irradiation Temp	Test Temp	Fluence (n/m²)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
177	27	1×10^{24} *	4.7×10^{24} *	306		35
177	27	4×10^{24}	1.9×10^{24}	314		35
177	27	4×10^{24}	1.9×10^{25}	326		35
177	27	2.4×10^{25}	1.1×10^{26}	358		35
177	27	2.4×10^{25}	1.1×10^{26}	341		35
149	149	1×10^{24} *	4.7×10^{24} *	276		35
149	149	4×10^{24}	1.9×10^{25}	234		35
149	149	2.4×10^{25}	1.1×10^{26}	298		35
149	149	2.4×10^{25}	1.1×10^{26}	297		35
177	177	1×10^{24} *	4.7×10^{24} *	247		35
177	177	4×10^{24}	1.9×10^{25}	248		35
177	177	2.4×10^{25}	1.1×10^{26}	258		35
177	177	2.4×10^{25}	1.1×10^{26}	279		35
60	27	1×10^{24}	5.4×10^{24}	332 ± 12	Irradiation temp . is approximate	36
60	27	4×10^{24}	2.2×10^{25}	347 ± 3	Irradiation temp . is approximate	36
60	27	2.4×10^{25}	1.3×10^{26}	420 ± 21	Irradiation temp . is approximate	36
60	27	7.9×10^{25}	1.7×10^{27}	570 ± 16	Irradiation temp . is approximate	36
60	27	2.2×10^{25}	4.9×10^{26}	429 ± 12	Irradiation temp . is approximate	36
60	27	1.5×10^{26}	3.2×10^{27}	596 ± 55	Irradiation temp . is approximate	36
60	27	1.9×10^{26}	1.5×10^{27}	494 ± 8.3	Irradiation temp . is approximate	36
60	27	9.3×10^{26}	1.2×10^{27}	427 ± 3	Irradiation temp . is approximate	36
60	27	1.6×10^{27}	9.2×10^{26}	350 ± 14	Irradiation temp . is approximate	36
60	27	1.9×10^{27}	1.0×10^{27}	380 ± 5.5	Irradiation temp . is approximate	36
60	27	2.0×10^{26}	4.2×10^{27}	682.4 ± 10.3	Irradiation temp . is approximate. Thermal fluence is e<0.78 eV.	37
-253	-253	1×10^{21}*	?	476	Tested in the Longitudinal Direction.	40
-253	-253	1×10^{21}*	?	454	Tested in the Longitudinal Direction.	40

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Irradiation Temp	Test Temp	Fluence (n/m²)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
65	23	2×10^{26}	4×10^{27} *	200	NOTCHED SPECIMEN.	37

1 Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

2 Thermal fluences are 2200 m/s (0.0255 eV) except those with an asterick, whose cut-off energy was not stated.

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Alloy Designation: 6061 Data Sheet No.: 4
Heat Treatment: T6 Form: 3/4-in. Dia. rod

Chemical Analysis % by Wt.										
Al	Bal.	Cu	0.23	Zn	0.05	Cr	0.22	Bi		Th	
Mg	0.88	Fe	0.38	Ni	0.03	Zr		Pb		Be	
Si	0.59	Mn	0.04	Ti	0.07	Ca		Misch Metal			

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Elastic Modulus 10^6 psi	Yield (2) Strength 1000 psi
		Room		38.2
212	1/2	Room		38.6
212	1/2	Room		32.9
212	1/2	Room		37.8
212	100	Room		33.3
212	100	Room		38.1
212	1000	Room		39.9
212	1000	Room		39.1
212	5000	Room		39.7
212	10000	Room		39.7
300	1/2	Room		38.5
300	1/2	Room		32.8
300	1/2	Room		38.0
300	4	Room		38.2
300	16	Room		38.6
300	100	Room		39.5
300	1000	Room		39.4
300	5000	Room		36.8
300	10000	Room		36.0
400	1/12	Room		37.3
400	1/6	Room		37.8
400	1/3	Room		38.3
400	1/2	Room		38.5
400	1/2	Room		38.2
400	4	Room		37.6
400	16	Room		34.9
400	20	Room		34.3
400	100	Room		31.3
400	1000	Room		22.9
400	5000	Room		17.1
400	10000	Room		16.2
500	1/2	Room		35.9
500	4	Room		24.4
500	100	Room		14.8
500	1000	Room		12.1
500	5000	Room		8.1
500	10000	Room		7.9
600	1/2	Room		15.5
600	4	Room		14.5
600	20	Room		11.7
600	100	Room		9.2
600	500	Room		8.1
600	1000	Room		8.2
600	10000	Room		7.7

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Elastic Modulus 10^6 psi	Yield (2) Strength 1000 psi
700	1/2	Room		12.4
700	1/2	Room		10.4
700	4	Room		9.1
700	20	Room		8.3
700	100	Room		8.3
800	1/2	Room		8.8
900	1/2	Room		9.8
1000	1/2	Room		10.3
212	1/2	212		35.8
212	100	212		35.9
300	1/2	300		33.4
300	4	300		33.6
300	16	300		33.7
300	100	300		35.0
300	200	300		34.7
300	1000	300		34.5
300	5000	300		32.5
300	10000	300		31.7
400	1/2	400		29.5
400	4	400		28.8
400	16	400		26.6
400	20	400		26.4
400	100	400		24.0
400	200	400		23.2
400	1000	400		18.0
400	5000	400		14.3
400	10000	400		13.9
500	1/2	500		19.1
500	4	500		15.4
500	100	500		10.9
500	1000	500		8.8
500	5000	500		5.9
500	10000	500		5.8
600	1/2	600		8.7
600	4	600		7.9
600	20	600		6.6
600	100	600		5.2
600	500	600		4.9
600	1000	600		4.7
600	10000	600		4.7
700	1/2	700		4.6
700	4	700		3.7
700	20	700		3.4
700	100	700		3.4
800	1/2	800		2.5
900	1/2	900		
1000	1/2	1000		

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

Contributor: Alcoa Research Laboratories
Comments: Rod rolled plus drawn.

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Test Temp Deg C	Strength MPa	Comments	AMIS Ref No
27	265	Average of 8 tests.	8
27	244		31
27	243		31
27	248	Annealed 1/2 h at 100°C	31
27	244	Annealed 1/2 h at 100°C	31
27	250	Annealed 1/2 h at 200°C	31
27	250	Annealed 1/2 h at 200°C	31
24	249	Tested after 50-day thermal aging @ 24°C	31
24	238	Tested after 50-day thermal aging @ 24°C	31
24	--	Tested after 50-day thermal aging @ 149°C	31
24	278	Tested after 50-day thermal aging @ 149°C	31
24	172	Tested after 50-day thermal aging @ 204°C	31
24	73.1	Tested after 50-day thermal aging @ 260°C	31
24	51	Tested after 50-day thermal aging @ 316°C	31
24	47.3	Tested after 50-day thermal aging @ 371°C	31
24	238	Tested after thermal aging at Test Temp	31
204	--	Tested after thermal aging at Test Temp	31
316	33.9	Tested after thermal aging at Test Temp	31
<100	276		32
~~60-65~~ 55	319	Tested* at 55°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
~~60-65~~ 55	288	Tested* at 55°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33
~~60-65~~ 100	292	Tested* at 100°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
~~60-65~~ 150	213	Tested* at 150°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
~~60-65~~ 200	186	Tested* at 200°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
~~60-65~~ 200	236	Tested* at 200°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33

* Tests were conducted on curved specimens.

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Test Temp Deg C	Strength MPa	Comments	AMIS Ref No
60-65	253		34
60-65	305		34
60-65	296		41
60-65	289		41
60-65	282		41
27	265		35
27	312		35
149	215		35
177	250		35
-253	321	Tested in the Longitudinal Direction	40

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Irradiation Temp	Test Temp	Fluence (n/m²)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal[2]	MPa		
65	27	~2 × 10^{24}	~6 × 10^{24}	306	Average of 23 tests. Irradiated in MTS to total fluence of 1.26 × 10^{25} n/m² with fast fluence (assumed >1 MeV) of ~1 × 10^{24} n/m². Thermal fluence is estimated.	8
43	27	2 × 10^{23}	7.4 × 10^{23} *	259		31
43	27	2 × 10^{23}	7.4 × 10^{23}	244		31
43	27	2 × 10^{23}	7.4 × 10^{23} *	241	Annealed 1/2 h at 73°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	234	Annealed 1/2 h at 103°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	246	Annealed 1/2 h at 130°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	244	Annealed 1/2 h at 150°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	247	Annealed 1/2 h at 180°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	249	Annealed 1/2 h at 200°C	31
116	24	2.8 × 10^{23} to 2 × 10^{24} *	8 × 10^{23} to 3 × 10^{24} *	246		31
129	24	"	"	268		31
146	24	"	"	269		31
199	24	"	"	179		31
212	24	"	"	63.4		31
216	24	"	"	123		31
244	24	"	"	47.8		31
253	24	"	"	45.5		31
254	24	"	"	64.2		31
271	24	"	"	64.9		31
316	24	"	"	61.5		31
321	24	"	"	42.8		31

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
338	24	2.8×10^{23} to 2×10^{24} *	8×10^{23} to 3×10^{24} *	38.5		31
356	24	"	"	64.9		31
404	24	"	"	--		31
135	135	2.8×10^{23} to 2.4×10^{24} *	"	256		31
199	199	"	"	178		31
216	216	"	"	116		31
244	244	"	"	78.6		31
253	253	"	"	52.8		31
271	271	"	"	55.2		31
304	304	"	"	36.5		31
316	316	"	"	29.6		31
348	348	"	"	27.2		31
348	348	"	"	28.8		31
356	356	"	"	25.3		31
404	404	"	"	21.4		31
418	418	"	"	22.2		31
434	434	"	"	18.7		31
467	467	"	"	--		31
485	485	"	"	--		31
<100		1×10^{25} *	1.3×10^{25}	301	Flux > 1MeV was 0.5 to 4 H 10^{18} n/m^2/s. Thermal flux is quoted as being 2 to 3 times larger than fast flux > 1 MeV.	32
<100		2.3×10^{25}	2.9×10^{25}	295	Flux > 1MeV was 0.5 to 4 × 10^{18} n/m^2/s	32
<100		9.5×10^{25}	1.2×10^{25}	369	Flux > 1MeV was 0.5 to 4 × 10^{18} n/m^2/s	32

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
<100		1.8×10^{26}	2.3×10^{26}	449	Flux > 1MeV was 0.5 to 4 × 10^{18} $n/m^2/s$	32
<100	150	3.3×10^{26}	4.1×10^{26}	392		32
<100	150	3.3×10^{26}	4.1×10^{26}	356		32
60-65	55	4.1×10^{26}	1.2×10^{27}	450	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	503	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	501	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	55	4.1×10^{26}	1.2×10^{27}	485	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	451	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	486	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	100	7.1×10^{26}	1.8×10^{27}	382	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	100	1.0×10^{27}	2.5×10^{27}	393	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	150	7.1×10^{26}	1.8×10^{27}	372	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
60-65	150	1.0×10^{27}	2.5×10^{27}	398	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	335	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	330	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	308	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	395	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65		1.43×10^{25}	3.1×10^{25}	302		34
60-65		3.9×10^{25}	6.4×10^{25}	365		34
60-65		8.5×10^{25}	1.4×10^{26}	383		34
60-65		1.9×10^{26}	3.1×10^{26}	381		34
60-65		2.6×10^{26}	4.4×10^{26}	398		34
60-65		5.1×10^{26}	8.5×10^{26}	429		34
60-65		7.2×10^{26}	1.2×10^{27}	426		34
60-65		1.1×10^{27}	1.9×10^{27}	450		34
60-65		1.1×10^{27}	1.9×10^{27}	447		34
60-65		1.8×10^{27}	3.0×10^{27}	436		34
60-65		1.8×10^{20}	5×10^{20}	283		41
60-65		1.8×10^{20}	5×10^{20}	274		41
60-65		5.5×10^{21}	1.5×10^{22}	296		41
60-65		5.5×10^{21}	1.5×10^{22}	295		41

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Deg C	Deg C	Fast	Thermal	MPa		
60-65		1.7×10^{22}	4.8×10^{22}	289		41
60-65		1.7×10^{22}	4.8×10^{22}	284		41
60-65		5.5×10^{22}	1.5×10^{23}	299		41
60-65		5.5×10^{22}	1.5×10^{23}	296		41
60-65		1.2×10^{23}	3.4×10^{23}	302		41
60-65		1.2×10^{23}	3.4×10^{23}	297		41
60-65		3.6×10^{23}	1×10^{24}	289		41
60-65		3.6×10^{23}	1×10^{24}	286		41
60-65		1.2×10^{24}	3.4×10^{24}	--		41
60-65		1.2×10^{24}	3.4×10^{24}	322		41
60-65		7.4×10^{24}	2.1×10^{25}	346		41
60-65		7.4×10^{24}	2.1×10^{25}	352		41
60-65		9.9×10^{24}	3.1×10^{25}	355		41
60-65		9.9×10^{24}	3.1×10^{25}	357		41
71	27	1×10^{24} *	4.7×10^{24} *	286		35
71	27	1×10^{24} *	4.7×10^{24} *	309		35
71	27	4×10^{24}	1.9×10^{25}	314		35
71	27	4×10^{24}	1.9×10^{25}	299		35
71	27	2.4×10^{25}	1.1×10^{26}	420		35
71	27	2.4×10^{25}	1.1×10^{26}	369		35
149	27	1×10^{24} *	4.7×10^{24} *	309		35
149	27	1×10^{24} *	4.7×10^{24} *	299		35
149	27	4×10^{24}	1.9×10^{25}	253		35
149	27	2.4×10^{25}	1.1×10^{26}	357		35
149	27	2.4×10^{25}	1.1×10^{26}	375		35

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
177	27	1×10^{24} *	4.7×10^{24} *	276		35
177	27	4×10^{24}	1.9×10^{24}	309		35
177	27	4×10^{24}	1.9×10^{25}	298		35
177	27	2.4×10^{25}	1.1×10^{26}	341		35
177	27	2.4×10^{25}	1.1×10^{26}	325		35
149	149	1×10^{24} *	4.7×10^{24} *	270		35
149	149	4×10^{24}	1.9×10^{25}	222		35
149	149	2.4×10^{25}	1.1×10^{26}	297		35
149	149	2.4×10^{25}	1.1×10^{26}	297		35
177	177	1×10^{24} *	4.7×10^{24} *	243		35
177	177	4×10^{24}	1.9×10^{25}	243		35
177	177	2.4×10^{25}	1.1×10^{26}	254		35
177	177	2.4×10^{25}	1.1×10^{26}	278		35
-253	-253	1×10^{21} *	?	379	Tested in the Longitudinal Direction.	40

1 Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

2 Thermal fluences are 2200 m/s (0.0255 eV) except those with an asterick, whose cut-off energy was not stated.

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Test Temp	Shear Strength	Comments	AMIS Ref No
Deg C	MPa		
-253	343		40

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal	MPa		
-253	-253	1×10^{21}		360		40

[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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Aluminum Alloy 6061-T6
Total Elongation
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Alloy Designation: 6061 Data Sheet No.: 4
Heat Treatment: T6 Form: 3/4-in. Dia. rod

Chemical Analysis % by Wt.											
Al	Bal.	Cu	0.23	Zn	0.05	Cr	0.22	Bi		Th	
Mg	0.88	Fe	0.38	Ni	0.03	Zr		Pb		Be	
Si	0.59	Mn	0.04	Ti	0.07	Ca		Misch Metal			

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Elastic Modulus 10^6 psi	Elong. % (3)
		Room		19.8
212	1/2	Room		18.5
212	1/2	Room		19.0
212	1/2	Room		19.5
212	100	Room		18.0
212	100	Room		19.0
212	1000	Room		18.5
212	1000	Room		18.5
212	5000	Room		18.0
212	10000	Room		19.0
300	1/2	Room		20.0
300	1/2	Room		19.0
300	1/2	Room		19.5
300	4	Room		18.5
300	16	Room		18.5
300	100	Room		18.0
300	1000	Room		17.0
300	5000	Room		18.0
300	10000	Room		18.0
400	1/12	Room		17.5
400	1/6	Room		17.0
400	1/3	Room		16.5
400	1/2	Room		17.5
400	1/2	Room		17.5
400	4	Room		16.0
400	16	Room		16.5
400	20	Room		17.0
400	100	Room		17.5
400	1000	Room		18.0
400	5000	Room		20.0
400	10000	Room		21.0
500	1/2	Room		16.5
500	4	Room		17.5
500	100	Room		21.0
500	1000	Room		23.0
500	5000	Room		31.0
500	10000	Room		32.0
600	1/2	Room		20.0
600	4	Room		21.5
600	20	Room		23.5
600	100	Room		29.5
600	500	Room		32.5
600	1000	Room		32.0
600	10000	Room		32.0
700	1/2	Room		22.5
700	1/2	Room		24.0
700	4	Room		28.0
700	20	Room		33.0
700	100	Room		30.0
800	1/2	Room		30.0
900	1/2	Room		29.5
1000	1/2	Room		26.5
212	1/2	212		19.0
212	100	212		18.5
300	1/2	300		21.5
300	4	300		21.0
300	16	300		21.5
300	100	300		20.0
300	200	300		21.0
300	1000	300		20.0
300	5000	300		22.0
300	10000	300		22.0
400	1/2	400		21.0
400	4	400		20.0
400	16	400		20.5
400	20	400		21.5
400	100	400		22.0
400	200	400		23.0
400	1000	400		25.0
400	5000	400		28.5
400	10000	400		31.5
500	1/2	500		19.5
500	4	500		24.0
500	100	500		32.5
500	1000	500		36.0
500	5000	500		59.0
500	10000	500		60.0
600	1/2	600		31.5
600	4	600		33.0
600	20	600		44.5
600	100	600		53.0
600	500	600		71.0
600	1000	600		68.0
600	10000	600		49.0
700	1/2	700		51.0
700	4	700		72.5
700	20	700		71.0
700	100	700		75.0
800	1/2	800		76.5
900	1/2	900		71.0
1000	1/2	1000		40.5

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

Contributor: Alcoa Research Laboratories
Comments: Rod rolled plus drawn.

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Test Temp Deg C	Elongation %	Comments	AMIS Ref No
27	17.5	Average of 8 tests.	8
27	13		31
27	14		31
27	15	Annealed 1/2 h at 100°C	31
27	15	Annealed 1/2 h at 100°C	31
27	9	Annealed 1/2 h at 200°C	31
27	10.9	Annealed 1/2 h at 200°C	31
24	13.7	Tested after 50-day thermal aging @ 24°C	31
24	12.2	Tested after 50-day thermal aging @ 24°C	31
24	7.9	Tested after 50-day thermal aging @ 149°C	31
24	9.2	Tested after 50-day thermal aging @ 149°C	31
24	9.1	Tested after 50-day thermal aging @ 204°C	31
24	11.6	Tested after 50-day thermal aging @ 260°C	31
24	23	Tested after 50-day thermal aging @ 316°C	31
24	19.6	Tested after 50-day thermal aging @ 371°C	31
24	12.2	Tested after thermal aging at Test Temp	31
204	13.9	Tested after thermal aging at Test Temp	31
316	29.8	Tested after thermal aging at Test Temp	31
<100	21		32
60-65	15.7	Tested* at 55°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	18.3	Tested* at 55°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33
60-65	16.9	Tested* at 100°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	12.5	Tested* at 150°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	9.1	Tested* at 200°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	13	Tested* at 200°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33

* Tests were conducted on curved specimens.

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Test Temp Deg C	Elongation %	Comments	AMIS Ref No
60-65	16.1		34
60-65	12.6		34
60-65	12.3		41
60-65	15.8		41
60-65	16		41
27	20		35
27	15		35
149	14		35
177	19		35
27	10.3±0.5		36
-253	24.1	Tested in the Longitudinal Direction	40

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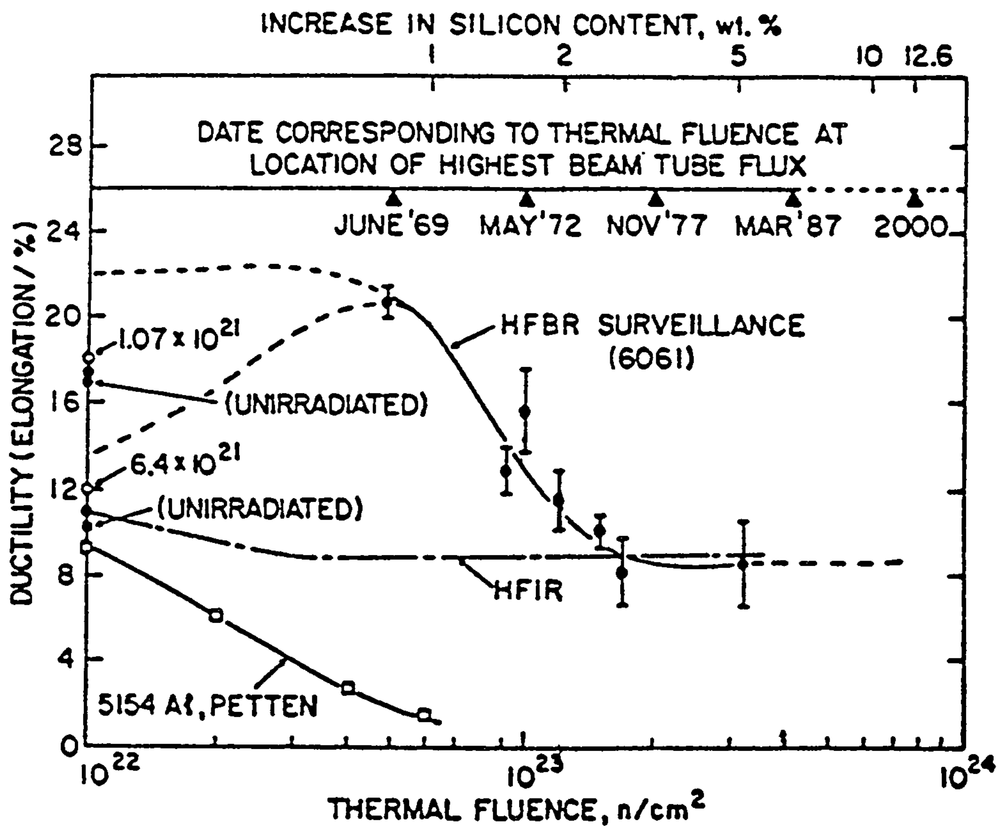

FIG. 11—*Effect of thermal neutron radiation on the ductility of aluminum alloys.*

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal[2]	%		
65	27	~2×10^{24}	~6×10^{24}	16.2	Average of 23 tests. Irradiated in MTS to total fluence of 1.26×10^{25} n/m^2 with fast fluence (assumed >1 MeV) of ~1×10^{24} n/m^2. Thermal fluence is estimated.	8
43	27	2×10^{23}	7.4×10^{23} *	12.4		31
43	27	2×10^{23}	7.4×10^{23}	14.1		31
43	27	2×10^{23}	7.4×10^{23} *	13.7	Annealed 1/2 h at 73°C	31
43	27	2×10^{23}	7.4×10^{23}	14.7	Annealed 1/2 h at 103°C	31
43	27	2×10^{23}	7.4×10^{23}	12.2	Annealed 1/2 h at 130°C	31
43	27	2×10^{23}	7.4×10^{23}	13.2	Annealed 1/2 h at 150°C	31
43	27	2×10^{23}	7.4×10^{23}	13.4	Annealed 1/2 h at 180°C	31
43	27	2×10^{23}	7.4×10^{23}	12.1	Annealed 1/2 h at 200°C	31
116	24	2.8×10^{23} to 2×10^{24} *	8×10^{23} to 3×10^{24} *	10.9		31
129	24	"	"	12		31
146	24	"	"	9.3		31
199	24	"	"	8		31
212	24	"	"	12.4		31
216	24	"	"	7.6		31
244	24	"	"	19.7		31
253	24	"	"	22.8		31
254	24	"	"	12.1		31
271	24	"	"	11.2		31
316	24	"	"	20.5		31
321	24	"	"	22.7		31

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
338	24	2.8×10^{23} to 2×10^{24} *	8×10^{23} to 3×10^{24} *	25		31
356	24	"	"	20.3		31
404	24	"	"	24.2		31
135	135	2.8×10^{23} to 2.4×10^{24} *	"	11.1		31
199	199	"	"	8.1		31
216	216	"	"	7.4		31
244	244	"	"	10.7		31
253	253	"	"	18.8		31
271	271	"	"	26.6		31
304	304	"	"	26.7		31
316	316	"	"	27.5		31
348	348	"	"	29.6		31
348	348	"	"	21.5		31
356	356	"	"	23.1		31
404	404	"	"	22.3		31
418	418	"	"	18.4		31
434	434	"	"	16.8		31
467	467	"	"	24		31
485	485	"	"	10.3		31
<100		1×10^{25} *	1.3×10^{25}	22	Flux > 1MeV was 0.5 to 4 H 10^{18} $n/m^2/s$. Thermal flux is quoted as being 2 to 3 times larger than fast flux > 1 MeV.	32
<100		2.3×10^{25}	2.9×10^{25}	21	Flux > 1MeV was 0.5 to 4 × 10^{18} $n/m^2/s$	32
<100		9.5×10^{25}	1.2×10^{25}	17	Flux > 1MeV was 0.5 to 4 × 10^{18} $n/m^2/s$	32

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Irradiation Temp	Test Temp	Fluence (n/m²)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
<100		1.8×10^{26}	2.3×10^{26}	17	Flux > 1MeV was 0.5 to 4 × 10^{18} n/m²/s	32
<100	150	3.3×10^{26}	4.1×10^{26}	18		32
<100	150	3.3×10^{26}	4.1×10^{26}	--		32
60-65	55	4.1×10^{26}	1.2×10^{27}	8	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	6.2	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	5.2	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	4.1×10^{26}	1.2×10^{27}	11.3	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	3.8	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	3.6	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	100	7.1×10^{26}	1.8×10^{27}	7.8	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	100	1.0×10^{27}	2.5×10^{27}	4.5	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	150	7.1×10^{26}	1.8×10^{27}	2.7	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33

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Irradiation Temp	Test Temp	Fluence (n/m²)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
60-65	150	1.0×10^{27}	2.5×10^{27}	2.9	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	1.8	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	0.5	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	4.8	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	3	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65		1.43×10^{25}	3.1×10^{25}	14.6		34
60-65		3.9×10^{25}	6.4×10^{25}	10.1		34
60-65		8.5×10^{25}	1.4×10^{26}	9.8		34
60-65		1.9×10^{26}	3.1×10^{26}	8.3		34
60-65		2.6×10^{26}	4.4×10^{26}	8.4		34
60-65		5.1×10^{26}	8.5×10^{26}	8.8		34
60-65		7.2×10^{26}	1.2×10^{27}	8.8		34
60-65		1.1×10^{27}	1.9×10^{27}	9.2		34
60-65		1.1×10^{27}	1.9×10^{27}	9.4		34
60-65		1.8×10^{27}	3.0×10^{27}	9.9		34
60-65		1.8×10^{20}	5×10^{20}	14.1		41
60-65		1.8×10^{20}	5×10^{20}	12		41
60-65		5.5×10^{21}	1.5×10^{22}	14.3		41
60-65		5.5×10^{21}	1.5×10^{22}	12.7		41

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
60-65		1.7×10^{22}	4.8×10^{22}	14.5		41
60-65		1.7×10^{22}	4.8×10^{22}	16.1		41
60-65		5.5×10^{22}	1.5×10^{23}	14.2		41
60-65		5.5×10^{22}	1.5×10^{23}	12.9		41
60-65		1.2×10^{23}	3.4×10^{23}	12.3		41
60-65		1.2×10^{23}	3.4×10^{23}	13.2		41
60-65		3.6×10^{23}	1×10^{24}	13.3		41
60-65		3.6×10^{23}	1×10^{24}	13.2		41
60-65		1.2×10^{24}	3.4×10^{24}	--		41
60-65		1.2×10^{24}	3.4×10^{24}	10.8		41
60-65		7.4×10^{24}	2.1×10^{25}	8.1		41
60-65		7.4×10^{24}	2.1×10^{25}	8.3		41
60-65		9.9×10^{24}	3.1×10^{25}	6.9		41
60-65		9.9×10^{24}	3.1×10^{25}	7.9		41
71	27	1×10^{24} *	4.7×10^{24} *	14		35
71	27	1×10^{24} *	4.7×10^{24} *	16		35
71	27	4×10^{24}	1.9×10^{25}	17		35
71	27	4×10^{24}	1.9×10^{25}	17		35
71	27	2.4×10^{25}	1.1×10^{26}	12		35
71	27	2.4×10^{25}	1.1×10^{26}	12		35
149	27	1×10^{24} *	4.7×10^{24} *	14		35
149	27	1×10^{24} *	4.7×10^{24} *	14		35
149	27	4×10^{24}	1.9×10^{25}	13		35
149	27	2.4×10^{25}	1.1×10^{26}	10		35
149	27	2.4×10^{25}	1.1×10^{26}	7		35

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Deg C	Deg C	Fast	Thermal	%		
177	27	1×10^{24} *	4.7×10^{24} *	16		35
177	27	4×10^{24}	1.9×10^{24}	6		35
177	27	4×10^{24}	1.9×10^{25}	19		35
177	27	2.4×10^{25}	1.1×10^{26}	11		35
177	27	2.4×10^{25}	1.1×10^{26}	13		35
149	149	1×10^{24} *	4.7×10^{24} *	14		35
149	149	4×10^{24}	1.9×10^{25}	16		35
149	149	2.4×10^{25}	1.1×10^{26}	11		35
149	149	2.4×10^{25}	1.1×10^{26}	13		35
177	177	1×10^{24} *	4.7×10^{24} *	16		35
177	177	4×10^{24}	1.9×10^{25}	20		35
177	177	2.4×10^{25}	1.1×10^{26}	14		35
177	177	2.4×10^{25}	1.1×10^{26}	9		35
60	27	1×10^{24}	5.4×10^{24}	15 ± 1	Irradiation temp . is approximate	36
60	27	4×10^{24}	2.2×10^{25}	17	Irradiation temp . is approximate	36
60	27	2.4×10^{25}	1.3×10^{26}	12	Irradiation temp . is approximate	36
60	27	7.9×10^{25}	1.7×10^{27}	8.2 ± 1.6	Irradiation temp . is approximate	36
60	27	2.2×10^{25}	4.9×10^{26}	20.7 ± 0.7	Irradiation temp . is approximate	36
60	27	1.5×10^{26}	3.2×10^{27}	8.6 ± 2	Irradiation temp . is approximate	36
60	27	1.9×10^{26}	1.5×10^{27}	10.2 ± 0.7	Irradiation temp . is approximate	36
60	27	9.3×10^{26}	1.2×10^{27}	11.6 ± 1.4	Irradiation temp . is approximate	36
60	27	1.6×10^{27}	9.2×10^{26}	12.9 ± 1.1	Irradiation temp . is approximate	36
60	27	1.9×10^{27}	1.0×10^{27}	15.7 ± 1.9	Irradiation temp . is approximate	36
60	27	2.0×10^{26}	4.2×10^{27}	7.2 ± 0.75	Irradiation temp . is approximate. Thermal fluence is E<0.78 eV.	37

See following page for table footnotes.

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[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

[2] Thermal fluences are 2200 m/s (0.0255 eV) except those with an asterick, whose cut-off energy was not stated.

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Test Temp Deg C	Elongation %	Comments	AMIS Ref No
27	--	Average of 8 tests.	8
27	12.5		31
27	13.4		31
27	14.5	Annealed 1/2 h at 100°C	31
27	14.7	Annealed 1/2 h at 100°C	31
27	8.2	Annealed 1/2 h at 200°C	31
27	9.9	Annealed 1/2 h at 200°C	31
24	13.3	Tested after 50-day thermal aging @ 24°C	31
24	11.5	Tested after 50-day thermal aging @ 24°C	31
24	7	Tested after 50-day thermal aging @ 149°C	31
24	8	Tested after 50-day thermal aging @ 149°C	31
24	7.8	Tested after 50-day thermal aging @ 204°C	31
24	9.3	Tested after 50-day thermal aging @ 260°C	31
24	20.8	Tested after 50-day thermal aging @ 316°C	31
24	17.8	Tested after 50-day thermal aging @ 371°C	31
24	11.5	Tested after thermal aging at Test Temp	31
204	5	Tested after thermal aging at Test Temp	31
316	6.8	Tested after thermal aging at Test Temp	31
<100	--		32
60-65	10.7	Tested* at 55°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	13	Tested* at 55°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33
60-65	8.3	Tested* at 100°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	5.2	Tested* at 150°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	3.1	Tested* at 200°C, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	4.5	Tested* at 200°C, CHS=0.2, strain rate=3.3 x 10^{-5}/s	33

* Tests were conducted on curved specimens.

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Test Temp Deg C	Elongation %	Comments	AMIS Ref No
60-65	10.8		34
60-65	7.4		34
60-65	7.7		41
60-65	10.1		41
60-65	9.8		41

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Irradiation Temp	Test Temp	Fluence (n/m²)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal[2]	%		
65	27	~2 × 10^{24}	~6 × 10^{24}	--	Average of 23 tests. Irradiated in MTS to total fluence of 1.26 × 10^{25} n/m² with fast fluence (assumed >1 MeV) of ~1 × 10^{24} n/m². Thermal fluence is estimated.	8
43	27	2 × 10^{23}	7.4 × 10^{23} *	11.4		31
43	27	2 × 10^{23}	7.4 × 10^{23}	13.4		31
43	27	2 × 10^{23}	7.4 × 10^{23} *	13	Annealed 1/2 h at 73°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	13.4	Annealed 1/2 h at 103°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	11.9	Annealed 1/2 h at 130°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	12.5	Annealed 1/2 h at 150°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	12.9	Annealed 1/2 h at 180°C	31
43	27	2 × 10^{23}	7.4 × 10^{23}	11.2	Annealed 1/2 h at 200°C	31
116	24	2.8 × 10^{23} to 2 × 10^{24} *	8 × 10^{23} to 3 × 10^{24} *	9.3		31
129	24	"	"	11		31
146	24	"	"	8.2		31
199	24	"	"	6.5		31
212	24	"	"	10		31
216	24	"	"	5.8		31
244	24	"	"	17.8		31
253	24	"	"	20.5		31
254	24	"	"	10.3		31
271	24	"	"	9.7		31
316	24	"	"	18.8		31
321	24	"	"	21.2		31

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Irradiation Temp	Test Temp	Fluence (n/m²)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
338	24	2.8×10^{23} to 2×10^{24} *	8×10^{23} to 3×10^{24} *	22.8		31
356	24	"	"	18		31
404	24	"	"	--		31
135	135	2.8×10^{23} to 2.4×10^{24} *	"	7.9		31
199	199	"	"	5.8		31
216	216	"	"	3.4		31
244	244	"	"	4.5		31
253	253	"	"	5.1		31
271	271	"	"	7.1		31
304	304	"	"	6.7		31
316	316	"	"	5.5		31
348	348	"	"	3.6		31
348	348	"	"	2.6		31
356	356	"	"	0.7		31
404	404	"	"	1		31
418	418	"	"	0.8		31
434	434	"	"	1		31
467	467	"	"	--		31
485	485	"	"	--		31
<100		1×10^{25} *	1.3×10^{25}	--	Flux > 1MeV was 0.5 to 4 H 10^{18} n/m²/s. Thermal flux is quoted as being 2 to 3 times larger than fast flux > 1 MeV.	32
<100		2.3×10^{25}	2.9×10^{25}	--	Flux > 1MeV was 0.5 to 4 × 10^{18} n/m²/s	32
<100		9.5×10^{25}	1.2×10^{25}	--	Flux > 1MeV was 0.5 to 4 × 10^{18} n/m²/s	32

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
<100		1.8×10^{26}	2.3×10^{26}	--	Flux > 1MeV was 0.5 to 4 × 10^{18} $n/m^2/s$	32
<100	150	3.3×10^{26}	4.1×10^{26}	--		32
<100	150	3.3×10^{26}	4.1×10^{26}	--		32
60-65	55	4.1×10^{26}	1.2×10^{27}	3.4	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	4	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	3.5	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	4.1×10^{26}	1.2×10^{27}	6.5	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	3.8	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	3.6	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	100	7.1×10^{26}	1.8×10^{27}	2.2	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	100	1.0×10^{27}	2.5×10^{27}	1.3	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	150	7.1×10^{26}	1.8×10^{27}	0.95	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33

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Irradiation Temp	Test Temp	Fluence (n/m²)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
60-65	150	1.0×10^{27}	2.5×10^{27}	0.94	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	0.8	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	0.2	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	2	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	1.2	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65		1.43×10^{25}	3.1×10^{25}	9.7		34
60-65		3.9×10^{25}	6.4×10^{25}	6.2		34
60-65		8.5×10^{25}	1.4×10^{26}	5.1		34
60-65		1.9×10^{26}	3.1×10^{26}	3.1		34
60-65		2.6×10^{26}	4.4×10^{26}	3.6		34
60-65		5.1×10^{26}	8.5×10^{26}	4.2		34
60-65		7.2×10^{26}	1.2×10^{27}	4.3		34
60-65		1.1×10^{27}	1.9×10^{27}	4.6		34
60-65		1.1×10^{27}	1.9×10^{27}	4.7		34
60-65		1.8×10^{27}	3.0×10^{27}	4.5		34
60-65		1.8×10^{20}	5×10^{20}	8.5		41
60-65		1.8×10^{20}	5×10^{20}	7.6		41
60-65		5.5×10^{21}	1.5×10^{22}	8.7		41
60-65		5.5×10^{21}	1.5×10^{22}	7.7		41

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Irradiation Temp	Test Temp	Fluence (n/m²)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
60-65		1.7×10^{22}	4.8×10^{22}	9.1		41
60-65		1.7×10^{22}	4.8×10^{22}	9.8		41
60-65		5.5×10^{22}	1.5×10^{23}	9.5		41
60-65		5.5×10^{22}	1.5×10^{23}	8.1		41
60-65		1.2×10^{23}	3.4×10^{23}	7.4		41
60-65		1.2×10^{23}	3.4×10^{23}	8.7		41
60-65		3.6×10^{23}	1×10^{24}	8.5		41
60-65		3.6×10^{23}	1×10^{24}	7.4		41
60-65		1.2×10^{24}	3.4×10^{24}	5		41
60-65		7.4×10^{24}	2.1×10^{25}	2.6		41
60-65		7.4×10^{24}	2.1×10^{25}	2.6		41
60-65		9.9×10^{24}	3.1×10^{25}	2.3		41
60-65		9.9×10^{24}	3.1×10^{25}	2.8		41
149	149	2.4×10^{25}	1.1×10^{26}	--->	YS & UTS are equal. Uniform strain should be zero. Irradiation temp . is approximate.	35
149	149	2.4×10^{25}	1.1×10^{26}	--->	"	35
177	177	2.4×10^{25}	1.1×10^{26}	--->	YS & UTS are nearly equal. Uniform strain must be low. Irradiation temp . is approximate.	35
177	177	2.4×10^{25}	1.1×10^{26}	--->	"	35

1 Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

2 Thermal fluences are 2200 m/s (0.0255 eV) except those with an asterick, whose cut-off energy was not stated.

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Alloy Designation: 6061 Data Sheet No.: 4
Heat Treatment: T6 Form: 3/4-in. Dia. rod

Chemical Analysis % by Wt.												
Al	Bal.	Cu	0.23	Zn	0.05	Cr	0.22	Bi		Th	
Mg	0.88	Fe	0.38	Ni	0.03	Zr		Pb		Be	
Si	0.59	Mn	0.04	Ti	0.07	Ca		Misch Metal			

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	R. A. %
		Room	50.0
212	1/2	Room	48.0
212	1/2	Room	47.0
212	1/2	Room	48.0
212	100	Room	48.0
212	100	Room	48.0
212	1000	Room	50.0
212	1000	Room	49.0
212	5000	Room	47.0
212	10000	Room	48.0
300	1/2	Room	50.0
300	1/2	Room	49.0
300	1/2	Room	49.6
300	4	Room	50.0
300	16	Room	44.0
300	100	Room	47.0
300	1000	Room	49.0
300	5000	Room	52.0
300	10000	Room	52.0
400	1/12	Room	50.0
400	1/6	Room	50.0
400	1/3	Room	50.0
400	1/2	Room	48.7
400	1/2	Room	50.0
400	4	Room	51.0
400	16	Room	52.0
400	20	Room	53.0
400	100	Room	55.0
400	1000	Room	56.0
400	5000	Room	60.0
400	10000	Room	60.0
500	1/2	Room	51.0
500	4	Room	55.0
500	100	Room	64.0
500	1000	Room	62.0
500	5000	Room	65.0
500	10000	Room	65.0
600	1/2	Room	62.0
600	4	Room	63.0
600	20	Room	61.0
600	100	Room	65.0
600	500	Room	66.0
600	1000	Room	66.0
600	10000	Room	69.0

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	R. A. %
700	1/2	Room	63.0
700	1/2	Room	63.0
700	4	Room	64.0
700	20	Room	65.0
700	100	Room	67.0
800	1/2	Room	64.5
900	1/2	Room	64.6
1000	1/2	Room	62.0
212	1/2	212	52.4
212	100	212	53.0
300	1/2	300	58.6
300	4	300	59.0
300	16	300	58.0
300	100	300	55.0
300	200	300	58.0
300	1000	300	58.0
300	5000	300	59.0
300	10000	300	59.0
400	1/2	400	59.0
400	4	400	61.0
400	16	400	64.0
400	20	400	67.0
400	100	400	67.0
400	200	400	69.0
400	1000	400	71.0
400	5000	400	74.0
400	10000	400	74.0
500	1/2	500	63.0
500	4	500	73.0
500	100	500	80.0
500	1000	500	83.8
500	5000	500	87.0
500	10000	500	88.0
600	1/2	600	77.9
600	4	600	82.0
600	20	600	88.0
600	100	600	92.0
600	500	600	93.0
600	1000	600	94.0
600	10000	600	92.0
700	1/2	700	89.0
700	4	700	94.0
700	20	700	94.0
700	100	700	95.0
800	1/2	800	93.0
900	1/2	900	76.0
1000	1/2	1000	48.0

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

Contributor: Alcoa Research Laboratories
Comments: Rod rolled plus drawn.

