REPORT 2275

MATERIALS PROPERTIES DATA BOOK. 3 ap

REVISION OF ~~15 JULY 1970~~ *delete*

VOLUME 1. 2 ap.

INTRODUCTION AND LIGHT METALS

30 AUGUST 1970

CONTRACT SNP-1

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A DIVISION OF AEROJET - GENERAL

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FOREWORD

This Data Book was prepared in partial fulfillment of Contract SNP-1 of the Space Nuclear Propulsion Office, a joint office of the National Aeronautics and Space Administration and the Atomic Energy Commission, with the Aerojet Nuclear Systems Company. Guidance of the work was the responsibility of the Cleveland Extension of SNPO.

Sheets based either wholly or in part on technical contributions by the Westinghouse Astro-nuclear Laboratory are identified by WANL's insignia.

Contributions of data from persons or organizations are solicited, and if included in the Data Book, proper acknowledgment will be made. Communications relevant to such contributions or for related matters should be addressed to the Manager, Materials and Processes Section, Aerojet Nuclear Systems Company, Sacramento, California, under whose supervision the work is being accomplished.

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AUTHORIZATION FOR USE

This Materials Properties Data Book has been previously established, and continues in effect, as the basic design criterion for materials usage within the NERVA Program, subject to interpretation or extrapolation by the Aerojet Nuclear Systems Company, Materials and Processes Section.

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INTRODUCTION

A. GENERAL

The purpose of this Materials Properties Data Book is to provide the standard reference for materials properties for use by all groups involved with the analysis, design, fabrication, or test responsibilities of the NERVA Project.

Beginning with sheets included in the revision of 30 June 1968, data approved as final design criteria will be identified in green at the top and bottom of sheets with the legend: "Approved for Use in NERVA Final Design." Those sheets not so approved will bear a legend in red: "NRO and SNPO Concurrence Required for Use in NERVA Final Design;" or white sheets, which are not marked with either legend, are from earlier editions, and will require the same concurrence.

The Data Book includes physical, mechanical, and chemical properties of interest for many materials of significance to the NERVA Program and in addition, data on the effects of irradiation on materials. Information is also provided concerning material processing, as for example, heat treatment procedures, with special emphasis on specifications. Where the heat treatment or product form is not stated on the curve sheet, this information was not available in the references used. Material suppliers are given.

Radiation effects data are provided for both metallic and non-metallic materials. Since radiation is cumulative, degraded properties such as elongation must be considered in design for the determination of ductile or brittle material classification. However, in cases where a property such as yield strength is enhanced, the higher value must not be used to increase the design allowable. Test data from irradiation of materials are shown as 80% of average. Radiation effects data for both tensile strengths and elongation are given for polymers since, unlike metals, both properties are degraded by irradiation. Caution should be exercised in application of these values.

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1. ORGANIZATION

The Data Book has been organized for the most effective use of the data by the design engineer. Each of the ten sections, identified by a Roman numeral as listed, concerns a particular material or a group of closely related materials:

Volume I	{	I	Light Metal Alloys (Aluminum, Titanium, etc.)
		II	Nickel-Base Alloys
Volume I-A	{	III	Refractory Metals and Alloys
		IV	Other Non-Ferrous Metals and Alloys (Cobalt, Copper, etc.)
Volume 2	{	V	Ferrous Alloys
		VI	Nuclear Materials (Fuels, Neutron Controls, Beryllium, etc.)
		VII	Graphites
Volume 3	{	VIII	Refractory Ceramics
		IX	Adhesives
		X	Plastics

These major sections are further divided into sub-sections for groups of similar materials; for example, Section I is composed of Sub-Sections A (aluminum alloys) and B (titanium alloys). These sub-sections are again subdivided into the individual materials or alloys, identified by Arabic numbers. The Table of Contents gives a complete listing of sub-sections, with the materials contained in each grouping.

The section for each individual material contains descriptive Basic Data Sheets, with pertinent data relative to properties, characteristics, and other related information, together with curve sheets for graphic presentation of the parameters.

The data for a specific property are presented as functions of temperature on a single page. Since it was desired that the data for different materials should be readily comparable, the scale ranges were standardized as much as possible. This standardization was carried out, not only within single alloy systems, but where feasible, to groupings of materials as well.

The page number within each section is determined by the property presented on that page, as listed on Page 5.

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The full page identification is established by combining, in this order, the Roman numeral for the Material Section, a capital letter for the sub-section identification, and an Arabic numeral for the individual material (see listing in Table of Contents), all arrayed over an Arabic numeral for the page number. As an illustration, I-B-10/3 identifies the Light Metals group, sub-section Titanium, individual material Ti-5Al-2.5Sn, and the properties of Ultimate and Tensile Yield Strengths. When additional sheets are required, a letter is added to the Arabic numeral; for example, the reference sheet could be supplemented by sheets I-B-10/3A, 3B, etc.

Parameters to be included in the Data Book are tabulated below, identified by the pages on which they may be found in each section. Certain of these parameters are normally printed in blue, in contrast to the usual black, while red is occasionally used to relieve congestion.

Correlation of Page Numbers, Parameters, and Color of Printing

Parameter	Page	Parameter	Page
Basic Data	1, 2	Stress vs. Strain	
Adhesive Shear Strength	3	Ordinate Scale A	8
Ultimate Tensile Strength (Design Values)	3	Ordinate Scale B	8*
Tensile Yield Strength (Design Values)	3*	Impact Strength	9
Notched Tensile Strength	3*	Rockwell Hardness	9*
Compressive Yield Strength	4*	Reduction of Area (Design Values)	10
Ultimate Shear Strength	4	Elongation (Design Values)	10*
Shear Yield Strength	4*	Modulus of Elasticity	11
Flexural Strength (Design Values)**	4*	Modulus of Rigidity	11*
Ultimate Bearing Strength	4	Thermal Expansion	12
Bearing Yield Strength	4*	Thermal Conductivity	13
Peel Strength	4*	Specific Heat	13*
Fatigue Strength		Diffusivity	14
as Function of Cycles to Failure	5	Emissivity (or Emittance)	14*
as Function of Temperature	5	Poisson's Ratio	15
Stress to Rupture and Creep (Creep in blue)		Density	15*
as Function of Temperature	6	Electrical Resistivity	16
as Function of Time	7	Dielectric Strength	16-A
		Leak Rate	17

*Blue overlay. All other printing normally black, except that red is used to simplify congested displays of data.

**Graphites only.

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2. DATA PRESENTATION

a. Adjustment of Data

To provide more usable design information, adjustments have been made, as required, for pertinent data.

Data for some of the materials were consolidated by the use of a $\pm 10\%$ rule, where considered desirable for clarity. Curves for different conditions of the same material which were found to be within $\pm 10\%$ of each other were, in some cases, averaged into a single curve, with an applicable note designating the conditions represented. In this manner the number of curves was reduced in the interest of greater ease in using the data. This rule was also applied to the room temperature ends of curves which extended only above or below that temperature; that is, a curve from one data source running from cryogenic to room temperature, if the differences were minor, would be joined to a curve from another data source running from room temperature to elevated temperature.

In addition, room temperature specification minima were incorporated by constructing curves using average data and then proportioning the curves to the specification minimum.

b. Identification of Primary Strength Properties

In accordance with MIL-HNDBK-5A, certain primary strength properties have been identified as A or S basis:

- A Basis - The value above which at least 99% of the population of values is expected to fall, with a confidence of 95%.
- S Basis - The specified minimum value of the governing Military Specification or SAE Aerospace Material Specification for this material; the statistical assurance associated with this value not being known.

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c. Categories of Primary Strength Properties

Technical Directive 69-28, SNPO-C to NRO, June 4, 1969, established the following minimum Criteria for Materials Properties Data Book and Materials Tests when data are to be used for design:

1. Mean values for each level of a primary variable (a main effect in the test plan) must be determined from at least 8 values.
2. Estimate of the random variance for the measurement of interest must be determined from at least 15 degrees of freedom.
3. If more than one estimate of the random variance is available, these can and should be combined if these variance estimates are not significantly different at an α level of 0.10.
4. Tests for significant differences between mean values will be at α level of 0.05.
5. The Data Release Memoranda and Materials Data Book shall identify all test variables which are used to establish each set of statistical data presented.

The intent of TD 69-28 is to establish data of such statistical accuracy that there is a 95% confidence that 99% of the population will exceed it. Properties will therefore be categorized as "A", "B", "C", or "D" Data, in accordance with these interpretations of TD 69-28:

<u>Category</u>	<u>Degree of Statistics</u>	<u>Source</u>	<u>Form or Condition</u>	<u>Test Environment</u>
A	TD 69-28 Required Min. Population of 15 Degrees of Freedom (99-95)	NERVA-Tested Specimens	As Used in NERVA	As Used in NERVA
B	Intent of TD 69-28 Adjusted to an Effective Population of 15 (99-95)	Literature, Handbook, or Other Tests	Adjusted from Available Information, if Necessary	As Used in NERVA
C	Conservative Engineering Estimate of Statistical Allowable	Any Competent Source	Adjusted from Available Information, If Necessary	As Used in NERVA
D	None	Conservative Engineering Judgment	Adjusted from Available Data	Adjusted from Available Data

Categories "A" and "B" Data will be considered as approved for final design criteria, and will be identified by green strips at top and bottom of sheets in accordance with paragraph 2, page 3 of this Introduction; Categories "C" and "D" Data will normally not be published. Where statistical properties are not required or available, data will be presented without category classification, and identified with red strips, also in accordance with page 3.

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d. Design Properties

Minimum allowable values are being generated for the following, and will be published when available:

Tensile ultimate strength	Fatigue
Tensile yield strength (0.2% offset)	Goodman diagrams
Reduction of area	Creep
Elongation	Stress-rupture

The fracture toughness parameter K_{Ic}

All other mechanical properties will be presented as averages. The materials allowables are obtained by the following methods:

For Design (Identified by blue call-out blocks on the curve sheet, and by values printed in blue on the basic data sheets). Statistically established data in accordance with paragraph 2, c, page 7, attaining the desired 99% probability and 95% confidence. For method see paragraph 2, e, on page 9.

For Information (Identified by black callout blocks on the curve sheet)

1. Specification minima, "S" basis per MIL-HNDBK-5A, taken from government or AMS specification.
2. 80% of average data for metals; 70% of average for graphites. Data presented on this basis are considered temporary pending replacement by statistically established limits.

Physical properties used in design are to be shown as average, maximum, and minimum values. Where necessary, statistical properties data will be developed for design purposes.

Normally, design values have been calculated on the basis of 1/2 hour exposure to the temperature shown. Other temperature exposures are so listed on the sheets.

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e. Statistical Analysis of Material Test Data

Test for Homogeneity of Data. Box's modification of the Bartlett's test is used to test for homogeneity of data. The test is first applied to all test data of a single alloy including data taken from all heats, test temperatures, and directions at the 90% confidence level. As the test continues to reject the hypothesis that the data are homogeneous, the variables responsible are eliminated; first, test temperature, and then test direction. In general, if the data taken at all test temperatures are not homogeneous, then all test temperatures are treated separately to produce a smooth curve of test variables versus temperature.

One-Way Analysis of Variance. A one-way analysis of variance is applied to data which includes the heat-to-heat variation and within-heat variation at the 95% confidence level. If the heat-to-heat variation is significant, an effective $N(N_e)$ is computed using the Satterthwaite approximation. N is the sample size, and N_e is the reduced sample size due to uncertainty in the estimate of heat-to-heat variation.

Computation of Design Allowables. Minimum design allowables (F_{ty} or F_{tu}) are computed using the formula

$$F_{tu} \text{ or } F_{ty} = \bar{X} - k S,$$

where: $\bar{X}$ is the grand mean, k is the one-sided tolerance factor obtained by using $N-1$ or N_e , whichever is appropriate, and S is the pooled standard deviation.

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f. Symbology

Properties symbols used in the Data Book were chosen to be consistent with those used in MIL-HNDBK-5-A.

Curves of property values are graphically presented by the use of coded lines to identify the nature of the data presented.

For example, design minima are normally shown by solid black lines for ultimate tensile strength and reduction of area, and by solid blue lines for tensile yield strength and elongation. The entire line code is shown by the table following, as amplified by the notes on page 11.

LINE CODES

ITEM NO.	APPLICATION	TAPE SAMPLE
1	Design Values for Properties F_{TU} , F_{TY} , e , and RA all graphite properties except for Items 6 and 7	—————
2	Average Values for Properties F_{TU} , F_{TY} , e , and RA	///////
3	Annealed or Hot-Worked Metals	///////
4	Cold-Worked Metals	———
5	Unknown Condition and/or Form	———
6	Estimated, Interpolated, or Extrapolated Data	
7	Notched Tensile Strength (all forms and conditions)	———

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NOTES APPLICABLE TO LINE CODES

- Item 1 For design values for ultimate tensile strength, tensile yield strength, reduction of area, and percentage elongation. Ultimate tensile strength and reduction of area will be in black; tensile yield strength and percentage elongation will be in blue. In addition, this code will be used for all graphite values, except where the use of items 6 or 7 is desirable.
- Item 2 For average values of properties (F_{TU} , F_{TY} , RA, and e) other than design values. Applied to all forms and treatments for metals and non-metals, where known. The form and treatment are given in the note box.
- Item 3 For annealed or hot-worked metals. This includes such conditions as solution-treated, recrystallized, hot rolled, forged, cast, etc. This line code does not apply to the design properties, but does include all others. Values used are averages.
- Item 4 For non-design properties of materials strengthened by cold working. Property values used are averages. The design values are described in Item 1 above.
- Item 5 For average values of a property which is influenced by condition and/or form, when these are unknown.
- Item 6 Estimated, interpolated, or extrapolated data. See explanatory information in note box.
- Item 7 Required for notched tensile strength since this property is plotted on the same page as design properties.

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3. BEARING PROPERTIES

F_{BRU} is the maximum stress withstood by a bearing specimen, and F_{BRY} is the stress at an offset of 2.0% of the hole diameter of a bearing stress-deformation curve.

The bearing stress is obtained by dividing the load on a pin bearing against the edge of a hole (of diameter "D") by the bearing area, where the area is the product of the pin diameter and the sheet thickness ("t"). "e" is the edge distance measured from the hole center to the edge of the material in the direction of applied stress.

Tabular values are for $e/D = 2.0$, unless otherwise stated.

Bearing values are applicable for D/t ratios from 1 to 5.5; for greater ratios they must be substantiated by test.

4. MODULUS OF ELASTICITY

Both static and dynamic moduli of elasticity were used when available.

The static modulus of elasticity is obtained by taking the ratio of the stress to the strain at some point in the elastic range of the stress-strain curve for a material.

The dynamic modulus of elasticity is obtained by vibrating a specimen of the material at its resonant frequency with strain amplitudes of the order of 10^{-5} in./in. The elastic modulus is calculated from the density, geometry, and the resonant frequency. Generally, the dynamic modulus is slightly greater than the static modulus because of the low strain magnitude of the dynamic test. Dynamic modulus is considered to be more appropriate for vibration environments than the static modulus.

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5. THERMAL EMISSIVITY AND EMITTANCE

As used in this publication, the differences between the terms "Emittance" and "Emissivity" are important. These terms may be defined as:

Emittance (ϵ) Ratio of rate of radiant emission (the ability to send out radiant energy) from a body, because of temperature, to that of a blackbody at the same temperature.

Emissivity (ϵ') As in emittance, but for an opaque homogeneous material with an optically smooth surface composed of the same material. Then, emissivity of an opaque material is the lower limiting value approached by its emittance as its surface is made more smooth, to an optimum of optical smoothness.

These variations of emittance are utilized at times in data presented herein:

Hemispherical Emittance (ϵ_h) Ratio of radiance from a body, because of temperature, to that of a blackbody at the same temperature.

Normal Emittance (ϵ_n) Ratio of steradianance from a body, because of temperature, to that of a blackbody at the same temperature, in the direction normal to the surface.

Total Emittance (ϵ_t) Ratio of total radiance from a body, because of temperature, to that of a blackbody at the same temperature.

In addition, these items are defined for better understanding of the above:

Radiance (R) Rate of radiant-energy emission from a unit area of a source in all radial directions of the over-spreading hemisphere.

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Steradian (B) Rate of radiant energy emission per unit solid angle, and per unit of projected area of a source in a stated angular direction from the surface (usually normal).

For additional information, see DMIC Report 177, November 1962 (Ref 62-87), and WADC Report 56-222, October 1966 (Ref. 56-11). Also see NASA SP-31, 1963, and NASA SP-55, March 1964.

6. GOODMAN DIAGRAMS

Where available data permitted, modified Goodman diagrams were developed and added to the Basic Data Sheets. These diagrams show the average fatigue effects (not minimum properties) of a static stress superimposed on an alternating stress, and are based upon the tensile strength of the material and the fatigue life under one condition of stress. The fatigue life was taken from S-N curves representing a loading condition of $R = -1$, in which R is the ratio of the minimum stress to the maximum stress.

As presented, the diagrams focus on the static tensile strength as the limiting mean stress. The yield strength is shown, and the allowable stresses can be limited by this value to prevent permanent deformation during service.

Under the condition quoted for each diagram, the limiting stress values are conservative. Changes in the method of loading, however, will significantly change the limiting stress values (allowable stresses for axial loading are lower than those for flexural loading). The allowable stresses will also tend to vary with the product (sheet, bar, etc) and with the method of manufacture. These changes will generally not be as great as those introduced by a change in the method of loading.

Another consideration is that the data were obtained with ground or polished specimens. These will have surfaces superior to those found in service.

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7. APPENDICES

Appendix A has been added to the Data Book to incorporate information on the plastic bending modulus, a concept which permits stress analysis of stress patterns where plastic strain occurs. A general discussion, with explanatory charts, is included. It is anticipated that this discussion will permit the calculation of plastic bending modulus charts for applicable materials. When such calculations are made, the resultant charts will be added to the Appendix.

Appendix B (to be published) will be concerned with the effects of irradiation upon the properties of materials. It will be based upon a similar section in former editions of the Data Book, but will be based on complete re-editing and re-analysis of contents. The data will be presented in a more graphic and usable manner, but be arranged in the same order, and use the same material code numbers, as does the body of the Data Book.

8. DATA SOURCES

The data presented were selected by a critical review of the content of over 725 sources, which are listed in the following Section. The references include U.S. Government publications from such origins as the Air Force, the National Bureau of Standards, and the National Aeronautics and Space Administration. Reports issued by such non-governmental research organizations as Battelle Memorial Institute, Southern Research Institute, and the University of California were also used. Another group of sources was the publications of the materials producing companies, such as Union Carbide Corporation and International Nickel Company. The publications of the engineering societies were utilized, including those of the American Society for Metals and the American Society for Testing and Materials. Data generated by such organizations as Westinghouse Astronautical Laboratory and Aerojet-General Corporation have also been included.

Reference code numbers for the sources of data are given on the sheet to which they apply.

The reference list is in reverse chronological order by year of publication, i.e., 1969, 1968, 1967, 1966, 1965, etc.

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REFERENCES

References to source materials for this Data Book are tabulated in the following pages. Reference material is identified numerically by the last two digits of the year of publication, followed by a consecutive number for the listing within that calendar year. Thus, Ref. 65-4 designates the fourth item listed for 1965.

Redundancy in descriptions of items has been minimized by the use of abbreviations to designate those sources which appear several times in the listing, and by elimination of corporate addresses for better known firms or publishing houses. These abbreviations include the following:

AEC	U. S. Atomic Energy Commission	LMSC	Lockheed Missiles and Space Company
AFML	Air Force Materials Laboratory Wright-Patterson Air Base, Ohio	MPDC	Mechanical Properties Data Center for AFML, Belfour Stullen, Inc., Traverse City, Michigan
AFSC	Air Force Systems Command Wright-Patterson Air Base, Ohio	NASA	National Aeronautics and Space Administration
AGC	Aerojet-General Corporation	NBS	National Bureau of Standards
AIAA	American Institute of Aeronautics and Astronautics	NRO	Nuclear Rocket Operations of AGC (was REON) (Superseded by ANSC)
Alcoa	Aluminum Company of America	ORNL	Oak Ridge National Laboratory of AEC
ANS	American Nuclear Society	REIC	Radiation Effects Information Center of DMIC
ANSC	Aerojet Nuclear Systems Company (was NRO)	REON	Rocket Engine Operations - Nuclear, of AGC (Superseded by NRO)
Armco	Armco Steel Corporation	SAE	Society of Automotive Engineers
ASM	American Society for Metals	SNPO	Space Nuclear Propulsion Office (Joint Office of NASA and AEC) (-C, -W, -N, etc., in Cleveland, Washington, Nevada, etc.)
ASME	American Society of Mechanical Engineers	SRI	Southern Research Institute, Birmingham, Alabama
ASTE	American Society of Tool Engineers	Stellite	Stellite Division of Union Carbide
ASTM	American Society for Testing and Materials	TIMET	Titanium Metals Corporation of America
Battelle	Battelle Memorial Institute, Columbus, Ohio	TPRC	Thermophysical Properties Research Center, Purdue University
CEC	Cryogenic Engineering Conferences (published title: <u>Advances in Cryogenic Engineering</u>) K. D. Timmerhaus, Editor	USS	United States Steel Corp
DMIC	Defense Materials Information Center, Battelle	WADD	Wright Air Development Division Wright-Patterson Air Base, Ohio
DOD	Department of Defense	WANL	Westinghouse Astronuclear Laboratories, Pittsburgh, Pa., with these suffixes designating report types.
GD/A	General Dynamics Astronautics Division	PR	- Progress Report
GD/FW	General Dynamics, Fort Worth Facility	TME	- Technical Memorandum
GE	General Electric Company	TNR	- Technical Report
Huntington	Huntington Alloys Products Division of INCO		
INCO	International Nickel Company		
LASL	Los Alamos Scientific Laboratories of AEC		

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REFERENCES - 1970

The following Data Release Memoranda, NRO Materials and Processes Staff, D.J. Lamvermeyer to H.M. Blue, covering materials listed:

70-1	DRM	M-1	<u>Inconel 718 Nickel Alloy</u>
70-2	DRM	M-2	<u>AISI Type 347 Stainless Steel</u>
70-3	DRM	M-3	<u>7039-T63 Aluminum Alloy</u>
70-4	DRM	M-4	<u>Ti 5 Al-2.5 Sn, ELI</u>
70-5	DRM	M-5	<u>A-286 Iron-Nickel Chromium Alloy</u>
70-6	DRM	M-6	<u>Fibrous Graphite (AG Carb 101)</u>
70-7	DRM	M-7	<u>6061-T6 Aluminum Alloy</u>
70-8	DRM	M-8	<u>2024 Aluminum Alloy</u>
70-9	DRM	M-9	<u>Ti 6 Al-4V, ELI</u>
70-10	DRM	M-10	<u>AISI Type 301 Stainless Steel</u>
70-11	DRM	M-11	<u>Bearings and Lubricants</u>
70-12	DRM	M-12	<u>Hastelloy X Nickel Alloy</u>
70-13			
70-14	DRM	M-14	<u>Polyimide Vespel "SP-1"</u>
70-15	DRM	M-15	<u>Udimet 630 Nickel Alloy</u>
70-16	DRM	M-16	<u>18 Ni Maraging Steel</u>
70-17	DRM	M-17	<u>Waspaloy Nickel Alloy</u>
70-18	DRM	M-18	<u>AISI Type 304 Stainless Steel</u>
70-19	DRM	M-19	<u>AISI Type 440C Stainless Steel</u>
70-20	DRM	M-20	<u>5083-H323 Aluminum Alloy</u>
70-21	DRM	M-21	<u>7075-T73 Aluminum Alloy</u>
70-22	DRM	M-22	<u>7175-T73 Aluminum Alloy</u>
70-23	DRM	M-23	<u>Synergistic Effects, gH₂, Radiation Effects</u>
70-24	DRM	M-24	<u>Aluminum Oxide</u>
70-25	DRM	M-25	<u>Aluminum Base Metal</u>
70-26	Letter, re <u>Statistical Data for S-200 Beryllium Block, and Ti-5Al-2.5 Sn(ELI) Bar</u> , A.C. Sanderson (WANL) to J.L. Dooling (ANSC), April 3, 1970		
70-27	J.M. Davidson, et al. <u>Cryogenic Radiation Effects on Aluminum 7039 and Hastelloy X</u> , ANSC Report RN-S-0053, April 1970		
The following NDS-Boulder Laboratories <u>Progress Reports to NASA on Cryogenic Research and Development</u> :			
70-28	<u>Thirty-Seventh Progress Report, for Period Ending March 31, 1970, Report 9754</u>		
70-29	<u>Thirty-Eighth Progress Report, for Period Ending June 30, 1970, Report 9759</u>		
70-30	<u>Thirty-Ninth Progress Report, for Period Ending September 30, 1970</u>		
70-31	<u>Fortieth Progress Report, for Period Ending December 31, 1970</u>		

DATE	15 JULY 1970
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REFERENCES
REFERENCES - 1970 (CONTINUED)

- 70-32 Private Communication re Inconel 718, D.J. Tillach (INCO) to H.M. Blue (ANSC), June 31, 1970
- 70-33 Memo, F.J. Flens to L.D. Johnson (NRO), Preliminary Pressure Vessel Materials Tensile Properties Data, NRO Materials Memo 69-232, 6 January 1970
- 70-34 Memo, F.J. Flens to C.W. Funk (ANSC), Tensile Properties of 7039-T63, ANSC Materials Memo 70-155, 23 April 1970
- 70-35 NERVA Materials Developments, Third Quarter, Contract Year 1970 (April, May, and June), ANSC Report S131-PR3, July 1970
- 70-36 Final Report GTR-21, High-Temperature Radiation Effects on René 41, Waspaloy, and Inconel 718, ANSC Report S110-GTR 21- W183, May 1970

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SUPERSEDES 15 MAR 1970

REFERENCES
REFERENCES - 1969

- 69-1 R.L. Kesterson and R.A. Nadler (WANL), The Effect of Hydrogen and Temperature on Mechanical Properties of the Ti-5al-2.5 Sn ELI Alloy, Paper presented at Western Metal and Tool Exposition Conference, Los Angeles, California, March 10-14, 1969
- 69-2 C.E. Dixon, John Stadig, et al, Final Report, GTR-19 Test to Determine Cryogenic Radiation Effects on Structural Materials, NRO Report RN-S-0520, September 1969
- The following paper from the ASME Metals Engineering and Pressure Vessels & Piping Conference, Washington, D.C., March 31-April 2, 1969:
- 69-3 I. Lemay, et al, "Effects of Some Gaseous Environments of the Creep of a Stainless Steel", Paper 69-MET-3
- 69-4 $\bar{x}$ Values of AISI 347 Forgings and Bar, Memo, V.E. Kahle (NRO Materials Group) to H.M. Blue (NRO), 7 May 1969
- 69-5 Statistical Values of Ti-5al-2.5 Sn ELI Forgings and Bar, Memo, W.F. Emmons (NRO Materials Group) to H.M. Blue (NRO), February 1969
- 69-6 $\bar{x}$ Values of Ti-5al-2.5 Sn (ELI) Forgings and Bar, Memo, V.E. Kahle (NRO Materials Group) to H.M. Blue (NRO), 8 August 1969
- 69-7 Statistical Properties, Vacuum Hot-Pressed Beryllium Block, Letter, M.K. Wright (WANL) to J.L. Dooling (NRO), 26 June 1969
- 69-8 Statistical Values of Ti-5al-2.5 Sn (ELI) Forgings and Bar, NRO Materials and Processes Staff Data Release Memorandum 3, 15 September 1969
- The following NBS-Boulder Laboratories Progress Reports to NASA on Cryogenic Research and Development:
- 69-9 A.F. Clark, et al, Thirty-third Progress Report, for Period Ending March 31, 1969, Report 9728
- 69-10 A.F. Clark, et al, Thirty-fourth Progress Report, for Period Ending June 30, 1969, Report 9737
- 69-11 Thirty-fifth Progress Report, for Period Ending September 30, 1969, Report 9742
- 69-12 J. G. Hust, et al, Thirty-sixth Progress Report, for Period Ending December 31, 1969, Report 9750
- 69-13 G. V. Smith, An Evaluation of the Yield, Tensile, Creep, and Rupture Strengths of Wrought 304, 316, 321, and 347 Stainless Steels at Elevated Temperatures, ASTM Data Series DS 552 as Supplement to Publication DS5, formerly STP 124 (Ref 52-1, February 1961)
- 69-14 E. E. Palmer, et al, NERVA Irradiation Program, GTR Test 21, Volume 3 - Thermal Conductivity and Electrical Resistivity of Selected NERVA Materials, GD/FW Report FZK 351-3, NJD-20, prepared for SNPO-C under Contract AF29(601)-7077, 14 November 1969
- 69-15 Forged Inconel 718, Metallurgical Report, Coulter Steel and Forge Company, Emeryville, California, to AGC-Sacramento, AGC P.O. G106220, 27 May 1969
- 69-16 J. G. Hust, et al, Thermal Conductivity, Electrical Resistivity and Thermopower of Aerospace Alloys from 4° to 300°K, NBS - Boulder Report 9732, June 1969

DATE 30 SEPT 1969**SUPERSEDES****REFERENCES****REFERENCES - 1969 (CONTINUED)****RESERVED FOR FUTURE ADDITIONS**

DATE	30 SEPT 1969
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REFERENCES
REFERENCES - 1968

- 68-1 V. Kachur, Thermal Conductivity of Carb-I-Tex 700, WANL Memo MFD:VK:2718, 23 January 1968
 - 68-2 Preliminary Test Data, GTR-21 Irradiation Testing, R. McDaniel (GD/FW) to J.E. Stadig (NRO), 29 March 1968
 - 68-3 H.J. Wagner, et al, Nickel Base Alloys, Alloy 718, Processes and Properties Handbook, DMIC, under Contract F33615-68-C-1325 for AFML, February 1968
 - 68-4 R.C. Simon, et al, Design Properties of Waspalox, DMIC Technical Note, 29 February 1968
 - 68-5 Aerospace Structural Metals Handbook, AFML-TR-68-115 (formerly ASD-TR-63-741), MPDC for AFML, Contract F33615-67-C-1254, March 1968 (Supersedes Ref. 67-8)
- The following papers from Volume 3, Journal of Metals, 1968:
- 68-6 A.J. Nachtigall, et al, "Fatigue Behavior of Rocket Engine Materials, to -452° F", pp 425-443
 - 68-7 R.D. Weltzin, et al, "Impact Fatigue Testing of Titanium Alloys", pp 469-482
 - 68-8 K.E. Fritz, et al, "High Strength Turbo-generator Retaining Ring Forgings of an Age-Hardenable Austenitic Alloy." (A-286) pp 629-645
 - 69-9 J.O. Lyst, "Effects of Cold-Working on Fatigue Strength of Heat-Treated Aluminum Alloys, A Review of ARL Data and the Literature", pp 996-1017
- The following NBS-Boulder Laboratories Progress Reports to NASA on Cryogenic Research and Development:
- 68-10 J.G. Hurst, et al, Twenty-Ninth Progress Report, for Period Ending 31 March 1968, Report 9707, March 31, 1968
 - 68-11 J.G. Hurst, et al, Thirtieth Progress Report, for Period Ending 30 June 1968, Report 9713, June 30, 1968
 - 68-12 J.G. Hurst, et al, (Thermal Conductivity), A.F. Clark, et al, (Electrical Resistivity), Thirty-First Progress Report, for Period Ending 30 September 1968, Report 9717, September 30, 1968
 - 68-13 A.F. Clark, et al, Thirty-Second Progress Report, for Period Ending 31 December 1968, Report 9720, December 31, 1968
 - 68-14 Armco Titanium and Titanium Alloys - Bar, Wire, and Billets, Product Data Brochure T-1, Armco, August 1968
 - 68-15 Armco 21-6-9 Stainless Steel, Product Data Brochure S-26-b, with Data on AISI 304, 310, and 347, Armco, February 1968
 - 68-16 Armco A-286, Product Data Brochure SA-1a, Armco, September 1968 (Supersedes Ref 66-34)
 - 68-17 D.P. Moon, et al (Battelle), Elevated Temperature Properties of Selected Superalloys, ASTM Data Series DS-7S1 (Supplement to Publications DS-7, Ref. 54-2), DMIC and the ASTM-ASME-MPC Joint Committee on Properties of Metals, July 1968

DATE 15 JULY 1970

SUPERSEDES 15 MAR 1970

REFERENCES
REFERENCES - 1968 (CONTINUED)

The following unpublished Data Sheets from Alcoa Research Laboratories, Typical Mechanical Properties at Various Temperatures (L.W. Mayer, Editor):

- 68-18 A 356-T61 Permanent Mold, 17 June 1968
 - 68-19 2014-T6 16 February 1968
 - 68-20 2014-T6 Forgings, 16 February 1968
 - 68-21 2219-T851 Plate, 26 February 1968
 - 68-22 7039-T63, -T651 Plate, 26 February 1968
 - 68-23 7075-T76, 28 August 1968
 - 68-24 7075-T73, 28 August 1968
 - 68-25 7075-T6, -T651, 5 September 1968
 - 68-26 2021-T81 Plate, 26 February 1968
 - 68-27 5454-0, 17 June 1968
 - 68-28 5454-H32, 17 June 1968
 - 68-29 5454-H34, 17 June 1968
 - 68-30 Proposed Revisions to Metallic Materials and Elements for Aerospace Vehicle Structures, Mil-Hndbk-5A (Ref. 67-5), Thirty-Sixth Coordination Meeting, Boston, Massachusetts, September 1968
 - 68-31 R.A. Schultz, Alcoa Aluminum Alloy 2021, Green Letter, Application Engineering Division, Alcoa, April 1968
 - 68-32 Metallic Materials and Elements for Aerospace Vehicle Structures, Mil-Hndbk - 5A, Supplement of 1 December 1968
 - 68-33 Statistical Data, 5al-2.5 Sn (ELI), letter M.T. Johnson (WANL) to J.L. Dooling (NRO), October 8, 1968
 - 68-34 R.W. Fenn, et al, Test Methods for Evaluating Mechanical Properties of Anisotropic Materials (Beryllium), Final Report for Period 1 May 1967 - 1 Nov. 1968, Contract F 33615-67-C1290, Lockheed Missiles and Space Company, Palo Alto, Calif., for AFML, 27 Nov. 1968
 - 68-35 R.P. Shogan, Tensile Properties of Irradiated Ti-5% al -2.5% Sn ELI at Cryogenic Temperatures, WANL TME-1860, November 1968
- The following paper from Transactions, AIME, Volume 242, No. 5, 1968
- 68-36 T. W. Watson, et al, "Thermal Conductivity of Four Heat Resistant Alloys," pp 844-6, 1968
 - 68-37 Aluminum Standards and Data, First Edition, The Aluminum Association, New York, April 1968
 - 68-38 Inconel Alloy 718, Brochure T-39, INCO, February 1968

DATE	30 SEPT 1969
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REFERENCES
REFERENCES - 1967

- 67-1 Reynolds Aluminum Pure and Alloyed Foundry Ingot, Reynolds Metal Company, undated, received 1967
- 67-2 Standards for Aluminum Mill Products, 1967, Aluminum Association, New York (Supersedes Ref. 66-4)
- 67-3 Engineering Properties of Inconel Alloy X-750, Technical Bulletin T-38, February 1967
- 67-4 Private Communication, re Udimet 630, T.W. Cowan (Special Metals Corp.) to S. Goodman (NRO), 16 June 1967
- 67-5 Metallic Materials and Elements for Aerospace Vehicle Structures, Mil-Hndbk-5A, Superseding Mil-Hndbk-5, DOD, supplement of 20 November 1966 (received July 1967)
- 67-6 C.E. Dixon, C.W. Funk, W. Weleff, High Temperature Radiation Embrittlement of Hastelloy X, Inconel 625, and AISI 347, Paper ANS-LOG 207, presented at Annual Meeting, ANS, San Diego, Calif., June 1967
- 67-7 C.E. Dixon, et al, Unpublished Results, AGC-GD/FW Test Data of Materials Irradiation Test GTR-19, May 1967 (Superseded by Ref. 69-2)
- 67-8 Aerospace Structural Metals Handbook, Syracuse University Institute, AFSC Project 7381, Contract AF stet through Supplement of March 1967. (Supersedes Ref. 66-25)
- 67-9 Coors Alumina and Beryllia Properties Handbook, Bulletin 952, Coors Ceramics, Received 1967
- 67-10 J.A. Vaccari, Assoc. Editor, "New Findings Stretch Titanium Performance Limits", Materials Engineering, p. 94, May 1967
- 67-11 B. Phillips, "Materials for Use Above 3000° F", Research/Development, p. 22-25, May 1967
- 67-12 R.M. Evans, et al, (Battelle), "Welding Characteristics of High-Strength Aluminum Alloys", Materials in Design Engineering, pp 74-79, March 1967
- 67-13 Mechanical Properties Data - 7039 Aluminum Plate - T6151, Battelle, Contract AF 33(615)-2494 for AFML, March 1967
- 67-14 Telecon, Re Specific Heat of 2219 Aluminum, R.L. Shollenberger (WANL) and S. Goodman (NRO), 14 August 1967
- 67-15 P.J. Levine, Radiation Effects on Inconel Alloy 718, WANL-TME-1572, March 1967
- 67-16 Haynes Alloy No. 25, Stellite, February 1967
- 67-17 J.J. Lombardo, C.E. Dixon, and J.A. Begley, "Cryogenic Radiation Effects on NERVA Structural Materials," in ASTM STP 426, Effects of Radiation on Structural Materials, November 1967 (Supersedes Ref. 66-3)
- 67-18 T.C. Sullivan (NASA), Uniaxial and Biaxial Fracture Toughness of Extra Low Interstitial 5Al-2.5 Sn Titanium Alloy Sheet at 20°K, TN-D-4016 (DMIC 68968), June 1967
- 67-19 Private Communication, B.R. Feick of Huntington Alloys to R.L. Shollenberger of WANL, June 1967
- 67-20 H.H. Hausner, Editor, The Beryllium Metal Handbook, General Astrometals Corp., 1967
- 67-21 Y.S. Touloukian, Editor, Thermophysical Properties of High Temperature Solid Materials, Vols. 1 through 6, TPRC, published by the MacMillan Company, 1967 Edition (Supersedes Ref. 66-26)
- 67-22 D.L. Harrod, et al, Fracture Toughness of Neutron Irradiated Beryllium, WANL-TME-1656, September 1967
- 67-23 J.S. Beay, Consolidation of Reconstituted Pyrolytic Graphite into Thermal Insulating Shapes, WANL-TME-1605, September 1967
- 67-24 R.P. Shogan, Irradiation Effects on the Mechanical and Electrical Properties of P-03, H4LM, and 780-T Graphites, WANL-TME-1637, July 1967

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1967 (CONTINUED)

- 67-25 R.P. Shogan, Irradiation Effects on the Mechanical Properties of S-200 Grade Beryllium and Lockalloy at Cryogenic Temperatures, WANL-TME-1655, September 1967
- 67-26 Preliminary Information to DMIC received through FAA-SST Program, 1967
- 67-26 Unpublished Data received by DMIC under Air Force Contract AF 33(657)-15787
- 67-27 Superseded by Ref. 69-2
- 67-28 Unpublished Fatigue Data from Armco Steel (DMIC 63803) no date
- 67-29 Unpublished Data received by DMIC from an Air Force Contract
- 67-30 Private Communication received by DMIC from Brush Beryllium Corp.
- 67-31 NERVA Materials Developments, Fourth Quarter - Contract Year 1967, NRO Report RN-S-0441, November 1967
- 67-32 Metallic Materials and Elements for Aerospace Vehicle Structures, Mil-Hndbk-5A Superseding Mil-Hndbk-5 (Ref. 67-5) DOD, Supplement of 1 November 1967
- 67-33 Alloy Performance Data, Waspaloy, Special Metals, Inc., New Hartford, N.Y., undated, received 1967 (Supersedes Ref. 60-39)
- 67-34 Telecon, re Bolt Materials, R. Lingscheid (Standard Pressed Steel, Santa Ana Calif.) and S. Goodman (NRO), 6 and 18 July 1967
- 67-35 NERVA Materials Developments, Second Quarter, Contract Year 1967 (1 January - 31 March), NRO Report RN-S-0393, May 1967
- 67-36 Phoebus 2 Materials Final Report, NRO Report RP-SR-0002, September 1967
- 67-37 L.W. Mayer, Alcoa Aluminum Alloy 2219, Alcoa Green Letter, Alcoa, June 1967 (Supersedes Ref. 63-62)
- 67-38 V. Kachur, Design Properties of Carb-I-Tex 700 Graphite, unpublished WANL Data, October 1967
- 67-39 L.L. France, et al, (all of WANL), Mechanical Behavior of a Continuous Filament Carbon Composite, Paper 67-173, 5th Aerospace Sciences Meeting of AIAA, New York, N.Y., January 1967
- 67-40 Alloy Digest, Engineering Alloys Digest, Inc., Publishers, Upper Montclair, N.J., no specific date, but periodically updated
- 67-41 V. Kachur, Evaluation of SX-5 Graphite, WANL TME-1632, June 1967
- 67-42 R.P. Shogan, Irradiation Effects on the Mechanical and Electrical Properties of P-03, H4LM, and 780T Graphites, WANL-TME-1637, July 1967
- The Following Progress Reports to NASA on Cryogenic Research and Development, NBS-Boulder Laboratories:
 - 67-43 J.J. Hust, et al, Twenty-Sixth Report, Period Ending June 30, 1967, Report 9286, June 30, 1967
 - 67-44 A.F. Clark, Twenty-Seventh Report, Period Ending September 30, 1967, Report 9291, September 30, 1967
 - 67-45 A.F. Clark, et al, Twenty-Eighth Report, Period Ending December 31, 1967, Report 9299, December 31, 1967
- 67-46 Pyroid Bearings with Directional Properties, (re Pyrolytic Graphite), Tech. Report, Pyrogenics Division, Space Age Materials Corp., Subsidiary of Pfizer, undated, but received in 1967
- 67-47 Fabrication of Chromium-Nickel Stainless Steel 300 Series, INCO, January 1967
- 67-48 Aircraft Designer's Handbook for Titanium and Titanium Alloys, Tech. Report AFML-TR-67-142, DMIC, for Federal Aviation Agency and AFML, March 1967

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SUPERSEDES 30 SEPT 1969

REFERENCES
REFERENCES - 1967 (CONTINUED)

The following Papers from Volume 13, Advances in Cryogenic Engineering, Proceedings of the 1967 Cryogenic Engineering Conference, Stanford University, August 21-23, 1967:

- 67-49 R.L. Lake, et al, "Burst Tests of Pre-Flawed Welded Aluminum Alloy Pressure Vessels at -320°F", Paper E-4, pp 278-293
- 67-50 J.G. Kaufman, et al, "Tensile Properties and Notch Toughness of Aluminum Alloys at -452° F in Liquid Helium", Paper E-5, pp 294-308
- 67-51 J.L. Christian, et al, "Mechanical Properties of Titanium Alloys at Cryogenic Temperature", Paper E-7, pp 318-333
- 67-52 Armco 17-4-PH Precipitation Hardening Stainless Steel, Bar and Wire, Product Data Brochure S-6a, Armco, June 1967
- 67-53 Armco 17-7-PH Precipitation Hardening Stainless Steel, Sheet and Strip, Product Data Brochure S-30, Armco, May 1967
- 67-54 R.P. Reed, et al, "Low Temperature (295 to 4K) Mechanical Properties of Selected Copper Alloys", pp 370-392, Volume 2, Journal of Metals, 1967
- 67-55 J.G. Kaufman, et al, "Aluminum Fills Cryogenic Needs", Oil and Gas Journal, December 11, 1967
- 67-56 Welded Austenitic Chromium - Nickel Stainless Steels - Techniques and Properties, INCO, April 1967
- 67-57 Alcoa Aluminum Handbook, Alcoa, 1967 (Supersedes Ref. 62-14)
- 67-58 R.L. Kesterson, The Cryogenic and Ambient Tensile and Compression Properties of Hot-Pressed Block Beryllium, WANL-TME-1619, June 1967
- 67-59 F. T. Inouye, et al, Application of Alloy 718 in M-1 Engine Components, Report NASA CR-788, Contractor Report by AGC for Lewis Research Center, Contract NAS 3-2555, June 1967

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1966

- 66-1 Letter, J.J. Beereboom (REON) to A.A. Madieros (SNPO-C), 4 April 1966
- 66-2 Mechanical Properties of Tungsten and TZM Sheet Produced in the Refractory Metal Sheet Rolling Program, Part II, Contract N600 (19)-59530, SRI, 17 Jan. 1966
- 66-3 J.J. Lombardo, C.E. Dixon, J.A. Begley, Cryogenic Radiation Effects on NERVA Structural Materials, Paper presented at 69th Annual Meeting, ASTM, Atlantic City, N.J., 1 July 1966. (Replaced by Ref. 67-17)
- 66-4 Standards for Aluminum Mill Products 1966, (8th Edition), The Aluminum Association (Superseded by Ref. 67-2)
- 66-5 S.L. Israel, et al, Thermal Properties of Solid and Porous Tungsten to 5000° F, Report NASA CR-402, United Nuclear Corp. White Plains, N.Y., March 1966
- 66-6 Fifth Annual Report - High-Temperature Materials Programs, Part A, Nuclear Materials and Propulsion Operation, Atomic Products Division, GE, Cincinnati, Contract AT (40-1)-2847, for the AEC, February 1966
- 66-7 V. Kachur, Evaluation of New Graphites for NERVA Support Blocks, WANL-TME-1377, (C-RD, Title Unclassified), February 1966
- 66-8 Suppliers' Literature, Poco Graphite, Inc., Dallas, Texas, Undated
- 66-9 Phoebus-2 Six Months Material Development Report for 15 February through 15 August 1966, Report AGC RP-DR-0004, Contract SNPC-35, September 1966
- 66-10 Metallic Materials and Elements for Aerospace Vehicle Structures, Mil-Hndbk-5A, Superseding Mil-Hndbk-5, (Ref. 65-34), DOD, Issue of February 8, 1966
- 66-11 V. Kachur, Mechanical and Thermophysical Properties of the Filler Strip Stock, WANL Report (Unpublished), September 1966
- 66-12 Cryogenic Materials Data Book, ML-TDR-64-280 (PB 171809, Revised), Aug. 1964, AFSC, with Supplements through March 1966 (Supersedes Ref. 65-1)
- 66-13 Silastic 891 RTV Rubber, Bulletin 08-237, Dow Corning Corp., August 1966
- 66-14 J.J. Lynch, et al, Engineering Properties of Ceramics, Battelle Report AFML-TR-66-52, AFSC Contract AF 33(615)-2316, June 1966
- 66-15 J. Sessler et al, Materials Data Handbook, Aluminum Alloy 2219, Dept. of Chemical Engineering and Metallurgy, Syracuse University Research Institute, for NASA-Marshall Space Flight Center, Contract NAS-8-11345, March 1966 (Same as Ref. 66-28)
- 66-16 Epoxy Resin Adhesive, WANL Specification PDS 30165, January 1966
- 66-17 Instrumentation, Reactor Installation - Transitioning and Electrical Checkout, WANL Specification PS 294681, July 1966
- 66-18 Instrumentation Cable Transitioning - Nuclear Environment, WANL Specification PS 294649, July 1966
- 66-19 Epoxi-Patch Kit, Brochure, Hysol Corp., Olean, N.Y. undated
- 66-20 Application Instructions SR-4 Strain Gage Bonding Cement EPY-150 Room Temperature Epoxy, Baldwin-Lima-Hamilton, Waltham, Mass., undated
- 66-21 Sauereisen No. DW 30 Electrical Cement, Brochure, Sauereisen Cements Co., Pittsburgh, Pa., Undated
- 66-22 Instructions for Use of Grade P-514 Carbon Cement, Technical Data Sheet 5305, Great Lakes Carbon Corp., New York, N.Y., Undated

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1966 (CONTINUED)

- 66-23 Armstrong Epoxy Resin Adhesives, Bulletin 564, Armstrong Products Co., Warsaw, Indiana, Undated
- 66-24 R.E. Baker and R.E. Nightingale (Private Communication), Battelle - Northwest, May 1966
- 66-25 Aerospace Structural Metals Handbook, Syracuse University Institute, AFSC Project 7381, Contract AF 33(615)-1184, through Supplement of March 1966, (Supersedes Ref. 65-61)
- 66-26 Y.S. Touloukian, Director, Thermophysical Properties Research Center Data Book, TPRC, AFSC Contract AF 33(613)-2281, 1964, with Supplements through June 1966
- 66-27 Bishop Technical Data Sheet Grade AM-350, Data Sheet 7-21, J. Bishop and Co. Platinum Works, Malverne, Pa., August 1966
- 66-28 J. Sessler, et al, Materials Data Handbook, Aluminum Alloy 2219, Dept. of Chemical Engineering and Metallurgy, Syracuse University Research Institute for NASA-Marshall Space Flight Center, Contract NAS-8-11345, March 1966 (Same as Ref. 66-15)
- 66-29 Letter, Internal within INCO, Corrections to Bulletin S-3, Current Data Report, Inconel 718, Revision of Ref. 64-63, November 22, 1966
- 66-30 J.E. Campbell, "Low-Temperature Properties", DMIC Review of Recent Developments, Mechanical Properties of Metals, DMIC, November 23, 1966
- 66-31 Titanium, Brooks and Perkins, Inc., Detroit, Michigan, July 1966
- 66-32 Uniloy 302-304-304L Stainless Steels, Universal-Cyclops Specialty Steel Div., 1966
- 66-33 Uniloy Hardenable 400 Series Stainless Steels, Universal-Cyclops Specialty Steel Div., 1966
- 66-34 Armco A-286, Product Data Brochure SA-1; Armco, November 1966 (Superseded by Ref. 68-16)
- 66-35 C.A. Schwanbeck, Effects of Nuclear Radiation on Metals at Cryogenic Temperatures, Lockheed Nuclear Products Report LAC ER-8673 for NASA Under Contract NAS 3-7985, published as NASA Report CR-72056, August 1966
- 66-36 Engineering Properties of Inconel Alloy 625, Technical Bulletin T-42, Huntington Alloys
- 66-37 Y.S. Touloukian, Editor, Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents, and Their Oxides, TPRC, NBS Sub-Contract CST-7590, February 1966
- 66-38 Armco 17-7 PH and PH 15-7 Mo Stainless Steel Sheet and Strip, Armco, May 1966
- 66-39 Hastelloy Alloy C, Stellite, May 1966
- 66-40 Comparative Properties of Union Carbide High-Temperature Alloys, Stellite, April 1966
- 66-41 L.G. Beall, et al, Mechanical Property Evaluations of Newly Developed Structural Materials, Report AFML-TR-66-155, Battelle, for AFML, April 1966
- 66-42 Haynes Tantalum, Stellite, October 1966
- 66-43 A.V. Levy, Unalloyed Wrought Tungsten, Sheet and Plate, Materials Data Sheet 4.1.1, AGC, November 1966
- 66-43 H.D. Hanes, et al, Physical Metallurgy of Beryllium, DMIC Report 230, to Director, Defense Research and Engineering, June 1966
- 66-44 R.L. Kesterson, Tensile Properties of I-400 Grade Beryllium at Cryogenic Temperatures, WANL-TME-1550, December 1966
- 66-45 Standard Specification for Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes, ASTM B 163-66; 1966