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Test Temp Deg C	Reduction of Area %	Comments	AMIS Ref No
27	49		35
27	33		35
149	44		35
177	50		35
-253	40	Tested in the Longitudinal Direction	40

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Irradiation Temp	Test Temp	Fluence (n/m²)		Reduction of Area	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal[2]	%		
71	27	1×10^{24} *	4.7×10^{24} *	44		35
71	27	1×10^{24} *	4.7×10^{24} *	31		35
71	27	4×10^{24}	1.9×10^{25}	26		35
71	27	4×10^{24}	1.9×10^{25}	26		35
71	27	2.4×10^{25}	1.1×10^{26}	36		35
71	27	2.4×10^{25}	1.1×10^{26}	50		35
149	27	1×10^{24} *	4.7×10^{24} *	39		35
149	27	1×10^{24} *	4.7×10^{24} *	43		35
149	27	4×10^{24}	1.9×10^{25}	22		35
149	27	2.4×10^{25}	1.1×10^{26}	32		35
149	27	2.4×10^{25}	1.1×10^{26}	25		35
177	27	1×10^{24} *	4.7×10^{24} *	44		35
177	27	4×10^{24}	1.9×10^{25}	22		35
177	27	4×10^{24}	1.9×10^{25}	44		35
177	27	2.4×10^{25}	1.1×10^{26}	32		35
177	27	2.4×10^{25}	1.1×10^{26}	29		35
149	149	1×10^{24} *	4.7×10^{24} *	48		35
149	149	4×10^{24}	1.9×10^{25}	46		35
149	149	2.4×10^{25}	1.1×10^{26}	53		35
149	149	2.4×10^{25}	1.1×10^{26}	41		35
177	177	1×10^{24} *	4.7×10^{24} *	42		35
177	177	4×10^{24}	1.9×10^{25}	50		35
177	177	2.4×10^{25}	1.1×10^{26}	40		35
177	177	2.4×10^{25}	1.1×10^{26}	22		35

[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

[2] Thermal fluences are 2200 m/s (0.0255 eV) except those with an asterick, whose cut-off energy was not stated.

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Engineering Stress-Strain

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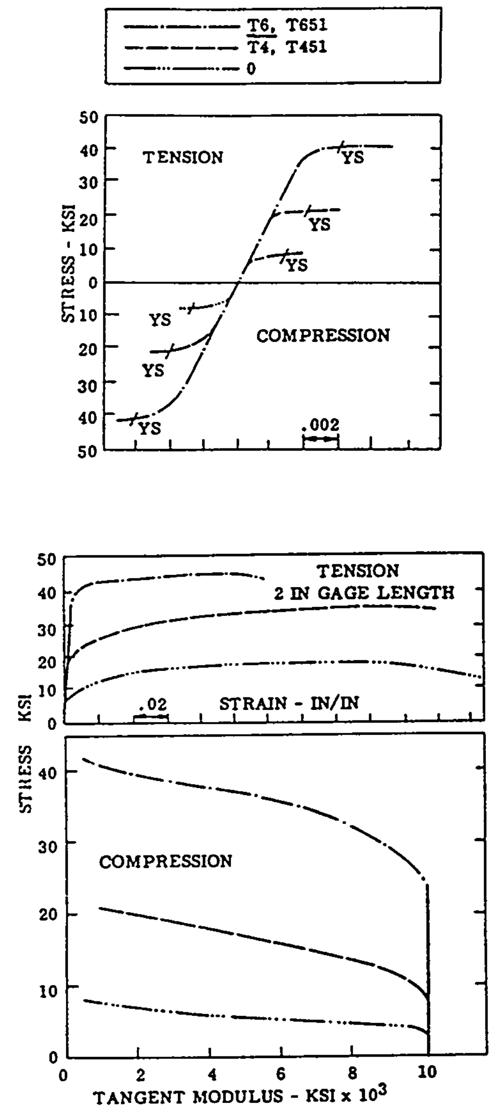
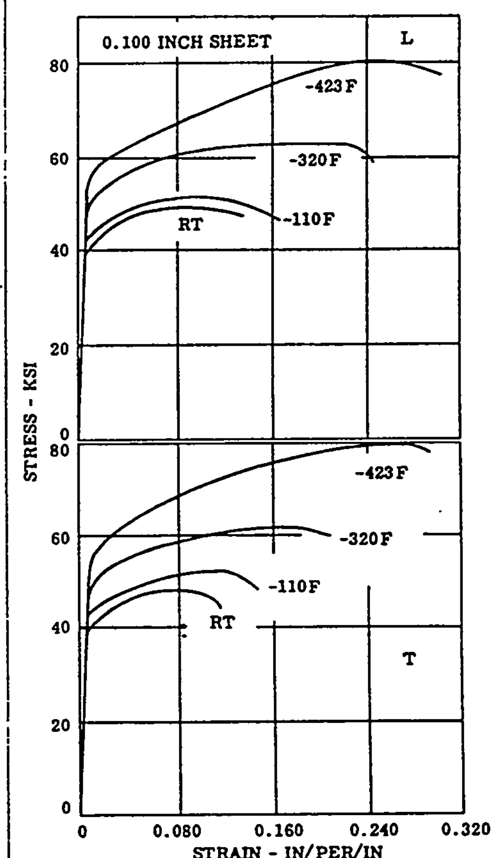


TYPICAL STRESS-STRAIN CURVES FOR 6061 EXTRUSIONS



STRESS-STRAIN CURVES FOR 6061-T6 ALUMINUM SHEET

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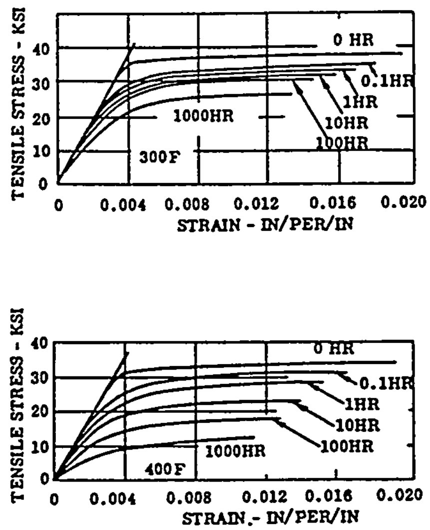
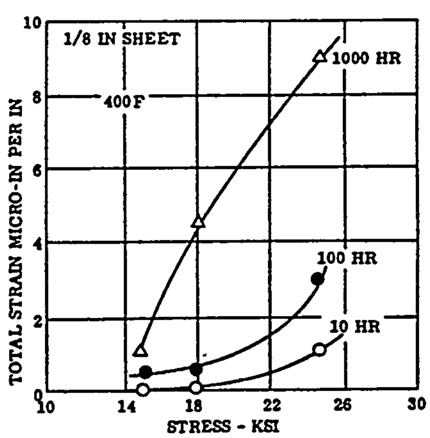


ISOCHRONOUS STRESS - STRAIN CURVES FOR 6061-T6 ALUMINUM



ISOCHRONOUS STRESS TOTAL STRAIN CURVES FOR 6061-T6 SHEET

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Aluminum Alloy 6061-T6

Engineering Stress-Strain

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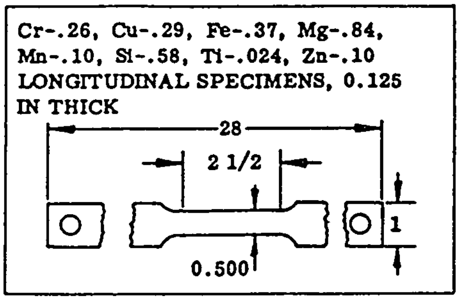

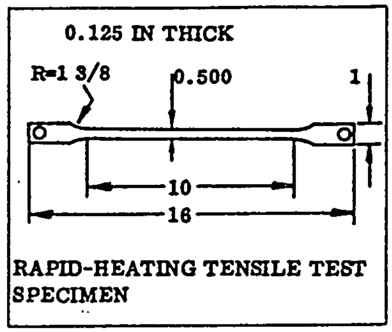

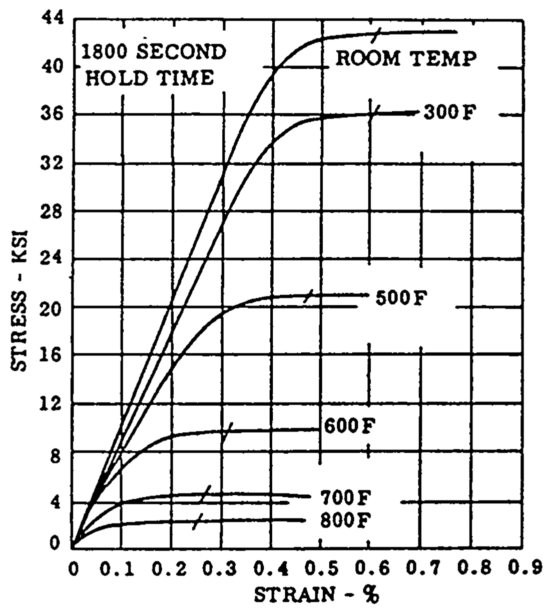

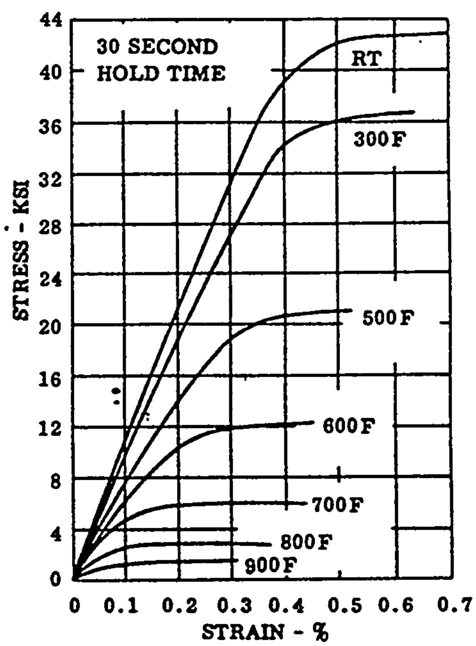

TYPICAL TENSILE STRESS-STRAIN CURVES FOR 6061-T6 ALUMINUM

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Engineering Stress-Strain

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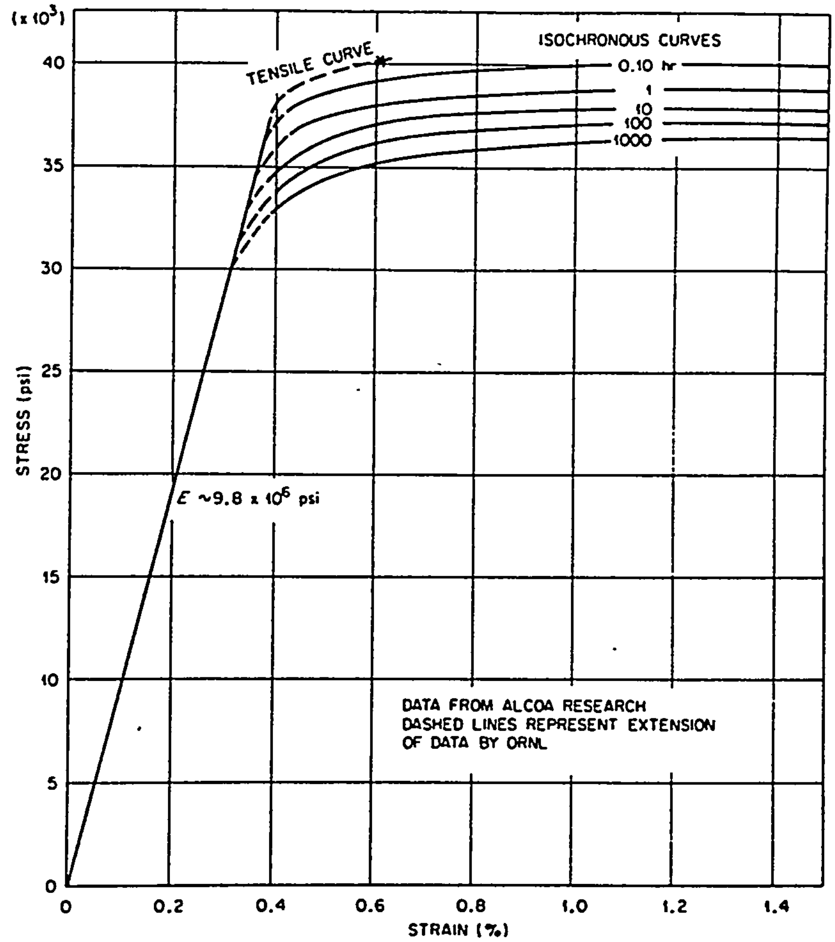

Stress-Strain Curves for 6061-T6 Aluminum Tested at 212°F.

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Aluminum Alloy 6061-T6

Engineering Stress-Strain

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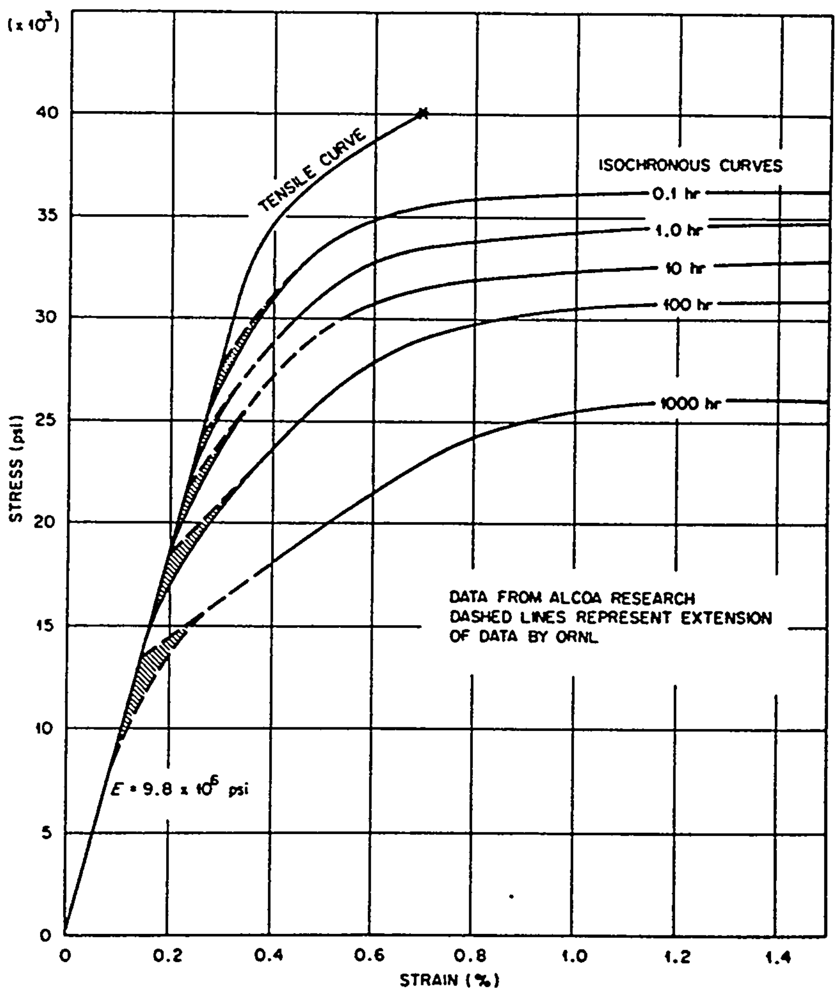

Stress-Strain Curves for 6061-T6 Aluminum Tested at 300°F.

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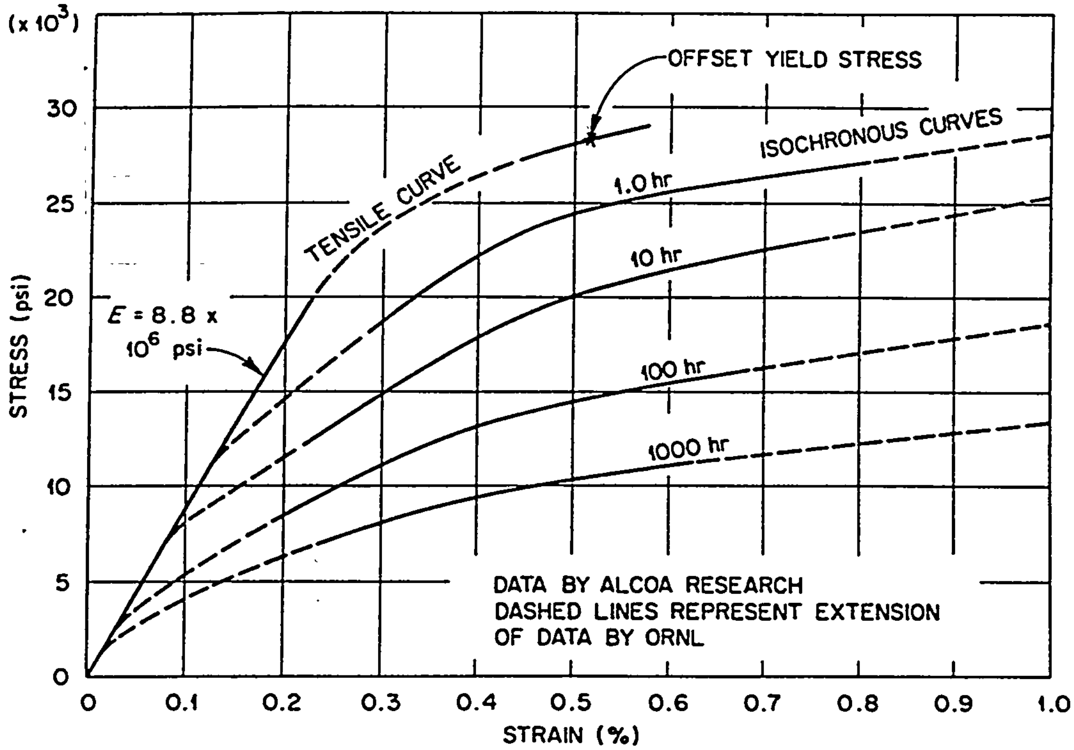

Stress-Strain Curves for Aluminum Alloy 6061-T6 Tested at 400°F.

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Aluminum Alloy 6061-T6

Engineering Stress-Strain

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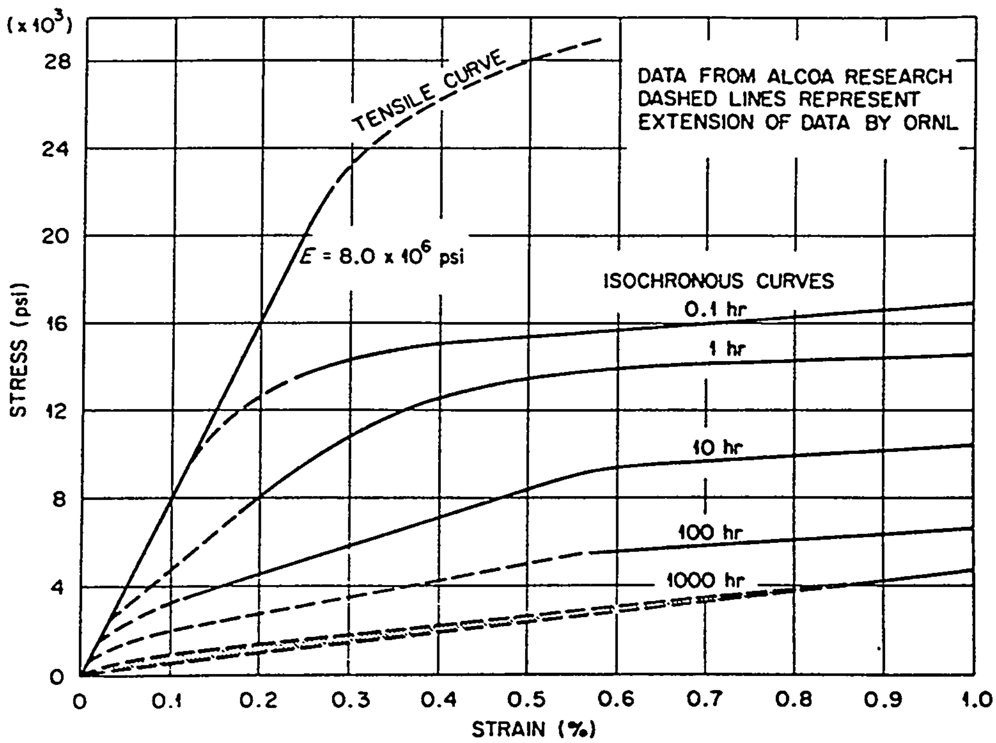

Stress-Strain Curves for 6061-T6 Aluminum Tested at 500°F.

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Aluminum Alloy 6061-T6 Weldments

Engineering Stress-Strain

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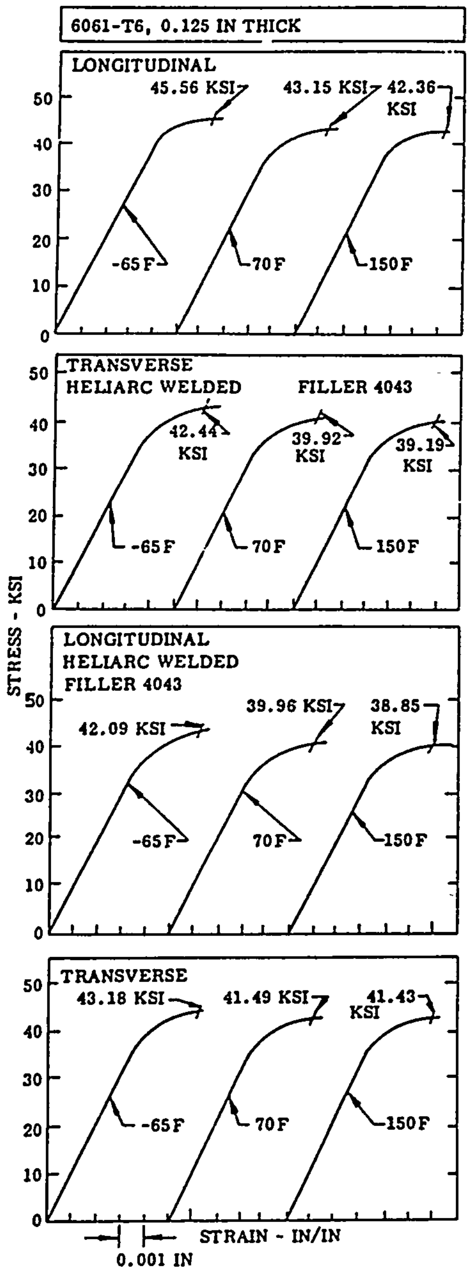

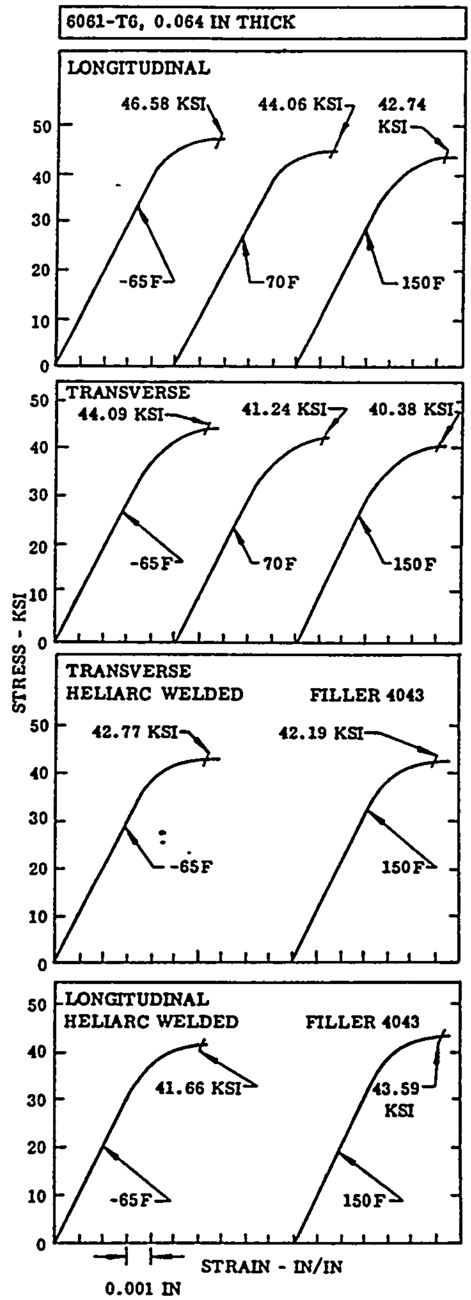

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Aluminum Alloy 6061-T6
Engineering
Stress-Strain
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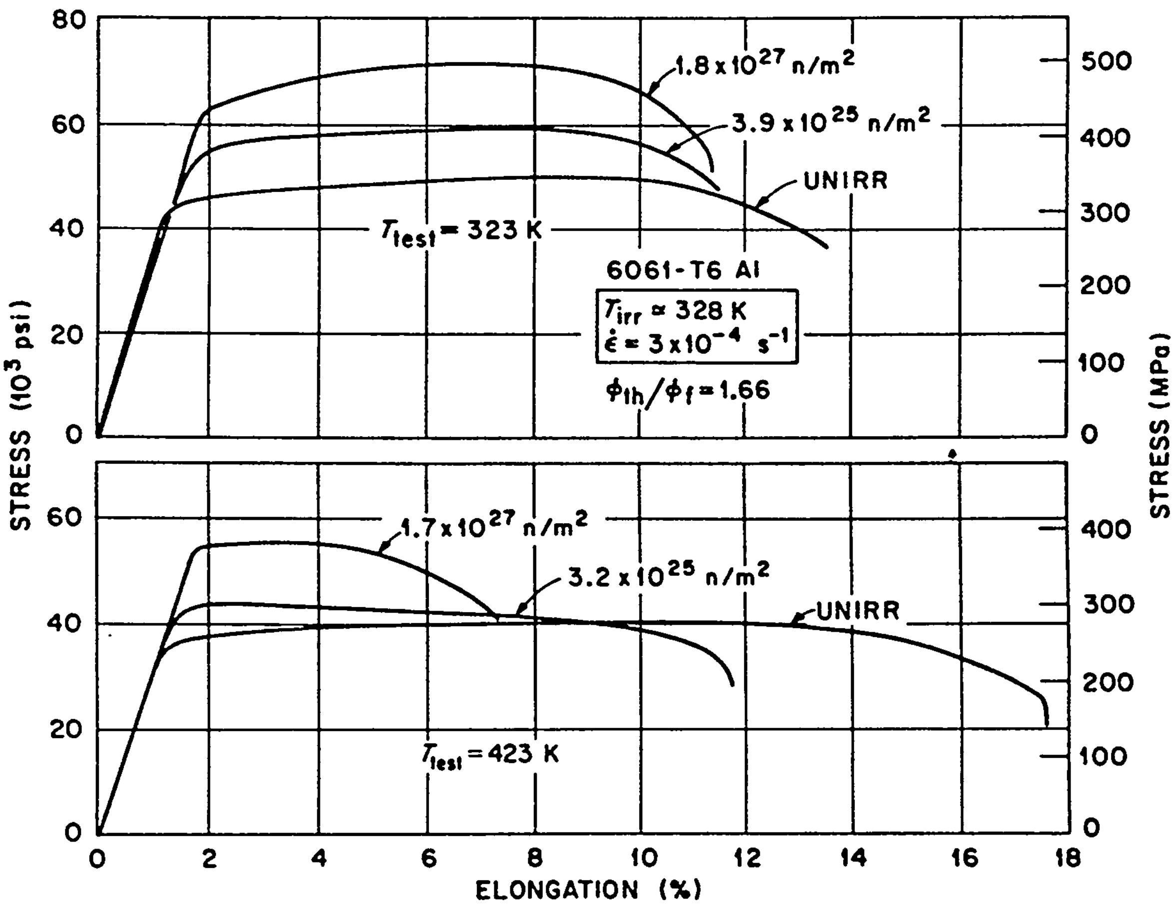

FIG. 1—*Changes in shapes of tensile curves of 6061 alloy in originally precipitation-hardened ("T6") condition at various neutron fluences. The fast fluence is indicated, and the thermal-to-fast fluence ratio is 1.66.*

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Aluminum Alloy 6061-T6

Creep and Rupture Strengths

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Alloy Designation: 6061 Data Sheet No.: 1

Heat Treatment: T6 Form: 0.065-in. bare sheet

Chemical Analysis % by Wt.										
Al	Bal.	Cu	0.21	Zn	0.03	Cr	0.24	Bi		Th
Mg	1.01	Fe	0.29	Ni		Zr		Pb		Be
Si	0.57	Mn	0.05	Ti	0.03	Ca		Misch Metal		

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Elastic Modulus 10^6 psi	Yield (2) Strength 1000 psi	Tensile Strength 1000 psi	Elong. % (3)	R. A. %
		Room		39.9	46.9	15.2	

CREEP AND RUPTURE STRENGTHS

Temp. °F	Stress for Indicated Creep Rate - 1000 psi		Stress for Rupture in Time Indicated - 1000 psi (4)				
	0.01 %/hr.	0.001 %/hr.	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.
90	44.5				46.5	45.0	43.9
212	37.0	35.0				37.9	36.3
300	31.0	28.0			33.0	31.0	29.5
400	18.4	13.5			23.0	18.7	13.0

STRESSES FOR INDICATED DEFORMATIONS (5)

Temp. °F	1 % Total Deformation					2 % Total Deformation				
	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.
212		36.7	35.9	34.7		38.0	37.4	36.8	36.2	35.6
300		32.5	31.4	29.6	27.8	34.6	33.3	32.1	30.7	27.7
400		26.2	21.7	17.3	11.3			22.5	18.1	12.8

Temp. °F	0.5% Total Deformation					% Deformation				
	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.
300	30.2	29.5	28.4	26.5	24.5					
400		24.0	19.6	15.0	10.0					

ORIGINAL CREEP AND RUPTURE DATA

Temp. °F	Stress 1000 psi	Test Duration hours (6)	Inter-cept % (7)	Minimum Creep Rate % / hr.	Transition Time, hours (8)	Total Ext., % (Creep Test)	Total Elong., % (Rupture Test)
90	35.33	1000	0.345	<0.000016		0.360	
90	44.25	394.35R	6.21	0.00875			11.50
90	44.50	167.55R	6.79	0.0235			14.20
90	45.45	9.34R	8.56	0.133			11.20
90	46.00	2.30R	10.00	0.480			12.00
212	35.00	1000	1.00	0.00110		2.43	
212	36.00	1098.70R	1.45	0.00221			10.30
212	37.00	344.44R	2.48	0.00850			10.80
212	37.43	53.22R	3.82	0.0948			14.40
212	38.00	25.90R	3.36	0.266			15.00
300	10.00	1000	0.160	0.00001		0.196	
300	25.00	1000	0.365	0.00027		0.727	
300	29.00	410.31R	0.53	0.00197			7.50
300	30.00	202.42R	0.715	0.0047			7.83
300	31.00	121.74R	0.87	0.0101			7.83
300	33.50	5.41R	1.82	1.02			14.0
300	35.00	0.81R	2.08	8.92			16.2
400	5.00	1000	0.12	0.00002		0.164	
400	10.00	1000	0.208	0.000277		5.24	
400	14.00	741.12R	0.27	0.00135			7.33
400	15.00	510.75R	0.235	0.00233			5.65
400	17.00	190.95R	0.28	0.00580			7.66
400	19.00	75.36R	0.29	0.0142			7.83
400	24.00	5.45R	0.34	0.164			10.80

Contributor: College of Engineering, University of California

Comments: Tested parallel to rolling direction.

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Vol 2 - Material Property Analyses

AS-RECEIVED INFORMATION

Aluminum Alloy 6061-T6
Impact Strength
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Test Temp	Impact Energy	Comments	AMIS Ref No
Deg C	Joules		
-40	4.2 ± 0.1	Subsize Charpy Tests	37
23	2.21 ± 0.26	Subsize Charpy Tests	37
99	2.07 ± 0.07	Subsize Charpy Tests	37

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Aluminum Alloy 6061-T6

Fracture Mechanics Properties

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Table 1. Fracture toughness data from HANSAL-T1, Phases I and II

Specimen	Phase	Temperature (°C)	K_J[a] (2605) MPa√m	K_J[a] (2605) ksi√in.	Tearing modulus (T) (2623)
			Unirradiated		
102	I	21	33.0	30.1	0.02
131[b]			33.8	30.8	—
142		26	33.6	30.6	0.53
134[c]			32.1	29.3	0.82
108[b]	II		32.1	29.3	—
107[d]	I	95	29.9	27.2	-0.43
144			30.8	28.0	0.94
103			30.2	27.5	0.43
156		150	32.3	29.4	3.12
101			31.3	28.5	1.83
133			32.6	29.6	3.16
			Irradiated		
104	I	26	33.9	30.9	0.24
118			34.8	31.7	0.97
122[b]			35.6	32.3	—
138	II		33.3	30.3	0.48
158[d]			31.6	28.8	-0.43
124[e]			28.7	26.1	—
105	I	95	31.7	28.9	0.02
127			32.2	29.3	0.02
147[d]	II		32.4	29.4	-0.07
135			29.5	26.9	0.80
143			29.7	27.1	0.37
111[b]	I	150	30.5	27.7	—
114[d]			27.3	24.9	0.86
154	II		26.1	23.7	0.19
151			23.4	21.3	0.30
132[d]			26.2	23.8	-0.15

[a]Based on J-integral formulation from ASTM E1152-87 with conversion to K by $K^2 = JE$ (E = elastic modulus).
[b]Estimated - too few data points in J-R curve.
[c]Improperly side grooved - one side too deep.
[d]Concave upward curve fit.
[e]Specimen tested without unloadings, so no stable crack extension has been included.

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Aluminum Alloy 6061-T6

Plain-strain Static Fracture Toughness (K_{Ic})

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Test Temp Deg C	K_{Ic} MPa√m	Comments	AMIS Ref No
	21.75	K_{Ic} derived from Charpy data.	37

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Aluminum Alloy 6061-T6
Plane-Strain Static Fracture Toughness (K_{Ic})
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Irradiation Temp	Test Temp	Fluence (n/m²)		K_{Ic}	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal[1]	MPa√m		
65		2×10^{26}	4×10^{27} *	8.72 ± 0.08	K_{Ic} Derived from Charpy data.	37
65		2×10^{26}	4×10^{27} *	7.7 to 8.8	K_{Ic} Derived from notched tensile data.	37

[1] Thermal fluences are 2200 m/s (0.0255eV) except those with an asterick, whose cut-off energy was not stated.

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Aluminum Alloy 6061-T6
Impact Strength
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Irradiation Temp	Test Temp	Fluence (n/m²)		Impact Energy	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal[1]	Joules		
65	24	2×10^{26}	4×10^{27} *	0.34 ± 0.03	Subsize Charpy tests.	37
65	99	2×10^{26}	4×10^{27} *	0.31 ± 0.03	Subsize Charpy tests.	37

[1] Thermal fluences are 2200 m/s (0.0255eV) except those with an asterick, whose cut-off energy was not stated.

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Aluminum Alloy 6061-T6
Elastic Stress Intensity Factor, Converted (K_J)
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Test Temp Deg C	K_J[1] MPa√m	Comments	AMIS Ref No
21	33	0.45 T C(T) specimens. Crack length agreement = -36%. Number of Crack Jumps = 2.	38
21	30.8	Estimated, too few points. 0.45 T C(T) specimens. Crack length agreement = -30%. Number of Crack Jumps = 2.	38
26	33.6	Crack length agreement = -33%. Number of Crack Jumps = 2.	38
26	32.1	Improperly side grooved - one side too deep. Crack length agreement = -22%. Number of Crack Jumps = 3.	38
95	27.2	Concave upward. Crack length agreement = -31%. Number of Crack Jumps = 3.	38
95	30.8	Crack length agreement = -25%. Number of Crack Jumps = 4.	38
95	30.2	Crack length agreement = -31% Number of Crack Jumps = 2.	38
150	32.3	Crack length agreement = -33%. Number of Crack Jumps = 2.	38
150	31.3	Crack length agreement = -32%. Number of Crack Jumps = 2.	38
150	32.6	Crack length agreement = -25%. Number of Crack Jumps = 3.	38

[1] Based on J-integral formulation from ASTM E 1152-87 with conversion to K by $K^2 = JE$ (E = elastic modulus).

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Aluminum Alloy 6061-T6
Elastic Stress Intensity Factor
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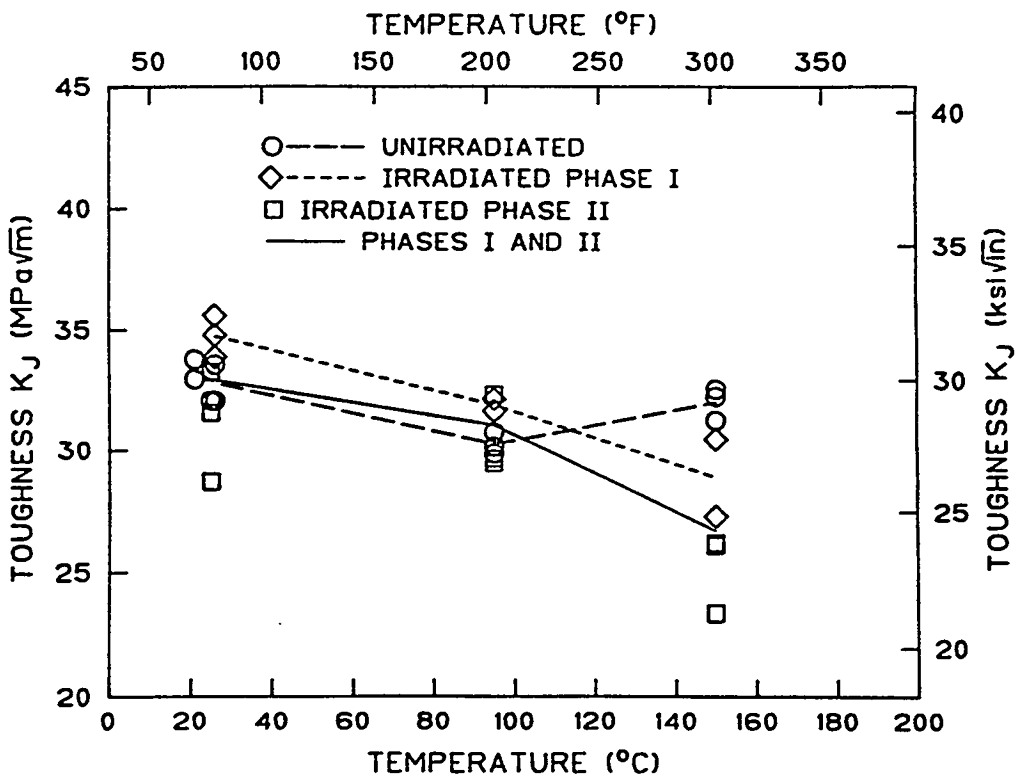

Fig. 1. Fracture toughness results from Phases I and II from the HANSAL-T1 capsule. Irradiation has little effect on the toughness at 25 or 95°C, but at 150°C irradiation results in significantly lower toughness.

See Page 1.2 for a listing of the above values.

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Aluminum Alloy 6061-T6
Elastic Stress Intensity Factor, Converted (K_J)
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Irradiation Temp	Test Temp	Fluence (n/m²)		K_J[1]	Comments	AMIS Ref No
Deg C	Deg C	Fast[2]	Thermal	MPa√m		
95	26	~5.5 × 10^{25}	~1.1× 10^{26}	33.9	Crack length agreement = -32%. Number of Crack Jumps = 7. Thermal fluence, E<0.4eV.	38
95	26	~5.5 × 10^{25}	~1.1× 10^{26}	34.8	Crack length agreement = -24%. Number of Crack Jumps = 4. Thermal fluence, E<0.4eV.	38
95	26	~5.5 × 10^{25}	~1.1× 10^{26}	35.6	Crack length agreement = -85%. Number of Crack Jumps = 2. Thermal fluence, E<0.4eV.	38
95	95	~5.5 × 10^{25}	~1.1× 10^{26}	31.7	Crack length agreement = -29%. Number of Crack Jumps = 5. Thermal fluence, E<0.4eV.	38
95	95	~5.5 × 10^{25}	~1.1× 10^{26}	32.2	Crack length agreement = -27%. Number of Crack Jumps = 3. Thermal fluence, E<0.4eV.	38
95	150	~5.5 × 10^{25}	~1.1× 10^{26}	30.5	Crack length agreement = -36%. Number of Crack Jumps = 5. Value estimated, too few points. Thermal fluence, E<0.4eV.	38
95	150	~5.5 × 10^{25}	~1.1× 10^{26}	27.3	Crack length agreement = -23%. Number of Crack Jumps = 6. Concave upwards. Thermal fluence, E<0.4eV.	38

[1] Based on J-integral formulation from ASTM E 1152-87 with conversion to K by $K^2 = JE$ (E = elastic modulus).

[2] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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Aluminum Alloy 6061-T6
Critical Crack Size
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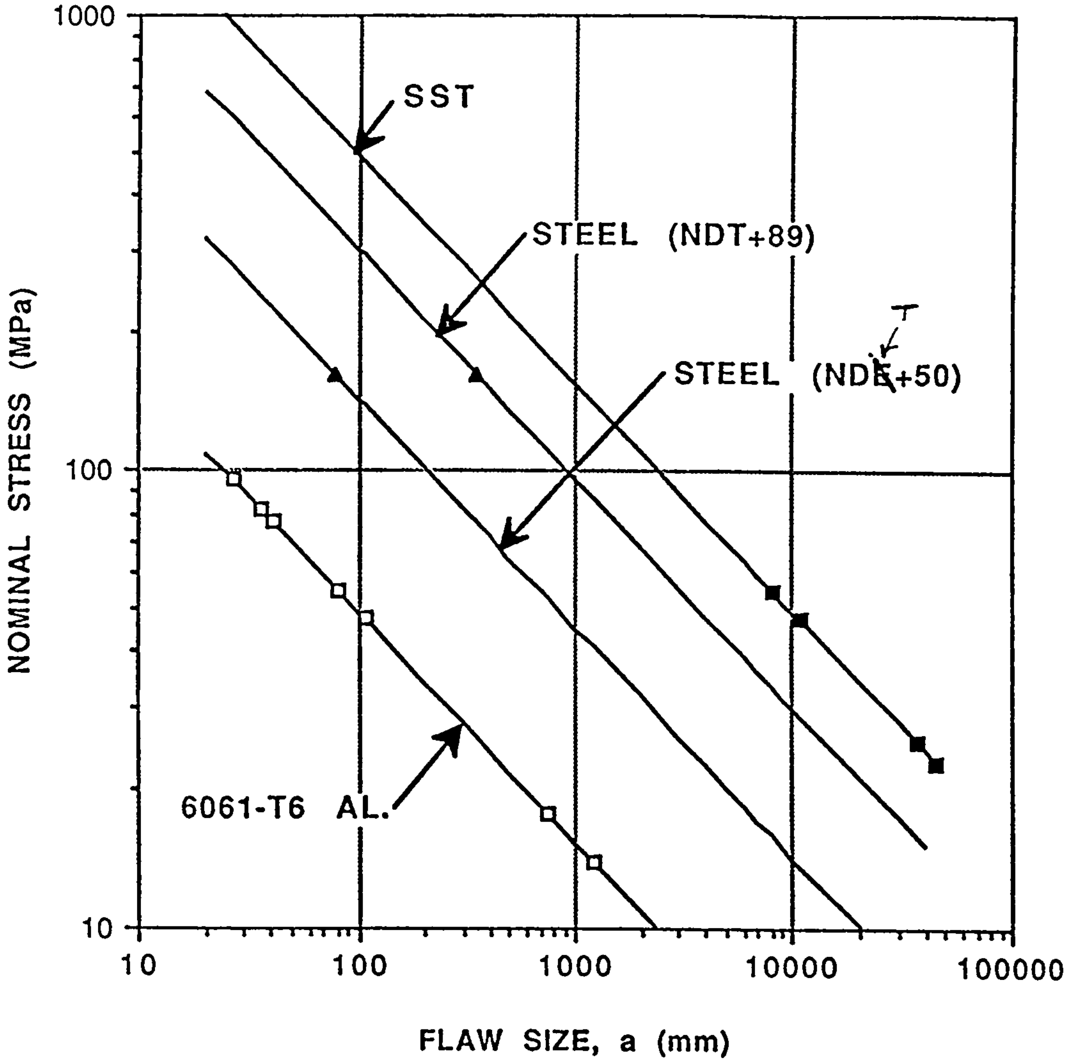

Fig. 7. Effect of stress level on critical flaw size for aluminum, steel and stainless steel.

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Aluminum Alloy 6061-T6
Critical Crack Size
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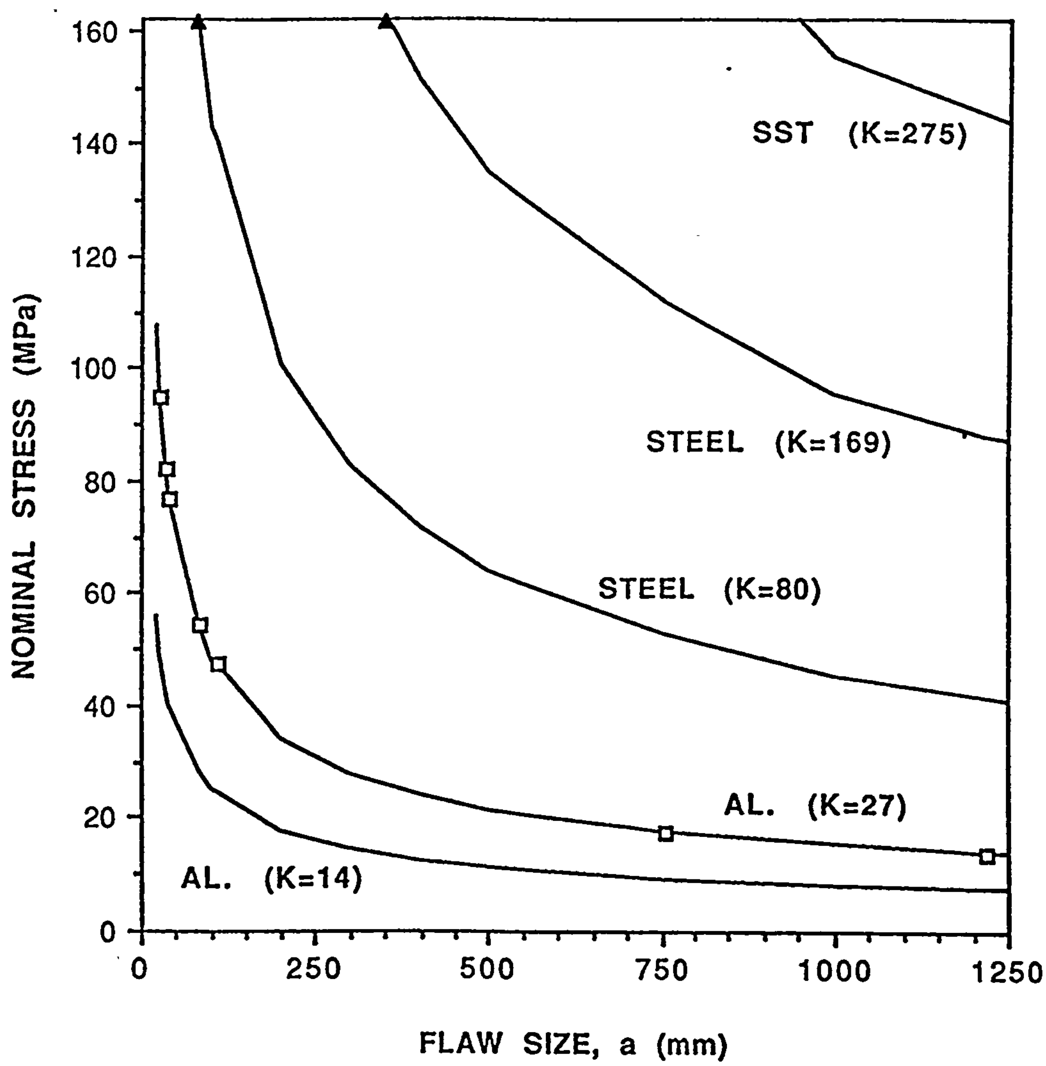

Fig. 8. Relationship between stress and flaw length for 6061-T6 aluminum, pressure vessel steel, and 316LN stainless steel.

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Aluminum Alloy 6061-T6
Thermal Conductivity
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Heat treat. & remarks

total solution treated and stress relieved to produce a permanent set of 2% nominal (3 < x < 1.5)

R. P. Tye, R. W. Hayden, and S. C. Spinney

Table IV. Thermal Conductivity for T6061 T6 Aluminum Alloy

T, °F	T, °C	T, K	As-received k, W/mK	Heat-treated k meas, W/mK	Heat-treated k calc, W/mK
-321	-196	77	—	—	
-279	-173	100	106	129	
-189	-123	150	123	142	
-99	-73	200	132	153	
81	27	300	161	174	
261	127	400	177	187	(192)
441	227	500	186	195	(193)
621	327	600	193	195	(195)
801	427	700	—	193	(189)

T6061 Al Alloy

The results are summarized in Table IV. Above 500 K *k* remained approximately constant and there was an indication that at 560 K a maximum had been attained. This resulted in a constant value for *L* above 450 K. This behavior would be predicted by use of the empirical relationship of Powell and Hickman [30] for aluminum alloys. At temperatures above 350 K the experimental results are within ±2.5%. At temperatures below 300 K no direct comparison of results can be made for either condition since the Powell–Hickman relationship is only valid above 300 K.

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Aluminum Alloy 6061-T6
Electrical Resistivity
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Table IV. Electrical Resistivity for T6061 T6 Aluminum Alloy

T, °F	T, °C	T, K	As-received $10^8 \rho$, Ωm	Heat-treated $10^8 \rho$, Ωm
-321	-196	77	1.54	1.02
-279	-173	100	1.75	1.34
-189	-123	150	2.34	1.92
-99	-73	200	2.97	2.51
81	27	300	4.15	3.69
261	127	400	5.36	4.88
441	227	500	6.46	6.08
621	327	600	7.46	7.28
801	427	700	—	8.70

*$10^8 \rho$, Ωm 294 K	*$10^8 \rho$, Ωm 4.2 K	Heat treat. & remarks
4.11–4.15	1.24	total solution treated and stress relieved to produce a permanent set of 2% nominal (3 < x < 1.5)

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Aluminum Alloy 6061-T6
Irradiation Swelling
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Irradiation Temp	Test Temp	Fluence (n/m^2)		Irridiation Swelling	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal[2]	%		
60-65	55	4.1×10^{26}	1.2×10^{27}	0.72	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	2.6	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	3	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	55	4.1×10^{26}	1.2×10^{27}	0.72	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	55	1.2×10^{27}	2.6×10^{27}	2.2	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	55	1.3×10^{27}	3.0×10^{27}	2.2	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3 x 10^{-3}/s	33
60-65	100	7.1×10^{26}	1.8×10^{27}	1.34	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	100	1.0×10^{27}	2.5×10^{27}	1.9	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	150	7.1×10^{26}	1.8×10^{27}	1.34	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	150	1.0×10^{27}	2.5×10^{27}	1.9	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	1.55	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3 x 10^{-5}/s	33

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Irradiation Temp	Test Temp	Fluence (n/m²)		Irridiation Swelling	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
60-65	200	1.3×10^{27}	3.1×10^{27}	2.2	Curved specimen from hydraulic tube, CHS=0.002, strain rate=3.3×10^{-5}/s	33
60-65	200	8.6×10^{26}	2.0×10^{27}	1.55	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33
60-65	200	1.3×10^{27}	3.1×10^{27}	2.2	Curved specimen from hydraulic tube, CHS=0.2, strain rate=3.3×10^{-3}/s	33

1 Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

2 Thermal fluences are 2200 m/s (0.0255 eV) except those with an asterick, whose cut-off energy was not stated.

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T651 Heat Treatment

"T651" is the designation used for material stretched after solution heat treatment. No further stretching or straightening after the initial stretching is performed on the material. The amount of stretching performed is as follows:

Plate: 1.5 to 3% permanent set.

Rolled or Cold-Finished Rod and Bar: 1 to 3% permanent set.

Die or Ring Forgings and Rolled Rings: 1 to 5% permanent set.

Note that material in the T651 condition may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

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TABLE 1. SPECIFICATIONS

SB-209	Sheet and Plate
SB-210	Drawn Seamless Tube
SB-241/SB-241M	Seamless Pipe and Seamless Extruded Tube
SB-221	Extruded Bar, Rod, and Shape
SB-247	Die and Hand Forgings

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Aluminum Alloy 6061-T651

Design Stress Intensity Values, S_m

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TABLE 3. DESIGN STRESS INTENSITY VALUES, S_m, FOR 6061-T651 ALUMINUM

Spec. No.	Temper	Size or thickness (in)	Specified Min. Tensile Strength (ksi)	Specified Min. Yield Strength (ksi)	Notes	Allowable Stress, ksi, for Metal Temp., °F, Not Exceeding 100	150	200	250	300
Sheet and Plate										
SB-209										
	T651	0.250-4.000	42	35	(1)(2)	14.0	14.0	14.0	13.4	11.3
	T651	4.001-6.000	40	35	(1)(2)	13.3	13.3	13.3	13.0	11.1
	T6,T651 Wld.	All	24		(1)	8.0	8.0	8.0	7.9	7.3

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TABLE 5. TENSILE STRENGTH VALUES, S_u, FOR 6061-T651 ALUMINUM

Spec. No.	Temper	Size or thickness (in)	Specified Min. Tensile Strength (ksi)	Tensile Strength, ksi, for Metal Temp., °F, Not Exceeding 100	150	200	250	300
Sheet and Plate								
SB-209								
	T651	0.250-4.000	42	42.0	42.0	42.0	40.2	33.9
	T651	4.001-6.000	40	40.0	40.0	40.0	39.0	33.3
	T6,T651 Wld.	All	24	24.0	24.0	24.0	23.7	21.9

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6061-T651
Yield Strength Values, Sy
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TABLE 4. VALUES OF YIELD STRENGTH S_y FOR 6061-T651 ALUMINUM

Spec. No.	Temper	Thickness, in.	Specified Minimum Yield, ksi	Notes	Yield Strength, ksi (Multiply by 1000 to Obtain psi), for Metal Temp., °F, Not Exceeding						
					100	150	200	250	300	350	400
Sheet and Plate SB-209	T651	0.250-6.000	35		35.0	34.6	33.7	32.4	27.4	20.0	13.3

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Aluminum Alloy 6061-T651

Static, Short-Term Properties

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TABLE 1 - Tensile Properties for Unnotched Specimens of 6061-T651[a] Aluminum
(Tested by Aluminum Company of America)

Testing[b] Temp Deg F	UTS psi	YS 0.05% Offset psi	YS 0.02% Offset psi	Elongation in 4D %	R.A. %
78	46,400	37,600	40,600	15	28
212	43,200	34,100	37,900	18	31
300	38,700	32,300	35,600	18	42
350	35,400	31,000	33,500	18	45
400	32,500	29,800	31,100	16	48
450	30,400	27,400	29,300	14	41
500	24,400	21,900	23,900	16	45
600	13,700	11,900	12,900	25	68
700	9,200	7,700	8,500	29[c]	81
800	5,100	4,100	4,600	44	91

[a] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompaning the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

[b] Test conducted in accordance with ASTM specifications E 8-69 after soaking 0.1h at the testing temperature.

[c] Broke near the end of the gage length.

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Static, Short-term Properties

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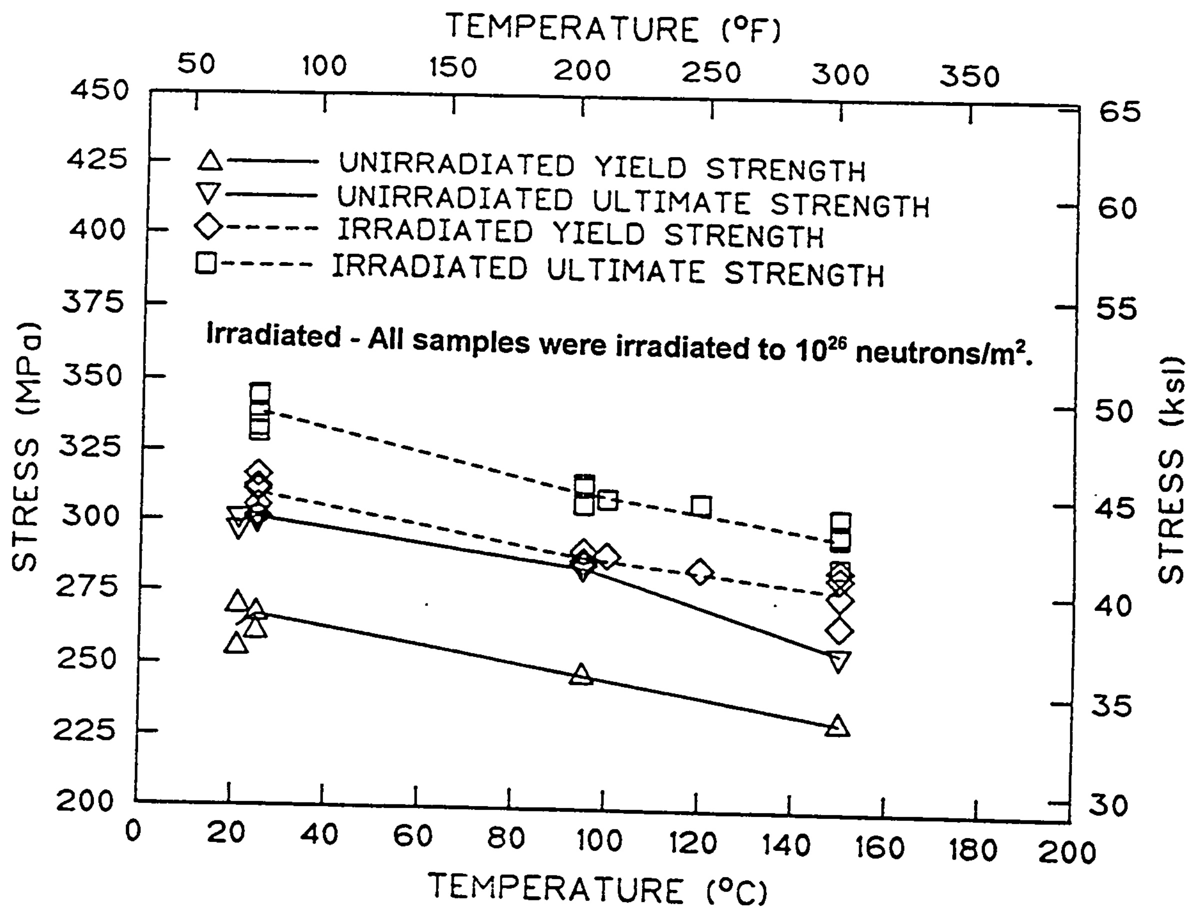

Fig. 4. The effect of irradiation and test temperature on the strength of 6061-T651 aluminum. The yield and ultimate strengths are significantly increased by irradiation.

See Page 1.3 for a listing of the above values.

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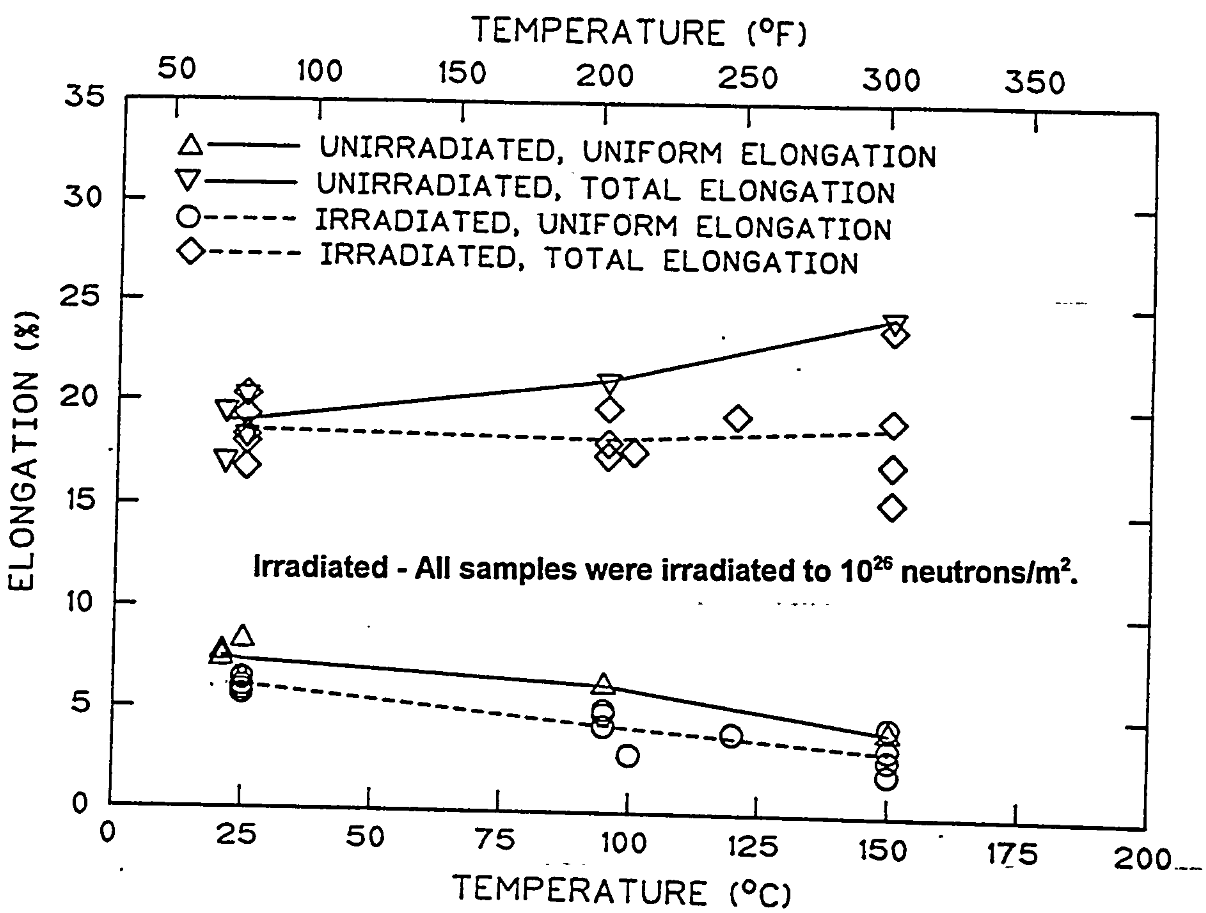

Fig. 5. The effect of irradiation and test temperature on ductility of 6061-T651 aluminum.

See Page 1.3 for a listing of the above values.

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Aluminum Alloy 6061-T651

Static, Short-term Properties

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Table 1. Tensile data

Specimen number	Temperature (°C)	Yield strength (MPa)	Yield strength (ksi)	Ultimate strength (MPa)	Ultimate strength (ksi)	Elongation (%) Uniform	Elongation (%) Total	σ_u/σ_y
				Unirradiated				
235	21	270	39.1	301	43.7	7.4	19.5	1.12
272		255	37.0	297	43.1	7.7	17.1	1.16
208	26	261	37.8	300	43.5	8.3	20.7	1.15
255		267	38.7	302	43.8	6.4	17.3	1.13
264	95	247	35.8	284	41.2	6.3	21.2	1.15
241	150	231	33.5	255	37.0	4.1	24.4	1.10
Irradiated - All samples were irradiated to 10^{26} neutrons/m^2.								
204	26	311	45.1	339	49.1	6.5	20.3	1.09
252		312	45.3	345	50.0	6.4	18.3	1.10
207		301	43.7	334	48.4	5.7	18.0	1.11
233		316	45.9[a]	344	49.9	6.1	16.8	1.09
215		305	44.3	332	48.1	5.9	19.3	1.09
273	95	290	42.1	314	45.6	4.3	17.5	1.08
244		287	41.6	313	45.4	4.9	19.8	1.09
256		285	41.4	307	44.5	5.1	18.1	1.07
226	100	289	41.9	309	44.8	2.9	17.7	1.07
222	120	284	41.2	308	44.6	4.0	19.5	1.09
237	150	281	40.8	296	42.9	2.8	17.2	1.05
261		284	41.2	303	43.9	3.3	19.3	1.07
211		275	39.9	285	41.4	2.1	15.4	1.04
265		265	38.4	297	43.1	4.4	23.8	1.12

[a] Estimated value, gap in X-Y record.

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6061-T651
Ultimate Tensile Strength
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Test Temp Deg C	Strength MPa	Comments	AMIS Ref No
60-65	276		41
60-65	275		41
60-65	288		41
60-65	292		41
60-65	298		41
60-65	297		41
~95	301		38
~95	297		38
~95	300		38
~95	302		38
~95	284		38
~95	255		38
24	324	Tested in the Longitudinal Direction	39
24	325	Tested in the Transverse Direction	39
-84	353	Tested in the Longitudinal Direction	39
-84	347	Tested in the Transverse Direction	39
-196	407	Tested in the Longitudinal Direction	39
-196	414	Tested in the Transverse Direction	39

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Ultimate Tensile Strength
Effect of Strain Rate
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Effect of Strain Rate on the UTS at Room Temperature

Strain Rate	UTS
s^{-1}	ksi
1.00×10^{-4}	40.4
1.00×10^{-4}	40
1.00×10^{-4}	40.7
1.66×10^{-2}	43.6
1.66×10^{-2}	43.5
1.66×10^{-2}	43.3
1.00×10^{-2}	39.7
1.00×10^{-2}	41.2
1.00×10^{-2}	41.7
0.93	42.2
0.91	42.5
0.92	42.3
6.6	41.9
7.6	40.4
8.2	42.1
4.40×10^{2}	42.4
3.10×10^{2}	40.7
3.30×10^{2}	42.3
3.50×10^{2}	42.7
1.00×10^{3}	42.2
1.00×10^{3}	41.3
1.00×10^{3}	41.6

Metals tend to increase in strength as the strain rate is increased, and the strain rate effect tends to increase with temperature. The values above show that for this material the effect on strength of even a wide difference in strain rate is only on the order of 10 percent.

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6061-T6511
Ultimate Tensile Strength
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Test Temp	Strength
Deg C	MPa
27	303.8
27	299
27	301.1
66	289.4
66	291.4
66	294.2
121	296.3
121	272.8
121	274.9
204	231.5
204	228.1
204	231.5
260	177.1
260	177.8
260	184.7

The material for these tests was supplied by the Aluminum Association in the form of bar stock. The chemical composition was: 0.59% Si, 0.32% Fe, 0.27% Cu, 0.03% Mn, 0.95% Mg, 0.06% Cr, 0.00 % Ni, 0.06% Zn, 0.03% Ti, 0.00% Pb, and Balance of Al. Note that the material was in the T6511 condition which means the material may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

The tensile tests were performed on standard 0.505-inch diameter specimens with a strain rate of 0.005 inch/inch/minute.

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Ultimate Tensile Strength

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
60-65		1.8×10^{20}	5×10^{20}	285		41
60-65		1.8×10^{20}	5×10^{20}	269		41
60-65		1.8×10^{20}	5×10^{20}	285		41
60-65		1.8×10^{20}	5×10^{20}	297		41
60-65		1.8×10^{20}	5×10^{20}	298		41
60-65		8.3×10^{20}	2.3×10^{21}	289		41
60-65		8.3×10^{20}	2.3×10^{21}	289		41
60-65		8.3×10^{20}	2.3×10^{21}	280		41
60-65		5.5×10^{21}	1.5×10^{22}	306		41
60-65		5.5×10^{21}	1.5×10^{22}	302		41
60-65		8.5×10^{21}	2.4×10^{22}	273		41
60-65		8.5×10^{21}	2.4×10^{22}	287		41
60-65		8.5×10^{21}	2.4×10^{22}	296		41
60-65		1.7×10^{22}	4.8×10^{22}	300		41
60-65		1.7×10^{22}	4.8×10^{22}	297		41
60-65		5.5×10^{22}	1.5×10^{23}	303		41
60-65		5.5×10^{22}	1.5×10^{23}	302		41
60-65		1.2×10^{23}	3.4×10^{23}	300		41
60-65		1.2×10^{23}	3.4×10^{23}	300		41
60-65		3.6×10^{23}	1.0×10^{24}	299		41
60-65		3.6×10^{23}	1.0×10^{24}	301		41
60-65		1.2×10^{24}	3.4×10^{24}	302		41
60-65		7.4×10^{24}	2.1×10^{25}	315		41
60-65		7.4×10^{24}	2.1×10^{25}	314		41
60-65		9.9×10^{24}	3.1×10^{25}	327		41
60-65		9.9×10^{24}	3.1×10^{25}	313		41

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
~95	26	~5.5×10^{25}	~1.1×10^{26}	339	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5×10^{25}	~1.1×10^{26}	345	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5×10^{25}	~1.1×10^{26}	334	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5×10^{25}	~1.1×10^{26}	344	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5×10^{25}	~1.1×10^{26}	332	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5×10^{25}	~1.1×10^{26}	314	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5×10^{25}	~1.1×10^{26}	313	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5×10^{25}	~1.1×10^{26}	307	Thermal fluence, E<0.78 eV.	38
~95	100	~5.5×10^{25}	~1.1×10^{26}	309	Thermal fluence, E<0.78 eV.	38
~95	120	~5.5×10^{25}	~1.1×10^{26}	308	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5×10^{25}	~1.1×10^{26}	296	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5×10^{25}	~1.1×10^{26}	303	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5×10^{25}	~1.1×10^{26}	285	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5×10^{25}	~1.1×10^{26}	297	Thermal fluence, E<0.78 eV.	38
-196	24	8.8×10^{21} *	?	322	Tested in the Longitudinal Direction	39
-196	24	8.8×10^{21}	?	332	Tested in the Transverse Direction	39
-196	24	4.2×10^{22}	?	339	Tested in the Longitudinal Direction	39
-196	24	4.2×10^{22}	?	325	Tested in the Transverse Direction	39
-196	24	1.9×10^{23}	?	329	Tested in the Longitudinal Direction	39
-196	24	1.9×10^{23}	?	325	Tested in the Transverse Direction	39
-196	-84	8.8×10^{21} *	?	356	Tested in the Longitudinal Direction	39
-196	-84	8.8×10^{21}	?	356	Tested in the Transverse Direction	39
-196	-84	4.0×10^{22}	?	358	Tested in the Longitudinal Direction	39
-196	-84	4.0×10^{22}	?	356	Tested in the Transverse Direction	39
-196	-84	2×10^{24}	?	375	Tested in the Longitudinal Direction	39
-196	-84	2×10^{24}	?	380	Tested in the Transverse Direction	39
-196	-196	8.8×10^{21} *	?	436	Tested in the Longitudinal Direction	39

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Irradiation Temp	Test Temp	Fluence (n/m²)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
-196	-196	8.8×10^{21}	?	421	Tested in the Transverse Direction	39
-196	-196	4.2×10^{22}	?	454	Tested in the Longitudinal Direction	39
-196	-196	4.2×10^{22}	?	443	Tested in the Transverse Direction	39
-196	-196	2.0×10^{23}	?	498	Tested in the Longitudinal Direction	39
-196	-196	2.0×10^{23}	?	503	Tested in the Transverse Direction	39

[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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6061-T651
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Test Temp Deg C	Strength MPa	Comments	AMIS Ref No
60-65	251		41
60-65	250		41
60-65	265		41
60-65	269		41
60-65	276		41
60-65	274		41
~95	270		38
~95	255		38
~95	261		38
~95	267		38
~95	247		38
~95	231		38
24	309	Tested in the Longitudinal Direction	39
24	292	Tested in the Transverse Direction	39
-84	328	Tested in the Longitudinal Direction	39
-84	307	Tested in the Transverse Direction	39
-196	352	Tested in the Longitudinal Direction	39
-196	344	Tested in the Transverse Direction	39

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Aluminum Alloy
6061-T651
Yield Strength
Effect of Strain Rate
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Effect of Strain Rate on the YS at Room Temperature

Strain Rate (0.2% Offset)	Yield Strength
s^{-1}	ksi
1.00×10^{-4}	37.2
1.00×10^{-4}	36.7
1.00×10^{-4}	38
1.66×10^{-2}	40.5
1.66×10^{-2}	40.2
1.66×10^{-2}	41
1.00×10^{-2}	36.6
1.00×10^{-2}	37.7
1.00×10^{-2}	38.2
0.9	40.3
0.9	40.6
0.9	40.2
6.6	39.7
7.6	38
8.2	39.5
4.40×10^{2}	39.8
3.10×10^{2}	37.3
3.30×10^{2}	39.2
3.50×10^{2}	39.8
1.00×10^{3}	39.5
1.00×10^{3}	39.4
1.00×10^{3}	40

Metals tend to increase in strength as the strain rate is increased, and the strain rate effect tends to increase with temperature. The values above show that for this material the effect on strength of even a wide difference in strain rate is only on the order of 10 percent.

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Aluminum Alloy
6061-T6511
Yield Strength
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Test Temp	Yield Strength
Deg C	MPa
27	277
27	273.5
27	274.2
66	266.6
66	270.1
66	270.8
121	263.2
121	257
121	261.1
204	231.5
204	228.1
204	231.5
260	174.3
260	177.8
260	183.3

The material for these tests was supplied by the Aluminum Association in the form of bar stock. The chemical composition was: 0.59% Si, 0.32% Fe, 0.27% Cu, 0.03% Mn, 0.95% Mg, 0.06% Cr, 0.00 % Ni, 0.06% Zn, 0.03% Ti, 0.00% Pb, and Balance of Al. Note that the material was in the T6511 condition which means the material may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

The tensile tests were performed on standard 0.505-inch diameter specimens with a strain rate of 0.005 inch/inch/minute.

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Irradiation Temp Deg C	Test Temp Deg C	Fluence (n/m^2) Fast	Fluence (n/m^2) Thermal	Strength MPa	Comments	AMIS Ref No
60-65		1.8×10^{20}	5×10^{20}	261		41
60-65		1.8×10^{20}	5×10^{20}	249		41
60-65		1.8×10^{20}	5×10^{20}	263		41
60-65		1.8×10^{20}	5×10^{20}	276		41
60-65		1.8×10^{20}	5×10^{20}	275		41
60-65		8.3×10^{20}	2.3×10^{21}	263		41
60-65		8.3×10^{20}	2.3×10^{21}	268		41
60-65		8.3×10^{20}	2.3×10^{21}	258		41
60-65		5.5×10^{21}	1.5×10^{22}	285		41
60-65		5.5×10^{21}	1.5×10^{22}	283		41
60-65		8.5×10^{21}	2.4×10^{22}	256		41
60-65		8.5×10^{21}	2.4×10^{22}	264		41
60-65		8.5×10^{21}	2.4×10^{22}	269		41
60-65		1.7×10^{22}	4.8×10^{22}	278		41
60-65		1.7×10^{22}	4.8×10^{22}	274		41
60-65		5.5×10^{22}	1.5×10^{23}	281		41
60-65		5.5×10^{22}	1.5×10^{23}	281		41
60-65		1.2×10^{23}	3.4×10^{23}	282		41
60-65		1.2×10^{23}	3.4×10^{23}	284		41
60-65		3.6×10^{23}	1.0×10^{24}	272		41
60-65		3.6×10^{23}	1.0×10^{24}	278		41
60-65		1.2×10^{24}	3.4×10^{24}	287		41
60-65		7.4×10^{24}	2.1×10^{25}	303		41
60-65		7.4×10^{24}	2.1×10^{25}	300		41
60-65		9.9×10^{24}	3.1×10^{25}	315		41
60-65		9.9×10^{24}	3.1×10^{25}	304		41

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
~95	26	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	311	Thermal fluence, E<0.78 eV.	38
~95	26	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	312	Thermal fluence, E<0.78 eV.	38
~95	26	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	301	Thermal fluence, E<0.78 eV.	38
~95	26	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	316	Thermal fluence, E<0.78 eV.	38
~95	26	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	305	Thermal fluence, E<0.78 eV.	38
~95	95	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	290	Thermal fluence, E<0.78 eV.	38
~95	95	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	287	Thermal fluence, E<0.78 eV.	38
~95	95	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	285	Thermal fluence, E<0.78 eV.	38
~95	100	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	289	Thermal fluence, E<0.78 eV.	38
~95	120	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	284	Thermal fluence, E<0.78 eV.	38
~95	150	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	281	Thermal fluence, E<0.78 eV.	38
~95	150	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	284	Thermal fluence, E<0.78 eV.	38
~95	150	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	275	Thermal fluence, E<0.78 eV.	38
~95	150	$\sim 5.5 \times 10^{25}$	$\sim 1.1 \times 10^{26}$	265	Thermal fluence, E<0.78 eV.	38
-196	24	8.8×10^{21} *	?	306	Tested in the Longitudinal Direction	39
-196	24	8.8×10^{21}	?	306	Tested in the Transverse Direction	39
-196	24	4.2×10^{22}	?	323	Tested in the Longitudinal Direction	39
-196	24	4.2×10^{22}	?	301	Tested in the Transverse Direction	39
-196	24	1.9×10^{23}	?	319	Tested in the Longitudinal Direction	39
-196	24	1.9×10^{23}	?	303	Tested in the Transverse Direction	39
-196	-84	8.8×10^{21} *	?	338	Tested in the Longitudinal Direction	39

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Irradiation Temp	Test Temp	Fluence (n/m²)		Strength	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	MPa		
-196	-84	8.8×10^{21}	?	328	Tested in the Transverse Direction	39
-196	-84	4.0×10^{22}	?	352	Tested in the Longitudinal Direction	39
-196	-84	4.0×10^{22}	?	338	Tested in the Transverse Direction	39
-196	-84	2×10^{24}	?	374	Tested in the Longitudinal Direction	39
-196	-84	2×10^{24}	?	370	Tested in the Transverse Direction	39
-196	-196	8.8×10^{21} *	?	417	Tested in the Longitudinal Direction	39
-196	-196	8.8×10^{21}	?	376	Tested in the Transverse Direction	39
-196	-196	4.2×10^{22}	?	447	Tested in the Longitudinal Direction	39
-196	-196	4.2×10^{22}	?	428	Tested in the Transverse Direction	39
-196	-196	2.0×10^{23}	?	488	Tested in the Longitudinal Direction	39
-196	-196	2.0×10^{23}	?	493	Tested in the Transverse Direction	39

1 Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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Test Temp Deg C	Total Elongation %	Comments	AMIS Ref No
60-65	10.8		41
60-65	11.2		41
60-65	14.3		41
60-65	13.1		41
60-65	11.6		41
60-65	11.5		41
~95	19.5		38
~95	17.1		38
~95	20.7		38
~95	17.3		38
~95	21.2		38
~95	24.4		38
24	16.5	Tested in the Longitudinal Direction	39
24	16.6	Tested in the Transverse Direction	39
-84	17.7	Tested in the Longitudinal Direction	39
-84	18.4	Tested in the Transverse Direction	39
-196	24.1	Tested in the Longitudinal Direction	39
-196	23.3	Tested in the Transverse Direction	39

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Effect of Strain Rate on the Elongation at Room Temperature

Testing Machine[1]	Strain Rate (0.2% Offset)	Elongation[2]
	s^{-1}	%
H	1.00×10^{-4}	10.3
H	1.00×10^{-4}	10.2
H	1.00×10^{-4}	9.5
I	1.66×10^{-2}	18.2
I	1.66×10^{-2}	19
I	1.66×10^{-2}	17.2
H	1.00×10^{-2}	10.6
H	1.00×10^{-2}	12.5
H	1.00×10^{-2}	13.1
H	0.9	18.9
H	0.9	22.9
H	0.9	17.9
H	6.6	18.8
H	7.6	16.9
H	8.2	12.5
HPB	4.40×10^{2}	11.2
HPB	3.10×10^{2}	14.3
HPB	3.30×10^{2}	14.7
HPB	3.50×10^{2}	14.7
HPB	1.00×10^{3}	15.6
HPB	1.00×10^{3}	14.9
HPB	1.00×10^{3}	15.8

[1] I = Instron, H = Hydraulic, HPB = Hopkinson pressure bar.

[2] Gage length: 2 inches for Instron tests, 0.5 inch for other tests.

The increase in elongation was almost entirely by extension of the necking portion of the stress-strain curve. This is due to the time dependence nature of ductile fracture.

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Test Temp	Total Elongation
Deg C	%
27	17.5
27	17.5
27	19
66	17.5
66	17
66	17.5
121	19
121	19
121	19.5
204	23
204	22
204	22
260	18.5
260	19.5
260	19.5

The material for these tests was supplied by the Aluminum Association in the form of bar stock. The chemical composition was: 0.59% Si, 0.32% Fe, 0.27% Cu, 0.03% Mn, 0.95% Mg, 0.06% Cr, 0.00 % Ni, 0.06% Zn, 0.03% Ti, 0.00% Pb, and Balance of Al. Note that the material was in the T6511 condition which means the material may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

The tensile tests were performed on standard 0.505-inch diameter specimens with a strain rate of 0.005 inch/inch/minute.