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

REFERENCES

REFERENCES - 1966 (CONTINUED)

- 66-46 Graphite Tape, WANL Purchasing Department Specification 30182-1, October 1966
- 66-47 Private Communication re Titanium 6Al-4V, G. Wang, (TPRC) to R. Hall (Lockheed California Co.), (DMIC 63650), March 1966
- 66-48 B.J. Alperin, Fatigue Properties of an Annealed Ti-6Al-4V Forging, Douglas Aircraft Co., Long Beach, Calif., Laboratory Report IR-AD-3043 (DMIC 65474), July 1966
- 66-49 D. Jones, Compression Mechanical Properties of Titanium Alloys, McDonnell Aircraft Co., Final Report 513-605 (DMIC 67192), December 1966
- 66-50 A.A. Blatherwick, Fatigue, Creep, and Stress-Rupture Properties of Microtung, Super A-286, and Inconel 718, University of Minnesota Tech. Report AFML-TR-65-447, Contracts AF 33(657) -7453 and AF 33(615) -1122, (DMIC 65927), June 1966
- 66-51 L.G. Beall, et al, Mechanical Property Evaluations of Newly Developed Structural Materials, Battelle Report AFML-66-155, Contract AF 33(615) - 2494 (DMIC 65123), April 1966
- 66-52 C.L. Dotson, The Mechanical Properties of Tungsten and TZM Sheet Produced in the Refractory Metal Sheet Rolling Program, Part 2, Statistical Analysis of the Tensile Properties of TZM Sheet, SRI Report 7564-1479-X1, Contract Bu Nav Weps N600 (19)-59350 (DMIC 63476), January 1966
- 66-53 J. O'Conner, Evaluation of Cross-Rolled Beryllium Sheet, McDonnell Aircraft Research Report E055 (DMIC 66093), April, 1966
- 66-54 Lescaloy 718 VAC ARC, Latrobe Steel Co., March 1966
- 66-55 J. Sessler, et al, Materials Data Handbook, Aluminum Alloy 5456, Dept. of Chemical Engineering and Metallurgy, Syracuse University Research Institute, for NASA - Marshall Space Flight Center, Contract NAS-8-11345, May 1966
- 66-56 C.W. Rohl, et al, "Fiber Reinforced Carbon and Graphite," Research/Development, p. 21, July 1966
- 66-57 1-400 Grade Beryllium, Technical Information Sheet, Brush Beryllium, Received August 1966
- 66-58 C.J. Slunder, et al, Thermal and Mechanical Treatments for Nickel and Selected Nickel Base Alloys and Their Effects on Mechanical Properties, U.S. Army Missile Command, Report NASA-TM-X53-443, 20 April 1966
- 66-59 F.T. Inouye, et al, Summary of Materials Technology of M-1 Engine, AGC Technology Report NASA CR-54961, Contract NAS 3-2555, 22 July 1966
- 66-60 J. Sessler, et al, Materials Data Handbook, Inconel Alloy 718, Dept. of Chemical Engineering and Metallurgy, Syracuse University Research Institute, for NASA - Marshall Space Flight Center, Contract NAS 8-11345, September 1966
- 66-61 Uniloy 321-347-348 Stainless Steels, Universal-Cyclops Specialty Steel Div., 1966
- 66-62 Selection of Stainless Steels, Universal Cyclops Specialty Steel Div., 1966
- 66-63 E.A. Kovacevitch, Elevated Temperature Fatigue Studies of Wrought Stress-Relieved TZM Alloy, Airesearch Mfg. Division, The Garrett Corp., for Wright-Patterson Air Force Base, AFAPL-TR-66-134, December 1966

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1966 (CONTINUED)

The following Materials Data Handbooks, by J. Sessler and V. Weiss, Dept. of Chemical Engineering and Metallurgy, Syracuse University Institute, for NASA - Marshall Space Flight Center, Contract NAS-8-11345, July 1966:

- 66-64 Aluminum Alloy 6061, July 1966
- 66-65 Aluminum Alloy 7075, August 1966
- 66-66 Aluminum Alloy 2014, April 1966
- 66-67 Type 301 Stainless Steel, June 1966

The following papers from Volume 12, Advances in Cryogenic Engineering, Proceedings of the 1966 Cryogenic Engineering Conference, at University of Colorado Engineering Research Center (Boulder, Colorado) and NBS Institute for Materials Research, June 13-15, 1966:

- 66-68 J.W. Coursen, et al, "Notch Toughness of Some Aluminum Alloy Castings at Cryogenic Temperatures", Paper G-2, pp 473-483
- 66-69 J.L. Christian, "Mechanical Properties of Several Nickel-Base Alloys at Room and Cryogenic Temperatures", Paper G-7, pp 520-531
- 66-70 W. Weleff, "Radiation Effects on Shear Strength of Several Alloys at Liquid Hydrogen Environment", Paper G-9, pp 544-556

66-71 Metallic Materials and Elements for Aerospace Vehicle Structure, Mil-Hndbk -5A, amplifying Ref. 66-10, DOD, Supplement of 30 November 1966

66-72 How to Use Titanium, TIMET, August 1966

66-73 Armco 17-4PH Precipitation-Hardening Stainless Steel, Sheets and Strip, Product Data Brochure S-9A, Armco, April 1966 (Supersedes Ref. 65-37)

66-74 Armco 17-7PH Precipitation-Hardening Stainless Steel, Bar and Wire, Product Data Brochure S-29, Armco, July 1966

The following unpublished Data Sheets, Typical Mechanical Properties at Various Temperatures, from Alcoa Research Laboratories:

- 66-75 356-T6 Sand Castings, 18 December 1966
- 66-76 2024-T4, 31 December 1966
- 66-77 5456-0, 11 March 1966
- 66-78 5456-H321, 11 March 1966
- 66-79 7075-T6, -T6511 Extrusion, 4 April 1966
- 66-80 7075-T6 Die Forgings, 4 April 1966

66-81 E.A. Franco-Ferreira, Progress Report, ORNL to SNPO-C, Contract SNC-17, 14 October 1966, covering Period from August 1966 through September 30, 1966

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1965

- 65-1 Cryogenic Materials Data Book, ML-TDR-64-280 (PB171809, Revised) AFSC, Aug. 1964, with Supplements through July 1965
- 65-2 Alloy Digest Sheet Ni-102, Engineering Alloys Digest, Upper Montclair, N.J., 1965
- 65-3 Udimet 718 Alloy Performance Data, Special Metals, Inc., New Hartford, N.Y., 1965
- 65-4 Properties of Ti-6 Al-4V, Titanium Engineering Bulletin No. 1, TIMET, Revised February 1965
- 65-5 Titanium and Titanium Alloy Sheet, Strip and Plate, Specification MIL-T-9046, September 1965
- 65-6 R.A. Nadler, Mechanical Properties of Vacuum Hot Pressed and Extruded Beryllium, WANL-TME-1106, February 1965
- 65-7 T.K. Redden, et al, "Making TD Nickel Parts" - Metals Progress, January 1965
- 65-8 Alloy Digest Sheet Ni-103, Engineering Alloys Digest, Inc., Upper Montclair, N.J., July 1965
- 65-9 E.A. Franco-Ferreira, Materials Evaluation Program, 5th Progress Report, ORNL Central Files Report 65-2-54, February 1965
- 65-10 Titanium Alloy Sheet and Strip, SAE Specification AMS 4907, September 1965
- 65-11 UNITEMP HX Technical Data, Universal Cyclops Steel Co., 1965
- 65-12 Technical Literature, Basic Carbon Co., Undated
- 65-13 The Industrial Graphite Handbook, Union Carbide Corporation, 1965
- 65-14 G.R. Kilp, Destructive Test Evaluation of NRX-A2 Fuel Elements, WANL-TNR-194, Jan 1965 (C-RD, Title Unclassified)
- 65-15 G.R. Kilp, Destructive Test Evaluation of NRX-A3 Fuel Elements, WANL-TNR-200, May 1965 (C-RD, Title Unclassified)
- 65-16 G.R. Kilp, Destructive Test Evaluation of NRX-A4 Fuel Elements, WANL-TNR-207, Dec 1965 (C-RD, Title Unclassified)
- 65-17 Unpublished Test Data, WANL Materials Department, 1965
- 65-18 P.S. Hessinger, Beryllium Oxide Booms in Space Age, Technical Report E-6, National Beryllia Corp., North Bergen, N.J., Undated
- 65-19 G.E. Parker, Status Report on Flexible Poison Wire Development - WANL-TME-1172, May 1965
- 65-20 J. Fredrickson, et al, (Union Carbide Corp.), "Boron Nitride in Aerospace Application", Metals Progress, February 1965
- 65-21 Boron Nitride, Catalog Section H-8745EC, National Carbon Co., Not Dated
- 65-22 E.G. Kendall, et al, (Aerospace Corp.), "Non-Metallic Materials for High Temperature Structural Applications" - Symposium on Newer Structural Materials in Aerospace Vehicles, ASTM STP 379, 1965
- 65-23 V. Kachur, Properties of P-03 Graphite, WANL-TME-1031, January 1965
- 65-24 V. Kachur, et al, Isostatically Molded P-03 Graphite for Large Structures, WANL-TME-1190, June 1965
- 65-25 Technical Literature, Pure Carbon Co. Inc., not dated
- 65-26 Armalon, Technical Bulletin, DuPont Plastics Dept., Wilmington, Del., 1965
- 65-27 Technical Properties of DuPont "Teflon" TFE-Fluoro-Carbon Resin, Metallurgical Consultants, Inc., Montebello, Calif., 1965
- 65-28 Technical Bulletin AE-132, Adhesive Engineering Company, San Carlos, Calif., 1965
- 65-29 Metlbond 402 Adhesive, Technical Bulletin, Narmco Materials Division, Whittaker Corp., Costa Mesa, Calif., January 1965
- 65-30 Kapton, Technical Bulletin, DuPont Plastics Dept., Wilmington, Del., 1965

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1965 (CONTINUED)

- 65-31 "Materials Selector Issue", Materials in Design Engineering, 62, No. 5, Mid-October 1965
- 65-32 Handbook of Huntington Alloys, 3rd Edition, Huntington Alloys, January 1965
- 65-33 Alloy Sheet and Plate, Corrosion Resistant, SAE Specification AMS 5536, February 1965
- 65-34 Metallic Materials and Elements for Flight Vehicle Structures, Mil-Hndbk-5, August 1962 with supplements through 1 June 1965 (Supersedes Ref. 61-2)
- 65-35 Inconel Alloy 718 Design Properties, Data Sheet 3.4.1, Liquid Rocket Operations, AGC, 1965
- 65-36 A.M. DeGoer, et al, "Thermal Conductivity of BeO", J. of Nuclear Materials, 17, 159, 1965
- 65-37 Armco 17-4 PH Precipitation-Hardening Stainless Steel Sheets and Strip, Product Data Bulletin S-9A, Armco, November 1965 (Superseded by Ref. 66-73)
- 65-38 Alloy Sheet and Plate, Corrosion and Heat Resistant, SAE Specification AMS 5536, February 1965
- 65-39 H.W. Wyatt, Statistical Summary of Production Beryllium Sheet Mechanical Properties for the Year 1964, Brush Beryllium Company Tech. Information Sheet 112, January 1965
- 65-40 Arc-Cast Tungsten -25% Rhenium, Preliminary Draft, Technical Bulletin, Cyclops Corp., Bridgeville, Pa., October 1965
- 65-41 Tungsten - 26% Rhenium Seamless Tubing, Hoskins Mfg. Co., Detroit, Mich., Received 1965
- 65-42 Carb-I-Tex, Bulletin 112, Basic Carbon Corp., Sanborn, N.Y., 1965
- 65-43 Bulletin 148, Basic Carbon Corp., Sanborn, N.Y., 1965
- 65-44 V. Kachur, Design Properties of Carb-I-Tex Graphite, WANL Memo (unpublished), November 1965
- 65-45 V. Kachur, Design Properties of TS-699 Graphite, WANL Memo (unpublished), November 1965
- 65-46 Design Ahead with Purebon Carbon-Graphites for Mechanical Applications, Pure Carbon Co., St. Mary, Pa., 1965
- 65-47 J. Valentich, Mechanical and Thermophysical Properties of Ten Grades of Graphite, Report 19653, Westinghouse R & D Center, September 1965
- 65-48 Thermal Expansion of Six Grades of Graphite, Final Report, SRI, under Contract to Westinghouse, Pittsburgh, August 1965
- 65-49 W.H. Duckworth, et al, Refractory Ceramics of Interest in Aerospace Structural Applications - A Material Selector Handbook, Supplement 2, Battelle Report for AFML, 1965 (Revision of Ref. 64-18)
- 65-50 H.G. Thornton, NERVA Materials Irradiation Program, Volume 3, GTR Test 17 - AGC Materials Test, Report FZK-263-3, Contract AF 29(601)-6643, GD/FW, 30 December 1965
- 65-51 J.N. Locke, Pressure Vessel Material Investigation and Research, REON Report RN-TM-0157, June 1965
- 65-52 Epoxy Resin Sealant, WANL Specification PDS 30167, May 1965
- 65-53 Sealing, Moisture-Cables, WANL Specification PS 294624, December 1965
- 65-54 Cement, Electrical, WANL Specification PDS 30174, May 1965
- 65-55 Armstrong Epoxies Product Data Armstrong Activator "W", Brochure, Armstrong Products Co., Warsaw, Indiana, March 1965
- 65-56 W.W. Johnson (ORNL), "Electrical Resistivity of Beryllium Oxide," High Temperature Thermometry, Papers presented at Seminar, AEC Headquarters, on 24-26 February 1965, Report WASH-1067 (TID-4500), March 1966

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1965 (CONTINUED)

- 65-57 J.J. Dillon, et al, Cryogenic and Elevated Temperature Properties of 7039 Aluminum Plate and Weldments, Report ACF-412-262, ACF Industries, Albuquerque Division, October 1965
- 65-58 Letter, Y.S. Touloukian (TPRC) to C.W. Funk (REON), April 1965
- 65-59 Aluminum Alloy 7039, Kaiser Aluminum and Chemical Corp., June 1965
- 65-60 Inconel 718, AGC Material Data Sheet 3.4.1, October 1965 (Same as Ref. 65-35)
- 65-61 Aerospace Structural Metals Handbook, Syracuse University Institute, AFSC Project 7381, Contract AF 33(615)-1184, through Supplement of March 1965 (Supersedes Ref. 64-8)
- 65-62 C.R. Denaburg, Low Temperature Mechanical Properties of Aluminum Alloy 2219-T87, 0.040-in. thick sheet through 5.000-in. thick plate, NASA Tech. Memo TM-X-53332, Marshall Space Flight Center, September 1965
- 65-63 James E. Campbell (Battelle), Copper, Brass, Bronze Application Data 104/5, Copper Development Institute, Inc., New York City, undated, received 1965
- 65-64 Working Data, Selection, Description, Fabrication, Carpenter Stainless and Heat Resisting Steels, Carpenter Steel Co., Reading, Pennsylvania, 1965
- 65-65 R.Q. Barr, et al, Development of High Toughness in Unalloyed Molybdenum, Technical Data, Climax, 1965
- 65-66 Molybdenum for Nuclear Energy Applications, A Perspective, Climax Molybdenum Company, undated, received 1965
- 65-67 G.W. Birdsall, Editor, The Aluminum Data Book, Reynolds Metals Company, Richmond, Virginia, 1965
- 65-68 Engineering Properties of Incoloy Alloy 800, Technical Bulletin T-40, Huntington Alloys, 1965
- 65-69 H.J. Busboom, et al, Radiation Damage in Incoloy-800, General Electric - San Jose, a paper for the ANS Winter Meeting, November 1965, prepared for the AEC under Contract AT(04-3)-189, November 1965
- 65-70 Basic Facts about Titanium, Reactive Metals, Inc., Niles, Ohio, 1965
- 65-71 A.V. Levy, Type 347 Stainless Steel, AGC Material Data Sheet 3.2.2, September 1965
- 65-72 L.P. Rice, Metallurgy and Properties of Thorium-Strengthened Nickel, Battelle, DMIC Memo 210, Contract AF 33(615)-1121, October 1965
- 65-73 "Metals Reference Issue", p. 43, Machine Design, 9 September 1965
- 65-74 Hastelloy Alloy N, Stellite, May 1965
- The following Tentative Specifications for Nickel-Iron-Chromium Alloy, ASTM:
 - 65-75 Seamless Pipe and Tube, ASTM B 407 - 65 T; Revised 1965
 - 65-76 Rod and Bar, ASTM B 408 - 65 T; Revised 1965
 - 65-77 Plate, Sheet, and Strip, ASTM B 409 - 65 T; Revised 1965
- 65-78 A.J. McCulloch, et al, Fatigue Behavior of Sheet Materials for the Supersonic Transport, Technical Report AFML-TR-64-399, Volumes I and II, Lockheed-California Company to AFML, (DMIC 62422), January 1965
- 65-79 R.D. Betts, et al, Weld Efficiencies of Inconel 718 Gas Tungsten Arc Welds in the -423 to 1500° F Temperature Range, North American Aviation, Canoga Park, Final Report MPR 5-175-363, (DMIC 63649), July 1965

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

REFERENCES

REFERENCES - 1965 (CONTINUED)

- 65-80 Low Temperature Properties of a Large Inconel 718 Forging for Two Heat Treated Conditions, North American - Rocketdyne Report MPR 5-175-08, (DMIC 63743), January 1965
- 65-81 E.B. Tilley, Evaluation of Inconel 718 Alloy, Solar Division, International Harvester Company, San Diego, Calif., Research Report RDR 1181-2 (DMIC 66577), June 1965
- 65-82 T.K. Redden, Development of Joining Techniques for TD Nickel, GE-Cincinnati, Report DM 65-61 (USAF IPR 3-8-211), Contract AF 33(615)-1403, (DMIC 59154), February 1965
- 65-83 L.P. Rice, Metallurgy and Properties of Thoria-Strengthened Nickel, Battelle DMIC Memo 210 (DMIC 62770), October 1965
- 65-84 Bending Fatigue Tests of 17-4PH Stainless Steel Cast Sheet, Boeing Company (DMIC 68007), 1965
- 65-85 J.J. Glackin, et al, Evaluation of Fasteners and Fastener Materials for Space Vehicles, Final Report to MSFC, Contract NAS 8-11125, December 1965
- 65-86 S.H. Bush, et al, "The Effects of Neutron Exposure and Reactor Environments on Stainless Steel", Advances in the Technology of Stainless Steels and Related Alloys, STP 369, ASTM, April 1965
- 65-87 Haynes Investment Cast Steels, Stellite, August 1965
- 65-88 T.E. Tietz, et al, Behavior and Properties of Refractory Metals, Standard University Press, 1965
- The following papers from Volume II, Advances in Cryogenic Engineering, Proceedings of the 1965 Cryogenic Engineering Conference, at Rice University, Houston, Texas, August 23-25, 1965:
- 65-89 D.T. Eash, "A Cryostat for Izod Impact Testing," Paper G-1, pp 401-408
- 65-90 S.W. McLaren, et al, "Cryogenic Design Data and Criteria of Aerospace Materials subjected to Uniaxial and Biaxial Stress States," Paper G-8, pp 453-469
- The following paper from ASTM-STP No. 387, Behavior of Materials at Cryogenic Temperatures, a Symposium Presented at the 68th Annual Meeting, ASTM, Lafayette, Indiana, June 13-18, 1965:
- 65-91 R.L. Powell, "Thermophysical Properties of Metals at Cryogenic Temperatures," pp 134-148
- 65-92 M. Field, et al, "Machining Titanium Alloys", Metal Progress, February 1965
- The following unpublished Data Sheets from Alcoa Research Laboratories, Typical Mechanical Properties at Various Temperatures, (L.W. Mayer, Editor):
- 65-93 2014-T81 and -T851, 17 December 1965
- 65-94 6061-T6, T651, 7 December 1965
- 65-95 7178-T61, 25 October 1965
- 65-96 5083-H321, 25 June 1965
- 65-97 D.E. Kunkle, et al, "Densities of Wrought Aluminum Alloys", pp 226-240, Journal of Metals, 1965
- 65-98 E.A. Franco-Ferreira, Fifth Progress Report to SNPO-C, Materials Evaluation Program, September 1, 1964 through February 1, 1965, ORNL Central Files No. 65-2-54, 26 February 1965
- 65-99 Steels for Elevated Temperature Service, U.S. Steel, 1965 (Supersedes Ref. 49-1)
- 65-100 W.F. Simmons, et al, (Battelle), Report on the Elevated Temperature Properties of Stainless Steels, Data Series Publication DS-5-51, ASTM, December 1965

DATE	15 JULY 1970
-------------	--------------

SUPERSEDES	15 MAR 1970
-------------------	-------------

REFERENCES
REFERENCES - 1965 (CONTINUED)

- 65-101 S. Katzoff, editor, Symposium on Thermal Radiation of Solids, Held at San Francisco, California, March 4, 5, 6, 1964, NASA SP-55 (Air Force ML-TDR-64-159, published 1965)
- 65-102 V. Frick, Thermal Expansion of TPA Materials, AGC Materials Development Report 65-146, M-1 Program, 2 March 1965

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1964

- 64-1 Thermal Expansion Characteristics of Various Materials, Unpublished Test Data, WANL, not dated
- 64-2 Mechanical Properties of Various Materials, Unpublished Test Data, WANL, not dated
- 64-3 Superseded by Ref. 65-34
- 64-4 Hastelloy Alloy X, Stellite Div., Union Carbide Corp., October 1964
- 64-5 Fabrication of Hastelloy Alloys, Stellite, December 1964
- 64-6 Effects of Low Temperatures on Structural Materials, NASA-SP-5012, Marshall Space Flight Center, December 1964
- 64-7 Cryogenic Tensile Properties of Selected Materials, REON Report 2712, January 1964
- 64-8 Aerospace Structural Metals Handbook, Syracuse University Institute, AFSC Project 7381, Contract AF 33(616)-7792, through Supplement of March 1964 (supersedes Ref. 63-56)
- 64-9 P.J. Levine, Evaluation of Thoria Dispersion Hardened Nickel for NERVA Applications, WANL-TME-755, April 1964, (C-RD, Title Unclassified)
- 64-10 V. Kachur, Properties of P-03 Graphite, WANL-TME-1031, November 1964
- 64-11 V. Kachur, Survey of Graphite Materials for NRX-B Module Tubes, WANL-TME-741, April 1964
- 64-12 "Wrought Austenitic Stainless Steel", Materials and Process Manual 224, Materials in Design Engineering, Reinhold Publ. Corp., October 1964
- 64-13 Determination of Low-Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colo., October 1964
- 64-14 J.A. Begley, Gadolinium Stainless Steel Development, Part I, WANL-TME-672, February 1964 (C-RD, title unclassified)
- 64-15 Progress Report, NERVA Nuclear Sub-System, WANL-PR(J)-033, August 1964 (C-RD, title unclassified)
- 64-16 P.J. Levine, Evaluation of NI-SPAN-C 902 for NERVA Fasteners, WANL-TME-741, March 1964
- 64-17 "Coppers", Materials and Process Manual 226, Materials in Design Engineering, Reinhold Publ. Corp., December 1964
- 64-18 J.R. Hague, et al, Refractory Ceramics of Interest in Aerospace Structural Applications - A Materials Selection Handbook, Battelle Report RTD-TDR-63-4102, (for the American Ceramic Society, Inc.), 1964
- 64-19 E.K. Storms, A Critical Review of Refractories, LASL Report TID-4500 (31st Edition), AEC Contract N-7405-Eng. 36, Aug. 1964
- 64-20 W.D. Wood, et al, Thermal Properties of High Temperature Materials - Battelle Report RSIC-202 (for U.S. Army Missile Command, Redstone Arsenal), June 1964
- 64-21 Boron Nitride, Mechanical and Refractory Properties, Technical Data Sheet 1B164, Carborundum Co., not dated
- 64-22 J.C. Hedge, et al, Thermal Properties of Fifteen Refractory Materials, AIAA Publication CP-8, 1964
- 64-23 E.E. Kerlin and E.T. Smith, Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum and Cryo-temperatures on Engineering Materials - Report FZK-188-1, Vol. I, GD/FW, May 1964
- 64-24 APCO 1252, Product Technical Bulletin, Applied Plastics Co., El Segundo, Calif., January 1964
- 64-25 A.V. Levy, Pyrolytic Graphite, Material & Fabrication Data Sheets, Vol. II, AGC, April 1964
- 64-26 Aluminum Alloy Castings, High Strength, Specification MIL-A-21180, January 1964

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

REFERENCES

REFERENCES - 1964 (CONTINUED)

- 64-27 Heat Treatment of Nickel-Base Alloy (19Cr-5Cb-3Mo-Ti-Al), AGC Process Specification 46604, April 1964
- 64-28 Heat Treatment of Nickel-Base Alloy (19Cr-5Cb-3Mo-Ti-Al), AGC Process Specification 46626, January 1964
- 64-29 The Industrial Graphite Engineering Handbook, Carbon Products Division of Union Carbide, April 1964
- 64-30 M.F. Berard, et al, Elevated Temperature Properties of Grades ATJ and H-249 Graphite, AGC Report M-548 for LMSC, Contract NOw 63-0050c (FBM), July 1964
- 64-31 D-979, Bulletin SS-79, Allegheny Ludlum Steel Corp., April 1964
- 64-32 Specification M3603B for Alloy D979, Lycoming Division, AVCO Corp., April 1964
- 64-33 Tungsten-25% Rhenium Alloy GE-125, Temporary Product Data Sheet, GE-Detroit, August 1964
- 64-34 Rhenium and Alloys, Chase Publication RE-3, Chase Brass and Copper Co., 1964
- 64-35 P.E. Armstrong, et al, Dynamic Young's Modulus Measurements above 1000° C on Some Pure Polycrystalline Metals and Commercial Graphites, Trans. of Metallurgical Society of AIME, Vol. 230, August 1964
- 64-36 P.T.B. Shaffer, "High Temperature Materials", Vol. 1, Materials Index, Plenum Press, N.Y., 1964
- 64-37 W.D. Wood, et al, "High Temperature Materials", Vol. 3, Thermal Radiative Properties, Plenum Press, N.Y. 1964
- 64-38 Letter, re Inconel 718, H.L. Eiselstein (Huntington Alloys) to R.F. Bechtold (AGC), 9 March 1964
- 64-39 Silastic Adhesives, Bulletin 09-061, Dow Corning Corp., Feb. 1964
- 64-40 Materials Symposium - Seventh Annual Proceedings, Society of Aerospace Materials and Process Engineers, 1964
- The following WANL Specifications:
- 64-41 Resin Base Adhesives, PDS 30151, April 1964
- 64-42 Carbon Base Cement, PDS 30159, October 1964
- 64-43 Bonding, Graphite to Graphite, PS 294518, November 1964
- 64-44 Silicone Rubber Adhesive, PDS 30163, February 1964
- 64-45 Bonding, Purge Seal Boots to Pressure Vessels, PS 294600, February 1964
- 64-46 Repair of Defects in Structural Graphite, PS 294566, April 1964
- 64-47 D.E. Baker, Journal of Nuclear Materials, 12 (1964), pp 120-124
- 64-48 D.A. Roberts, Review of Recent Developments, Nickel-Base and Cobalt-Base Alloys, DMIC, September 1964
- 64-49 Pure Beryllium Oxide Ceramic Components and Assemblies; Technical Data, National Beryllia Corporation, Haskell, New Jersey, May 1964
- 64-50 H. Braun, et al, "Recent Developments in the Technology of Arc-Cast Molybdenum", Climax Molybdenum Co., Reprint from Plansee Proceedings 1964 - Metals for the Space Age, Reutte/Tyrol, June 1964
- 64-51 D.A. Roberts, Review of Recent Developments, Nickel-Base and Cobalt-Base Alloys, DMIC, February 1964
- 64-52 Basic Product, Crucible Waspaloy, Crucible Steel Company, Pittsburgh, August 1964
- 64-53 Unitemp Waspaloy, Universal Cyclops Steel Corporation; undated, received 1964
- 64-54 Properties of Waspaloy Sheet, Data Sheet, Stellite, June 1964

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1964 (CONTINUED)

The following from Special Metals, Inc., New Hartford, N.Y.:

- 64-55 Udimet 630 (Preliminary Release), undated, received 1964
- 64-56 Udimet 630, Preliminary Alloy Evaluation Summary, December 1964
- 64-57 Udimet 700, Alloy Performance Data, undated, received 1964
- 64-58 Fabrication, Joining, and Finishing of Nickel-Base Superalloys, undated, received 1964
- 64-59 Carpenter Waspaloy, Data Sheet, Carpenter Steel Company, undated, received 1964

The following AEC R and D Reports, by GE-Vallecitos for AEC, Contract AT(04-3)-189:

- 64-60 C.N. Spalario, Incoloy-800 for Nuclear Fuel Sheaths, Report GEAP-4633, July 1964
- 64-61 R.R. Kirby, et al, Fabrication of Fuel Cladding from Incoloy-800, Report GEAP-4557, April 1964
- 64-62 Myron B. Reynolds, Strain-Cycle Phenomena in Thin-Wall Tubing, Report GEAP-4462, January 1964
- 64-63 Current Data Report, Inconel Alloy 718, INCO (supersedes Ref. 61-35), November 1964
- 64-64 Hot Hardness of Wrought Udimet 700, Udimet 50, and Udimet 41 Barstock, Special Metals, Inc., undated, received 1964
- 64-65 Local Aging of Inconel 718, AGC Specification 46688, September 1964

The following Data Sheets, Jones and Laughlin Steel Corp.:

- 64-66 J&L Type 303 Stainless Steel, April 1964
- 64-67 J&L Type 304 Stainless Steel, April 1964
- 64-68 J&L Type 347 Stainless Steel, April 1964
- 64-69 J&L Type 440C Stainless Steel, April 1964
- 64-70 R.B. Dull, Research and Development on Advanced Graphite Materials, Vol. XXVI: Physical Properties of Some Newly Developed Graphite Grades, National Carbon Co. for AFSC, WADD TR 61-72, Contract AF 33(616)-6915, May 1964
- 64-71 Cryogenic Properties of Haynes Alloys, Stellite, March 1964
- 64-72 A.V. Levy, Forged Unalloyed Tungsten, Materials Data Sheet 4.1.7, AGC, July 1964
- 64-73 A.V. Levy, Plasma Arc Sprayed Tungsten, Materials Data Sheet 4.1.6, AGC, May 1964
- 64-74 Grafoil Data Sheets, High Temperature Materials, Inc., received 1964
- 64-75 R.C. Goodspeed, Evaluation of Foil-Type Pyrolytic Graphite Insulating Sleeves, WANL-TME-969 (C-RD), October 1964
- 64-76 Low Temperature Properties of Cast Inconel 718, North American-Rocketdyne, Canoga Park, Calif., Progress Report No. 1, Report MPR 4-251-399, (DMIC 63673), June 1964
- 64-77 T.K. Redden, et al, Development of Joining Techniques for TD Nickel, GE-Cincinnati, Report DM64-299, (IPR 1-8-211, USAF), Contract AF 33(615)-1403, (DMIC 56695), August 1964
- 64-78 Z.R. Wolanski, Material Evaluation - 17-4 pH CRES, H-900 Condition, Fatigue Characteristics, GD/FW, Tech. Memo 3287, (DMIC 66105), June 1964
- 64-79 A.V. Levy, ATJ Molded Graphite, Materials Data Sheet 5.2.1, AGC, 9 April 1964
- 64-80 A.V. Levy, Pyrolytic Graphite, Materials Data Sheet 5.1.1, AGC, 29 April 1964

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

REFERENCES

REFERENCES - 1964 (CONTINUED)

64-81 The Ultimate Strength, Elastic Modulus, and Poisson's Ratio of Grades ATJ and H-249 Graphite in Tension and Compression from 70° F to 5000° F, SRI report to AGC, Purchase Order S-427192-OP, 20 July 1964

The following GD/A Reports by J.L. Christian, et al, under Contract AF 33(657)-11289, Physical and Mechanical Properties of Pressure Vessel Materials for Application in a Cryogenic Environment:

64-82 Report 63-0818-4, for WADD, Contract AF 33(657)-11289, Phase II, Quarterly Progress Report for Period Ending 15 August 1964

64-83 Report ASD-TDR-62-258, Part III, for AFSC, under Contract AF 33(657)-11289, December 1964

The following papers from Volume 10, Advances in Cryogenic Engineering, Proceedings of the 1964 Cryogenic Engineering Conference, University of Colorado Engineering Research Center, Boulder, Colorado, August 18-21, 1964:

64-84 F.R. Schwartzberg, et al, "Fatigue Behavior of Aluminum and Titanium Sheet Materials Down to -423° F", Paper A-1, pp 1-13

64-85 R.P. Reed, et al, "An Anomalous Decrease of the Elastic Moduli at Very Low Temperatures in Some 300 Series Stainless Steels", Paper A-5, pp 46-49

64-86 W. Weleff, et al, "Cryogenic Tensile Properties of Selected Aerospace Materials", Paper A-2, pp 14-25

64-87 W. Weleff, et al, "Shear Strength of Several Alloys at Liquid Hydrogen Temperatures", Paper A-6, pp 50-55

64-88 T.F. Kiefer, et al, "Charpy Impact Testing at 20°-K, Paper A-7, pp 56-62

64-89 J.L. Christian, et al, "Mechanical Properties of Several 2000 and 6000 Series Aluminum Alloys", Paper A-8, pp 63-76

64-90 Titanium Welding Procedures, Titanium Engineering Bulletin No. 6, TIMET, Revised September 1964

64-91 Titanium, Form No. 186, Harvey Titanium, Division of Harvey Aluminum, 1964

The following unpublished Data Sheets, Mechanical Properties at Various Temperatures, Alcoa Research Laboratories:

64-92 2014-T6 Extrusions, 25 May 1964

64-93 2014-T6, 10 April 1964

64-94 7079-T6 Extrusions, 7 April 1964

64-95 7079-T6 and -T651 Products (Except Extrusions), 10 April 1964

64-96 7178-T651 Products, Except Extrusions, 19 June 1964

64-97 5083-0, 30 January 1964

The following papers from Volume LVII, Transactions of American Society for Metals, 1964:

64-98 J.L. Christian, et al, "Effects of Cold Rolling on the Mechanical Properties of Type 310 Stainless Steel at Room and Cryogenic Temperatures", pp 199-207

64-99 M.I. Jacobson, "Tensile Properties of Extruded Beryllium from 195 to 200°C", pp 482-493

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES
REFERENCES - 1964 (CONTINUED)

The following papers from Volume 64, Proceedings, ASTM, 1964:

- 64-100 R.F. Broderick, et al, "Fatigue, Tension, and Stress-Rupture Tests of Tungsten at 6000°F with an Electron-Beam Furnace", pp 505-515
- 64-101 J.O. Lyst, "Variation in Fatigue Properties of Aluminum Alloys 2014-T6, 7075-T6, and 7079-T6 with Respect to Direction of Working", pp 581-594
- 64-102 D.Y. Wang, "Fatigue Behavior of Tantalum and the Effect of Strain Aging", pp 595-611
- 64-103 T.G. Kollie, et al, "A Thermal Comparator Apparatus for Thermal Conductivity Measurements from 50 to 400°C," Nuclear Metallurgy, Volume X, International Symposium on Compounds of Interest in Nuclear Reactor Technology, IMD Special Report 13, Metallurgical Society of AIME, 1964

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1963

- 63-1 Bulletin - (Excerpts from Journal of Teflon) Dixon Corporation, Bristol, Rhode Island
- 63-2 R.L. Lowell, et al, Cryogenic Properties of Reactor Materials, unpublished report, NBS
- 63-3 Data Obtained from First Irradiation Test of Structural Materials, REON Report 2473, April 1963
- 63-4 Preliminary Data for Consutrode Melted D-979 Alloy, Report 06052, Allegheny-Ludlum Steel Corporation, 1963
- 63-5 Technical Data on Stainless Steel, J.T. Ryerson Division, Allegheny-Ludlum Steel Corporation, 1963
- 63-6 Beryllium in Aerospace Structures, Brush Beryllium Co., 1963
- 63-7 Mechanical Properties of Aluminum Alloys at Cryogenic Temperatures, Report 23242, GD-San Diego, 1963
- 63-8 Pyrolytic Graphite Handbook, GE, June 1963
- 63-9 Superseded by Ref. 63-24
- 63-10 Mechanical Properties of Ni-SPAN-C Iron-Nickel-Chromium Alloy 902, pre-publication data, INCO, July 1963
- 63-11 Lescalloy 718 Vac Arc, Data Sheet, Latrobe Steel Company, July 1963
- 63-12 Unpublished Test Data, Advanced Materials Laboratory, National Carbon Company, 1963
- 63-13 Bulletin 101 JB, National Carbon Company, 1963
- 63-14 Superseded by Ref. 62-29
- 63-15 Westinghouse Figuring Book 103994, WANL, 1963
- 63-16 Test Data supplied to WANL by vendors: Alco Products Inc., Baldwin-Lima-Hamilton Corp., and Ladish Forging Co., 1963
- 63-17 Materials for Advanced Technology, Carborundum, Zirconium, and Zirconium Alloys, Carborundum Company, 1963
- 63-18 Superseded by Ref. 63-78
- 63-19 Aluminum Alloy 7039 Bulletin, Kaiser Aluminum and Chemical Co., 1963
- 63-20 Hastelloy Alloy C, Stellite, June 1963
- 63-21 Mechanical and Physical Properties of the Austenitic Chromium-Nickel Stainless Steels at Elevated Temperatures, INCO, 1963
- 63-22 Mechanical and Physical Properties of the Austenitic Chromium-Nickel Stainless Steels at Sub-Zero Temperatures, INCO, 1963
- 63-23 Supplementary Information to Brochure on Kaiser Aluminum Alloy 7039 - Kaiser Aluminum and Chemical Co., June 1963
- 63-24 Engineering Properties of Inconel Alloy X-750, Bulletin T-38, Huntington Alloys, 1963
- 63-25 TD Nickel Sheet - Dispersion Strengthened Nickel, New Product Information Data Sheet A-31353, DuPont Metals Co., Revision of June 1963
- 63-26 Private Communication, DuPont Metals Co., March 1963
- 63-27 TD Nickel Sheet - Dispersion Strengthened Nickel, New Product Information Data Sheet A-30682, DuPont Metals Co., April 1963
- 63-28 Allegheny Free Machining Stainless Steels Types 303 EZ, 416, 430F, Data Sheet, Allegheny-Ludlum Steel Corp., 1963
- 63-29 See Ref. 64-8

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1963 (CONTINUED)

- 63-30 Types 347, 348 and 321, Data Sheet, Allegheny-Ludlum Steel Corp., 1963
- 63-31 Private Communication, H.A. Wilson Co. (Division of Engelhard Industries), 13 November 1963
- 63-32 Engineering Properties of Ni-SPAN-C-902, Bulletin T-31, Huntington Alloys, 1963
- 63-33 K.A. Warren, et al, Tensile and Impact Properties of Selected Materials from 20° to 300° K, NBS Monograph 63, June 1963
- 63-34 Lescalloy A-286 Vac-Arc, Data Sheet, Latrobe Steel Co., 1963
- 63-35 A.J. Rothman, Beryllium Oxide for Nuclear Propulsion Applications, Report UCRL-7428 - Lawrence Radiation Laboratory, University of California, July 1963
- 63-36 Data Book, Vol. 3 Non-metallic Elements, Compounds and Mixtures, TPRC, 1963 (and as Supplemented)
- 63-37 The Thermal Properties of Twenty-Six Solid Materials to 5000°F or Their Destruction Temperature, SRI, Report ASD-TDR-62-765, (for Aeronautical Systems Division, WADD), January 1963, (Supplements 62-100)
- 63-38 J.R. Hague, et al, Refractory Ceramics of Interest in Aerospace Structural Applications - A Materials Selection Handbook, Battelle Report RDT-TDR-63-4102, WADD Contract AF-33(657)-8326, October 1963
- 63-39 Engineering Properties of Tantalum and Tantalum Alloys, DMIC Report 189, Battelle, September 1963
- 63-40 The Engineering Properties of Molybdenum and Molybdenum Alloys, DMIC Report 190, Battelle, September 1963
- 63-41 Properties of "Vespel" Fabricated Parts, DuPont Plastics Dept., Wilmington, Del.
- 63-42 Technical Information on Epon Adhesives, Bulletin SC-60-112, Rev., Shell Chemical Co., May 1963
- 63-43 J.L. Christian, et al, Physical and Mechanical Properties of Pressure Vessel Materials for Application in a Cryogenic Environment, Part II, GD/A Report ASD-TDR-62-258, for WADD, April 1963
- 63-44 Inconel Nickel-Chromium Alloy 625, Supplementary Data, Brochure S-22, Huntington Alloys, April 1963
- 63-45 Aluminum Alloy Bar, Rod and Wire, Rolled, Drawn or Cold Finished, 2024, Federal Specification QQ-A-225/6, December 1963
- 63-46 Aluminum Alloy Sand Castings, Federal Specification QQ-A-601c, Amd 2, October 1963
- 63-47 High Temperature Materials and Reactor Component Development Programs, Second Annual Revision, Vol. I, "Materials", GEMP 177A, General Electric Co., Cincinnati, Ohio, February 1963
- 63-48 F.F. Schmidt, et al, Engineering Properties of Tungsten and Tungsten Alloys, DMIC Report 191, Battelle, September 1963
- 63-49 Bonding Instrumentation to Graphite, WANL Specification PS 294583, September 1963
- 63-50 Silicone Rubber Base Adhesives, WANL Specification PDS 30152, October 1963
- 63-51 H. Nicholson, Evaluation of Orifice Cements for the NERVA Engine, WANL TME-571, November 1963 (C-RD, Title Unclassified)
- 63-52 Armco Precipitation Hardening Stainless Steel Technical Data Manual, Armco, undated
- 63-53 Alloy Digest, Engineering Alloys Digest, Upper Montclair, N.J.
- 63-54 R. Hultgren, et al, Selected Values of Thermodynamic Properties of Metals and Alloys, John Wiley & Sons, 1963
- 63-55 C.V. Lovoy, Low Temperature Mechanical Properties of Aluminum Alloys X2119 and 2219, Internal Note IN-P and VE-M-63-4, Marshall Space Flight Center, March 1963

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1963 (CONTINUED)

- 63-56 Aerospace Structural Metals Handbook, Syracuse University Institute, AFSC Project 7381, Contract AF 33(616)-7792, through Revision of December 1963 (supersedes Ref. 62-51)
 - 63-57 Haynes Alloy No. R-41, Brochure, Stellite, April 1963
 - 63-58 C.C. Lacy, et al (Boeing), "How to Heat Treat Space Age Materials", Metal Progress, March 1963
 - 63-59 G - E Alloy Rene' 41, Data Sheet, Engineering Alloys Digest, Upper Montclair, N.J., January 1963
 - 63-60 Carpenter Vacumeltrol 41, Technical Data Sheet, Carpenter Steel Co., undated, received 1963
 - 63-61 Mechanical and Physical Properties, Austenitic Chromium-Nickel Stainless Steels at Ambient Temperatures, INCO, 1963
 - 63-62 L.W. Mayer, Alcoa Aluminum Alloy 2219, Alcoa Green Letter, not released for publication, revised November 1963 (supersedes Ref. 62-3) (superseded by Ref. 67-37)
 - 63-63 "Machining Heat Treated HS-25 and Inconel Alloy 700", Metal Progress, Data Sheet, April 1963
 - 63-64 Review of Recent Developments, Titanium and Titanium Alloys, DMIC, 13 December 1963
 - 63-65 A.V. Levy, Titanium Alloy 5Al-2.5Sn, Materials Data Sheet 1.4.2, AGC, February 1963
 - 63-66 A.S. Ginsburgh, Unalloyed Molybdenum Forgings, Materials Data Sheet 4.2.1, AGC, January 1963
 - 63-67 Low Temperature Data Sheet, Types 304 and 304L Stainless Steels, INCO, March 1963
 - 63-68 Allegheny Stainless Steel Stabilized Chromium-Nickel Grades Types 347, 348, and 321, Blue Sheet, Allegheny-Ludlum Steel Corp., March 1963
 - 63-69 Allegheny-Ludlum Stainless Steels, Types 440A, B, and C, and 420, Blue Sheet, Allegheny-Ludlum Steel Corp., May 1963
 - 63-70 C.R. Manning, et al, Investigation of a New Nickel Alloy Strengthened by Dispersed Thorium, NASA Report TN-D-1944, July 1963
 - 63-71 Chromium-Nickel Stainless Steel Data, Section 1, Bulletin C, INCO, 1963
 - 63-72 V. Weiss, et al, Further Material Evaluation for Supersonic Transport Aircraft, Syracuse University Research Institute, Final Report MET.E. 873-6312-F, Contract NASr-43, (DMIC 64353), December 1963
 - 63-73 C. Panseri, et al, Fatigue Behavior of the Ti-6Al-4V Alloy at Normal and Hetero-normal Temperatures, Third ICAF-AGARD Symposium on Aeronautical Fatigue, Rome, (DMIC 67015), April 1963
 - 63-74 Stainless Steel Sheet and Strip Manual, Jones and Laughlin Steel Corp., undated, received 1963
 - 63-75 Stainless Steel Bar Manual, Jones and Laughlin Steel Corp., 1963
 - 63-76 6 Al-4V Titanium, Materials Data Sheet 1.4.1, AGC, February 1963
 - 63-77 "Chapter V, Machining Molybdenum - TZM Alloy", Reprinted by Climax-Molybdenum from Final Report on Machining of Refractory Materials, AFML Technical Documentary Report ASD-TDR-581, Contract AF 33(600)-42349, July 1963
- The following paper from Volume 9, Advances in Cryogenic Engineering, Proceedings of the 1963 Cryogenic Engineering Conference, University of Colorado and NBS - Boulder Laboratories, Boulder, Colorado, August 19-21, 1963
- 63-78 F.W. DeMoney, "Performance of a New Cryogenic Aluminum Alloy, 7039", Paper C-3, pp 112-123
 - 63-79 2024-T3, Mechanical Properties at Various Temperatures, Unpublished Data, Alcoa Research Laboratories, 6 September 1963

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1963 (CONTINUED)

- 63-80 J.L. Christian, et al, "Structural Alloys for Cryogenic Service", Metal Progress, pp 101-142, March 1963
- 63-81 J.L. Christian, et al, "A Study of Brittle Fracture in Cryogenic Alloys", pp 103-106, Metal Progress, May 1963
- 63-82 J.L. Taylor, et al, "Tensile Properties of Tungsten from 2500° to 5400° F in vacuum," pp 643-655, Transactions ASM, Volume 56, 1963
- The following papers from Proceedings, ASTM, Volume 63, 1963:
- 63-83 E. DiCesare, "Mechanical Properties of Cold-Drawn Martensitic SAE 4340 Steel Rod," pp 517-534
- 63-84 J.L. Christian, et al, "Effects of Impurity Elements and Cold-Rolling on the Mechanical Properties of Ti-5Al-2.5Sn Alloy at Room and Cryogenic Temperatures," pp 578-597
- 63-85 J.L. Shannon, Jr., "Effects of Several Production and Fabrication Variables on Sharp Notch Properties of 5Al-2.5Sn Titanium Alloy Sheet at Liquid Hydrogen Temperatures," pp 809-823
- 63-86 J.C. Richmond, Editor, Measurement of Thermal Radiation Properties of Solids, NASA Sp-31, 1963

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

REFERENCES

REFERENCES - 1962

- 62-1 "The New Graphites", Union Carbide Co., Reprint of Article from Metals Progress, December 1962
- 62-2 R.L. Smith and J.W. Miser, Unpublished NASA report, NASA Lewis Research Center, January 1962
- 62-3 Alcoa Aluminum Alloy 2219, Alcoa Green Letter, not released for publication, revised December 1962 (superseded by Ref. 63-62)
- 62-4 MST 5Al-2.5Sn Titanium Alloy Data Sheet, Reactive Metals Products Division, 1962
- 62-5 Stainless Steel Working Data, Carpenter Steel Co., 1962
- 62-6 Comparative Properties of Haynes High-Temperature Alloys, Stellite, June 1962
- 62-7 Supplementary Data Report, Inconel 718, Huntington Alloys, September 1962
- 62-8 Inconel X-750 - Supplementary Data, Huntington Alloys, 1962
- 62-9 Lescolloy 718 - Mechanical Properties, Latrobe Steel Co., May 1962
- 62-10 Lescolloy A-286, Data Sheet, Latrobe Steel Co., July 1962
- 62-11 The New World of Carbon and Graphite, Manual 199, Union Carbide Corp., September 1962
- 62-12 Pyrolytic Graphite, High Temperature Materials, Inc., Lowell, Mass., February 1962
- 62-13 Inconel Alloy 718, Brochure S-24, Huntington Alloys, September 1962
- 62-14 Alcoa Aluminum Handbook, Alcoa, 1962 (superseded by Ref. 67-57)
- 62-15 J.L. Christian, Mechanical Properties of High Strength Sheet Materials at Cryogenic Temperatures, GD/A, Report ERR-AN-255, (DMIC 61909), November 1962
- 62-16 Superseded by Ref 62-85
- 62-17 R.L. Flucker, et al, Alcoa Aluminum-Magnesium Alloys Suitable for Structural Welding Applications, Alcoa Green Letter 143, August 1962
- 62-18 Aluminum Alloy Bar, Rod and Shapes, 7079, Interim Federal Specification QQ-A-00200/12, May 1962
- 62-19 Titanium and Titanium Alloy Bars, Forgings and Forging Stock, Specification MIL-T-9047, May 1962
- 62-20 Hastelloy Alloy "N", Stellite, April 1962
- 62-21 Research and Development on Advanced Graphite Materials - Report WADD-TR-61-72, Vol VII, Aeronutronics Division of Ford Motor Co., Newport Beach, Calif., June 1962
- 62-22 Preliminary Data - Inconel Alloy 625, Huntington Alloys, 1962 (date est.)
- 62-23 Elevated Temperature Tensile Properties of Inconel 625, McDonnell Aircraft Report 513-327, October 1962
- 62-24 Letter from B. Duncan to R. Skalka (WANL), 9 October 1962
- 62-25 Working Data, Carpenter Stainless and Heat Resisting Steels, Carpenter Steel Co., 1962
- 62-26 Superseded by Ref. 65-1
- 62-27 Superseded by Ref. 62-84
- 62-28 Haynes Alloy No. 25, Stellite, June 1962
- 62-29 Unpublished Test Data, WANL, 1962

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

REFERENCES

REFERENCES - 1962 (CONTINUED)

- 62-30 Superseded by Ref. 62-82
- 62-31 R.F. Crawford, et al, Strength, Efficiency, and Design Data for Beryllium Structures, Lockheed Missiles and Space Co., Report ASD-TR-61-692 for Aeronautical Systems Division, Wright-Patterson Air Force Base, Contract AF 33(616)-6905, Project 1368. February 1962
- 62-32 Beryllium Oxide, Technical Data, Technical Bulletin 3140-A, The Beryllium Corporation, April 1962
- 62-33 R.A. Beryrev, Beryllium Oxide Properties and Applications, AEC Report TR-6175, 1962
- 62-34 Huntington Alloys - Index of Government and Engineering Society Specifications, 12th Ed., Huntington Alloys, February 1962
- 62-35 Refractory Grain Properties and Applications, Norton Co., Worcester, Mass., 1962
- 62-36 J.A. McGurty, et al, (GE), Tungsten/Tungsten-Rhenium Thermocouple Research and Development, paper presented at SAE National Aeronautics Meeting, April 1962
- 62-37 Haynes Tantalum, Stellite, April 1962
- 62-38 Superseded by Ref. 62-2
- 62-39 Arc-Cast Molybdenum and its Alloys, Universal-Cyclops Steel Corp., 1962
- 62-40 Further Investigations of Notch Sensitivity of Refractory Metals, Battelle Report ASD-TDR-62-1004, December 1962
- 62-41 TZM Development Data, Climax Molybdenum Co., January 1962
- 62-42 Heat Treatment of Steels, Military Specification MIL-H-006875, March 1962
- 62-43 A.S. Ginsburgh, ZTA Graphite, Materials Data Sheet 5.3.1, AGC, November 1962
- 62-44 Heat Treatment of Aluminum Alloys, Specification MIL-8-6088, October 1962
- 62-45 Determination of the Tensile Properties Up to 4500° F and the Impact Ductile-Brittle Transition Temperature of Unalloyed Molybdenum Forgings - SRI Report 5376-1364-XII, June 1962
- 62-46 New Design Data for Teflon, Teflon Design and Engineering Data - DuPont, 1962
- 62-47 Beryllium for Structural Applications, DMIC 168, Battelle, May 1962
- 62-48 6061-T6 Products, Mechanical Properties at Various Temperatures, unpublished data, Alcoa Research Laboratories, Aug. 1962
- 62-49 Materials and Engineering Test Program, WANL-TNR-049, March 1962, (C-RD, Title Unclassified)
- 62-50 Sylvania Tungsten, Chemical and Metallurgical Division, Sylvania, Towanda, N.Y., 1962
- 62-51 G. Sachs, Air Weapons Materials Application Handbook, Metals and Alloys, ARDC-TR-59-66, Syracuse University Institute, (December 1959) and First Supplement (August 1962)
- 62-52 Industrial Graphite Engineering Handbook, Union Carbide, 1962
- 62-53 SRI Report ASD-TDR-62-575, 20-402, 1962
- 62-54 C.E. Cataldo, Weldability Studies, 5456-H343 and 2219-T87 Aluminum Alloy Plates, Internal Note IN-P & VE-M-62-2, Marshall Space Flight Center, April 1962
- 62-55 2024-T86 Products, Mechanical Properties at Various Temperatures, Unpublished Data, Alcoa Research Laboratories August 1962
- 62-56 ELI Titanium for Liquid Hydrogen Applications, Titanium Data for the Aerospace Industry, TIMET, December 1962

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1962 (CONTINUED)

- 62-57 Superseded by Ref. 62-79
- 62-58 2219-T62 Tensile Properties at Sub-Zero Temperatures (Smooth and Notched Specimens), Unpublished graph, Alcoa, October 1962
- 62-59 F.J. Flens, Weldability Investigation of Haynes Alloy No. 25 and Rene' 41, AGC Report TM 154 LRP, Contract AF 04(697) - 521, August 1962
- 62-60 CM-R 41, Vacuum Melted Nickel Base Alloy, Technical Data, Alloy Specialist, Cannon Muskegon Corporation, Muskegon, Michigan, undated, received 1962
- 62-61 Alloy Performance Data, Udimet 41, Technical Data, Special Metals, Inc., undated, received 1962
- 62-62 M.M. Lemco, et al, Determination of the Effects of Elevated Temperature Materials Properties of Several High Temperature Alloys, ASD-TDR-61-529, June 1962
- 62-63 Complex Weldments of Titanium 5Al-2.5Sn - save weight . . ., Titanium Data for the Aerospace Industry, TIMET, undated, received 1962
- 62-64 A.S. Ginsburgh, Unalloyed Wrought Tantalum, Materials Data Sheet 4.3.1, AGC, November 1962
- 62-65 A.S. Ginsburgh, Molybdenum - 0.5 Ti-0.8 Zr Alloy (TZM), Materials Data Sheet 4.2.2, AGC, October 1962
- 62-66 J.L. Christian, Physical and Mechanical Properties of Pressure Vessel Materials for Application in a Cryogenic Environment, GD/A Report ASD-TDR-62-258, prepared for Aeronautical Systems Division, AFSC, under Contract AF 33(616) -7719, March 1962
- 62-67 A.S. Ginsburgh, 95% Dense Unalloyed Pressed and Sintered Tungsten, Materials Data Sheet 4.1.3, AGC, November 1962
- 62-68 A.S. Ginsburgh, 90% Dense Unalloyed Pressed and Sintered Tungsten, Materials Data Sheet 4.1.2, AGC, November 1962
- 62-69 Lescalloy 718 VAC ARC Property Data, Latrobe Steele Co., (DMIC 50031), August 1962
- 62-70 John G. McBride, et al, Creep-Rupture Properties of Six Elevated Temperatures Alloys, Report WADD - TR-61 - 199, prepared by New England Materials Laboratory, Inc., Medford, Mass., for Aeronautical Systems Divisions, AFSC, under Contract AF 33(616)-6200, August 1962
- The following unpublished data sheets, Mechanical Properties at Various Temperatures, Alcoa Research Laboratories:
- 62-71 2014-T6 Products Except Extrusions, 13 August 1962 (Superseded by Ref 68-19)
- 62-72 2014-T6 Extrusions, 13 August 1962 (Superseded by Ref. 64-92)
- 62-73 5456-H321, 29 August 1962 (Superseded by Ref. 66-78)
- 62-74 A.F. Hooper, Compilation of Materials Research Data, First Quarterly Progress Report, Phase I, Convair Astronautics Report MRG-307, Contract AF 33(616)-7984, September 1962
- 62-75 A.S. Ginsburgh, Unalloyed Beryllium Block, Materials Data Sheet 1.2.1, AGC, 22 October 1962

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES · 1962 (CONTINUED)

The following papers from Volume 8, Advances in Cryogenic Engineering, Proceedings of the 1962 Cryogenic Engineering Conference, University of California, Los Angeles, California, August 14-16, 1962:

- 62-76 W.T. Ziegler, et al, "Specific Heat and Thermal Conductivity of Four Commercial Titanium Alloys from 20°K to 300° K", Paper E-6, pp 268-277
- 62-77 B.L. Rhodes, et al, "Thermal Expansion of Several Technical Metals from -255° to 300° C", Paper E-7, pp 278 - 286
- 62-78 A.W. Brisbane, "The Influence of Loading Rate and Stress Concentration Factors on Notch Properties of Three Sheet Alloys at Room Temperature, -78°, and -196° C", Paper L-4, pp 641-653
- 62-79 J.G. Kauffman, et al, "The Properties of Aluminum Alloy 2219 Sheet, Plate, and Welded Joints at Low Temperatures", Paper L-6, pp 661-670
- 62-80 L.P. Rice, et al, "Tensile Property Evaluation of One 5000 - Series Aluminum Alloy at the Temperature of Liquid Helium", Paper L-7, pp 671-677
- 62-81 J.G. Kauffman, et al, "Notch Sensitivity of Aluminum Alloy Sheet and Plate at -320° F Based Upon Notch-Yield Ratio", Paper L-8, pp 678-685

The following Papers from Proceedings, ASTM, Volume 62, 1962:

- 62-82 W.J. Salmen, et al, "Tensile Properties of Beryllium, from Room Temperature to 1600° F", pp 653-664
- 62-83 J.G. Kauffman, et al, "Fatigue Strengths of Recrystallized and Unrecrystallized Heat-Treated Aluminum Alloys", pp 742-755
- 62-84 T.S. DeSisto, "Low Temperature Charpy, True Stress-Strain, and Notched Tensile Properties of Base and Weld Deposits of AISI Types 301, 310, 316, and 347 Stainless Steels", pp 756-764
- 62-85 C.F. Hickey, Jr., "Mechanical Properties of Titanium and Aluminum Alloys at Cryogenic Temperatures", pp 765-777
- 62-86 Schwartzberg, et al, "Mechanical Properties of an Alpha Titanium Alloy at Cryogenic Temperatures", pp 816-824
- 62-87 W.D. Wood, et al, Thermal Radiative Properties of Selected Materials, DMIC Report 177, Volume 1 of 2, November 1962

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1961

- 61-1 L. Simbeck, et al, Preparation of Special Graphite Grades for Jet Propulsion Laboratory High Temperature Studies, Fifth Biennial Conference on Carbon, Pennsylvania State University, June 1961
- 61-2 Strength of Metal Aircraft Elements, MIL-HNDBK-5, March 1961 (superseded by Ref. 65-34)
- 61-3 E.A. Eldridge, et al, Report on Physical Properties of Metals and Alloys, Cryogenic to Elevated Temperatures, ASTM, STP, 296, 1961
- 61-4 See Ref. 61-11
- 61-5 Inconel 718, Current Data Report, Huntington Alloys, May 1961
- 61-6 Taylor Technical Data Bulletin 3.3.1, Taylor Fibre Co., July 1961
- 61-7 Inco 718 - Cryogenic Properties, C.A. Morris, Wyman-Gordon Company, Worcester, Mass., (Interoffice memo to J.E. Coyne), October 1961
- 61-8 D. Pickner, "Columbium, A Bright Future - But How Soon?," Materials in Design Engineering, Report 190, December 1961
- 61-9 Private Communication from Armco, December 1961
- 61-10 Inconel Alloy 718, Brochure S-3, Huntington Alloys, May 1961
- 61-11 J.E. Campbell, Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, DMIC 148, Battelle, February 1961
- 61-12 T. Lyman, editor, Metals Handbook, Vol. I, Properties and Selection of Metals, ASM, 1961
- 61-13 Mechanical Properties of Graphite, Memorandum CMF-13, LASL, November 1961
- 61-14 Technical Data Sheet No. 5520E, Great Lakes Carbon Corp., 1961
- 61-15 Crucible 303 Stainless Steel Data Sheet, Issue 6, Crucible Steel Co., 1961
- 61-16 Materials Symposium, ASD Technical Report 61-322, WADD, July 1961
- 61-17 M.P. Hanson, Smooth and Sharp-Notch Tensile Properties of Cold Reduced AISI 301 and 304L Stainless Steel Sheet at 75°, -320° and -423° F., NASA TND-592, February 1961
- 61-18 A. Goldsmith, et al, Armour Research Foundation, Handbook of Thermophysical Properties of Solid Materials, Vols. 1-5, Rev. Ed., WADC TR-58-476, The MacMillan Co., N.Y., 1961
- 61-19 Projects Nos. 7350, 7381 and 7-817, Contract AF 33(616)-6915, WADD, National Carbon Co., 1961
- 61-20 R.J. Favor, et al, Investigation of Fatigue Behavior of Certain Alloys in the Temperature Range, RT to -423° F, WADD-TR-61-132, Battelle, Contract AF 33(616)-6888, January 1961
- 61-21 R.B. Stewart, et al, A Compendium of the Properties of Materials at Low Temperatures, WADD-TR-60-56, Part 4, Cryogenic Engineering Laboratory, NBS-Boulder, December 1961
- 61-22 W.H. Hill, et al, Elevated Temperature Dynamic Elastic Moduli of Various Metallic Materials, WADD-TR-60-438, March 1961
- 61-23 T.E. Leitz, et al, Mechanical Oxidation and Thermal Property Data for Seven Refractory Metals and Their Alloys, Final Report 2-36-61-1, Missiles and Space Division, Lockheed, September 1961
- 61-24 FM-47, Technical Bulletin, American Cyanamid Co., August 1961
- 61-25 FM-1000, Technical Bulletin, American Cyanamid Co., October 1961

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES
REFERENCES - 1961 (CONTINUED)

- 61-26 HT 424, Technical Bulletin, American Cyanamid Co., August 1961
- 61-27 The Effect of Nuclear Radiation on Structural Metals, REIC Report 20, Battelle, September 1961
- 61-28 G. Artmur, "Ceramics Properties", Nuclear Engineering, June 1961
- 61-29 G. Artmur, "Ceramics - Thermal Conductivity", Nuclear Engineering, April 1961
- 61-30 Preliminary Data, A718, Allegheny Ludlum Steel Corp., undated, 1961
- 61-31 Hastelloy X Data Sheet, Stellite, 1961
- 61-32 R 41, Brochure SS72, Allegheny Ludlum Steel Corporation, 1961
- 61-33 Vacuum Induction Melted Wrought Alloys, Technical Data, Special Metals, Inc., New Hartford, N.Y., undated, received 1961
- 61-34 R.Q. Barr, et al, Room-Temperature Creep Rate of Molybdenum and Effect of Strain Rate on Tensile Properties of Molybdenum, Climax Molybdenum Co., Reprint from Proceedings of ASTM, 61, 1961
- 61-35 Current Data Report, Inconel 718, INCO, May 1961 (superseded by Ref. 64-63)
- 61-36 Supplementary Data Report, Inconel Nickel Chromium Alloy 718, INCO, September 1961
- 61-37 Waspaloy, Allegheny Ludlum Nickel Base Alloy for High Temperatures, Data Sheet, Allegheny Ludlum Steel Corporation, 1961
- 61-38 Udimet 700 Alloy Performance Data, Data Sheet, Metals Division, Kelsey-Hayes Company, undated, received 1961
- 61-39 W. Stuart Lyman, A Statistical Summary of Mechanical-Property Data for Titanium Alloys, DMIC Memo 87, Battelle, Feb. 1961
- 61-40 W.D. Wood, et al, Emissance of Titanium and Titanium Alloys, DMIC Memo 91, Battelle, March 1961
- 61-41 J.J. Graber, et al, ETR Radiation Damage Surveillance Programs, Progress Report 1, Report IDO-16628, Idaho Operations of AEC, January 1961
- 61-42 J.B. Fieldhouse, et al, Measurement of Thermal Properties, Report WADD-TR-60-904, July 1961
- 61-43 2014-T6 Extrusions, Mechanical Properties at Various Temperatures, Unpublished Data, Alcoa Research Laboratories, 10 May 1961
- 61-44 Practical Data for Metallurgists, Tinken Roller Bearing Co., Steel and Tube Division, April 1961
- 61-45 R.J. Corruccini, et al, Thermal Expansion of Technical Solids at Low Temperature, NBS Monograph 29, May 1961
- The following papers from Volume 7, Advances in Cryogenic Engineering, Proceedings of the 1961 Cryogenic Engineering Conference, University of Michigan, Ann Arbor, Michigan, August 15-17, 1961:
 - 61-46 F.W. DeMoney, et al, "Tensile and Impact Properties of 7075-T6 and 7079-T6 Plate, Hand Forgings, and Tensile Properties of Plate MIG Weldments Between 75° and -320° F, Paper K-6, pp 466-477
 - 61-47 L.P. Rice, et al, "Tensile Behavior of Parent-Metal and Welded 5000-Series Aluminum Alloy Plate at Room and Cryogenic Temperatures", Paper K-7, pp 478-489
 - 61-48 J.A. Nock, Jr., et al, "A New High-Strength Aluminum Alloy", (2219), Metal Progress, pp 87-91, September 1961
- 61-49 R.E. Gaumer, et al, Thermal Radiative Control Surfaces for Spacecraft, LMSD Report. 704014, AF Contracts AF 04(647)-563, -564, and -558, March 1961

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1960

- 60-1 C.R. Tipton, Jr. (Editor), Reactor Handbook, 2nd Ed., Vol. I (Materials), Interscience Publishing Co., N.Y., 1960
- 60-2 Superseded by Ref. 61-18
- 60-3 E.F. Gowan, Jr., Beryllium Fasteners, Report TR-60-7-807, Standard Pressed Steel Co., Jenkintown, Pa., for Air Materials Command, August 1960
- 60-4 T.W. Watson, et al, Thermal Conductivity of Some Commercial Iron-Nickel Alloys, ASME Paper 70-WA-47, December 1960
- 60-5 R.M. McClintock, et al, Mechanical Properties of Structural Materials at Low Temperatures, NBS Monograph 13, 1960
- 60-6 C.E. Messer, Tufts University, A Survey Report on Lithium Hydride, NYO-9470, AEC, October 1960
- 60-7 M.E. Langston, et al, Physical Properties of Some Nickel-Base Alloys, DMIC Report 129, May 1960
- 60-8 R.J. Favor, et al, Design Information on Nickel-Base Alloys for Aircraft and Missiles, DMIC Report 132, July 1960
- 60-9 R.J. Favor, et al, Design Information on 17-7 PH Stainless Steel for Aircraft and Missiles, DMIC Report 137, September 1960
- 60-10 Alcoa Aluminum Alloy 2219, Alcoa Green Letter, October 1960 (Superseded by Ref. 62-3)
- 60-11 Comparative Properties of Haynes High-Temperature Alloys, Stellite, October 1960
- 60-12 Basic Data Report, Inconel 718, Huntington Alloys, September 1960
- 60-13 Graphitite, Bulletin GS-101-1, Graphite Specialties Corp., Niagara Falls, New York, 1960
- 60-14 Alcoa Structural Handbook, Alcoa, 1960 (Superseded by Ref. 62-14)
- 60-15 A.F. Hooper, Selection of Materials for Cryogenic Applications in Missiles and Aerospace Vehicles, MRG-132-1, GD/A, February 1960
- 60-16 R.F. Steidel, et al, "The Tensile Properties of Some Engineering Materials at Moderate Rates of Strain", ASTM Bulletin, pp 57-64, July 1960
- 60-17 Unpublished Report, NBS, 1960
- 60-18 Memorandum N-3-933, LASL, December 1960
- 60-19 Superseded by Ref. 61-18
- 60-20 Tantalum and Tantalum Alloys, DMIC Report 133, Battelle, July 1960
- 60-21 R.B. Stewart, et al, A Compendium of the Properties of Materials at Low Temperatures, WADD-TR-60-56, Parts 1-3, Cryogenic Engineering Laboratory, NBS, October 1960
- 60-22 Molybdenum Metal, Climax Molybdenum Company, 1960
- 60-23 Physical and Mechanical Properties of Commercial Molybdenum-Base Alloys, DMIC Report 140, Battelle, November 1960
- 60-24 Alloy Sheet and Strip, Corrosion and Heat Resistant, SAE Specification AMS 5509, January 1960
- 60-25 Van Vliet, Coatings for the Aerospace Environments, Aeronautical Systems Division, Report WADD-TR-60-773, November 1960
- 60-26 V.D. Barth, Physical and Mechanical Properties of Tungsten and Tungsten-Base Alloys, DMIC Report 127, Battelle, March 1960
- 60-27 Typical Properties of Tungsten, Tantalum, Molybdenum, and Columbium, Fansteel Metallurgical Co., North Chicago, Illinois, 1960

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1960 (CONTINUED)

- 60-28 A.G. Ingram, et al, Notch Sensitivity of Refractory Metals, Battelle Report WADD-TR-60-258, September 1960
 - 60-29 L. Green, Jr., High Temperature Stress-Strain Measurements on Polycrystalline Graphites, Aeronutronic Division, Ford Motor Co., October 1960
 - 60-30 V.J. Johnson, General Editor, Compendium of Properties of Materials at Low Temperature, Vols. I, II, and III, WADD 60-56, October 1960
 - 60-31 Optics and Spectroscopy (USSR), 8 (3), 212-3, 1960
 - 60-32 See Ref. 60-1
 - 60-33 S.P. Kaprielyan, "Working Rene' 41 Into Your Design", Aircraft and Missiles, November 1960
 - 60-34 L.A. Weisenberg and R.J. Morris, "How to Fabricate Rene' 41", Metal Progress, November 1960
 - 60-35 F.T. Inouye, Evaluation of Rene' 41 Forging, AGC Report LRP-MM-161, September 1960
 - 60-36 Udimet 41, Technical Data, Metals Division, Kelsey-Hayes Company, undated, Received 1960
 - 60-37 M.M. Lemcoe, et al, "Design Criteria for 6Al-4V Titanium Alloy at Room and Elevated Temperature", ASTM Bulletin, pp 41-46, May 1960
 - 60-38 F.T. Inouye, Properties of Waspaloy Alloy Forging, AGC Report MM-156, April 1960
 - 60-39 Waspaloy Alloy Performance Data, Metals Division, Kelsey-Hayes Company, New Hartford, New York, undated, Received 1960 (Superseded by Ref. 67-33)
 - 60-40 C.K. Franklin, et al, Effects of Irradiation on Mechanical Properties of Tantalum, Report BMI-1476, Battelle, November 1960
 - 60-41 J.R. Hunter, Low Temperature Properties of the Stainless Steels, Allegheny Ludlum Steel Co., 1960
 - 60-42 Properties of Beryllium, General Astrometals Corp. Bulletin, 1960
 - 60-43 J.M. Lambase, Inco 718 Parent Metal and Weld Joint Design Allowables, North American Aviation-Los Angeles Report TFD 60-915 (DMIC 61646) December 1960
 - 60-44 C.T. Sims, et al, "Properties of Refractory Metals Containing Rhenium", Transactions ASM, Volume LII, p 929, 1960
 - 60-45 G.E. Darwin, et al, Metallurgy of the Rarer Metals -7, Beryllium, Academic Press, Inc., New York, 1960
- The following papers from Volume 6, Advances in Cryogenic Engineering, Proceedings of the 1960 Cryogenic Engineering Conference, University of Colorado and National Bureau of Standards, August 23-25, 1960:
- 60-46 C.J. Guntner, et al, "Mechanical Properties of Four Stainless Steels at Temperatures Between 300° and 20°K", Paper J-1, pp 565-576
 - 60-47 T.S. DeSisto, et al, "Low Temperature Mechanical Properties of 300 Series Stainless Steel and Titanium", Paper J-2, pp 577-586
 - 60-48 F.W. DeMoney, "The Fatigue Properties of Aluminum Alloy 5083-H113 Plate and Butt Weldments at 75° and -300°F", Paper J-4, pp 590-603
 - 60-49 J.L. Christian, et al, "Properties of 7000 Series Aluminum Alloys at Cryogenic Temperatures", Paper J-5, pp 604-621
 - 60-50 J.G. Kaufman, et al, "New Data on Aluminum Alloys for Cryogenic Applications", Paper J-8, pp 637-649

DATE 15 JULY 1970

SUPERSEDES 15 MAR 1970

REFERENCES
REFERENCES - 1960 (CONTINUED)

The following papers from Volume 60, Proceedings, ASTM, 1960:

- 60-51 G. Sachs, et al, "Low-Cycle Fatigue of Pressure-Vessel Materials, pp 512-529
- 60-52 J.Y. Mann, "The Fatigue Notch Sensitivity of Annealed Copper", pp 602-609
- 60-53 F. Garofalo, "Temperature Dependence of the Elastic Module of Several Stainless Steels", pp 738-749

The following papers from STP 287, Symposium on Low-Temperature Properties of High-Strength Aircraft and Missile Materials, Papers Presented at the 63rd Annual Meeting, ASTM, June 30, 1960 (published 1961):

- 60-54 M.P. Hanson, et al, "Sharp-Notch Behavior of Some High-Strength Sheet Aluminum Alloys and Welded Joints at 75°, -320°, and -423°F", pp 3-22
- 60-55 W.R. Lucas, et al, "Some Low-Temperature Properties of Aluminum Alloy Weldments", pp 23-36
- 60-56 V. Weiss, et al, "Thermal Cycling Under Constant Load to Low Temperatures of Aluminum and Magnesium Alloys", pp 37-50
- 60-57 G.B. Espey, et al, "Sharp-Edge-Notch Tensile Characteristics of Several High-Strength Titanium Sheet Alloys at Room and Cryogenic Temperatures", pp 74-107
- 60-58 John H. Belton, et al, "Materials for Use at Liquid Hydrogen Temperatures", pp 108-121
- 60-59 George Sachs, et al, "Effect of Stress Concentration on Tensile Strength of Titanium and Steel Alloy Sheet at Various Temperatures", pp 122-135
- 60-60 J.F. Watson, et al, "Mechanical Properties of High-Strength 301 Stainless Steel Sheet at 70°, -320°, and -423°F in the Base Metal and Welded Joint Configuration", pp 136-149
- 60-61 Charles R. Mayne, "Effect of Zerotolling on Properties of Modified Type 347 Stainless Steel", pp 150-158
- 60-62 J.E. Campbell, et al, "Properties of Some Precipitation-Hardening Stainless Steels and Low-Alloy High Strength Steels at Very Low Temperatures", pp 158-169
- 60-63 J.F. Watson, et al, "Low-Temperature Properties of Cold-Rolled AISI Types 301, 302, 304ELC, and 310 Stainless Steel Sheets", pp 170-195
- 60-64 A. Hurlich, "Summation of STP 287", pp 215-225
- 60-65 Fatigue Properties of High-Strength Titanium and Stainless Steel Alloys, TIMET, January 1960
- 60-66 O.H. Olson, et al, Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials, WADC TR 56-222, Part III, April 1960
- 60-67 R.F. Barrow, "Low Temperature Properties of Engineering Materials." Machine Design, Volume 32, pp 189-195, 1960

The following unpublished Data Sheet from Alcoa Research Laboratory, Typical Mechanical Properties at Various Temperatures (L. W. Mayer, Editor)

- 60-68 6061 Aluminum Alloy

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1959

- 59-1 Thermodynamics and Transport Properties of Gases, Liquids, and Solids, Y.S. Touloukian, Chairman, ASME Symposium Proceedings, McGraw-Hill, New York, 1959
- 59-2 J.W. Holladay, Heat Capacity of Beryllium, DMIC Memo 36, Battelle, October 1959
- 59-3 High Temperature Alloy D-979, Allegheny-Ludlum Steel Corp., January 1959
- 59-4 Alcoa Aluminum Handbook, Alcoa, 1959 (Superseded by Ref. 62-14)
- 59-5 Molybdenum Metal, Technical Notes, Climax Molybdenum Co., February 1959
- 59-6 Beryllium Design Data, Lockheed Aircraft Report LMSD-48472, 1959
- 59-7 Inconel X, Bulletin T-38, Huntington Alloys, August 1959
- 59-8 Industrial Graphite Engineering Handbook, National Carbon Co., 1959
- 59-9 Allegheny-Ludlum Stainless Steel, Type 301, Data Sheet, Allegheny-Ludlum Steel Corp., 1959
- 59-10 Superseded by Ref. 59-1
- 59-11 D-979 Alloy Tentative Minimum Guaranteed Properties, Allegheny-Ludlum Steel Corp., January 1959
- 59-12 Crucible Titanium Manual, Crucible Steel Co., Pittsburgh, Pa., 1959
- 59-13 W.L. Bruckert, "Production and Quality of Molybdenum Mill Products", from Fabrication of Molybdenum, ASM, 1959
- 59-14 Physical and Mechanical Properties of Tantalum, DMIC Memorandum 32, Battelle, August 1959
- 59-15 W.F. Brown, Jr., et al, Influence of Stress Concentrations at Elevated Temperatures and the Effects of Nonsteady Load and Temperature Conditions on the Creep of Metals, ASTM STP-260, December 1959
- 59-16 Udimet 700 (High Temperature Alloy), Data Sheet, Engineering Alloys Digest, Inc., Upper Montclair, N.J., March 1959
- 59-17 Titanium Grades and Properties, Republic Steel Corporation, Cleveland, Ohio, 1959
- 59-18 Type 301 Stainless Steel, Blue Sheet, Allegheny-Ludlum Steel Co., December 1959
- 59-19 Pratt and Whitney, 1959
- 59-20 Stainless Steel Handbook, Allegheny-Ludlum Steel Corp., 1959
- 59-21 Allegheny-Ludlum Data, Steels and Alloys, Allegheny-Ludlum Steel Corp., 1959
- The following papers from Volume 5, Advances in Cryogenic Engineering, Proceedings of the 1959 Cryogenic Engineering Conference, University of California, Berkeley, California:
 - 59-22 J.F. Watson, "Mechanical Properties of High-Strength 301 Stainless Steel Sheet at 70°, -320°, and -423° F in the Base Metal and Welded Joint Configurations", Paper H-4, pp 406-420
 - 59-23 R.D. Oeleman, et al, "The Tensile and Impact Properties of Plate and Welds of Aluminum Alloy 5083-H113 Between 75° and -320° F", Paper H-6, pp 430-438
- The following papers from Volume 59, Proceedings, ASTM, 1959:
 - 59-24 F. Garofalo, "Creep-Rupture Behavior of Notched and Unnotched Specimens of Type 304, 316, and 321 Austenitic Stainless Steels", pp 957-972
 - 59-25 F. Garofalo, "Effect of Environment on Creep and Creep-Rupture Behavior of Several Steels at Temperatures of 1000° to 1200° F", pp 973-984

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES

REFERENCES - 1959 (CONTINUED)

RESERVED FOR FUTURE ADDITIONS

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES
REFERENCES - 1958

- 58-1 ASTE Technical Paper No. 176, Collected papers from semiannual meeting of the ASTE in Los Angeles, California, September - October 1958
- 58-2 C.F. Lucks, et al, Thermal Properties of Thirteen Metals, ASTM STP 227, February 1958
- 58-3 Alcoa Structural Handbook, Alcoa, 1958 (Superseded by Ref. 59-4)
- 58-4 K.G. Wilke, Beryllium Fabrication, Brush Beryllium Co., 1958
- 58-5 Measurements of Mechanical Properties of Pure and Uranium-Loaded Graphites at Elevated Temperatures, AGC Report 1537, 23 December 1958 (Classified Confidential; Title Unclassified)
- 58-6 Lithium Hydride, Bulletin 102, Foote Mineral Co., Philadelphia, Pa., undated
- 58-7 Lithium Hydride, Bulletin 203-856, Lithium Corporation of America, Minneapolis, Minn., undated
- 58-8 R.L. McGee, et al, Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures, Battelle Report WADC-TR-58-386, Contract AF 33(616)-3542, November 1958
- 58-9 Technical Data on Allegheny-Ludlum Alloy D-979, Allegheny-Ludlum Steel Corp., 6 March 1958
- 58-10 Rene' 41, Vacuum Melted Alloy, Brochure VM-107, Metallurgical Products Dept., GE-Detroit
- 58-11 Unitemp Waspalloy, Engineering Alloys Digest, Inc., Upper Montclair, New Jersey, December 1958
- 58-12 Thermal Properties of Titanium and Titanium Alloys, DMIC Memorandum 1, Battelle, August 1958
- 58-13 H.T. Watanabe, Radiation Damage Studies Program-ETR Loop Materials, Progress Report III, IDO-16475, Idaho Operations of AEC, September, 1958
- 58-14 J.K. Childs, Determination of Materials Design Criteria for 6Al-4V Titanium Alloy at Room and Elevated Temperatures, SRI Report WADC-TR-58-246, (DMIC 30598), May 1958
- 58-15 G.E. Best, Waspalloy, GE Data Sheet, Source 389, September 1958
- 58-16 Utica Metals, 1958
- 58-17 H.T. Betz, et al, Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials, WADC TR 56-222, Part II, ASTIA Document 202493, October 1958
- 58-18 O.H. Olson, et al, Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials, WADC TR 56-222, Part II, Supplement I, ASTIA Document 202494, October 1958
- 58-19 I.B. Fieldhouse, et al, (Armour Research Foundation), Measurements of Thermal Properties, pp 1-79, WADC TR 58-274 (AD 206-892), 1958

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES
REFERENCES - 1957

- 57-1 Properties of Titanium Alloys at Elevated Temperatures, Titanium Metallurgical Laboratory Report 82, Battelle, September 1957
- 57-2 OFHC Brand Copper Technical Survey, The American Metal Climax Company, Ltd., 1957
- 57-3 W.P. Weber, et al, Properties of Beryllium Oxide and Carbides of Beryllium, Molybdenum, Niobium, Tantalum, and Titanium, Battelle Report BMI-1165, 1957
- 57-4 T.R.P. Gibb, Jr., et al, A Survey Report on Lithium Hydride, AEC Report NYO-3957, Rev., August 1957
- 57-5 The Physical Properties of Titanium and Titanium Alloys, Titanium Metallurgical Laboratory Report 73, Battelle, July 1957
- 57-6 J.G. Weinberg, et al, An Evaluation of Fatigue Properties of Titanium and Titanium Alloys, Titanium Metallurgical Laboratory Report 77, Battelle, July 1957
- The following paper from Volume 57, Proceedings, ASTM, 1957:
 - 57-7 J.W. Pugh, "Tensile and Creep Properties of Tungsten at Elevated Temperatures", 1957
- 57-8 Allegheny Free Machining Stainless Steels, Types 303, 416, 430F, Blue Sheet, Allegheny-Ludlum Steel Co., 1957
- 57-9 Materials Properties Design Criteria for Metals, Parts 1 through 7, Battelle, 1956-57
- The following papers from Volume 3, Advances in Cryogenic Engineering, Proceedings of the 1957 Cryogenic Engineering Conference, National Bureau of Standards, Boulder, Colorado, August 19-21, 1957:
 - 57-10 R.P. Mikesell, et al, "The Impact Testing of Various Alloys at Low Temperatures", Paper F-4, pp 316-324
 - 57-11 W.J. Hall, et al, "Thermal Conductivities of Common Commercial Alloys", Paper G-6, pp 408-415
- 57-12 H. Inouye, High-Thermal Conductivity Fin Material for Radiators, ORNL, Contract W-7405-eng-26 (Based on P. A. Haythorne in Iron Age, No. 13, Volume (62, pp-85-95, 1948) 1957

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES

REFERENCES - 1956

- 56-1 Marshall Ward (H.A. Wilson Co.), "Constant Modulus Alloy for Elastic Elements", Product Engineering, July 1956
- 56-2 Elevated Temperature Properties of Coppers and Copper-Base Alloys, ASTM, 1956
- 56-3 Stainless Steel Handbook, Allegheny-Ludlum Steel Corporation, 1956
- 56-4 S.M. Lang, et al, "Some Physical Properties of High-Density Thorium Dioxide", Journal of American Ceramic Society, V. 39, No. 12, 1956
- 56-5 M.H. Bartz, Radiation Damage Observations at MTR, Report TID-7515, Part 1, AEC Technical Information Services Extension, 1956
- 56-6 Elevated Temperature Properties of 50% Cold-Drawn A-286, Technical Data Sheet 556-13, Allegheny-Ludlum Steel Co., May 1956
- 56-7 A. Grodner, Stainless Steel for Pressure Vessels, Welding Research Council Bulletin 31, November 1956
- The following papers from Volume 2, Advances in Cryogenic Engineering, Proceedings of the 1956 Cryogenic Engineering Conference, National Bureau of Standards, Boulder, Colorado, September 5-7, 1956:
 - 56-8 R.H. Kropschot, et al, "Mechanical Properties of Some Engineering Materials Between 20°K and 300°K", Paper C-2, pp 93-99
 - 56-9 E.T. Wessel, "The Performance Characteristics of Low Temperature Tension Testing Apparatus and Its Application in Industry", Paper D-4, pp 126-135
 - 56-10 R.L. Powell, et al, "Thermal Conductivities of Copper and Copper Alloys", Paper E-3, pp 166-171
- 56-11 H.T. Betz, et al, Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials, WADC TR-56-222, Part I, ASTIA Document AD-110458, October 1956
- 56-12 N. V. Zavaritskii, et al, "Heat Conductivity of Technical Materials at Low Temperatures," Zhurnal Tekhnicheskii, Fiziki, Volume 26, No. 9, pp 2032 - 2036, September 1956

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

REFERENCES
REFERENCES - 1955

- 55-1 Machining Kaiser Aluminum, Kaiser Aluminum and Chemical Co., 1955
- 55-2 Welding Alcoa Aluminum, Alcoa, 1955
- 55-3 Interpretation of ASME Boiler and Pressure Vessel Code, ASME, 1955
- 55-4 J.C. Wilson, et al, Effects of Neutron Irradiation in Steel, Proc. ASTM, 55 (1), 689, 1955
- 55-5 Strength of Metal Aircraft Elements, Bulletin ANC-5, Issued Jointly by U.S. Air Force, Navy, and Dept. of Commerce, March 1955 (Superseded by Mil-Hndbk-5, Ref. 61-2)

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES
REFERENCES - 1954

- 54-1 Taylor Technical Data Bulletin 3.4.3, Taylor Fibre Co., December 1954
 - 54-2 W.F. Simmons, et al, The Elevated Temperature Properties of Selected Super-strength Alloys, ASTM STP-160, August 1954
 - 54-3 R.V. Steele, et al, Effect of Neutron Flux on Mechanical Properties of Aluminum Alloys, LRL Report 145, May 1954
 - 54-4 D.C. Leeser, "Manual 107", Materials and Methods Magazine, August 1954
 - 54-5 C.R. Sutton, et al, "Radiation Effects on Reactor Materials-Metals", Nucleonics, 12 (8, 9), 13, 1954
 - 54-6 W.W. Beaver, et al, (Brush Beryllium Co.), "Mechanical Properties of Beryllium Fabricated by Powder Metallurgy", Transactions AIME, in Journal of Metals, Vol. 6, No. 5, pp 559-573, May 1954
 - 54-7 D.E. Miller, Determination of Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures, AF Technical Report 6517, Part 4, Armour Research Foundation, Illinois Institute of Technology, for WADD, Contract AF 33(038)-8681, Project 7360, December 1954
- The following papers from Volume 1, Advances in Cryogenic Engineering, Proceedings of the 1954 Cryogenic Engineering Conference, National Bureau of Standards, Boulder, Colorado, September 8-10, 1954:
- 54-8 R.H. Kropschot, "The Mechanical Properties Testing Program at the NBS-AEC Cryogenic Engineering Laboratory", Paper G-1, pp 235-241
 - 54-9 C.A. Swenson, "The Compressive Strengths of Some Technical Metals Between 4.2° and 300°K", Paper G-3, pp 251-255
 - 54-10 V. Krivobok, et al, Forming of Austenitic Chromium-Nickel Stainless Steels, Chapter 1, INCO, 1954
 - 54-11 A. K. Smith, Basic Equations and Data for the Evaluation of Heat Transfer Surface Requirements and Pressure Drop of Pressurized Water to Steam Heat Exchangers, AEC DTS WIAP-M-38, 1954

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES

REFERENCES - 1953

- 53-1 H. Masumoto, et al, "On the Anomaly of the Specific Heat at High Temperature in Alpha Phase Alloys of Iron and Chromium", Science Reports of the Research Institute, Series A 5, 203, Tohoku University, Sendai, Japan, 1953
- 53-2 Welding Aluminum, Reynolds Metals Co. 1953
- 53-3 W. W. Tyler, et al, "Some Low Temperature Properties of Titanium Alloy RC-130-Band Stainless Steel," Transactions AIME, paper 197, pp 1104-6, 1953

REFERENCES - 1952

- 52-1 Report on the Elevated Temperature Properties of Stainless Steel, ASTM STP 124, January 1952
- 52-2 I Estermann, et al, "Heat Conduction in Alloys at Low Temperatures," J of Appl. Physics, Volume 23, pp-578 -588, May 1952

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES
REFERENCES - 1951

- 51-1 J.W. Spretnak, et al, "Notched and Unnotched Tensile and Fatigue Properties of Ten Engineering Alloys at 25°C and -196°C", Volume 43, Transactions, ASM, pp 547-570, 1951
- 51-2 R. Berman, "The Thermal Conductivity of Some Alloys at Low Temperatures," Volume 42, pp 642 - 50, Philosophical Magazine 1951
- 51-3 C. F. Lucks, et al, The Experimental Measurement of Thermal Conductivities, Specific Heats, and Densities of Metallic, Transparent, and Protective Materials, Volume 1, pp 1-127, USAF TR 6145 (ATT 117715), 1951
- 51-4 R. W. Powers, et al, The Thermal Conductivity of Metals and Alloys at Low Temperatures, Data on Iron and Several Steels between 25 and 300K. Influence of Alloying Constituents, pp 1-14, USAF TR 264-6, 1951
- 51-5 J. E. Zimmerman, Doctoral Dissertation, Carnegie Inst. of Technology, pp 1-54, 1951
- 51-6 "Thermal Conductivity of Various Materials vs Temperature," Materials and Methods Volume 33, page 107, June 1951

REFERENCES - 1950

- 50-1 D.E. Furman, "Thermal Expansion Characteristics of Stainless Steels Between -300° and 1000° F", Journal of Metals (Transactions AIME), Volume 188, April 1950

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

REFERENCES
REFERENCES - 1949

- 49-1 Superseded by Ref. 65-99
- 49-2 P.C. Ginnings, et al, Specific Heat of Beryllium Between 0° and 900° C, NBS-5, March 1949
- 49-3 J. Miller, et al, Utilization of Low Alloy Materials for High Temperature Service Applications, AF TR-5929, Air Materiel Command, Wright-Patterson Air Base, June 1949
- 49-4 J.L. Zambrow, et al, "Mechanical Properties, including Fatigue of Aircraft Alloys at Very Low Temperatures", Volume 41, Transactions, ASM, pp 480-518, 1949

REFERENCES - 1948

- 48-1 Metals Handbook, ASM, 1948

DATE 15 MAR 1970**SUPERSEDES** 30 SEPT 1969**REFERENCES****REFERENCES - 1947**

- 47-1 J.R. Frederick, A Study of the Elastic Properties of Various Solids by means of Ultrasonic Pulse Techniques, Doctors Thesis, University of Michigan, 1947

REFERENCES - 1946

DATE 15 MAR 1970

SUPERSEDES 30 SEPT 1969

REFERENCES

REFERENCES - 1939

- 39-1 S. A. Zlunitzin, et al, "Heat Conductivity of Industrial Alloys at Low Temperatures", Zhur, Tekh, Fig., 9 (9) pp 805-7, 1939

REFERENCES - 1938

- 38-1 C.H. Lorig, et al, "Mechanical Properties of Copper at Elevated Temperatures", Metals and Alloys, Vol. 9, No. 3, March 1938

DATE 1 MAY 1966

SUPERSEDES

**LIGHT METALS
AND ALLOYS**

MATERIALS DATA

**I
LIGHT METALS AND ALLOYS**

**A
ALUMINUM AND ALUMINUM ALLOYS**

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

THIS ALLOY POSSESSES EXCELLENT CASTABILITY HIGH CORROSION RESISTANCE, AND GOOD WELDABILITY.

BASIS FOR DESIGN VALUES OF F_{TU} , F_{TY} , F_{SU} , F_{BRU} , AND F_{BRY} IS VALUE ABOVE WHICH 99% OF THE POPULATION OF VALUES IS EXPECTED TO FALL, WITH A CONFIDENCE OF 95%.

VALUES IN PARAGRAPH E-1 ARE BASED ON SAND CASTINGS AND PERMANENT MOLD CASTINGS, AS NOTED

B. COMMERCIAL DESIGNATIONS

356 ALUMINUM ALLOY

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SAND CASTING T6	QQ-A-601 AMS 4217 ASTM-B-26 COMP SG 70A
PERMANENT MOLD CASTING T51 T6	AMS 4286 AMS 4284 QO-A-596
T7	ASTM-B-108 COMP SG 70A
INVESTMENT CASTINGS T6	AMS 4260

SUPPLIERS

ALUMINUM FOUNDRIES

D. CHEMICAL COMPOSITION (%)

ELEMENT	Cu	Mg	Mn	Fe	Si	Zn	Ti	Others	Al
MAXIMUM	0.25	0.40	0.35	0.60	7.5	0.35	0.25	0.15	BAL.
MINIMUM		0.20			6.5			*	

SOURCE FEDERAL SPECIFICATION QQ-A-601
* 0.05 EACH MAXIMUM

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	-T6	
	SAND CASTINGS	PERM. MOLD CASTINGS
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	
	30,000	33,000
TENSILE YIELD STRENGTH F_{TY}	PSI	
	20,000	22,000
COMP. YIELD STRENGTH F_{CY}	PSI	
	20,000	22,000
ULTIMATE SHEAR STRENGTH F_{SU}	PSI	
	25,000	25,000
SHEAR YIELD STRENGTH F_{SY}	PSI	
ULTIMATE BEARING STRENGTH F_{BRU}	PSI	
$e/D = 1.5$	48,000	46,000
$e/D = 2.0$	63,000	59,000
YIELD BEARING STRENGTH F_{BRY}	PSI	
$e/D = 1.5$	34,000	35,000
$e/D = 2.0$	40,000	40,000
ELONGATION e	%	
	3.0	3.0
REDUCTION OF AREA RA	%	
MODULUS OF ELASTICITY E	10^6 PSI	
	10.3	
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI	
	10.3	
MODULUS OF RIGIDITY G	10^6 PSI	
	3.85	
POISSON'S RATIO		
HARDNESS		
PLASTIC BENDING MODULUS	(SEE APPENDIX A)	

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.097
SPECIFIC HEAT C	BTU/LB - °F
(AT 212°F)	0.23
THERMAL CONDUCTIVITY k	$\frac{BTU - FT}{HR - FT^2 - °F}$
	87
MEAN COEFF. LIN. THERMAL EXPANS. α	$\frac{10^{-6} IN.}{IN. - °F}$
68° - 212°F	11.9
ELECTRICAL RESISTIVITY R	MICROHM - IN.
	1.74

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
	1035 - 1135°F
PHASE CHANGES	
THIS ALLOY IS PRECIPITATION HARDENABLE	
THERMAL CONDUCTIVITY VS. TEMPERATURE	

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE	1 MAY 1966
SUPERSEDES	

BASIC DATA
I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T7	SOLUTION HEAT TREATED AND ARTIFICIALLY AGED AT A HIGHER TEMPERATURE THAN FOR -T6
-T51	ARTIFICIALLY AGED ONLY, TO IMPROVE MECHANICAL PROPERTIES, DIMENSIONAL STABILITY OR BOTH; USED FOR EXTRUSIONS AND CASTINGS

J. SERVICE LIMITS
NON-RADIATION SERVICE LIMITS:

MAXIMUM SERVICE TEMPERATURE = 300°F

K. PROCESSING
SURFACE TREATMENT
CLEANING
METHODS

ORGANIC SOLVENTS: EMULSION, SOLVENT, OR VAPOR DE-GREASE

CHEMICAL EMULSIFICATION: SODIUM-SILICATE INHIBITED TRI-SODIUM PHOSPHATE, OR SODIUM CARBONATE PLUS DILUTE H₂SO₄ RINSE.

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE
DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED.
FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

ANODIZING

ANODIZE IN ACCORDANCE WITH MIL-A-8625

THERMAL TREATMENT (PER MIL-H-6088)

AGE AT 300° TO 320°F FOR 1-6 HOURS (-T6) OR
AGE AT 430° TO 450°F FOR 1-6 HOURS (-T7)

STRESS RELIEF

HEAT TO 650°-750°F FOR 2 HOURS AND AIR COOL TO ROOM TEMPERATURE

HARDENING TREATMENT

SOLUTION HEAT TREAT AT 980°-1010°F, INCL., FOR 6 TO 18 HOURS

QUENCH IN WATER AT 150 TO 212°F

AGE AT 300° TO 320°F FOR 1 TO 6 HOURS.

K. PROCESSING (CONTINUED)
JOINING
METHOD

TIG OR MIG WELDING PREFERRED.

FILLER METAL

4043; FOR REPAIR AT FOUNDRIES, PARENT METAL COMPOSITION IS USED

WELD DEPOSIT CHARACTERISTIC

WELD DOES NOT RESPOND TO HEAT TREATMENT FOR PARENT METAL. ANY INCREASE IN STRENGTH OF DEPOSIT FOLLOWING HEAT TREATMENT MAY BE ATTRIBUTED TO WELD DILUTION FROM PARENT METAL. THIS, IN TURN, IS A FUNCTION OF SECTION THICKNESS.