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
60-65		1.8×10^{20}	5×10^{20}	12.1		41
60-65		1.8×10^{20}	5×10^{20}	10.8		41
60-65		1.8×10^{20}	5×10^{20}	14.1		41
60-65		1.8×10^{20}	5×10^{20}	10.1		41
60-65		1.8×10^{20}	5×10^{20}	11		41
60-65		8.3×10^{20}	2.3×10^{21}	13.3		41
60-65		8.3×10^{20}	2.3×10^{21}	14.4		41
60-65		8.3×10^{20}	2.3×10^{21}	11.7		41
60-65		5.5×10^{21}	1.5×10^{22}	11.3		41
60-65		5.5×10^{21}	1.5×10^{22}	11.1		41
60-65		8.5×10^{21}	2.4×10^{22}	10.7		41
60-65		8.5×10^{21}	2.4×10^{22}	11.9		41
60-65		8.5×10^{21}	2.4×10^{22}	12.7		41
60-65		1.7×10^{22}	4.8×10^{22}	11.6		41
60-65		1.7×10^{22}	4.8×10^{22}	12.6		41
60-65		5.5×10^{22}	1.5×10^{23}	10.7		41
60-65		5.5×10^{22}	1.5×10^{23}	10.8		41
60-65		1.2×10^{23}	3.4×10^{23}	10.1		41
60-65		1.2×10^{23}	3.4×10^{23}	9.7		41
60-65		3.6×10^{23}	1.0×10^{24}	11.5		41
60-65		3.6×10^{23}	1.0×10^{24}	11.3		41
60-65		1.2×10^{24}	3.4×10^{24}	10.3		41
60-65		7.4×10^{24}	2.1×10^{25}	10.7		41
60-65		7.4×10^{24}	2.1×10^{25}	8.9		41
60-65		9.9×10^{24}	3.1×10^{25}	9.7		41
60-65		9.9×10^{24}	3.1×10^{25}	9.7		41

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	20.3	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	18.3	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	18	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	16.8	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	19.3	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5 × 10^{25}	~1.1 × 10^{26}	17.5	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5 × 10^{25}	~1.1 × 10^{26}	19.8	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5 × 10^{25}	~1.1 × 10^{26}	18.1	Thermal fluence, E<0.78 eV.	38
~95	100	~5.5 × 10^{25}	~1.1 × 10^{26}	17.7	Thermal fluence, E<0.78 eV.	38
~95	120	~5.5 × 10^{25}	~1.1 × 10^{26}	19.5	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	17.2	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	19.3	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	15.4	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	23.8	Thermal fluence, E<0.78 eV.	38
-196	24	8.8 × 10^{21} *	?	16.4	Tested in the Longitudinal Direction	39
-196	24	8.8 × 10^{21}	?	15.9	Tested in the Transverse Direction	39
-196	24	4.2 × 10^{22}	?	16.3	Tested in the Longitudinal Direction	39
-196	24	4.2 × 10^{22}	?	16.4	Tested in the Transverse Direction	39
-196	24	1.9 × 10^{23}	?	15.6	Tested in the Longitudinal Direction	39
-196	24	1.9 × 10^{23}	?	15.2	Tested in the Transverse Direction	39
-196	-84	8.8 × 10^{21} *	?	17.1	Tested in the Longitudinal Direction	39
-196	-84	8.8 × 10^{21}	?	16.5	Tested in the Transverse Direction	39
-196	-84	4.0 × 10^{22}	?	15.9	Tested in the Longitudinal Direction	39
-196	-84	4.0 × 10^{22}	?	16.3	Tested in the Transverse Direction	39
-196	-84	2 × 10^{24}	?	10.7	Tested in the Longitudinal Direction	39
-196	-84	2 × 10^{24}	?	12.3	Tested in the Transverse Direction	39
-196	-196	8.8 × 10^{21} *	?	19.9	Tested in the Longitudinal Direction	39

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Irradiation Temp	Test Temp	Fluence (n/m²)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
-196	-196	8.8×10^{21}	?	18.5	Tested in the Transverse Direction	39
-196	-196	4.2×10^{22}	?	13.9	Tested in the Longitudinal Direction	39
-196	-196	4.2×10^{22}	?	15.4	Tested in the Transverse Direction	39
-196	-196	2.0×10^{23}	?	9.5	Tested in the Longitudinal Direction	39
-196	-196	2.0×10^{23}	?	12.1	Tested in the Transverse Direction	39

[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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Uniform Elongation
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Test Temp Deg C	Uniform Elongation %	Comments	AMIS Ref No
60-65	5.7		41
60-65	5.7		41
60-65	7.6		41
60-65	6.7		41
60-65	6.3		41
60-65	6		41
~95	7.4		38
~95	7.7		38
~95	8.3		38
~95	6.4		38
~95	6.3		38
~95	4.1		38
24	6.5	Tested in the Longitudinal Direction	39
24	6.9	Tested in the Transverse Direction	39
-84	8.5	Tested in the Longitudinal Direction	39
-84	8.1	Tested in the Transverse Direction	39
-196	11.9	Tested in the Longitudinal Direction	39
-196	13.6	Tested in the Transverse Direction	39

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
60-65		1.8×10^{20}	5×10^{20}	6.5		41
60-65		1.8×10^{20}	5×10^{20}	4.9		41
60-65		1.8×10^{20}	5×10^{20}	7		41
60-65		1.8×10^{20}	5×10^{20}	5		41
60-65		1.8×10^{20}	5×10^{20}	6.2		41
60-65		8.3×10^{20}	2.3×10^{21}	6.5		41
60-65		8.3×10^{20}	2.3×10^{21}	6.3		41
60-65		8.3×10^{20}	2.3×10^{21}	6.1		41
60-65		5.5×10^{21}	1.5×10^{22}	6.2		41
60-65		5.5×10^{21}	1.5×10^{22}	5.5		41
60-65		8.5×10^{21}	2.4×10^{22}	5.5		41
60-65		8.5×10^{21}	2.4×10^{22}	6.6		41
60-65		8.5×10^{21}	2.4×10^{22}	6.4		41
60-65		1.7×10^{22}	4.8×10^{22}	6.3		41
60-65		1.7×10^{22}	4.8×10^{22}	6.8		41
60-65		5.5×10^{22}	1.5×10^{23}	5.4		41
60-65		5.5×10^{22}	1.5×10^{23}	6		41
60-65		1.2×10^{23}	3.4×10^{23}	5		41
60-65		1.2×10^{23}	3.4×10^{23}	5.3		41
60-65		3.6×10^{23}	1.0×10^{24}	6.5		41
60-65		3.6×10^{23}	1.0×10^{24}	6.5		41
60-65		1.2×10^{24}	3.4×10^{24}	4.9		41
60-65		7.4×10^{24}	2.1×10^{25}	4		41
60-65		7.4×10^{24}	2.1×10^{25}	3.8		41
60-65		9.9×10^{24}	3.1×10^{25}	4.1		41
60-65		9.9×10^{24}	3.1×10^{25}	3.4		41

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Aluminum Alloy
6061-T651
Uniform Elongation
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Irradiation Temp	Test Temp	Fluence (n/m^2)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal	%		
60-65		1.8×10^{20}	5×10^{20}	6.5		41
60-65		1.8×10^{20}	5×10^{20}	4.9		41
60-65		1.8×10^{20}	5×10^{20}	7		41
60-65		1.8×10^{20}	5×10^{20}	5		41
60-65		1.8×10^{20}	5×10^{20}	6.2		41
60-65		8.3×10^{20}	2.3×10^{21}	6.5		41
60-65		8.3×10^{20}	2.3×10^{21}	6.3		41
60-65		8.3×10^{20}	2.3×10^{21}	6.1		41
60-65		5.5×10^{21}	1.5×10^{22}	6.2		41
60-65		5.5×10^{21}	1.5×10^{22}	5.5		41
60-65		8.5×10^{21}	2.4×10^{22}	5.5		41
60-65		8.5×10^{21}	2.4×10^{22}	6.6		41
60-65		8.5×10^{21}	2.4×10^{22}	6.4		41
60-65		1.7×10^{22}	4.8×10^{22}	6.3		41
60-65		1.7×10^{22}	4.8×10^{22}	6.8		41
60-65		5.5×10^{22}	1.5×10^{23}	5.4		41
60-65		5.5×10^{22}	1.5×10^{23}	6		41
60-65		1.2×10^{23}	3.4×10^{23}	5		41
60-65		1.2×10^{23}	3.4×10^{23}	5.3		41
60-65		3.6×10^{23}	1.0×10^{24}	6.5		41
60-65		3.6×10^{23}	1.0×10^{24}	6.5		41
60-65		1.2×10^{24}	3.4×10^{24}	4.9		41
60-65		7.4×10^{24}	2.1×10^{25}	4		41
60-65		7.4×10^{24}	2.1×10^{25}	3.8		41
60-65		9.9×10^{24}	3.1×10^{25}	4.1		41
60-65		9.9×10^{24}	3.1×10^{25}	3.4		41

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Irradiation Temp	Test Temp	Fluence (n/m²)		Uniform Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	6.5	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	6.4	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	5.7	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	6.1	Thermal fluence, E<0.78 eV.	38
~95	26	~5.5 × 10^{25}	~1.1 × 10^{26}	5.9	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5 × 10^{25}	~1.1 × 10^{26}	4.3	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5 × 10^{25}	~1.1 × 10^{26}	4.9	Thermal fluence, E<0.78 eV.	38
~95	95	~5.5 × 10^{25}	~1.1 × 10^{26}	5.1	Thermal fluence, E<0.78 eV.	38
~95	100	~5.5 × 10^{25}	~1.1 × 10^{26}	2.9	Thermal fluence, E<0.78 eV.	38
~95	120	~5.5 × 10^{25}	~1.1 × 10^{26}	4	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	2.8	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	3.3	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	2.1	Thermal fluence, E<0.78 eV.	38
~95	150	~5.5 × 10^{25}	~1.1 × 10^{26}	4.4	Thermal fluence, E<0.78 eV.	38
-196	24	8.8 × 10^{21} *	?	6.2	Tested in the Longitudinal Direction	39
-196	24	8.8 × 10^{21}	?	6.7	Tested in the Transverse Direction	39
-196	24	4.2 × 10^{22}	?	6.6	Tested in the Longitudinal Direction	39
-196	24	4.2 × 10^{22}	?	7.7	Tested in the Transverse Direction	39
-196	24	1.9 × 10^{23}	?	5.4	Tested in the Longitudinal Direction	39
-196	24	1.9 × 10^{23}	?	5.5	Tested in the Transverse Direction	39
-196	-84	8.8 × 10^{21} *	?	7.2	Tested in the Longitudinal Direction	39
-196	-84	8.8 × 10^{21}	?	7.2	Tested in the Transverse Direction	39
-196	-84	4.0 × 10^{22}	?	5.4	Tested in the Longitudinal Direction	39
-196	-84	4.0 × 10^{22}	?	6.2	Tested in the Transverse Direction	39
-196	-84	2 × 10^{24}	?	0.1	Tested in the Longitudinal Direction	39
-196	-84	2 × 10^{24}	?	1.5	Tested in the Transverse Direction	39
-196	-196	8.8 × 10^{21} *	?	8.1	Tested in the Longitudinal Direction	39

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Irradiation Temp	Test Temp	Fluence (n/m²)		Total Elongation	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal	%		
-196	-196	8.8×10^{21}	?	8.9	Tested in the Transverse Direction	39
-196	-196	4.2×10^{22}	?	0.5	Tested in the Longitudinal Direction	39
-196	-196	4.2×10^{22}	?	0.5	Tested in the Transverse Direction	39
-196	-196	2.0×10^{23}	?	0.6	Tested in the Longitudinal Direction	39
-196	-196	2.0×10^{23}	?	0.6	Tested in the Transverse Direction	39

[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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Test Temp	Reduction of Area	Comments	AMIS Ref No
Deg C	%		
24	49.2	Tested in the Longitudinal Direction	39
24	50.2	Tested in the Transverse Direction	39
-84	46.8	Tested in the Longitudinal Direction	39
-84	48.3	Tested in the Transverse Direction	39
-196	43.7	Tested in the Longitudinal Direction	39
-196	42.3	Tested in the Transverse Direction	39

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Aluminum Alloy
6061-T6511
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Test Temp	Reduction of Area
Deg C	%
27	57.7
27	60
27	57.2
66	59
66	57.7
66	57
121	60
121	63.4
121	67.5
204	73.7
204	75
204	71.5
260	60.7
260	63
260	64.6

The material for these tests was supplied by the Aluminum Association in the form of bar stock. The chemical composition was: 0.59% Si, 0.32% Fe, 0.27% Cu, 0.03% Mn, 0.95% Mg, 0.06% Cr, 0.00 % Ni, 0.06% Zn, 0.03% Ti, 0.00% Pb, and Balance of Al. Note that the material was in the T6511 condition which means the material may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

The tensile tests were performed on standard 0.505-inch diameter specimens with a strain rate of 0.005 inch/inch/minute.

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Irradiation Temp	Test Temp	Fluence (n/m^2)		Reduction of Area	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal	%		
-196	24	8.8×10^{21} *	?	48.9	Tested in the Longitudinal Direction	39
-196	24	8.8×10^{21}	?	46.5	Tested in the Transverse Direction	39
-196	24	4.2×10^{22}	?	47	Tested in the Longitudinal Direction	39
-196	24	4.2×10^{22}	?	52.9	Tested in the Transverse Direction	39
-196	24	1.9×10^{23}	?	45.1	Tested in the Longitudinal Direction	39
-196	24	1.9×10^{23}	?	49.3	Tested in the Transverse Direction	39
-196	-84	8.8×10^{21} *	?	48.3	Tested in the Longitudinal Direction	39
-196	-84	8.8×10^{21}	?	47.9	Tested in the Transverse Direction	39
-196	-84	4.0×10^{22}	?	47.9	Tested in the Longitudinal Direction	39
-196	-84	4.0×10^{22}	?	46.7	Tested in the Transverse Direction	39
-196	-84	2×10^{24}	?	48.1	Tested in the Longitudinal Direction	39
-196	-84	2×10^{24}	?	52.9	Tested in the Transverse Direction	39
-196	-196	8.8×10^{21} *	?	45.5	Tested in the Longitudinal Direction	39
-196	-196	8.8×10^{21}	?	42.8	Tested in the Transverse Direction	39
-196	-196	4.2×10^{22}	?	39.8	Tested in the Longitudinal Direction	39
-196	-196	4.2×10^{22}	?	40	Tested in the Transverse Direction	39
-196	-196	2.0×10^{23}	?	40	Tested in the Longitudinal Direction	39
-196	-196	2.0×10^{23}	?	42.6	Tested in the Transverse Direction	39

[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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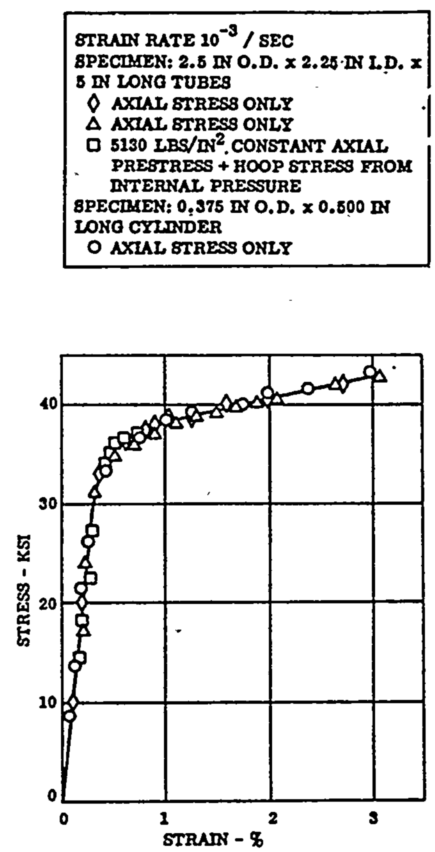

UNIAXIAL AND BIAXIAL STRESS-STRAIN CURVES FOR 6061-T651 ALUMINUM

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Materials Technology Corporation)

Temp Deg F	Stress, ksi	Rupture Time hours	Comments
200	38	119	
200	37	718	
200	37	2,522	
200	36	4,613	
200	35.5	22,200	Data from AMIS Ref. 25
275	33	382	
300	33	73	
300	30	700	
300	28	1,682	
300	24	10,739	Data obtained subsequent to analysis
300	21	28,300	Data from AMIS Ref. 25
350	26	148	

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by University of Michigan)

Temp	Stress,	Rupture Time	Comments
Deg F	ksi	hours	
350	26	163	
350	24	446	
350	22.5	868	
350	21	1,912	
350	21	1,663	
350	20	2,814	
350	16.5	14,705	Rupture data obtained subsequent to analysis.
350	14	26,500	Data from AMIS Ref. 25
375	21	397	
375	17	2,063	
400	26	6.1	
400	24	19	
400	21	70	
400	21	74	
400	21	72	
400	21	67	
400	21	72	
400	21	69	
400	17	474	
400	13	2,445	
400	10	28,300	Data from AMIS Ref. 25
400	8.5	60,000	Data from AMIS Ref. 25
450	17	22.4	

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Aluminum Alloy 6061-T651

Stress-Rupture Strength

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Temp	Stress	Rupture Time	Comments
Deg F	ksi	hours	
450	13	121	
450	13	182	
450	11	632	
450	9	4,156	
450	7	13,200	Data from AMIS Ref. 25
450	4	64,000	Data from AMIS Ref. 25
500	13	9.2	
500	11	77	
500	9	394	Overheated 14 Kelvins for short period during the test.
500	7	1,081	Overheated 14 Kelvins for short period during the test.
500	6	1,838	
500	5	2,824	
500	3	28,300	Data from AMIS Ref. 25
550	9	28.8	
550	7	153	
550	4	753	
550	2.5	44,800	Data from AMIS Ref. 25
600	7	20	
600	4	126	

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Aluminum Company of America)

Temperature	Stress	Rupture Time
deg F	ksi	h
212	38	29
212	37	925
250	36	63
250	35	549
300	35	1.4
300	33	96
300	32	285
300	30	1,017
350	29	42
350	26	208
350	24	470
400	26	7
400	24	16
400	22	50
400	21	108
400	19	194
400	17	468
450	21	4.8
450	17	27
450	13	177
450	13	257
450	11	681
450	11	941
500	17	1.7

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Temperature	Stress	Rupture Time
deg F	ksi	h
500	13	11
500	13	23
500	13	33
500	11	64
500	11	82
500	95	278
500	95	271
500	8	721
500	8	1,078
550	13	1
550	11	6
550	9.5	27
550	8	76
550	8	102
550	6	224
550	6	244
550	4	763
600	9.5	2.4
600	8	11
600	6	38
600	6	45
600	4	130
600	4	144
600	3	502
650	6	8.5
650	4	29
650	3	79

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Temperature	Stress	Rupture Time
deg F	ksi	h
650	3	115
650	2.5	721
650	2	10,700
700	3	15
700	3	20
700	2.5	181
700	2.5	227
700	2	1,086
750	2	332

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Temperature	Stress	Rupture Time	Comments
deg F	ksi	h	
650	3	115	
650	2.5	721	
650	2	10,700	Data from AMIS Ref. 25
700	3	15	
700	3	20	
700	2.5	181	
700	2.5	227	
700	2	1,086	
750	2	332	

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by University of Michigan)

Temperature deg F	Stress ksi	Rupture Time h	N/S Ratio[2]	Comments
300	30	2,688	1.11	Tested by Materials Technology Corporation.
350	26	827	1.15	Tested by Materials Technology Corporation.
350	24	1,067	1.09	
350	19	2,137	0.92	This value seems questionable.
350	19	16,224	1.17	
400	26	110	1.29	
400	21	233	1.15	
400	18	946	1.18	
400	14	4,544	1.12	
500	11	435	1.25	
500	8	2,142	1.2	
600	2.5	8,896	>1.15	Discontinued.

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

[2] N/S = (Notched Specimen Rupture Strength)/(Unnotched Specimen Rupture Strength for Same Life)

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Materials Technology Corporation)

Temp	Stress,	Minimum Creep Rate
Deg F	psi	%/h
200	38,000	0.0083
200	37,500	0.0015
200	37,000	0.00025
200	36,500	0.00004
275	33,000	0.0004
300	30,000	0.0003
300	28,000	0.00006
300	24,000	0.00003

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Materials Technology Corporation)

Temp	Stress,	Minimum Creep Rate	Comments
Deg F	psi	%/h	
350	26	0.0018	
350	24	0.00091	
350	22.5	0.00055	
350	21	0.00022	
350	21	0.00036	
350	20	0.000155	
350	16.5	0.000013	Rupture data obtained subsequent to analysis.
375	21	0.001	
375	17	0.000175	
400	26	0.043	
400	24	0.02	
400	21	0.0068	
400	21	0.0048	
400	21	0.0065	
400	21	0.0073	
400	21	0.0063	
400	21	0.0074	
400	17	0.00083	
400	13	0.000185	
450	13	0.0039	
450	13	0.0028	
450	11	0.00144	

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Temp	Stress,	Minimum Creep Rate	Comments
Deg F	psi	%/h	
450	9	0.000194	
500	13	0.069	
500	11	0.0106	
500	9	0.00315	Overheated 14 Kelvins for short period during the test.
500	7	0.00071	Overheated 14 Kelvins for short period during the test.
500	6	0.00035	
500	5	0.00021	
550	7	0.0042	
550	4	0.00088	
600	4	0.0044	

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Aluminum Alloy
6061-T651
Secondary Creep Rate
Page Revision 0.0
AMBK Update No. 0

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

Temp	Secondary Creep Rate	Stress
Deg F	%/h	ksi
200	2.49E-05	36.5
200	5.64E-05	37
200	0.000239	37.2
200	0.008604	39.1
250	0.000987	36.3
250	0.014951	37.3
275	0.000376	34.1
275	0.000668	34.4
275	0.002882	34.9
275	0.004949	35.8
300	1.52E-05	21.2
300	2.89E-05	24.7
300	5.88E-05	29.4
300	0.000159	31.9
300	0.000293	31.1
300	0.00068	32.7
300	0.008549	34.9
350	1.29E-05	15.9
350	1.59E-05	13.9
350	0.000152	19.9
350	0.000211	21.3
350	0.000347	20.9
350	0.000533	22.5

Temp	Secondary Creep Rate	Stress
Deg F	%/h	ksi
350	0.000878	23.7
350	0.001752	25.7
350	0.004432	29.8
375	0.000171	17.1
375	0.000976	21.7
400	1.94E-06	8.4
400	1.07E-05	9.8
400	0.000173	12.8
400	0.000791	16.5
400	0.004725	21.4
400	0.006433	21.1
400	0.006657	21.5
400	0.007252	21.3
400	0.020057	24.7
400	0.043683	26.7
450	8.89E-06	3.9
450	3.02E-05	7
450	0.000185	9.1
450	0.000956	10.8
450	0.001341	10.9
450	0.002316	12.7
450	0.002794	12.7
450	0.003893	12.7

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Aluminum Alloy 6061-T651
Secondary Creep Rate
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Temp	Secondary Creep Rate	Stress
Deg F	%/h	ksi
450	0.009421	16.6
450	0.049434	22
500	3.36E-05	3.7
500	0.000209	4.8
500	0.000705	7
500	0.003096	8.5
500	0.010828	10.2
500	0.035378	12.2
550	4.30E-05	2.4
550	0.001259	5.6
550	0.004273	6.8
550	0.007957	7.8
550	0.010289	7.85
550	0.036061	9
550	0.071307	12.5
600	0.000133	2
600	0.002234	4
600	0.003171	4
600	0.004592	4
600	0.009626	5.8
600	0.04539	7.7

Temp	Secondary Creep Rate	Stress
Deg F	%/h	ksi
650	0.002546	2.3
650	0.007108	2.8
650	0.02113	3.7
700	0.004574	1.87
700	0.006618	1.91
700	0.015968	2.4

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Aluminum Alloy
6061-T6511
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Test Temp	Time	Phase I[1] Residual Stress
Deg F	Hours	ksi
80	1.01E-02	38.8
80	1.02E-01	38
80	1.02E+00	37.5
80	9.69E+00	36.7
80	1.03E+02	36.6
80	9.74E+02	35.6
150	1.00E-02	38.2
150	2.01E-02	37.4
150	2.49E-02	37.2
150	2.93E-02	37.2
150	1.01E-01	36.8
150	1.01E+00	35.9
150	9.76E+00	35.1
150	9.99E+02	33.7
250	9.77E-03	36.5
250	1.49E-02	35.4
250	1.91E-02	35
250	2.50E-02	34.5
250	3.01E-02	34.3
250	9.74E-02	34.1
250	1.03E+00	33.7
250	9.72E+00	32.9
250	1.02E+02	32.4
250	9.58E+02	31.8
400	9.91E-03	33.1
400	1.51E-02	31.4
400	1.93E-02	30.3

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Stress Relaxation

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Test Temp	Time	Phase I[1] Residual Stress
Deg F	Hours	ksi
400	2.55E-02	29.4
400	3.98E-02	28.3
400	7.90E-02	27.8
400	1.01E-01	27.5
400	3.39E-01	26.8
400	3.96E-01	26.8
400	4.83E-01	27
400	5.87E-01	27.1
400	6.94E-01	26.8
400	7.75E-01	26.7
400	8.60E-01	26.5
400	9.75E-01	26.1
400	1.50E+00	24.5
400	1.00E+01	19.3
400	1.06E+02	13.9
400	5.09E+02	10.9
400	6.18E+02	10.7
400	7.22E+02	10.7
400	7.90E+02	10.7
400	8.85E+02	10.7
400	9.62E+02	10.7
500	9.69E-03	23.8
500	1.47E-02	17.6
500	1.89E-02	15.3
500	3.02E-02	12.8
500	5.11E-02	11.7
500	1.05E-01	11.2

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Test Temp	Time	Phase I[1] Residual Stress
Deg F	Hours	ksi
500	1.01E+00	10.6
500	2.02E+00	10.6
500	3.16E+00	9.8
500	4.22E+00	9.1
500	5.13E+00	8.6
500	1.04E+01	7.2
500	9.20E+01	4.7
500	5.23E+02	3.2
500	6.32E+02	2.9
500	7.13E+02	3
500	7.92E+02	3.1
500	8.77E+02	3.1
500	9.57E+02	3.1

[1] The Phase I tests were run with an initial strain equal to 100% of the strain at the 0.2% offset yield point. The Phase II tests (see Page 2) were run with an initial strain equal to 80% of the strain at the 0.2% offset yield point. See Page 3 for Residual Stress After 1000 Hours.

The material for these tests was supplied by the Aluminum Association in the form of bar stock. The chemical composition was: 0.59% Si, 0.32% Fe, 0.27% Cu, 0.03% Mn, 0.95% Mg, 0.06% Cr, 0.00 % Ni, 0.06% Zn, 0.03% Ti, 0.00% Pb, and Balance of Al. Note that the material was in the T6511 condition which means the material may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

The relaxation tests were performed on 0.505-inch diameter specimens with a gage length of six inches.

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Test Temp	Time	Phase II[1] Residual Stress
Deg F	Hours	ksi
80	9.81E-03	39.5
80	9.25E-02	38.6
80	9.68E-01	38.6
80	9.57E+00	38.3
80	9.53E+01	36.9
80	9.81E+02	35.8
150	9.68E-03	39.1
150	9.41E-02	37.9
150	9.51E-01	37.7
150	9.95E+00	36.3
150	9.87E+01	36
150	2.85E+02	35.8
150	9.87E+02	33.2
250	9.82E-03	36.5
250	9.30E-02	30.2
250	2.82E-01	28.6
250	9.74E-01	28.1
250	1.02E+01	27.9
250	9.91E+01	27.2
250	9.42E+02	25.3
400	9.85E-03	32.8
400	9.97E-02	23
400	9.66E-01	19.5
400	1.04E+01	17
400	1.02E+02	13
400	3.50E+02	9.9
400	9.65E+02	8.6

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Test Temp	Time	Phase II[1] Residual Stress
Deg F	Hours	ksi
500	9.72E-03	24.4
500	1.10E-02	22.5
500	1.47E-02	20.9
500	9.99E-02	17.3
500	4.57E-01	15.1
500	9.98E-01	13.1
500	1.07E+01	7.9
500	1.03E+02	4
500	4.18E+02	2.3
500	1.03E+03	1.9

[1] The Phase I tests (See Page 1) were run with an initial strain equal to 100% of the strain at the 0.2% offset yield point. The Phase II tests were run with an initial strain equal to 80% of the strain at the 0.2% offset yield point. See Page 3 for Residual Stress After 1000 Hours.

The material for these tests was supplied by the Aluminum Association in the form of bar stock. The chemical composition was: 0.59% Si, 0.32% Fe, 0.27% Cu, 0.03% Mn, 0.95% Mg, 0.06% Cr, 0.00 % Ni, 0.06% Zn, 0.03% Ti, 0.00% Pb, and Balance of Al. Note that the material was in the T6511 condition which means the material may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

The relaxation tests were performed on 0.505-inch diameter specimens with a gage length of six inches.

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Test Phase[1]	Test Temp	Residual Stress After 1000 Hours
	Deg F	ksi
Phase I	69.3	36.9
Phase I	150.1	34.5
Phase I	197.6	33.1
Phase I	250.8	32.1
Phase I	300	26.2
Phase I	350.8	16.6
Phase I	401.6	11.1
Phase I	449.9	6.9
Phase I	499.2	3.1

Test Phase[1]	Test Temp	Residual Stress After 1000 Hours
	Deg F	ksi
Phase II	70	36.2
Phase II	98.8	35.4
Phase II	149.7	33.3
Phase II	198.6	29.9
Phase II	251.1	24.6
Phase II	297.9	18
Phase II	349.9	12.4
Phase II	402	8.4
Phase II	449.4	5.6
Phase II	496.7	2.2

[1] The Phase I tests (See Page 1) were run with an initial strain equal to 100% of the strain at the 0.2% offset yield point. The Phase II tests were run with an initial strain equal to 80% of the strain at the 0.2% offset yield point. All tests were performed on 0.505-inch diameter specimens with a gage length of six inches.

The material for these tests was supplied by the Aluminum Association in the form of bar stock. The chemical composition was: 0.59% Si, 0.32% Fe, 0.27% Cu, 0.03% Mn, 0.95% Mg, 0.06% Cr, 0.00 % Ni, 0.06% Zn, 0.03% Ti, 0.00% Pb, and Balance of Al. Note that the material was in the T6511 condition which means the material may receive minor straightening, after the T651 stretching treatment, to comply with standard tolerances.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Materials Technology Corporation)

Temp	Stress,	Elongation
Deg F	psi	%
200	38,000	14
200	37,500	12
200	37,000	12
200	36,500	12
275	33,000	11
300	33,000	16
300	30,000	10
300	28,000	9
300	24,000	5
350	26,000	9

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Strain at Fracture, Elongation

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by University of Michigan)

Temp Deg F	Stress, ksi	Elongation %	Comments
350	26	7	
350	24	7	
350	22.5	9	
350	21	5	
350	21	7	
350	20	6	
350	16.5	5	Rupture data obtained subsequent to analysis.
375	21	5	
375	17	10	
400	26	10	
400	24	8	
400	21	7	
400	21	8	
400	21	7	
400	21	5	
400	21	8	
400	21	8	
400	17	10	
400	13	10	
450	17	11	
450	13	13	
450	13	31	

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Temp	Stress	Elongation	Comments
Deg F	ksi	%	
450	11	9	
450	9	7	
500	13	16	
500	11	13	
500	9	12	Overheated 14 Kelvins for short period during the test.
500	7	18	Overheated 14 Kelvins for short period during the test.
500	6	21	
500	5	23	
550	9	19	
550	7	24	
550	4	31	
600	7	25	
600	4	30	

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Aluminum Company of America)

Temp	Stress	Elongation
Deg F	ksi	%
212	38	18
212	37	14
250	36	14
250	35	18
300	35	20
300	33	12
300	32	16
300	30	10
350	29	12
350	26	10
350	24	8
400	26	8
400	24	8
400	22	8
400	21	8
400	19	12
400	17	10
450	21	10
450	17	14
450	13	12
450	13	8
450	11	8
450	11	10

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Temp	Stress	Elongation
Deg F	ksi	%
500	17	12
500	13	15
500	13	18
500	13	17
500	11	12
500	11	12
500	95	11
500	95	20
500	8	14
500	8	11
550	13	16
550	11	18
550	9.5	18
550	8	19
550	8	18
550	6	29
550	6	24
550	4	34
600	9.5	22
600	8	24
600	6	34
600	6	26
600	4	31
600	4	34
600	3	42
650	4	34
650	3	48
650	3	40

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Temp	Stress	Elongation
Deg F	ksi	%
650	2.5	18
700	3	42
700	3	42
700	2.5	35
700	2.5	32

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Materials Technology Corporation)

Temp	Stress,	R. A.
Deg F	psi	%
200	38,000	40
200	37,500	38
200	37,000	35
200	36,500	38
275	33,000	39
300	33,000	40
300	30,000	33
300	28,000	28
300	24,000	15
350	26,000	32

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Strain at Fracture, Reduction of Area

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Materials Technology Corporation)

Temp	Stress,	R. A.	Comments
Deg F	psi	%	
350	26	30	
350	24	24	
350	22.5	22	
350	21	16	
350	21	24	
350	20	20	
350	16.5	23	Rupture data obtained subsequent to analysis.
375	21	22	
375	17	26	
400	26	38	
400	24	33	
400	21	20	
400	21	26	
400	21	25	
400	21	23	
400	21	28	
400	21	22	
400	17	37	
400	13	35	
450	17	38	
450	13	46	
450	13	39	

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Temp Deg F	Stress, psi	R. A. %	Comments
450	11	30	
450	9	16	
500	13	62	
500	11	38	
500	9	37	Overheated 14 Kelvins for short period during the test.
500	7	63	Overheated 14 Kelvins for short period during the test.
500	6	79	
500	5	82	
550	9	38	
550	7	72	
550	4	86	
600	7	77	
600	4	88	

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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Creep-rupture Data for Unnotched Specimens of 6061-T651 Aluminum[1]

(Tested by Aluminum Company of America)

Temperature Deg F	Stress ksi	R. A. %
212	38	51
212	37	48
250	36	51
250	35	45
300	35	51
300	33	51
300	32	47
300	30	43
350	29	52
350	26	15
350	24	26
400	26	51
400	24	36
400	22	29
400	21	36
400	19	26
400	17	36
450	21	44
450	17	48
450	13	47
450	13	42
450	11	29
450	11	29
500	17	51

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Temperature	Stress	R. A.
Deg F	ksi	%
500	13	64
500	13	63
500	13	64
500	11	48
500	11	45
500	95	39
500	95	61
500	8	50
500	8	45
550	13	70
550	11	65
550	9.5	71
550	8	70
550	8	69
550	6	84
550	6	86
550	4	95
600	9.5	74
600	8	79
600	6	86
600	6	87
600	4	93
600	4	94
600	3	95
650	4	94
650	3	96
650	3	95
650	2.5	48

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Temperature	Stress	R. A.
Deg F	ksi	%
700	3	81
700	3	97
700	2.5	69
700	2.5	69

[1] 1.25 in. plate supplied by Reynolds Metal Company. The weight % composition was: 0.68 Si, 0.25 Cu, 0.02 Ti, 0.52 Fe, 0.04 Mn, 0.94 Mg, 0.24 Cr, 0.05 Zn, balance Al. The Certificate of Confirmation accompanying the metal included the following results: UTS: 46.3 & 43.7 ksi, 0.2% YS: 42.2 & 42.2 ksi, Elongation in 2 inches: 13.5 & 13.5 %.

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**AS-RECEIVED INFORMATION **

Aluminum Alloy 6061-T651

Plane-stress Crack-arrest Fracture Toughness (K_a)

Page Revision 0.0

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Test Temp	K_a	Comments	AMIS Ref No
Deg C	MPa√m		
-196	46.2	25.4mm thick compact tension specimens.	39
-196	42.8	25.4mm thick compact tension specimens.	39
-84	46	25.4mm thick compact tension specimens.	39
27	35.2	25.4mm thick compact tension specimens.	39

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Aluminum Alloy 6061-T651

Plane-stress Crack-arrest Fracture Toughness (K_a)

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Irradiation Temp	Test Temp	Fluence (n/m²)		K_a	Comments	AMIS Ref No
Deg C	Deg C	Fast[1]	Thermal	MPa√m		
~196	-196	1.3×10^{18} *	?	52.5	25.4mm thick compact tension specimens.	39
~196	-196	1.3×10^{18}	?	52.6	25.4mm thick compact tension specimens.	39
~196	-196	1.4×10^{19}	?	41.4	25.4mm thick compact tension specimens.	39
~196	-196	1.3×10^{19}	?	46.5	25.4mm thick compact tension specimens.	39
~196	-84	1.3×10^{18}	?	44.7	25.4mm thick compact tension specimens.	39
~196	-84	1.3×10^{19}	?	44.3	25.4mm thick compact tension specimens.	39
~196	27	1.3×10^{18}	?	42.4	25.4mm thick compact tension specimens.	39
~196	27	1.4×10^{19}	?	42.6	25.4mm thick compact tension specimens.	39

[1] Fast Fluences with asterisks have been converted to E >0.1 MeV by assuming that $\phi_{>0.1MeV} = 2\phi_{>1MeV}$.

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**AS-RECEIVED INFORMATION **

Aluminum Alloy
6061-T651
Tearing Modulus (T)
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Test Temp Deg C	Tearing Modulus	Comments	AMIS Ref No
21	0.02		38
26	0.53		38
26	0.82		38
95	-0.43		38
95	0.94		38
95	0.43		38
150	3.12		38
150	1.83		38
150	3.16		38

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Aluminum Alloy
6061-T651
Tearing Modulus (T)
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Irradiation Temp	Test Temp	Fluence (n/m^2)		Tearing Modulus	Comments	AMIS Ref No
Deg C	Deg C	Fast	Thermal			
95	26	~5.5 × 10^{25}	~1.1× 10^{26}	0.24	Thermal fluence, E<0.4eV.	38
95	26	~5.5 × 10^{25}	~1.1× 10^{26}	0.97	Thermal fluence, E<0.4eV.	38
95	95	~5.5 × 10^{25}	~1.1× 10^{26}	0.02	Thermal fluence, E<0.4eV.	38
95	95	~5.5 × 10^{25}	~1.1× 10^{26}	0.02	Thermal fluence, E<0.4eV.	38
95	150	~5.5 × 10^{25}	~1.1× 10^{26}	-0.86	Thermal fluence, E<0.4eV.	38

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Aluminum Alloy 6063
Melting Point
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TABLE NF-2
TYPICAL PHYSICAL PROPERTIES OF MATERIALS

Material	Approx. Melting Range, °F
6063	1140–1210

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Aluminum Alloy 6063
Specific Heat
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TABLE NF-2
TYPICAL PHYSICAL PROPERTIES OF MATERIALS

Material	Specific Heat, Btu/lb/°F at 212°F
6063	0.23

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Aluminum Alloy 6063
Thermal Diffusivity
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TABLE TCD (CONT'D)
NOMINAL COEFFICIENTS OF THERMAL DIFFUSIVITY (TD)

6063 Alloy	
°F	TD
75	3.34
100	3.30
150	3.23
200	3.18
250	3.13
300	3.09
350	3.04
400	3.00

GENERAL NOTE:
TC is the thermal conductivity, Btu/hr-ft-°F, and TD is the thermal diffusivity, ft²/hr:

$$TD = \frac{TC\ (Btu/hr\text{-}ft\text{-}°F)}{Density\ (lb/ft^3) \times Specific\ Heat\ (Btu/lb\text{-}°F)}$$

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Aluminum Alloy 6063
Thermal Conductivity
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NOMINAL COEFFICIENTS OF THERMAL CONDUCTIVITY (TC)

°F	6063 Alloy TC
75	120.8
100	120.3
150	119.7
200	119.1
250	118.3
300	118.3
350	117.9
400	117.6

GENERAL NOTE:
TC is the thermal conductivity, Btu/hr-ft-°F, and TD is the thermal diffusivity, ft²/hr:

$$TD = \frac{TC\ (Btu/hr\text{-}ft\text{-}^\circ F)}{Density\ (lb/ft^3) \times Specific\ Heat\ (Btu/lb\text{-}^\circ F)}$$

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Aluminum Alloy 6063
Coefficient of Thermal Expansion
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Table TE-2 1992 SECTION II

TABLE TE-2
NOMINAL COEFFICIENTS OF THERMAL EXPANSION FOR ALUMINUM ALLOYS

Materials	Coef-ficient	Temperature, °F 70	100	150	200	250	300	350	400
6063	A	12.58	12.77	13.07	13.38	13.68	13.91	14.30	14.60
	B	...	12.67	12.82	12.98	13.13	13.29	13.44	13.59
	C	0	0.0046	0.0123	0.0202	0.0284	0.0367	0.0452	0.0538

GENERAL NOTE:
Coefficient A is the instantaneous coefficient of thermal expansion × 10^{-6} (in./in./°F). Coefficient B is the mean coefficient of thermal expansion × 10^{-6} (in./in./°F) in going from 70°F to indicated temperature. Coefficient C is the linear thermal expansion (in./ft) in going from 70°F to indicated temperature.