FORMING

NONE

MACHINABILITY

MACHINABILITY IN RELATION TO OTHER ALUMINUM ALLOYS IS GOOD

L. REFERENCES

NP-62-44
NP-64-3
NP-64-8
NP-59-4

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

HIGH STRENGTH ALUMINUM CASTING ALLOY

DESIGN PROPERTY BASIS:

FOR F_{Tij} , F_{Ty} , F_{Su} , F_{Bru} , F_{Bry} VALUES ARE THOSE ABOVE WHICH 99% OF THE POPULATION OF VALUES WILL FALL WITH A CONFIDENCE OF 95% FOR $\%e$ - MINIMUM VALUE

VALUES IN PARAGRAPH E-1 ARE BASED ON CASTINGS, T61 CONDITION, SOLUTION TREATED AND AGED, IN THE CLASSES SHOWN, PER SPEC MIL-A-21180

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
CASTINGS	MIL-A-21180 AMS 4218

SUPPLIERS

ALUMINUM FOUNDRIES

D. CHEMICAL COMPOSITION (%)

ELEMENT	Cu	Mg	Mn	Fe	Si	Zn	Ti	Al
MAXIMUM	0.20	0.40	0.10	0.20	7.5	0.10	0.20	Bal.*
MINIMUM		0.20			6.5			

SOURCE MIL-A-21180

* OTHER 0.05 EACH, 0.15 TOTAL

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

CASTINGS, T61 CONDITIONS (SOLUTION TREATED & AGED)

CLASS	1	2	10	11	12
TENSILE ULTIMATE STRENGTH F_{Tu}					
	38,000	40,000	38,000	33,000	32,000

TENSILE YIELD STRENGTH F_{Ty}					
	28,000	30,000	28,000	27,000	22,000

COMP. YIELD STRENGTH F_{Cy}					
	28,000	30,000	28,000	27,000	22,000

SHEAR STRENGTH F_{Su}					
	27,000	28,000	27,000	23,000	22,000

BEARING STRENGTH, ULTIMATE F_{Bru}					
$e/D=1.5$	53,000	56,000	53,000	46,000	45,000
$e/D=2.0$	68,000	72,000	68,000	59,000	58,000

BEARING STRENGTH, YIELD F_{Bry}					
$e/D=1.5$	45,000	48,000	45,000	43,000	35,000
$e/D=2.0$	50,000	54,000	50,000	40,000	40,000

ELONGATION e					
	5	3	5	3	2

REDUCTION OF AREA RA					

MODULUS OF ELASTICITY E					
	10.4				

MODULUS OF RIGIDITY G					
	3.9				

COMP. MODULUS OF ELASTICITY E_c					
	10.5				

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ		LB/IN ³
	0.097	
SPECIFIC HEAT C		BTU/LB - °F
(AT 212°F)	0.23	
THERMAL CONDUCTIVITY k		BTU - FT HR - FT ² - °F
(AT 77°F)	88	
MEAN COEFF. LIN. THERMAL EXPANS. α		10 ⁻⁶ IN. IN. - °F
(68 - 212°F)	11.9	
ELECTRICAL RESISTIVITY R		MICROHM - IN.
	1.74	

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
	1035°F-1135°F

PHASE CHANGES

THIS ALLOY IS PRECIPITATION HARDENABLE.

THERMAL CONDUCTIVITY VS. TEMPERATURE

F. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

IRRADIATION AND TEST AT -423°F
DOSAGE, 5×10^{16} NVT, $E > 1.0$ MEV

	AVERAGE CONTROL VALUE	AVERAGE TEST VALUE
RA	6.3%	*
e	1.5%	*

REF. NP-66-3

*NO SIGNIFICANT CHANGE FROM CONTROL VALUES.

DATE	1 MAY 1966
SUPERSEDES	

BASIC DATA
I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-T61	SOLUTION TREATED, BOILING WATER QUENCHED, AND ARTIFICIALLY AGED.

J. SERVICE LIMITS

RADIATION SERVICE LIMITS
SEE REDUCTION OF AREA CURVE, SHEET 9

NON-RADIATION SERVICE LIMITS
MAXIMUM SERVICE TEMPERATURE = 300°F

K. PROCESSING
SURFACE TREATMENT
CLEANING
METHODS

ORGANIC SOLVENTS: EMULSION, SOLVENT, OR VAPOR
DE-GREASE

CHEMICAL EMULSIFICATION: SODIUM-SILICATE INHIBITED
TRI-SODIUM PHOSPHATE, OR SODIUM CARBONATE PLUS
DILUTE H₂SO₄ RINSE.

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE
DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED.
FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

ANODIZING

IN ACCORDANCE WITH MIL-A-8625

THERMAL TREATMENT
STRESS RELIEF

TO REMOVE COLD WORK: HEAT TO 650°F (MAX. 775°F) FOR
1/2 TO 2 HOURS AND AIR COOL.

TO SOFTEN AFTER HEAT TREATMENT: HEAT TO 775°F FOR 1
HOUR MINIMUM, COOL TO 500°F AT 50° OR LESS PER HOUR,
THEN AIR COOL.

HARDENING TREATMENT

SOLUTION HEAT TREAT AT 980°-1010°F, INCL., FOR 6 TO 18
HOURS.

QUENCH IN WATER AT 150 TO 212°F.

AGE AT 300° TO 320°F FOR 6 TO 10 HOURS.

K. PROCESSING (CONTINUED)
JOINING
WELDING

TIG OR MIG PREFERRED
FILLER METAL: 4043 (FOR REPAIR OF CASTING AT
FOUNDRY, PARENT METAL COMPOSITION IS USED)
WELD DEPOSIT DOES NOT RESPOND TO HEAT TREAT-
MENT FOR PARENT METAL. ANY INCREASE IN
STRENGTH OF WELD DEPOSIT FOLLOWING HEAT
TREATMENT MAY BE ATTRIBUTED TO WELD DILUTION
BY PARENT METAL, WHICH IS A FUNCTION OF
SECTION THICKNESS

FORMING

CASTING ONLY

MACHINABILITY

MACHINABILITY IN RELATION TO OTHER ALUMINUM ALLOYS IS GOOD

L. REFERENCES

NP-62-44
NP-64-3
NP-64-8
NP-66-3

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

DESIGN PROPERTIES BASIS:

FOR F_{TU} , F_{TY} , F_{CY} , F_{SU} , F_{BRU} , F_{BRY} - VALUES ARE THOSE ABOVE WHICH 99% OF THE POPULATION OF VALUES WILL FALL WITH A CONFIDENCE OF 95% FOR $\frac{1}{2}$ - MIN.

VALUES IN PARAGRAPH E-1 ARE BASED ON SHEET AND PLATE, IN THE T6 AND T651 CONDITIONS, IN THE THICKNESSES SHOWN; ON SHEET 1A, VALUES ARE FOR FORMS AND CONDITIONS SHOWN THEREON.

FOR GOODMAN DIAGRAM OF 2014-T4, SEE PAGE 2.

ALCLAD SHEET AND PLATE HAVE ULTIMATE TENSILE AND TENSILE YIELD STRENGTH 2-4% LESS THAN THE BASE METAL.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET AND PLATE	
CONDITION-0	AMS 4028
CONDITION-T6	AMS 4029
PLATE CONDITION-T61	AMS 4014
SHEET AND PLATE, ALL CONDITIONS	ASTM-B-209
ALCLAD SHEET AND PLATE	QQ-A-250/3 ASTM-B-209

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.
HARVEY ALUMINUM CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT*	Cu	Mg	Mn	Fe	Si	Zn	Cr	Ti
MAXIMUM	5.0	0.80	1.2	1.0	1.2	0.25	0.10	0.15
MINIMUM	3.9	0.20	0.40	-	0.50	-	-	-

SOURCE AMS 4028

* OTHERS: EACH 0.05, TOTAL 0.15 BAL. AL.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET AND PLATE, -T6 AND -T651 CONDITIONS				
THICKNESS - INCHES				
0.02 - 0.039	0.04 - 1.5	1.5 - 2	2 - 3	
TENSILE ULTIMATE STRENGTH	F_{TU}	PSI		
64,000	67,000	67,000	65,000	
TENSILE YIELD STRENGTH	F_{TY}	PSI		
57,000	59,000	59,000	57,000	
COMP. YIELD STRENGTH	F_{CY}	PSI		
-	61,000	61,000	59,000	
ULTIMATE SHEAR STRENGTH	F_{SU}	PSI		
-	41,000	41,000	39,000	
SHEAR YIELD STRENGTH	F_{SY}	PSI		

ULTIMATE BEARING STRENGTH	F_{BRU}	PSI
e/D = 1.5 -	101,000	98,000
e/D = 2.0 -	127,000	124,000

YIELD BEARING STRENGTH	F_{BRY}	PSI
e/D = 1.5 -	84,000	83,000
e/D = 2.0 -	94,000	94,000

ELONGATION	e	%
6	(.04-.5") 8	3
	(.5-1") 6	
	(1-1.5") 4	

REDUCTION OF AREA	RA	%
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MODULUS OF ELASTICITY	E	10^6 PSI
	10.5	

COMP. MODULUS OF ELASTICITY	E_C	10^6 PSI
	10.7	

MODULUS OF RIGIDITY	G	10^6 PSI
	4.0	

POISSON'S RATIO

HARDNESS

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY	ρ	LB/IN ³
	0.101	
SPECIFIC HEAT	C	BTU/LB - °F
(AT 212°F)	0.23	
THERMAL CONDUCTIVITY	k	BTU - FT HR - FT ² - °F
(AT 77°F)	0 111 -T6 89 -T4 87	
MEAN COEFF. LIN. THERMAL EXPANS.	α	10^{-6} IN. IN. - °F
(68°F TO 212°F)	12.5	
ELECTRICAL RESISTIVITY	R	MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	980° - 1180°F
---------------	---------------

PHASE CHANGES

THIS ALLOY WILL UNDERGO PRECIPITATION UPON NATURAL OR ARTIFICIAL AGING.

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

THIS ALLOY IS SUBJECT TO STRESS-CORROSION CRACKING. IN THIS RESPECT IT IS COMPARABLE TO 7075-T6 AND 7079-T6 ALUMINUM ALLOYS. ALCLAD 2014 IS IMMUNE TO STRESS-CORROSION CRACKING. IN ALLOY 2014, THE -T6 CONDITION IS THE MOST RESISTANT TO STRESS-CORROSION.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

BAR, ROD AND SHAPES, ROLLED, DRAWN, OR COLD FINISHED

-T6 OR -T651 TEMPER

SEE A, PAGE 1-A-20/1 FOR DESIGN BASIS

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, ROD, WIRE & SHAPES	QQ-A-225/4 ASTM-B-211 AMS 4121 QQ-A-266
STRUCTURAL SHAPES EXTRUDED OR ROLLED	MIL-A-25994

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE VALUES UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

BAR, ROD, AND SHAPES

ROLLED, DRAWN, OR COLD FINISHED - T6 OR -T651

THICKNESS OR DIAMETER (IN.)

TO 1 1 TO 2 2 TO 3

	TENSILE ULTIMATE STRENGTH F_{TU}	PSI
LONG	65,000	65,000
TRANS	64,000	62,000

	TENSILE YIELD STRENGTH F_{TY}	PSI
LONG	55,000	55,000
TRANS	53,000	51,000

	COMP. YIELD STRENGTH F_{CY}	PSI
LONG	53,000	53,000
TRANS	-	-

	SHEAR STRENGTH F_{SU}	PSI
LONG	38,000	38,000
TRANS	38,000	38,000

	BEARING STRENGTH, ULTIMATE F_{BRU}	PSI
e/D=1.5	98,000	-
e/D=2.0	124,000	-

	BEARING STRENGTH, YIELD F_{BRY}	PSI
e/D=1.5	77,000	-
e/D=2.0	88,000	-

	ELONGATION e	%
LONG	8	8
TRANS	4	2

	REDUCTION OF AREA RA	%
LONG	8	8
TRANS	4	2

	MODULUS OF ELASTICITY E	10^6 PSI
LONG	10.5	10.5
TRANS	10.5	10.5

	MODULUS OF RIGIDITY G	10^6 PSI
LONG	4.0	4.0
TRANS	4.0	4.0

	COMP. MODULUS OF ELASTICITY E_c	10^6 PSI
LONG	10.7	10.7
TRANS	10.7	10.7

	PLASTIC BENDING MODULUS	(SEE APPENDIX A)
LONG		
TRANS		

A. GENERAL

EXTRUDED ROD, BAR AND SHAPES - T6 TEMPER

CROSS-SECTION AREA ≤ 25 IN²

SEE A, PAGE 1-A-20/1 FOR DESIGN BASIS

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, RODS AND SHAPES EXTRUDED	QQ-A-200/2 QQ-A-261 AMS 4153 ASTM-B-221
STRUCTURAL SHAPES EXTRUDED OR ROLLED	MIL-A-25994

SUPPLIERS

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE VALUES UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

ROD, BAR, AND SHAPES

EXTRUDED - T6

THICKNESS OR DIAMETER (IN.)

.125 TO .5 .5 TO .75 .75 TO 1.5

	TENSILE ULTIMATE STRENGTH F_{TU}	PSI
LONG	60,000	64,000
TRANS	60,000	63,000

	TENSILE YIELD STRENGTH F_{TY}	PSI
LONG	53,000	58,000
TRANS	53,000	54,000

	COMP. YIELD STRENGTH F_{CY}	PSI
LONG	55,000	60,000
TRANS	53,000	57,000

	SHEAR STRENGTH F_{SU}	PSI
LONG	35,000	37,000
TRANS	35,000	39,000

	BEARING STRENGTH, ULTIMATE F_{BRU}	PSI
e/D=1.5	90,000	96,000
e/D=2.0	114,000	109,000

	BEARING STRENGTH, YIELD F_{BRY}	PSI
e/D=1.5	74,000	81,000
e/D=2.0	85,000	84,000

	ELONGATION e	%
LONG	7	7
TRANS	5	2

	REDUCTION OF AREA RA	%
LONG	7	7
TRANS	5	2

	MODULUS OF ELASTICITY E	10^6 PSI
LONG	10.5	10.5
TRANS	10.5	10.5

	MODULUS OF RIGIDITY G	10^6 PSI
LONG	4.0	4.0
TRANS	4.0	4.0

	COMP. MODULUS OF ELASTICITY E_c	10^6 PSI
LONG	10.7	10.7
TRANS	10.7	10.7

	PLASTIC BENDING MODULUS	(SEE APPENDIX A)
LONG		
TRANS		

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-0	ANNEALED BY HEATING UNTIL MATERIAL IS OVER-AGED. IT IS THEN IN ITS SOFTEST CONDITION.
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T651	SOLUTION TREATED, STRESS RELIEVED BY STRETCHING TO PRODUCE A PERMANENT SET OF 1-1/2% (NOMINAL), BUT NOT LESS THAN 1% OR MORE THAN 3%, AND ARTIFICIALLY AGED. MATERIAL SHALL RECEIVE NO FURTHER STRAIGHTENING AFTER STRETCHING.

J. SERVICE LIMITS

NON-RADIATION SERVICE LIMITS
FROM -423°F TO 400°F, HIGHER TEMPERATURES OR EXCESSIVELY LONG TIME EXPOSURE AT 350°F RESULTS IN OVER-AGING AND MARKED DECREASE IN STRENGTH.

K. PROCESSING

SURFACE TREATMENT

CLEANING
EMULSION, SOLVENT OR VAPOR DE-GREASING; SODIUM-SILICATE-INHIBITED TRISODIUM PHOSPHATE OR SODIUM CARBONATE PLUS DILUTE H₂SO₄ RINSE; ULTRASONIC; DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE;
DO NOT USE SODIUM HYDROXIDE UNLESS AN ETCH IS DESIRED. (FOLLOW ALL ACID TREATMENTS WITH WATER RINSE)

ANODIZING
ANODIZE PER MIL-A-8625, TYPE 2

THERMAL TREATMENT

STRESS-RELIEF
TO REMOVE COLD WORK: HEAT TO 650°F (MAX. 775°F) FOR 1/2 TO 2 HOURS, AND AIR COOL.

TO SOFTEN AFTER HEAT TREATMENT: HEAT TO 775°F FOR 1 HOUR, MIN., COOL TO 500°F AT MAX. RATE OF 50°F/HOUR, THEN AIR COOL.

HARDENING
SOLUTION HEAT TREAT AT 925° TO 945°F INCL. FOR 20 MIN. TO 4 1/2 HRS. IN ACCORDANCE WITH THICKNESS, QUENCH IN WATER OR WATER SPRAY.

AGE AT 340° - 360°F FOR 8 - 12 HRS.

K. PROCESSING (CONTINUED)

JOINING

WELDING
RESISTANCE, ELECTRON BEAM, AND TIG METHODS REQUIRE SPECIAL TECHNIQUES AND TRAINING OF PERSONNEL. USE 4043 OR 2319 FILLER METAL

IF WELDED IN - T6 TEMPER, THESE AS-WELDED PROPERTIES RESULT:
4043 ALLOY, 65% EFFICIENT, 47,000 PSI UTS
2319 ALLOY, 80% EFFICIENT, 57,000 PSI UTS

FORMING

LARGE BEND RADIUS REQUIRED FOR COLD FORMING EXCEPT IN 0 TEMPER, -T6 TEMPER FORMABLE AT 300°-400°F.

MACHINABILITY

MACHINABILITY IN RELATION TO OTHER ALUMINUM ALLOYS IS GOOD.

L. REFERENCES

NP-55-1
NP-64-3
NP-65-1
NP-62-44
P-63-3

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

THIS MATERIAL IS HEAT TREATABLE (PRECIPITATION HARDENABLE) AND AMONG THE STRONGEST ALUMINUM ALLOYS. THE CORROSION RESISTANCE OF 2024 IS INFERIOR TO THAT OF ALLOYS WHICH HAVE LITTLE OR NO COPPER.

SECTION E ON THIS PAGE APPLIES TO BAR, WIRE, AND ROD WHICH HAS BEEN MANUFACTURED BY ROLLING OR DRAWING. COLD-FINISHED MATERIAL IS INCLUDED. THE DIMENSIONS GIVEN ARE MINIMUM THICKNESS OF CROSS-SECTION, OR DIAMETER. THESE VALUES APPLY TO -T4 AND -T351 TEMPER.

FOR THE FOLLOWING PROPERTIES: F_{TY} , F_{TU} , F_{CY} , F_{SU} , F_{BRU} , AND F_{BRV} , THE VALUES USED ARE THOSE ABOVE WHICH 99% OF THE POPULATION OF VALUES IS EXPECTED TO FALL WITH A CONFIDENCE OF 95%. ELONGATION IS A MINIMUM VALUE. ALL OTHER PROPERTY VALUES ARE AVERAGES.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, ROD & WIRE; ROLLED OR DRAWN	QQ-A-225/6 QQ-A-268 AMS 4119 AMS 4120 ASTM-B-211

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Cu	Mg	Mn	Fe	Si	Zn	Cr	Al
MAXIMUM	4.9	1.8	0.90	0.50	0.50	0.25	0.10	BAL.*
MINIMUM	3.8	1.2	0.30	—	—	—	—	—

SOURCE NP-63-45

* OTHERS: EACH - 0.05, TOTAL = 0.15

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

BAR, WIRE, AND ROD, -T4 AND -T351 CONDITIONS

	THICKNESS - INCHES		
	TO 1	1-2	2-3
TENSILE ULTIMATE STRENGTH F_{TU}	PSI		
LONG.	63,000	61,000	62,000
TRANS.	62,000	60,000	57,000
TENSILE YIELD STRENGTH F_{TY}	PSI		
LONG.	44,000	42,000	40,000
TRANS.	40,000	40,000	38,000
COMP. YIELD STRENGTH F_{CY}	PSI		
LONG.	38,000	38,000	32,000
TRANS.	43,000	42,000	—
ULTIMATE SHEAR STRENGTH F_{SU}	PSI		
	38,000	36,000	37,000
SHEAR YIELD STRENGTH F_{SY}	PSI		

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
e/D = 1.5	95,000
e/D = 2.0	120,000

YIELD BEARING STRENGTH F_{BRV}	PSI
e/D = 1.5	62,000
e/D = 2.0	70,000

ELONGATION e	%
8	6
	10

REDUCTION OF AREA RA	%
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MODULUS OF ELASTICITY E	10^6 PSI
10.5	

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
10.7	

MODULUS OF RIGIDITY G	10^6 PSI
4.0	

POISSON'S RATIO	
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HARDNESS	
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PLASTIC BENDING MODULUS	(SEE APPENDIX A)
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2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
0.100	
SPECIFIC HEAT C	BTU/LB - °F
(AT 212°F)	0.23
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
(AT 77°F)	0 111 -T6 87 -T4 70
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
(68° - 212°F)	12.6
ELECTRICAL RESISTIVITY R	MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	935°F TO 1180°F
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PHASE CHANGES	
THIS ALLOY IS PRECIPITATION-HARDENABLE.	

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k (BTU - FT HR - FT ² - °F)
-423	11
-350	29
-300	37
-250	45
-200	50
-150	54
-100	58
0	65
68	70
200	78
400	100
600	108
800	100

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

THE 2024 ALLOY WHEN IN THE -T3 AND -T4 CONDITIONS IS SUBJECT TO STRESS-CORROSION CRACKING. ALCLAD 2024 IS NOT SUBJECT TO STRESS-CORROSION.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

SECTION E ON THIS PAGE APPLIES TO EXTRUDED BARS, RODS AND SHAPES. ALL VALUES ARE FOR THE -T4 TEMPER.

DESIGN VALUE BASIS IS THE SAME AS THAT FOR BAR AND ROD.

CROSS-SECTIONAL AREA DIFFERENCES DO NOT AFFECT PROPERTIES WHEN AREAS ARE LESS THAN 25 SQ. IN. EXTRUSIONS WITH GREATER AREAS SHOW AN EFFECT ON PROPERTIES.

FOR GOODMAN DIAGRAM OF 2024-T4 BAR, 0.750-IN DIA., SEE PAGE 2

FOR THE FOLLOWING PROPERTIES: F_{TY} , F_{TU} , F_{CY} , F_{SU} , F_{BRU} , AND F_{BRY} , THE VALUES USED ARE THOSE ABOVE WHICH 99% OF THE POPULATION OF VALUES IS EXPECTED TO FALL WITH A CONFIDENCE OF 95%. ELONGATION IS A MINIMUM VALUE. ALL OTHER PROPERTY VALUES ARE AVERAGES.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, RODS, SHAPES AND TUBES	QQ-A-200/3
BAR, RODS AND SHAPES	QQ-A-267
EXTRUSIONS (-T4)	AMS 4152
EXTRUSIONS (-T3510)	AMS 4164
EXTRUSIONS (-T3511)	AMS 4165
	ASTM-B-221

SUPPLIERS

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									
SOURCE									

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

EXTRUDED BAR, ROD, AND SHAPES - THICKNESS, INCHES

-T4 CONDITION		
0.05-0.25	0.5-0.75	0.75-1.5
TENSILE ULTIMATE STRENGTH	F_{TU}	PSI
57,000	60,000	65,000
TENSILE YIELD STRENGTH	F_{TY}	PSI
42,000	44,000	46,000
COMP. YIELD STRENGTH	F_{CY}	PSI
38,000	39,000	39,000
ULTIMATE SHEAR STRENGTH	F_{SU}	PSI
30,000	32,000	32,000
SHEAR YIELD STRENGTH	F_{SY}	PSI

ULTIMATE BEARING STRENGTH	F_{BRU}	PSI
e/D = 1.5	85,000	85,000
e/D = 2.0	108,000	108,000

YIELD BEARING STRENGTH	F_{BRY}	PSI
e/D = 1.5	59,000	60,000
e/D = 2.0	67,000	64,000

ELONGATION	e	%
LONG.	12	12
REDUCTION OF AREA	RA	%

MODULUS OF ELASTICITY	E	10^6 PSI
	10.5	
COMP. MODULUS OF ELASTICITY	E_C	10^6 PSI
	10.7	
MODULUS OF RIGIDITY	G	10^6 PSI
	4.0	

POISSON'S RATIO

HARDNESS

PLASTIC BENDING MODULUS (SEE APPENDIX A)

A. GENERAL

SECTION E ON THIS PAGE APPLIES TO SHEET AND PLATE. THE TEMPER IS INDICATED.

DESIGN VALUE BASIS IS THE SAME AS THAT FOR BAR AND ROD.

2024 SHEET AND PLATE ARE USUALLY USED AS ALCLAD TO ELIMINATE CORROSION AND STRESS-CORROSION PROBLEMS. THE ALCLAD FORMS HAVE 2 - 4% LOWER TENSILE ULTIMATE STRENGTH AND TENSILE YIELD STRENGTH THAN THE UNCLAD MATERIAL.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET AND PLATE	QQ-A-250/4
	QQ-A-355
	ASTM-B-209
PLATE (T351)	AMS 4033
SHEET AND PLATE - (O TEMPER)	AMS 4035
SHEET AND PLATE (T3 AND T4)	AMS 4037
ALCLAD SHEET & PLATE	QQ-A-250/5
	QQ-A-362

SUPPLIERS

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									
SOURCE									

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SHEET AND PLATE, THICKNESS, INCHES

-T4 CONDITION		
0.01-0.25	0.25-0.5	0.5-1
TENSILE ULTIMATE STRENGTH	F_{TU}	PSI
LONG.	65,000	65,000
TRANS.	64,000	62,000
TENSILE YIELD STRENGTH	F_{TY}	PSI
LONG.	48,000	46,000
TRANS.	42,000	40,000
COMP. YIELD STRENGTH	F_{CY}	PSI
LONG.	40,000	38,000
TRANS.	45,000	43,000
ULTIMATE SHEAR STRENGTH	F_{SU}	PSI
	40,000	38,000
SHEAR YIELD STRENGTH	F_{SY}	PSI

ULTIMATE BEARING STRENGTH	F_{BRU}	PSI
e/D = 1.5	98,000	95,000
e/D = 2.0	124,000	120,000

YIELD BEARING STRENGTH	F_{BRY}	PSI
e/D = 1.5	69,000	62,000
e/D = 2.0	79,000	70,000

ELONGATION	e	%
	12	8
REDUCTION OF AREA	RA	%

MODULUS OF ELASTICITY	E	10^6 PSI
	10.5	
COMP. MODULUS OF ELASTICITY	E_C	10^6 PSI
	10.7	
MODULUS OF RIGIDITY	G	10^6 PSI
	4	

POISSON'S RATIO

HARDNESS

PLASTIC BENDING MODULUS (SEE APPENDIX A)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-W	SOLUTION HEAT-TREATED. AN UNSTABLE TEMPER APPLICABLE ONLY TO ALLOYS WHICH SPONTANEOUSLY AGE AT ROOM TEMPERATURE AFTER SOLUTION HEAT-TREATMENT. THIS DESIGNATION IS SPECIFIC ONLY WHEN THE PERIOD OF NATURAL AGING IS INDICATED: FOR EXAMPLE, W1/2 HOUR.
-T3	SOLUTION HEAT-TREATED AND THEN COLD WORKED. APPLIES TO PRODUCTS WHICH ARE COLD WORKED TO IMPROVE STRENGTH, OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING IS RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T351	SOLUTION HEAT-TREATED AND STRESS-RELIEVED BY STRETCHING TO PRODUCE A PERMANENT SET OF 1-3%. MATERIAL SHALL RECEIVE NO FURTHER STRAIGHTENING AFTER STRETCHING. MATERIAL IS NATURALLY AGED TO PRODUCE A SUBSTANTIALLY STABLE CONDITION.
-T4	SOLUTION HEAT-TREATED AND NATURALLY AGED TO A SUBSTANTIALLY STABLE CONDITION. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT, OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T86	SOLUTION TREATED, COLD-WORKED APPROXIMATELY 6%, AND ARTIFICIALLY AGED.

J. SERVICE LIMITS
NON-RADIATION SERVICE LIMITS

FROM -423° TO 400°F INCL. HIGHER TEMPERATURES OR EXCESSIVELY LONG EXPOSURE AT 400°F RESULTS IN OVERAGING AND MARKED DECREASE IN STRENGTH.

K. PROCESSING
SURFACE TREATMENT
CLEANING:

 EMULSION, SOLVENT OR VAPOR DEGREASE; SODIUM SILICATE INHIBITED TRI-SODIUM PHOSPHATE OR SODIUM CARBONATE PLUS DILUTE H₂SO₄; ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BI-SULFATE

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

ANODIZING:

ANODIZE IN ACCORDANCE WITH MIL-A-8625

THERMAL TREATMENT (PER MIL-H-6088)
STRESS RELIEF

1. TO REMOVE COLD WORK, HEAT TO 650°F FOR 1/2 TO 2 HRS AND AIR COOL
2. TO SOFTEN AFTER HEAT TREATMENT HEAT TO 775°F FOR 1 HOUR MIN. COOL TO 500°F AT NOT MORE THAN 50°F PER HOUR, THEN AIR COOL

HARDENING

1. SOLUTION HEAT TREAT AT 910°F TO 930°F INCL. FOR 20 MIN. TO 4.5 HRS. IN ACCORDANCE WITH THICKNESS, QUENCH IN WATER OR WATER SPRAY.
2. AGE AT 370 TO 380°F FOR 16 HRS. TO AGE -T4 TO -T6 TEMPER.

ARTIFICIAL AGING OF ALCLAD 2024 TO BE DONE PER MIL-A-8705.

K. PROCESSING (CONTINUED)
JOINING
WELDING:

WELDABILITY FOR FUSION WELDING RATED POOR, HOWEVER, ALLOY HAS BEEN TIG WELDED IN SPECIAL INSTANCES. WELDABILITY FOR RESISTANCE WELDING RATED GOOD.

FORMING

CAN ONLY BE FORMED COLD WHEN IN -O TEMPER. -T3 AND -T4 TEMPER CANNOT BE HOT FORMED UNLESS SUBSEQUENTLY AGED.

FAIRLY COLD FORMABLE IMMEDIATELY AFTER QUENCHING FROM SOLUTION TREATING TEMPERATURE (COND. W)

MACHINABILITY

MACHINABILITY IN RELATION TO OTHER ALUMINUM ALLOYS IS GOOD.

L. REFERENCES

NP-53-2, NP-55-1, NP-55-2, NP-58-5, NP-62-44, NP-64-3, NP-65-1, P-63-3.

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA
A. GENERAL

THIS ALLOY HAS GOOD STRENGTH PROPERTIES UP TO 300°F AND DOWN TO -423°F. IT IS SUITABLE FOR FORGING AND FUSION WELDING.

SECTION E ON THIS PAGE APPLIES TO SHEET AND PLATE. THICKNESS AND TEMPER ARE GIVEN IN SECTION E.

DESIGN PROPERTY BASIS FOR F_{TU} , F_{TY} , F_{CY} , F_{SU} , F_{BRU} , F_{BRY} THE VALUES OF THESE PROPERTIES ARE THOSE ABOVE WHICH 99% OF THE POPULATION OF VALUES IS EXPECTED TO FALL, WITH A CONFIDENCE OF 95%.

FOR α , THE VALUES ARE MINIMA

FOR OTHER PROPERTIES, THE VALUES ARE AVERAGES.

FOR GOODMAN DIAGRAM OF 2219-T87 0.100-IN. SHEET, SEE PAGE 2.

B. COMMERCIAL DESIGNATIONS
C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET AND PLATE	MIL-A-8920
SHEET AND PLATE (-O TEMPER)	AMS 4031
FORGINGS (-T6)	AMS 4143
FORGINGS (-T852)	AMS 4144
WELDING ROD AND WIRE (2319)	AMS 4191

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT*	Cu	Mg	Mn	Fe	Si	V	Ti	Zr	Zn
MAXIMUM	6.8	0.02	0.40	0.30	0.20	0.15	0.10	0.25	0.10
MINIMUM	5.8	-	0.20	-	-	0.05	0.02	0.10	-

SOURCE MIL-A-8920

* OTHERS: 0.05 EACH, 0.15 TOTAL AL: BALANCE

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SHEET AND PLATE - THICKNESS (IN.)

	-T62 0.04 - 2	-T81 0.04 - 0.25	-T851 0.25 - 2	-T87 0.25 - 2
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	PSI	PSI	PSI
LONG.	54,000	60,000	60,000	62,000
TRANS.	54,000	61,000	61,000	63,000

TENSILE YIELD STRENGTH F_{TY}	PSI	PSI	PSI	PSI
LONG.	36,000	45,000	45,000	50,000
TRANS.	36,000	44,000	44,000	50,000

COMP. YIELD STRENGTH F_{CY}	PSI	PSI	PSI	PSI
LONG.	38,000	46,000	46,000	50,000
TRANS.	38,000	47,000	47,000	53,000

SHEAR STRENGTH F_{SU}	PSI	PSI	PSI	PSI
	32,000	35,000	35,000	36,000

BEARING STRENGTH ULTIMATE F_{BRU}	PSI	PSI	PSI	PSI
e/D=1.5	81,000	88,000	88,000	91,000
e/D=2.0	108,000	116,000	116,000	120,000

BEARING STRENGTH YIELD F_{BRY}	PSI	PSI	PSI	PSI
e/D=1.5	58,000	66,000	66,000	70,000
e/D=2.0	68,000	75,000	75,000	80,000

ELONGATION ϵ	%	%	%	%
L & T	6	6	6	5

REDUCTION OF AREA RA	%	%	%	%
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MODULUS OF ELASTICITY E	10^6 PSI	10^6 PSI	10^6 PSI	10^6 PSI
	10.5	10.5	10.5	10.5

MODULUS OF RIGIDITY G	10^6 PSI	10^6 PSI	10^6 PSI	10^6 PSI
	4.0	4.0	4.0	4.0

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI	10^6 PSI	10^6 PSI	10^6 PSI
	10.8	10.8	10.8	10.8

PLASTIC BENDING MODULUS	SEE APPENDIX A)	SEE APPENDIX A)	SEE APPENDIX A)	SEE APPENDIX A)
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2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.102

SPECIFIC HEAT C BTU/LB - °F

(AT 212°F) 0.23

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F

(AT 77°F) 74

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN. / IN. - °F

(68° TO 212°F) 12.4

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

1010°F - 1190°F

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES
H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

SEE ELONGATION CHART

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-0	ANNEALED BY HEATING UNTIL MATERIAL IS OVER-AGED. IT IS THEN IN ITS SOFTEST CONDITION.
-T31	SOLUTION TREATED AND COLD WORKED A NOMINAL 1% (AGES TO -T81).
-T37	SOLUTION TREATED AND COLD WORKED A NOMINAL 7% (AGES TO -T87).
-T352	SOLUTION HEAT-TREATED AND STRESS RELIEVED BY COMPRESSING TO PRODUCE A PERMANENT SET OF 1 TO 3%. MATERIAL SHALL RECEIVE NO FURTHER STRAIGHTENING AFTER STRETCHING. MATERIAL IS NATURALLY AGED TO PRODUCE A SUBSTANTIALLY STABLE CONDITION.
-T4	SOLUTION HEAT-TREATED AND NATURALLY AGED TO A SUBSTANTIALLY STABLE CONDITION. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT, OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T42	MATERIAL PURCHASED TO ANY CONDITION AND SUBSEQUENTLY SOLUTION TREATED BY THE USER, AGED NATURALLY TO A SUBSTANTIALLY STABLE CONDITION.
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T62	MATERIAL PURCHASED IN ANY TEMPER AND SUBSEQUENTLY SOLUTION TREATED AND AGED BY THE USER.
-T81	SOLUTION TREATED, COLD-WORKED APPROXIMATELY 1%, AND AGED.
-T851	SOLUTION HEAT TREATED AND STRESS-RELIEVED BY STRETCHING TO PRODUCE A PERMANENT SET OF 1-1/2% NOMINAL (1-3%). MATERIAL SHALL RECEIVE NO FURTHER STRAIGHTENING AFTER STRETCHING. MATERIAL IS ARTIFICIALLY AGED AFTER STRETCHING.
-T87	SOLUTION TREATED, COLD WORKED APPROXIMATELY 7%, AND ARTIFICIALLY AGED.

J. SERVICE LIMITS

RADIATION SERVICE LIMITS
SEE SECTION H

NON-RADIATION SERVICE LIMITS

FROM -423 TO 300°F.

EXPOSURE TO HIGHER TEMPERATURES, OR EXCESSIVELY LONG HOLDING PERIODS AT 300°F RESULTS IN OVER-AGING AND MARKED DECREASE IN STRENGTH.

K. PROCESSING

SURFACE TREATMENT

CLEANING

METHODS

EMULSION, SOLVENT, OR VAPOR DEGREASE;

SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE, OR SODIUM CARBONATE PLUS DILUTE H_2SO_4 ;

ULTRASONIC.

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE.

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT (PER MIL-H-6088)

STRESS RELIEF

TO REMOVE COLD WORK - HEAT TO 650°F FOR 1/2 TO 2 HOURS AND AIR COOL

TO SOFTEN AFTER HEAT TREATMENT - HEAT TO 775°F FOR 1 HOUR MIN., COOL TO 500°F AT NOT MORE THAN 50°F PER HOUR, THEN AIR COOL

HARDENING

SOLUTION TREAT 990° - 1010°F FOR 20 MIN. TO 4 1/2 HRS, IN ACCORDANCE WITH THICKNESS, QUENCH IN WATER OR WATER SPRAY. MATERIAL IS NOW IN -T4 CONDITION.

K. PROCESSING (CONTINUED)

AGING

START WITH -T4,	AGE AT 375°F	18 HR TO -T6
-T352,	AGE AT 350°F	10 HR TO -T85
-T42 (THRU 1"),	AGE AT 375°F	36 HR TO -T62
-T42 (ABOVE 1"),	AGE AT 375°F	18 HR TO -T62
-T31,	AGE AT 350°F	18 HR TO -T81
-T37,	AGE AT 325°F	14 HR TO -T87

JOINING

WELDING:

METHODS

TIG, ELECTRON BEAM, RESISTANCE

FILLER

2319 ALUMINUM ALLOY

EFFICIENCY AND STRENGTHS

1. -T81 AND -T87, 55 TO 75%; 40,000-50,000 PSI AS-WELDED
2. RE-HEAT TREATED TO -T62 AFTER WELDING, 95%; 60,000-65,000 PSI.

FORMING

COMPARABLE TO 2024

COLD-FORMING IN -0 TEMPER PREFERRED.

MACHINABILITY

MACHINABILITY IN RELATION TO OTHER ALUMINUM ALLOYS IS GOOD.

L. REFERENCES

NP-65-1
NP-64-3
NP-63-3

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE	1 MAY 1966
SUPERSEDES	

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

0.16
0.12
0.08
0.04
0

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

THE BASIS FOR THE DATA IN SECTION E IS THAT OF
GUARANTEED MINIMA FOR TEMPER AND THICKNESSES SHOWN

FOR GOODMAN DIAGRAM TYPICAL OF VARIOUS FORMS,
SIZES, AND METHODS OF MANUFACTURE, SEE PAGE 2

B. COMMERCIAL DESIGNATIONS
C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, ROD & SHAPES, EXTRUDED	QQ-A-00200/4 MIL-A-19005 ASTM-B-221
FORGINGS	ASTM-B-247
PIPE, EXTRUDED OR DRAWN	ASTM-B-241 ASTM-B-345
PLATE AND SHEET	QQ-A-00250/6A MIL-A-17958 SAE-AMS-4056 SAE-AMS-4057 SAE-AMS-4058 SAE-AMS-4059 ASTM-B-209
STD. STRUCTURAL SHAPES	MIL-A-19005 ASTM-B-308
TUBE, DRAWN	MIL-T-52234
TUBE, EXTRUDED	MIL-T-52234 ASTM-B-221

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
MAXIMUM	0.40	0.40	0.10	1.0	4.9	0.25	0.25	0.15
MINIMUM	-	-	-	0.30	4.0	0.05	-	-

SOURCE NP-62-14 *OTHER: 0.05 EACH AND
0.15 TOTAL
BAL: ALUMINUM

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET AND PLATE - THICKNESS (IN.)

-0	-H112	-H323
0.05 - 0.75	0.25 - 1.50	0.05 - 1
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	
40,000 (MIN)	40,000 (MIN)	45,000 (MIN.)

TENSILE YIELD STRENGTH F_{TY}	PSI
18,000 (MIN)	18,000 (MIN)
	34,000 (MIN.)

COMP. YIELD STRENGTH F_{CY}	PSI
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SHEAR YIELD STRENGTH F_{SY}	PSI
22,000	24,200
	24,750

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
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ELONGATION	%
16 (MIN.)	12 (MIN.)
	10 (MIN.) EXCEPT FOR .051-.125; 8 (MIN.)

REDUCTION OF AREA	RA
	%

MODULUS OF ELASTICITY	E
	10^6 PSI
	10.3

MODULUS OF RIGIDITY	G
	10^6 PSI
	SHEAR 3.8

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
	10.2

PLASTIC BENDING MODULUS	(SEE APPENDIX A)
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2. PHYSICAL PROPERTIES

DENSITY	ρ	LB/IN ³
	0.096	
SPECIFIC HEAT	C	BTU/LB - °F
(AT 212°F)	0.23	
THERMAL CONDUCTIVITY	k	BTU - FT HR - FT ² - °F
	67.5	
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F	
(68-212°F)	13.2	
ELECTRICAL RESISTIVITY	R	MICROHM - IN.
(-0 TEMPER)	2.34	

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	1065°F-1180°F
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PHASE CHANGES

THIS ALLOY MAY ONLY BE HARDENED BY COLD WORKING.

THERMAL CONDUCTIVITY VS. TEMPERATURE
G. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES
H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-0	FULL ANNEALED MATERIAL IS IN ITS SOFTEST CONDITION.
-H112	APPLIES TO PRODUCTS WHICH ACQUIRE SOME TEMPER FROM SHAPING PROCESSES NOT HAVING SPECIAL CONTROL OVER THE AMOUNT OF STRAIN-HARDENING OR THERMAL TREATMENT, BUT FOR WHICH THERE ARE MECHANICAL PROPERTY LIMITS OR MECHANICAL PROPERTY TESTING IS REQUIRED, E.G., AS EXTRUDED.
-H321	STRAIN HARDENED LESS THAN THE AMOUNT REQUIRED FOR A CONTROLLED HALF-HARD TEMPER, THEN STABILIZED BY LOW-TEMPERATURE ANNEAL
-H323	STRAIN HARDENED TO ONE-QUARTER HARD TEMPER AND THAN STABILIZED TO BETWEEN ONE-QUARTER AND ONE-HALF HARD FOR RESISTANCE TO STRESS-CORROSION CRACKING
-H343	SIMILAR TO -H323 BUT HALF-HARD TEMPER

J. SERVICE LIMITS

MAXIMUM SERVICE TEMPERATURE = 150°F

K. PROCESSING

SURFACE TREATMENT

CLEANING

METHODS

EMULSION, SOLVENT, OR VAPOR DEGREASE;
SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE,
OR SODIUM CARBONATE PLUS DILUTE H_2SO_4 ;

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE.
DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED
FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

THIS ALLOY IS NON-PRECIPITATION-HARDENABLE
ANNEAL AT 775°F

K. PROCESSING (CONTINUED)

JOINING

WELDING METHOD: TIG AND MIG

FILLER METAL: 5356

FORMING

NOT SUITABLE FOR EXTENSIVE FORMING AT ROOM TEMPERATURE.

HOT WORKING AT 425°F $\pm$ 25°F WILL AVOID THE ADVERSE EFFECT OF COLD WORKS AND HIGH RESIDUAL STRESSES.

MACHINABILITY

MACHINABILITY RELATIVE TO OTHER ALUMINUM ALLOYS IS POOR.

L. REFERENCES

NP-63-4
NF-62-14
NP-66-4

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

DESIGN PROPERTIES IN SECTION E ARE FROM MIL-HDBK-5.

VALUES IN PARAGRAPH E-1 ARE FOR TEMPER AND THICKNESSES SHOWN

B. COMMERCIAL DESIGNATIONS
C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, ROD & SHAPES EXTRUDED AND ROLLED	QQ-A-00200/6 MIL-A-21559 ASTM B-221 (EXTRUDED)
PIPE, EXTRUDED OR DRAWN	MIL-P-25995 ASTM B-241
PLATE AND SHEET	QQ-A-00250/10 MIL-A-21598 ASTM B-209
STD. STRUCTURAL SHAPE	MIL-A-21599 ASTM B-308
TUBE, DRAWN	ASTM B-234
TUBE, EXTRUDED	ASTM B-221

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others
MAXIMUM	0.40	0.10	1.0	3.0	0.20	0.25	0.20	0.15	0.05 EA
MINIMUM	-	-	-	0.5	2.4	0.05	-	-	-

SOURCE NP-62-14 BAL. AI

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES
SHEET AND PLATE - THICKNESS, INCHES

	-0 TEMPER 0.02-3	-H34 TEMPER 0.20-1
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	PSI
31,000	39,000	
TENSILE YIELD STRENGTH F_{TY}	PSI	PSI
12,000	28,500	
COMP. YIELD STRENGTH F_{CY}	PSI	PSI
12,000	28,000	
ULTIMATE SHEAR STRENGTH F_{SU}	PSI	PSI
19,000	23,000	
SHEAR YIELD STRENGTH F_{SY}	PSI	PSI

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
e/D = 1.5 46,000	57,000
e/D = 2.0 62,000	78,000

YIELD BEARING STRENGTH F_{BRY}	PSI
e/D = 1.5	
e/D = 2.0	

ELONGATION e	%
0.02-0.03 12	4
0.03-0.05 14	4
0.05-0.113 16	-
0.113- 3 18	-
0.05-0.16 -	6
0.16-0.25 -	7
0.25- 1 -	10
MODULUS OF ELASTICITY E	10^6 PSI

10.2

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
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10.4

MODULUS OF RIGIDITY G	10^6 PSI
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3.85

POISSON'S RATIO
HARDNESS
PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
0.097	
SPECIFIC HEAT C	BTU/LB - °F
(AT 212°F) 0.23	
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
78	
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
(68-212°F) 13.1	
ELECTRICAL RESISTIVITY R	MICROHM - IN.

F. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES

IN ACCELERATED TESTS, ALLOY 5454 HAS DEMONSTRATED FREEDOM FROM STRESS-CORROSION CRACKING IN BOTH COLD-WORKED AND ANNEALED TEMPER AFTER HEATING FOR 4 YEARS AT 212°F. THIS ALLOY IS RECOMMENDED FOR WELDED STRUCTURAL APPLICATIONS WHERE TEMPERATURES WILL EXCEED 150°F FOR LONG PERIODS OF TIME.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	1055° - 1180°F
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PHASE CHANGES
THERMAL CONDUCTIVITY VS. TEMPERATURE
H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-0	FULL ANNEALED; MATERIAL IS IN ITS SOFTEST CONDITION
-H32	STRAIN HARDENED AND THAN STABILIZED AT ONE-QUARTER HARD
-H34	STRAIN-HARDENED AND THAN STABILIZED AT ONE-HALF HARD
-H112	APPLIES TO PRODUCTS WHICH ACQUIRE SOME TEMPER FROM SHAPING PROCESSES NOT HAVING SPECIAL CONTROL OVER THE AMOUNT OF STRAIN-HARDENING OR THERMAL TREATMENT, BUT FOR WHICH THERE ARE MECHANICAL PROPERTY LIMITS OR MECHANICAL PROPERTY TESTING IS REQUIRED

J. SERVICE LIMITS

MAXIMUM SERVICE TEMPERATURE +300°F

K. PROCESSING
SURFACE TREATMENT
CLEANING
METHODS

EMULSION, SOLVENT, OR VAPOR DEGREASE;

SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE,
OR SODIUM CARBONATE PLUS DILUTE H_2SO_4 ;

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE,

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

ANNEALING - HEAT TO 650°F-800°F. HOLD TILL ALL PARTS OF LOAD REACH THE REQUIRED TEMPERATURE. COOL IN STILL AIR.

K. PROCESSING (CONTINUED)
JOINING

WELDING METHOD: TIG AND MIG

FILLER METAL: 5554 OR 5356

FORMING
MACHINABILITY

MACHINABILITY RELATIVE TO OTHER ALUMINUM ALLOYS
5454-0 P00R
5454-H34 FAIR

L. REFERENCES

NP-60-14
NP-62-14
NP-62-17

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

USED FOR APPLICATIONS REQUIRING A WELDABLE MODERATE STRENGTH ALLOY HAVING GOOD CORROSION RESISTANCE.

THE PROPERTY VALUES IN SECTION E ARE MINIMA FOR TEMPER AND THICKNESSES SHOWN FOR F_{TU} , F_{TY} , and e_2 FOR RA, THE VALUE IS 80% OF AVERAGE.

FOR GOODMAN DIAGRAM FOR 0.100-IN. SHEET, H 343, SEE PAGE 2.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, ROD AND SHAPES EXTRUDED	QQ-A-00200/7 MIL-A-21170 ASTM B-221
BAR, ROD & SHAPES, ROLLED	QQ-A-00200/7 MIL-A-21170
FORGINGS	ASTM-B-247
PIPE, EXTRUDED OR DRAWN	MIL-P-25995 ASTM B-241 ASTM-B-345
PLATE AND SHEET	QQ-A-00250/9 MIL-A-19842 ASTM B-209
STD. STRUCTURAL SHAPES	MIL-A-21170 MIL-A-25994 ASTM B-308
TUBE, EXTRUDED	ASTM B-221

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Mg	Mn	Cu	Cr	Si+Fe	Zn	Ti	Others	TOT
MAXIMUM	5.5	1.0	0.10	0.20	0.40	0.25	0.20	0.15	
MINIMUM	4.7	0.5	-	0.5	-	-	-	0.05	EACH
SOURCE	NP-61-12 BAL. Al								

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES			
SHEET AND PLATE		EXTRUSIONS	
	-0	-H 321	-H 112
	0.05-2 IN.	0.025-0.62 IN.	TO 5 IN.
TENSILE ULTIMATE STRENGTH F_{TU}	PSI		
	42,000	46,000	42,000
TENSILE YIELD STRENGTH F_{TY}	PSI		
	19,000	31,500	19,000
COMP. YIELD STRENGTH F_{CY}	PSI		
	19,000	31,500	19,000
ULTIMATE SHEAR STRENGTH F_{SU}	PSI		
	26,000	27,000	24,000
SHEAR YIELD STRENGTH F_{SY}	PSI		
	11,000	19,000	-
ULTIMATE BEARING STRENGTH F_{BRU}	PSI		
$e/D = 1.5$	63,000	67,000	59,000
$e/D = 2.0$	84,000	84,000	76,000
YIELD BEARING STRENGTH F_{BRY}	PSI		
$e/D = 1.5$	32,000	46,000	34,000
$e/D = 2.0$	38,000	53,000	-
ELONGATION e	%		
	16	12	12
REDUCTION OF AREA RA	%		
(PLATE)	17	-	-
MODULUS OF ELASTICITY E	10^6 PSI		
TENSILE	10.2		
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI		
	10.4		
MODULUS OF RIGIDITY G	10^6 PSI		
	3.85		
POISSON'S RATIO			
HARDNESS	BHN *		
TEMPER	-0	-H112	-H311
HARDNESS	75	75	86
			90
*500 K _g LOAD AND 10-MM BALL			
PLASTIC BENDING MODULUS (SEE APPENDIX A)			

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
(AT 68°F)	0.096
SPECIFIC HEAT C	BTU/LB - °F
(AT 212°F)	0.23
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
(AT 77°F)	67.7
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
(68-212°F)	13.3
ELECTRICAL RESISTIVITY R	MICROHM - IN.
(AVERAGE OF ALL TEMPS)	2.35

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	1060 - 1180°F
PHASE CHANGES	NONE
THERMAL CONDUCTIVITY VS. TEMPERATURE	

F. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE

HIGH RESISTANCE TO ATTACK BY HIGH HUMIDITY, SALT SPRAY, INDUSTRIAL AND MARINE ATMOSPHERES.