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Aluminum Alloy 6063-T6
Ultimate Tensile Strength
Page Revision 0.0
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Alloy Designation: 6063 Data Sheet No.: 2
Heat Treatment: T6 Form: Extruded rod

Chemical Analysis % by Wt.													
Al	Bal.	Cu	0.01	Zn		Cr		Bi		Th			
Mg	0.67	Fe	0.15	Ni		Zr		Pb		Be			
Si	0.39	Mn	0.01	Ti		Ca		Misch Metal					

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Tensile Strength 1000 psi
		Room	35.3
212	1/2	Room	35.8
212	100	Room	36.3
212	1000	Room	37.1
212	5000	Room	38.0
212	10000	Room	37.8
300	1/2	Room	35.9
300	100	Room	37.4
300	360	Room	35.6
300	1000	Room	35.7
300	5000	Room	29.8
300	10000	Room	28.6
300	11064	Room	28.0
300	19200	Room	26.8
350	10	Room	35.9
400	1/2	Room	35.4
400	1	Room	24.4
400	2	Room	34.1
400	12	Room	27.5
400	100	Room	25.3
400	1000	Room	20.3
400	5000	Room	18.0
400	21912	Room	14.5
400	10000	Room	16.0
500	1/2	Room	34.6
500	1/2	Room	32.9
500	1	Room	24.6
500	3	Room	25.86
500	8	Room	20.3
500	8	Room	19.48
500	16	Room	20.6
500	100	Room	19.3
500	1000	Room	12.4
500	1000	Room	13.9
500	2400	Room	12.4
500	6096	Room	13.5
500	16920	Room	12.1
600	1/2	Room	23.6
600	8	Room	13.94
600	100	Room	14.2
600	1824	Room	12.6
700	1/2	Room	14.4
700	1/2	Room	21.8
700	3	Room	13.7
700	100	Room	12.9
700	8	Room	13.4

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Tensile Strength. 1000 psi
700	1992	Room	10.9
212	1/2	212	31.2
212	24	212	31.4
212	144	212	31.4
212	600	212	32.1
212	1200	212	32.0
212	2400	212	32.6
212	4800	212	32.7
212	9600	212	32.7
212	19200	212	33.1
300	1/2	300	28.2
300	24	300	28.7
300	144	300	29.6
300	600	300	28.4
300	792	300	28.8
300	1200	300	27.6
300	2400	300	26.5
300	4800	300	23.8
300	9600	300	22.24
300	19200	300	20.9
300	41040	300	19.9
350	10	350	26.3
400	1/2	400	24.1
400	1/2	400	24.0
400	6	400	20.3
400	6	400	21.8
400	24	400	19.2
400	24	400	18.3
400	144	400	15.7
400	600	400	14.1
400	1200	400	13.0
400	2400	400	12.1
400	4800	400	11.1
400	9600	400	8.84
400	12384	400	8.67
400	19200	400	7.8
500	1/2	500	14.5

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Tensile Strength 1000 psi
500	1/2	500	13.4
500	6	500	12.6
500	24	500	9.2
500	144	500	6.8
500	600	500	5.7
500	1200	500	5.5
500	21792	500	5.0
600	1/2	600	5.4
600	6	600	4.7
600	24	600	4.8
600	144	600	3.8
600	600	600	3.6
600	1536	600	2.5
700	1/2	700	2.9
700	24	700	2.5
700	144	700	2.2
700	600	700	2.0
800	1/2	800	1.8
900	1/2	900	.9
1000	1/2	1000	.8

Contributor: Alcoa Research Laboratories.
Comments:

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

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Aluminum Alloy 6063-T6
Yield Strength
Page Revision 0.0
AMBK Update No. 0

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Alloy Designation: 6063 Data Sheet No.: 2
Heat Treatment: T6 Form: Extruded rod

Chemical Analysis % by Wt.											
Al	Bal.	Cu	0.01	Zn		Cr		Bi		Th	
Mg	0.67	Fe	0.15	Ni		Zr		Pb		Be	
Si	0.39	Mn	0.01	Ti		Ca		Misch Metal			

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Yield (2) Strength 1000 psi
		Room	30.8
212	1/2	Room	30.9
212	100	Room	31.4
212	1000	Room	32.5
212	5000	Room	33.4
212	10000	Room	34.1
300	1/2	Room	30.8
300	100	Room	33.6
300	360	Room	32.3
300	1000	Room	32.3
300	5000	Room	24.85
300	10000	Room	23.0
300	11064	Room	22.6
300	19200	Room	20.9
350	10	Room	32.9
400	1/2	Room	31.7
400	1	Room	18.4
400	2	Room	30.7
400	12	Room	22.4
400	100	Room	18.8
400	1000	Room	12.9
400	5000	Room	9.9
400	21912	Room	5.9
400	10000	Room	7.8
500	1/2	Room	30.8
500	1/2	Room	29.3
500	1	Room	18.5
500	3	Room	19.8
500	8	Room	13.3
500	8	Room	12.16
500	16	Room	13.0
500	100	Room	11.5
500	1000	Room	5.0
500	1000	Room	5.6
500	2400	Room	5.2
500	6096	Room	5.2
500	16920	Room	4.9
600	1/2	Room	16.8
600	8	Room	5.64
600	100	Room	6.1
600	1824	Room	4.4
700	1/2	Room	5.1
700	1/2	Room	14.6
700	3	Room	4.7
700	100	Room	4.3
700	8	Room	4.8
700	1992	Room	3.6

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Yield (2) Strength 1000 psi
212	1/2	212	28.2
212	24	212	28.1
212	144	212	28.5
212	600	212	28.9
212	1200	212	29.7
212	2400	212	30.1
212	4800	212	30.1
212	9600	212	30.92
212	19200	212	31.1
300	1/2	300	25.8
300	24	300	26.6
300	144	300	27.8
300	600	300	26.4
300	792	300	27.5
300	1200	300	26.3
300	2400	300	24.8
300	4800	300	21.8
300	9600	300	20.1
300	19200	300	18.6
300	41040	300	16.8
350	10	350	23.9
400	1/2	400	22.5
400	1/2	400	21.7
400	6	400	19.0
400	6	400	19.6
400	24	400	17.2
400	24	400	15.7
400	144	400	13.3
400	600	400	11.4
400	1200	400	10.2
400	2400	400	9.2
400	4800	400	7.9
400	9600	400	5.92
400	12384	400	5.55
400	19200	400	4.7
500	1/2	500	12.5

Prior Exposure (1) Temp. °F	Prior Exposure (1) Time, hr.	Test Temp. °F	Yield (2) Strength 1000 psi
500	1/2	500	12.0
500	6	500	10.4
500	24	500	6.9
500	144	500	5.1
500	600	500	3.8
500	1200	500	3.8
500	21792	500	3.5
600	1/2	600	4.9
600	6	600	3.8
600	24	600	3.8
600	144	600	2.9
600	600	600	3.0
600	1536	600	2.0
700	1/2	700	2.4
700	24	700	1.9
700	144	700	1.8
700	600	700	1.5
800	1/2	800	1.5
900	1/2	900	1.2
1000	1/2	1000	

Contributor: Alcoa Research Laboratories
Comments:

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

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Aluminum Alloy 6063-T6
Total Elongation
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****AS-RECEIVED INFORMATION *****

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Alloy Designation: 6063 Data Sheet No.: 2
Heat Treatment: T6 Form: Extruded rod

Chemical Analysis % by Wt.											
Al	Bal.	Cu	0.01	Zn		Cr		Bi		Th	
Mg	0.67	Fe	0.15	Ni		Zr		Pb		Be	
Si	0.39	Mn	0.01	Ti		Co		Misch Metal			

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	Elong. % (3)
		Room	15.4
212	1/2	Room	16.0
212	100	Room	15.0
212	1000	Room	14.5
212	5000	Room	13.0
212	10000	Room	13.0
300	1/2	Room	16.0
300	100	Room	13.0
300	360	Room	14.5
300	1000	Room	12.5
300	5000	Room	18.0
300	10000	Room	18.0
300	11064	Room	20.5
300	19200	Room	21.0
350	10	Room	13.0
400	1/2	Room	14.5
400	1	Room	21.5
400	2	Room	15.5
400	12	Room	20.0
400	100	Room	21.0
400	1000	Room	23.5
400	5000	Room	27.0
400	21912	Room	42.5
400	10000	Room	34.5
500	1/2	Room	15.0
500	1/2	Room	16.0
500	1	Room	21.5
500	3	Room	21.0
500	8	Room	22.5
500	8	Room	23.5
500	16	Room	23.0
500	100	Room	24.5
500	1000	Room	43.0
500	1000	Room	43.0
500	2400	Room	43.0
500	6096	Room	44.0
500	16920	Room	47.5
600	1/2	Room	22.5
600	8	Room	36.5
600	100	Room	43.0
600	1824	Room	45.0
700	1/2	Room	37.5
700	1/2	Room	23.0
700	3	Room	37.0
700	100	Room	42.5
700	8	Room	41.0
700	1992	Room	41.5

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	Elong. % (3)
212	1/2	212	18.0
212	24	212	18.5
212	144	212	18.0
212	600	212	16.0
212	1200	212	17.5
212	2400	212	15.5
212	4800	212	15.0
212	9600	212	15.0
212	19200	212	14.5
300	1/2	300	19.0
300	24	300	17.0
300	144	300	15.0
300	600	300	13.0
300	792	300	14.0
300	1200	300	14.5
300	2400	300	14.0
300	4800	300	16.5
300	9600	300	20.5
300	19200	300	21.5
300	41040	300	23.5
350	10	350	13.5
400	1/2	400	17.0
400	1/2	400	15.0
400	6	400	18.5
400	6	400	16.0
400	24	400	19.5
400	24	400	21.0
400	144	400	25.0
400	600	400	29.0
400	1200	400	30.0
400	2400	400	34.0
400	4800	400	39.0
400	9600	400	49.0
400	12384	400	46.5
400	19200	400	55.5
500	1/2	500	23.0

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	Elong. % (3)
500	1/2	500	25.0
500	6	500	26.5
500	24	500	43.0
500	144	500	54.5
500	600	500	71.5
500	1200	500	65.0
500	21792	500	68.0
600	1/2	600	39.5
600	6	600	49.5
600	24	600	48.5
600	144	600	62.5
600	600	600	83.0
600	1536	600	107.0
700	1/2	700	90.0
700	24	700	105.0
700	144	700	97.0
700	600	700	110.0
800	1/2	800	120.0
900	1/2	900	181.0
1000	1/2	1000	159.0

Contributor: Alcoa Research Laboratories.
Comments:

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

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**AS-RECEIVED INFORMATION **

Aluminum Alloy 6063-T6
Reduction of Area
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AMBK Update No. 0

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Alloy Designation: 6063 Data Sheet No.: 2
Heat Treatment: T6 Form: Extruded rod

Chemical Analysis % by Wt.													
Al	Bal.	Cu	0.01	Zn		Cr		Bi		Th	
Mg	0.67	Fe	0.15	Ni		Zr		Pb		Be	
Si	0.39	Mn	0.01	Ti		Ca		Misch Metal			

SHORT-TIME TENSILE PROPERTIES

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	R. A. %
		Room	34.7
212	1/2	Room	33.5
212	100	Room	30.5
212	1000	Room	29.1
212	5000	Room	25.0
212	10000	Room	26.0
300	1/2	Room	34.0
300	100	Room	27.7
300	360	Room	36.0
300	1000	Room	33.1
300	5000	Room	64.5
300	10000	Room	65.0
300	11064	Room	69.0
300	19200	Room	73.0
350	10	Room	35.0
400	1/2	Room	34.4
400	1	Room	80.0
400	2	Room	50.0
400	12	Room	75.0
400	100	Room	76.5
400	1000	Room	82.0
400	5000	Room	79.0
400	21912	Room	75.0
400	10000	Room	74.0
500	1/2	Room	40.5
500	1/2	Room	55.0
500	1	Room	80.0
500	3	Room	78.0
500	8	Room	84.0
500	8	Room	84.0
500	16	Room	82.0
500	100	Room	81.5
500	1000	Room	85.0
500	1000	Room	80.3
500	2400	Room	85.0
500	6096	Room	83.0
500	16920	Room	84.0
600	1/2	Room	80.6
600	8	Room	82.0
600	100	Room	79.4
600	1824	Room	84.0
700	1/2	Room	80.0
700	1/2	Room	82.9
700	3	Room	82.0
700	100	Room	83.0
700	8	Room	82.0
700	1992	Room	85.0

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	R. A. %
212	1/2	212	44.7
212	24	212	44.4
212	144	212	42.2
212	600	212	41.1
212	1200	212	39.1
212	2400	212	35.3
212	4800	212	34.3
212	9600	212	32.2
212	19200	212	31.7
300	1/2	300	36.2
300	24	300	30.8
300	144	300	28.0
300	600	300	25.8
300	792	300	29.0
300	1200	300	31.7
300	2400	300	36.9
300	4800	300	50.1
300	9600	300	62.0
300	19200	300	67.0
300	41040	300	79.0
350	10	350	28.0
400	1/2	400	27.0
400	1/2	400	27.1
400	6	400	34.5
400	6	400	31.9
400	24	400	42.2
400	24	400	48.3
400	144	400	64.1
400	600	400	82.7
400	1200	400	87.2
400	2400	400	88.7
400	4800	400	90.2
400	9600	400	90.1
400	12384	400	88.4
400	19200	400	88.0
500	1/2	500	43.8

Prior Exposure (1) Temp. °F	Time, hr.	Test Temp. °F	R. A. %
500	1/2	500	46.3
500	6	500	62.0
500	24	500	90.8
500	144	500	94.4
500	600	500	95.4
500	1200	500	95.3
500	21792	500	96.0
600	1/2	600	48.2
600	6	600	96.0
600	24	600	96.9
600	144	600	97.4
600	600	600	98.3
600	1536	600	99.9
700	1/2	700	99.0
700	24	700	99.0
700	144	700	99.8
700	600	700	99.9
800	1/2	800	99.9
900	1/2	900	99.0
1000	1/2	1000	99.9

Contributor: Alcoa Research Laboratories.
Comments:

(1.) Conditions of exposure, if any, between heat treatment and testing.
(2.) 0.2% offset yield strength unless otherwise specified.
(3.) Elongation in 2 inches unless otherwise specified.
(4.) Extrapolated values indicated by *.
(5.) Total deformation includes deformation during loading.
(6.) Duration of rupture test indicated by R.
(7.) The intercept is the projection back to zero time from the portion of the test showing the minimum or second-stage creep rate.
(8.) The transition time is the beginning of the third stage, or an accelerating creep rate.

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Young's Modulus
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TABLE TM-2
MODULI OF ELASTICITY *E* OF ALUMINUM AND ALUMINUM ALLOYS FOR GIVEN TEMPERATURES

Material	Modulus of Elasticity E = Value Given × 10^6 psi, for Temp., °F, of							
	−325	−200	−100	70	200	300	400	500
A96063 (6063)	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1

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Aluminum Alloy 6063-T6

Creep and Rupture Strengths

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Alloy Designation: 6063 Data Sheet No.: 3

Heat Treatment: T6 Form:

Chemical Analysis % by Wt.											
Al	Bal.	Cu	0.02	Zn		Cr		Bi		Th	
Mg	0.69	Fe	0.19	Ni		Zr		Pb		Be	
Si	0.36	Mn	0.01	Ti		Ca		Misch Metal			

CREEP AND RUPTURE STRENGTHS

Temp. °F	Stress for Indicated Creep Rate - 1000 psi		Stress for Rupture in Time Indicated - 1000 psi (4)				
	0.0001 %/hr.	0.001 %/hr.	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.
90	32.5	34.9			38.0	37.0	35.0
212	24.6	27.2			32.0	29.5	28.0
300	14.5	19.5				23.0	17.5
400	3.7	7.3			15.5	12.5	7.5

STRESSES FOR INDICATED DEFORMATIONS (5)

Temp. °F	1.0% Total Deformation					0.1 % Total Deformation				
	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.	0.1 hr.	1 hr.	10 hr.	100 hr.	1000 hr.
212		31.2	30.0	28.8			30.3	28.6	24.8	
300			24.0	22.5			23.2	21.5	19.1	14.5
400			15.0	11.0	5.8			13.2	9.0	

ORIGINAL CREEP AND RUPTURE DATA

Temp. °F	Stress 1000 psi	Test Duration hours (6)	Inter-cept % (7)	Minimum Creep Rate % / hr.	Transition Time, hours (8)	Total Ext., % (Creep Test)	Total Elong., % (Rupture Test)
90	30.00	1000	0.345	<0.000016		0.04	
90	34.00	1000	2.205	0.001565		3.35	
90	36.00	118.47 R	3.91	0.0261			9.7
90	37.00	642.95 R	2.96	0.00657			9.0
90	38.00	21.02 R	4.765	0.1028			7.3
90	39.00	Broke	on loading				
212	22.00	1000	0.309	<0.000022		0.09	
212	25.00	1000	0.424	<0.000221		0.45	
212	28.00	893.96 R	0.405	0.00253			6.5
212	31.00	19.06 R	0.640	0.316			10.8
212	32.00	7.8 R	0.990	0.716			11.0
300	7.50	1000	0.140	<0.000015		0.07	
300	15.00	1000	0.255	0.000185		0.28	
300	20.04	441.80 R	0.326	0.00164			3.5
300	22.00	194.46 R	0.390	0.00444			4.0
300	24.00	24.82 R	0.41	0.0973			13.0
400	2.69	1000	0.104	0.000068		0.14	
400	8.50	569.89 R	0.173	0.001981			6.3
400	12.00	97.28 R	0.206	0.00959			9.0
400	15.00	16.34 R	0.272	0.039			9.5

Contributor: University of California

Comments: Tested parallel to direction of extrusion.

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304 Stainless Steel (UNS S30400) is one of a series of iron-chromium-nickel alloys noted for their corrosion resistance, oxidation resistance, and relatively high strength at elevated temperatures. It is based on the "18-8" basic alloy 302 SS (18% Chromium, 8 % Nickel), with the carbon content lowered to provide better corrosion resistance in welded components. It has an austenitic (face-centered cubic) structure that facilitates fabrication. The alloy cannot be hardened by heat treatment, but it can be hardened and strengthened by cold work. It is used in both high and low temperature applications.

Applications include equipment for the nuclear, pharmaceutical, textile, paper, petroleum, farm, hospital, and food processing industries.

Certain minor modifications have been made to the basic 304 SS chemical composition to produce materials with specific properties. See under Stainless Steels 304L, 304LN, 304H, and 304N.

The basic heat treatment is solution annealing, which is accomplished by heating at 1255 K (982 C, 1800 F) to 1339 K (1066 C, 1950 F) for 30 minutes to one hour per inch of thickness, followed by air cooling or quenching, depending on section size. Note that cooling to 700 K (427 C, 800 F) should be completed within 3 minutes to prevent "sensitization" and preserve corrosion resistance. Sheet and tube annealing is at 1311 K (1038 C, 1900 F) to 1339 K (1066 C, 1950 F) for 10 minutes, followed by air cooling for thicknesses up to 1.6 mm (0.064 in.) and quenching for thicknesses of 1.7 mm (0.065 in.) or above.

304 SS is being used in the Advanced Neutron Source control rod drive mechanism, piping, pumps, valves, heat exchangers, accumulators, and reactor primary pressure boundary components.[1] These components are fabricated in the annealed condition.

[1] "Chapter 4. Reactor," Advanced Neutron Source Conceptual Safety Analysis Report, ORNL/ANS/INT-33/V2, p. 4.5-1ff, June 1992.

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304L Stainless Steel

Maximum Allowable Stress Values, S

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Product Form	Bar	Welded Tube	Welded Tube	Welded Tube	Welded Pipe	Welded Pipe	Forgings	Forgings	Forgings	Forgings
Spec. No.	SA-479	SA-688	SA-688	SA-688	SA-813	SA-814	SA-182	SA-182	SA-182	SA-336
Type/ Grade	304L	TP304L	TP304L	TP304L	TP304L	TP304L	F304L	F304L	F304L	
UNS No.	S30403		S30403	S30403				S30403	S30403	S30403
Class/Cond./Temper										304L
Applicability	Sec 8-1	Sec 3	Sec 8-1	Sec 8-1	Sec 3	Sec 3	Sec 3	Sec 8-1	Sec 8-1	Sec 8-1
Notes	Y,L	X,A,B,C, D	Y,E,F	Y,F	X,A,B,C, D	X,A,B,C, D	X,B,D,I	Y,E	Y	Y
Temperature, Deg F	Maximum Allowable Stress, ksi									
-20	16.3	15.7	14.2	14.2	15.7	15.7	15.6	16.3	16.3	16.3
100	16.3	15.7	14.2	14.2	15.7	15.7	15.6	16.3	16.3	16.3
200	14.3	15.7	14	12.2	15.7	15.7	15.4	15.4	14.3	14.3
300	12.8	15.3	13	10.9	15.3	15.3	14.2	14.2	12.8	12.8
400	11.7	14.7	12.5	9.9	14.7	14.7	13.6	13.6	11.7	11.7
500	10.9	14.4	12.3	9.3	14.4	14.4	13.4	13.4	10.9	10.9
600	10.3	14	11.9	8.8	14	14	13.3	13.3	10.3	10.3
650	10.1	13.7	11.7	8.6	13.7	13.7	13.2	13.1	10.1	10.1
700	10	13.5	11.5	8.5	13.5	13.5	13.1	13.1	10	10
750	9.8	13.3	11.3	8.3	13.3	13.3	13	13	9.8	9.8
800	9.7	13	11.1	8.2	13	13	12.9	12.9	9.7	9.7
850										
900										
950										
1000										
1050										
1100										
1150										
1200										

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Product Form	Fittings	Fittings	Fittings	Fittings	Forgings	Smls. Tube	Smls. Tube	Smls. Tube	Plate	Plate
Spec. No.	SA-403	SA-403	SA-403	SA-403	SA-182	SA-213	SA-213	SA-213	SA-240	SA-240
Type/ Grade	304L	304L	304L	304L	F304L	TP304L	TP304L	TP304L	304L	304L
UNS No.	S30403	S30403	S30403	S30403			S30403	S30403		S30403
Class/Cond./Temper	CR	WP-W	WP-WX	WPS						
Applicability	Sec 8-1	Sec 8-1	Sec 8-1	Sec 8-1	Sec 3	Sec 3	Sec 8-1	Sec 8-1	Sec 3	Sec 8-1
Notes	Y,E,F	Y,E,F	Y,E,F	Y,E	X,B,Q,D	X,A,B,D	Y,E	Y	X,B,D	Y,E
Temperature, Deg F	Maximum Allowable Stress, ksi									
-20	13.3	13.3	13.3	15.7	15.7	15.7	16.7	16.3	15.7	16.7
100	13.3	13.3	13.3	15.7	15.7	15.7	16.7	16.3	15.7	16.7
200	13.3	13.3	13.3	15.7	15.7	15.7	16.5	14.3	15.7	16.5
300	13.3	13.3	13.3	15.7	15.3	15.3	15.3	12.8	15.3	15.3
400	13.1	13.1	13.1	15.5	14.7	14.7	14.7	11.7	14.7	14.7
500	12.2	12.2	12.2	14.4	14.4	14.4	14.4	10.9	14.4	14.4
600	11.5	11.5	11.5	13.5	14	14	14	10.3	14	14
650	11.2	11.2	11.2	13.2	13.7	13.7	13.7	10.1	13.7	13.7
700	11	11	11	12.9	13.5	13.5	13.5	10	13.5	13.5
750	10.7	10.7	10.7	12.6	13.3	13.3	13.3	9.8	13.3	13.3
800	10.5	10.5	10.5	12.4	13	13	13	9.7	13	13
850	10.3	10.3	10.3	12.1						
900										
950										
1000										
1050										
1100										
1150										
1200										

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Product Form	Plate	Wld. Tube	Wld. Tube	Wld. Tube	Smls. Pipe	Smls. Pipe	Wld. Pipe	Wld. & Smls. Pipe	Wld. Pipe	Wld. Pipe
Spec. No.	SA-240	SA-249	SA-249	SA-249	SA-312	SA-312	SA-312	SA-312	SA-312	SA-358
Type/ Grade	304L	TP304L	TP304L	TP304L	TP304L	TP304L	TP304L	TP304L	TP304L	304L
UNS No.	S30403		S30403	S30403	S30403	S30403	S30403		S30403	
Class/Cond./Temper										1
Applicability	Sec 8-1	Sec 3	Sec 8-1	Sec 8-1	Sec 8-1	Sec 8-1	Sec 8-1	Sec 3	Sec 8-1	Sec 3
Notes	Y	X,A,B,C, D	Y,E,F	Y,F	Y,E	Y	Y,E,F	X,A,B,C, D	Y,F	X,A,B,D
Temperature, Deg F	Maximum Allowable Stress, ksi									
-20	16.3	15.7	14.2	14.2	16.7	16.3	14.2	15.7	14.2	15.7
100	16.3	15.7	14.2	14.2	16.7	16.3	14.2	15.7	14.2	15.7
200	14.3	15.7	14	12.2	16.5	14.3	14	15.7	12.2	15.7
300	12.8	15.3	13	10.9	15.3	12.8	13	15.3	10.9	15.3
400	11.7	14.7	12.5	9.9	14.7	11.7	12.5	14.7	9.9	14.7
500	10.9	14.4	12.3	9.3	14.4	10.9	12.3	14.4	9.3	14.4
600	10.3	14	11.9	8.8	14	10.3	11.9	14	8.8	14
650	10.1	13.7	11.7	8.6	13.7	10.1	11.7	13.7	8.6	13.7
700	10	13.5	11.5	8.5	13.5	10	11.5	13.5	8.5	13.5
750	9.8	13.3	11.3	8.3	13.3	9.8	11.3	13.3	8.3	13.3
800	9.7	13	11.1	8.2	13	9.7	11.1	13	8.2	13
850										
900										
950										
1000										
1050										
1100										
1150										
1200										

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Product Form	Fittings	Wld. Fittings	Wld. Pipe	Bar	Bar
Spec. No.	SA-403	SA-403	SA-409	SA-479	SA-479
Type/ Grade	304L	304L	TP304L	304L	304L
UNS No.					S30403
Class/Cond./Temper	WP	WP-W			
Applicability	Sec 3	Sec 3	Sec 3	Sec 3	Sec 8-1
Notes	X,B,D	X,A,B,C, D	X,A,B,C, D	X,B	Y,E,L
Temperature, Deg F	Maximum Allowable Stress, ksi				
-20	15.7	15.7	15.7	15.7	15.7
100	15.7	15.7	15.7	15.7	15.7
200	15.7	15.7	15.7	15.7	15.7
300	15.3	15.3	15.3	15.3	15.3
400	14.7	14.7	14.7	14.7	14.7
500	14.4	14.4	14.4	14.4	14.4
600	14	14	14	14	14
650	13.7	13.7	13.7	13.7	13.7
700	13.5	13.5	13.5	13.5	13.5
750	13.3	13.3	13.3	13.3	13.3
800	13	13	13	13	13
850					
900					
950					
1000					
1050					
1100					
1150					
1200					

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Applicability of the values in the table is limited to the temperature ranges for the values shown (no extrapolation allowed).

Notes:

A The following are the abbreviations used for Product Forms: (a) Wld. - Welded; (b) Smls. - Seamless.

B At temperatures above 311 K (38 C, 100 F), the allowable stress values may exceed 62.5% (62.67% for High Nickel Alloys) and may also reach 90% yield strength (0.2% offset) at temperature. This may result in a permanent strain of as much as 0.1%. When this amount of deformation is not acceptable, the designer should reduce the design stress to obtain an acceptable deformation. Table Y-2 of ASME Code Section II, Part D, Subpart 1 lists multiplying factors which, when applied to the yield strength values shown in Table Y-1 of Section II, Part D, Subpart 1, will give an allowable stress that will result in lower levels of permanent strain.

C These S values do not include a longitudinal weld efficiency factor. For materials welded without filler metal, ultrasonic examination, radiographic examination, or eddy current examination, in accordance with NC-2550, shall provide a longitudinal weld efficiency factor of 1.00. Materials (welded with filler metal) meeting the requirements of NC-2560 shall receive a longitudinal weld efficiency factor of 1.00. Other longitudinal weld efficiency factors shall be in accordance with the following:

Type of Joint	Efficiency Factor
(a) Single butt weld, with filler metal	0.80
(b) Single or double butt well, without filler metal	0.85
(c) Double butt weld, with filler metal	0.90
(d) Single or double butt weld with radiography	1.00

D For external pressure chart references, see ASME Code Section II Tables I-14.1 or I-14.2 or Fig. NC-3133.8-1, as applicable.

E Due to the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 2/3 but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional changes due to permanent strain. These stress values are not recommended for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

F A factor of 0.85 has been applied in arriving at the maximum allowable stress values in tension for this material. Divide tabulated values by 0.85 for maximum allowable longitudinal tensile stress.

I Over 127 mm (5 in.)

L Use of external pressure charts for material in the form of barstock is permitted for stiffening rings only.

X When used for Class MC design, the stress values listed herein shall be multiplied by a factor of 1.1 (NE-3112.4); these values shall be considered as design stress intensities or allowable stress values as required by NE-3200 or NE-3300, respectively.

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Y (a) The stress values in this column may be interpolated to determine values for intermediate temperatures. (b) Stress values in restricted shear such as dowel bolts or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of area shall be 0.80 times the values shown in this column. (c) Stress values in bearing shall be 1.60 times the values in this column.

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Product Form	Forgings	Forgings	Forgings	Welded Pipe	Smls. Pipe	Smls. Pipe	Smls. Pipe	Fittings	Fittings
Spec. No.	SA-336	SA-336	SA-336	SA-358	SA-376	SA-376	SA-376	SA-403	SA-403
Type/ Grade				304N	TP304N	TP304N	TP304N	304N	304N
UNS No.		S30451	S30451			S30451	S30451	S30451	
Class/Cond./Temper	F304N	F304N	304N	1				CR	WP
Applicability	Sec 3	Sec 8-1	Sec 8-1	Sec 3	Sec 3	Sec 8-1	Sec 8-1	Sec 8-1	Sec 3
Notes	B,D	G	G	A,B,C,D	A,B,D	G,H	E,G,H	E,F,G	B,D
Temperature, Deg F	Maximum Allowable Stress, ksi								
-20	20	20	20	20	20	20	20	17	20
100	20	20	20	20	20	20	20	17	20
200	20	19.1	20	20	20	19.1	20	17	20
300	19	16.7	19	19	19	16.7	19	16.1	19
400	18.3	15	18.3	18.3	18.3	15	18.3	15.6	18.3
500	17.8	13.9	17.8	17.8	17.8	13.9	17.8	15.1	17.8
600	17.4	13.2	17.4	17.4	17.4	13.2	17.4	14.8	17.4
650	17.3	13	17.3	17.3	17.3	13	17.3	14.7	17.3
700	17.1	12.7	17.1	17.1	17.1	12.7	17.1	14.6	17.1
750	16.9	12.5	16.9	16.9	16.9	12.5	16.9	14.4	16.9
800	16.6	12.3	16.6	16.6	16.6	12.3	16.6	14.2	16.6
850		12.1	16.3			12.1	16.3	13.9	
900		11.8	15.9			11.8	15.9	13.5	
950		11.5	15.6			11.5	15.6	13.3	
1000		11.2	15			11.2	15	12.7	
1050		11	12.4			11	12.4	10.5	
1100		9.8	9.8			9.8	9.8	8.3	
1150		7.7	7.7			7.7	7.7	6.5	
1200		6.1	6.1			6.1	6.1	5.2	

See Page 1.3 for notes.

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Advanced Neutron Source

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****AS-RECEIVED INFORMATION ****

304N Stainless Steel

Maximum Allowable Stress Values, S

Page Revision 0.0

AMBK Update No. 0

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Product Form	Wielded Fittings	Fittings	Fittings	Bar	Wld. Tube	Wld. Tube	Wld. Tube
Spec. No.	SA-403	SA-403	SA-403	SA-479	SA-688	SA-688	SA-688
Type/ Grade	304N	304N	304N	304N	TP304N	TP304N	TP304N
UNS No.		S30451	S30451			S30451	S30451
Class/Cond./Temper	WP-W	WP-W	WP-WX				
Applicability	Sec 8-1	Sec 8-1	Sec 8-1	Sec 3	Sec 3	Sec 8-1	Sec 8-1
Notes	A,B,C,D	E,F,G	E,F,G	B	A,B,C,D	E,F,G	F,G
Temperature, Deg F	Maximum Allowable Stress, ksi						
-20	20	17	17	20	20	17	17
100	20	17	17	20	20	17	17
200	20	17	17	20	20	17	16.2
300	19	16.1	16.1	19	19	16.1	14.2
400	18.3	15.6	15.6	18.3	18.3	15.6	12.8
500	17.8	15.1	15.1	17.8	17.8	15.1	11.8
600	17.4	14.8	14.8	17.4	17.4	14.8	11.2
650	17.3	14.7	14.7	17.3	17.3	14.7	11.1
700	17.1	14.6	14.6	17.1	17.1	14.6	10.8
750	16.9	14.4	14.4	16.9	16.9	14.4	10.6
800	16.6	14.2	14.2	16.6	16.6	14.2	10.5
850		13.9	13.9			13.9	10.3
900		13.5	13.5			13.5	10
950		13.3	13.3			13.3	9.8
1000		12.7	12.7			12.7	9.5
1050		10.5	10.5			10.5	9.4
1100		8.3	8.3			8.3	8.3
1150		6.5	6.5			6.5	6.5
1200		5.2	5.2			5.2	5.2

See Page 1.3 for notes.

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**AS-RECEIVED INFORMATION **

304N Stainless Steel
Maximum Allowable Stress Values, S
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Applicability of the values in the tables is limited to the values shown (no extrapolation allowed).

Notes:

A The following are the abbreviations used for Product Forms: (a) Wld. - Welded; (b) Smls. - Seamless.

B At temperatures above 311 K (38 C, 100 F), the allowable stress values may exceed 62.5% (62.67% for High Nickel Alloys) and may also reach 90% yield strength (0.2% offset) at temperature. This may result in a permanent strain of as much as 0.1%. When this amount of deformation is not acceptable, the designer should reduce the design stress to obtain an acceptable deformation. Table Y-2 of ASME Code Section II, Part D, Subpart 1 lists multiplying factors which, when applied to the yield strength values shown in Table Y-1 of Section II, Part D, Subpart 1, will give an allowable stress that will result in lower levels of permanent strain.

C These S values do not include a longitudinal weld efficiency factor. For materials welded without filler metal, ultrasonic examination, radiographic examination, or eddy current examination, in accordance with NC-2550, shall provide a longitudinal weld efficiency factor of 1.00. Materials (welded with filler metal) meeting the requirements of NC-2560 shall receive a longitudinal weld efficiency factor of 1.00. Other longitudinal weld efficiency factors shall be in accordance with the following:

Type of Joint	Efficiency Factor
(a) Single butt weld, with filler metal	0.80
(b) Single or double butt well, without filler metal	0.85
(c) Double butt weld, with filler metal	0.90
(d) Single or double butt weld with radiography	1.00

D For external pressure chart references, see ASME Code Section II Tables I-14.1 or I-14.2 or Fig. NC-3133.8-1, as applicable.

E Due to the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 2/3 but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional changes due to permanent strain. These stress values are not recommended for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

F A factor of 0.85 has been applied in arriving at the maximum allowable stress values in tension for this material. Divide tabulated values by 0.85 for maximum allowable longitudinal tensile stress.

G At temperatures above 811 K (538 C, 1000 F), these stress values apply only when the carbon is 0.04% or higher on heat analysis.

H For temperatures above 811 K (538 C, 1000 F), these stress values apply only if the material is heat treated by heating it to a minimum temperature of 1311 K (1038 C, 1900 F).

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Alloy 600

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Alloy 600
Swelling
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The reference reported a practically insignificant amount of swelling in material damaged to a level of 75 displacements per atom (dpa).

In the study reported in the reference, three nickel alloys, Alloy X-750, Alloy 600, and Alloy 625, and a 20 % cold-worked Type 316 stainless steel were bombarded with 5-MeV nickel ions at 650 C (1202 F) to damage levels up to 90 displacements per atom. The damage was assessed metallographically. The results are shown in the following table.

Alloy	Temp	Dose	Helium	Void Density	Void Diameter	Void Volume Fraction
	Deg C	dpa	ppm	cm^{-2}	Angstroms	%
Alloy 600	625	110	21	6×10^{13}	320	0.12
Alloy 600	655	75	5	0	...	0
Alloy 625	655	45	5	0	...	0
Alloy X-750	655	60	5	3.2×10^{13}	730	0.6
20% CW 316SS	655	90	5	3.7×10^{13}	1,100	6.8

The 110 dpa dose came from an earlier experiment. Reference was also made to a previous study in which Alloy 600 and Alloy 625 also exhibited swelling resistance under *neutron* irradiation at approximately 600 C (1112 F) and 5×10^{22} neutrons per square centimeter (30 dpa).[1] The swelling resistance of the three nickel alloys was attributed primarily to their high nickel content.

Applicable Product Forms: The Alloy 600 material was annealed 1000 C (1832 F)/0.5 h. The results reported above are expected to apply to other heat treatments as well.

[1] W. K. Appleby, D. W. Sandusky, and U. E. Wolff, *Journal of Nuclear Materials*, Vol 43, 1972, p 213.

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Alloy 625

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Alloy 625
Swelling
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AMBK Update No. 0

****AS-RECEIVED INFORMATION *****

WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCE NO. 47

The reference reported a practically insignificant amount of swelling in material damaged to a level of 45 displacements per atom (dpa).

In the study reported in the reference, three nickel alloys, Alloy X-750, Alloy 600, and Alloy 625, and a 20 % cold-worked Type 316 stainless steel were bombarded with 5-MeV nickel ions at 650 C (1202 F) to damage levels up to 90 displacements per atom. The damage was assessed metallographically. The results are shown in the following table.

Alloy	Temp	Dose	Helium	Void Density	Void Diameter	Void Volume Fraction
	Deg C	dpa	ppm	cm^{-2}	Angstroms	%
Alloy 600	625	110	21	6×10^{13}	320	0.12
Alloy 600	655	75	5	0	...	0
Alloy 625	655	45	5	0	...	0
Alloy X-750	655	60	5	3.2×10^{13}	730	0.6
20% CW 316SS	655	90	5	3.7×10^{13}	1,100	6.8

The 110 dpa dose came from an earlier experiment. Reference was also made to a previous study in which Alloy 600 and Alloy 625 also exhibited swelling resistance under *neutron* irradiation at approximately 600 C (1112 F) and 5×10^{22} neutrons per square centimeter (30 dpa).[1] The swelling resistance of the three nickel alloys was attributed primarily to their high nickel content.

Applicable Product Forms: The Alloy 600 material was annealed 1100 C (2012 F)/0.5 h. The results reported above are expected to apply to other heat treatments as well.

1 W. K. Appleby, D. W. Sandusky, and U. E. Wolff, *Journal of Nuclear Materials*, Vol 43, 1972, p 213.

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Alloy X-750

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Alloy X-750
General Information
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WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCES NO. 6, 41, 42 AND 43

Alloy X-750 (UNS N07750) is an age-hardenable nickel-chromium-iron alloy used for its corrosion resistance, oxidation resistance, and high strength at temperatures to 1200 K. It has high creep-rupture strength at temperatures up to about 1100 K. It is frequently used in cryogenic applications, since it retains its properties down to liquid hydrogen temperatures.

Aluminum and titanium combine with nickel in the alloy to form the hardening component, $Ni_3(Al,Ti)$. The nature and composition of the chromium carbides formed during heat treatment also influence the mechanical properties.

Applications include rotor blades, wheels, and bolts in gas turbines, rocket engine thrust chambers, aircraft hot-air ducting systems and thrust reversers, large pressure vessels, forming tools, extrusion dies, heat-treating fixtures, springs, and fasteners.

A wide number of heat treatments are used, depending on the application and properties desired. The recommended heat treatments and the AMIS designation (Chemical Code) assigned to each treatment are as follows:

AMIS Chemical Code	Product Form	AMS Spec	Heat Treatment	Remarks
BI04A	Rods, Bars, and Forgings	5667	1625°F/24 hr., A.C., +1300°F/20 hr, A.C. (Equalizing plus Precipitation Treatment)	High Strength and Notch Rupture Ductility up to 1100°F.
BI04B	Rods, Bars, and Forgings	5670, 5671, and 5747	1800°F Anneal +1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 18 hr, A.C. (Solution Treatment plus Furnace-Cool Precipitation Treatment)	Increased Tensile Properties and Reduced Heat Treating Time for Service up to about 1100°F.
BI04C	Rods, Bars, and Forgings	—	1800°F Anneal +1400°F/1 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 6 hr, A.C. (Solution Treatment plus Short Furnace-Cool Precipitation Treatment)	Short Furnace-Cool Aging. Achieves only Slightly Lower Properties than does AMS 5670 and AMS 5671.