EXCELLENT RESISTANCE TO NATURAL FRESH WATER AND HIGHLY PURIFIED WATER.

NEGLECTIBLE ATTACK BY CONCENTRATED HNO₃.

RESISTANT TO ATTACK BY ORGANIC SOLVENTS.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-0	FULL ANNEALED; MATERIAL IS IN ITS SOFTEST CONDITION.
-H321	STRAIN HARDENED TO ONE-QUARTER-HARD TEMPER AND THEN STABILIZED TO ONE-EIGHTH HARD.
-H112	APPLIES TO PRODUCTS WHICH ACQUIRE SOME TEMPER FROM SHAPING PROCESSES NOT HAVING SPECIAL CONTROL OVER THE AMOUNT OF STRAIN-HARDENING OR THERMAL TREATMENT, BUT FOR WHICH THERE ARE MECHANICAL PROPERTY LIMITS OR MECHANICAL PROPERTY TESTING IS REQUIRED, E.G., AS EXTRUDED.
-H24	STRAIN HARDENED AND THEN PARTIALLY ANNEALED TO HALF-HARD CONDITION. (APPROXIMATELY SAME ULTIMATE STRENGTH AS THE CORRESPONDING H1 TEMPER AND SLIGHTLY HIGHER ELONGATIONS).
-H323	APPLY TO PRODUCTS THAT ARE SPECIALLY FABRICATED TO HAVE ACCEPTABLE RESISTANCE TO STRESS- CORROSION CRACKING
-H343	APPLY TO PRODUCTS THAT ARE SPECIALLY FABRICATED TO HAVE ACCEPTABLE RESISTANCE TO STRESS- CORROSION CRACKING

J. SERVICE LIMITS

MAXIMUM SERVICE TEMPERATURE +300°F

K. PROCESSING

SURFACE TREATMENT

CLEANING

METHODS

EMULSION, SOLVENT, OR VAPOR DEGREASE;

SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE, OR SODIUM CARBONATE PLUS DILUTE H_2SO_4 ;

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE.

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

ANNEALING

HEAT TO 775°F. HOLD UNTIL ENTIRE LOAD IS AT HEAT. COOL IN STILL AIR.

K. PROCESSING (CONTINUED)

JOINING

WELDING

METHOD
RESISTANCE, TIG AND MIG

FILLER METAL
FOR TIG AND MIG, 5356

FORMING

HOT WORKING TEMPERATURE: 600 - 900°F

MACHINABILITY

MACHINABILITY RELATIVE TO OTHER ALUMINUM ALLOYS:

5456-0 POOR
5456-H24 FAIR
5456-H321 FAIR

L. REFERENCES

NP-64-3
NP-64-8
NP-65-1
NP-65-31

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

MATERIALS DATA BOOK

6061
ALUMINUM ALLOYI-A-61
1

DATE 15 MAR 1970

SUPERSEDES 1 MAY 1966

BASIC DATA

A. GENERAL

6061 ALLOY IS A GENERAL-PURPOSE, HEAT-TREATABLE ALLOY WITH GOOD STRENGTH, FORMABILITY, WELDABILITY, AND VERY GOOD CORROSION RESISTANCE, WHICH IS NOT LOWERED SIGNIFICANTLY BY WELDING PROCESSES. IT IS THE MOST VERSATILE OF THE WROUGHT HEAT-TREATABLE ALLOYS. THE MACHINABILITY RATING IS EXCELLENT.

VALUES FOR F_{TU} , F_{TY} , F_{CY} , F_{SU} , F_{BRU} , F_{BRY} , AND e LISTED IN SECTION E ARE "A" BASIS RT VALUES FROM MIL-HNDBK-5A (REF 66-10); OTHER VALUES ARE AVERAGES FROM PUBLISHED DATA.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS

FORMS AND CONDITIONS		SPECIFICATIONS			
		AMS	FED QQ-A	MIL	ASTM
SHEET, PLATE	-0	4025	250/11		B-209
	-T4, T451	4026	250/11		B-209
	-T6, T651	4027	250/11	M-17999	B-209
BAR, SHAPES ROLLED, DRAWN	-0	4115	225/8		B-211
	-T4, T451	4116	225/8		B-211
	-T6, T651	4117	225/8		B-211
BAR, SHAPES EXTRUDED	-0	4160	200/8	A-12545	B-221
	-T4	4161	200/8	A-12545	B-221
	-T6	4150	200/8	A-12545	B-221
FORGINGS	-T4	4146			
	-T6	4127	367	A-22771	B-247
TUBING, PIPE	-0	4079	700/6		B-210
		4080			B-241
	-T4	4081	700/6	T-7081	B-210
					B-241
	-T6	4082		T-7081	B-210
		4083		T-10794	B-241

SUPPLIERS

ALUMINUM CO. OF AMERICA
REYNOLDS METALS
KAISER ALUMINUM AND CHEMICAL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Mg	Si	Cu	Cr	Fe	Mn	Zn	Ti	OTHERS
MAXIMUM	1.2	0.80	0.40	0.35	0.70	0.15	0.25	0.15	0.15 MAX. (TOTAL)
MINIMUM	0.80	0.40	0.15	0.15	-	-	-	-	0.05 MAX. (EACH)
SOURCE	REF. 66-25				BAL. AL				

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	SHEET AND PLATE		HAND FORGINGS *	
	-T4, -T451	-T6, -T651	-T6	
	0.010 - 2.00	0.010 - 2.00	4.00-IN.	
ULTIMATE TENSILE STRENGTH F_{TU}				KSI

L	-	42	38
LT	30	42	38
ST	-	-	37

TENSILE YIELD STRENGTH F_{TY}			KSI
---------------------------------	--	--	-----

L	-	35	36
LT	16	35	35
ST	-	-	33

COMP. YIELD STRENGTH F_{CY}			KSI
-------------------------------	--	--	-----

L	-	35	36
LT	16	36	36
ST	-	-	34

ULTIMATE SHEAR STRENGTH F_{SU}			KSI
----------------------------------	--	--	-----

	20	27	25
--	----	----	----

ULTIMATE BEARING STRENGTH F_{BRU}			KSI
-------------------------------------	--	--	-----

e/D = 1.5	48	67	61
e/D = 2.0	63	88	76

YIELD BEARING STRENGTH F_{BRY}			KSI
----------------------------------	--	--	-----

e/D = 1.5	22	50	54
e/D = 2.0	26	58	61

ELONGATION e			%
----------------	--	--	---

0.01 - 0.02 IN.	14	8	
0.02 - 0.25 IN.	16	10	
0.25 - 0.50 IN.	18	10	L 10
0.50 - 1.00 IN.	18	9	LT 8
1.00 - 2.00 IN.	16	8	ST 5
2.00 - 3.00 IN.	16	6	

REDUCTION OF AREA RA			%
------------------------	--	--	---

PROPORTIONED	-	22	26
--------------	---	----	----

MODULUS OF ELASTICITY E			10^6 PSI
---------------------------	--	--	------------

		9.9	
--	--	-----	--

COMP. MODULUS OF ELASTICITY E_C			10^6 PSI
-----------------------------------	--	--	------------

		10.1	
--	--	------	--

MODULUS OF RIGIDITY G			10^6 PSI
-------------------------	--	--	------------

		3.8	
--	--	-----	--

* MAX. CROSS-SECTIONAL AREA = 256 IN.

2. PHYSICAL PROPERTIES

DENSITY P	
-------------	--

LB/IN ³	0.0975
g/cc	2.70

SPECIFIC HEAT C	BTU/LB - °F
-------------------	-------------

(AT 212 F)	0.23
------------	------

MEAN COEFF. LINEAR THERMAL EXPANSION α	$\frac{10^{-6} \text{ IN.}}{\text{IN. - } ^\circ\text{F}}$
---	--

(68 TO 212 F)	13.0
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THERMAL CONDUCTIVITY k	$\frac{\text{BTU - FT}}{\text{HR - FT}^2 - ^\circ\text{F}}$
--------------------------	---

- 0 CONDITION	104
-T4 CONDITION	89
-T6 CONDITION	97

ELECTRICAL RESISTIVITY R	MICROHM - IN.
----------------------------	---------------

- 0 CONDITION	1.46
-T4 CONDITION	1.69
-T6 CONDITION	1.55

ELECTRICAL CONDUCTIVITY	% IACS
-------------------------	--------

- 0 CONDITION	EQ. VOL. - 47	EQ. WT. - 155
-T4 CONDITION	EQ. VOL. - 40	EQ. WT. - 132
-T6 CONDITION	EQ. VOL. - 43	EQ. WT. - 142

MAGNETIC PROPERTIES	
---------------------	--

NON-MAGNETIC	
--------------	--

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
---------------	--

	1080 - 1200 F
--	---------------

PHASE CHANGES	
---------------	--

THIS ALLOY IS PRECIPITATION-HARDENABLE.	
TRANSFORMATION TEMPERATURE - NONE	

SOLAR ABSORPTANCE a_s	%
-------------------------	---

AS RECEIVED	0.41
MECH. POLISHED AND DEGREASED	0.35
SANDBLASTED, 120-SIZE GRIT	0.60
CHEMICALLY CLEANED	0.18-0.44

F. THERMOPHYSICAL EFFECTS (CONTINUED)

THERMAL CONDUCTIVITY VS. TEMPERATURE	
--------------------------------------	--

G. CHEMICAL PROPERTIES

THIS ALLOY HAS GOOD RESISTANCE TO WEATHERING IN RELATIVELY SEVERE INDUSTRIAL AND SEA-COAST ATMOSPHERES. RESISTANCE TO STRESS CORROSION CRACKING IS EXCELLENT IN ALL TEMPER.

H. NUCLEAR PROPERTIES

THIS ALLOY IS LESS SUSCEPTIBLE TO RADIATION DAMAGE THAN THE LESS DUCTILE ALLOYS. GENERAL EFFECTS OF IRRADIATION ARE INCREASED YIELD AND ULTIMATE TENSILE STRENGTHS, AND DECREASED ELONGATION AT BREAK. YIELD STRENGTH, ULTIMATE STRENGTH, AND ELONGATION ARE AFFECTED IN THE ORDER LISTED.

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
2

DATE 15 MAR 1970
SUPERSEDES 1 MAY 1966

BASIC DATA

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-0	ANNEALED BY HEATING UNTIL MATERIAL IS OVER AGED, IT IS THEN IN ITS SOFTEST CONDITION.
-T4	SOLUTION HEAT-TREATED AND NATURALLY AGED TO A SUBSTANTIALLY STABLE CONDITION. APPLIES TO PRODUCTS WHICH ARE COLD WORKED AFTER SOLUTION HEAT-TREATMENT, OR IN WHICH THE EFFECTS OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD-WORKED AFTER SOLUTION HEAT-TREATMENT, OR IN WHICH THE EFFECTS OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T451 OR -T651	MATERIAL IN THE -T4 OR -T6 TEMPER, RESPECTIVELY, WHICH ARE STRESS-RELIEVED BY STRETCHING THE FOLLOWING AMOUNTS, AFTER SOLUTION HEAT-TREATMENT: PLATE 1 1/2% TO 3% PERMANENT SET ROD, BAR, SHAPES, EXTRUDED TUBE: 1% TO 3% PERMANENT SET

J. SERVICE LIMITS

CORROSION RESISTANCE GOOD. SEE SECTION G.

MAXIMUM SERVICE TEMPERATURE: 300 F.

K. TYPICAL FABRICATION CHARACTERISTICS

RELATIVE RATINGS A, B, C, D, IN DECREASING ORDER OF MERIT

	-0	-T4	-T6
RESISTANCE TO CORROSION	A	A	A
WORKABILITY (COLD)	A	C	C
MACHINABILITY	D	C	C

BRAZABILITY AND WELDABILITY RELATIVE RATINGS, DEFINED AS:

A. GENERALLY WELDABLE			
B. WELDABLE WITH SPECIAL TECHNIQUES			
	-0	-T4	-T6
BRAZABILITY	A	A	A
WELDABILITY	A	A	A
GAS	A	A	A
ARC	A	A	A
RESISTANCE			
(SPOT OR SEAM)	B	A	A
FORCEABILITY	-	-	-

L. PROCESSING

SURFACE TREATMENT

CLEANING METHODS:

EMULSION, SOLVENT, OR VAPOR DEGREASE;

SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE, OR SODIUM CARBONATE PLUS DILUTE H_2SO_4 ;

ULTRASONIC.

DE-SMUT WITH CHROMIC ACID AND SODIUM DISULFATE.

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED.

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE

THERMAL TREATMENT (PER MIL-H-6088)

COMPLETE ANNEALING (-0 CONDITION):
775 F FOR 2-3 HOURS. FURNACE COOL AT 50 F/HR., MAX. TO 500 F. COOL IN STILL AIR.

REMOVAL OF COLD WORK:
650-775 F. NO HOLD TIME REQD. COOLING NOT CRITICAL.

SOLUTION HEAT TREATMENT (-T4 AND -T42 TEMPER):
960-1025 F. HOLD UNTIL ENTIRE LOAD IS AT TEMPERATURE. COLD WATER QUENCH.

PRECIPITATION (AGING) TREATMENT (-T6, -T651.0, -T6411):
340-360 F. HOLD AT TEMPERATURE FOR 7.5-8.5 HOURS AIR COOL.

JOINING

RELEVANT SPECIFICATIONS:

WELDING, MIL-W-8604 AND MIL-W-22248
BRAZING, MIL-STD-645A AND MIL-B-7883

FUSION WELDING:

TIG AND MIG METHODS, WITH 4043, 5356, OR X4643 FILLER METAL

RESISTANCE WELDING:

CAN BE USED, BUT PRE-CLEANING IS NECESSARY.

NOT RECOMMENDED FOR ALLOY IN ANNEALED CONDITION.

L. PROCESSING (CONTINUED)

FORMING

HOT WORKING TEMPERATURE RANGE 500 - 900 F.

MACHINABILITY

MACHINABILITY RELATIVE TO OTHER ALUMINUM ALLOYS IS FAIR.

M. REFERENCES

70-7A	67-32	66-37	63-33
70-7B	67-50	66-64	62-81
69-2	66-3	65-1	62-85
68-13	66-10	65-51	61-12
68-37	66-12	65-94	60-54
67-7	66-25	64-86	54-3
67-17	66-35	64-89	54-7

N. GOODMAN DIAGRAMS

DATE 15 MAR 1970

SUPERSEDES
CATEGORY "B" DATA
TENSILE STRENGTHS

MATERIALS DATA BOOK

6061
ALUMINUM ALLOYI-A-61
3A

DATE 15 MAR 1970
SUPERSEDES

CATEGORY "B" DATA

TENSILE STRENGTHS

MATERIALS DATA BOOK

6061
ALUMINUM ALLOYI-A-61
3B

DATE 15 MAR 1970

SUPERSEDES

CATEGORY "B" DATA

TENSILE STRENGTHS

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
6

DATE 15 MAR 1970

SUPERSEDES

STRESS TO RUPTURE

AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
7

DATE 15 MAR 1970
SUPERSEDES

STRESS TO RUPTURE
AND CREEP
AS FUNCTION OF TIME

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
8

DATE 15 MAR 1970

SUPERSEDES

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
8A

DATE 15 MAR 1970

SUPERSEDES

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
8B

DATE 15 MAR 1970

SUPERSEDES

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
8C

DATE 15 MAR 1970

SUPERSEDES

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
9

DATE 15 MAR 1970
SUPERSEDES

IMPACT STRENGTH
HARDNESS

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
10

DATE 15 MAR 1970

SUPERSEDES

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
10A

DATE 15 MAR 1970

SUPERSEDES

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

6061
ALUMINUM ALLOYI-A-61
10B

DATE 15 MAR 1970

SUPERSEDES 15 SEPT 1967

ELONGATION
(AFTER IRRADIATION)DESIGN VALUES,
80 % OF AVERAGE

SEE INTRODUCTION, PAGE 3

EFFECTS OF IRRADIATION ON ELONGATION OF

6061-T6 ALUMINUM

UNLESS OTHERWISE NOTED
E > 1.0 MEV

FORM AND CONDITION	GAGE LENGTH (IN.)	TEMPERATURES (°F)			PRE- IRRADIATION CONTROL VALUES	POST-IRRADIATION VALUES DOSAGES GIVEN AS INTEGRATED NEUTRON FLUX (NVT) IN TERMS OF NEUTRONS/CM ²										NO. OF IRRADIATION SPECIMENS	REFERENCE	COMMENTS	
		IRRADIATION	POST- IRRADIATION ANNEAL	POST- IRRADIATION TEST		10 ¹⁶		10 ¹⁷		10 ¹⁸		10 ¹⁹		10 ²⁰					
						ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE				
1/4-IN. -T6 PL. LONG. TRANS. (a) * LONG. (a) *	2.00 (b) 2.00 (b) 2.00 (b)	-423 -423 -423		-423 -423 -423	19.5 7.0 5.0	22 9 8	5 x 10 ¹⁶ 5 x 10 ¹⁶ 5 x 10 ¹⁶									4 4 4	66-3 66-3 66-3	E > 0.5 MEV	
1/2-IN. -T6 PL.	0.5 (c)	-430		-430	24			24								5	66-35		
1/4-IN. -T6 PL. 1/4-IN. -T6 PL.	2.0 2.0	-423 -320		-423 -320	21 16.8			14.4 13.3	3 x 10 ¹⁷ 3 x 10 ¹⁷							4 4	69-2 69-2		
RING FORGING RING FORGING** PV FORGING		-320 -320 -320		-320 -320 -320	14.2 15.0 5.3					11.4 5.7 5.6	1.1x10 ¹⁸ 1.1x10 ¹⁸ 1.1x10 ¹⁸					3 3 3	69-2 69-2 69-2		
-T6 -T6		120 150		80 80	17 14									17.5 13	5.2x10 ²⁰	7 7	67-7 67-7		
(a) ALLOY 4043 FILLER ROD																			
(b) REDUCED SECTION 3/8-IN. x 1/8-IN.																			
(c) SPECIMEN REDUCED SECTION 1/8-IN. DIA.																			
* WELD																			
** AGED AFTER WELQ

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
11

DATE 15 MAR 1970
SUPERSEDES

MODULUS OF ELASTICITY
MODULUS OF RIGIDITY

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
12

DATE 15 MAR 1970

SUPERSEDES

THERMAL EXPANSION

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
13

DATE 15 MAR 1970
SUPERSEDES

THERMAL CONDUCTIVITY
SPECIFIC HEAT

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
14

DATE 15 MAR 1970
SUPERSEDES

THERMAL DIFFUSIVITY EMITTANCE

DATE 15 MAR 1970
SUPERSEDES

**DENSITY
POISSON'S RATIO**

MATERIALS DATA BOOK

6061
ALUMINUM ALLOY

I-A-61
16

DATE 15 MAR 1970

SUPERSEDES

ELECTRICAL RESISTIVITY

ELECTRICAL RESISTIVITY
MICROHM - IN.

MATERIALS DATA BOOK

7039
ALUMINUM ALLOYI-A-74
1

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

BASIC DATA

A. GENERAL

ALLOY 7039 IS A HEAT-TREATABLE, INTERMEDIATE STRENGTH ALLOY, WITH GOOD FORMABILITY, FORGEABILITY AND WELDABILITY. ITS PRINCIPAL DEFICIENCY IS ITS SIGNIFICANT SUSCEPTIBILITY TO STRESS CORROSION IN THE SHORT TRANSVERSE DIRECTION. IT HAS DEMONSTRATED RESISTANCE TO SPALLING FROM HIGH-VELOCITY IMPACT AND RESISTANCE TO CRACK PROPAGATION.

THE -T63 TEMPER HAS BETTER CRYOGENIC PROPERTIES THAN THE -T6 TEMPER.

DESIGN VALUES IN SECTION E FOR SHEET AND PLATE IN F_{TU} , F_{TY} , e , AND RA ARE 80% OF EXPERIMENTAL DATA OBTAINED FROM TRIAL LOTS. VALUES IN BLUE ARE 99% RELIABILITY - 95% CONFIDENCE DATA. VALUES IN SECTION E ARE AVERAGES OF LONGITUDINAL AND TRANSVERSE DATA.

B. COMMERCIAL DESIGNATIONS

AL 7039

C. AVAILABLE FORMS, SPECIFICATIONS.

FORMS AND CONDITIONS	SPECIFICATIONS
PLATE 0.75-4.0-IN.	MIL-A-46063
SHEET 0.006-0.249-IN.	ASTM B-209
FORGINGS (HEAT TREATED)	MIL-A-22771
FORGINGS CONTROLLED COMPOSITION	AGC-90181*
*STATISTICAL DESIGN VALUES BASED ON MATERIAL OF THIS SPECIFICATION	

SUPPLIERS

KAISER ALUMINUM AND CHEMICAL CO.
ALCOA

D. CHEMICAL COMPOSITION (%)

ELEMENT	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Bal
MAXIMUM	0.30	0.40	0.10	0.40	3.3	0.25	4.5	0.10	Al
MINIMUM	-	-	-	0.10	2.3	0.15	3.5	-	-

SOURCE REF. 65-59

OTHER ELEMENTS
0.05 MAX. EACH
0.15 MAX. TOTAL

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	SHEET AND PLATE		FORGINGS
	-T61	-T64	-T63
	0.19 - 0.5	0.5 - 1.5	0.13 - 0.63

ULTIMATE TENSILE STRENGTH F_{TU} KSI
53 47 - 59.3

TENSILE YIELD STRENGTH F_{TY} KSI

RADIAL 48 39 - 54.5

COMP. YIELD STRENGTH F_{CY} KSI

ULTIMATE SHEAR STRENGTH F_{SU} KSI

- - 40 -

ULTIMATE BEARING STRENGTH F_{BRU} KSI

$e/D = 1.5$
 $e/D = 2.0$

YIELD BEARING STRENGTH F_{BRY} KSI

$e/D = 1.5$
 $e/D = 2.0$

ELONGATION e %

9 12 8 10.6

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI

- - 10 -

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

POISSON'S RATIO

HARDNESS

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ 0.0989
g/cc 2.74

SPECIFIC HEAT C BTU/LB-°F

0.214

THERMAL CONDUCTIVITY k $\frac{BTU-FT}{HR-FT^2-°F}$

COND. -0 (AT 45 F) 88.9
COND. -T63 86

MEAN COEFF. LINEAR THERMAL EXPANSION $\frac{10^{-6} IN.}{IN. -°F}$

RT TO 212 F (-T61) 13.0

ELECTRICAL RESISTIVITY R MICROHM-IN

COND. -0 (AT 32 F) 1.87
COND. -T61 (AT 32 F) 1.72

ELECTRICAL CONDUCTIVITY (EQUAL VOLUME) % IACS

COND. -0 40
COND. -T61 38
COND. -T64 37

MAGNETIC PROPERTIES

NON-MAGNETIC

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

COND. -0 1070°-1180°F
COND. -T6, -T64 1090°-1180°F

THERMAL CONDUCTIVITY VS. TEMPERATURE (-T61)

TEMPERATURE $\frac{k}{°F}$ $\left(\frac{BTU-FT}{HR-FT^2-°F} \right)$

	-0	-T61 AND -T63
-423	16.87	-
-316	49.70	-
-280	55.02	-
-190	65.88	-
-100	75.70	73
-28	83.22	-
44	88.90	-
70	-	86
200	-	93
300	-	96
400	-	98

F. THERMOPHYSICAL EFFECTS (CONTINUED)

PHASE CHANGES

THIS IS A PRECIPITATION HARDENING ALLOY

SOLAR ABSORPTANCE (T63) α_s

AT 40 F MAX. .44
AT 40 F MIN. .18

SOLAR ABSORPTANCE VALUES ARE FUNCTIONS OF ON-SURFACE CONDITIONS AND DEGREE OF CLEANLINESS.

G. CHEMICAL PROPERTIES

ALLOY 7039 POSSESSES GENERAL CORROSION RESISTANCE TO MARINE AND INDUSTRIAL ATMOSPHERES SUPERIOR TO THE 2000 SERIES AND OTHER 7000 SERIES ALUMINUM ALLOYS.

-T63 TEMPER IS RECOMMENDED FOR MAXIMUM STRESS-CORROSION RESISTANCE. IN THIS TEMPER, STRESS CORROSION LIMITS USE TO A MAXIMUM OF 10 KSI SUSTAINED IN THE SHORT TRANSVERSE DIRECTION FOR LONG-TIME APPLICATIONS; FOR SHORTER DURATIONS, THE SUSTAINED STRESS LIMIT MAY BE INCREASED TO 15 KSI.

H. NUCLEAR PROPERTIES

ALUMINUM ALLOYS IRRADIATED AT ABOVE 80 F SUFFER MINOR, IF ANY, RADIATION DAMAGE. RADIATION DAMAGE AT -320 F AND LOWER TEMPERATURES CAN BE SIGNIFICANT TO DESIGN IF THERE ARE NO INTERMEDIATE WARMUPS.

THERMAL CONDUCTIVITY OF ALLOY 7039-T61 AT -320 F IS REDUCED ABOUT 5% WHEN IRRADIATED WITH $5 \times 10^{17} n/cm^2 > 1.0$ MEV.

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

BASIC DATA

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-T6	SOLUTION-TREATED AND ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION-TREATMENT, OR IN WHICH THE EFFECTS OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T61	A SOLUTION-TREATED AND ARTIFICIALLY AGED TREATMENT CYCLE PROPRIETARY TO KAISER.
-T63	A SOLUTION-TREATED AND ARTIFICIALLY AGED TREATMENT CYCLE PROPRIETARY TO ALCOA.
-T64	A SOLUTION-TREATED AND ARTIFICIALLY AGED TREATMENT CYCLE PROPRIETARY TO KAISER. TENSILE PROPERTIES OF THE ALLOY IN THE -T64 CONDITION ARE GENERALLY SUPERIOR TO TENSILE PROPERTIES IN THE -T61 CONDITION.

J. SERVICE LIMITS

MAXIMUM SERVICE TEMPERATURE = 300°F

K. PROCESSING

SURFACE TREATMENT

CLEANING METHODS:

EMULSION, SOLVENT, OR VAPOR DEGREASE.

SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE OR SODIUM CARBONATE PLUS DILUTE H₂SO₄ RINSE.

ULTRASONIC.

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE.

DO NOT USE SODIUM HYDROXIDE OR STRONG ALKALINE SOAP SOLUTIONS UNLESS ETCH IS DESIRED.

FOLLOW ALL ACID OR ALKALINE TREATMENTS WITH NEUTRALIZING AND WATER RINSES.

K. PROCESSING (CONTINUED)

THERMAL TREATMENT

FULLY HEAT TREATABLE

FULL ANNEAL:
HEAT TO 775 F, 2 HOURS, SLOW COOL.

SOLUTION TREAT:
HEAT TO 750 TO 850 F (SOAKING TIME VARIES WITH THICKNESS); IMMEDIATE WATER QUENCH.

NATURAL AGING:
ALLOY AGES RAPIDLY AT RT AND WITH MODERATE INCREASE OF STRENGTH.

ARTIFICIAL AGING:
AGING MAY BE SHORTENED BY HOLDING AT HIGHER TEMPERATURES, UP TO 300 F, BUT METHODS ARE PROPRIETARY.

JOINING

FUSION WELDING OF THIS ALLOY IS SUPERIOR TO OTHER COMMERCIALLY AVAILABLE HEAT-TREATABLE ALLOYS. DUCTILITY OF WELDMENTS DECREASES RAPIDLY WITH INCREASING THICKNESS.

WELD FILLERS: ALUMINUM ALLOYS 5039, 5183, AND 5356

WELDING METHODS: TIG OR MIG

IMPROVED TENSILE PROPERTIES ARE OBTAINED IN 7039 WELDMENTS BY POST-WELD HEAT TREATMENT. HOWEVER, SUCH POST-WELD HEAT TREATMENT IS NOT NECESSARY IN ORDER TO DEVELOP GOOD DUCTILITY AND RESISTANCE TO CRACKING UNDER RESTRAINT.

7039-T6 BASE METAL AND FULLY HEAT-TREATED WELDMENTS ARE SATISFACTORY FOR CRYOGENIC APPLICATIONS. THIS ALLOY IS MORE WELDABLE AND LESS NOTCH SENSITIVE THAN 7079-T6 ALUMINUM AND 6061-T6.

FILLER ALLOY 5039 DEVELOPS HIGHER STRENGTH THAN OTHER FILLERS, AND RESULTS IN WELD-STRENGTH EFFICIENCIES OF 80-95% FOR 7039 POST-WELD HEAT-TREATED WELDMENTS.

K. PROCESSING (CONTINUED)

FORMING

FORMABILITY IS SLIGHTLY BETTER THAN FOR OTHER HEAT-TREATABLE ALUMINUM ALLOYS.

TRANSVERSE GUIDED BEND TESTS (SEE ASTM E-190)

RATIO OF MIN. BEND RADIUS TO THICKNESS

	GAUGE, IN.				
	0.64	0.125	0.250	0.375	0.500
0-TEMPER	--	--	--	0.58	0.65
				1.5	1.5
				T0	T0
-T6 TEMPER	1.2	1.5	2.3	2.3	2.3

THE MINIMUM BEND RADIUS DECREASES WITH INCREASING TEMPERATURES OF BENDING.

HOT FORMING SHOULD BE FOLLOWED BY SOLUTION HEAT-TREATMENT AND AGING.

MACHINABILITY

AS READILY MACHINABLE AS OTHER HEAT-TREATABLE ALUMINUM ALLOYS, SUCH AS 7079. SHEARING SHOULD BE DONE BEFORE PRECIPITATION TREATMENT, SINCE CRACKS MAY OCCUR ON SHEARED EDGES IF SHEARING IS DONE AFTERWARDS. SAWING, MILLING, OR OTHER CUTTING OPERATIONS DO NOT CAUSE EDGE CRACKING.

L. GOODMAN DIAGRAM

M. REFERENCES

70-34	67-21
70-33	66-25
70-27	66-12
70- 3	65-61
69-16	65-59
69- 3	65-57
68-11	64-13
67-44	63-19
67-27	61-49

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
3

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

TENSILE STRENGTHS

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
3A

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

TENSILE STRENGTHS

MATERIALS DATA BOOK

7039
ALUMINUM ALLOYI-A-74
3BDATE 15 JULY 1970
SUPERSEDES

CATEGORY "A" DATA

TENSILE STRENGTHS

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
4

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
5

DATE 15 MAR 1967
SUPERSEDES

FATIGUE STRENGTH

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
8A

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

**IMPACT STRENGTH
HARDNESS**

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
10

DATE 15 JULY 1970
SUPERSEDES 15 SEPT 1967

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

7039
ALUMINUM ALLOYI-A-74
10A

DATE 15 JULY 1970

SUPERSEDES

CATEGORY "A" DATA

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
10B

DATE 15 JULY 1970
SUPERSEDES 15 SEPT 1967

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

7039
ALUMINUM ALLOYI-A-74
10C

DATE 15 JULY 1970

SUPERSEDES

ELONGATION
(AFTER IRRADIATION)DESIGN VALUES,
80 % OF AVERAGE

EFFECTS OF IRRADIATION ON ELONGATION OF

7039 ALUMINUM ALLOY
-T61 AND -T64 PLATEUNLESS OTHERWISE NOTED
E ≥ 1.0 MeV

SEE INTRODUCTION PAGE 3

FORM AND CONDITION	GAGE LENGTH (IN.)	TEMPERATURES (°F)			PRE- IRRADIATION CONTROL VALUES	POST-IRRADIATION VALUES DOSAGES GIVEN AS INTEGRATED NEUTRON FLUX (NVT) IN TERMS OF NEUTRONS/CM ²										NO. OF IRRADIATION SPECIMENS	REFERENCE	COMMENTS
		IRRADIATION	POST- IRRADIATION ANNEAL	POST- IRRADIATION TEST		10 ¹⁵		10 ¹⁶		10 ¹⁷		10 ¹⁸		10 ¹⁹				
						ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE			
-T61 PLATE	-	-320	-	-320	10.2					7.5	9 x10 ¹⁷					4	67-27	DUCTILE
-T61 PLATE	1.5	-320	-	-320	13.0			11.2	8.9x10 ¹⁶							3	70-27	DUCTILE
	1.5	-320	-20°-1 HR	-320	13.0					12.1	1.02x10 ¹⁷					3	70-27	DUCTILE
	1.5	-320	+80°-1 HR	-320	13.0					12.1	1.1 x10 ¹⁷					3	70-27	DUCTILE
-T61 PLATE WELDED *	1.5	-320	-20°-1 HR	-320	9.8			9.0	9.8x10 ¹⁶							3	70-27	DUCTILE
	1.5	-320	+80°-1 HR	-320	9.8					9.6	1.08x10 ¹⁷					3	70-27	DUCTILE
	1.5	-320		-320	9.8					9.8	1.12x10 ¹⁷					3	70-27	DUCTILE
1"-T64 PLATE	1.5	-320	-	-320	11.2			10.6	9.9x10 ¹⁶							3	70-27	DUCTILE
-T64 PLATE WELDED **	1.5	-320	-	-320	5.9					5.6	1.03x10 ¹⁷					3	70-27	BRITTLE
* 5039 WELDS, NATURALLY AGED. ** 5039 WELDS, TREATED TO -T61 AFTER WELDING

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
11

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

MODULUS OF ELASTICITY
MODULUS OF RIGIDITY

MATERIALS DATA BOOK

7039
ALUMINUM ALLOYI-A-74
12

DATE 15 JULY 1970
SUPERSEDES 15 MAR 1967

CATEGORY "B" DATA

THERMAL EXPANSION

MEAN COEFFICIENT - LINEAR THERMAL EXPANSION
 10^{-6} IN./IN. -°F

DATE 15 JULY 1970

SUPERSEDES 15 MAR 1967

CATEGORY "B" DATA
**THERMAL CONDUCTIVITY
SPECIFIC HEAT**

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
14

DATE 15 JULY 1970
SUPERSEDES

THERMAL DIFFUSIVITY
EMITTANCE

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
15

DATE 15 JULY 1970

SUPERSEDES

DENSITY
POISSON'S RATIO

106-J

MATERIALS DATA BOOK

7039
ALUMINUM ALLOY

I-A-74
16

DATE 15 JULY 1970
SUPERSEDES

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

THIS ALLOY POSSESSES VERY GOOD STRENGTH AND GOOD CORROSION RESISTANCE. ALLOY 7075 HAS GOOD FORMABILITY, AND IS HEAT TREATABLE. THIS ALLOY EXHIBITS LOW TOUGHNESS AT CRYOGENIC TEMPERATURES.

THE VALUES IN SECTION E FOR F_{TU} , F_{TY} , e , AND RA ARE MINIMA, TAKEN FROM MIL-HDBK-5. FORGING PROPERTIES ARE FOR 3-IN. MAXIMUM THICKNESS AT TIME OF HEAT TREATMENT.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, ROD AND SHAPES, EXTRUDED	QQ-A-00200/11 QQ-A-277 AMS 4154, 4168, 4169 ASTM-B-221
BAR, ROD AND SHAPES, ROLLED OR DRAWN	QQ-A-00225/9 QQ-A-282 AMS 4122, 4123 ASTM-B-211
FORGINGS	QQ-A-367, MIL-A-22771 AMS 4139, ASTM-B-247
PLATE AND SHEET	QQ-A-00250/12 QQ-A-283 AMS 4038, 4044, 4045 ASTM-B-209
TUBE, EXTRUDED	AMS 4154 AMS 4168 AMS 4169 ASTM-B-221

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
KAISER ALUMINUM AND CHEMICAL
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Zn	Mg	Cu	Cr	Mn	Fe	Si	Ti
MAXIMUM	6.1	2.9	2.0	0.40	0.30	0.7	0.50	0.20
MINIMUM	5.1	2.1	1.2	0.18	-	-	-	-

SOURCE NP-61-12
OTHER ELEMENTS
0.05 MAX EACH
0.15 MAX TOTAL
BAL AI

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

-T6 FORGINGS		THICKNESS-INCHES	
TO 144-IN. 2		-T6 SHEET AND PLATE	
0.004-0.25		0.25-0.5	
TENSILE ULTIMATE STRENGTH (MIN.)	F_{TU}	PSI	
66,000	77,000	77,000	
TENSILE YIELD STRENGTH (MIN.)	F_{TY}	PSI	
57,000	66,000	66,000	
COMP. YIELD STRENGTH (MIN.)	F_{CY}	PSI	
57,000	68,000	69,000	
ULTIMATE SHEAR STRENGTH (MIN.)	F_{SU}	PSI	
43,000	46,000	46,000	
SHEAR YIELD STRENGTH (MIN.)	F_{SY}	PSI	
-	38,000	38,000	
ULTIMATE BEARING STRENGTH (MIN.)	F_{BRU}	PSI	
e/D = 1.5	99,000	116,000	108,000
e/D = 2.0	-	-	-
YIELD BEARING STRENGTH (MIN.)	F_{BRY}	PSI	
e/D = 1.5	90,000	94,000	87,000
e/D = 2.0	-	-	-
ELONGATION	e	%	
LONGITUDINAL	9	8	8
TRANSVERSE	4	-	-
SHORT TRANSVERSE	2	-	-
REDUCTION OF AREA	RA	%	
MODULUS OF ELASTICITY	E	10^6 PSI	
	10.3		
COMP. MODULUS OF ELASTICITY	E_C	10^6 PSI	
	10.5		
MODULUS OF RIGIDITY	G	10^6 PSI	
	3.9		
POISSON'S RATIO			0.33
HARDNESS			
-0		RE 60	
-T6		RB 88	
PLASTIC BENDING MODULUS		(SEE APPENDIX A)	

2. PHYSICAL PROPERTIES

DENSITY	ρ	LB/IN ³
	0.101	
SPECIFIC HEAT	C	BTU/LB - °F
(AT 212°F)	0.23	
THERMAL CONDUCTIVITY	k	$\frac{BTU - FT}{HR - FT^2 - °F}$
(AT 77°F, T6 TEMPER)	76	
MEAN COEFF. LIN. THERMAL EXPANS.	α	$\frac{10^{-6} IN.}{IN. - °F}$
(68 TO 212°F)	12.9	
ELECTRICAL RESISTIVITY	R	MICROHM - IN.
(AT 68°F, T6 TEMPER)	2.27	

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	890-1180°F
PHASE CHANGES	
THIS ALLOY IS PRECIPITATION - HARDENABLE	
THERMAL CONDUCTIVITY VS. TEMPERATURE	
TEMPERATURE (°F)	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
-423	12
-350	31
-300	42
-250	48
-200	53
-100	61
0	67
68	72
200	79
400	99
600	102
800	97

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE IS SLIGHTLY SUPERIOR TO THAT OF ALUMINUM ALLOY 2024. STRESS CORROSION RESISTANCE IS ENHANCED BY USE OF T73 TEMPER.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

IRRADIATION AND TEST AT -423°F
DOSAGE, 5×10^{16} NVT, $E > 1.0$ MEV

AVERAGE CONTROL VALUE	AVERAGE TEST VALUE
0.250-IN. THICK PLATE	
RA	13% *
e	6% *

*NO SIGNIFICANT CHANGE FROM CONTROL VALUES.

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.
-T73	SOLUTION HEAT-TREATED AND AGED TO DEVELOP MECHANICAL PROPERTIES AND RESISTANCE TO STRESS-CORROSION CRACKING.

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

J. SERVICE LIMITS

MAXIMUM SERVICE TEMPERATURE = 300°F

K. PROCESSING

SURFACE TREATMENT

CLEANING

METHODS

EMULSION, SOLVENT, OR VAPOR DEGREASE;

SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE,
OR SODIUM CARBONATE PLUS DILUTE H_2SO_4 ;

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE.

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

K. PROCESSING (CONTINUED)

THERMAL TREATMENT (PER MIL-H-6088)

FULL ANNEALING: HEAT TO 775° - 850°F. HOLD AT TEMPERATURE FOR 2 HRS. AIR COOL. RE-HEAT TO 450°F. HOLD AT TEMPERATURE FOR 6 HRS. AIR COOL (O TEMPER)

REMOVAL OF COLD WORK: HEAT TO 650°F-775°F. HOLD UNTIL LOAD IS UNIFORMLY AT TEMPERATURE. AIR COOL [MATERIAL WILL COMMENCE TO PRECIPITATION HARDEN (AGE) AFTER 24 HRS].

SOLUTION HEAT TREATING: HEAT TO 860° - 890°F. (EXTRUSIONS MUST BE HEATED BETWEEN 860° - 880°F) HOLDING TIME DEPENDS ON HEATING METHOD AND DIMENSION (SEE MIL-H-6088). COLD WATER QUENCH (W TEMPER)

PRECIPITATION (AGE) HARDENING: HEAT TO 240° - 260°F. HOLD AT TEMPERATURE FOR 22 HRS. MIN. (T6 TEMPER)

MAXIMUM HEAT TREAT THICKNESS OR DIAMETER - 4 IN.

JOINING

THIS ALLOY CAN BE RESISTANCE WELDED BUT FUSION WELDING IS NOT GENERALLY RECOMMENDED.

FORMING

THE ALLOY IS READILY FORMED IN THE ANNEALED AND SOLUTION TREATED CONDITIONS, AND THE T6 CONDITIONS CAN BE FORMED AT ELEVATED TEMPERATURES.

HOT WORKING TEMPERATURE 500° - 850°F.

MACHINABILITY

MACHINABILITY RELATIVE TO OTHER ALUMINUM ALLOYS IS GOOD.

L. REFERENCES

NP-60-14
NP-61-12
NP-64-8
NP-65-1
NP-66-3

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

PAGE BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

7079 ALUMINUM ALLOY IS HEAT-TREATABLE. THE ALLOY HAS BETTER HARDENABILITY THAN 7075. THE STRENGTH AND DUCTILITY OF 7079 IS SUPERIOR TO THAT OF 7075 IN HEAVY SECTIONS. THE ALLOY EXHIBITS LOW NOTCH TOUGHNESS AT CRYOGENIC TEMPERATURES.

THE PROPERTY VALUES GIVEN IN SECTION E ARE PER MIL-HDBK-5. FORGING VALUES ARE FOR LONGITUDINAL DIRECTION.

B. COMMERCIAL DESIGNATIONS

79S (OBSOLETE)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BARS, SHAPES AND RODS EXTRUDED	QQ-A-00200/12 MIL-A-8825 AMS 4171 ASTM B-221
FORGING	QQ-A-367 MIL-A-22771 AMS 4136, 4138
PLATE	QQ-A-00250/17 MIL-A-8877 AMS 4024 ASTM B-209
SHEET	MIL-A-8877 ASTM B-209
TUBE, EXTRUDED	ASTM B-221

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Zn	Mg	Cu	Mn	Cr	Si	Fe	Ti
MAXIMUM	4.8	3.7	0.80	0.30	0.25	0.30	0.40	0.10
MINIMUM	3.8	2.9	0.40	0.10	0.10	-	-	-
SOURCE	NP-61-12							BAL Al
	OTHER ELEMENTS 0.05 EACH MAX 0.15 TOTAL MAX							

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	-T6 EXTRUSIONS TO 0.25 IN. THICKNESS INCHES	-T6 SHEET, PLATE TO 1-IN. THICKNESS INCHES	-T6 FORGINGS TO 72-IN. THICKNESS INCHES
TENSILE ULTIMATE STRENGTH F_{TU}	PSI		
	74,000	74,000	71,000
TENSILE YIELD STRENGTH F_{TY}	PSI		
	66,000	65,000	62,000
COMP. YIELD STRENGTH F_{CY}	PSI		
	67,000	65,000	65,000
ULTIMATE SHEAR STRENGTH F_{SU}	PSI		
	41,000	45,000	43,000
SHEAR YIELD STRENGTH F_{SY}	PSI		
ULTIMATE BEARING STRENGTH F_{BRU}	PSI		
e/D = 1.5	90,000	105,000	92,000
e/D = 2.0	120,000	135,000	121,000
YIELD BEARING STRENGTH F_{BRY}	PSI		
e/D = 1.5			
e/D = 2.0			
ELONGATION e	%		
	6	8	9
REDUCTION OF AREA RA	%		
MODULUS OF ELASTICITY E	10^6 PSI		
	10.3		
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI		
	10.5		
MODULUS OF RIGIDITY G	10^6 PSI		
	3.9		
POISSON'S RATIO			
	0.33		
HARDNESS			
PLASTIC BENDING MODULUS	(SEE APPENDIX A)		

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.099
SPECIFIC HEAT C	BTU/LB - °F
AT 212°F	0.23
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
AT 77°F	74
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
(68-212°F)	13.1
ELECTRICAL RESISTIVITY R	MICROHM - IN.
(AT 68°F, T6 TEMPER)	2.17

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
	900 - 1180°F
PHASE CHANGES	
HARDENING PHASE WILL PRECIPITATE AT ROOM AND ELEVATED TEMPERATURES (SEE SECTION K).	
THERMAL CONDUCTIVITY VS. TEMPERATURE	

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

TEMPER	DEFINITION
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.

J. SERVICE LIMITS

MAXIMUM SERVICE TEMPERATURE = 300°F

K. PROCESSING (CONTINUED)

JOINING

NOT ORDINARILY WELDED

FORMING

HOT WORKING TEMPERATURE 500° - 850°F.

MACHINABILITY

MACHINABILITY RELATIVE TO OTHER ALUMINUM ALLOYS IS GOOD.

L. REFERENCES

NP-61-12
NP-61-16
NP-62-18
NP-64-8

K. PROCESSING

SURFACE TREATMENT

CLEANING

METHODS

EMULSION, SOLVENT, OR VAPOR DEGREASE;

SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE, OR SODIUM CARBONATE PLUS DILUTE H₂SO₄;

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE.

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT (PER MIL-H-6088)*

FULL ANNEALING: HEAT TO 775°F. HOLD AT TEMPERATURE FOR 1 HR. COOL AT MAXIMUM RATE OF 50°F/HR UNTIL TEMPERATURE IS BELOW 500°F. THEN AIR COOL. (O TEMPER)

REMOVAL OF COLD WORK: HEAT TO 650° - 775°F. HOLD UNTIL ENTIRE LOAD IS AT TEMPERATURE. AIR COOL.

SOLUTION TREATMENT: HEAT TO 820 - 880°F. SEE MIL-H-6088 FOR SOAKING TIMES. WATER QUENCH (W TEMPER)

PRECIPITATION (AGE) TREATMENT:

ALTERNATE TREATMENTS: (EACH WILL GIVE T6 TEMPER)

(A) 5 DAYS AT ROOM TEMPERATURE FOLLOWED BY 48 HOURS IN THE TEMPERATURE RANGE OF 230°-250°F.

(T6 TEMPER)

(B) 6-10 HRS. AT 190°-210°F. (T6 TEMPER)

(C) 24-26 HRS. AT 240°-260°F. (T6 TEMPER)

*MAXIMUM HEAT TREATMENT THICKNESS OR DIAMETER, 7 IN.

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

THIS HEAT-TREATABLE ALLOY HAS HIGH STRENGTH ALTHOUGH SIMILAR TO ALLOY 7075 IN PROPERTIES, ITS USE IS LIMITED TO A CERTAIN RANGE OF THICKNESSES, AND SPECIAL CARE MUST BE EXERCISED TO OBTAIN FULL AGE HARDENING IN THIS ALLOY.

THE PROPERTY VALUES IN SECTION E ARE MINIMA, WHERE SO INDICATED. APPLICABLE THICKNESSES ARE INDICATED.

B. COMMERCIAL DESIGNATIONS

A78S (OBSOLETE)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BARS, AND SHAPES, EXTRUDED	MIL-A-9186 AMS 4158 ASTM B-221
PLATE AND SHEET	QQ-A-00250/14 MIL-A-9180 ASTM B-209
TUBE, EXTRUDED	ASTM B-221

SUPPLIERS

ALUMINUM CORPORATION OF AMERICA
REYNOLDS METALS CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Zn	Mg	Cu	Cr	Si	Fe	Mn	Ti
MAXIMUM	7.3	3.1	2.4	0.40	0.50	0.70	0.30	0.20
MINIMUM	6.3	2.4	1.6	0.18	-	-	-	-
SOURCE	NP-61-12			OTHER ELEMENTS 0.05 EACH MAX 0.15 TOTAL MAX				BAL Al

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SHEET AND PLATE, THICKNESS, INCHES

-T6

0.015-0.044 0.045-0.25

TENSILE ULTIMATE STRENGTH F_{TU} PSI

83,000 84,000

TENSILE YIELD STRENGTH F_{TY} PSI

73,000 73,500

COMP. YIELD STRENGTH F_{CY} PSI

75,000 76,000

ULTIMATE SHEAR STRENGTH F_{SU} PSI

50,000 50,000

SHEAR YIELD STRENGTH F_{SY} PSI

41,000 42,000

ULTIMATE BEARING STRENGTH F_{BRU} PSI

e/D = 1.5 124,000 126,000
e/D = 2.0 158,000 160,000

YIELD BEARING STRENGTH F_{BRV} PSI

e/D = 1.5 102,000 104,000
e/D = 2.0 117,000 118,000

ELONGATION e %

7 8

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI

10.3

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

3.9

POISSON'S RATIO

HARDNESS $R(15T)$

TEMPER HARDNESS $\frac{-0}{70}$ $\frac{-T6}{90}$

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.102

SPECIFIC HEAT C BTU/LB - °F

(AT 212°F) 0.23

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

73.0

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

(68° - 212°F) 13.0

ELECTRICAL RESISTIVITY R MICROHM - IN.