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Alloy X-750
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AMIS Chemical Code	Product Form	AMS Spec	Heat Treatment	Remarks
BI04D	Rods, Bars, and Forgings	5668	2100°F Anneal +1550°F/24 hr, A.C., +1300°F/20 hr, A.C. (Triple Heat Treatment)	Maximum Creep, Relaxation, and Rupture Strength above about 1100°F.
BI04E	Sheet, Strip, and Plate (Supplied in Annealed Condition)	5542	1300°F/20 hr, A.C. (Constant-Temperature Precipitation Treatment)	High Strength to 1300°F.
BI04F	Sheet, Strip, and Plate (Supplied in Annealed Condition)	5598	1350°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Precipitation-Treating Time of 18 hr, A.C. (Furnace-Cool Precipitation Treatment)	High Strength to 1300°F. (Increased Tensile Properties to about 1100°F.)
BI04G	Sheet, Strip, and Plate (Supplied in Annealed Condition)	——	1400°F/1 hr, F.C. to 1150°F, Hold at 1150°F for Total Time of 6 hr, A.C. (Short Furnace-Cool Precipitation Treatment)	Increased Tensile Properties and Reduced Heating Time for Service up to about 1100°F.
BI04H	Seamless Tubing	5582	1300°F/20 hr, A.C. (Constant-Temperature Precipitation Treatment)	High Strength up to about 1300°F.
BI04I	Wire, No. 1 Temper	5698	1350°F/16 hr (Constant-Temperature Precipitation Treatment)	For Springs Requiring Optimum Resistance to Relaxation from about 700° to 850°F and at Low or Moderate Stresses to about 1000°F.
BI04J	Wire, Spring Temper	5699	1200°F/4 hr, A.C. (Constant-Temperature Precipitation Treatment)	High Strength up to about 700°F.
BI04K	Wire, Spring Temper	5699	2100°F Anneal +1550°F/24 hr, A.C., +1300°F/20 hr, A.C. (Triple Heat Treatment)	For Springs for Service Requiring Maximum Relaxation Resistance at about 850° to 1200°F.

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Alloy X-750
General Information
Page Revision 0.0
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WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCES NO. 6, 41, 42 AND 43

Extensive use is being made of Alloy X-750 in the Advanced Neutron Source.[1] The parts being fabricated from this material include: Belleville springs, rollers, Delta-P plate, guide tube clamp, lower drive tube, hold-down spring, retainer spring, retainer plug, drive tube coupler, latch release tube, latch disk operator, lower drive tube, upper shock absorber spring retainer, shock absorber spring, lower shock absorber spring retainer, and inner drive tube. These components are fabricated in the annealed condition and aged 20 h at 705 C (AMS Specification Numbers 5542 or 5582), or are fabricated in the equalized condition (474 C/24 h, A.C.) and aged 20 h at 705 C (AMS 5667). AMS 5667 is designed to produce a minimum tensile strength of 1,138 MPa, a minimum yield strength of 724 MPa, and a minimum elongation of 20% for material having a thickness under 102 mm (4.0 inches). Spring material may be given one of the heat treatments specifically designed to produce relaxation resistance.

[1] "Chapter 4. Reactor," Advanced Neutron Source Conceptual Safety Analysis Report, ORNL/ANS/INT-33/V2, p. 4.5-1ff, June 1992.

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Alloy X-750
Chemical Composition
Page Revision 0.0
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Limiting Chemical Composition of Alloy X-750

Element	Weight Percent
Nickel (plus Cobalt)	70.00 min.
Chromium	14.00-17.00
Iron	5.00-9.00
Titanium	2.25-2.75
Aluminum	0.40-1.00
Columbium	0.70-1.20
Manganese	1.00 max.
Silicon	0.50 max.
Sulfur	0.010 max.
Copper	0.50 max.
Carbon	0.08 max.
Cobalt[1]	1.00 max.

[1] Determination not required for routine acceptance.

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Alloy X-750
Engineering
Stress-Strain
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AMBK Update No. 0

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-423 Deg F		-320 Deg F		70 Deg F	
Strain	**Stress**	**Strain**	**Stress**	**Strain**	**Stress**
in./in.	**ksi**	**in./in.**	**ksi**	**in./in.**	**ksi**
0	2	0	2	0	2
0.0005	20	0.0005	20	0.0005	20
0.001	33.7	0.001	33.7	0.001	33.7
0.0012	40	0.0012	40	0.0012	40
0.0018	60	0.0018	60	0.0018	60
0.002	67.8	0.002	67.8	0.002	67.8
0.0024	80	0.0023	80	0.0024	80
0.003	99.2	0.003	99	0.003	93.9
0.003	100	0.003	100	0.0033	100
0.004	120	0.004	115.4	0.004	106.4
0.004	120.2	0.0045	120	0.005	112.6
0.005	128.1	0.005	123.7	0.006	116.4
0.006	133.5	0.006	129.3	0.007	119.7
0.007	136.6	0.007	133.3	0.0071	120
0.008	139.2	0.008	136.5	0.008	122.7
0.0084	140	0.009	138.5	0.009	124.1
0.0098	143.7	0.0098	140.9	0.01	127.3

Applicable Product Forms: 0.050-inch Sheet, Annealed 1800 F, 1 h, F.C. to 1300 F, 20 h, A.C. Tests were made on Longitudinal samples in tension.

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Alloy X-750
Engineering
Stress-Strain
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-423 Deg F		-320 Deg F		-110 Deg F		Room Temperature	
Strain in./in.	Stress ksi	Strain in./in.	Stress ksi	Strain in./in.	Stress ksi	Strain in./in.	Stress ksi
0	0	0	0	0	0	0	0
0.004	40	0.004	40	0	40	0	40
0.002	80	0.002	80	0.002	80	0.002	80
0.004	120	0.004	120	0.004	120	0.004	120
0.006	160	0.005	156	0.011	148.6	0.01	140
0.01	160.1	0.007	160	0.017	160	0.034	160
0.04	185.6	0.04	178.6	0.04	172.8	0.04	162.3
0.067	200	0.08	194.8	0.08	189.2	0.08	174.3
0.08	204.9	0.095	200	0.12	197.4	0.12	183.3
0.12	218	0.12	207	0.135	200	0.16	189.7
0.16	228.2	0.16	216	0.16	203.2	0.2	193.9
0.2	236.5	0.2	223.9	0.2	207.6	0.257	163.9
0.221	240	0.24	230.1	0.24	210		
0.24	242.6	0.28	233.3	0.28	208.9		
0.28	246	0.32	227.3	0.295	200		
0.32	248.3	0.331	213.7	0.299	184.6		
0.339	249						

Applicable Product Forms: 0.150-inch diameter bar, stabilized + 1300 F, 20 h, A.C.

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Alloy X-750
Poisson's Ratio
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Temperature Deg F	Poisson's Ratio	Comments
-444.477	0.295	Note 1.
-394.364	0.296	Note 1.
-325.902	0.295	Note 1.
-304.219	0.295	Note 1.
-286.614	0.295	Note 1.
-248.003	0.295	Note 1.
-196.57	0.296	Note 1.
-141.127	0.297	Note 1.
-76.912	0.299	Note 1.
1.497	0.301	Note 1.
96.817	0.304	Note 1.
193.699	0.296	Note 2.
511.051	0.3	Note 2.
957.706	0.306	Note 2.
1,402.973	0.313	Note 2.

Notes:

1. The sources used by AMIS Ref. 6 were: R. L. Tobler, "Fracture of Structural Alloys at Temperatures Approaching Absolute Zero," Fracture, Vol. 3, 1977, and W. F. Weston and H. M. Ledbetter., "Low Temperature Elastic Properties of Nickel-Chromium-Iron Molybdenum Alloys," Materials Science and Engineering, Vol. 20, April 1975, p 287-290.

2. The source used by AMIS Ref. 6 was: R. J. Favor, W. P. Achback, and W. S. Hyler, "Materials - Property Design Criteria for Metals, Pt. 5; The conventional Short-Time Elevated-Temperature Properties of Selected Stainless Steels, TR55-150, Pt. 5, ASTIA Doc. AD 142069, October 1957.

Applicable Product Forms: All.

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Alloy X-750
Young's Modulus, Static Tension
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Temperature	Young's Modulus
Deg F	10^6 psi
80	31
500	28.7
1,000	25
1,200	23
1,350	21
1,500	18.5
1,600	--
1,800	--

Applicable Product Forms: All.

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Alloy X-750

Young's Modulus, Dynamic Tension

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Temperature	Young's Modulus
Deg F	10^6 psi
80	31
500	29.1
1,000	26.7
1,200	25.5
1,350	24.4
1,500	23.2
1,600	22.1
1,800	20

Applicable Product Forms: All.

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Alloy X-750
Shear Modulus
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Temperature Deg F	Shear Modulus 10^6 psi	AMIS Reference Number
-328	11.55	Ref. No. 6
-261	11.57	Ref. No. 6
-182	11.52	Ref. No. 6
-87	11.38	Ref. No. 6
-9	11.21	Ref. No. 6
73	11.05	Ref. No. 6
129	10.91	Ref. No. 6
174	10.8	Ref. No. 6
205	10.71	Ref. No. 6
80	11	Ref. No. 41
500	10.2	Ref. No. 41
1,000	9	Ref. No. 41
1,200	8.1	Ref. No. 41

Applicable Product Forms: All.

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Alloy X-750
Tangent Modulus
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Tangent Modulus at Room Temp	Stress
10^3 ksi	ksi
1.3	118
4	110.2
8	105.1
12	102.6
15.7	100
16	99.7
20	95.8
24	90.9
28	86.1
32	81.4
32.1	80
32.2	60
32.2	40
32.2	20
32.2	1

Tangent Modulus at 400 Deg F	Stress
10^3 ksi	ksi
1.2	110.1
4	102.1
5.4	100
8	98.7
12	97.1
16	95.1
20	92.4
24	88
28	82.6
29.1	80
29.3	60
29.4	40
29.5	20
29.6	1

Applicable Product Forms: 0.064-inch Sheet, Annealed + 1300 F, 20 h, A.C. Tests were made on Longitudinal and Transverse samples in compression.

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Alloy X-750
Secant Modulus
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Secant Modulus at Room Temp	Stress
10^3 ksi	ksi
13.4	120
14	120
16	117.3
20	114.3
24	111.4
28	106.9
30.6	100
32	90.2
32.2	80
32.3	60
32.4	40
32.5	20
32.6	0

Secant Modulus at400 Deg F	Stress
10^3 ksi	ksi
10.1	114.8
32	2.7
12	114
16	111.8
20	109.2
24	107.7
28	103.8
29.2	100
30.5	80
30.5	60
30.5	40
30.5	20
30.5	0

Applicable Product Forms: 0.064-inch Sheet, Annealed + 1300 F, 20 h, A.C. Tests were made on Longitudinal and Transverse samples in compression.

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Alloy X-750
Specific Heat Capacity
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Temperature	Specific Heat Capacity
Deg F	Btu/lb/F
-250	0.073
-200	0.08
-100	0.09
70	0.103
200	0.109
400	0.116
600	0.12
800	0.125
1,000	0.13
1,200	0.137
1,400	0.151
1,600	0.171
1,800	--

Applicable Product Forms: The above values were determined for Rod, Bar, and Forging material heat treated to AMS Specification 5668, i. e., 2100 F/3h, A.C., + 1550 F/24 h, A. C., + 1300 F/20 h, A. C. These values may be used with discretion on material of other forms and heat treatments.

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Alloy X-750
Specific Heat Capacity
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Temp Kelvins	Specific Heat Capacity cal/(g*K)	Comments
1	2.47E-5	Note 1.
2	4.91E-5	Note 1.
3	7.52E-5	Note 1.
4	1.03E-4	Note 1.
5	1.34E-4	Note 1.
6	1.76E-4	Note 1.
7	2.15E-4	Note 1.
8	2.55E-4	Note 1.
9	2.99E-4	Note 1.
10	3.48E-4	Note 1.
15	7.00E-4	Note 1.
20	1.24E-3	Note 1.
30	3.68E-3	Note 1.
40	8.43E-3	Note 1.
50	1.53E-2	Note 1.
60	2.67E-2	Note 1.
70	3.65E-2	Note 1.

Temp Kelvins	Specific Heat Capacity cal/(g*K)	Comments
80	4.70E-2	Note 1.
90	5.65E-2	Note 1.
100	6.55E-2	
150	8.20E-2	
200	9.10E-2	
300	1.04E-1	
400	1.12E-1	
500	1.18E-1	
600	1.20E-1	
700	1.25E-1	
800	1.30E-1	
900	1.40E-1	
1,000	1.49E-1	
1,100	1.60E-1	
1,200	1.80E-1	
1,300	2.15E-1	Extrapolated.

Notes

1. Calculated from Kopp-Neuman Law.

Applicable Product Forms: These values may be used with discretion on material of all forms and heat treatments.

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***AS-RECEIVED INFORMATION ***

Alloy X-750
Thermal Diffusivity
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Temperature	Thermal Diffusivity
Deg F	ft^2/h
-250	0.15
-200	0.143
-100	0.135
70	0.132
200	0.133
400	0.14
600	0.148
800	0.158
1,000	0.169
1,200	0.173
1,400	0.172
1,600	0.164
1,800	--

Applicable Product Forms: The above values were determined for Rod, Bar, and Forging material heat treated to AMS Specification 5668, i. e., 2100 F/3h, A.C., + 1550 F/24 h, A. C., + 1300 F/20 h, A. C. These values may be used with discretion on material of other forms and heat treatments.

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Alloy X-750
Thermal Diffusivity
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Temperature Kelvins	Thermal Diffusivity cm^2/s
1	0.28
5	0.71
10	0.79
25	0.47
50	0.124
75	0.055
100	0.038
150	0.034
200	0.033
250	0.033
300	0.033
400	0.035
500	0.038
600	0.041
700	0.044
800	0.047
900	0.048
1,000	0.048
1,100	0.048
1,200	0.046
1,300	0.042

Note: No experimental data were available. All of the above values were calculated or estimated.

Applicable Product Forms: These values may be used with discretion on material of all forms and heat treatments.

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Alloy X-750
Thermal Conductivity
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Temperature	Thermal Conductivity
Deg F	Btu/in/h/ft^2/F
-250	67
-200	70
-100	74
70	83
200	89
400	98
600	109
800	120
1,000	131
1,200	143
1,400	154
1,600	164
1,800	--

Applicable Product Forms: The above values were determined for Rod, Bar, and Forging material heat treated to AMS Specification 5668, i. e., 2100 F/3h, A.C., + 1550 F/24 h, A. C., + 1300 F/20 h, A. C. These values may be used with discretion on material of other forms and heat treatments.

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Temperature Kelvins	Thermal Conductivity W/(m*K)	Comments
0	0	
0.1	0.0006	Extrapolated Value.
1	0.24	Extrapolated Value.
5	0.33	Extrapolated Value.
10	0.96	Extrapolated Value.
25	3.4	Extrapolated Value.
50	6.6	Extrapolated Value.
75	8	Extrapolated Value.
100	8.7	Extrapolated Value.
150	9.6	
200	10.3	
250	11	
273	11.3	
300	11.7	
350	12.6	
400	13.5	
450	14.3	
500	15.2	
600	17	
700	18.8	
800	20.5	
900	22.3	
1,000	24	
1,100	25.8	

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Alloy X-750
Thermal Conductivity
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Temperature	Thermal Conductivity	Comments
Kelvins	W/(m*K)	
1,200	27.6	
1,300	29.3	Extrapolated Value.
1,400	31.1	Extrapolated Value.
1,500	32.8	Extrapolated Value.
1,600	34.6	Extrapolated Value.
1,665	35.8	Extrapolated Value.
1,800	33	Estimated Value (Liquid Material).

Applicable Product Forms: These values may be used with discretion on material of all forms and heat treatments.

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**AS-RECEIVED INFORMATION **

Alloy X-750

Mean Coefficient of Thermal Expansion

Page Revision 0.0

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Temperature	Mean Coefficient of Thermal Expansion
Deg F	in/in/F × 10^{-6}, from 70 F to Temperature Shown
-250	6.5
-200	6.6
-100	6.7
70	--
200	7
400	7.2
600	7.5
800	7.8
1,000	8.1
1,200	8.4
1,400	8.8
1,600	9.3
1,800	9.8

Applicable Product Forms: The above values were determined for Rod, Bar, and Forging material heat treated to AMS Specification 5668, i. e., 2100 F/3h, A.C., + 1550 F/24 h, A. C., + 1300 F/20 h, A. C. These values may be used with discretion on material of other forms and heat treatments.

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**AS-RECEIVED INFORMATION **

Alloy X-750
Electrical Resistivity
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Temperature	Electrical Resistivity
Deg F	ohm/circ mil/ft
70	731
200	739
400	746
600	761
800	771
1,000	783
1,200	786
1,400	775
1,600	761

Applicable Product Forms: The above values were determined for Rod, Bar, and Forging material heat treated to AMS Specification 5668, i. e., 2100 F/3h, A.C., + 1550 F/24 h, A. C., + 1300 F/20 h, A. C. These values may be used with discretion on material of other forms and heat treatments. The effect of heat treatment on the room temperature resistivity of hot-rolled bar is shown in the following table.

Effect of Heat Treatment on Room Temperature Resistivity of Hot-Rolled Bar.

Heat Treatment	Electrical Resistivity ohm/circ mil/ft
As Hot-Rolled	759
2000 F/h, A.C.	763
2100 F/2h, A.C., + 1500 F/24h A.C., + 1300 F/20 h, A.C.	724
1800 F/1 h, A.C., + 1350 F/8h, F.C. to 1150 F, Hold at 1150 F for a Total Time of 18 h, A.C.	739

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Alloy X-750
Electrical Resistivity
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Temperature Deg F	Electrical Resistivity microhm inch	Comments
-453	46.28	Precipitation-Treated Material.
-420	46.18	Precipitation-Treated Material.
-317	46.58	Precipitation-Treated Material.
-117	47.56	Precipitation-Treated Material.
32	48.35	Precipitation-Treated Material.
-453	47.58	Annealed material.
-420	47.39	Annealed material.
-322	47.61	Annealed material.
-113	48.5	Annealed material.
32	48.99	Annealed material.

Applicable Product Forms: These values may be used with discretion on material of all forms and heat treatments.

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Alloy X-750
Thermal Emissivity
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Temperature Kelvins	Thermal Emissivity	Comments
200	0.12	±0.02, Recommended Value
300	0.13	Recommended Value
400	0.145	Recommended Value
500	0.16	Recommended Value
222	0.14	Note 1.
278	0.15	Note 1.
333	0.16	Note 1.
222	0.2	Note 2.
278	0.21	Note 2.
333	0.22	Note 2.
589	0.69	Note 3.
700	0.705	Note 3.
811	0.73	Note 3.
922	0.755	Note 3.
1,033	0.765	Note 3.
1,144	0.795	Note 3.
1,255	0.82	Note 3.

Notes

1. Foil, hand buffed. Value computed from spectral reflectance measurements.
2. Foil, chemically polished. Value computed from spectral reflectance measurements.
3. Cleaned, polished and oxidized in air at 1366 K for 30 min. Stably oxidized condition, diffuse emitter.

Applicable Product Forms: These values may be used with discretion on material of all forms and heat treatments.

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Alloy X-750
Thermal Emissivity
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Temperature Deg F	Thermal Emissivity	Comments
-303	0.18	Note 1.
394	0.194	Note 1.
1,203	0.202	Note 1.
1,333	0.279	Note 1.
-297	0.046	Note 2.
525	0.086	Note 2.
709	0.084	Note 2.
864	0.117	Note 2.
955	0.092	Note 2.
1,051	0.094	Note 2.
1,222	0.143	Note 2.
1,438	0.173	Note 2.
1,571	0.147	Note 2.
1,736	0.194	Note 2.

Notes

1. Polished. Original source of values is: G. B. Wilkes, "Total Normal Emissivities and Solar Absorbtivities of Materials," WADC TR 54-42, March 1954.

2. Polished. Original source of values is: W. D. Wood, H. W. Deem, and C. F. Lucks, "The Emittance of Iron, Nickel, and Cobalt and Their Alloys," DMIC Memo 119, July 1961.

Applicable Product Forms: These values may be used with discretion on material of all forms and heat treatments.

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Alloy X-750
Density
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Temperature Kelvins	Density Kg/m^3
0	8.324
100	8.301
200	8.276
300	8.247
400	8.214
500	8.179
600	8.142
700	8.103
800	8.063
900	8.021
1,000	7.977
1,100	7.93
1,200	7.88
1,300	7.828
1,400	7.774
1,500	7.718
1,600	7.66

Applicable Product Forms: These values may be used with discretion on material of all forms and heat treatments. Note that the density is expected to be very dependent on composition.

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Alloy X-750
Swelling
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The reference reported a practically insignificant amount of swelling in material damaged to a level of 60 displacements per atom (dpa).

In the study reported in the reference, three nickel alloys, Alloy X-750, Alloy 600, and Alloy 625, and a 20 % cold-worked Type 316 stainless steel were bombarded with 5-MeV nickel ions at 650 C (1202 F) to damage levels up to 90 displacements per atom. The damage was assessed metallographically. The results are shown in the following table.

Alloy	Temp	Dose	Helium	Void Density	Void Diameter	Void Volume Fraction
	Deg C	dpa	ppm	cm^{-2}	Angstroms	%
Alloy 600	625	110	21	6×10^{13}	320	0.12
Alloy 600	655	75	5	0	...	0
Alloy 625	655	45	5	0	...	0
Alloy X-750	655	60	5	3.2×10^{13}	730	0.6
20% CW 316SS	655	90	5	3.7×10^{13}	1,100	6.8

The 110 dpa dose came from an earlier experiment. Reference was also made to a previous study in which Alloy 600 and Alloy 625 also exhibited swelling resistance under *neutron* irradiation at approximately 600 C (1112 F) and 5×10^{22} neutrons per square centimeter (30 dpa).[1] The swelling resistance of the three nickel alloys was attributed primarily to their high nickel content.

Applicable Product Forms: The Alloy X-750 material was given a non-standard heat treatment, 1100 C (2012 F)/0.5 h + 840 C (1544 F)/24 h to produce a dispersion of gamma prime containing 5×10^{14} particles/cm^3 with an average edge length of 600 Angstroms. The results reported above are expected to apply to other heat treatments as well.

1 W. K. Appleby, D. W. Sandusky, and U. E. Wolff, *Journal of Nuclear Materials*, Vol 43, 1972, p 213.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5667

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Alloy X-750, AMS 5667
Product Forms & Applicable Specifications
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WARNING - THIS IS AS-RECEIVED, UNREVIEWED INFORMATION FROM AMIS REFERENCE NO. 41 AND 44

In order to develop high strength and ductility at temperatures up to 593 C (1100 F), Alloy X-750 rod, bar, and forgings are given the following two-step precipitation treatment: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C. This treatment is described in AMS Specification 5667 (AMIS Ref. No. 44), which addresses bars, forgings, flash welded rings, and stock for forgings or flash welded rings. The required tensile properties are as follows:

Nominal Diameter or Section Thickness	Minimum Tensile Strength	Minimum Yield Strength at 0.2% Offset or at Extension Indicated	Extension Under Load	Minimum Elongation	Minimum Reduction of Area
inches	ksi	ksi	inch in 2 in.	% in 4D	%
Under 4.0	165	105	0.0108	20	25
4.0 and Over	160	100	0.0105	15	17

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Alloy X-750, AMS 5667
Ultimate Tensile Strength
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Temperature Deg F	Ultimate Tensile Strength ksi	Comments
85	174	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
300	168.25	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
400	165.5	30 mm bar hot-rolled before heat treating.
800	156	30 mm bar hot-rolled before heat treating.
1,000	152	30 mm bar hot-rolled before heat treating.
1,100	153.5	30 mm bar hot-rolled before heat treating.
1,200	136.5	30 mm bar hot-rolled before heat treating.
78	184	19 mm bar hot-rolled before heat treating..
600	169	19 mm bar hot-rolled before heat treating..
800	166	19 mm bar hot-rolled before heat treating..
1,000	163.5	19 mm bar hot-rolled before heat treating..
1,100	159	19 mm bar hot-rolled before heat treating..
1,200	143	19 mm bar hot-rolled before heat treating..
1,350	107	19 mm bar hot-rolled before heat treating..
1,500	65.4	19 mm bar hot-rolled before heat treating..

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were given the following heat treatment: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5667
Yield Strength
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Temperature Deg F	Yield Strength ksi	Comments
85	118.5	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
300	113.25	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
400	111.5	30 mm bar hot-rolled before heat treating.
800	107.5	30 mm bar hot-rolled before heat treating.
1,000	105	30 mm bar hot-rolled before heat treating.
1,100	105.5	30 mm bar hot-rolled before heat treating.
1,200	103	30 mm bar hot-rolled before heat treating.
78	126	19 mm bar hot-rolled before heat treating..
600	116.5	19 mm bar hot-rolled before heat treating..
800	114	19 mm bar hot-rolled before heat treating..
1,000	115	19 mm bar hot-rolled before heat treating..
1,100	112	19 mm bar hot-rolled before heat treating..
1,200	110	19 mm bar hot-rolled before heat treating..
1,350	98.3	19 mm bar hot-rolled before heat treating..
1,500	64.7	19 mm bar hot-rolled before heat treating..

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were given the following heat treatment: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5667
Total Elongation
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Temperature Deg F	Total Elongation %	Comments
85	26.8	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
300	26	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
400	26	30 mm bar hot-rolled before heat treating.
800	26.5	30 mm bar hot-rolled before heat treating.
1,000	25.5	30 mm bar hot-rolled before heat treating.
1,100	19	30 mm bar hot-rolled before heat treating.
1,200	10	30 mm bar hot-rolled before heat treating.
78	25	19 mm bar hot-rolled before heat treating..
600	23	19 mm bar hot-rolled before heat treating..
800	24	19 mm bar hot-rolled before heat treating..
1,000	20	19 mm bar hot-rolled before heat treating..
1,100	10	19 mm bar hot-rolled before heat treating..
1,200	7	19 mm bar hot-rolled before heat treating..
1,350	6	19 mm bar hot-rolled before heat treating..
1,500	17	19 mm bar hot-rolled before heat treating..

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were given the following heat treatment: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5667
Reduction of Area
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Temperature	Reduction of Area	Comments
Deg F	%	
85	45.4	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
300	44.1	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
400	42.7	30 mm bar hot-rolled before heat treating.
800	44.8	30 mm bar hot-rolled before heat treating.
1,000	40.7	30 mm bar hot-rolled before heat treating.
1,100	22	30 mm bar hot-rolled before heat treating.
1,200	17.7	30 mm bar hot-rolled before heat treating.
78	41.5	19 mm bar hot-rolled before heat treating..
600	35	19 mm bar hot-rolled before heat treating..
800	39	19 mm bar hot-rolled before heat treating..
1,000	25	19 mm bar hot-rolled before heat treating..
1,100	13	19 mm bar hot-rolled before heat treating..
1,200	7.8	19 mm bar hot-rolled before heat treating..
1,350	10	19 mm bar hot-rolled before heat treating..
1,500	19.5	19 mm bar hot-rolled before heat treating..

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were given the following heat treatment: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5667
Young's Modulus
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Temperature Deg F	Young's Modulus ksi	Comments
85	30.2	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
300	31.3	30 mm bar hot-rolled before heat treating. (Avg of 2 tests.)
400	29.1	30 mm bar hot-rolled before heat treating.
800	25.9	30 mm bar hot-rolled before heat treating.
1,000	23.2	30 mm bar hot-rolled before heat treating.
1,100	26.4	30 mm bar hot-rolled before heat treating.
1,200	21.7	30 mm bar hot-rolled before heat treating.

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were given the following heat treatment: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Alloy X-750, AMS 5667
Stress-Rupture Strength
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Smooth Bar

Temperature 1000 F		Temperature 1100 F		Temperature 1200 F		Temperature 1350 F	
Time Hours	Stress ksi	Time Hours	Stress ksi	Time Hours	Stress ksi	Time Hours	Stress ksi
30.9	130	22.9	110	18	84.1	10.5	50.8
31.6	129.9	31.6	105.5	22.7	80	12.8	50
62.2	125	33.1	105	31.4	75	24.1	45
100	121.2	49.1	100	31.6	74.9	31.6	42.5
118.7	120	67.4	95	49.2	70	39.6	40
180	115	99	90	72.2	65	70.7	35
272.5	110	100	89.9	100	62.3	100	32.7
316.2	107.8	140.8	85	128.1	60	134.5	30
405.9	105	203.5	80	235.9	55	234.1	24.7
651.3	100	316.2	75.1	316.2	52.7		
892.4	95	317	75	427.4	50		
1,000	93.7	519.4	70	856.9	45		
1,123.6	94.1	825.4	65	1,000	43.7		
		978.2	64.8	1,125.2	44.2		

See following page for Notched Bar values and Product Form information.

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Alloy X-750, AMS 5667
Stress-Rupture Strength
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Notched Bar

Temperature 1000 F		Temperature 1100 F		Temperature 1200 F		Temperature 1350 F	
Time Hours	Stress ksi	Time Hours	Stress ksi	Time Hours	Stress ksi	Time Hours	Stress ksi
27.1	153.6	21.1	120	14.5	70	10.3	53.7
31.6	151.7	26.7	115	22.3	65	16.7	50
40.3	150	31.6	111.2	31.6	60.3	30.4	45
54.1	145	31.8	110	32.7	60	31.6	44.8
73.8	140	37.1	105	57.7	55	58.5	40
95	135	43.1	100	100	50.9	100	35.7
100	134.1	48.1	95	113.2	50	109.8	35
121.2	130	57.5	90	266.2	45	220.5	30.3
155.9	125	68.9	85	316.2	43.8		
155.3	125	87.4	80	675.3	40		
206.3	120	100	77.4	1,000	37.8		
258.7	115	120.6	75	1,785.9	37.2		
310.3	110	158.8	70				
316.2	109.3	226.8	65				
374.4	105	316.2	61.1				
469.5	100	349.9	60				
580.5	95	608.9	55				
694.2	90	989.6	50				
855.4	85	1,000	50				
1,000	81.8	1,095.7	51.3				
1,033.3	80.5						

Applicable Product Forms: Bar Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C. Smooth bar, 7.6mm (0.3-in.) dia., 38mm (1.5 in.) long; notched bar, 50% 60° V-notch, 0.1mm (0.005-in.) root radius.

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Alloy X-750, AMS 5542

Stress Rupture Strength (Larson-Miller Parameter)

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Rupture		2.0% Creep		1.0% Creep		0.5% Creep		0.2% Creep		0.1% Creep	
Stress	Rupture Life	Stress	Rupture Life	Stress	Rupture Life	Stress	Rupture Life	Stress	Rupture Life	Stress	Rupture Life
ksi	L-M P[1]	ksi	L-M P[1]	ksi	L-M P[1]	ksi	L-M P[1]	ksi	L-M P[1]	ksi	L-M P[1]
23.8	132.2	21.6	130.4	21.1	124.8	20.9	122.2	22.8	101.2	22.5	94.8
24	131.8	22	130.5	21.4	125	21	122.3	22.9	100	22.6	95
24.2	130	22	130.6	21.4	125	21.9	120	23	99.1	23	90.2
24.2	130	22	130.5	21.6	125	22	119.5	23.5	95	23	90
24.2	130	22	130	21.7	125	22.8	115	23.9	90	23.4	85
24.8	125	23	125.6	21.8	125	23	113.6	24	88	23.8	80
25	122.5	23.1	125	22	124.3	23.5	110	24.2	85	24	77.4
25.3	120	24	120	22.9	120	23.9	105	24.5	80	24.2	75
25.5	115	24	119.9	23	119.8	24	104.1	24.9	75	24.5	70
25.7	110	24.5	115	23.9	115	24.3	100	25	73.1	24.8	65
26	105	24.9	110	24	113.3	24.6	95	25.2	70	25	60
26	104.8	25	108.7	24.3	110	24.9	90	25.4	65	25	58.8
26.3	100	25.2	105	24.8	105	25	88.4	25.7	60	25.2	55
26.6	95	25.7	100	25	102.2	25.2	85	26	56	25.5	50
26.9	90	26	95.3	25.2	100	25.6	80	26.1	55	25.8	45
27	87.8	26	95	25.6	95	26	75	26.3	50	25.8	41.5
27.2	85	26.4	90	26	90	26	74.6	26.6	42.5		
27.5	80	26.7	85	26	89.8	26.3	70				
27.8	75	27	80.5	26.3	85	26.7	65				
28	71.9	27	80	26.6	80	27	60.2				
28.2	70	27.4	75	27	75	27	60				
28.6	65	27.8	70	27	74.8	27.3	55				
28.9	60	28	66.8	27.3	70	27.7	50				
29	57.5	28.1	65	27.7	65	28	46.2				
29.1	55	28.5	60	28	60.4	28.1	45				
29.5	50	28.9	55	28	60	28.3	41.2				
29.7	45.2	29	52.8	28.4	55						
		29.2	50	28.9	50						
		29.5	44.7	29	47.8						
				29.2	45						
				29.1	42.8						

[1] Larsen-Miller Parameter, $P = (460 + T)(15 + \log t) \times 10^{-3}$, where T = Test Temperature, Deg F, and t = time, hours.

Applicable Product Forms:
Hot-Rolled Bar Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Alloy X-750, AMS 5667

Creep

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Temperature 1000 F		Temperature 1100 F		Temperature 1200 F		Temperature 1350 F		Temperature 1500 F	
Creep Rate	Stress	Creep Rate	Stress	Creep Rate	Stress	Creep Rate	Stress	Creep Rate	Stress
%/1000 h	ksi	%/1000 h	ksi	%/1000 h	ksi	%/1000 h	ksi	%/1000 h	ksi
5	102	1.3	66	2.5	48.5	9.5	23.6	11.5	10
10	109.7	1.6	69.4	4	51.5	10	24.7	15.8	11.2
15.8	112.1	2.5	75.1	6.3	55.9	10.5	25.1	25.1	12.7
25.1	113.9	4	78.7	10	60.2	15.8	28	39.8	14.3
39.8	117.1	6.3	85	12.8	63.1	25.1	31.8	56.9	15.8
63.1	120	10	87.2	15.8	64.9	39.8	36.1	63.1	16.5
100	124.3	15.8	87.9	25.1	70.1	51	39.8	100	18.7
158.5	128	25.1	91.1	39.8	72.8	63.1	42.3	158.5	21.1
251.2	131.6	39.8	92.9	63.1	73.9	100	47.9	251.2	23.9
299.3	133.3	63.1	94.1	100	76.2	158.5	50.4	301.4	25.1
		100	95.3	158.5	77.9	251.2	52.7	398.1	27.4
		143.4	99.4	251.2	80.1	398.1	54.1	500	27.3
				320	83	500	55.1		

Applicable Product Forms: Hot-Rolled Bar Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Temperature 1000 F		Temperature 1100 F		Temperature 1200 F		Temperature 1200 F		Temperature 1200 F	
Time Hours	Stress ksi	Time Hours	Stress ksi	Time Hours	Stress ksi	Time Hours	Stress ksi	Time Hours	Stress ksi
1.00E-01	59.6	1.00E-01	60.3	1.00E-01	56.3	1.00E-01	39.6	1.00E-01	19.6
3.16E-01	59.5	3.16E-01	60.2	3.16E-01	56.1	3.16E-01	39.5	3.16E-01	19.6
1.00E+00	59.2	1.00E+00	59.8	1.00E+00	54.6	1.00E+00	38.7	1.00E+00	19.7
3.16E+00	58.7	3.16E+00	58.9	3.16E+00	52.4	3.16E+00	37.2	3.16E+00	19.7
1.00E+01	58.6	1.00E+01	57.8	1.00E+01	48.4	1.00E+01	34.1	1.00E+01	19.1
3.16E+01	58.4	3.16E+01	56.2	3.16E+01	43.1	3.16E+01	30.7	3.16E+01	17.9
1.00E+02	58.2	1.00E+02	54.5	1.00E+02	35.6	1.00E+02	26.2	1.00E+02	16.5
3.16E+02	58.1	3.16E+02	52.5	3.16E+02	25.8	3.16E+02	20.6	3.16E+02	14.7
4.41E+02	57.8	7.72E+02	49.7	4.03E+02	24.2	1.00E+03	13.9	1.00E+03	12
						2.21E+03	8.3	1.03E+03	11.9

Applicable Product Forms: Hot-Rolled Bar Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Temperature	Stress
Deg F	ksi
0	68.2
100	68.2
200	68.2
300	68.4
400	68.8
500	69.1
600	69.3
700	69.9
800	70.7
900	73.8
977	78
1,000	77.2
1,100	69.3
1,200	57
1,300	44
1,400	31.1
1,504	21.7

High-Temperature Fatigue Strength (10^8 cycles). Rotating-beam Tests (3450 rpm).

Applicable Product Forms: Bar, Fine Grain Microstructure (ASTM 8), Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Temperature 1000 F		Temperature 78 F		Temperature 1200 F		Temperature 1350 F		Temperature 1500 F	
Cycles to Failure	Bending Stress ksi	Cycles to Failure	Bending Stress ksi	Cycles to Failure	Bending Stress ksi	Cycles to Failure	Bending Stress ksi	Cycles to Failure	Bending Stress ksi
4.03E+06	84.2	1.00E+06	75.5	2.78E+06	61.1	2.26E+06	61.4	2.53E+06	38.6
3.98E+06	83.8	1.58E+06	75	3.98E+06	60.6	2.51E+06	59.8	3.98E+06	36.8
6.31E+06	83.2	2.51E+06	74.3	6.31E+06	60.4	3.98E+06	54.2	6.31E+06	34.5
1.00E+07	82.6	3.98E+06	73.6	1.00E+07	60.2	6.31E+06	49.6	1.00E+07	32.4
1.58E+07	81.7	6.31E+06	72.8	1.58E+07	59.9	1.00E+07	46.2	1.58E+07	30.2
2.51E+07	81	1.00E+07	71.9	2.51E+07	59.7	1.58E+07	42.7	2.51E+07	27.6
3.98E+07	80.3	1.58E+07	71	3.98E+07	59.5	2.51E+07	40.7	3.98E+07	25.4
6.31E+07	79.4	2.51E+07	70.2	6.31E+07	59.2	3.98E+07	39.2	6.31E+07	23.2
1.00E+08	78.6	3.98E+07	69.6	9.92E+07	59	6.31E+07	38.2	1.01E+08	20.6
1.47E+08	78.4	6.31E+07	68.9			9.37E+07	37.8		
		1.00E+08	68.1						
		1.28E+08	68.3						

Applicable Product Forms: High-Temperature Fatigue Strength of 16mm (0.625-in.) Hot-Rolled Bar Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Room Temperature Fatigue Strength[1]

Smooth Bar		Notched Bar	
Cycles to Failure	Stress ksi	Cycles to Failure	Stress ksi
2.71E+05	91.6	2.65E+04	79.3
3.16E+05	92.3	3.16E+04	76.9
1.00E+06	85.9	1.00E+05	60.9
3.16E+06	80.6	3.16E+05	49.8
1.00E+07	75.9	1.00E+06	40.2
3.16E+07	73.9	3.16E+06	31.6
9.94E+07	73.4	1.00E+07	27
		3.16E+07	25.9
		1.00E+08	26.8
		1.08E+08	26.2

[1] R. R. Moore rotating-beam tests at 10,000 rpm. $K_t = 3.4$.

Applicable Product Forms: Room-Temperature Fatigue Strength of 19mm (0.75-in.) Hot-Rolled Bar Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Room Temperature Fatigue Strength[1]

Smooth Specimen		Notched Specimen	
Cycles to Failure	Max. Stress ksi	Cycles to Failure	Max. Stress ksi
4.94E+04	125.9	1.08E+05	67.1
5.62E+04	122.4	1.78E+05	59.7
1.00E+05	112.8	3.16E+05	51.6
1.78E+05	108.3	5.62E+05	45.2
3.16E+05	106.3	1.00E+06	40.2
5.62E+05	104.8	1.78E+06	38.1
1.00E+06	103.9	3.16E+06	37.1
1.78E+06	102.7	5.62E+06	37.1
3.16E+06	101.7	1.00E+07	37.2
5.62E+06	100.4	1.78E+07	37.2
9.03E+06	95.7	2.70E+07	35.5

1 Pull-pull Fatigue Strength.

Applicable Product Forms: Room-Temperature Fatigue Strength of 25.4mm (1-in.) Hot-Rolled Rod Equalized and Precipitation-treated: 885 C (1625 F)/24 h, A.C. + 704 C (1300 F)/20 h, A.C.

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Alloy X-750 sheet, strip, and plate are furnished in the annealed condition. In order to develop high strength at high temperatures and high relaxation resistance, the following one-step precipitation treatment is given: 1300 F/20 h, A.C. This treatment is described in AMS Specification 5542, which requires the room-temperature properties listed below.

Form & Size, inches	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation in 2 inches, %	Hardness, Rc
Annealed Condition				
Strip				
Under 0.010	140 max.			
0.010 to 0.025	130 max.		20 min.	
0.025 & Over	As agreed Upon Between Purchaser ahd Vendor			
Sheet				
0.010 to 0.024	140 max.		30 min.	
Over 0.024 to 0.125	130 max.	60 max.	40 min.	
Over 0.125 to 0.250	130 max.	65 max.	40 min.	
After Precipitation Treating (1300 F/20 h, A.C.)				
Strip				
Under 0.010	150 min.			30 min. (0.005 and Over)
0.010 to 0.025	155 min.		15	30
0.025 & Over	155 min.		15	30
Sheet				
0.010 to 0.250	165 min.	105 min.	20 min.	32 min.
Plate				
0.187 to 4.000	155 min.	100 min.	20 min.	30 min.