2.2

F. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES
F. THERMOPHYSICAL EFFECTS

MELTING RANGE

890° - 1165°F

PHASE CHANGES

THIS ALLOY IS PRECIPITATION - HARDENABLE.

THERMAL CONDUCTIVITY VS. TEMPERATURE

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

TEMPER DESIGNATIONS APPLICABLE TO THIS ALLOY MAY BE DEFINED IN THIS MANNER:

<u>TEMPER</u>	<u>DEFINITION</u>
-0	ANNEALED BY HEATING UNTIL MATERIAL IS OVER AGED. IT IS THEN IN ITS SOFTEST CONDITION.
-T6	SOLUTION HEAT-TREATED AND THEN ARTIFICIALLY AGED. APPLIES TO PRODUCTS WHICH ARE NOT COLD WORKED AFTER SOLUTION HEAT-TREATMENT OR IN WHICH THE EFFECT OF COLD WORK IN FLATTENING OR STRAIGHTENING MAY NOT BE RECOGNIZED IN APPLICABLE SPECIFICATIONS.

J. SERVICE LIMITS

MAXIMUM SERVICE TEMPERATURE = 300°F

K. PROCESSING
SURFACE TREATMENT
CLEANING
METHODS

EMULSION, SOLVENT, OR VAPOR DEGREASE;

 SODIUM-SILICATE-INHIBITED TRI-SODIUM PHOSPHATE,
OR SODIUM CARBONATE PLUS DILUTE H₂SO₄;

ULTRASONIC

DE-SMUT WITH CHROMIC ACID AND SODIUM BISULFATE.

DO NOT USE SODIUM HYDROXIDE UNLESS ETCH IS DESIRED

FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

THIS ALLOY DEVELOPS FULL HARDENING ON COLD WATER QUENCHING AND AGING IN PLATE OF THICKNESSES UP TO 1 1/2 INCH ONLY. IN EXTRUSIONS, FULL HARDENING IS OBTAINABLE ONLY UP TO 3/4 INCH. IT REQUIRES SHORTER QUENCH DELAY TIMES THAN OTHER ALLOYS. QUENCH DELAY IS 5 SEC. MAX. FOR 0.032 - 0.050 IN. THICKNESS AND 7 SEC. MAX FOR THICKNESSES OVER 0.050 IN.

SOLUTION TREATMENT

860 TO 930°F YIELDS 7178-W CONDITION

AGING

 240 TO 260°F FOR 22 HOURS MINIMUM
YIELDS 7178 -T6 CONDITION.

K. PROCESSING (CONTINUED)
JOINING
FORMING

HOT WORKING TEMPERATURE RANGE 500° - 850°F

MACHINABILITY

MACHINABILITY RELATIVE TO OTHER ALUMINUM ALLOYS:

7178-0	POOR
7178-T6	GOOD

L. REFERENCES

 NP-60-14
NP-62-14
NP-64-8

DATE 1 MAY 1966

SUPERSEDES

**LIGHT METALS
AND ALLOYS**

MATERIALS DATA

**I
LIGHT METALS AND ALLOYS**

**B.
TITANIUM AND TITANIUM ALLOYS**

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

Ti-5Al-2.5 Sn is an ALPHA-TYPE ALLOY. IT OFFERS GOOD STRENGTH UP TO 800°F. IT HAS EXCELLENT WELDABILITY. FORMABILITY IS LIMITED AND THE MATERIAL IS NOT HEAT-TREATABLE. THIS ALLOY CAN ONLY BE HARDENED BY COLD WORK.

THE BASIS FOR THE PROPERTY VALUES FOR F_{TU} , F_{TY} , AND e , IN SECTION E-1 IS THAT GIVEN IN MIL-HDBK-5; THE VALUE WHICH WILL BE EXCEEDED BY AT LEAST 99% OF THE POPULATION OF VALUES WITH A CONFIDENCE OF 95%. FOR RA, THE BASIS IS SPECIFICATION MINIMUM.

B. COMMERCIAL DESIGNATIONS

A-110 AT, MST-5Al-2.5 Sn, RS-110 C, ICI-317, HA-5137

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET & PLATE	MIL-T-9046 AMS 4910
BAR & FORGINGS	MIL-T-9047
BAR	AMS 4926
FORGINGS	AMS 4966
WIRE, WELDING	AMS 4953

SUPPLIERS

TITANIUM METALS CORP. OF AMERICA
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
REACTIVE METALS, INC. NILES, OHIO
HARVEY ALUMINUM CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Al	Sn	Fe	Mn	O	C	N	H	Other	Ti
MAXIMUM	6.00	3.00	0.50	0.30	0.20	0.15	0.07	0.020	0.40	Bal.
MINIMUM	4.00	2.00	-	-	-	-	-	-	-	-

SOURCE P-64-1

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE VALUES UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET & PLATE
ALL SIZES, ANNEALED

TENSILE ULTIMATE STRENGTH F_{TU} PSI
115,000

TENSILE YIELD STRENGTH F_{TY} PSI
110,000

COMP. YIELD STRENGTH F_{CY} PSI
115,000

SHEAR STRENGTH F_{SU} PSI
72,000

ULTIMATE BEARING STRENGTH F_{BRU} PSI
 $e/D = 1.5$ 160,000
 $e/D = 2.0$ 240,000

BEARING YIELD STRENGTH F_{BRY} PSI
 $e/D = 1.5$ 130,000
 $e/D = 2.0$ 185,000

ELONGATION e %
(0.025 IN. THICK & ABOVE) 10

REDUCTION OF AREA RA %
25

MODULUS OF ELASTICITY E 10^6 PSI
15.5

MODULUS OF RIGIDITY G 10^6 PSI

HARDNESS R_C
36 (MAX.)

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI
15.5

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³
0.162

SPECIFIC HEAT C BTU/LB - °F
(32°F) 0.126

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$

(32°F) 4.45

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN./IN. - °F
(68° TO 200°F) 5.2

ELECTRICAL RESISTIVITY R MICROHM - IN.
61.8

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2800° - 3000°F.

PHASE CHANGES

ALLOY TRANSFORMS, UPON COOLING, FROM BETA TO ALPHA + BETA AT 1900°-2000°F, AND FROM ALPHA + BETA TO ALPHA AT 1700°-1775°F

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k $\left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$
-100	3.89
0	4.21
32	4.31
100	4.52
200	4.85
400	5.55
600	6.30
800	7.11
1000	8.01
1200	8.96
1400	9.97
1500	10.48

G. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES

FORMED AND STRESSED PARTS ARE SUSCEPTIBLE TO STRESS CORROSION CRACKING, IF A HALIDE SURFACE FILM IS PRESENT AND IF THE PARTS ARE EXPOSED TO HIGH TEMPERATURES.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

-320° TO +1000°F (AMS SPECIFICATIONS RECOMMEND TO +800°F ONLY). BELOW -320°F USE ELI GRADE.

K. PROCESSING
SURFACE TREATMENT
DESCALING:

- (A) MOLTEN SALT DESCALING AND DILUTE ACID NEUTRALIZING*
(B) MIXED ACID PICKLING (HNO₃ & HF)*

CLEANING:

- (A) CAUSTIC SODA CLEANING AND DILUTE ACID NEUTRALIZING*
(B) EMULSION, DETERGENT, OR VAPOR DEGREASING ** AND DILUTE ACID NEUTRALIZING*
(C) ULTRASONIC CLEANING

* FOLLOW ALL ACID NEUTRALIZING WITH A WATER RINSE

** CHLORIDE COMPOUNDS CAN CAUSE STRESS-CORROSION CRACKING.

THERMAL TREATMENT

STRESS-RELIEF: 1000° - 1200°F. FOR 1 - 2 HRS.

FULL-ANNEAL: 1500°F FOR 30 MIN. OR 1600°F FOR 10 MIN.
A PROTECTIVE ATMOSPHERE IS REQUIRED FOR FULL ANNEALING.

K. PROCESSING (CONTINUED)
JOINING
WELDING

METHODS: TUNGSTEN - INERT GAS
RESISTANCE WELDING
ELECTRON BEAM WELDING

FILLER: PARENT METAL COMPOSITION

WELD EFFICIENCY: 90 - 100%

JOINT STRENGTH: 108,000 - 120,000 PSI

FORMING

FORGING RANGE: 1600° - 1900°F START
1400° - 1600°F FINISH

FOR FORMING AT ROOM TEMPERATURE, USE 5T BEND RADIUS MIN.

MACHINABILITY

REQUIRES LOW CUTTING SPEEDS, HIGH FEED RATES, USE OF SHARP TOOLS, AND USE OF COPIOUS AMOUNTS OF COOLANT CUTTING FLUID.

L. REFERENCES

P-63-3
NP-64-3
NP-64-8

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966

SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

STRESS TO RUPTURE
1000 PSI

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

DATE 1 MAY 1966

SUPERSEDES

DENSITY

ELECTRICAL RESISTIVITY

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIALTi-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOYI-B-11
1

DATE 30 SEPT 1969

SUPERSEDES 15 SEPT 1967

BASIC DATA

A. GENERAL

Ti-5Al-2.5Sn ELI is an ALPHA-TYPE CONSUMABLE-ELECTRODE DOUBLE-VACUUM MELT ALLOY. IT OFFERS GOOD STRENGTH AT TEMPERATURES TO 1000°F. IT HAS EXCELLENT STRENGTH AT CRYOGENIC TEMPERATURES, AND MEDIUM STRENGTH BUT VERY HIGH FRACTURE TOUGHNESS AT ROOM AND ELEVATED TEMPERATURES. ITS WELDABILITY IS EXCELLENT. FORMABILITY IS LIMITED. THIS MATERIAL IS NOT HEAT-TREATABLE AND CAN ONLY BE HARDENED BY COLD WORK.

THIS ALLOY HAS SPECIAL CONTROL OF INTERSTITIAL IMPURITIES (ESPECIALLY OXYGEN CONTENT) FOR CRYOGENIC APPLICATIONS. ELI GRADES CARRY A PRICE PREMIUM OF ABOUT 10 TO 20%. FURTHER REDUCTION OF INTERSTITIAL ELEMENTS WILL INCREASE TOUGHNESS, AS DOES RAPID COOLING FROM THE ANNEALING TEMPERATURE.

WARNING

A SEVERE EXPLOSION HAZARD MAY EXIST IF THIS ALLOY IS USED IN CONTACT WITH LO_2 OR GO_2 AT PRESSURES ABOVE 50 PSI.

B. COMMERCIAL DESIGNATIONS

A-95 AT, HA-5137 ELI, MST-5Al-2.5Sn ELI, RS-110C-L, Ti-5Al-2.5Sn ELI.

C. FORMS, SPECIFICATIONS, SUPPLIERS

FORMS & CONDITIONS	SPECIFICATIONS
SHEET, STRIP, AND PLATE	MIL-T-9046 AMS 4909
BAR AND FORGING	MIL-T-9047 AMS 4924

SUPPLIERS

CRUCIBLE STEEL CO.
REACTIVE METALS INC., NILES, OHIO
REPUBLIC STEEL CO.
TITANIUM METALS CORP. OF AMERICA

D. CHEMICAL COMPOSITION (%)

ELEMENT	Al	Sn	Fe	C	N	H	O	OTHER
MAXIMUM	5.75	3.0	0.25	0.05	.035	0.0125	0.12	0.30
MINIMUM	4.5	2.0	-	-	-	-	-	-

SOURCE NP-65-5

BAL. Ti

E. ROOM TEMPERATURE PROPERTIES

AVERAGE VALUES UNLESS OTHERWISE NOTED

1. MECHANICAL PROPERTIES (ANNEALED MATL.)

	SHEET	PLATE	FORGINGS	BAR
ULTIMATE TENSILE STRENGTH F_{TU}				KSI
80% OF AVE.	92	92	93	96
TENSILE YIELD STRENGTH F_{TY}				KSI
80% OF AVE.	82	82	87	89
COMP. YIELD STRENGTH F_{CY}				KSI
ULTIMATE SHEAR STRENGTH F_{SU}				KSI
HOT-ROLLED	-	86	-	-
ULTIMATE BEARING STRENGTH F_{BRU}				KSI
$c/D=1.5$ $c/D=2.0$				
BEARING YIELD STRENGTH F_{BRY}				KSI
$c/D=1.5$ $c/D=2.0$				
ELONGATION e				%
80% OF AVE.	-	16	15	16
REDUCTION OF AREA RA				%
80% OF AVE.	-	34	25	29
MODULUS OF ELASTICITY E				10^6 PSI
				16.0
COMP. MODULUS OF ELASTICITY E_C				10^6 PSI
MODULUS OF RIGIDITY G				10^6 PSI

2. PHYSICAL PROPERTIES

DENSITY ρ	
LB/IN ³	0.160
g/cc	4.43
SPECIFIC HEAT C	BTU/LB-°F
(72°F)	0.128
THERMAL CONDUCTIVITY k	$\frac{BTU-FT}{HR-FT^2-°F}$
(170°F)	4.74
MEAN COEFF. LIN. THERMAL EXPAN. α	$\frac{10^{-6} IN.}{IN-°F}$
(68° TO 200°F)	5.2
ELECTRICAL RESISTIVITY R	MICROH-IN
	61.8
ELECTRICAL CONDUCTIVITY	% IACS
VOLUME	1.1
MASS	2.1
MAGNETIC PROPERTIES	
NON-MAGNETIC PERMEABILITY AT 20 OERSTEDS	1.00005
F. THERMOPHYSICAL EFFECTS	
MELTING RANGE	2800°-3000°F
PHASE CHANGES	
ALLOY TRANSFORMS, UPON COOLING, FROM BETA TO ALPHA PLUS BETA AT 2000° TO 1900°F, AND FROM ALPHA PLUS BETA TO ALPHA AT 1775 TO 1700°F.	
THERMAL EMITTANCE AT 225°F	
NORMAL TOTAL POLISHED FIRST HEATING	0.18
NORMAL TOTAL OXIDIZED	0.17
THERMAL DIFFUSIVITY	FT^2/HR
	0.119

F. THERMOPHYSICAL EFFECTS (CONTINUED)

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k ($\frac{BTU-FT}{HR-FT^2-°F}$)
-414	0.87
-320	2.37
-190	3.35
-100	3.76
32	4.28
80	4.45
260	5.03
350	5.38
440	5.66
620	6.36
800	7.05
980	7.69
1160	8.38
1340	9.07
1520	9.77

G. CHEMICAL PROPERTIES

CORROSION

CHLORIDE COMPOUNDS CAN CAUSE STRESS CORROSION CRACKING. THIS ALLOY IS MORE SUSCEPTIBLE TO ELEVATED TEMPERATURE SOLID SALT CORROSION THAN OTHER COMMONLY USED Ti ALLOYS

DIRECTIONALITY

DEPENDING ON THE ROLLING AND ANNEALING CONDITIONS, α Ti-AL ALLOYS TEND TO DEVELOP A PREFERRED ORIENTATION WITH THE BASAL PLANE PARALLEL TO THE SHEET SURFACE. THIS TEXTURE INHIBITS STRAIN IN THE THICKNESS DIRECTION WHEN TENSILE STRESSES OCCUR PARALLEL TO THE SHEET PLANE.

H. NUCLEAR PROPERTIES

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIALTi-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOYI-B-11
2

DATE 30 SEPT 1969

SUPERSEDES 15 SEPT 1967

BASIC DATA

I. NOMENCLATURE

THE FOLLOWING TERMINOLOGY, PECULIAR TO TITANIUM ALLOYS, IS SUGGESTED BY THE APPLICABLE SUBCOMMITTEE OF THE ASM:

ALPHA - THE LOW-TEMPERATURE HEXAGONAL-CLOSE-PACKED PHASE OF TITANIUM (i.e., Ti-5Al-2.5Sn).

ALPHA-BETA STRUCTURE - A TWO-PHASE STRUCTURE OBTAINED IN MANY TITANIUM ALLOYS COMPOSED OF ALPHA AND BETA PHASES (i.e., Ti-6Al-4V).

ALPHA CASE - OXYGEN-ENRICHED LAYER NEAR THE SURFACE OF CONTAMINATED ALLOYS WHERE ALPHA IS STABILIZED BY THE CONTAMINATION.

ALPHA PRIME (ALSO CALLED MARTENSITE) - A SUPER-SATURATED SOLUTION OF ALPHA FORMED BY QUENCHING ALPHA-BETA ALLOYS FROM THE BETA FIELD OR ALPHA-BETA FIELD.

BETA - THE HIGH-TEMPERATURE, BODY-CENTERED-CUBIC ALLOTROPE OF TITANIUM.

CONTAMINATED LAYER - A TERM USED TO DESIGNATE A SURFACE THAT HAS BEEN CONTAMINATED BY OXYGEN DIFFUSION FROM THE ATMOSPHERE DURING ELEVATED-TEMPERATURE TREATMENTS (FABRICATION OR HEATING).

EQUILIBRATION - A TERM USED TO DESCRIBE PART OF AN ANNEALING TREATMENT DESIGNED TO APPROACH EQUILIBRIUM QUANTITIES AND COMPOSITIONS OF ALPHA AND BETA PHASES IN AN ALPHA-BETA ALLOY. THIS IS USUALLY FOLLOWED BY A STABILIZATION TREATMENT.

HYDROGEN CONTAMINATION - HYDROGEN PICKED UP IN THE METAL DURING PROCESSING OR USAGE RESULTING IN HYDROGEN CONTENTS ABOVE SPECIFICATION LIMITS. IT MAY BE REMOVED BY VACUUM ANNEALING OR BY MACHINING, IF CONCENTRATED NEAR THE SURFACE.

INTERSTITIAL CONTAMINATION - OXYGEN, NITROGEN, OR HYDROGEN PICKED UP DURING MELTING OR WELDING. THIS TERM IS USUALLY USED TO DESIGNATE UNIFORM CONTAMINATION AS DISTINCT FROM SURFACE OXYGEN CONTAMINATION.

OXIDE SCALE - THE SCALE FORMED ON TITANIUM ALLOYS WHEN HEATED IN AIR OR OXYGEN-BEARING ATMOSPHERES.

SOLUTION-TREATED STRUCTURE - THE MICROSTRUCTURE OBTAINED AS A RESULT OF THE SOLUTION-TREATING PORTION OF THE HEAT-TREATMENT CYCLE. MAY CONSIST OF AN ALPHA-BETA STRUCTURE, AN ALPHA-MARTENSITE STRUCTURE, A MARTENSITE STRUCTURE, OR A RETAINED-BETA STRUCTURE, DEPENDING ON THE SOLUTION-TREATING TEMPERATURE AND COMPOSITION OF THE ALLOY.

STABILIZATION - A TERM USED TO DESCRIBE AN ANNEALING TREATMENT WHICH PRECIPITATES MASSIVE ALPHA FROM BETA IN AN ALPHA-BETA ALLOY, RENDERING THE ALLOY IN A CONDITION WHERE NO FURTHER REACTION WILL TAKE PLACE DURING EXPOSURE AT SERVICE TEMPERATURES.

J. SERVICE LIMITS

PRIMARILY FOR CRYOGENIC APPLICATIONS TO -423°F.

DESIGN DATA ABOVE ROOM TEMPERATURE NOT GENERALLY AVAILABLE. HOWEVER, THE NORMAL INTERSTITIAL GRADE IS USED TO 1000°F (AMS SPECIFICATIONS RECOMMEND USAGE TO 800°F ONLY).

K. PROCESSING

SURFACE TREATMENT

DE-SCALING:

- (A) MOLTEN SALT DESCALING AND DILUTE ACID NEUTRALIZING *
(B) MIXED ACID PICKLING (HNO₃ + HF) *

CLEANING

- (A) CAUSTIC SODA CLEANING AND DILUTE ACID NEUTRALIZING *
(B) EMULSION, DETERGENT, OR VAPOR DEGREASING **
AND DILUTE ACID NEUTRALIZING *
(C) ULTRASONIC CLEANING

* FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

** CHLORIDE COMPOUNDS CAN CAUSE STRESS-CORROSION CRACKING

THERMAL TREATMENT

STRESS RELIEF:

1000°-1200°F FOR 1-2 HOURS, AIR COOL

FULL ANNEAL:

1500°F FOR 30 MIN. OR 1600°F FOR 10 MIN. PROTECTIVE ATMOSPHERE REQUIRED FOR FULL ANNEALING.

NON-HEAT TREATABLE

K. PROCESSING (CONTINUED)

JOINING

WELDING METHODS: TUNGSTEN-INERT GAS (TIG)
RESISTANCE WELD
ELECTRON BEAM WELDING

WELDING FILLER: PARENT METAL COMPOSITION

WELD EFFICIENCY: 90-100%

JOINT STRENGTH: 95,000-105,000 PSI

THIS ALLOY IS THE MOST EASILY WELDED OF THE TITANIUM ALLOYS.

FORMING

FORGING RANGE:

START 1600°-1925°F, FINISH 1400°-1650°F

FORMING:

ROOM TEMPERATURE MINIMUM BEND RADIUS: 5T

MACHINABILITY

REQUIRES LOW CUTTING SPEEDS, HIGH FEED RATES, USE OF SHARP TOOLS.

L. REFERENCES

69- 1	67-48	65-61	63-16
69- 5	66-10	65-70	63-35
69- 6	66-30	65-90	63-53
68- 9	66-31	64- 3	63-56
68-12	66-35	64- 7	63-64
68-13	66-37	64- 8	63-84
67- 7	66-70	64-84	62-56
67-27	65- 1	63- 3	62-63
67-43			62-66

M. GOODMAN DIAGRAMS

DATE 30 SEPT 1969
SUPERSEDES 15 SEPT 1967

TENSILE STRENGTHS

SHEET AND PLATE, ANNEALED

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIALTi-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOYI-B-11
3A

DATE 30 SEPT 1969
SUPERSEDES 15 SEPT 1967

TENSILE STRENGTHS

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
4

DATE 30 SEPT 1969
SUPERSEDES

STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11

DATE 30 SEPT 1969
SUPERSEDES

BASIC DATA

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**EXTRA LOW
INTERSTITIAL**

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

DATE 30 SEPT 1969

SUPERSEDES 15 SEPT 1967

FATIGUE STRENGTH

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
8
(UPPER)

DATE 30 SEPT 1969
SUPERSEDES 1 MAY 1966

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
8
(LOWER)

DATE 30 SEPT 1969
SUPERSEDES 1 MAY 1966

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
9

DATE 30 SEPT 1969
SUPERSEDES 15 SEPT 1967

IMPACT STRENGTH
HARDNESS

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
10

DATE 30 SEPT 1969
SUPERSEDES 15 SEPT 1967

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
10A

DATE	30 SEPT 1969
SUPERSEDES	15 SEPT 1967

**REDUCTION OF AREA
ELONGATION**

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
10B

DATE 30 SEPT 1969
SUPERSEDES 15 SEPT 1967

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIALTi-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOYI-B-11
10C

DATE 30 SEPT 1969

SUPERSEDES 15 SEPT 1967

ELONGATION
(AFTER IRRADIATION)

DESIGN VALUES,
80% OF AVERAGE

EFFECTS OF IRRADIATION ON ELONGATION OF

Ti - 5Al - 2.5 Sn (ELI)

UNLESS OTHERWISE NOTED
E > 1.0 MEV

SEE INTRODUCTION, PAGE 3

FORM AND CONDITION	GAGE LENGTH (IN.)	TEMPERATURES (°F)			PRE- IRRADIATION CONTROL VALUES	POST-IRRADIATION VALUES DOSAGES GIVEN AS INTEGRATED NEUTRON FLUX (NVT) IN TERMS OF NEUTRONS/CM ²										NO. OF IRRADIATION SPECIMENS	REFERENCE	COMMENTS
		IRRADIATION	POST- IRRADIATION ANNEAL	POST- IRRADIATION TEST		10 ¹⁵		10 ¹⁶		10 ¹⁷		10 ¹⁸		10 ¹⁹				
						ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE	ELONG. - %	DOSAGE			
1/4-IN. PL	2.0 (b)	-423		-423	13.5			15	5 x 10 ¹⁶							4	66-3	TIG WELD EB WELD
1/4-IN. PL *	2.0 (b)	-423		-423	4.5			5	5 x 10 ¹⁶							4	66-3	
1/4-IN. PL	2.0 (b)	-423	80	-423	13			9	5 x 10 ¹⁶							4	63-3	
3/8-IN. PL	2.0	-423		-423	5.5					4	4 x 10 ¹⁷					4	67-7	
1/2-IN. RD	0.5 (c)	-430		-430	8			9	7.5 x 10 ¹⁶							3	66-35	
BAR (a)	1.5 (d)	-320		-320	13					3.5	6 x 10 ¹⁷					3	66-3	
BAR (a)	1.5 (d)	-320	80	-320	13					7.5	6 x 10 ¹⁷					3	66-3	
BAR (a)	1.5 (d)	-320	80	80	13					10.5	6 x 10 ¹⁷					3	66-3	
3/8-IN. PL	2.0	-320		-320	10					9	4 x 10 ¹⁷					3	67-7	
FORGINGS (a)		-320		-320	8.6					6.1	9 x 10 ¹⁷					4	67-27	
FORGINGS (a)		-320		-320	12.7					7.2	9 x 10 ¹⁷					4	67-27	
FORGINGS (a)		-320		-320	11.4					5.8	9 x 10 ¹⁷					4	67-27	
ANNEALED 1125° F/1HR., UNLESS OTHERWISE NOTED																		
(a) ANNEALED 1500° F/1 HR., A.C.																		
(b) REDUCED SECTION 3/8-IN. x 1/8-IN.																		
(c) REDUCED SECTION 1/8-IN., E ≥ 0.5 MEV.																		
(d) REDUCED SECTION 0.2-IN. DIA.																		
(e) STRESS RELIEVED AFTER WELD, 1200 F/3 HR, AC																		
* WELDED																		

ANNEALED 1125°F/1HR., UNLESS OTHERWISE NOTED

(a) ANNEALED 1500°F/1 HR., A.C.

(b) REDUCED SECTION 3/8-IN. x 1/8-IN.

(c) REDUCED SECTION 1/8-IN., E > 0.5 MEV.

(d) REDUCED SECTION 0.2-IN. DIA.

(e) STRESS RELIEVED AFTER WELD,
1200 F/3 HR, AC

* WELDED

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
11

DATE	30 SEPT 1969
SUPERSEDES	15 SEPT 1967

MODULUS OF ELASTICITY
MODULUS OF RIGIDITY

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIALTi-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOYI-B-11
12

DATE 30 SEPT 1969

SUPERSEDES

VALUES OF MEAN COEFFICIENT ARE FROM
ROOM TEMPERATURE TO INDICATED TEMPERATURE

THERMAL EXPANSION

MEAN COEFFICIENT - LINEAR THERMAL EXPANSION
10⁻⁶ IN./IN. °F

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
13

DATE 30 SEPT 1969
SUPERSEDES 15 SEPT 1967

DATE 30 SEPT 1969
SUPERSEDES

**THERMAL DIFFUSIVITY
EMITTANCE**

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
15

DATE 30 SEPT 1969

SUPERSEDES

DENSITY
POISSON'S RATIO

MATERIALS DATA BOOK

EXTRA LOW
INTERSTITIAL

Ti-5Al-2.5 Sn
(A 110-AT)
TITANIUM ALLOY

I-B-11
16

DATE 30 SEPT 1969
SUPERSEDES 15 SEPT 1967

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

THIS MATERIAL IS AN ALPHA-BETA TYPE TITANIUM ALLOY AND IS HEAT TREATABLE. IN THE ANNEALED CONDITION IT HAS SUPERSEDED MANY OF THE NON-HEAT-TREATABLE ALLOYS BECAUSE OF ITS GOOD STRENGTH AND STABILITY UP TO 750°F. IMPACT STRENGTH AND NOTCH TOUGHNESS ARE GOOD AT CRYOGENIC TEMPERATURES. THE ALLOY CAN BE FORMED USING SPECIAL METHODS AND IT IS OF FAIR WELDABILITY.

DESIGN PROPERTY BASIS

- FOR F_{TU} , F_{TY} , e , AND RA:
SOLUTION-TREATED & AGED CONDITION WITH THICKNESS ≥ 0.187 , AS STATED IN NP-64-3. THE PROPERTY VALUE INDICATED IS THAT ABOVE WHICH AT LEAST 99% OF THE POPULATION OF VALUES IS EXPECTED TO FALL WITH A CONFIDENCE OF 95%.
- ALL OTHERS BASED ON MIN. VALUES OF PROCUREMENT SPECS

B. COMMERCIAL DESIGNATIONS

MST-6Al-4V, C-120 AV, RS-120A, HA-6510

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP & PLATE	MIL-T-9046 AMS 4911
BAR, FORGINGS	MIL-T-9047 MIL-T-12117 AMS 4928

SUPPLIERS

TITANIUM METALS CORP. OF AMERICA
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
REACTIVE METALS, INC.
HARVEY ALUMINUM CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Al	V	Fe	O	C	N	H	Other Total
MAXIMUM	6.75	4.50	0.30	0.15	0.10	0.07	0.015	0.40
MINIMUM	5.50	3.50	-	-	-	-	-	-
SOURCE	P-65-2							
	BAL Ti							

I. MECHANICAL PROPERTIES

ANNEALED		SOLUTION TREATED & AGED			
SHEET & PLATE		SHEET & PLATE			
ALL SIZES		TO 0.187 IN.	0.187 TO 0.25 IN.	0.25 TO 0.75 IN.	
TENSILE ULTIMATE STRENGTH F_{TU}		MIN	PSI		
130,000	157,000	160,000	160,000		
TENSILE YIELD STRENGTH F_{TY}		MIN	PSI		
120,000	143,000	145,000	145,000		
COMP. YIELD STRENGTH F_{CY}		MIN	PSI		
LONG 126,000	152,000	154,000			
TRANS 126,000	160,000	162,000			
SHEAR STRENGTH F_{SU}		MIN	PSI		
76,000	98,000	100,000			
BEARING STRENGTH, ULTIMATE F_{BRU}		MIN	PSI		
e/D=1.5 191,000	232,000	236,000			
e/D=2.0 244,000	281,000	286,000			
BEARING STRENGTH, YIELD F_{BRY}		MIN	PSI		
e/D=1.5 163,000	207,000	210,000			
e/D=2.0 198,000	229,000	232,000			
ELONGATION e		MIN	%		
8	3	3	8	6	
REDUCTION OF AREA RA			%		
MODULUS OF ELASTICITY E		10^6 PSI			
		16.0			
MODULUS OF RIGIDITY G		10^6 PSI			
		6.1			
COMP. MODULUS OF ELASTICITY E_C		10^6 PSI			
		16.4			
MODULUS OF RUPTURE F_{st}		PSI			
(TORSION, ANNEALED BAR)		117,000			
PLASTIC BENDING MODULUS		(SEE APPENDIX A)			

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

ANNEALED		SOLUTION TREATED & AGED			
BAR AND FORGING		BAR AND FORGING			
TO 3 IN.		TO 1 IN.	1 TO 2 IN.	2 TO 3 IN.	
TENSILE ULTIMATE STRENGTH F_{TU}		PSI			
130,000	160,000	150,000		140,000	
TENSILE YIELD STRENGTH F_{TY}		PSI			
120,000	150,000	140,000		130,000	
COMP. YIELD STRENGTH F_{CY}		PSI			
126,000					
SHEAR STRENGTH F_{SU}		PSI			
80,000					
BEARING STRENGTH, ULTIMATE F_{BRU}		PSI			
e/D=1.5 196,000					
e/D=2.0 248,000					
BEARING STRENGTH, YIELD F_{BRY}		PSI			
e/D=1.5 174,000					
e/D=2.0 205,000					
ELONGATION e		%			
10	10	8		8	
REDUCTION OF AREA RA		%			
MODULUS OF ELASTICITY E		10^6 PSI			
		16.0			
MODULUS OF RIGIDITY G		10^6 PSI			
		16.4			
COMP. MODULUS OF ELASTICITY E_C		10^6 PSI			
		16.4			
PLASTIC BENDING MODULUS		(SEE APPENDIX A)			

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³	0.160
SPECIFIC HEAT C	BTU/LB - °F	(AT 68°F) 0.135
THERMAL CONDUCTIVITY k	BTU - FT / HR - FT ² - °F	(AT 68°F) 3.8
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. / IN. - °F	(RT TO 200°F) 4.8
ELECTRICAL RESISTIVITY R	MICROHM - IN.	67

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	2800° - 3000°F
PHASE CHANGES	ALLOY TRANSFORMS ON COOLING FROM BETA TO ALPHA + BETA: 1700°-1800°F FOR SHEET AND 1775°-1850°F FOR BAR
THERMAL CONDUCTIVITY VS. TEMPERATURE	
TEMPERATURE (°F)	k (BTU - FT / HR - FT ² - °F)
68	3.8
600	5.9
1600	10.5

G. CHEMICAL PROPERTIES

CHLORIDE COMPOUNDS CAN CAUSE STRESS - CORROSION CRACKING

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

RECOMMENDED FOR STRENGTH & MAXIMUM CREEP
RESISTANCE TO 1000°F
ELONGATION IS GOOD TO -320°F., BUT DROPS OFF RAPIDLY
TO < 5% AT -423°F.
REDUCTION OF AREA IS GOOD AT -423°F.

K. PROCESSING

SURFACE TREATMENT *

DESCALING:

1. VARIOUS MOLTEN SALT BATHS FOLLOWED BY DILUTE
MINERAL ACID NEUTRALIZING
2. MIXED ACID PICKLE (HF-HNO₃)

CLEANING:

1. CAUSTIC SODA CLEANING AND DILUTE MINERAL ACID
NEUTRALIZING
2. EMULSION, DETERGENT, OR VAPOR DEGREASING, FOLLOWED
BY DILUTE MINERAL ACID NEUTRALIZING
3. ULTRASONIC

* FOLLOW ALL ACID TREATMENTS WITH WATER RINSE, SINCE
CHLORIDE COMPOUNDS CAN CAUSE STRESS CORROSION
CRACKING.

THERMAL TREATMENT

STRESS RELIEF:

1. COLD WORKED MATERIAL 1000 - 1200°F (1-8 HRS)
2. WELDS OR ANNEALED MATERIAL 900°F (20 HRS)
1000°F (2 HRS)
1100°F (1 HR)
3. FOR WELDS IN SOLUTION TREATED MATERIAL:
900°F (15 HRS), 1000°F (4 HRS), WILL RESULT IN AGING
OF PARENT METAL
4. FOR WELDS IN SOLUTION TREATED AND AGED MATERIAL:
900°F (15 HRS), 1000°F (5 HRS)

HARDENING:

FOR SHEET

SOLUTION TREAT AT 1600-1700°F
WATER QUENCH & AGE AT 1000°F (4 HR.) OR AT 925°F (4-8 HR).

FOR HEAVY SECTIONS

SOLUTION TREAT AT 1750°F
WATER QUENCH & AGE AT 1000°F (4 HR) OR AT 925°F (4-8 HR).

K. PROCESSING (CONTINUED)

JOINING

WELD EFFICIENCY AND JOINT STRENGTH:

ANNEALED, AS-WELDED

100% EFFICIENCY, 147,000-PSI JOINT STRENGTH

SOLUTION TREAT, WELD, AGE AT 900°F (4 HR.)

97% EFFICIENCY, 170,000-PSI JOINT STRENGTH

WELDED IN SOLUTION-TREATED AND AGED CONDITIONS

93% EFFICIENCY, 167,000-PSI JOINT STRENGTH

WELDING METHODS

TIG
RESISTANCE
ELECTRON BEAM

FILLER METAL

PARENT METAL COMPOSITION

FORMING

FORGING TEMPERATURE RANGE 1600° - 1800°F. FINISHING
TO BE DONE BELOW THE BETA TRANSUS TEMPERATURE
(1750°F OR UNDER)

COLD FORMING

1. ANNEALED MATERIAL AT ROOM TEMPERATURE, 4.5-5 T
BEND RADIUS REQUIRED. CAN BE FORMED AT TEMPERATURES
UP TO 1500°F AT LOWER BEND RADIUS AND WITH REDUCED
SPRING BACK
2. SOLUTION TREATED MATERIAL - USE TEMPERATURES
BELOW 500°F. IF OVER-AGING IS PERMITTED, FORM IN RANGE
OF 1000°-1100°F
3. SOLUTION TREATED AND AGED. FORM ONLY AT
1000° TO 1100°F

MACHINABILITY

REQUIRES LOW CUTTING SPEEDS, HIGH FEED RATES, USE
OF SHARP TOOLS, AND USE OF COPIOUS AMOUNTS OF
CUTTING FLUID

L. REFERENCES

NP-64-3
NP-64-8
NP-65-1
NP-65-4
P-65-5

APPROXIMATE MODIFIED GOODMAN DIAGRAM
Ti-6Al-4V ALLOY, ANNEALED
FLEXURE LOAD AT RT
0.072-IN. THICK SHEET
REF. NP-65-1

APPROXIMATE MODIFIED GOODMAN DIAGRAM
Ti-6Al-4V ALLOY, ANNEALED
FLEXURE LOAD AT -320°F
0.072-IN. THICK SHEET
REF. NP-65-1

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

**REDUCTION OF AREA
ELONGATION**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

DENSITY

ELECTRICAL RESISTIVITY

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

THIS MATERIAL IS AN ALPHA-BETA TYPE TITANIUM ALLOY AND IS HEAT TREATABLE. THE ALLOY CAN BE FORMED USING SPECIAL METHODS AND IS OF FAIR WELDABILITY. ITS EXTRA-LOW INTERSTITIAL CONTENT PERMITS HIGHER DUCTILITY AND NOTCH TOUGHNESS AT CRYOGENIC TEMPERATURES THAN THE NORMAL INTERSTITIAL GRADE.

THE VALUES IN SECTION E-1 ARE SPECIFICATION MINIMA,

B. COMMERCIAL DESIGNATIONS

HA-6510 ELI; RS-120A-L; C 120-AV ELI

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR & FORGINGS	MIL-T-9047
SHEET AND PLATE	MIL-T-9046
SHEET	AMS 4907
ARMOR PLATE	MIL-T-46077

SUPPLIERS

TITANIUM METALS CORP OF AMERICA
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
REACTIVE METALS CO., NILES, OHIO
HARVEY ALUMINUM CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Al	V	Fe	O	C	N	H	BALANCE
MAXIMUM	6.50	4.50	0.25	0.13	0.08	0.05	0.0125	Ti
MINIMUM	5.50	3.50	-	-	-	-	-	

SOURCE NP-65-10

OTHER ELEMENTS
0.10 EACH MAX.
0.40 TOTAL MAX.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE VALUES UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SHEET		BAR & PLATE	
ANNEALED		ANNEALED	
0.008 TO 0.025	0.026 TO 0.187 IN.	TO 1 IN.	1 TO 2 IN.
TENSILE ULTIMATE STRENGTH F_{TU}	PSI		
130,000	130,000	130,000	125,000

TENSILE YIELD STRENGTH F_{TY}	PSI
120,000	120,000

COMP. YIELD STRENGTH F_{CY}	PSI
-------------------------------	-----

SHEAR STRENGTH F_{SU}	PSI
-------------------------	-----

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
-------------------------------------	-----

ELONGATION e	%
8.0	10.0

REDUCTION OF AREA RA	%
------------------------	---

MODULUS OF ELASTICITY E	10^6 PSI
16	

MODULUS OF RIGIDITY G	10^5 PSI
-------------------------	------------

COMP. MODULUS OF ELASTICITY E_c	10^6 PSI
16.4	

MODULUS OF RUPTURE F_{ST}	PSI
(TORSION, ANNEALED BAR)	117,000 127,000

PLASTIC BENDING MODULUS	(SEE APPENDIX A)
-------------------------	------------------

2. PHYSICAL PROPERTIES

DENSITY ρ	LB./IN. ³
----------------	----------------------

0.160	
-------	--

SPECIFIC HEAT C	BTU/LB. - °F
-------------------	--------------

(AT 68°F)	0.135
-----------	-------

THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
--------------------------	---------------------------------------

(AT 68°F)	3.8
-----------	-----

MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
---	---------------------------

(RT TO 200°F)	4.8
---------------	-----

ELECTRICAL RESISTIVITY R	MICROHM - IN.
----------------------------	---------------

67	
----	--

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
---------------	--

2800 - 3000°F	
---------------	--

PHASE CHANGES	
---------------	--

ALLOY TRANSFORMS ON COOLING FROM BETA TO ALPHA
+ BETA AT 1750 - 1800°F FOR SHEET, 1775-1850°F FOR BAR

THERMAL CONDUCTIVITY VS. TEMPERATURE	
--------------------------------------	--

TEMPERATURE (°F)	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
68	3.8
200	4.4
400	5.2
600	6.0
800	6.7
1000	7.5
1200	8.3
1400	9.4
1600	10.4

F. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES
CORROSION RESISTANCE

MEDIUM	BEHAVIOR
NITRIC ACID	EXCELLENT FOR ALL CONCENTRATIONS AND TO BOILING POINT. TITANIUM HAS PYROPHORIC TENDENCIES IN RED FUMING NITRIC ACID BELOW 2% WATER AND 10-20% NITROGEN DIOXIDE CONTENTS
SULFURIC ACID	RESISTS ATTACK IN DILUTE SOLUTIONS AT LOW TEMPERATURES. AT HIGHER TEMPERATURE AND CONCENTRATIONS, INHIBITORS ALLOW EFFECTIVE APPLICATION
HYDROFLUORIC ACID	RAPIDLY ATTACKED
ORGANIC SALTS	GENERALLY GOOD, BORDERLINE PASSIVITY IN FORMIC AND TRICHLOROACETIC ACIDS
INORGANIC SALTS	CHLORIDES MAY CONTRIBUTE TO STRESS CORROSION - CRACKING
CHLORINATED SOLVENTS AND COMPOUNDS	THE CHLORINE MAY CONTRIBUTE TO STRESS-CORROSION CRACKING
ALKALIES	EXCELLENT FOR ALL CONCENTRATIONS AND TO BOILING POINT, EXCEPT BOILING, OF CONCENTRATED POTASSIUM HYDROXIDE
HYDROGEN	HYDROGEN IS READILY ABSORBED FROM HYDROGENATING SOLUTIONS AT ROOM TEMPERATURE AND FROM THE ATMOSPHERE AT ELEVATED TEMPERATURES. EMBRITTLEMENT IS THE RESULT. SAFE LIMITS SET AT 125 - 150 PPM MAXIMUM.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

GOOD NOTCH TOUGHNESS AT CRYOGENIC TEMPERATURES TO -423°F. RADIATION EFFECTS SHOULD BE EVALUATED

K. PROCESSING
SURFACE TREATMENT
CLEANING

- (A) MOLTEN SALT DESCALING FOLLOWED BY DILUTE ACID NEUTRALIZING*
- (B) CAUSTIC SODA CLEANING FOLLOWED BY DILUTE ACID NEUTRALIZING*
- (C) EMULSION, DETERGENT, OR VAPOR DE-GREASING FOLLOWED BY DILUTE ACID NEUTRALIZING*
- (D) ACID PICKLING - HF + HNO₃ ACIDS
- (E) ULTRASONIC CLEANING

*FOLLOW ALL ACID TREATMENTS WITH WATER RINSE

THERMAL TREATMENT
STRESS-RELIEF:

COLD WORKED MATERIAL
1000°F - 1200°F, 1 - 8 HRS. AT TEMPERATURE
ANNEALED MATERIAL OR WELDS
900°F (20 HRS. AT TEMP.), OR 1000°F (2 HRS. AT TEMP.)
OR 1100°F (1 HR. AT TEMP.)

HARDENING: NOT NORMALLY USED, SINCE SOLUTION TREATED AND AGED MATERIAL HAS POOR NOTCH TOUGHNESS AT CRYOGENIC TEMPERATURES OF -320°F AND LOWER.

K. PROCESSING (CONTINUED)
JOINING

WELDING - METHODS: TUNGSTEN - INERT GAS
RESISTANCE
ELECTRON BEAM

FILLER: PARENT METAL COMPOSITION
EFFICIENCY AND JOINT STRENGTHS:
ANNEALED, AS WELDED - 100% EFF. 147,000 PSI
JOINT STRENGTH.

FORMING

FORGING - 1600° - 1800°F. - FINISH BELOW THE BETA TRANSUS TEMPERATURE (1750°F OR LESS)

COLD FORMING - ANNEALED MATERIAL - AT ROOM TEMPERATURE 4.5-5T BEND RADIUS REQUIRED.

HOT FORMING - CAN BE FORMED AT TEMPERATURES UP TO 1500°F. AT LOWER BEND RADII AND WITH REDUCED SPRING BACK THAN IN COLD FORMING.

MACHINABILITY

REQUIRES LOW CUTTING SPEEDS, HIGH FEED RATES, USE OF SHARP TOOLS.

L. REFERENCES

NP-62-19
NP-64-8
NP-65-4
NP-65-5
NP-65-10
NP-65-1

APPROXIMATE MODIFIED GOODMAN DIAGRAM
TI-6Al-4V (ELI), SOLUTION TREATED & AGED
AXIAL LOAD AT RT
0.100-IN. THICK SHEET
REF. NP-65-1

APPROXIMATE MODIFIED GOODMAN DIAGRAM
TI-6Al-4V (ELI), SOLUTION TREATED AND AGED
AXIAL LOAD AT -320°F
0.100-IN. THICK SHEET
REF. NP-65-1

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

THERMAL EXPANSION
SPECIFIC HEAT

DATE 1 MAY 1966

SUPERSEDES

**NICKELS AND
NICKEL-BASE ALLOYS**

MATERIALS DATA

**II
NICKELS AND NICKEL BASE ALLOYS**

**A.
SOLUTION - HARDENING ALLOYS**

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

HASTELLOY "C" HAS EXCELLENT CORROSION RESISTANCE IN MANY ENVIRONMENTS. HIGH TEMPERATURE MECHANICAL PROPERTIES ARE VERY GOOD, PERMITTING USE IN THE 1600° - 1800°F RANGE. IT IS AVAILABLE IN MANY FORMS AND IT IS READILY FABRICATED. THIS ALLOY IS NON-AGE-HARDENING.

FOR F_{TU} , F_{TY} , e , AND RA , THE DESIGN DATA IN SECTION E-1 ARE SPECIFICATION MINIMA. PROPERTIES ARE GIVEN FOR SOLUTION-TREATED MATERIAL.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
PLATE, SHEET AND STRIP	MIL-N-18088
SHEET	AMS 5530
SHEET AND PLATE	ASTM-B-334
BARS & FORGINGS	AMS 5750
ROD	ASTM-B-336
WELD WIRE	ASTM-B-304 CLASS ERN-7C
ELECTRODE, COATED	MIL-E-22200/3 ASTM-B-295 CLASS E3-N1C

SUPPLIERS

STELLITE DIVISION
UNION CARBIDE CORP.
KOKOMO, INDIANA

D. CHEMICAL COMPOSITION (%)

ELEMENT	(1) Co	(2) Cr	(3) Mo	(4) W	(5) Fe	(6) Si	(7) Mn	(8) C
MAXIMUM	2.50	16.50	17.00	4.50	7.00	1.00	1.00	0.08
MINIMUM	-	14.50	15.00	3.00	4.00	-	-	-
SOURCE	AMS 5530	(2)	(1)	(1)	(1)	(1)	(1)	(1)
		(3)	(3)	(3)	(3)	(3)	(3)	(3)

COBALT, IF DETERMINED

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SHEET	PLATE	PLATE
ALL THICKNESSES	0.1875-0.750 INCL.	0.750-2.50, INCL.

TENSILE ULTIMATE STRENGTH F_{TU} PSI
115,000 100,000 90,000

TENSILE YIELD STRENGTH F_{TY} PSI
50,000 45,000 45,000

COMP. YIELD STRENGTH F_{CY} PSI
50,000 45,000 45,000

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e %
40 30 24

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI
28.5

MODULUS OF RIGIDITY G 10^6 PSI

COMP. MODULUS OF ELASTICITY E_c 10^6 PSI

PLASTIC BENDING MODULUS (SEE APPENDIX A)

BAR	BAR
0.312 - 1.5 IN. DIA	1.5 - 3 IN. DIA

TENSILE ULTIMATE STRENGTH F_{TU} PSI
111,000 100,000

TENSILE YIELD STRENGTH F_{TY} PSI
46,000 46,000

COMP. YIELD STRENGTH F_{CY} PSI
46,000 46,000

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e %
20 20

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

COMP. MODULUS OF ELASTICITY E_c 10^6 PSI

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ
LB./IN.³ 0.323
G./CC

SPECIFIC HEAT C BTU/LB. °F
0.0920

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F
(392°F) 6.5

MEAN COEFF. LINEAR THERMAL EXPANSION α 10^{-6} IN. / IN. - °F
(70-200°F) 6.6

ELECTRICAL RESISTIVITY R MICROHM - IN.
51.0

MAGNETIC PROPERTIES

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2310°-2450°F

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k (BTU - FT / HR - FT ² - °F)
392	6.5
572	7.3
752	8.2
932	9.0
1112	9.8

G. CHEMICAL PROPERTIES

RESISTANT TO OXIDIZING AND REDUCING ATMOSPHERES UP TO 2000°F. RESISTANT TO MANY ORGANIC AND MINERAL ACIDS FROM ROOM TEMPERATURE TO THEIR BOILING POINTS.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

NON-RADIATION SERVICE LIMITS
-423°F TO 2000°F FOR RESISTANCE TO OXIDIZING AND REDUCING ATMOSPHERES, ALSO FOR GENERAL STRUCTURAL APPLICATIONS.

WHEN HIGHLY STRESSED OR SUBJECT TO REPEATED THERMAL SHOCK, MAXIMUM SERVICE TEMPERATURE SHOULD BE IN RANGE OF 1600° - 1800°F.

K. PROCESSING
SURFACE TREATMENT
CLEANING*

ELECTROLYTIC AND NON-ELECTROLYTIC MOLTEN SALT DE-SCALING AND DILUTE ACID NEUTRALIZING.

HF - HNO₃ ACID PICKLE.

CAUSTIC-SODA CLEANING AND DILUTE ACID NEUTRALIZING.

EMULSION, DETERGENT, OR VAPOR DEGREASE, AND DILUTE ACID NEUTRALIZING

ULTRASONIC

*FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

SOLUTION HEAT-TREAT (ANNEAL) AT 2225°F ± 25°F AND WATER QUENCH OR AIR COOL, DEPENDING ON MASS.