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Alloy X-750, AMS 5542
Ultimate Tensile Strength
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Temperature Deg F	Ultimate Tensile Strength ksi	Comments
-423	234	0.063-in. annealed sheet tested in the Transverse Direction
-423	233	0.063-in. annealed sheet tested in the Longitudinal Direction
-423	253.3	0.25-in. Cold-Rolled Annealed Sheet
-320	212	0.063-in. annealed sheet tested in the Transverse Direction
-320	214	0.063-in. annealed sheet tested in the Longitudinal Direction
-100	--	0.063-in. annealed sheet tested in the Transverse Direction
-100	189	0.063-in. annealed sheet tested in the Longitudinal Direction
78	174	0.063-in. annealed sheet tested in the Transverse Direction
78	174	0.063-in. annealed sheet tested in the Longitudinal Direction
78	177	0.050-in. Cold-Rolled Annealed Sheet
78	170.5	Annealed sheet tested in the Longitudinal Direction
78	166	Annealed sheet tested in the Transverse Direction
78	179.5	Annealed sheet tested in the Longitudinal Direction
78	180	Annealed sheet tested in the Transverse Direction
78	165	0.062-in. annealed sheet tested in the Longitudinal Direction
78	170.5	0.062-in. annealed sheet tested in the Longitudinal Direction
78	171.5	0.062-in. annealed sheet tested in the Longitudinal Direction
78	166	0.062-in. annealed sheet tested in the Transverse Direction
78	172	0.062-in. annealed sheet tested in the Transverse Direction
78	175	0.062-in. annealed sheet tested in the Transverse Direction
78	170	0.062-in. annealed sheet tested in the "Average" Orientation
78	175.1	0.25-in. Cold-Rolled Annealed Sheet
400	167	0.050-in. Cold-Rolled Annealed Sheet

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Ultimate Tensile Strength
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Temperature	Ultimate Tensile Strength	Comments
Deg F	ksi	
800	151	0.050-in. Cold-Rolled Annealed Sheet
1,000	154	0.050-in. Cold-Rolled Annealed Sheet
1,100	135	0.050-in. Cold-Rolled Annealed Sheet
1,200	123	0.050-in. Cold-Rolled Annealed Sheet
1,300	110	0.050-in. Cold-Rolled Annealed Sheet
1,500	80.3	0.050-in. Cold-Rolled Annealed Sheet

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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Alloy X-750, AMS 5542
Ultimate Tensile Strength
Notch Sensitivity
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Temp Deg F	*Ultimate[1] Tensile Strength* *ksi*	*Yield[1] Strength* *ksi*	Notched Ultimate Tensile Strength ksi	Ratio, Notched/Unnotched Tensile Strength	Comments
-423	310	*266*	202	0.7	Sharp-Edge Notch. Cold-Rolled (67%) Sheet tested in the Longitudinal Direction
-423	*234*	*139*	201	0.86	0.063-in. annealed sheet tested in the Transverse Direction
-423	*233*	*134*	199	0.85	0.063-in. annealed sheet tested in the Longitudinal Direction
-320	*212*	*130*	184	0.87	0.063-in. annealed sheet tested in the Transverse Direction
-320	*214*	*130*	184	0.86	0.063-in. annealed sheet tested in the Longitudinal Direction
-100	--	--	175	--	0.063-in. annealed sheet tested in the Transverse Direction
-100	*189*	*122*	174	0.92	0.063-in. annealed sheet tested in the Longitudinal Direction
78	*174*	*118*	168	0.97	0.063-in. annealed sheet tested in the Transverse Direction
78	*174*	*118*	168	0.97	0.063-in. annealed sheet tested in the Longitudinal Direction
78	245	*233*	180	0.65	Sharp-Edge Notch. Cold-Rolled (67%) Sheet tested in the Longitudinal Direction

[1] The values shown in italics are reported elsewhere in this document. They are given here for comparison purposes.

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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Alloy X-750, AMS 5542
Yield Strength
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Temperature Deg F	Yield Strength (0.2% Offset) ksi	Comments
-423	139	0.063-in. annealed sheet tested in the Transverse Direction
-423	134	0.063-in. annealed sheet tested in the Longitudinal Direction
-320	130	0.063-in. annealed sheet tested in the Transverse Direction
-320	130	0.063-in. annealed sheet tested in the Longitudinal Direction
-100	--	0.063-in. annealed sheet tested in the Transverse Direction
-100	122	0.063-in. annealed sheet tested in the Longitudinal Direction
78	118	0.063-in. annealed sheet tested in the Transverse Direction
78	118	0.063-in. annealed sheet tested in the Longitudinal Direction
78	122.5	0.050-in. Cold-Rolled Annealed Sheet
78	116	Annealed sheet tested in the Longitudinal Direction
78	116	Annealed sheet tested in the Transverse Direction
78	124	Annealed sheet tested in the Longitudinal Direction
78	128	Annealed sheet tested in the Transverse Direction
78	115	0.062-in. annealed sheet tested in the Longitudinal Direction
78	116	0.062-in. annealed sheet tested in the Longitudinal Direction
78	116	0.062-in. annealed sheet tested in the Longitudinal Direction
78	116	0.062-in. annealed sheet tested in the Transverse Direction
78	114.5	0.062-in. annealed sheet tested in the Transverse Direction
78	122	0.062-in. annealed sheet tested in the Transverse Direction
78	116.6	0.062-in. annealed sheet tested in the "Average" Orientation
400	112	0.050-in. Cold-Rolled Annealed Sheet

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AS-RECEIVED INFORMATION

Alloy X-750, AMS 5542
Yield Strength
Page Revision 0.0
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Temperature	Yield Strength (0.2% Offset)	Comments
Deg F	ksi	
800	107	0.050-in. Cold-Rolled Annealed Sheet
1,000	112	0.050-in. Cold-Rolled Annealed Sheet
1,100	105.5	0.050-in. Cold-Rolled Annealed Sheet
1,200	105.5	0.050-in. Cold-Rolled Annealed Sheet
1,300	100	0.050-in. Cold-Rolled Annealed Sheet
1,500	76.4	0.050-in. Cold-Rolled Annealed Sheet

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5542
Yield Strength
(Notch Sensitivity)
Page Revision 0.0
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Temp	*Ultimate[1] Tensile Strength*	Yield Strength	*Sharp-Edge Notch[1] Ultimate Tensile Strength*	*Ratio, Notched/Unnotched Tensile Strength*	Comments
Deg F	*ksi*	ksi	*ksi*		
-423	*310*	266	*202*	*0.65*	Cold-Rolled (67%) Sheet tested in the Longitudinal Direction
78	*245*	233	*180*	*0.7*	Cold-Rolled (67%) Sheet tested in the Longitudinal Direction

[1] The values in italics are reported elsewhere in this document. They are repeated here for comparison.

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5542
Yield Strength
(Under Compression)
Page Revision 0.0
AMBK Update No. 0

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Temperature	Compressive Yield Strength (0.2% Offset)	Comments
Deg F	ksi	
78	121	Annealed sheet tested in the Longitudinal Direction
78	122.5	Annealed sheet tested in the Transverse Direction
78	127	Annealed sheet tested in the Longitudinal Direction
78	130	Annealed sheet tested in the Transverse Direction

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5542
Shear Strength
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Temperature	Shear Strength, ksi[1]		Comments
Deg F	Single Shear	Double Shear	
78	123.5	111	0.062-in. annealed sheet tested in the Longitudinal Direction
78		111.5	0.062-in. annealed sheet tested in the Longitudinal Direction
78	125	112.5	0.062-in. annealed sheet tested in the Longitudinal Direction
78		112	0.062-in. annealed sheet tested in the Longitudinal Direction
78	123	112.5	0.062-in. annealed sheet tested in the Transverse Direction
78		111.5	0.062-in. annealed sheet tested in the Transverse Direction
78	122.5	113	0.062-in. annealed sheet tested in the Transverse Direction
78		113	0.062-in. annealed sheet tested in the Transverse Direction
78	123.5	112.1	0.062-in. annealed sheet tested in the "Average" Orientation
78	118		0.25-in. Cold-Rolled Annealed Sheet. Shear Strength/Tensile Strength Ratio = 0.674.
-423	152.8		0.25-in. Cold-Rolled Annealed Sheet. Shear Strength/Tensile Strength Ratio = 0.603.

[1] Double-shear specimens were machined from shoulders of single-shear specimen after testing.

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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****AS-RECEIVED INFORMATION ****

Alloy X-750, AMS 5542
Total Elongation
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Temperature Deg F	Total Elongation %	Comments
-423	31	0.063-in. annealed sheet tested in the Transverse Direction
-423	30	0.063-in. annealed sheet tested in the Longitudinal Direction
-320	30	0.063-in. annealed sheet tested in the Transverse Direction
-320	31	0.063-in. annealed sheet tested in the Longitudinal Direction
-100	--	0.063-in. annealed sheet tested in the Transverse Direction
-100	30	0.063-in. annealed sheet tested in the Longitudinal Direction
78	25	0.063-in. annealed sheet tested in the Transverse Direction
78	25.5	0.063-in. annealed sheet tested in the Longitudinal Direction
78	27	0.050-in. Cold-Rolled Annealed Sheet
78	26.5	Annealed sheet tested in the Longitudinal Direction
78	28	Annealed sheet tested in the Transverse Direction
78	26	Annealed sheet tested in the Longitudinal Direction
78	26	Annealed sheet tested in the Transverse Direction
400	30	0.050-in. Cold-Rolled Annealed Sheet
800	33	0.050-in. Cold-Rolled Annealed Sheet
1,000	26	0.050-in. Cold-Rolled Annealed Sheet
1,100	10.5	0.050-in. Cold-Rolled Annealed Sheet
1,200	6	0.050-in. Cold-Rolled Annealed Sheet
1,300	3.5	0.050-in. Cold-Rolled Annealed Sheet
1,500	11	0.050-in. Cold-Rolled Annealed Sheet

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5542
Hardness
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Temperature Deg F	Hardness	Comments
78	36	0.062-in. annealed sheet tested in the Longitudinal Direction
78	36	0.062-in. annealed sheet tested in the Longitudinal Direction
78	36	0.062-in. annealed sheet tested in the Transverse Direction
78	35	0.062-in. annealed sheet tested in the Transverse Direction
78	36	0.062-in. annealed sheet tested in the "Average" Orientation

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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Alloy X-750, AMS 5542
Modulus of Elasticity
(Under Compression)
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Temperature Deg F	Compressive Modulus of Elasticity	Comments
78	29.7	Annealed sheet tested in the Longitudinal Direction
78	30.5	Annealed sheet tested in the Transverse Direction
78	30.4	Annealed sheet tested in the Longitudinal Direction
78	31	Annealed sheet tested in the Transverse Direction

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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Alloy X-750, AMS 5542
Stress Rupture Strength
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****AS-RECEIVED INFORMATION ****

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Temperature Deg F	Stress ksi	Rupture Life hours	Comments
1,200	70	21.5	0.031-in. Cold-Rolled, Annealed Sheet
1,200	70	17	0.031-in. Cold-Rolled, Annealed Sheet
1,350	40	42.8	0.031-in. Cold-Rolled, Annealed Sheet
1,350	40	49.5	0.031-in. Cold-Rolled, Annealed Sheet
1,500	20	40.4	0.031-in. Cold-Rolled, Annealed Sheet
1,500	20	43.9	0.031-in. Cold-Rolled, Annealed Sheet
1,200	70	72.3	0.093-in. Cold-Rolled, Annealed Sheet
1,200	70	98.9	0.093-in. Cold-Rolled, Annealed Sheet
1,350	40	130.4	0.093-in. Cold-Rolled, Annealed Sheet
1,350	40	116.8	0.093-in. Cold-Rolled, Annealed Sheet
1,500	20	63.7	0.093-in. Cold-Rolled, Annealed Sheet
1,500	20	77.6	0.093-in. Cold-Rolled, Annealed Sheet

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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****AS-RECEIVED INFORMATION *****

Alloy X-750, AMS 5542

Stress Rupture Strength (Larson-Miller Parameter)

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AMBK Update No. 0

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Stress ksi	Rupture Life Larsen-Miller Parameter[1]	Comments
70	31	Cold-Rolled, Annealed Sheet
69.3	31.5	Cold-Rolled, Annealed Sheet
68	32	Cold-Rolled, Annealed Sheet
66.4	32.5	Cold-Rolled, Annealed Sheet
64	33	Cold-Rolled, Annealed Sheet
59.3	33.5	Cold-Rolled, Annealed Sheet
54.2	34	Cold-Rolled, Annealed Sheet
49	34.5	Cold-Rolled, Annealed Sheet
43.7	35	Cold-Rolled, Annealed Sheet
39.4	35.5	Cold-Rolled, Annealed Sheet
34.7	36	Cold-Rolled, Annealed Sheet
30.9	36.5	Cold-Rolled, Annealed Sheet
27.2	37	Cold-Rolled, Annealed Sheet
24.1	37.5	Cold-Rolled, Annealed Sheet
21.7	38	Cold-Rolled, Annealed Sheet
18.4	38.5	Cold-Rolled, Annealed Sheet
16	39	Cold-Rolled, Annealed Sheet
13.4	39.5	Cold-Rolled, Annealed Sheet
10.8	40	Cold-Rolled, Annealed Sheet
9.1	40.5	Cold-Rolled, Annealed Sheet

[1] Larsen-Miller Parameter, $P = (460 + T)(17.5 + \log t) \times 10^{-3}$, where T = Test Temperature, Deg F, and t = time, hours.

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5542

Fatigue Strength (Krouse Tests)

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Stress	Fatigue Strength[1]	Comments
ksi	Cycles to Failure	
70.1	1.92E+05	Cold-Rolled, Annealed Sheet
60	3.86E+05	Cold-Rolled, Annealed Sheet
51.2	1.80E+06	Cold-Rolled, Annealed Sheet
41.1	2.48E+06	Cold-Rolled, Annealed Sheet
33.3	3.03E+06	Cold-Rolled, Annealed Sheet
34.8	3.89E+06	Cold-Rolled, Annealed Sheet
35.5	9.11E+06	Cold-Rolled, Annealed Sheet
25	2.28E+07	Cold-Rolled, Annealed Sheet
30.4	2.70E+07	Cold-Rolled, Annealed Sheet
24.9	3.29E+07	Cold-Rolled, Annealed Sheet

[1] Krouse tests, completely reversed bending.

Applicable Product Forms: Subsequent to the conditions stated in the Comments column, all materials were Precipitation-Treated 1300 F/20 h, A.C.

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5542

Fatigue Strength (Smooth & Notched)

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S_{mean}	Stress ksi	Fatigue Strength, Smooth[1] Cycles to Failure	Fatigue Strength, Notched[1] Cycles to Failure	Comments
0	30	2.53E+07		
0	35	9.54E+06	5.72E+06	
0	40	5.44E+06	3.42E+06	
0	45	3.33E+06	2.03E+06	
0	50	2.07E+06	1.22E+06	
0	55	1.38E+06	7.83E+05	
0	60	9.62E+05	5.24E+05	
0	65	6.86E+05	3.82E+05	
0	70	5.02E+05	2.62E+05	
0	75	3.72E+05	1.92E+05	
0	80	2.78E+05	1.50E+05	
0	85	2.08E+05	1.14E+05	
0	90	1.65E+05	9.24E+04	
0	95	1.37E+05	7.71E+04	
0	100	1.07E+05	6.35E+04	
0	105	8.98E+04	5.20E+04	
0	110	7.85E+04	4.52E+04	
0	115	6.88E+04	4.07E+04	
$0.5S_{max}$	50	7.20E+06		
$0.5S_{max}$	55	3.66E+06		
$0.5S_{max}$	60	2.45E+06	7.04E+06	
$0.5S_{max}$	65	1.84E+06	2.81E+06	
$0.5S_{max}$	70	1.46E+06	1.72E+06	
$0.5S_{max}$	75	1.13E+06	1.16E+06	
$0.5S_{max}$	80	8.76E+05	8.25E+05	
$0.5S_{max}$	85	6.58E+05	5.96E+05	

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**AS-RECEIVED INFORMATION **

Alloy X-750, AMS 5542

Fatigue Strength (Smooth & Notched)

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S_{mean}	Stress	Fatigue Strength, Smooth	Fatigue Strength, Notched	Comments
	ksi	Cycles to Failure	Cycles to Failure	
$0.5S_{max}$	90	5.14E+05	4.59E+05	
$0.5S_{max}$	95	4.33E+05	3.50E+05	
$0.5S_{max}$	100	3.42E+05	2.74E+05	
$0.5S_{max}$	105	2.78E+05	2.14E+05	
$0.5S_{max}$	110	2.31E+05	1.69E+05	
$0.5S_{max}$	115	1.90E+05	1.31E+05	
$0.5S_{max}$	120	1.59E+05	1.07E+05	

[1] All tests were performed at Room Temperature (300 K).

Applicable Product Forms: Cold-Rolled, Annealed Sheet Precipitation-Treated 1300 F/20 h, A.C., Transverse Specimens.

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****AS-RECEIVED INFORMATION *****

Alloy X-750, AMS 5698

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****AS-RECEIVED INFORMATION****

Alloy X-750, AMS 5698
Stress Relaxation
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The reference determined that the relaxation behavior could be adequately described by a creep law that was linear in neutron fluence and applied stress. The derived creep coefficient was 1.0×10^{-12} $(Pa{*}dpa)^{-1}$ for springs irradiated up to 4.2 dpa (3751 d) at an in-reactor temperature of 644 K (371 C, 700 F).

Applicable Product Forms: Springs. The tested springs were fabricated from 1.2 mm wire, had a free length of 5.1 cm, an id of 8.7 mm, an od of 1.1 cm, and had 16 total coils. After fabrication, the springs were heat treated at 1005 K (732 C, 1350 F) 16/h, A.C. They were then compressed and held for 1 h at 698 K (425 C, 800 F). The chemical composition was:

Nickel	73.32 %
Chromium	15.56 %
Iron	6.42 %
Titanium	2.17 %
Niobium	0.87 %
Aluminum	0.61 %

Manganese	0.58 %
Silicon	0.36 %
Cobalt	0.07%
Copper	0.05 %
Carbon	0.03 %
Sulfur	0.007 %

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Light Water (H_20)
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**AS-RECEIVED INFORMATION **

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Light Water (H_2O)
Latent Heat of Vaporization
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H_2O LATENT HEAT OF VAPORIZATION

$$LtnHt = (A + BT + CT^2 + DT^3)^{1/2} ,$$

where

A = 6254828.560,
B = -11742.337953,
C = 6.336845,
D = -0.049241,

T = temperature (°C),
$LtnHt$ (kJ/kg).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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**AS-RECEIVED INFORMATION **

Advanced Neutron Source

Light Water (H_2O)
Saturated Liquid
Specific Heat
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H_2O SATURATED LIQUID SPECIFIC HEAT

$$C_P = [(A + CT)/(1 + BT + DT^2)]^{1/2},$$

where

A = 17.48908904,
$B = -1.67507 \times 10^{-3}$,
C = -0.03189591,
$D = -2.8748 \times 10^{-6}$,

T = temperature (°C),
C_p (kJ/kg•K).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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Light Water (H_2O)
Saturated Liquid
Enthalpy
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H_2O SATURATED LIQUID ENTHALPY

$$LqEntl = (A + CT + ET^2) / (1 + BT + DT^2),$$

where

A = 0.786889159,
B = -0.001874457,
C = 4.163042560,
D = -3.334×10^{-7},
E = -0.007798602,

T = temperature (°C),
LqEntl (kJ/kg).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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Light Water (H_2O)
Saturated Vapor Enthalpy
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H_2O SATURATED VAPOR ENTHALPY

$$VapEntl = A + BT^{5/2} + CT^3 + DT^{1/2}[\ln(T)] ,$$

where

A = 2488.301071,
B = 6.2698272 × 10^{-4},
C = -3.953072 × 10^{-5},
D = 3.562872385,

T = temperature (°C),
VapEntl (kJ/kg).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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Light Water (H_2O)
Saturated Liquid
Thermal Conductivity
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H_2O SATURATED LIQUID THERMAL CONDUCTIVITY

$$Cond = (A + BT + CT^2 + DT^3)\ ,$$

where

$A = 0.5677829144$,
$B = 1.8774171 \times 10^{-3}$,
$C = -8.1790 \times 10^{-6}$,
$D = 5.66294775 \times 10^{-9}$,

T = temperature (°C),
Cond (W/m•K).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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Light Water (H_2O)
Saturated Liquid
Dynamic Viscosity
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H_2O SATURATED LIQUID DYNAMIC VISCOSITY

$$DynVisc = exp[(A + CT)/(1 + BT + DT^2)] ,$$

where

A = -6.325203964,
$B = 8.705317 \times 10^{-3}$,
C = -0.088832314,
$D = -9.657 \times 10^{-7}$,

T = temperature (°C),
DynVisc (Pa•s).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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Light Water (H_2O)
Surface Tension
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H_2O SURFACE TENSION

$$Sftens = AX^B(1 + CX) ,$$

where

X = (373.99 - T)/647.15,
A = 235.8×10^{-3},
B = 1.256,
C = -0.625,

T = temperature (°C),
Sftens (N/m).

The physical property correlations for saturated light water are applicable over a temperature range of 20–300°C. This temperature range corresponds to a pressure range of 0.0025–8.5 MPa.

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Light Water (H_2O)
Saturation Pressure
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H_2O SATURATION PRESSURE

$$P_{sat} = exp[(A + CT + ET^2) / (1 + BT + DT^2 + FT^3)] ,$$

where

A = -7.395489709,
$B = 4.884152 \times 10^{-3}$,
$C = 3.6337285 \times 10^{-2}$,
$D = 4.308960 \times 10^{-6}$,
$E = 2.651419 \times 10^{-5}$,
$F = -4.14934 \times 10^{-9}$,

T = temperature (°C),
P_{sat} (MPa).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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**AS-RECEIVED INFORMATION **

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Light Water (H_2O)
Saturated Vapor Density
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H_2O SATURATED VAPOR DENSITY

$$VapDen = (A + CT + ET^2 + GT^3)/(1 + BT + DT^2 + FT^3 + HT^4),$$

where

$A = -4.375094 \times 10^{-4}$,
$B = -6.947700 \times 10^{-3}$,
$C = 7.662589 \times 10^{-4}$,
$D = 2.418897 \times 10^{-5}$,
$E = -5.963920 \times 10^{-6}$,
$F = -4.227966 \times 10^{-8}$,
$G = 2.867976 \times 10^{-7}$,
$H = 2.594175 \times 10^{-11}$,

T = temperature (°C),
VapDen (kg/m^3).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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**AS-RECEIVED INFORMATION **

Light Water (H_2O)
Saturated Liquid Density
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H_2O SATURATED LIQUID DENSITY

$$LiqDen = (A + BT_F + CT_F^2),$$

where

$T_F = 1.8T + 32,$
$A = 1004.789042,$
$B = -0.046283,$
$C = -7.9738 \times 10^{-4},$

T = temperature (°C),
$LiqDen$ (kg/m^3).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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Light Water (H_2O)
Saturation Temperature
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H_2O SATURATION TEMPERATURE (as a function of pressure)

$$T_{sat} = (A + CX)/(1 + BX + DX^2) ,$$

where

$X = \ln(P)$,
$A = 179.9600321$,
$B = -0.1063030$,
$C = 24.2278298$,
$D = 2.951 \times 10^{-4}$,

P = absolute pressure (MPa),
T_{sat} (°C).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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H_2O SATURATION TEMPERATURE (as a function of saturated liquid enthalpy)

$$T_{sat} = A + Bh + Ch^{5/2} + Dh^3 ,$$

where

A = 0.0835777361,
B = 0.2377936769,
$C = 5.1932951 \times 10^{-7}$,
$D = -2.2208153 \times 10^{-8}$,

h = liquid enthalpy (kJ/kg),
T_{sat} (°C).

The physical property correlations for saturated light water are applicable over a temperature range of 20-300°C. This temperature range corresponds to a pressure range of 0.0025-8.5 MPa.

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Heavy Water (D_2O)
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Heavy Water (D_2O)
Latent Heat of Vaporization
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D_2O LATENT HEAT OF VAPORIZATION

$$LtnHt = (A + BX + CX^2)^{1/2} ,$$

where

X = 371.49 - T,
A = 508093.6669,
B = 17006.921765,
C = -11.009078,

T = temperature (°C),
LtnHt (kJ/kg).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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Heavy Water (D_2O)
Saturated Liquid
Specific Heat
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D_2O SATURATED LIQUID SPECIFIC HEAT

$$C_P = (A + BT_1 + CT_1^2 + DT_1^3),$$

where

$T_1 = (1.8T + 491.67) \times 10^{-4}$,
A = 2.237124,
B = 122.217151,
C = -2303.384060,
D = 13555.737878,

T = temperature (°C),
C_P (kJ/kg•K).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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D_2O SATURATED LIQUID ENTHALPY

$$LqEntl = A + BT^2 + CT / ln(T) ,$$

where

A = -81.40815291,
B = 0.00274496,
C = 21.13005836,

T = temperature (°C),
LiqEntl (kJ/kg).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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D_2O SATURATED VAPOR ENTHALPY

$$VapEntl = A + BT[ln(T)] + CT^3 \ ,$$

where

A = 2337.404845,
B = 0.335900,
C = -1.30643×10^{-5},

T = temperature (°C),
$VapEntl$ (kJ/kg).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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D_2O SATURATED LIQUID THERMAL CONDUCTIVITY

$$Cond = (A + BT_1 + CT_1^2 + DT_1^3),$$

where

$T_1 = (1.8T + 491.67) \times 10^{-4}$,
$A = -0.4521496$,
$B = 36.0743280$,
$C = -357.9973221$,
$D = 924.0219962$,

T = temperature (°C),
Cond (W/m•K).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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D_2O SATURATED LIQUID DYNAMIC VISCOSITY

$$DynVisc = (A + BT_F\ C/T_F + D/T_F^2)$$

where

$T_F = 1.8T + 32$,
$A = 1.111606 \times 10^{-4}$,
$B = 9.46 \times 10^{-8}$,
$C = 0.0873655375$,
$D = 0.4111103409$,

T = Temperature (°C),
DynVisc (Pa•s).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature range corresponds to a pressure range of 0.012-3.9 MPa.

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Heavy Water (D_2O)
Surface Tension
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D_2O SURFACE TENSION

$$Sftens = AX^B(1 + CX) ,$$

where

$X = (371.49 - T)/644.65,$
$A = 2.44835759 \times 10^{-1},$
$B = 1.269,$
$C = -6.60709649 \times 10^{-1},$

T = temperature (°C),
Sftens (N/m).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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Heavy Water (D_2O)
Saturation Pressure
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D_2O SATURATION PRESSURE

$$P_{sat} = exp(A + B/T_K + C \times ln(T_K) + DT_K) ,$$

where

T_K = T + 273.16,
A = 95.720020,
B = -8439.470752,
C = -13.496506,
D = 0.012010,

T = temperature (°C),
P_{sat} (MPa).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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D_2O SATURATED VAPOR DENSITY

$$VapDen = exp[(A + CT + ET^2)/(1 + BT + DT^2)] \quad ,$$

where

A = -5.456208705,
$B = 2.386228 \times 10^{-3}$,
C = 0.060526809,
$D = -1.15778 \times 10^{-5}$,
$E = -1.11360 \times 10^{-4}$,

T = temperature (°C),
VapDen (kg/m^3).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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Heavy Water (D_2O)
Saturated Liquid Density
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D_2O SATURATED LIQUID DENSITY

$$LiqDen = (A + BT_F + CT_F^2)\ ,$$

where

$T_F = 1.8T + 32,$
$A = 1117.772605,$
$B = -0.077855,$
$C = -8.42 \times 10^{-4},$

T = temperature (°C),
$LiqDen$ (kg/m^3).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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Heavy Water (D_2O)
Saturation Temperature
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D_2O SATURATION TEMPERATURE (as a function of pressure)

$$T_{sat} = exp(A + BX + CX^2 + DX^3) \ ,$$

where

$X = \ln(P)$,
$A = 5.194927982$,
$B = 0.236771673$,
$C = -2.615268 \times 10^{-3}$,
$D = 1.708386 \times 10^{-3}$,

P = absolute pressure (MPa),
T_{sat} (°C).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50-250 °C. This temperature ranges corresponds to a pressure range of 0.012-3.9 MPa.

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D_2O SATURATION TEMPERATURE (as a function of saturated liquid enthalpy)

$$T_{sat} = A + Bh[\ln(h)] + Ch^2[\ln(h)],$$

where

A = 11.34352515,
B = 0.03875871,
C = -5.733 × 10^{-6},

h = liquid enthalpy (kJ/kg),
T_{sat} (°C).

The physical property correlations for saturated heavy water are applicable over a temperature range of 50–250 °C. This temperature ranges corresponds to a pressure range of 0.012–3.9 MPa.

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PRESENTATION

The *ANS Materials Databook* (*AMBK*) is being provided as the initial hardcopy version of the collection of materials information known as the ANS Materials Information System (AMIS). The final hardcopy version, the *ANS Materials Handbook* (*AMHB*), will be a reviewed and approved version of the *AMBK*. The computer version is known as the ANS Materials Database (AMDB). Some format differences will of necessity exist between the hardcopies and the AMDB, but both versions will contain virtually the same information. The following discussion is written for the hardcopy versions (the *AMBK* and *AMHB*). A description specifically for the AMDB will be contained in a database users' guide provided to authorized users of the database. The general formats of the hardcopy and computer versions will be similar so that the user may switch back and forth between the two without confusion.

ORGANIZATION - VOLUMES 1 AND 2

Format

General Arrangement

Volumes 1 and 2 are organized by material type starting initially with elements and progressing as needed through alloys and other types of materials. The indexing is "open ended," allowing for the insertion of pages without the necessity of renumbering current pages. This arrangement also makes it possible to keep together pages that treat identical or related subjects. Tabbed dividers are provided to facilitate page location.

Table of Contents-Materials

This contents listing shows all materials currently covered in the *AMBK*. The list is located at the front of each volume, behind a green tab labeled CONTENTS.

Revision Control

A Revision Control page is located behind the green Revision Control tab in the front of each volume. The Revision Control page will be updated each time a package of new or revised pages is issued. It will provide a cumulative listing of the date of all new issues.

Table of Contents-Properties

A table listing all properties currently covered for each material is located behind the yellow tab at the beginning of each materials section.

Units

An international group of experts in database design has recommended the International System of Units (SI) for use by all electronically stored values and data.[1] To be consistent with this policy, the goal is to provide SI units in the AMIS. However, because of time considerations in the production of the "as-received" portion of the *AMBK*, the data in that portion are presented in the units supplied by the sources. Conversion between SI and U.S. customary or other units is left to the user. U.S. customary units are defined by the National Bureau of Standards (NBS Misc. Publ. MP233, December 20, 1960). ASTM Standard E-380, *Metric Practice Guide,* is used as the major reference for all considerations (symbols, style, usage, rules, etc.) in conversion and use of the SI system.

<u>Page Design</u>

Headers and Footers

Each page in the *AMBK* contains a uniform heading similar to that shown in Fig. A-1. Figure A-1 contains bracketed letters to indicate the use of the various boxes and lines as explained below. Supplementary information and notes will also be provided, when appropriate, at the bottom of each page.

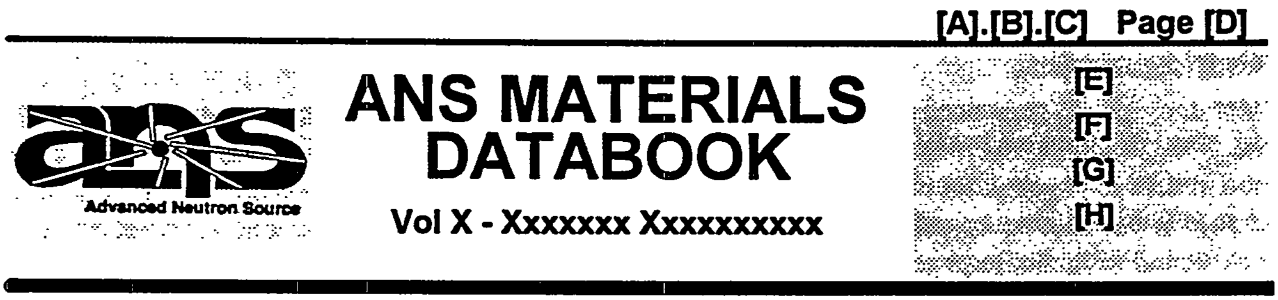

Fig. A-1 Illustration of Page Heading for *AMBK*.

Author:	Writing Group:
Applicable Product Forms:	
Notes:	

Fig. A-2 Illustration of Supplementary Information

[1] H. Krockel, K. Reynard, and J. Rumble, "Factual Materials Databanks, The Need for Standards," VAMAS Technical Working Area 10, Versailles Project on Advanced Materials and Standards, July 1987.

Page Body

The *AMBK* contains two main classes of information: (1) "as-received" information presented in the form in which it is received, and (2) "drafts" of an analyzed and summarized data presentations that will be submitted for peer review. See the Introduction of this databook for a discussion of "draft" and "as-received" information. The main differences in the page design of these two types of information is that the body of "as-received" information will generally be in the form of pages copied directly from the data sources, while the body of "draft" information will be more uniform and formal.

Collation Control Code

Each page in the Update Packages will contain a sequence number on the lower right-hand corner. This number will be used by the printers to assemble the pages of each package in the correct order.

Page Indexing

The indexing or arrangement of property pages in the body of the Handbook uses four indexing parameters in the following order: (A) Chemical Code, (B) Property Code, (C) Environment Code, and (D) Page Number. These codes are located at the top of each page. A, B, and C are separated by a decimal, with the Page Number on the right margin as shown in the example in Fig. A-1. The pages are arranged alphanumerically according to these four parameters, as explained in the following.

Chemical Code

Each material (to be spelled out in E of Fig. A-1) is cataloged by a five-character Chemical Code (A in Fig. A-1) consisting of three identifying parameters. The following explanation uses Type 316L Stainless Steel as an example.

Parts - Parts refer to the first and most general material chemical division, which is primarily by material type. Each Part is identified by a rose-colored tabbed divider. The Part Code is a letter and is the first character of the Chemical Code, for example:

Part B - Alloys

Groups - Groups designate the second material chemical division, which is by material "family," and is characterized by a common compositional trait. Each Group is identified by a blue-tabbed divider. The Group Code is a letter and is the second character of the Chemical Code, for example:

Part B - Alloys

Group F - Iron Alloys

Sections - Sections designate the last material chemical division, which is by specific material or alloy. Each Section is identified by a yellow-tabbed divider. The Section Code makes up the last three characters of the Chemical Code and may contain either letters or numbers. The first two characters identify the material by chemical composition. Numbers are used here to designate structural materials, whereas letters designate bonding materials, platings and coatings. The third character is used to differentiate manufacturing processes or minor chemical variations when they will have a significant impact on the reported data. This third character is always present, even when not used to identify a unique process or chemical variation. The character begins with the letter A and increments alphabetically. Continuing the example:

Part B - Alloys

Group F - Iron Alloys

Section 04B - 316L Stainless Steel

Thus the complete Chemical Code for 316 L Stainless Steel is: BF04B.

A complete list of the Chemical Codes for those materials currently proposed for the AMIS is given in Appendix B.

Property Code

The pages in each section are arranged according to the property (to be spelled out in F of Fig. A-1) described on each page. Each property is identified in numerical order by a four- or five-character Property Code Number (B in Fig. A-1). The first four characters are digits, and the fifth, when used, is a letter. Each property is then identified according to four parameters:

Property Type - This is the most general division of properties. The Property Code designation is by whole one-thousands, for example:

2000 - Mechanical Properties

3000 - Physical Properties

Property Sub-Type - The second property division divides each general property type into sub-types, and the Property Code designation is by whole one-hundreds, for example:

2000 - Baseline Mechanical Properties

2100 - Static, Short-Term Properties

2200 - Static, Long-Term Properties

Specific Property - The third and fourth digits of the Property Code identify the specific property, for example:

2101 - Ultimate Tensile Strength

2102 - Yield Strength

Property Form - The fifth digit, when used, designates differences such as presentation formats of the same property. For example, 3114A is used for *linear* thermal expansion, and 3114B for the *coefficient* of thermal expansion.

A complete tabulation of Property Codes and their definitions is given in Appendix C.

Environment Code

Each property description will represent values determined for a specific environment. Each environment is assigned a specific Environment Code (C in Fig. A-1)

A complete list of the Environment Codes used is given in Appendix D.

Page Numbering

The page numbering (D in Fig. A-1) of pages containing technical information runs consecutively from 1.1-1.X or 2.1-2.X, etc., for each Property Code. The integer portion of the page number designates differences such as average and minimum values, under the same Property Code. The page numbering of non technical pages such as Tables of Contents, Introduction, etc., generally uses integer numbers.

ORGANIZATION - VOLUME 3

Volume 3 is organized by process subject rather than by material. Individual materials are treated only in those sections for which such treatment is consistent and appropriate to the specific process being described. Standardized page headings are used, and the information is generally provided in narrative form. The actual format is unspecified because of the difficulty in establishing firm guidelines for such a wide variety of topics. Emphasis is placed on brevity, with factual, to-the-point statements.

ORGANIZATION - VOLUME 4

A plain format is used for Volume 4, with no sectioning of the references by volume or subject matter. Thus the References section consists of a simple listing of the references cited in Volumes 1 to 3 in the *chronological* order in which they are added to the first three volumes. The Bibliography section has no correlation with other sections of the databook or handbook, thus stands alone with respect to the numbering of entries. The appendices are separated into sections in accordance with the subject matter and are separated by green tabs.

UPDATING - ALL VOLUMES

Page Revision Number

Specific pages will be revised regularly as new information is developed. Each revision will be documented, and will be labeled with a unique number or code. This code, the Page Revision Number (G in Fig. A-1), is a two-part decimal number in the form A.B referring to the version of the reported information. The integer part of the number (A) will begin at zero (0) with the first issue of each page, and will be incremented only in cases where actual value/data or information changes have occurred (that is, not for typographical corrections). The decimal part of the number (B) indicates only typographical corrections or editorial changes. It will begin at zero and be incremented only in cases where typographical corrections or editorial changes are involved. It will be reset to zero each time the integer part (A) is incremented, i.e., each time there is an actual change in the reported information.

The following list shows how the materials to be covered in the ANS Materials Information System are placed in the various designations (Part, Group, and Section) of the Chemical Code. The user may notice that there appear to be gaps in the chemical codes listed below. This is because the codes of this relatively limited number of materials are adapted from a much larger basic indexing system used by several different material property handbook and database projects covering a wide range of materials. It was found there are definite cost and accuracy benefits in using the Chemical Code notations from one "standard" system rather than developing a new list of codes for each project. See Appendix A of Volume 4 - Supporting Documentation, for a complete explanation of the Chemical Code indexing system.

Part-Group-Section Designations	Chemical Code	Manufacturing/ Process Code
Part A - Elements	Axxx	
Group A - Metals	AAxx	
Group B - Metalloids	ABxx	
Group C - Non-Metals	ACxx	
Part B - Alloys	Bxxx	
Group A - Beryllium Alloys	BAxx	
Group B - Aluminum Alloys	BBxx	
Generic (All Aluminum Alloys)	BB00	
Generic 6061	BB01	
6061-T6	BB01A	T6
6061-T0	BB01B	T0
6061-T651	BB01C	T651
6061-T6 Weldments	BB01D	T6/WL
2024	BB02A	
6063-T6	BB03A	T6
Group F - Iron Alloys	BFxx	
304 Stainless Steel	BF01A	
304L Stainless Steel	BF01B	

Part-Group-Section Designations	Chemical Code	Manufacturing/ Process Code
304LN Stainless Steel	BF01C	
304H Stainless Steel	BF01D	
304N Stainless Steel	BF01E	
302 Stainless Steel	BF02A	
316 Stainless Steel	BF04A	
316L Stainless Steel	BF04B	
316LN Stainless Steel	BF04C	
20% Cold-Worked 316SS	BF04D	CW20
321 Stainless Steel	BF05A	
A-286 Steel	BF06A	
17-4 PH Stainless Steel	BF07A	
410 Stainless Steel	BF08A	
Nitronic 60 Stainless Steel	BF10A	
Group I - Nickel Alloys	BIxx	
Alloy 600	BI01	
Alloy 625	BI02	
Alloy 718	BI03	
Generic Alloy X-750	BI04	
Alloy X-750, ANS 5667	BI0	
Alloy X-750, AMS 5542	BI04E	
Group J - Zirconium Alloys	BJxx	
Zircaloy	BJ01	

ANS MATERIALS DATABOOK

Advanced Neutron Source

Vol 2 - Material Property Analyses

HANDBOOK FORMAT

Chemical Codes

Page Revision 0.0

AMBK Update No. 0

Part-Group-Section Designations	Chemical Code	Manufacturing/ Process Code
Part G - Other Materials	Gxxx	
Group M - Hydrogen Compounds	GMxx	
Light Water (H_2O)	GM01A	
Heavy Water (D_2O)	GM01B	

The following pages describe the properties that may be addressed. Property Codes are organized as follows:

1xxx - General Information

2xxx - Mechanical Properties

3xxx - Physical Properties

4xxx - Chemical/Nuclear Properties

5xxx - Friction/Wear/Self-Welding Behavior

Special Note on Fracture Mechanics and Probabilistic Parameters: The fracture mechanics parameters for all conditions of loading are treated in separate sections under the 2600 and 2700 series of Property Codes, respectively.