K. PROCESSING (CONTINUED)
JOINING
WELDING

METHODS: TIG (RECOMMENDED), MIG, METALLIC ARC, RESISTANCE, ELECTRON BEAM

FILLER: PARENT METAL COMPOSITION

WELD EFFICIENCY AND JOINT STRENGTHS:

TIG OR MIG	METALLIC ARC
SHEET 80-85% 105-123,000 PSI	85-90% 112-115,000 PSI
PLATE 80-90% 100-132,000 PSI	80-100% 100-132,000 PSI

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

HASTELLOY C/MIL-E-17496

HASTELLOY C/ASTM-B-304, CL. ER NiMo-5

FORMING

FORGING TEMPERATURE RANGE 1900° - 2250°F
READILY COLD FORMED.

MACHINABILITY

READILY MACHINED AT COMPARATIVELY LOW CUTTING SPEEDS. TUNGSTEN CARBIDE CUTTING TOOLS RECOMMENDED.

L. REFERENCES

NP-63-20
NP-64-4
P-55-1

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**IMPACT STRENGTH
BRINELL HARDNESS**

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
10⁻⁶ IN./IN.-°F

0.16

0.12

0.08

0.04

0

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

HASTELLOY ALLOY N HAS GOOD OXIDATION RESISTANCE. IT ALSO RESISTS AGING AND EMBRITTLEMENT. FABRICATION CAN BE READILY ACCOMPLISHED.

DESIGN PROPERTIES IN SECTION E-1 ARE 80% OF AVERAGE VALUES FOR F_{TU} , F_{TY} , e , AND RA.

B. COMMERCIAL DESIGNATIONS

INOR-8

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, PLATE, BAR, BARE WELDING WIRE, COATED WELDING ELECT- RODES, SAND-SHELL AND INVESTMENT CASTINGS	NONE

SUPPLIERS

HAYNES STELLITE COMPANY
KOKOMO, INDIANA
ALLVAC, MONROEVILLE, N.C.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Cr	Mo	Fe	Si	Mn	C	B	S
MAXIMUM	3.00	18.00	5.00	1.00	0.8	0.08	0.01	0.02
MINIMUM	6.00	15.00	-	-	-	0.04	-	-
SOURCE	NP-62-20	W	Co	P	Cu	AHTi	Ni	Bal.
	MAX	0.50	0.20	0.01	0.35	0.5		

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SOLUTION-TREATED

0.063-IN. SHEET 0.25-IN. BAR
INVEST. CAST

TENSILE ULTIMATE STRENGTH F_{TU} PSI
92,000 69,000

TENSILE YIELD STRENGTH F_{TY} PSI
36,000 30,000

COMP. YIELD STRENGTH F_{CY} PSI

ULTIMATE SHEAR STRENGTH F_{SU} PSI

SHEAR YIELD STRENGTH F_{SY} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

c/D 1.5
c/D 2.0

YIELD BEARING STRENGTH F_{BRY} PSI

c/D 1.5
c/D 2.0

ELONGATION e

41 30
(AS-WELDED) 30

REDUCTION OF AREA RA

MODULUS OF ELASTICITY E 10^6 PSI

DYNAMIC 31.7
STATIC 43.0

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

POISSON'S RATIO

(70°F) 0.294

HARDNESS

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.317

SPECIFIC HEAT C BTU/LB - °F

(AT 212°F) 0.100

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

(AT 212°F) 6.6

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

(70° - 400°F) 6.45

ELECTRICAL RESISTIVITY R MICROHM - IN.

(AT 75°F) 54.7

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2375°F - 2750°F

PHASE CHANGES

RESISTS AGING. ELEMENTS REMAIN IN SOLID SOLUTION IN THE 1100°-1600°F RANGE. TENSILE TESTS HAVE INDICATED NO TENDENCY TOWARD EMBRITTLEMENT FOR PROLONGED PERIODS AT 1500°F.

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
(°F)

212	6.6
392	7.4
572	8.3
752	9.15
932	10.4
1112	11.7
1292	13.8

F. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES

RESISTANT TO FLUORIDES AT HIGH TEMPERATURES.

GOOD OXIDATION RESISTANCE IN AIR. SHOWS PROMISE FOR CONTINUOUS OPERATIONS AT TEMPERATURES TO 1800°F. INTERMITTENT USE AT TEMPERATURES TO 1900°F MAY BE POSSIBLE. NO MEASURABLE OXIDATION AT TEMPERATURES TO 1200°F.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

SEE SECTION G FOR CORROSION RESISTANCE TEMPERATURE
RANGE OF SERVICE: 75 - 1700°F

K. PROCESSING

SURFACE TREATMENT

THERMAL TREATMENT

SOLUTION TREATMENT TEMPERATURE 2165°F. HOLDING TIME
DEPENDENT UPON THICKNESS. SOLUTION TREATMENT
RECOMMENDED AFTER HOT OR COLD WORKING.

JOINING

WELDING

METHOD

TUNGSTEN-INERT GAS (TIG). WELDING VARIABLES
SHOULD BE ADJUSTED TO ENSURE MINIMUM HEAT
INPUT.

FILLER

PARENT METAL COMPOSITION

PRE-HEAT
NONE

K. PROCESSING (CONTINUED)

JOINT DESIGN

30-50% GREATER GAP REQUIRED THAN IN STAINLESS-
STEEL WELDING.

PRE-WELD CLEANING

WIRE BRUSHING, FOLLOWED BY ACETONE OR FREON RINSE.

MULTIPLE-PASS WELDING

INTERPASS TEMPERATURE SHOULD BE BELOW 200°F.
REMOVE SURFACE OXIDES WITH ROTARY FILE AFTER
EACH PASS. CLEAN AS IN PRE-WELD CLEANING.

FOR PARENT METAL WELDED TO ITSELF, SELECT THE
FOLLOWING WELD ROD:

HASTELLOY N/AGC 90058, COMP. HASTELLOY N
(REQUIRED ON ALL NERVA WELDING)

FORMING

READILY FORGED

HOT WORKING RANGE: 1600 - 2150°F

HASTELLOY N HAS BEEN EXTRUDED, AND HAS BEEN FABRICATED
INTO SEAMLESS, WELDED, AND DRAWN TUBING.

FORMABILITY (AVERAGE OF 4 TESTS):

FORM	CONDITION	ERICHSEN CUP DEPTH (MM)
SHEET, 0.063"	HEAT TREATED FOR 8 MIN. AT 2150°F, RAPID AIR COOLED	13.4

MACHINABILITY

L. REFERENCES

NP-62-20

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF ELASTICITY
 10^6 PSI

MODULUS OF RIGIDITY

MODULUS OF RIGIDITY
 10^6 PSI

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

THIS ALLOY IS NON-HEAT-TREATABLE. IT HAS VERY GOOD OXIDATION RESISTANCE AND IS USED AT TEMPERATURES UP TO 2200°F.

DESIGN VALUES OF F_{TU} , F_{TY} , AND e IN SECTION E-1 ARE SPECIFICATION MINIMA.

PROPERTIES IN SECTION E OF THIS PAGE ARE FOR SHEET AND PLATE IN THE SOLUTION-TREATED (ANNEALED) CONDITION.

B. COMMERCIAL DESIGNATIONS

UNITEMP HX
HASTELLOY X

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET AND PLATE	AMS 5536
TUBING, SEAMLESS	AMS 5587
TUBING, WELDED	AMS 5588
BAR & FORGINGS	AMS 5754
WIRE, BARE, WELDING	AMS 5798
ELECTRODE, COATED, WELDING	AMS 5799
CASTINGS, INVESTMENT	AMS 5390

SUPPLIERS

UNION CARBIDE CORP.
STELLITE DIVISION
KOKOMO, INDIANA
UNIVERSAL-CYCLOPS STEEL CORP.
BRIDGEVILLE, PA.

D. CHEMICAL COMPOSITION (%)

ELEMENT*	Cu	Cr	Mo	W	Fe	C	Si	Mn
MAXIMUM	2.50	23.00	10.00	1.00	20.00	0.15	1.00	1.00
MINIMUM	0.50	20.50	8.00	0.20	17.00	0.05	-	-

SOURCE NP-65-33

* Ni - BALANCE

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET AND PLATE ANNEALED
THICKNESS, INCHES

	< 0.187	0.187 TO 2	> 2
TENSILE ULTIMATE STRENGTH F_{TU}	100,000	100,000	95,000

TENSILE YIELD STRENGTH F_{TY}	45,000	40,000	40,000
---------------------------------	--------	--------	--------

COMP. YIELD STRENGTH F_{CY}			
-------------------------------	--	--	--

ULTIMATE SHEAR STRENGTH F_{SU}			
----------------------------------	--	--	--

SHEAR YIELD STRENGTH F_{SY}			
-------------------------------	--	--	--

ULTIMATE BEARING STRENGTH F_{BRU}			
-------------------------------------	--	--	--

$e/D = 1.5$
 $e/D = 2.0$

YIELD BEARING STRENGTH F_{BRY}			
----------------------------------	--	--	--

$e/D = 1.5$
 $e/D = 2.0$

ELONGATION e	35.0		
----------------	------	--	--

REDUCTION OF AREA RA			
------------------------	--	--	--

MODULUS OF ELASTICITY E	10^6 PSI		
	29.0		

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI		
	29.0		

MODULUS OF RIGIDITY G	10^6 PSI		
-------------------------	------------	--	--

POISSON'S RATIO			
-----------------	--	--	--

HARDNESS			
----------	--	--	--

PLASTIC BENDING MODULUS	(SEE APPENDIX A)		
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2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
----------------	--------------------

0.297

SPECIFIC HEAT C	BTU/LB - °F
-------------------	-------------

0.116

THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
--------------------------	---------------------------------------

(70°F) 5.23

MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
---	---------------------------

(79 - 200°F) 7.70

ELECTRICAL RESISTIVITY R	MICROHM - IN.
----------------------------	---------------

46.6

F. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES

OXIDIZING RESISTANT TO 2200°F. RESISTANT TO REDUCING ATMOSPHERES, CARBURIZING, AND NITRIDING.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
---------------	--

2300°F-2470°F

PHASE CHANGES	
---------------	--

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
70	5.23
200	6.33
500	7.86
1100	11.96
1300	13.21
1500	14.46
1700	15.71

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

IRRADIATION AT 120°F TO LEVEL OF 5×10^{19} NVT (FAST) PRODUCED NO SIGNIFICANT CHANGE IN ELONGATION FROM CONTROL VALUE OF 52%, WHEN TESTED AT 80°F.

SEVERE LOSS OF DUCTILITY AND STRESS-RUPTURE LIFE CAN OCCUR WHEN POST-IRRADIATION TEST TEMPERATURES EXCEED 1000°F. THRESHOLD FOR THIS LOSS IS AS LOW AS 10^{15} NVT (THERMAL). IT IS DEPENDENT UPON BORON CONTENT, AND IS ENHANCED AT LOW STRAIN RATES, OF APPROX. 0.002 IN./IN.-MIN.

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

NON-RADIATION SERVICE LIMITS
-423°F TO 2200°F

RADIATION SERVICE LIMITS
MAXIMUM SERVICE TEMPERATURE NOT YET ESTABLISHED,
BUT WILL PROBABLY BE IN THE 1000°F - 1200°F RANGE.

K. PROCESSING

SURFACE TREATMENT

CLEANING*

ELECTROLYTIC AND NON-ELECTROLYTIC MOLTEN SALT
DE-SCALING AND DILUTE ACID NEUTRALIZING.

HF - HNO₃ ACID PICKLE.

CAUSTIC-SODA CLEANING AND DILUTE ACID NEUTRALIZING.

EMULSION, DETERGENT, OR VAPOR DEGREASE, AND DILUTE
ACID NEUTRALIZING

ULTRASONIC

*FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

SOLUTION HEAT TREATMENT

ANNEAL AT 2150°F ± 25°.
RAPID AIR COOL OR WATER QUENCH.
HOLDING TIME AT TEMPERATURE 30-MIN. MAX.

K. PROCESSING (CONTINUED)

JOINING

WELDING

METHOD: TIG (RECOMMENDED), MIG,
METALLIC ARC (COATED ELECTRODE), ELECTRON BEAM,
RESISTANCE, SIGMA

FILLER: PARENT METAL

WELD EFFICIENCIES AND JOINT STRENGTHS

METHOD	SHEET	PLATE
METALLIC ARC	96% - 100,000 PSI	96% - 110,000 PSI
TIG OR MIG	96% - 110,000 PSI	94% - 107,000 PSI
SIGMA	90% - 103,000 PSI	93% - 106,000 PSI

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE
FOLLOWING WELD RODS:

AISI 680 HASTELLOY X/AGC 90058, COMP. HASTELLOY X
(REQUIRED ON ALL NERVA WELDING)
AISI 680 (HASTELLOY X)/AMS 5798
AISI 680 (HASTELLOY X)/AMS 5799

FORMING

FORGING: 1750°F - 2200°F
CAN BE COLD FORMED - POWER REQUIREMENTS HIGHER THAN
FOR STAINLESS STEEL

MACHINABILITY

MACHINABLE, BUT LOW CUTTING SPEEDS AND AMPLE FLOW
OF COOLANT IS REQUIRED. TUNGSTEN CARBIDE TOOLS
RECOMMENDED.

L. REFERENCES

NP-60-8
NP-61-27
NP-63-47
NP-64-4

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

INCONEL 625 IS A HIGH - STRENGTH, CORROSION - RESISTANT NICKEL - BASE ALLOY. THIS ALLOY IS NOT HEAT - TREATABLE.

THE VALUES GIVEN IN SECTION E ARE AVERAGES EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE LATTER PROPERTIES ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

INCONEL 625

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET BAR TUBE	NONE

SUPPLIERS

INTERNATIONAL NICKEL CO.
HUNTINGTON ALLOY PRODUCTS DIV.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Ni	Cr	Mo	Cb+Ta	C	Mn	Si	Fe
NOMINAL	61.0	22.0	9.0	4.0	0.05	0.15	0.30	3.0

SOURCE NP-62-22

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} 99,000 PSI

TENSILE YIELD STRENGTH F_{TY} 43,000 PSI

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e 46.5 %

REDUCTION OF AREA RA 46.0 %

MODULUS OF ELASTICITY E 29.8 10^6 PSI

MODULUS OF RIGIDITY G 11.4 10^6 PSI

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.305

SPECIFIC HEAT C BTU/LB - °F

(CALCULATED) 0.098

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F

5.7

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN. / IN. - °F

(70-200°F) 7.1

ELECTRICAL RESISTIVITY R MICROHM - IN.

49.5

MAGNETIC PROPERTIES

POISSON'S RATIO

0.308

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2350° - 2460°F

PHASE CHANGES

THIS MATERIAL IS NOT PRECIPITATION - HARDENING

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k (BTU - FT / HR - FT ² - °F)
-250	4.1
-200	4.3
-100	4.8
0	5.3
70	5.7
100	5.8
200	6.3
400	7.3
600	8.2
800	9.1
1000	10.8
1200	11.0
1400	12.0
1600	13.2
1800	14.6

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSION VS. TEMPERATURE

G. CHEMICAL PROPERTIES

RESISTANT TO OXIDATION AT HIGH TEMPERATURES

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

RT TO 2000°F.

DATA ON CRYOGENIC PROPERTIES NOT AVAILABLE.

K. PROCESSING
SURFACE TREATMENT *
DE-SCALING:

ELECTROLYTIC AND NON-ELECTROLYTIC MOLTEN SALT BATHS
FOLLOWED BY DILUTE ACID NEUTRALIZE

MIXED ACID PICKLE (HF & HNO₃)

CLEANING:

CAUSTIC SODA CLEANING FOLLOWED BY DILUTE ACID
NEUTRALIZING

EMULSION, DETERGENT, OR VAPOR DEGREASE FOLLOWED BY
DILUTE ACID NEUTRALIZING.

ULTRASONIC

* FOLLOW ALL ACID NEUTRALIZING WITH WATER RINSE.

THERMAL TREATMENT
ANNEALING:

1600° - 2100°F.
HOLD FOR 1 HOUR AT TEMPERATURE
AIR COOL

K. PROCESSING (CONTINUED)
JOINING
WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT THE
FOLLOWING WELD ROD:

INCONEL 625/AGC 90058, COMP, INCONEL 625

FORMING
MACHINABILITY
L. REFERENCES

NP-62-22
NP-65-9
NP-65-39

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

DATE 1 MAY 1966

SUPERSEDES

POISSON'S RATIO

POISSON'S RATIO

ELECTRICAL RESISTIVITY

ELECTRICAL RESISTIVITY
MICROHM-IN.

TEMPERATURES IN 100° F

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DATE 1 MAY 1966

SUPERSEDES

**NICKELS AND
NICKEL-BASE ALLOYS**

MATERIALS DATA

**II
NICKELS AND NICKEL BASE ALLOYS**

**B.
PRECIPITATION - HARDENING ALLOYS**

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

THIS HEAT-TREATABLE NICKEL-BASE ALLOY POSSESSES EXCELLENT CORROSION AND OXIDATION RESISTANCE UP TO 1800°F.

THE DESIGN PROPERTIES ARE FROM MIL-HDBK-5, AND ARE SPECIFICATION MINIMA FOR F_{TU} , F_{TY} , e , AND RA

B. COMMERCIAL DESIGNATIONS

INCONEL X, SUPERSEDED BY INCONEL X-750

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET AND PLATE	MIL-N-7786 AMS 5542
SHEET AND PLATE (VAC. MELT)	AMS 5598
BARS AND FORGINGS	MIL-N-8550 AMS 9667 AMS 5668
BARS (VAC. MELT)	AMS 5669
FORGINGS (VAC. MELT)	AMS 5671
TUBING, SEAMLESS	AMS 5582
WIRE, BARE, WELDING	MIL-R-5031 AMS 5778
ELECTRODE, COATED	AMS 5779
WIRE, NO. 1 TEMPER	AMS 5698
WIRE, SPRING TEMPER	AMS 5699

SUPPLIERS

HUNTINGTON ALLOY PROD. DIV.
INTERNATIONAL NICKEL CO., INC.
HUNTINGTON, W. VA.
UNIVERSAL-CYCLOPS STEEL CO.
BRIDGEVILLE, PENNA.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	S	Cr	Co*	Ti	Cu
MAXIMUM	0.05	1.00	.50	0.01	17.00	1.00	2.75	0.50
MINIMUM	-	-	-	-	14.00	-	2.25	-
SOURCE					Al	Fe	Cb&Ta	Ni
AMS 5542					1.00	9.00	1.20	-
*IF DETERMINED					0.40	5.00	0.70	70.00

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET & STRIP, ALL SIZES

MILL ANNEALED AND AGED

BARS AND FORGINGS

< 4.0 IN. DIA. > 4.0 IN. DIA.

TENSILE ULTIMATE STRENGTH F_{TU} PSI
155,000 165,000 160,000

TENSILE YIELD STRENGTH F_{TY} PSI
100,000 105,000 100,000

COMP. YIELD STRENGTH F_{CY} PSI
100,000 105,000 100,000

SHEAR STRENGTH F_{SU} PSI
101,000 107,000 104,000

BEARING STRENGTH, ULTIMATE F_{BRU} PSI
 $e/D=1.5$ 232,000 240,000 237,000
 $e/D=2.0$ 294,000 304,000 313,000

BEARING STRENGTH, YIELD F_{BRY} PSI
 $e/D=1.5$ 150,000 157,000 150,000
 $e/D=2.0$ 180,000 189,000 180,000

ELONGATION e %
20.0 20.0 15.0
(APPLICABLE TO 0.010-IN.
THICKNESS AND OVER)

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI
31.0

MODULUS OF RIGIDITY G 10^6 PSI
11.0

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI
31.0

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ
LB./IN.³ 0.298
g/cc

SPECIFIC HEAT C BTU/LB. - °F
(70-212°F) 0.105

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$
(AT 200°F) 7.45

MEAN COEFF. LINEAR THERMAL EXPANSION α $\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$
(80-200°F) 6.7

ELECTRICAL RESISTIVITY R MICROHM - IN.
47.9

MAGNETIC PROPERTIES

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2540°-2600°F

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMP. (°F)	k $\left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$
70	6.98
200	9.0
400	8.17
600	9.08
800	10.00
1000	10.92
1200	11.92
1400	12.83
1600	13.67

F. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

CAN BE USED IN OXIDIZING ATMOSPHERES TO 2000°F. HIGHLY RESISTANT TO CHLORIDE IN STRESS CORROSION CRACKING EVEN IN THE FULLY AGE-HARDENED CONDITION.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

IRRADIATION AND TEST AT -423°F
DOSAGE, 5×10^{16} NVT, E > 1.0 MEV

	AVERAGE CONTROL VALUE	AVERAGE TEST VALUE
1/4-IN. PLATE e	31%	*

IRRADIATION AND TEST AT -320°F
DOSAGE, 9×10^{17} NVT.

BAR e	25%	19%
-------	-----	-----

*NO SIGNIFICANT CHANGE FROM CONTROL VALUE.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

AC = AIR COOLED

R = IN FATIGUE, THE ALGEBRAIC RATIO OF
THE MINIMUM STRESS TO THE MAXIMUM
STRESS IN ONE CYCLE, THAT IS,

$$R = \frac{S_{MIN}}{S_{MAX}}$$

J. SERVICE LIMITS

NON-RADIATION SERVICE LIMITS

-423°F TO 1800°F FOR CORROSION AND OXIDATION
RESISTANCE

-423°F TO 1300°F FOR STRUCTURAL APPLICATIONS

K. PROCESSING

SURFACE TREATMENT

CLEANING*

ELECTROLYTIC AND NON-ELECTROLYTIC MOLTEN SALT
DE-SCALING AND DILUTE ACID NEUTRALIZING.

HF - HNO₃ ACID PICKLE.

CAUSTIC-SODA CLEANING AND DILUTE ACID NEUTRALIZING.

EMULSION, DETERGENT, OR VAPOR DEGREASE, AND DILUTE
ACID NEUTRALIZING

ULTRASONIC

*FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

STRESS-RELIEF

1625°F, 4 HOURS, FOR WELDMENTS.

HARDENING

SHEET

AGE AT 1300°F FOR 20 HOURS AND AIR COOL, OR

DOUBLE AGE BY HEATING AT 1350°F FOR 8 HOURS,
FURNACE COOLING TO 1150°F, HOLDING FOR 8 HOURS,
AND THEN AIR COOLING.

BARS AND FORGINGS - FOR SERVICE ABOVE 1100°F

SOLUTION-TREAT AT 2100°F FOR 2 TO 4 HOURS, AIR COOL;
AGE AT 1550°F FOR 24 HOURS, AIR COOL; THEN AGE AT
1300°F FOR 20 HOURS, AND AIR COOL.

BARS AND FORGINGS - FOR SERVICE BELOW 1100°F

STRESS EQUALIZE AT 1625°F FOR 24 HOURS, THEN
AGE AT 1300°F FOR 20 HOURS AND AIR COOL.

K. PROCESSING (CONTINUED)

JOINING

WELDING

MATERIAL SHOULD BE IN ANNEALED OR SOLUTION-TREATED
CONDITION BEFORE WELDING.

METHODS

TIG, RESISTANCE

FILLER METAL

PARENT METAL, INCONEL FILLER METAL 69

WELD EFFICIENCY AND JOINT STRENGTHS

AS WELDED: ANNEAL & DOUBLE AGE

AFTER WELDING:

64% - 123,000 PSI AVG

90% - 174,000 PSI AVG

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE
FOLLOWING WELD RODS:

AIISI 688 (INCONEL X-750)/MIL-R-5031, CL. 14

AIISI 688 (INCONEL X-750)/AMS 5779

FORMING

FORGING RANGE 1800° - 2200°F

DEEP DRAW AND SPIN IN ANNEALED CONDITION

MACHINABILITY

EASILY MACHINED IN SOLUTION ANNEALED CONDITION. BEST
PRACTICE IS TO ROUGH MACHINE IN THIS CONDITION, THEN
AGE HARDEN AND FINISH MACHINE WITH SMALL CUTS.

L. REFERENCES

NP-64-3

NP-63-9

NP-65-34

NP-66-3

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966

SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

**REDUCTION OF AREA
ELONGATION**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

TEMPERATURES IN 100° F

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

THIS NICKEL-BASE ALLOY IS USED AT TEMPERATURES TO 1300°F. IT IS READILY WELDED IN BOTH THE ANNEALED AND AGED CONDITIONS.

THIS ALLOY HAS GOOD OXIDATION RESISTANCE TO 1800°F.

THE DATA IN SECTION E ON THIS PAGE APPLIES TO THE SOLUTION HEAT-TREATED AND DOUBLE-AGED CONDITIONS.

THE VALUES OF F_{TU} , F_{TY} , AND e IN SECTION E ARE SPECIFICATION MINIMA FOR HEAT TREATMENT A. THE VALUES OF E , G AND E_C ARE AVERAGES OF AVAILABLE DATA

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET AND PLATE	AMS 5596 AMS 5597
BAR AND FORGINGS	AMS 5662 AMS 5664 AMS 5663

SUPPLIERS: HUNTINGTON ALLOY PRODUCTS DIV.
INTERNATIONAL NICKEL CO., INC.
HUNTINGTON, WEST VA.
SPECIAL METALS, INC., NEW HARTFORD, N.Y.
LATROBE STEEL CORP., LATROBE, PA.
ALLVAC METALS CO., MONROE, N. CAROLINA

D. CHEMICAL COMPOSITION (%) REFERENCE: AMS 5596

ELEMENT	C	Cr	Ni+	Mo	Cb+Ta	Ti	Al	B
MAXIMUM	0.10	21.00	55.00	3.30	5.50	1.15	0.80	0.006
MINIMUM	0.03	17.00	50.00	2.80	5.00	0.65	0.40	0.002
	Mn	Si	Cu	Co	P	S	Fe	
	0.35+0.39	0.10+1.00	0.015				BAL	

* MAX. + Ni+Co, IF Co NOT DETERMINED

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	SHEET AND PLATE ALL SIZES	BAR ALL SIZES
TENSILE ULTIMATE STRENGTH F_{TU}	180,000	185,000
L & T		180,000
LONGITUDINAL		
TRANSVERSE		
TENSILE YIELD STRENGTH F_{TY}	150,000	150,000
L & T		150,000
LONGITUDINAL		
TRANSVERSE		
COMP. YIELD STRENGTH F_{CY}		

ULTIMATE SHEAR STRENGTH F_{SU} PSI

SHEAR YIELD STRENGTH F_{SY} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

e/D 1.5
e/D 2.0

YIELD BEARING STRENGTH F_{BRY} PSI

e/D 1.5
e/D 2.0

ELONGATION e

L & T 15
LONGITUDINAL 12
TRANSVERSE 10

REDUCTION OF AREA RA

MODULUS OF ELASTICITY E 10^6 PSI

29.6

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

28.0

MODULUS OF RIGIDITY G 10^5 PSI

11.4

POISSON'S RATIO

0.294

HARDNESS

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ
LB./IN.³ 0.297
g./cc

SPECIFIC HEAT C BTU/LB - °F

(70°F) 0.101 BTU - FT
HR - FT² - °F

THERMAL CONDUCTIVITY k

(/5°F) 6.7 10^{-6} IN.
IN. - °F

MEAN COEFF. LINEAR THERMAL EXPANSION α

(75-200°F) 7.1

ELECTRICAL RESISTIVITY R MICROHM - IN.

48

MAGNETIC PROPERTIES

F. THERMOPHYSICAL EFFECTS

MELTING RANGE 2260°-2440°F

PHASE CHANGES

THIS ALLOY IS PRECIPITATION (AGE) HARDENABLE. THE HARDENING PHASE IS Ni_3 Cb (ETA PHASE), WHICH WILL COMPLETELY DISSOLVE IN THE MATRIX WHEN HEATED TO 1900° - 1950°F

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k (BTU - FT HR - FT ² - °F)
75	6.7
300	7.5
600	8.75
900	10.1
1200	11.3
1500	12.75

F. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

EXCELLENT CORROSION RESISTANCE, INCLUDING RESISTANCE TO BOTH OXIDIZING AND REDUCING ATMOSPHERES AT ELEVATED TEMPERATURES.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

IRRADIATION AND TEST AT 320°F
DOSAGE, 7×10^{17} NVT, $E > 1.0$ MEV

	AVERAGE CONTROL VALUES	AVERAGE TEST VALUE
0.032-IN. SHEET		
e	12.6%	*
0.125-IN. DIA. BAR		
e	12.5%	8.4%

* NO SIGNIFICANT CHANGE FROM CONTROL VALUES.

IRRADIATION AND TEST AT 1000°F
DOSAGE, 7×10^{19} NVT

	AVERAGE CONTROL VALUES	AVERAGE TEST VALUES
TIME TO STRESS RUPTURE		
AT 70,000 PSI	21 HR.	2.2 HR
AT 60,000 PSI	270 HR.	21 HR

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

NON-RADIATION SERVICE LIMITS

-423°F TO 1300°F, INCL.

RADIATION SERVICE LIMIT

MAXIMUM SERVICE TEMPERATURE NOT FIRMLY ESTABLISHED, BUT PROBABLY WILL BE IN THE 1000°F - 1200°F RANGE

K. PROCESSING

SURFACE TREATMENT

CLEANING*

ELECTROLYTIC AND NON-ELECTROLYTIC MOLTEN SALT DE-SCALING AND DILUTE ACID NEUTRALIZING.

HF - HNO₃ ACID PICKLE

CAUSTIC-SODA CLEANING AND DILUTE ACID NEUTRALIZING.

EMULSION, DETERGENT, OR VAPOR DEGREASE, AND DILUTE ACID NEUTRALIZING

ULTRASONIC

*FOLLOW ALL ACID TREATMENTS WITH WATER RINSE.

THERMAL TREATMENT

A. FOR OPTIMUM TENSILE (AND STRESS-
RUPTURE) PROPERTIES PER REF. NP-64-28

SOLUTION ANNEAL AT 1750° TO 1800°F FOR 1 HR, AIR COOL.
AGE AT 1325°F FOR 8 HR, COOL 100°F/HR TO 1150°F,
HOLD AT 1150°F FOR 8-10 HR, AIR COOL

B. FOR TENSILE STRENGTH, TOUGHNESS, AND OPTIMUM
DUCTILITY IN THICK-SECTION BARS AND FORGINGS, AND
LOW-TEMPERATURE PROPERTIES PER REF. NP-64-27.

SOLUTION ANNEAL AT 1950°F FOR 1 HR, AIR COOL.
AGE AT 1350° TO 1400°F FOR 8 HR, COOL 100°F/HR.
TO 1200°F, HOLD AT 1200°F FOR 8-10 HR, AIR COOL.

K. PROCESSING (CONTINUED)

JOINING

WELDING

METHODS: TIG (RECOMMENDED)

RESISTANCE

ELECTRON BEAM

FILLER METAL:

INCONEL 718 (RECOMMENDED)

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

INCONEL 718/AGC 90094, COMP. 1

AISI 683 (RENE' 41)/AGC 90094, COMP. 2

AISI 688 (INCONEL X-750)/MIL-R-5031, CL. 14

AISI 688 (INCONEL X-750)/AMS 5779

FORMING

FORGING TEMPERATURE RANGE 1700° - 2050°F

MACHINABILITY

MACHINABLE IN BOTH SOLUTION-HEAT-TREATED AND AGE-HARDENED CONDITIONS. BETTER TOOL LIFE IS OBTAINED WHEN MACHINED IN SOLUTION-TREATED CONDITION. SMOOTHER FINISHES ARE OBTAINED BY MACHINING IN AGE-HARDENED CONDITION.

L. REFERENCES

NP-66-3 NP-64-27
NP-65-2 NP-62-13
NP-65-3 NP-61-10
NP-64-28 NP-60-12

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966

SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

0.16
0.12
0.08
0.04
0

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

**NICKELS AND
NICKEL-BASE ALLOYS**

MATERIALS DATA

**II
NICKELS AND NICKEL BASE ALLOYS
C.
DISPERSION - HARDENING ALLOYS**

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

TD NICKEL IS A HIGH TEMPERATURE ALLOY CONSISTING OF THORIA DISPERSED IN A NICKEL MATRIX. IT HAS HIGHER STRENGTH THAN CONVENTIONAL NICKEL AND COBALT-BASE SUPER ALLOYS ABOVE 2000°F AND GOOD HIGH TEMPERATURE STABILITY DUE TO THE INHERENT THERMAL STABILITY OF THORIA. THE ALLOY HAS GOOD OXIDATION RESISTANCE AND EXHIBITS EXCELLENT LONG TIME CREEP-RUPTURE PROPERTIES.

THE BASIS FOR THE DESIGN DATA IN SECTION E-1 IS 80% OF THE AVERAGE VALUE FOR F_{TU} , F_{TY} , e , AND RA .

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, BAR, ROD, WIRE, TUBING AND FASTENERS	NONE

SUPPLIERS

DU PONT METAL PRODUCTS

D. CHEMICAL COMPOSITION (%)

ELEMENT	ThO ₂	Ni							
MAXIMUM	2.0*	Bal.							
MINIMUM									

SOURCE NP-64-8

*NOMINAL

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

STRESS RELIEVED 1 HR AT 2000°F

TENSILE ULTIMATE STRENGTH F_{TU} PSI

BAR 52,000 SHEET 66,000

(NOTCHED) 89,500

TENSILE YIELD STRENGTH F_{TY} PSI

36,000 44,000

COMP. YIELD STRENGTH F_{CY} PSI

ULTIMATE SHEAR STRENGTH F_{SU} PSI

SHEAR YIELD STRENGTH F_{SY} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

$e/D = 1.5$
 $e/D = 2.0$

YIELD BEARING STRENGTH F_{BRY} PSI

$e/D = 1.5$
 $e/D = 2.0$

ELONGATION e %

10 18

REDUCTION OF AREA RA %

71

MODULUS OF ELASTICITY E 10^6 PSI

DYNAMIC 18.4

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

POISSON'S RATIO

HARDNESS R_B

86-92

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.322

SPECIFIC HEAT C BTU/LB - °F

0.107

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

(AT 70°F) 50

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

(70° - 1000°F) 8.5

ELECTRICAL RESISTIVITY R MICROHM - IN.

2.98

F. THERMOPHYSICAL EFFECTS

MELTING POINT

2650°F

PHASE CHANGES

NONE, EXCEPT THAT AGGLOMERATION OF ThO₂ PARTICLES TENDS TO OCCUR DURING FUSION WELDING. TD NICKEL IS HARDENABLE BY COLD WORK ONLY.

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	$k \left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
70	50
500	32
1100	25
1500	27
1700	28

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSION VS. TEMPERATURE
TOTAL NORMAL EMISSION (HEATED IN AIR)

TEMP. (°F)	EMISSION
1600	0.55
2000	0.65
2400	0.72

G. CHEMICAL PROPERTIES

GOOD OXIDATION AND CORROSION RESISTANCE AT HIGH TEMPERATURES. SURFACE OXIDATION AT 2000°F ATTACKS UNIFORMLY AND APPARENTLY HAS NO EFFECT IN THE GRAIN BOUNDARIES.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

THE RADIATION LEVELS DUE TO ACTIVITY OF THE INCLUDED THORIUM, WHICH ARE EXPERIENCED DURING HANDLING AND FABRICATION, ARE WELL BELOW THE TOLERANCES ESTABLISHED FOR PERSONNEL SAFETY BY AEC.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

TEMPERATURE RANGE OF SERVICE -423°F TO 2400°F.

K. PROCESSING
SURFACE TREATMENT

SAND BLASTING AND/OR BELT ABRADING MAY BE USED FOR REMOVAL OF SCALE (120-180 GRIT ALUMINA WET BELTS)

CHEMICAL SURFACE CONDITIONING

 50% BY VOLUME H₂O
 25% BY VOLUME OR 48% (BY WEIGHT) HF
 12.5% BY VOLUME OF 42° Be HNO₃
 12.5% BY VOLUME OF 66° Be H₂SO₄
 SOLUTION TO BE USED AT ROOM TEMPERATURE,
 RINSE WITH HOT WATER.

THERMAL TREATMENT

 BAR STRESS RELIEF: 1800°F 2 HRS. HOLDING TIME
 MAXIMUM IN AIR-NATURAL GAS MIXTURE (RATIO 6:1 TO 10:1).
 HEAT TREATING IN ARGON, OR VACUUM IS ALSO SUITABLE
 BUT PURE HYDROGEN ATMOSPHERE SHOULD BE AVOIDED.
 SHEET STRESS RELIEF: 1800° - 2000°F, 15 MINUTES HOLD-
 ING TIME IN ENDOTHERMIC GAS, CRACKED AMMONIA, ARGON
 OR VACUUM.

 AIR TREATMENTS MAY BE USED IF MAXIMUM SURFACE
 BRIGHTNESS IS NOT REQUIRED.

K. PROCESSING (CONTINUED)
JOINING
WELDING

 METHODS: RESISTANCE.-IN GENERAL, FUSION WELDING IS NOT
 RECOMMENDED. FUSION AND ELECTRON BEAM WELDING CAUSE
 AGGLOMERATION OF THE THORIA. HOWEVER, SOUND TIG WELDS
 HAVE BEEN MADE IN 0.050 IN. SHEET AT 12 IPM, 98 AMPS,
 AND 9.5 VOLTS, WITH ARGON PROTECTION. FILLER METALS
 PREFERRED ARE PURE NICKEL, HASTELLOY W, AND RENE' 41.

BRAZING

 BRAZING ALLOYS: GE-8100 OR HASTELLOY "X"
 ATMOSPHERE: HYDROGEN OR VACUUM.

DIFFUSION BONDING

 TD NICKEL DIFFUSION BONDS ITSELF WITH NO DETERIORATION
 OF PARENT METAL MICRO-STRUCTURE (24 HRS, 2000°F,
 VACUUM, SLIGHT PRESSURE).

FORMING

 MOST FORMING CAN BE CARRIED OUT AT ROOM TEMPERATURE
 WITH A MINIMUM BEND RADIUS OF 2T. ROLLING, FORGING,
 DRAWING AND SHEARING ARE PERFORMED USING STANDARD
 SHOP PRACTICES.

MACHINABILITY

 MACHINING MAY BE ACCOMPLISHED BY USING MODERATE
 CUTTING SPEEDS AND HEAVY FEEDS.

L. REFERENCES

 NP-63-25
 NP-63-26
 NP-63-27
 NP-64-8
 NP-64-9
 NP-65-7
 NP-65-8

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

DATE

1 MAY 1966

SUPERSEDES

**REFRACTORY
METALS AND ALLOYS**

MATERIALS DATA

III

REFRACTORY METALS AND ALLOYS

A.

MOLYBDENUM AND MOLYBDENUM ALLOYS

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

MOLYBDENUM HAS THE ADVANTAGES OF HIGH MELTING TEMPERATURE, LOW DENSITY, HIGH MODULUS OF ELASTICITY, EXCELLENT STRENGTH-TO-DENSITY RATIO AT ELEVATED TEMPERATURES WITH SMALL ALLOY ADDITIONS, AND HIGH THERMAL AND ELECTRICAL CONDUCTIVITY. IT HAS LOW THERMAL EXPANSION AND RELATIVELY LOW THERMAL-NEUTRON CAPTURE CROSS-SECTION. IT IS LIMITED BY ITS POOR OXIDATION RESISTANCE AT ELEVATED TEMPERATURES, POOR LOW TEMPERATURE DUCTILITY, AND WELD BRITTLENESS.

THE ROOM TEMPERATURE PROPERTIES IN SECTION E ARE AVERAGES, EXCEPT FOR ULTIMATE TENSILE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA, WHICH ARE 80% OF AVERAGE.

MAY BE MADE BY POWDER METALLURGY TECHNIQUES AND CONSUMABLE ELECTRODE ARC CASTING PROCESSES.

B. COMMERCIAL DESIGNATIONS

MOLYBDENUM, COMMERCIAL PURE

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
FORGINGS, STRESS-RELIEVED	ASTM B-384
BILLETS	ASTM B-385
SHEET, STRIP, PLATE	ASTM B-386
AND FOIL	
BAR, ROD AND WIRE	ASTM B-387
TUBE	WAL - PDS - 30032

SUPPLIERS CLIMAX MOLYBDENUM CORP.
UNIVERSAL-CYCLOPS STEEL CORP.
FANSTEEL METALLURGICAL CORP.
SYLVANIA (TOWANDA, PENNA.)
NATIONAL RESEARCH CORP.
WESTINGHOUSE ELECTRIC CORP.
GENERAL ELECTRIC CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	O	N	Fe	Ni	Si	Mo
MAXIMUM	.040	.003	.001	.020	.010	.010	
MINIMUM	.010						99.9

SOURCE ASTM B-384 B-385, B-386 & B-387, TYPE 1

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

	AS ROLLED	STRESS RELIEVED	RE-CRYSTALLIZED
TENSILE ULTIMATE STRENGTH F_{TU}			PSI
BAR	81,000	72,000	54,000
TENSILE YIELD STRENGTH F_{TY}			PSI
BAR	63,000	66,000	44,000
COMP. YIELD STRENGTH F_{CY}			PSI
	-	83,000	-
ULTIMATE SHEAR STRENGTH F_{SU}			PSI
	-	83,000	-
SHEAR YIELD STRENGTH F_{SY}			PSI
ULTIMATE BEARING STRENGTH F_{BRU}			PSI
e/D = 1.5			
e/D = 2.0			
YIELD BEARING STRENGTH F_{BRY}			PSI
e/D = 1.5			
e/D = 2.0			
ELONGATION e			%
	32	33	33
REDUCTION OF AREA RA			%
	49	55	30
MODULUS OF ELASTICITY E			10^6 PSI
DYNAMIC		46.4	
STATIC		47.2	
COMP. MODULUS OF ELASTICITY E_C			10^6 PSI
MODULUS OF RIGIDITY G			10^6 PSI
		17	
POISSON'S RATIO			
HARDNESS			
PLASTIC BENDING MODULUS			(SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.369
SPECIFIC HEAT C	BTU/LB - °F
	0.059
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
	78.8
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
(70 - 212°F)	2.70
ELECTRICAL RESISTIVITY R	MICROHM - IN.
	2.2
MAGNETIC PROPERTIES	
	PARAMAGNETIC

F. THERMOPHYSICAL EFFECTS

MELTING TEMPERATURE	4730°F
PHASE CHANGES	NONE
THERMAL CONDUCTIVITY VS. TEMPERATURE	
TEMPERATURE (°F)	k (BTU - FT HR - FT ² - °F)
-423	161
-320	130
-100	80
0	79
75	78
200	75
500	74
1000	68
1500	64
2000	57
2500	51
3000	46
3500	42
4000	40*
4500	39*

* (ESTIMATED TREND 3540°F - 4540°F)

F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMISSIVITY VS. TEMPERATURE

TEMP (°F)	EMISSIVITY (%) AS RECEIVED	EMISSIVITY (%) CLEANED
-310	4.0	4.0
40	2.5	1.5
290	2.5	1.0
540	3.5	3.0
790	5.0	4.5
1040	8.0	6.5
1290	11.5	9.0

G. CHEMICAL PROPERTIES
COMPATIBILITY:

REACTS WITH OXYGEN; ALLOYS WITH TUNGSTEN, VANADIUM, TITANIUM, TANTALUM, COLUMBIUM, AND CHROMIUM IN SOLID SOLUTION; AND IRON, NICKEL, COBALT, ALUMINUM, AND SILICON, FORMING A SECOND PHASE OF RELATIVELY LOW ALLOY CONTENT.

CORROSION RESISTANCE:

HIGH RESISTANCE TO MINERAL ACIDS AND LIQUID METALS, AND TO WATER. CORRODED BY FUSED ALKALIS AND MOLten OXIDIZING SALTS

OXIDATION RESISTANCE:

MoO₃ BEGINS TO SUBLIME ABOVE 932°F. AND AT 1110°F VOLATILIZATION IS SIGNIFICANT. EXISTENCE OF MOLten MoO₃ ABOVE 1472°F LEADS TO CATASTROPHIC OXIDATION IN ORDINARY ATMOSPHERES.

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

IRRADIATION IN GENERAL INCREASES TENSILE YIELD STRENGTH, AND DUCTILE-BRITTLE TRANSITION TEMPERATURE.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

SERVICE TEMPERATURE MAXIMUM IS 1000°F IN OXYGEN BEARING ENVIRONMENT.
MUST BE COATED FOR USE IN OXIDIZING ATMOSPHERE ABOVE 1000°F

K. PROCESSING
SURFACE TREATMENT

TREATED BY SEVERAL METHODS FOR OXIDATION RESISTANCE AND RESISTANCE TO GALL AND WEAR. CLEAN AND DEGREASE BY CONVENTIONAL METHODS.

THERMAL TREATMENT

STRESS RELIEF TEMPERATURE = 1600 - 1800°F
ANNEALING TEMPERATURE = 1800 - 2200°F

K. PROCESSING (CONTINUED)
JOINING

CAN BE WELDED TO ITSELF AND ANY MATERIAL WITH WHICH IT READILY ALLOYS BY ARC, ELECTRIC RESISTANCE, PERCUSSION, FLASH, OR ELECTRON BEAM TECHNIQUES. CAN ALSO BE BRAZED AND MECHANICALLY JOINED. ARC FUSION WELDS OF POWDER, METALLURGICAL GRADES, GENERALLY ARE BRITTLE AND WILL EXHIBIT WELD CRACKING IN HEAVY SECTION JOINTS.

FORMING

INITIAL BREAKDOWN OF THE INGOT IS USUALLY BY EXTRUDING, WITH FORGING AT 2150° TO 2350°F, AND FINISHING AT 1500° TO 1700°F.

CAN ALSO BE FORMED BY SPINNING, SHEARING, STAMPING, PUNCHING, HYDRO FORMING, BENDING, AND DRAWING.

A GUIDE TO FABRICATION
TEMPERATURE FOR UNALLOYED MOLYBDENUM

MACHINABILITY

BEST WITH UNIFORM FIBROUS GRAIN PRODUCED WITH NORMAL AMOUNTS OF WORKING.

L. REFERENCES

NP-59-13	NP-61-22
NP-60-21	NP-61-23
NP-60-22	NP-62-39
NP-60-23	NP-63-40
NP-61-18	NP-65-31

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE _____

1 MAY 1966

SUPERSEDES

STRESS VS STRAIN

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

0.16

0.12

0.08

0.04

0

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

POISSON'S RATIO

POISSON'S RATIO

ELECTRICAL RESISTIVITY

ELECTRICAL RESISTIVITY
MICROHM-IN.

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

TZM MOLYBDENUM ALLOY IS SUPERIOR IN STRESS-RUPTURE STRENGTH AND RECRYSTALLIZATION TEMPERATURE TO EITHER PURE MOLYBDENUM OR THE 0.5 TI - MOLYBDENUM ALLOY.

VALUES OF F_{TU} AND F_{TY} ARE 95% CONFIDENCE VALUES

B. COMMERCIAL DESIGNATIONS

MOLYBDENUM - 0.5 TITANIUM - 0.08 ZIRCONIUM ALLOY

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET	
PLATE	
FORGING BILLETS	
BARS ROLLED OR SWAGED	

SUPPLIERS

CLIMAX MOLYBDENUM CO.
SYLVANIA
UNIVERSAL CYCLOPS

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Ti	Zr	H	Fe	Ni	N	O
MAXIMUM	0.04	0.55	0.12	0.0005	0.010	0.002	0.002	0.025
MINIMUM	0.01	0.04	0.06	-	-	-	-	-

SOURCE NP-64-B

MAX .003 BAL.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SHEET, ANNEALED

TENSILE ULTIMATE STRENGTH F_{TU} 120,000 PSI

TENSILE YIELD STRENGTH F_{TY} 101,000 PSI

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e 16.0 %

REDUCTION OF AREA RA 55.0 %

MODULUS OF ELASTICITY E 10⁶ PSI
(STATIC) 45.0

MODULUS OF RIGIDITY G 10⁶ PSI

COMP. MODULUS OF ELASTICITY E_C 10⁶ PSI

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ
LB./IN.³ 0.309
g/cc

SPECIFIC HEAT C BTU/LB. - °F

(70°F) 0.065 BTU - FT
HR - FT² - °F

THERMAL CONDUCTIVITY k

(212°F) 04.5
MEAN COEFF. LINEAR THERMAL EXPANSION α 10⁻⁶ IN./IN. - °F

(70-212°F) 2.7 X 10⁻⁶

ELECTRICAL RESISTIVITY R MICROHM - IN.

(70°F) 2.05

MAGNETIC PROPERTIES

F. THERMOPHYSICAL EFFECTS

MELTING POINT
4730°F APPROX

PHASE CHANGES
NONE

THERMAL CONDUCTIVITY VS. TEMPERATURE

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSIONITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

THIS ALLOY NEEDS PROTECTION AGAINST OXIDATION AT TEMPERATURES ABOVE 1000°F, UNLESS THE EXPOSURE TIMES ARE VERY SHORT, OR THE ATMOSPHERE IS NEUTRAL, REDUCING, OR VACUUM.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

RT TO 1000°F IN OXIDIZING ATMOSPHERE WITHOUT SURFACE PROTECTION

K. PROCESSING

SURFACE TREATMENT

THERMAL TREATMENT

RECRYSTALLIZATION TEMPERATURE DEPENDS ON THE EXTENT OF PRIOR REDUCTION.

ANNEALING AND STRESS RELIEF MUST BE PERFORMED IN A NEUTRAL OR REDUCING ATMOSPHERE.

STRESS RELIEF: 2100° - 2400°F., 15 MIN. - 1 HR.

ANNEALING: 2500°F - 2550°F, HOLD 1 HR

THIS ALLOY IS NOT HARDENABLE BY HEAT TREATMENT. IT CAN BE HARDENED BY MECHANICAL DEFORMATION AT TEMPERATURES BELOW THE RECRYSTALLIZATION TEMPERATURE.

K. PROCESSING (CONTINUED)

JOINING

THIS ALLOY CAN BE FUSION AND RESISTANCE WELDED. A PREHEATING TO 400° TO 600°F IS RECOMMENDED. THOROUGH CHEMICAL CLEANING OR ELECTROPLATING OF SURFACE TO BE JOINED IS ESSENTIAL, FUSION WELDING SHOULD BE DONE IN AN ATMOSPHERE FREE OF NITROGEN AND OXYGEN.