General Note: These property codes are taken from a "unified" set of property codes that is continually being compiled and added to. This unified set is used in several different material property collections for different purposes, such as advanced diesel engines, nuclear reactors, isotopic power, and optical systems. It may therefore seem to reflect an emphasis on specific areas that are of no interest to some users. For instance, properties such as Burst Pressure or Transient Burst Strength that refer to nuclear reactor piping may have no relevance in optical materials applications. Rather than prepare a separate listing for each application, it was decided to retain one central list for the use of all. An important factor in this decision was the current emphasis on electronic database networks and the need to promote continuity and consistency among individual databases.

1000 GENERAL INFORMATION - Information/data/characteristics that apply to all forms of the material and are not a function of other parameters. Special notes may also be added here.

1100 **Chemical Composition/Stoichiometry/Crystal Structure** - These items are listed as needed, with primary emphasis on compositional ranges.

1200 **Product Forms/Applicable Specifications** - A list of product forms of interest and the applicable specifications (ASTM, ASME, RDT, others).

1300 **Minimum Specified Properties** - The room temperature minimum properties as specified by the applicable specifications per product form (if minimum properties vary with product form).

1400 **Design Stress Intensity Value, S_m,** - The Design Stress Intensity Value from the ASME Boiler and Pressure Vessel Code (BPVC). The criteria used to determine S_m are defined in Appendix 2 of Section II, "Materials, Part D - Properties," of the BPVC. These criteria make use of a *detailed analysis of the three principal stresses,* whereas the Maximum Allowable Stress Value, S (Property Code 1500) is based on the use of *standard configurations*. Calculated values of S_m for various materials are given in Tables 2A, 2B, and 4 of Section II, "Materials, Part D - Properties," of the BPVC.

1500 **Maximum Allowable Stress Value, S** - The Maximum Allowable Stress Value at temperature from the ASME BPVC. It may be considered to be the maximum stress quantity permitted in a given material used in a constructed part. It is a material and application-specific maximum stress that is considered to be safe for the part in service; it is determined by applying specified reducing factors to a critical stress value (e.g. specified minimum tensile or yield stresses). The criteria used are defined in Appendix 1 of Section II, "Materials, Part D - Properties," of the ASME BPVC. These criteria are based on the use of *standard configurations*, whereas the Design Stress Intensity Value, S_m (Property Code 1400) is based more on a *detailed analysis of stresses*. Calculated values of S for various materials are given in Tables 1A, 1B, and 3 of Section II, "Materials, Part D - Properties," of the BPVC.

1600 Tensile Strength Values, S_u - Tensile strength values from the ASME Boiler and Pressure Vessel Code and Code Cases.

1700 Yield Strength Values, S_y - Yield Strength Values from the ASME Boiler and Pressure Vessel Code and Code Cases.

2000 MECHANICAL PROPERTIES - Properties describing the behavior of materials of specific geometries under the influence of mechanical loading.

2100 **Static, Short-Term Properties** - Properties that do not exhibit a time dependence under non-impact conditions. All properties listed as 21xx are obtained from uniaxial, monotonic loading. For Fracture Mechanics Parameters, see under Property Code 2600.

2101 Ultimate Tensile Strength - The maximum tensile stress which a material is capable of sustaining. Tensile strength is calculated from the maximum load during a tension test carried to rupture and the original cross-sectional area of the specimen. (Ref. ASTM E-6)

2102 Yield Strength - The stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain. Expressed as 0.2% offset yield strength unless stated otherwise. (Ref. ASTM E-6)

2103 Proportional Elastic Limit - The greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). (Ref. ASTM E-6)

2104 Shear Strength - The maximum shear stress which a material is capable of sustaining. Shear strength is calculated from the maximum load during a shear or torsion test and is based on the original dimensions of the cross section of the specimen. (Ref. ASTM E-6)

2105A Total Elongation - The increase in the gage length per unit length of the undeformed gage length, measured after fracture of the specimen within the gage length. (Ref. ASTM E-6)

2105B Uniform elongation - The maximum increase in gage length that occurs before necking of the specimen begins. (Ref. ASTM E-6)

2106 Reduction of Area - The difference between the original cross-sectional area of a tension test specimen and the area of its smallest cross section (measured at or after fracture) divided by the original cross-sectional area of the specimen. (Ref. ASTM E-6)

2107 True Stress-Strain - A curve or expression of true stress versus true strain. True strain is the natural logarithm of the ratio of the deformed length to the undeformed gage length. True stress is the applied force per unit of the deformed cross-sectional area at the moment of the force measurement.

2108 Engineering Stress-Strain - A curve or expression of engineering stress versus engineering strain. Engineering strain is the change per unit length of a linear dimension referred to the undeformed gage length. Engineering stress is the applied force per unit area of the undeformed cross section.

2109 Hardness - The resistance of a material to deformation, particularly permanent deformation, indentation, or scratching. There is no absolute scale for hardness; therefore, to express hardness quantitatively, each type of test has its own scale of arbitrarily defined hardness. See also the definition of indentation hardness in ASTM E-6.

2110 Poisson's Ratio - The ratio of transverse contraction of a strained specimen to its longitudinal elongation. (See also ASTM E-6.)

2111 Young's Modulus (Modulus of Elasticity) - The ratio of stress to corresponding strain below the proportional limit. This value is obtained in tension or compression tests, or from ultrasonic velocity measurements. (Ref. ASTM E-6)

2112 Shear Modulus (Modulus of Rigidity) - The ratio of stress to corresponding strain below the proportional limit. This value is obtained in shear or torsion tests. (Ref. ASTM E-6)

2113 Tangent Modulus - The slope of the engineering stress-strain curve at any specified stress or strain. (Ref. ASTM E-6)

2114 Bulk Modulus - Ratio of stress to change in volume of a material subjected to axial loading. Related to Young's modulus (E) and Poisson's ratio (ν) by the following equation:

$$K = \frac{E\nu}{3(1-2\nu)}$$

2115 Rupture Modulus - Nominal elastically calculated maximum stress at fracture in a bend test or torsion test. In bending, it is the bending moment at fracture divided by the section modulus. In torsion, it is the torque at fracture divided by the polar section modulus. See ASTM E-6 for further notes on modulus of rupture in bending and modulus of rupture in torsion.

2116 Compressive Strength - The maximum compressive stress which a material is capable of sustaining. It is calculated from the maximum load during a compression test and the undeformed cross-sectional area of the specimen. (Ref. ASTM E-6)

2117 Bending Strength - Also called flexural strength. Maximum fiber stress developed in a specimen just before it cracks or breaks in a flexure test.

2118 Fracture Stress - True stress generated in a material at fracture.

2119 Vicat Softening Point - A test of the heat softening characteristics of a material. (Ref. ASTM D1525)

2120 Taber Abrasion - Resistance of a material to abrasion. (Ref. ASTM D1044)

2121 Elastic Stiffness - A measure of the dimensional change of a material along crystallographic planes, generally a change in length.

2122 Isothermal Compressibility - Reciprocal of Bulk Modulus.

2123 Spall Strength - The stress necessary to cause the material surface to spall or splinter, resulting in material fracture or ejection.

2124 Secant Morulus - The slope of a line extending from the origin to a specified point on the stress-strain curve.

2200 **Static, Long-Term Properties** - Properties that exhibit a time dependence effect under nonimpact conditions. For Fracture Mechanics Parameters, see under Property Code 2600.

2201 Effects of Prior Creep on Tensile Ductility - Total elongation measured in a tensile test on materials subjected to some specified amount of prior creep service.

2202 Stress-Rupture Strength - The stress that will cause fracture in a creep test in a specified time and environment. (Ref. ASTM E-6)

2203 Burst Pressure (Biaxial) - The pressure at which a tube material bursts or allows gas leakage when subjected to internal pressurization.

2204 Uniform D/D (Biaxial) - The net increase in tube diameter per unit length of the undeformed diameter under burst pressure testing, measured away from the failure area (far enough so that effects of rupture are not included).

2205 Time to Tertiary Creep - For a given stress and environment, the time measured from the initiation of the loading to the onset of the departure from secondary creep. Methods used to determine the onset of departure must be defined with the relationship since there are no universally accepted methods at this time.

2206 Creep - Strain occurring under a given constant stress expressed as a function of time and environment. This Property Code generally includes a creep equation depicting the strain - time temperature - stress relationship; however, expressions for minimum creep rate may also be included.

2207 Stress Relaxation - The time-dependent decrease in stress in a constrained specimen at a constant temperature. (Ref. ASTM E-6)

2208A Strain at Fracture, Elongation - The strain at failure for constant load temperature conditions, expressed percent elongation.

2208B Strain at Fracture, Reduction of Area - The strain at failure for constant load temperature conditions, expressed as reduction of area.

2209 Isochronous Stress-Strain Curve - A curve of applied stress versus total strain for fixed times, e.g., the locus of total strains accumulated when different constant stresses are applied for a fixed time. These curves may be generated through use of the stress-strain relationship (2108) and the creep equation (2206) or by other graphical means.

2300 **Dynamic, Short-Term Properties** - Properties characteristic of high rate loading conditions. For Fracture Mechanics Parameters, see under Property Code 2600.

2301 Strain Rate Effects - The effects of controlled strain rate, in loading, on the stress-strain characteristics. Strain rate effects may be depicted for a number of tensile properties within this single Property Code number.

2302 Impact Strength - Energy required to fracture a specimen subjected to shock loading, as in an impact test. It is an indication of the toughness of the material and is reported as energy absorbed or lateral expansion versus test temperature.

2303 Ductile-to-Brittle Transition Temperature - The temperature, determined in a series of impact tests at decreasing temperatures, at which metals undergo a transition from ductile to brittle behavior.

2304 Thermal Shock Resistance - The ability of a material to withstand high stresses resulting from the development of a steep temperature gradient in the material. Conditions under which the property is measured must be specified.

2305 Coefficient of Restitution - A coefficient that expresses the degree to which a pair of colliding bodies approach perfect elasticity. It is the negative ratio of the relative velocity after collision to the relative velocity before collision.

2306 Toughness for Tensile Instability - The area under an engineering stress-strain curve out to the departure from uniform elongation, from a uniaxial tensile test.

2307 Transient Burst Strength - The strength exhibited by a tubular product subjected to rapid application of internal pressure.

2308 Transient Burst Ductility - The relative increase in tube diameter during rapid burst pressure testing, measured away from the failure area (far enough away so that effects of rupture are not included).

2400 **Cyclic Loading Properties** - Properties that describe the behavior of materials subjected to a repeating sequence of loading values. For Fracture Mechanics Parameters, see under Property Code 2600.

2401-2410 Strain-Controlled Fatigue Properties - Descriptions of the behavior of material cycled between defined levels and duration of deformation or strain. Property Codes and definitions are provided as needed.

2401 Strain-Controlled Fatigue - Expressions of cycles to failure as a function of axial strain range. Cycles to failure may be the total cycles to specimen separation, N_f; or cycles at which the load carrying capacity drops 5%, N_5; or the point of initiation of a crack of given length, N_0. Strain range may be expressed as total or plastic strain.

2411-2420 Stress-Controlled Fatigue Properties - Descriptions of the behavior of material cycled between defined levels and duration of load or stress. Property Codes and definitions are provided as needed.

2411 Stress-Controlled Fatigue - Expressions of cycles to failure as a function of axial stress. This property is analogous to Strain-Controlled Fatigue and is typically used to report high cycle fatigue (HCF), where elastic strains predominate.

2421-2430 Cyclic Stress-Strain Properties - Mechanical properties associated with representing the stress-strain response of the material as it is cycled between fixed strain limits. The independent variables include the strain range, temperature, and material. The properties data are those required to implement inelastic analysis guidelines. The properties and their physical interpretation differ for various materials. These differences result from characteristic trends of cyclic hardening and softening and are identified within recommended inelastic analysis equations or specific materials. Property Codes and definitions are provided as needed.

2421 Cyclic Yield Strengths - Discrete monotonic and cyclic yield strengths s_0, s_1, s_2 versus strain range from bilinear representations.

2422 Cyclic Yield Parameters - Discrete monotonic and cyclic yield parameters k_0, k_1, k_2 versus strain range from bilinear cyclic stress-strain curves.

2423 Plastic Modulus and Slope Parameter - Plastic modulus E_p and slope parameter C versus strain range from bilinear stress-strain representations.

2424 Cyclic Stress-Strain Curves - Plots of and equations for nonlinear cyclic stress-strain curves.

2431-2440 Creep-Fatigue - Materials behavior under combined creep and fatigue loading conditions, involving complex interactions among stress, time, temperature, and environment. Property Codes and definitions are provided as needed. For Fracture Mechanics Parameters, see under Property Code 2600.

2441-2450 Fatigue Design Curves - ASME Code design curves describing design limits based on the fatigue properties of materials.

2441 Allowable Amplitude of Alternating Stress Intensity -

2500 **Viscoelastic Properties** - Properties of elastic materials having time-dependent viscous effects. The following Property Codes are limited to plastics or polymers.

2501 Flexural Strength - The loading (bending) at failure of a stressed beam, or stress at 5% strain. (Ref. ASTM D790)

2502 Flexural Modulus - "Stiffness in Flexure," a measure of the relative stiffness. (Ref. ASTM D747)

2503 Breaking Elongation - Elongation at fracture in tensile loading. (Ref. ASTM D638)

2504 Deformation Under Load - Ability of a material to withstand continuous short-term compression without yielding and loosening at temperature. (Ref. ASTM D621)

2505 Axial Fatigue Endurance Limit - Relative endurance of a material to withstand a repetitive axial bending stress. (Ref. ASTM E466-76)

2506 Flexural Fatigue Endurance Limit - Ability of a material to withstand a repetitive cantilever-type bending stress. (Ref. ASM D671-71)

2507 Flexural Strain - The maximum strain occurring in the outer fibers at the failure of a material subjected to beam-type flexural stress. (Ref. ASTM D790-71)

2508 Viscoelastic Creep - Strain occurring under a given constant stress expressed as a function of time and environment, limited to polymeric materials that exhibit viscoelastic properties. (Ref. ASTM D2990-77)

2509 Static Modulus (Elastomer) - The tensile stress of an elastomeric material required to produce a specified ultimate elongation (often specified as 100 or 200% modulus). (Ref. ASTM D412-75)

2510 Deflection Temperature - Temperature at which a polymeric material exceeds a specified deflection when a specified beam loading stress is applied. (Ref. ASTM D648-72)

2511 Heat Aging - Deterioration of an elastomeric material when exposed to a specified time and temperature in an air oven. (Ref. ASTM D573-67)

2512 Compression Set - The failure of an elastomeric material to recover original thickness after sustained compressive stress. (Ref. ASTM D395-69)

2600 **Fracture Mechanics Properties** - Fracture Mechanics has been defined as "an engineering discipline that quantifies the conditions under which a load-bearing body can fail due to the enlargement of a dominant crack contained in that body." The discipline of fracture mechanics embodies some parameters, such as the critical value of the crack extension force, that are generally considered as material properties. Such parameters are provided as an aid to designers and safety analysts. Caution should be urged, however, in the application of the reported fracture mechanics parameters since the "property" can be strongly affected by the analysis method used to measure it, especially under nonlinear and dynamic conditions.

These parameters, which consider material noncontinuity and nonhomogeneity, provide a quantitative method for estimating the development and extension of macroscopic cracks. Significant parameters include (1) a toughness (energy-absorption) factor, (2) applied stress, (3) size of crack, (4) operating temperature, (5) crack growth rate data incorporating the "state of stress," and (6) hold time.

2601-2620 Linear Elastic Fracture Mechanics Parameters

2601 Plane-strain Static Fracture Toughness (K_{Ic}) -The crack-extension resistance under conditions of crack-tip linear-elastic plane-strain, slow (static) rates of loading, negligible plastic-zone adjustment, and maximum constraint (relatively thick material); the critical value of the stress intensity factor (K) under these conditions; the value of K at which crack propagation becomes rapid under these conditions. (ASTM E616-89)

2602 Plane-strain Intermediate Fracture Toughness (K_{Ic})t)] - The crack-extension resistance under conditions of crack-tip linear-elastic plane-strain, rapid (intermediate between slow and impact) rates of loading and negligible plastic-zone adjustment, and maximum constraint (relatively thick material); the critical value of the stress intensity factor (K) under these conditions; the value of K at which crack propagation becomes rapid under these conditions. (ASTM E616-89)

2603 Plane-strain Dynamic Fracture Toughness (K_{Id}) - The crack-extension resistance under conditions of crack-tip linear-elastic plane-strain, dynamic (impact) rates of loading, negligible plastic-zone adjustment, and maximum constraint (relatively thick material); the critical value of the stress intensity factor (K) under these conditions; the value of K at which crack propagation becomes rapid under these conditions. (ASTM E399)

2604 Plane-strain Crack-arrest Fracture Toughness, (K_{Ia}) - The value of crack-arrest fracture toughness; the crack-extension resistance under conditions of crack-tip linear-elastic plane-strain, dynamic (essentially, since the crack is *propogating* during the test) rates of loading of a crack-line-wedge-loaded compact-type specimen, negligible plastic-zone adjustment, and maximum constraint (relatively thick material); the critical value of the stress intensity factor (K) at crack arrest under these conditions; the value of K at which crack propagation becomes arrested under these conditions. (ASTM E616-89)

2605 Elastic Stress Intensity Factor converted from Plastic Stress Intensity Factor (K_J) - The elastic stress-intensity factor as calculated from the plastic stress-intensity factor using the relationship $J = K^2/E$, where J = Plastic Stress Intensity Factor, K = Elastic Stress Intensity Factor, and E = Young's Modulus.

2606 Plane-stress Static Fracture Toughness (K_c) - The crack-extension resistance under conditions of crack-tip linear-elastic plane-stress, slow (static) rates of loading, negligible plastic-zone adjustment, and minimum constraint (relatively thin and/or brittle material); the critical value of the stress intensity factor (K) under these conditions; the value of K at which crack propagation becomes rapid under these conditions. (ASTM E616-89)

2607 Plane-stress Intermediate Fracture Toughness[$K_c(t)$] - The crack-extension resistance under conditions of crack-tip linear-elastic plane-stress, rapid (intermediate between slow and impact) rates of loading and negligible plastic-zone adjustment, and minimum constraint (relatively thin and/or brittle material); the critical value of the stress intensity factor (K) under these conditions; the value of K at which crack propagation becomes rapid under these conditions.

2608 Plane-stress Dynamic Fracture Toughness (K_d) - The crack-extension resistance under conditions of crack-tip linear-elastic plane-stress, dynamic (impact) rates of loading, negligible plastic-zone adjustment, and minimum constraint (relatively thin and/or brittle material); the critical value of the stress intensity factor (K) under these conditions; the value of K at which crack propagation becomes rapid under these conditions.

2609 Plane-stress Crack-arrest Fracture Toughness, (K_a) - The value of crack-arrest fracture toughness; the crack-extension resistance under conditions of crack-tip linear-elastic plane-stress, dynamic (essentially, since the crack is *propogating* during the test) rates of loading of a crack-line-wedge-loaded compact-type specimen, negligible plastic-zone adjustment, and minimum constraint (relatively thin and/or brittle material); the critical value of the stress intensity factor (K) at crack arrest under these conditions; the value of K at which crack propagation becomes arrested under these conditions.

2610 Fatigue Crack Growth Rate, da/dN, [L] - The rate of crack extension caused by constant-amplitude fatigue loading, expressed in terms of crack extension versus stress intensity range. (ASTM E616)

2611 Critical Crack Size - The crack size that will cause fracture for a given combination of stress, material fracture toughness, and structural geometry.

2621-2640 Elastic-Plastic Fracture Mechanics Parameters

2621 J-integral (J) - In relatively ductile or plastic material, a mathematical expression characterizing the fracture toughness. A line or surface integral that encloses the crack front from one crack surface to the other.

2622 Plane-strain Fracture Toughness (J_{Ic}) - The crack-extension resistance under conditions of crack-tip linear-elastic plane-strain, slow (static) rates of loading, appreciable plastic-zone effects, and maximum constraint (relatively thick material); the critical value of the stress intensity factor (K) under these conditions; the value of K at which crack propagation becomes rapid under these conditions; in relatively ductile or plastic material, the value of the J-integral (J) required to propagate a crack.. (ASTM E616-89)

2623 Tearing Modulus (T) - In applications allowing small amounts of crack growth in ductile materials, the Tearing Modulus is an estimation of the additional load carrying capacity over that associated with crack initiation.

2641-2660 Time-Dependent Fracture Mechanics Parameters

2641 C*-integral (C*) - The path-independent energy rate line integral that determines the strength of the crack-tip fields in material undergoing steady-state creep. Analogous to J-integral.

2642 Creep Crack Growth Rate, da/dt - The rate of crack extension caused by a constant creep load, expressed in terms of crack extension versus an appropriate parameter.

2700 **Probabilistic Parameters**[1] - Statistical material parameters estimated as functions of temperature, specimen loading, specimen geometry, and type of defect. These parameters are used to predict the reliability of brittle materials in specific component geometries and loadings. The probabilistic approach is based in the "weakest link theory," which is based on the premise that the reliability of a chain is the product of the survival probabilities of each link. This approach is commonly used to describe the strength characteristics of monolithic ceramic components containing volume or surface flaws and loaded in uniaxial tension. For failure induced by volume flaws, the strength characteristics are expressed in terms of a probability function whose basic form is:

$$P_{sV} = \exp-\left[\int_V N_V(\sigma)dV\right], \text{ where}$$

P_{sV} = the **probability of survival,**

P_{fV} = $1-P_{sV}$, the probability of failure,

V = the **component volume** (the subscript V indicates volume-dependent terms),

$N_V(\sigma)$ = the **crack density function** (the number of flaws per unit volume that have a strength equal to or less than the value of σ, and

$\int_V N_V(\sigma)dV$ = **risk-of-rupture value**

For failure induced by surface flaws, the above expressions are given in terms of component surface area, and the term V is replaced by S.

The variations of the basic probability of survival function use a two or three parameter power function for the crack density function. The parameters are considered to be material properties, and are temperature and process dependent. The following Property Codes and definitions describe the parameters associated with currently used variations and enhancements to the above basic form.

The probability of survival (or failure) of a fully characterized component material is commonly represented in a plot of the probability vs fracture stress.

1 S. J. Schneider, Jr., "Ceramics and Glasses," *Engineered Materials Handbook*, Vol 4, ASM International, December 1991, p 700-708.

2701-2720 Weibull Material Parameters - Statistical material functions advanced by Waloddi Weibull, with application to components that fail due to internal or surface flaws.[2,3] For application to failure from surface flaws, the term V in these expressions is replaced by S.

2701 Weibull Probability of Survival - The form of this function is the same as the basic form described under Property Code 2700:

$$P_{sV} = \exp-\left[\int_V N_V(\sigma)dV\right]$$

This function is often expressed as the Probability of Failure:

$$P_{fV} = 1 - P_{sV}$$

The Weibull variations on the parameters are described in the following Property Codes.

2702 Weibull Crack Density Function - $N_V(\sigma)$, Weibull's power function for the crack density function. The basic three-parameter function is represented as:

$$N_V(\sigma) = \left(\frac{\sigma-\sigma_{uV}}{\sigma_{oV}}\right)^{mV}.$$

For ceramics, the term σ_{uV} is usually equated to zero (see Property Code 2704), and the equation becomes a two-parameter function:

$$N_V(\sigma) = \left(\frac{\sigma}{\sigma_{oV}}\right)^{mV}.$$

The parameters and their various forms are described in the following Property Codes.

2703 Weibull Principal Stress - σ, the stress (or stresses, in multi-axial configurations) applied to the component.

2704 Weibull Threshold Stress - σ_{uV} in Property Code 2702. Also known as the **Location Parameter,** it is the value of applied stress below which the failure probability is zero. *It is usually set to zero for ceramics, yielding a two-parameter Crack Density Function.*

2705 Weibull Characteristic Strength - σ_{oV} in Property Code 2702. Also known as the Scale Parameter, it corresponds to the stress level at which a specific fraction of a population of unit-volume (or unit-area) specimens would fail. In

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2 W. Weibull, "A Statistical Distribution Function of Wide Applicability," *J. Appl. Mech.*, Vol 18, 3 1951, p 293-297.

3 W. Weibull, "A Statistical Theory for the Strength of Materials," *Ing. Vetenskaps Akad. Handlinger*, No. 151, 1939.

the two-parameter Weibull function, this fraction is 0.6321. The dimensions of the scale parameter are stress(volume)$^{1/mV}$.

2706 Weibull Modulus - m_V, also known as the Weibull **Shape Parameter** or **Weibull Slope**. It is a measure of the degree of strength dispersion (strength variability).

2707 Weibull Uniaxial Crack Density Coefficient - k_{wV}, the reciprocal of $\sigma_{oV}^{m_V}$ in Property Code 2702.

2708 Weibull Extreme Fiber Stress - σ_f, also called the **Modulus of Rupture (MOR)**. In the Flexural Test Failure Probability version of the Weibull Probability of Survival function (Property Code 2701), this term replaces the Weibull Principal Stress, σ, in Property Code 2702. Thus, the modified Weibull Probability of Survival becomes the **Flexural Test Failure Probability**:

$$P_f = 1 - \exp\left[-\left(\frac{\sigma_f}{\sigma_\theta}\right)^m\right].$$

See Property Code 2709 for a definition of the term σ_θ.

2709 Weibull Characteristic Strength - σ_θ, defined as the uniform stress or extreme fiber stress at which the probability of failure of a component is 0.6321. It is a special variation of σ_{oV}, the Threshold Stress, in property Code 2702. It is used in the Flexural Test Failure Probability version of Property Code 2701 (see Property Code 2707). It is also known as the **Characteristic Modulus of Rupture, MOR$_\theta$**.

2721-2740 Batdorf Material Parameters - Statistical material parameters advanced by S. B. Batdorf.[4,5] Batdorf's approach couples linear elastic fracture mechanics with the Weibull weakest link theory[1].

3000 PHYSICAL PROPERTIES - Properties describing the physical nature of materials.

3100 **Thermal Properties** - Properties defined in terms of temperature or heat quantities.

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[4] S. B. Batdorf and J. G. Crose, "A Statistical Theory for the Fracture of Brittle Structures Subjected to Nonuniform Polyaxial Stresses," *J. Appl. Mech.*, Vol 41, June 1974, p 459-464.

[5] S. B. Batdorf and H. L. Heinisch, Jr., "Weakest Link Theory Reformulated for Arbitrary Fracture Criterion," *J. Am. Cer. Soc.*, Vol 61, 1978, p 355-358.

3101 Maximum Service Temperature - The maximum temperature at which a material will perform its intended function for a specified period of time. (Failure criteria must be described in every case.)

3102 Healing Temperature - The temperature at which a specified property or condition will revert to its original value or state. (Special tests and/or definitions may be required for some materials.)

3103 Melting Point - The temperature at which melting begins, described as the solidus and/or liquidus temperature.

3104 Heat of Fusion - The quantity of heat absorbed or liberated in the change from solid to liquid or liquid to solid.

3105 Boiling Point - The temperature at which a liquid boils.

3106 Heat of Vaporization - The quantity of heat absorbed or liberated in the change from liquid to vapor or vapor to liquid.

3107 Flammability - The susceptibility of a material to burn, as determined by any specified test. (Primarily devoted to plastics.)

3108 Specific Heat Capacity - The amount of heat per unit mass necessary to produce a unit increase in temperature.

3109 Enthalpy - The sum of the internal energy and the product of the specific volume and the pressure. The Critical Energy is the Enthalpy at a specific point of the phase change process, such as incipient melt, complete melt, threshold vaporization, or complete vaporization.

3110 Thermal Diffusivity - The thermal conductivity divided by the product of density and heat capacity.

3111 Heat of Sublimation - The quantity of head absorbed or liberated when a material changes directly from solid to vapor or vapor to solid.

3112 Thermal Conductivity - The calculation of transfer of heat by conduction, through unit thickness, across unit area for unit difference in temperature.

3113 Prandtl Number - A dimensionless number related to the ratio of momentum diffusivity divided by thermal diffusivity. The Prandtl number is the product of specific heat and viscosity divided by thermal conductivity.

3114A Linear Thermal Expansion - The average change in length with change in temperature.

3114B Instantaneous Coefficient of Thermal Expansion - The instantaneous change in length with change in temperature.

3114C Mean Coefficient of Thermal Expansion - The mean Coefficient of thermal expansion in going from a base temperature (usually Room Tempertaure) to a higher temperature.

3115 Entropy - A quantity depending on the quantity of heat in a body and on its temperature, which, when multiplied by any lower temperature, gives the unavailable energy or unavoidable waste when mechanical work is derived from the heat energy of the body.

3116 Free Energy of Formation - The change in free energy when a compound at standard conditions is formed from the elements of the same standard condition.

3117 Heat of Formation - The heat of reaction when a compound at standard conditions is formed from the element at the same standard conditions.

3118 Free Energy Function - The quotient resulting from the division of the difference in the free energy (F) and enthalpy (H) by the absolute temperature (T) at standard conditions: (F - H)/T.

3119 Heat of Sublimation - The net heat change when a material is transformed from a solid to a vapor without forming a liquid phase.

3120 Thermal Stability - The observed or measured effect of exposure to elevated temperature.

3121 Gruneisen - A thermodynamic parameter defined by: $(3\alpha B)/(\rho Cp)$, where α = Coefficient of Thermal Expansion, B = Bulk Modulus , ρ = Density, and Cp = Specific Heat.

3122 Debye Temperature - A characteristic temperature computed from values of Cv determined at the lowest available test temperature.[6] The equation used to determine the Debye Temperature is based on classical thermodynamic considerations, and varies with the type of material under consideration.1,2 An approximation generally used for non-metal elements or compounds is:

$C_V = 464.5(T^3/\Theta^3)$ cal/(g mole-K), and for metals is

$C_V = 464.5(T^3/\Theta^3) + bT$, where

Θ = Debye Temperature, Kelvins,
T = Temperature at C_v approximation, Kelvins,

[6] E. F. Obert, "Concepts of Thermodynamics," McGraw-Hill, 1960, p 56, 388.

C_v = Heat Capacity at constant volume, and

b = a constant representing free electron contributions of conductivity, unique to the material (e.g., b for copper is 0.0001777 cal/(g mole-K^3).

3200 **Electrical/Magnetic Properties** - Properties defined in terms of electrical or magnetic quantities.

3201 Electrical Resistivity - The reciprocal of the conductivity of a material. The conductivity of a material is the electric current density per unit potential gradient in an isothermal system.

3202 Dielectric Strength - The maximum electric intensity which a dielectric material can withstand without breakdown.

3203 Dielectric Coefficient - A number that describes the ability of a dielectric material to neutralize the electrical charge across parallel conducting plates.

3204 Dissipation Factor - The tangent of the loss angle or the cotangent of the phase angle. (Ref. ASTM D150)

3205 Magnetic Permeability - A magnetic constant used to determine the flux density within a material.

3206 Arc Resistance - The resistance to the formation of a conducting path through a material, as determined by a specific test method. (Ref. ASTM D495)

3207 Seebeck Potential - The electrical potential resulting from dissimilar metal junctions at different temperatures.

3300 **Optical Properties** - Properties describing the interactions of electromagnetic radiation with materials.

In the broad sense, the optics of materials encompasses all the phenomena involving interactions of electromagnetic radiation with materials.[7] Traditionally, three major processes of interaction have been considered possible:[8] absorption, reflection, and transmission. For any one sample, the sum of the ratios of the incident to the exiting radiation of each of these processes is unity. Interactions such as the photoelectric effect, the emission of X-rays, magneto-optical phenomena, etc., which involve

[7] A. V. Sokolov, Optical Properties of Metals, American Elseiver Publishing Company, Inc., New York, 1967.

[8] W. G. Driscoll and W. Vaughan, Handbook of Optics, Optical Society of America, 1978.

energy-matter transformation or the effect of externally induced magnetic, electrical, or other energy fields are divided into their own categories in the following listing.

The description of the interaction of electromagnetic radiation with material can be divided into two sometimes overlapping "schools" of related terminology. One, used by the solid state physics community, is devoted to the description of microscopic interactions. The other, used by the optics community, is most useful in the computation of the optical properties of devices.

A material may affect both the velocity and intensity of electromagnetic radiation passing through it.[9] In the classical physical sense, these effects may be completely described by two spectral parameters.[10] These parameters may be of the real and imaginary parts of the complex dielectric function, E, or of the complex electrical conductivity, s, or of the complex refractive index, N. E and s are most useful in the microscopic interpretation of optical properties and are the terms of choice in the solid state physics community. N is useful for the computation of the optical properties of devices and is commonly used in the optics community. These functions are interrelated as follows:

$$Ee0 = (e_1 + ie_2)e0 \quad s = s_1 + is_2 \quad N = n - ik$$

$$s = we_0(E - 1) \qquad N = SQR(E)$$

$$e_1 = n^2 - k^2 \qquad 2n^2 = +e_1 + SQR(e_1{}^2 + e_2{}^2)$$

$$e_2 = 2nk \qquad 2k^2 = -e_1 + SQR(e_1{}^2 + e_2{}^2)$$

The real part, n, of the complex refractive index is defined as the ratio of the velocity of electromagnetic radiation in a vacuum to its velocity in the material. The imaginary part of the refractive index, k, is the "absorption coefficient," "extinction coefficient," or "damping coefficient."

3301-3310 Absorptance Properties - Properties describing the absorption characteristics of a material.

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9 B. H. Billings, ed., "Optics - Fundamental Definitions, Standards, and Photometric Units," Chapter 6a in American Institute of Physics Handbook, ed. D. E. Gray, McGraw-Hill, 1972.

10 "Optical Materials, Part 2: Properties," in CRC Handbook of Laser Science and Technology, Vol. IV, ed. M. J. Weber, CRC Press, 1986.

3301 Absorptance, *a* - The ratio of the absorbed radiant flux to the incident radiant flux. (Ref. ASTM E903)

3311-3310 Reflectance Properties - Properties describing the reflecting characteristics of a material.

3311 Total Reflectance, T_s - The ratio of the reflected (luminous) flux, in all directions including specular and diffuse, to that similarly reflected from an ideal, perfectly reflecting, isotropically diffusing surface. (Ref. ASTM E429)

3312 Diffuse Reflectance, D_s - The ratio of the reflected (luminous) flux, in all directions except the specular direction, to that similarly reflected from an ideal, perfectly reflecting, isotropically diffusing surface. (Ref. ASTM E429)

3313 Diffuse Reflectance Ratio, DRR - The ratio of diffuse reflectance to total reflectance, multiplied by 100 to provide a scale upon which the diffuse reflectance ratio of an ideal, perfectly reflecting, isotropically diffusing surface is 100. (Ref. ASTM E429)

3314 Specular Reflectance, Ss - The difference between the total and diffuse reflectances, Ts - Ds. (Ref. AST M E429)

3315 Specular Reflectance Ratio, SRR - The ratio of specular reflectance to total reflectance, multiplied by 100. (Ref. ASTM E429)

3321-3330 Transmittance Properties - Properties describing the transmission characteristics of a material.

3321 Transmittance, t - The ratio of the transmitted radiant flux to the incident radiant flux. (Ref. ASTM E903)

3322 Index of Refraction, n - The ratio of the velocity of light in a vacuum to the velocity of light of a particular wavelength in any substance. It is the real component of the complex index of refraction N=n-ik.

3323 Absorption Coefficient, k - In metal, a parameter measuring the damping of light waves as a result of the skin effect, and the attendant reflection of a large fraction of the incident energy back into the external medium. It is the imaginary component of the complex index of refraction N=n-ik.

3331-3340 Photoelectric Properties - The characteristics of the ejection of electrons from the surface of a material by incident electromagnetic radiation.

3341-3350 Photogalvanic Properties - The characteristics of the production of an e.m.f. in a closed circuit (without an external source of current) of a material as a result of incident electromagnetic radiation.

3351-3360 Thermal Radiative Properties - The characteristics of electromagnetic radiation emission resulting from thermal activity of an object.

3351 Thermal Emissivity - A quantity lying between zero and unity, depending on the nature of the material surface. It is the ratio of the radiating power of a nonblack body to that of a black body. The quantity is used to calculate the rate of emission of radiant energy.

3400 Other Physical Properties

3401 Viscosity - A number which indicates the resistance of a fluid to flow.

3402 Surface Tension - Two fluids in contact exhibit phenomena due to molecular attractions that appear to rise from a tension in surface of separation.

3403 Vapor Pressure (Saturation Pressure) - The pressure at which a liquid and its vapor can exist in equilibrium at a given temperature.

3404 Density - Mass per unit volume.

3405 Porosity - The amount of pores contained in a material, connected and unconnected.

3406 Speed of Sound - The magnitude of the velocity of sound transmission in a material.

3407 Isothermal Compressibility - The fractional increase in volume per unit increase in pressure at constant temperature:

$$B_t = -\frac{1}{v}\frac{dv}{dp\tau}$$

3408 Water Vapor Permeability - The rate of transfer of water vapor through a barrier material. (Ref. ASTM E398)

3409 Water Absorption - The rate of absorption of water by material when immersed. (Ref. ASTM D570)

3410 Gas Permeability - The steady-state rate of transmission of a gas through a material in the form of film, sheeting, and laminates. (Ref. ASTM 01434)

3411 Permeability - The steady-state rate of transmission of a liquid or gas through a material.

3412 Critical Constant - The temperature above which a substance cannot exist in two phases, no matter how great the pressure.

3413 Critical Temperature - The temperature above which a gas cannot be liquified by pressure alone.

3414 Critical Pressure - The pressure under which a substance may exist as a gas in equilibrium with the liquid at the critical temperature.

4000 CHEMICAL/NUCLEAR/ATOMIC PROPERTIES - Properties that describe the chemical or nuclear behavior of materials, including the effect of impurities.

4100 Compatibility (Surface Reactions) - A description of the surface effect of materials that undergo reactions with the following (list types of effects--roughness, protective film, etc.):

4101 Reactions with Liquid Na, NaK, or Caustic.

4102 Reactions with Gases.

4103 Reaction with Aqueous Media.

4104 Reactions with Organics.

4105 Reactions with Fuel and Fission or Transmutation Products.

4106 Reactions with Plasma.

4107 Reactions with Other Substances.

4200 Metallurgical and Other Material Properties

4201 Time-Temperature Transformations - Transformation diagrams that describe the microstructural changes of a material in terms of Time and Temperature.

4202 Diffusion Characteristics - Description of the diffusion process in a material or system under specified conditions, including chemical gradients, temperature gradients, microstructure of base material, and system impurities.

4203 Recrystallization Temperature - The approximate minimum temperature at which complete recrystallization of a cold-worked metal occurs within a specified time.

4204 Grain Growth - A description of the change in size of grains in polycrystalline metal, usually occurring during heating at elevated temperatures.

4205 Glass Transition Temperature - Temperature or temperature range for the change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one. (Ref. ASTM D747-64)

4206 Oxygen Redistribution - The redistribution of oxygen or oxygen vacancies in metal oxide compounds.

4207 Grain Size - A measure of the areas or volumes of crystalline grains in a polycrystalline material.

4300 **Nuclear Properties**

4301 Cross Section - The average number of individual processes occurring per target nucleus per incident neutron.

4302 Burnup - The proportion of the total fuel material that is consumed during reactor operation.

4303 Energy/Event - Total energy released per fission or fusion which ultimately appears as heat in a defined reactor system.

4304 Attenuation - An expression describing the decrease in the rate, amount, or energy of a substance as it penetrates another.

4305 Gas Generation - A description of the gases created within a substance during irradiation.

4306 Other

4400 **Atomic Properties**

4401 Atomic Number - The characteristic number of protons in the nucleus of a neutral atom of an element. The common symbol for atomic number is "Z."

4402 Atomic Weight - The average relative weight of an element compared to carbon, which is taken to have an atomic weight of 12.

5000 **TRIBOLOGICAL BEHAVIOR - The friction and wear behavior of a material considering key parameters such as materials involved (like or different materials in contact), pressure of contact, surface roughness, substrate properties for coatings, and impurities in coolants, in the following situations:**

5100 **Liquid Metal Service**

5101 Endurance Life

5102 Load-Carrying Capacity

5103 Coefficient of Friction

5104 Wear Life vs Load

5105 High-Temperature Performance

5106 Low-Temperature Performance

5200 **Inert Gas Service**

5201 Endurance Life

5202 Load-Carrying Capacity
5203 Coefficient of Friction
5204 Wear Life vs Load
5205 High-Temperature Performance
5206 Low-Temperature Performance

5300 **Air Service**
5301 Endurance Life
5302 Load-Carrying Capacity
5303 Coefficient of Friction
5304 Wear Life vs Load
5305 High-Temperature Performance
5306 Low-Temperature Performance

5400 **Other Media**
5401 Endurance Life
5402 Load-Carrying Capacity
5403 Coefficient of Friction
5404 Wear Life vs Load
5405 High-Temperature Performance
5406 Low-Temperature Performance

Advanced Neutron Source

ANS MATERIALS DATABOOK

Vol 4 - Supporting Documentation

HANDBOOK FORMAT
Environment Codes
Page Revision 0.0
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The environment in which a material is exposed to prior to or during tested can have a dramatic effect on the test results. The AMIS provides, along with the Chemical Code and Property Code, an Environment Code to specify the test or pretest environments that impact the material's properties. The codes and their meanings are as follows:

Environment	Environment Code
Vacuum	E0
Air	E1
Neutron Irradiation	E2
Argon	E3
Nitrogen	E4

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