FORMING

SHEET AND WIRE UP TO 0.020 INCH IN THE STRESS-RELIEVED CONDITION CAN BE COLD FORMED BY CONVENTIONAL METHODS. MATERIALS THICKER THAN 0.020 IN. SHOULD BE HEATED AT 200° TO 1000°F, DEPENDING ON SECTION THICKNESS. PREHEATING OF TOOL IS RECOMMENDED.

FORGING, STARTING TEMPERATURE IS 2350°F MAXIMUM, AND FINISHING TEMPERATURE IS 1900°F MINIMUM.

A GUIDE TO FABRICATION
TEMPERATURE FOR TZM ALLOY

MACHINABILITY

THE USE OF HIGH-SPEED STEEL AND CARBIDE TOOLS IS RECOMMENDED FOR THIS ALLOY.

SHEARING AND PUNCHING CAN BE PERFORMED AT 200° TO 1000°F.

L. REFERENCES

NP-59-13
NP-62-45
NP-64-8
NP-65-31
NP-66-2

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

IMPACT STRENGTH
ROCKWELL HARDNESS

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

TEMPERATURES IN 100° F

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DATE 1 MAY 1966

SUPERSEDES

**REFRACTORY
METALS AND ALLOYS**

MATERIALS DATA

III

REFRACTORY METALS AND ALLOYS

B.

TANTALUM AND TANTALUM ALLOYS

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DATE

1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

TANTALUM HAS MODERATE ROOM TEMPERATURE STRENGTH, WHICH DECREASES COMPARATIVELY SLOWLY WITH INCREASING TEMPERATURE. IT HAS A VERY LOW DUCTILE-BRITTLE TRANSITION TEMPERATURE. HIGH PURITY TANTALUM IS DUCTILE AT LIQUID HYDROGEN TEMPERATURE. THIS MATERIAL IS USED FOR HEAT SHIELDS, LIQUID METAL APPLICATIONS, THERMOCOUPLE SHEATHS, ION VACUUM PUMPS AND STRUCTURAL PARTS. IT HAS EXCELLENT FABRICABILITY AND GOOD CORROSION RESISTANCE. OXIDATION RESISTANCE AT ELEVATED TEMPERATURES IS POOR. THIS MATERIAL IS READILY ATTACKED BY HYDROGEN AT ELEVATED TEMPERATURES.

TENSILE PROPERTIES VARY WIDELY DEPENDENT UPON COLD WORK, IMPURITY LEVEL, RE-CRYSTALLIZATION TREATMENT, AND GRAIN SIZE. STRAIN RATE AFFECTS F_{TU} AND F_{TY} , BUT HAS LITTLE EFFECT ON DUCTILITY.

ROOM TEMPERATURE PROPERTIES IN SECTION E ARE AVERAGES, EXCEPT FOR F_{TU} , F_{TY} , e , AND RA , WHICH ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

COMMERCIAL TANTALUM, METALLURGICAL GRADE

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
INGOTS & FLAT MILL PRODUCT, ANNEALED	ASTM B-364
INGOTS & FLAT MILL PRODUCTS, COLD-WORKED	ASTM B-364
ROD AND WIRE-ANNEALED OR AS DRAWN	ASTM B-365
PLATE, SHEET, STRIP & FOIL	AMS 7849

SUPPLIERS KAWECKI CHEMICAL CO., N.Y., N.Y.
FANSTEEL METALLURGICAL CORP., CHICAGO
HAYNES STELLITE CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Co	Fe	Ni	Si	Ti	W	H
MAXIMUM	0.03	0.10	0.02	0.02	0.03	0.01	0.03	0.01
MINIMUM	-	-	-	-	-	-	-	-
SOURCE	ASTM B-364							
	ASTM B-365							

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET	BAR
ANNEALED COLD WORKED COLD WORKED	ANNEALED WROUGHT & SR
TENSILE ULTIMATE STRENGTH F_{TU}	PSI
42,400 110,000 73,600	34,400 38,400

TENSILE YIELD STRENGTH F_{TY}	PSI
36,800 100,000 70,400	24,000 35,200

COMP. YIELD STRENGTH F_{CY}	PSI
-------------------------------	-----

SHEAR STRENGTH F_{SU}	PSI
-------------------------	-----

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
-------------------------------------	-----

ELONGATION e	%
16.0 23.0 12.0 32.0	18.0

REDUCTION OF AREA RA	%
48.0 58.0	61.0

MODULUS OF ELASTICITY E	10^6 PSI
27.2	

MODULUS OF RIGIDITY G	10^6 PSI
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HARDNESS - ROCKWELL	
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B-60-70 C30	
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COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
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PLASTIC BENDING MODULUS	(SEE APPENDIX A)
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2. PHYSICAL PROPERTIES

DENSITY ρ	
LB/IN ³	0.6
g/cc	16.6

SPECIFIC HEAT C	BTU/LB - °F
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(70°F)	0.033
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THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
--------------------------	---------------------------------------

(212°F)	31.5
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MEAN COEFF. LINEAR THERMAL EXPANSION α	10^{-6} IN./IN. - °F
---	------------------------

(70°-212°F)	3.7
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ELECTRICAL RESISTIVITY R	MICROHM - IN.
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(70°F)	4.88
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MAGNETIC PROPERTIES	10^{-6} CGS UNITS
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SUSCEPTIBILITY	0.489
----------------	-------

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	5425°F
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PHASE CHANGES	
---------------	--

THERMAL CONDUCTIVITY VS. TEMPERATURE	
--------------------------------------	--

TEMPERATURE (°F)	k (BTU - FT / HR - FT ² - °F)	LB/IN ³	LB/IN ³
	0.596	0.527	
75	33.6	19.7	
800	37.4	24.1	
1600	41.4	28.7	
2400	44.1	31.9	
3200	46.3	34.6	
4000	48.5	37	
4800	49.6	39	

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMITTANCE VS. TEMPERATURE	EMITTANCE, TOTAL
TEMPERATURE °F	HEMISPHERICAL*

400	0.10
750	0.13
1100	0.15
1472	0.20

* POLISHED, COMM. PURE Ta (NP-60-25)

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE:
RESISTANT EXCEPT TO FUMING SULFURIC ACID, FLUORINE, HYDROFLUORIC ACID, ALKALIS, CONCENTRATED POTASSIUM HYDROXIDE, SODIUM HYDROXIDE, SULFUR TRIOXIDE, AND AIR ABOVE 480°F

OXIDATION RESISTANCE:
A STABLE OXIDE FILM IS FORMED BELOW 572°F. A PROTECTIVE COATING IS NECESSARY FOR ELEVATED TEMPERATURE SERVICE IN AIR ABOVE 1800°F.

HYDROGEN RESISTANCE
TANTALUM REACTS READILY WITH HYDROGEN AT ELEVATED TEMPERATURES

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

WITHSTANDS CORROSION BY SOME LIQUID METALS UP TO HIGH TEMPERATURES, AND HAS BEEN USED IN CONTACT WITH LIQUID SODIUM AT 3000°F. TANTALUM THERMOCOUPLE SHEATHS HAVE STOOD UP WELL IN NUCLEAR REACTOR SERVICE.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

HAS BEEN USED TO 4500°F. HOWEVER ULTIMATE TENSILE STRENGTH DROPS TO APPROXIMATELY 25% OF RT AT 2000°F AND TO APPROXIMATELY 5% OF RT AT 4000°F

OXIDATION LIMITS UNCOATED USE TO 900°F. WHEN COATED, LIMIT MAY BE EXTENDED TO 3000°F FOR RELATIVELY LONG LIMITS, OR 3500°F FOR 1 MIN. DURATION. COATINGS REDUCE MECHANICAL PROPERTIES.

K. PROCESSING
SURFACE TREATMENT

CONVENTIONAL CLEANING METHODS AND MATERIALS, EXCEPT HOT CAUSTICS MAY BE USED. CAN ALSO BE PICKLED AND POLISHED, BUT NOT TO A MIRROR-LIKE FINISH.

THERMAL TREATMENT

ANNEAL BETWEEN 2372° TO 2552°F FOR 1-HR. IN A VACUUM, ARGON OR HELIUM. RECRYSTALLIZATION TEMPERATURE IS 1832° TO 2552°F DEPENDING UPON DEGREE OF COLD WORK. ANNEAL AT 2250°F AND FURNACE COOL TO OBTAIN MATERIAL FOR DEEP DRAWING AND SUBSEQUENT WORKING.

STRESS RELIEVE AT 1800°F, 1 HR

K. PROCESSING (CONTINUED)
JOINING

MAY BE WELDED TO ITSELF AND CERTAIN OTHER METALS BY INERT GAS ARC AND RESISTANCE WELDING. CARBON ARC, AND ELECTRON BEAM WELDING, CANNOT BE GAS-TORCH WELDED.

FORMING

COLD FORMING IS PREFERRED BECAUSE OF POOR OXIDATION RESISTANCE. READILY DRAWN, FORMED, STAMPED, CUT, AND BLANKED BY CONVENTIONAL METHODS. ANNEALED TANTALUM HAS A TENDENCY TO SEIZE, TEAR, OR GALL.

MACHINABILITY

SIMILAR TO THAT OF STAINLESS STEELS IN RESPECT TO GALL OR SEIZE. HIGH SPEED TOOLS WITH MAXIMUM RAKE, CLEARANCE, AND GOOD CUTTING EDGE STRENGTH IN CONNECTION WITH HIGH SPEEDS (100 SFPM MINIMUM) ARE RECOMMENDED FOR BEST RESULTS. CARBON TETRACHLORIDE, TRI-CHLORO, OR TETRACHLOROETHANE ARE SATISFACTORY AS CUTTING FLUIDS.

L. REFERENCES

NP-60-20
NP-61-4
NP-62-37
NP-63-39
NP-64-8
NP-65-31

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

IMPACT STRENGTH
ROCKWELL HARDNESS

IMPACT STRENGTH
FT-LB

100
80
60
40
20
0

ROCKWELL HARDNESS

REDUCTION OF AREA
ELONGATION

REDUCTION OF AREA
%

80
60
40
20
0

%
ELONGATION

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

POISSON'S RATIO

ELECTRICAL RESISTIVITY

ELECTRICAL RESISTIVITY
MICROHM-IN.

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DATE 1 MAY 1966

SUPERSEDES

**REFRACTORY
METALS AND ALLOYS**

MATERIALS DATA

**III
REFRACTORY METALS AND ALLOYS
C.
TUNGSTEN AND TUNGSTEN ALLOYS**

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DATE 1 MAY 1966

SUPERSEDES

**OTHER NON-FERROUS
METALS AND ALLOYS**

MATERIALS DATA

IV

OTHER NON-FERROUS METALS AND ALLOYS

A.

COBALT AND COBALT ALLOYS

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

AISI 670 IS ESSENTIALLY NON-HEAT TREATABLE, HOWEVER THE ALLOY MAY BE HARDENED BY COLD WORK. SOLUTION TREATING AND RAPID COOLING BEFORE COLD WORKING LEADS TO AN ADDITIONAL MODERATE INCREASE IN STRENGTH ON AGING. THE PROPERTIES IN THESE CONDITIONS VARY WITH THE CARBON CONTENT. THE TREATMENT IS GIVEN IN SECTION K. BOTH STRENGTH AND WEAR PROPERTIES ARE INCREASED FOR SERVICE AT HIGH TEMPERATURES AS A RESULT OF THIS TREATMENT.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGES, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE PROPERTIES ARE 80% OF AVERAGE FOR THE BAR AND PLATE. IN THE SHEET, THEY ARE GUARANTEED MINIMA.

B. COMMERCIAL DESIGNATIONS

WROUGHT: HAYNES ALLOY NO. 25, HS-25, L-605 WF-11
CAST: HAYNES ALLOY 36

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET (ST)	AMS 5537
BAR, FORGINGS (ST)	AMS 5759
ELECTRODE, COATED	MIL-E-22200
	AMS 5797
WIRE, WELDING (BRIGHT ANNEALED)	AMS 5796

SUPPLIERS

HAYNES STELLITE DIV.
UNION CARBIDE CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Ni	Cr	W	Fe	C	Si	Mn	P
MAXIMUM	11.0	21.0	16.0	3.0	0.15	1.0	2.0	0.040
MINIMUM	9.0	19.0	14.0	-	0.05	-	1.0	-

SOURCE: NP-64-3

030 BAL.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

BAR, ANN.	SHEET, ANN.	PLATE ANNEALED
1-IN. BAR	0.044 TO 0.130	
TENSILE ULTIMATE STRENGTH F_{TU}	120,000	130,000
		112,000

TENSILE YIELD STRENGTH F_{TY}	56,000	55,000
		56,000

COMP. YIELD STRENGTH F_{CY}		PSI
BEARING RACES, COMPRESSED 30-35% AND AGED AT 1100°F FOR 4 HRS.		
5-IN. DIA. BLANK	276,000	
6-IN. DIA. BLANK	237,000	

SHEAR STRENGTH F_{SU}		PSI
-------------------------	--	-----

ULTIMATE BEARING STRENGTH F_{BRU}		PSI
-------------------------------------	--	-----

ELONGATION e	52.0	45.0
		46.0

REDUCTION OF AREA RA		%
------------------------	--	---

MODULUS OF ELASTICITY E		10^6 PSI
	33.0	

MODULUS OF RIGIDITY G		10^6 PSI
-------------------------	--	------------

COMP. MODULUS OF ELASTICITY E_C		10^6 PSI
-----------------------------------	--	------------

PLASTIC BENDING MODULUS	(SEE APPENDIX A)	
-------------------------	------------------	--

2. PHYSICAL PROPERTIES

DENSITY ρ		LB/IN ³
	0.33	

SPECIFIC HEAT C		BTU/LB-°F
	0.092	

THERMAL CONDUCTIVITY k		BTU-FT HR-FT ² -°F
	5.4	

MEAN COEFF. LIN. THERMAL EXPANS. α		10^{-6} IN. IN.-°F
(70°-212°F)	6.83	

ELECTRICAL RESISTIVITY R		MICROHM-IN.
	34.9	

MAGNETIC PROPERTIES

NON-MAGNETIC

POISSON'S RATIO

0.288

F. THERMOPHYSICAL EFFECTS
MELTING RANGE

2425°-2570°F

PHASE CHANGES

THIS ALLOY IS SUBJECT TO SOME PRECIPITATION AT ELEVATED TEMPERATURES

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k $\left(\frac{\text{BTU-FT}}{\text{HR-FT}^2\text{-°F}} \right)$
70	5.4
100	5.6
200	6.8
500	8.1
700	9.3
900	10.5
1100	11.9
1300	13.1
1500	14.3
1700	15.9

F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMISSION VS. TEMPERATURE
G. CHEMICAL PROPERTIES
CORROSION RESISTANCE:

ALLOY IS RESISTANT TO WET CHLORINE AT ROOM TEMPERATURE AND TO HYDROCHLORIC AND NITRIC ACIDS AT CERTAIN CONCENTRATIONS AND TEMPERATURES.

OXIDATION RESISTANCE:

ALLOY IS RESISTANT TO OXIDIZING AND CARBURIZING ATMOSPHERES UP TO 2000°F IN CONTINUOUS SERVICE AND UP TO 1600°F IN INTERMITTENT SERVICE.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

THIS ALLOY DOES NOT FIND APPLICATION IN REACTORS.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

RC = HARDNESS, ROCKWELL C SCALE
 RAC = RAPID AIR COOLED
 WQ = WATER QUENCHED
 AC = AIR COOLED
 CR = COLD ROLLED
 ANN = ANNEALED
 HT = HEAT TREATED

J. SERVICE LIMITS

RT TO 2000°F.

K. PROCESSING
SURFACE TREATMENT

SCALE CAN BE REMOVED BY NORMAL PICKLING, SODIUM HYDRIDE DESCALING, OR BLASTING WITH MILD ABRASIVES.

THERMAL TREATMENT

HEATING OF THIS ALLOY SHOULD BE DONE IN A NEUTRAL OR SLIGHTLY OXIDIZING ATMOSPHERE. OVERHEATING SHOULD BE AVOIDED, AND THE TEMPERATURE AND TIME OF ANY HEATING SHOULD BE KEPT AT A MINIMUM TO AVOID GRAIN COARSENING. LARGE GRAINS CANNOT BE ELIMINATED BY HEAT TREATING.

SOLUTION TREAT OR ANNEAL SHEET

2225° TO 2275°F, 10 MIN., RAPID AIR COOL OR WATER QUENCH.

PLATE, BAR AND FORGINGS, 1/4 IN. AND HEAVIER
 2225° TO 2290°F, WATER QUENCH.

AGE SOLUTION TREATED AND SUBSEQUENTLY COLD WORKED MATERIAL

900° TO 1200°F, 4 TO 16 HR, PREFERABLY 1100°F, 4 HR. COMMERCIAL REDUCTIONS ARE BETWEEN 15 AND 45%. A MODERATE AMOUNT OF COLD WORK FOLLOWED BY AGING INCREASES CREEP RUPTURE STRENGTH AT TEMPERATURES UP TO 1800°F. HIGHER REDUCTIONS ARE NOT RECOMMENDED BECAUSE OF RESULTING LOW DUCTILITY.

WIRE FOR SPRINGS FOR SERVICE UP TO 1400°F
 START WITH SOLUTION-TREATED CONDITION AND COLD DRAW 15 TO 1/4 HARD CONDITION.
 THIS MATERIAL IS SUPERIOR TO INCONEL X-75 AT 1200° TO 1400°F, AT WHICH POINT INCONEL X-75 BECOMES EMBRITTLED.
 DISCS FOR BEARING RACES: COMPRESS 30 TO 35 1100°F, 4 HR, TO A HARDNESS OF 51 TO 52 RC.

K. PROCESSING (CONTINUED)
JOINING

FUSION WELDING CAN BE PERFORMED MANUALLY OR AUTOMATICALLY BY THE INERT GAS ARC WELDING METHOD WITH A MINIMUM OF HEAT INPUT USING EITHER TUNGSTEN OR CONSUMABLE L 605 ELECTRODES. FOR MANUAL ARC WELDING, COATED L-605 ELECTRODES ARE AVAILABLE. THE SIGMA METHOD IS ALSO SUITABLE. THE ALLOY CAN BE SPOT, SEAM, PROJECTION, AND FLASH WELDED BY RESISTANCE METHODS. HIGH PRESSURES ARE REQUIRED BECAUSE OF THE HIGH HARDNESS OF THE ALLOY AT ELEVATED TEMPERATURES.
 BRAZING BY THE FURNACE METHOD CAN BE PERFORMED IN DRY HYDROGEN AT 2150°F FOR SERVICE UP TO 1800°F. TORCH BRAZING IS NOT RECOMMENDED.

FORMING

ALTHOUGH THIS ALLOY HAS EXCELLENT DUCTILITY IN THE ANNEALED CONDITION, FREQUENT INTERMEDIATE ANNEALS ARE NEEDED DURING SEVERE FORMING BECAUSE OF THE HIGH RATE OF STRAIN HARDENING. HEATING TO A TEMPERATURE OF 450°F CAN BE USED WITH ADVANTAGE FOR FORMING SHEET AND OTHER PRODUCTS.
 FORGING STARTING TEMPERATURE 2250°F. MAXIMUM, FINISHING TEMPERATURE 1800°F, MINIMUM.

MACHINABILITY

MACHINABILITY OF THIS ALLOY IS BEST IN THE ANNEALED CONDITION, ALTHOUGH COLD WORKED MATERIAL, WITH HARDNESSES UP TO 50 RC IS ALSO MACHINABLE. THE SAME TECHNIQUES AS USED FOR AUSTENITIC STAINLESS STEELS ARE SUITABLE. VERY SHARP TOOLS, PREFERABLY CEMENTED CARBIDE TOOLS, POSITIVE CUTS AT SLOW FEEDS AND SPEEDS, AND RIGID EQUIPMENT SHOULD BE USED. A GOOD COMMERCIAL SOLUBLE OIL IS SATISFACTORY AS COOLANT AND LUBRICANT.

L. REFERENCES

P 62-28
 NP-64-8

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966

SUPERSEDES

**FATIGUE STRENGTH
AS FUNCTION OF
CYCLES TO FAILURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

**OTHER NON-FERROUS
METALS AND ALLOYS**

MATERIALS DATA

**IV
OTHER NON-FERROUS METALS AND ALLOYS**

**B.
COPPER AND COPPER ALLOYS**

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

THE OUTSTANDING CHARACTERISTICS OF OFHC COPPER ARE ITS VERY HIGH THERMAL AND ELECTRICAL CONDUCTIVITY, AND ITS RESISTANCE TO CORROSION. IT CAN BE FORMED BY MOST OF THE METHODS USED FOR WORKING METALS. IT IS NOT RESISTANT TO SULFUR COMPOUNDS NOR TO HIGH TEMPERATURE OXIDATION. IT DOES RESIST MOST ATMOSPHERES, GROUND WATERS, AND SEA WATER. IT CAN BE JOINED BY PRESSURE WELDING AND GAS-SHIELDED ARC WELDING. IT CAN BE SOFT SOLDERED OR SILVER BRAZED.

THE PROPERTIES IN SECTION E ARE AVERAGES, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE LATTER PROPERTIES ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

OXYGEN FREE COPPER, OF COPPER, AND O.F.H. COPPER

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
FLAT PRODUCTS	Q0-C-576 ASTM-B8, B124, B133, B152 (OF), B187 (OF), B272
RODS AND BARS	Q0-C-502 ASTM-B12 - (OF), B49, B124, -B133, B187(OF)
WIRE	ASTM-B 1-B2-B3-B33, B189 - B298
TUBE	ASTM-B-13(OF), B68(OF), B75(OF) B88, B111, B188 (OF), B280
PIPE	ASTM B42 (OF), B188 (OF)
SHAPES	ASTM-B124-B133-B187(OF)
WELDING RODS	Q0-R-571 CLASS FSRCu-1, MIL-R-19631 TYPE FS-RCu-1

SUPPLIERS

AMERICAN METALS CLIMAX CO..
REVERE COPPER AND BRASS INC
CHASE BRASS AND COPPER CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Cu								
MAXIMUM									
MINIMUM	99.95								

SOURCE ASTM B-170

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU}	PSI
ANNEALED	25,000
1/4 HARD	30,000
1/2 HARD	33,000
HARD	40,000
SPRING TEMPER	44,000
TENSILE YIELD STRENGTH F_{TY}	PSI
ANNEAL	8,000
1/4 HARD	24,000
1/2 HARD	26,000
HARD	36,000
SPRING TEMPER	40,000
COMP. YIELD STRENGTH F_{CY}	PSI

SHEAR STRENGTH F_{SU}	PSI
-------------------------	-----

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
-------------------------------------	-----

ELONGATION e	%
ANNEALED	45%
1/4 HARD	25%
1/2 HARD	14%
HARD	6%
SPRING TEMPER	4%

REDUCTION OF AREA RA	%
------------------------	---

MODULUS OF ELASTICITY E	10^6 PSI
	17

MODULUS OF RIGIDITY G	10^6 PSI
-------------------------	------------

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
-----------------------------------	------------

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.321

SPECIFIC GRAVITY	
	8.89

SPECIFIC HEAT C	BTU/LB - °F
-------------------	-------------

THERMAL CONDUCTIVITY k	$\frac{BTU - FT}{HR - FT^2 - °F}$
	226

MEAN COEFF. LIN. THERMAL EXPANS. α	$\frac{10^{-6} IN.}{IN. - °F}$
(32-572°F)	9.3

ELECTRICAL RESISTIVITY R	MICROHM - IN.
	4.34

MAGNETIC PROPERTIES

NON-MAGNETIC

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
	1949° TO 1981°F

PHASE CHANGES

NONE

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	$k \left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
---------------------	--

-100 240

60 226

900 192

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSIVITY VS. TEMPERATURE

BETWEEN 1800°F AND 2100°F EMISSIVITY IS:
15% OF BLACK BODY FOR 7000 Å LIGHT
25% OF BLACK BODY FOR 6000 Å LIGHT
37% OF BLACK BODY FOR 5500 Å LIGHT
45% OF BLACK BODY FOR 5000 Å LIGHT

G. CHEMICAL PROPERTIES

COPPER RESISTS THE ATMOSPHERE, ALL NATURAL FRESH AND SALT WATERS, AND ALKALINE SOLUTIONS, EXCEPT THOSE CONTAINING AMMONIUM IONS. IT ALSO RESISTS MOST ORGANIC COMPOUNDS AND ALL ACIDS EXCEPT THE STRONG OXIDIZING ACIDS, SUCH AS NITRIC AND CONCENTRATED SULFURIC ACID WHEN BOILING. IT RESISTS HYDROFLUORIC ACID BUT NOT HYDROCHLORIC ACID, IT DOES RESIST DRY CHLORINE BUT NOT WET CHLORINE.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

COPPER IS NOT VERY STRONG AND THE STRENGTHENING EFFECT OF COLD WORKING IS REMOVED BY ANNEALING AT 500°F.

COPPER IS NOT RESISTANT TO HYDROCHLORIC ACID, NOR IS IT RESISTANT TO WET CHLORINE. IT IS NOT RESISTANT TO NITRIC ACID, COLD OR HOT, NOR IS IT RESISTANT TO BOILING CONCENTRATED SULFURIC ACID. IT DOES NOT RESIST HIGH TEMPERATURE OXIDATION.

K. PROCESSING
SURFACE TREATMENT

AS A GENERAL RULE, NO SURFACE TREATMENTS ARE APPLIED TO COPPER.

THERMAL TREATMENT

THE ONLY THERMAL TREATMENT EFFECTIVE ON COPPER IS ANNEALING AFTER COLD WORKING. THIS REACHES COMPLETION AT TEMPERATURES AS LOW AS 500°F.

K. PROCESSING (CONTINUED)
JOINING

COPPER CAN BE JOINED WITH THE SILVER BRAZING ALLOYS, AND WITH THE LEAD TIN SOLDERS. IT CAN BE WELDED BY PRESSURE WELDING AND ARC WELDED USING THE GAS-SHIELDED ARC PROCESSES.

FORMING

COPPER IS VERY DUCTILE AND CAN BE WORKED BY ANY DESIRED HOT OR COLD METHOD. COLD REDUCTIONS OF AS MUCH AS 90% CAN BE ACCOMPLISHED BETWEEN ANNEALS.

MACHINABILITY

COPPER MACHINES POORLY, HAVING A MACHINABILITY INDEX 20% OF FREE-CUTTING BRASS.

L. REFERENCES

NP-61-12
NP-48-1

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

TEMPERATURES IN 100° F

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DATE 1 MAY 1966

SUPERSEDES

**OTHER NON-FERROUS
METALS AND ALLOYS**

MATERIALS DATA

**IV
OTHER NON-FERROUS METALS AND ALLOYS
C.
ZIRCONIUM AND ZIRCONIUM ALLOYS**

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DATE

1 MAY 1966

SUPERSEDES

FERROUS ALLOYS

MATERIALS DATA

V

FERROUS ALLOYS

A.

CARBON AND LOW-ALLOY STEELS

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

AISI 1025 IS A LOW CARBON STEEL OF HIGH FORMABILITY, WELDABILITY, AND MACHINABILITY.

THE PROPERTIES GIVEN IN SECTION E-1 ARE AVERAGES, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE LATTER PROPERTIES ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

1025 STEEL

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
TUBING, SEAMLESS AND WELDED	MIL-T-5066 AMS 5675
BAR STOCK	QQ-S-633 (HOT OR COLD FIN.) QQ-S-634 (COLD FIN.)
PLATE	QQ-S-635
SHEET AND STRIP	QQ-S-638
TUBING	QQ-S-830
1025 SEAMLESS AND WELDED AIRCRAFT QUALITY	MIL-T-5061
STRUCTURAL TUBING	MIL-T-16343

SUPPLIERS

STEEL COMPANIES, GENERALLY

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	P	S	Fe			
MAXIMUM	0.280	0.60	0.040	0.040	Bal.			
MINIMUM	0.220	0.30	-	-				

SOURCE NP-64-3

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES
TUBE, SHEET AND BAR, COLD-FINISHED

TENSILE ULTIMATE STRENGTH F_{TU} PSI
55,000

TENSILE YIELD STRENGTH F_{TY} PSI
36,000

COMP. YIELD STRENGTH F_{CY} PSI
36,000

SHEAR STRENGTH F_{SU} PSI
35,000

ULTIMATE BEARING STRENGTH F_{BRU} PSI
 $e/D = 2.0$ 90,000

ELONGATION e %
22.0

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI
29.0

MODULUS OF RIGIDITY G 10^6 PSI
11.0

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI
29.0

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.284

SPECIFIC HEAT C BTU/LB - °F

0.116

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

30.0

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

68°F TO 212°F 6.78

ELECTRICAL RESISTIVITY R MICROHM - IN.

19.0

MAGNETIC PROPERTIES

THIS ALLOY IS FERROMAGNETIC

F. THERMOPHYSICAL EFFECTS
MELTING RANGE

2700° - 2750°F

PHASE CHANGES

MATERIAL UNDERGOES ALLOTROPIC TRANSFORMATIONS WHICH HAVE NO SIGNIFICANT EFFECT ON DESIGN PROPERTIES.

THERMAL CONDUCTIVITY VS. TEMPERATURE
F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMISSION VS. TEMPERATURE
G. CHEMICAL PROPERTIES

THIS STEEL WILL CORRODE IN ANY BUT A VERY DRY ATMOSPHERE. IT REQUIRES PROTECTION FROM NORMAL ATMOSPHERES, AS WELL AS ANY MORE CORROSIVE ENVIRONMENT.

THIS ALLOY IS FREQUENTLY USED IN THE CARBURIZED CONDITION.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

GENERALLY USED IN NORMAL ATMOSPHERIC TEMPERATURE RANGE: -50° TO $+150^{\circ}\text{F}$.

APPLICATIONS AT HIGHER TEMPERATURES ARE LIMITED BY LACK OF RESISTANCE TO OXIDATION AND OTHER CHEMICAL ATTACK.

K. PROCESSING
SURFACE TREATMENT
CLEANING:

VAPOR DEGREASING, ULTRASONIC, CAUSTIC SODA DEGREASING, EMULSION CLEANING, ETC.

THERMAL TREATMENT (PER MIL-H-6875)
NORMALIZING:

HEAT TO 1600° - 1700°F ., AIR COOL.

ANNEALING:

HEAT TO 1575° - 1650°F ., FURNACE COOL TO AT LEAST 900°F .

SUB-CRITICAL ANNEALING:

HEAT TO 1225° - 1275°F ., AIR COOL.

HARDENING:

HEAT TO 1575° - 1650°F ., WATER QUENCH.

TEMPERING:

HEAT TO 1125° - 1175°F ., AIR COOL (FOR TENSILE STRENGTH OF 70,000 PSI).

K. PROCESSING (CONTINUED)
JOINING

READILY WELDED BY ALL METHODS.

FORMING

MAY BE FORMED READILY COLD. FORGING OR HEADING MAY BE DONE HOT OR COLD DEPENDING UPON DESIGN OF THE PART.

MACHINABILITY

EXCELLENT

L. REFERENCES

NP-62-42
NP-64-3
NP-65-31

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

AISI 4340 IS AN OIL OR AIR HARDENING STEEL. IT HAS THE HIGHEST HARDENABILITY OF ANY OF THE LOW ALLOY AISI STEELS, WHICH INDICATES THAT 4 1/2 -IN. DIA BARS OF 4340 CAN BE FULL-HARDENED. AISI 4340 CAN BE FORGED AND ROLLED INTO ANY DESIRED SHAPE. THE ALLOY IS NOT SUITABLE FOR DEEP DRAWING, BUT IT MAY READILY BE EITHER SHEAR SPUN, OR CAST TO SHAPE. IT HAS USEFUL ELEVATED TEMPERATURE STRENGTH TO 900°F. AISI 4340 HAS BEEN USED AT HIGHER STRENGTH LEVELS THAN ANY OF THE COMMON LOW ALLOY STEELS. TENSILE STRENGTHS OF 280,000 PSI ARE ATTAINABLE, AND MUCH HIGHER STRENGTH LEVELS CAN BE REACHED BY SPECIAL PROCESSES.

ULTIMATE TENSILE STRENGTHS IN SECTION E, 1 ARE SPECIFICATION MIL-H-6875 RANGES, EXCEPT FOR THE TEMPER RANGE AND THE RESULTING ULTIMATE TENSILE STRENGTH OF 260,000 - 280,000 RANGE, WHICH MUST BE SPECIFIED BY THE USER. THE TENSILE YIELD, ELONGATION, AND REDUCTION OF AREA ARE 80% OF SCATTER BAND MINIMA FOR EACH TENSILE STRENGTH RANGE, AND ARE DERIVED FROM REF. NP-64-8.

B. COMMERCIAL DESIGNATIONS

AISI 4340

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
CASTINGS	AMS 5330; 5331
BARS FORGING & TUBING	AMS 6414, 6415, MIL-S-5000 QQ-S-624 ASTM-A-304, -322, -331
SHEET, PLATE AND STRIP	QQ-S-627 ASTM-A-505, -506, -607
WIRE	ASTM-A-547
PIPE AND TUBING	ASTM-A-519
BOLTS	ASTM-A-540
SHEET AND PLATE	QQ-S-626

SUPPLIERS

STEEL COMPANIES GENERALLY

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	Ni	Cr	Mo	S	P
MAXIMUM	0.43	0.95	0.35	2.00	0.95	0.30	.025	.025
MINIMUM	0.38	0.60	0.20	1.55	0.65	0.20		

SOURCE
E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

APPROX TEMPERING TEMPERATURE - °F	1050°	925°	850°	425°
TENSILE ULTIMATE STRENGTH F_{TU}				PSI
	160,000	180,000	200,000	260,000
	180,000	200,000	220,000	280,000

TENSILE YIELD STRENGTH F_{TY}				PSI
	112,000	144,000	152,000	176,000

COMP. YIELD STRENGTH F_{CY}				PSI
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SHEAR STRENGTH F_{SU}				PSI
-------------------------	--	--	--	-----

ULTIMATE BEARING STRENGTH F_{BRU}				PSI
-------------------------------------	--	--	--	-----

ELONGATION e				%
	16	13	12	8

REDUCTION OF AREA RA				%
	44	33	32	28

MODULUS OF ELASTICITY E				10^6 PSI
				28.5

MODULUS OF RIGIDITY G				10^6 PSI
				11

COMP. MODULUS OF ELASTICITY E_C				10^6 PSI
				29

PLASTIC BENDING MODULUS				(SEE APPENDIX A)
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2. PHYSICAL PROPERTIES

DENSITY ρ		LB/IN ³
	0.284	

SPECIFIC HEAT C		BTU/LB - °F
	.11	

THERMAL CONDUCTIVITY k		BTU - FT HR - FT ² - °F
	21.7	

MEAN COEFF. LIN. THERMAL EXPANS. α		10^{-6} IN. IN. - °F
0 TO 200°F	6.3	

ELECTRICAL RESISTIVITY R		MICROHM - IN.
	11.7	

MAGNETIC PROPERTIES

ALLOY IS FERROMAGNETIC TO CURIE TEMPERATURE, WHICH IS APPROXIMATELY 1300°F.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
	2580° TO 2680°F.

PHASE CHANGES	
EUTECTOID = A_1	1290°F
ALPHA TO GAMMA = A_3	1380°F

THERMAL CONDUCTIVITY VS. TEMPERATURE
F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMISSIVITY VS. TEMPERATURE
G. CHEMICAL PROPERTIES

AISI 4340 HAS THE GENERAL CHARACTERISTICS COMMON TO ALL LOW ALLOY STEELS. IT MUST BE PROTECTED FROM THE ATMOSPHERE, ALTHOUGH DRY OXYGEN AT ROOM TEMPERATURE DOES NOT ATTACK IT.

ALMOST ALL ACIDS, EVEN WHEN DILUTE, DISSOLVE AISI 4340.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

AISI 4340 CAN BE HAD IN WIDE RANGES OF STRENGTH AND TOUGHNESS. IN THE HIGH STRENGTH VERSION THE IMPACT RESISTANCE AND CRYOGENIC PROPERTIES ARE IMPAIRED, BUT AS THE STRENGTH IS LOWERED THE TOUGHNESS INCREASES.

THE UPPER TEMPERATURE RANGE OF SERVICE OF THIS ALLOY IS SET BY THE TEMPERING TEMPERATURE REQUIRED BY THE STRENGTH LEVEL SELECTED. IN A MATERIAL HEAT TREATED TO 260,000 TO 280,000 PSI ULTIMATE TENSILE STRENGTH, THE MINIMUM TEMPERING TEMPERATURE IS 400°F. WHICH IS THEN THE MAXIMUM SERVICE TEMPERATURE FOR 4340 STEEL AT THIS STRENGTH LEVEL. THE LOWER SERVICE TEMPERATURE LIMIT OF SERVICE FOR 4340 IS SIMILARLY AFFECTED BY STRENGTH LEVEL.

K. PROCESSING
SURFACE TREATMENT

AISI 4340 CAN BE NITRIDED, AND NICKEL AND CHROMIUM PLATED.

THE SURFACE OF PARTS EXPOSED TO THE ATMOSPHERE MUST BE EITHER PAINTED OR PLATED FOR PROTECTION, OR COVERED IN SOME OTHER FASHION, SUCH AS BY GREASE OR OIL.

THERMAL TREATMENT

AISI 4340 CAN BE HARDENED TO VERY HIGH STRENGTHS WITH ACCOMPANYING LOSS OF DUCTILITY. HOWEVER, HIGHER TEMPERING TEMPERATURES PRODUCE LOWER STRENGTH AND INCREASED DUCTILITY.

BEST MACHINABILITY IS IN THE ANNEALED OR SPHEROIDIZED CONDITION.

HEAT TREATMENT (PER MIL-H-6875)
ANNEALING:

1575°-1650°F. HOLD 1 HOUR PER INCH OF THICKNESS OR FRACTION THEREOF, FURNACE COOL TO 700°F BEFORE AIR COOLING

HARDENING:

1475°-1550°F. HOLD 1 HOUR PER INCH OF THICKNESS OR FRACTION THEREOF, QUENCH IN OIL.

TEMPERING:

APPROX. TEMPERING TEMP. FOR TENSILE STRENGTH OF	
1,050°F	160,000 - 180,000 PSI UTS
925°F	180,000 - 200,000 PSI UTS
850°F	200,000 - 220,000 PSI UTS
400°F - 450°F*	260,000 - 280,000 PSI UTS

* NOT COVERED IN MIL-H-6875

K. PROCESSING (CONTINUED)
JOINING

AISI 4340 CAN BE BOLTED, RIVETED, AND WELDED. WELDING REQUIRES PREHEATING, INTERPASS TEMPERATURE CONTROL, POSTHEATING, AND STRESS RELIEF.

FORMING

AISI 4340 CAN BE FORGED AND ROLLED TO ANY DESIRED SHAPE. SHEET CAN BE FORMED BUT NOT DEEP DRAWN. PLATE AND SHEET CAN BE SHEAR FORMED.

MACHINABILITY

PROPERLY ANNEALED 4340 IS NOT DIFFICULT TO MACHINE. FOR MAXIMUM MACHINABILITY, THE CARBIDES MUST BE SPHEROIDIZED; SPHEROIDIZATION IS JUSTIFIABLE ONLY WHEN THERE IS EXTENSIVE MACHINING. FOR SINGLE PIECES SUBJECTED TO LATHE WORK, A SIMPLE MILL ANNEALING WILL GENERALLY SUFFICE.

L. REFERENCES

NP-61-12	NP-65-31
NP-48-1	NP-62-42
	NP-64-8

DATE 1 MAY 1966

SUPERSEDES

FERROUS ALLOYS

MATERIALS DATA

**V
FERROUS ALLOYS**

**B.
AUSTENITIC STAINLESS STEELS**

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DATE 1 MAY 1966
SUPERSEDES

BASIC DATA
A. GENERAL

AISI 301 IS AN AUSTENITIC STAINLESS STEEL. ITS PRINCIPAL ALLOYING ELEMENTS ARE CHROMIUM AND NICKEL. AISI 301 COMBINES EXCEPTIONAL CORROSION RESISTANCE WITH EXCELLENT FORMABILITY IN THE ANNEALED CONDITION. AISI 301 CAN BE STRENGTHENED CONSIDERABLY BY COLD-WORKING.

THE PROPERTIES GIVEN IN SECTION E ARE AISI GUARANTEED MINIMUM PROPERTIES FOR ULTIMATE TENSILE STRENGTH, TENSILE YIELD STRENGTH, AND ELONGATION. ALL OTHER ARE AVERAGE.

B. COMMERCIAL DESIGNATIONS

AISI TYPE 301 (WROUGHT)
CF - 20 (CAST)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP & PLATE - ST (ANNEALED)	MIL-S-5059, QQ-S-766 AMS 5515, AMS 5516
SHEET & STRIP (1/4 HARD)	MIL-S-5059 AMS 5517
(1/2 HARD)	MIL-S-5059 AMS 5518
(FULL HARD)	MIL-S-5059 AMS 5519
BAR, COLD DRAWN (100 KSI (125 KSI))	AMS 5636 AMS 5637
BAR & FORGINGS	MIL-S-7720 QQ-S-763
WIRE (SPRING TEMPER)	AMS 5688

SUPPLIERS

ALLEGHENY - LUDLUM STEEL CO.
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
U. S. STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Fe
MAXIMUM	0.15	2.00	1.00	.045	.030	18.00	8.00	Bal.
MINIMUM	-	-	-	-	-	16.00	6.00	-

SOURCE NP-64-8

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ANNEALED	1/4 HARD	1/2 HARD	3/4 HARD	FULL HARD
TENSILE	ULTIMATE	STRENGTH	F_{TU}	PSI
88,000	100,000	120,000	140,000	148,000

TENSILE	YIELD	STRENGTH	F_{TY}	PSI
32,000	60,000	88,000	108,000	112,000

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

(DYNAMIC) 10.6

COMP. MODULUS OF ELASTICITY E_c 10^6 PSI

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.286

SPECIFIC HEAT C BTU/LB - °F

0.11

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F

7.74

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN. / IN. - °F

9.2

ELECTRICAL RESISTIVITY R MICROHM - IN.

28.3

MAGNETIC PROPERTIES

NON-MAGNETIC IN ANNEALED CONDITION, BUT BECOMES MAGNETIC WHEN COLD-WORKED.

F. THERMOPHYSICAL EFFECTS
MELTING RANGE

2550° - 2650°F.

PHASE CHANGES

HEATING OR COLD WORKING MAY CAUSE TRANSFORMATION. COLD WORK CAN CAUSE TRANSFORMATION TO MARTENSITE. HEATING IN TEMPERATURE RANGE OF 800 - 1600°F CAN CAUSE CARBIDE PRECIPITATION. CARBIDES CAN BE RE-DISSOLVED BY ANNEALING.

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k (BTU - FT / HR - FT ² - °F)
-250	6.4
-200	6.8
-100	7.5
68	8.6
200	9.4
400	10.4
600	11.3
800	12.2
1000	13.1
1200	13.9
1400	14.6
1600	15.3

REF. NP-61-3

F. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES

CORROSION RESISTANCE, WHILE HIGH, IS THE LOWEST OF THE AUSTENITIC STAINLESS STEELS.

IF SLOW COOLED THROUGH THE RANGE OF 800 TO 1600°F, THE RESULTING CARBIDE PRECIPITATION CAN SENSITIZE THE METAL TO INTERGRANULAR ATTACK WHEN EXPOSED TO CORROSIVE MEDIA.

AISI 301 IS NOT SUBJECT TO HYDROGEN EMBRITTLEMENT.

OXIDATION RESISTANCE IS HIGH UP TO 1700°F FOR CONTINUOUS SERVICE, AND UP TO 1600°F FOR INTERMITTENT SERVICE.

USE, OR PROLONGED HEATING IN THE 800°F-1600°F RANGE, WILL SENSITIZE THIS MATERIAL.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

AUSTENITIC STAINLESS STEELS RETAIN THEIR HIGH IMPACT STRENGTH AFTER IRRADIATION IN CONTRAST TO FERRITIC STEELS, WHICH MAY BECOME EMBRITTLED.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

R = IN FATIGUE, THE ALGEBRAIC RATIO OF
THE MINIMUM STRESS TO THE MAXIMUM
STRESS IN ONE CYCLE, THAT IS,

$$R = \frac{S_{\text{MIN}}}{S_{\text{MAX}}}$$

J. SERVICE LIMITS
ANNEALED MATERIAL

-423°F TO 1800°F (IN OXIDIZING ATMOSPHERE, 1700°F
MAXIMUM FOR CONTINUOUS SERVICE & 1600°F MAXIMUM
FOR INTERMITTENT SERVICE).

COLD WORKED MATERIAL

-423°F TO 900°F, TOLERATES HYDROGEN ENVIRONMENT
OVER ENTIRE TEMPERATURE RANGE.

K. PROCESSING
SURFACE TREATMENT

DESCALING IS GENERALLY DONE IN SOLUTIONS OF
NITRIC AND HYDROFLUORIC ACIDS. MOLTEN CAUSTIC
SODA BATHS ARE ALSO WIDELY USED FOR DESCALING.
FOR REMOVING HEAVY SCALE, SAND OR VAPOR BLASTING
SHOULD PRECEDE PICKLING.

THE USE OF CHLORINATED HYDROCARBONS, SUCH AS
TRICHLOROETHYLENE, SHOULD BE AVOIDED SINCE THEY
MAY CONTRIBUTE TO STRESS-CORROSION CRACKING.

THERMAL TREATMENT

ZINC AND LEAD PARTICLES MUST BE REMOVED BEFORE
HEAT TREATMENT IN ORDER TO AVOID EMBRITTLEMENT.

STRESS RELIEVING:

400°F/36 HRS MAX. TO 800°F/8 HRS MAX. TO IMPROVE
ELASTIC CHARACTERISTICS AND COMPRESSIVE YIELD
STRENGTH. AFTER FORMING, STRESS RELIEVE TO PREVENT
STRESS CRACKING AT 600°F FOR 1/2 TO 2 HRS AS
ALTERNATE TO FULL ANNEAL.

SOLUTION TREATING OR ANNEALING

1950 TO 2050°F HOLD AT TEMPERATURE 1 HR PER INCH
OF THICKNESS, OR 3 TO 5 MINUTES PER 0.10 INCH OF
THICKNESS FOR CROSS-SECTIONS UNDER 1.0 INCH, THEN
WATER QUENCH. COOLING TO 800°F SHOULD OCCUR WITHIN
3 MINUTES MAX.

K. PROCESSING (CONTINUED)
JOINING

HARD TEMPERERS OF TYPE 301 STAINLESS STEEL ARE
UNSUITABLE FOR FUSION WELDING AND BRAZING.

ANNEALED MATERIAL IS READILY WELDED BY ALL
TECHNIQUES. CARBIDE PRECIPITATION OCCURS IN THE
WELD AND HEAT AFFECTED ZONE. TYPE 308 ELECTRODES
OR FILLER ROD ARE GENERALLY USED.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE
FOLLOWING WELD RODS:

AISI 308/MIL-R-5031, CL. 1
AISI 308 ELC/MIL-R-5031, CL. 16
ER 308/ASTM-A-371, CL. ER308
ER 308L/ASTM-A-371, CL. ER308L

FORMING
FORGING:

STARTING TEMPERATURE 2300°F MAXIMUM; FINISHING
TEMPERATURE, 1500°F.

FORMABILITY:

GOOD BY ALL METHODS; INTERMEDIATE STRESS RELIEF
COMMONLY REQUIRED.

CASTING:

GOOD

MACHINABILITY

APPROXIMATELY 50% OF MILD CARBON STEELS

L. REFERENCES

NP-61-12
NP-64-8
NP-64-31

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE**

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
BEARING**

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

STRESS VS STRAIN

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

TYPE 303 CONTAINS ADDITIONS OF SULFUR, WHILE TYPE 303 SE CONTAINS ADDITIONS OF SELENIUM. THESE ADDITIONS ARE MADE FOR THE PURPOSE OF IMPROVING MACHINABILITY. AS A RESULT THEY HAVE POORER FORMABILITY AND CORROSION RESISTANCE THAN TYPE 302.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGES, EXCEPT FOR ULTIMATE TENSILE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA, WHICH ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

WROUGHT: TYPE 303 AND TYPE 303 SE
CAST: CF-16F

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, FORGINGS (SOLUTION TREATED OR ANNEALED), BILLETS	AMS 5640 QQ-S-763
BAR, FORGINGS (SWAGINGS), FORGING STOCK	AMS 5641 QQ-S-763
BAR, COLD DRAWN	AMS 5738
BAR, FORGINGS, (COLUMBIUM STABILIZED)	AMS 5642

SUPPLIERS ALLEGHENY - LUDLUM STEEL CO.
CRUCIBLE STEEL
REPUBLIC STEEL
U.S. STEEL

D. CHEMICAL COMPOSITION (%) (TYPE 303)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Nb
MAXIMUM	0.15	2.00	1.00	0.040	0.035	16.00	10.00	0.75
MINIMUM	-	-	-	-	0.18	17.00	3.00	-

SOURCE NP-64-8
Cu Fe
0.50 BAL

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} ALL FORMS ANNEALED 72,000 PSI

TENSILE YIELD STRENGTH F_{TY} 30,000 PSI

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION ALL FORMS ANNEALED e 40.0 %

REDUCTION OF AREA RA 58.0 %

MODULUS OF ELASTICITY E 10^6 PSI
26.3

MODULUS OF RIGIDITY G 10^6 PSI

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

HARDNESS - ROCKWELL B SCALE 84

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³
0.286

SPECIFIC HEAT C BTU/LB - °F
0.118

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$
9.3

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$
(RT TO 200°F) 9.27

ELECTRICAL RESISTIVITY R MICROHM - IN.
29.5

MAGNETIC PROPERTIES

NON-MAGNETIC IN ANNEALED CONDITION. WHEN SEVERELY COLD-WORKED, THIS MATERIAL BECOMES SLIGHTLY MAGNETIC.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2550° - 2590°F

PHASE CHANGES

SUBJECT TO CARBIDE PRECIPITATION AT 800° TO 1600°F. IN COLUMBIUM-STABILIZED ALLOY, THE PRECIPITATION OF CARBIDES DOES NOT REDUCE CORROSION RESISTANCE, SINCE CHROMIUM CARBIDES DO NOT FORM.

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$
0	9.33
200	9.56
400	10.00
600	10.67
800	11.37
1000	12.63
1200	14.33
1400	15.11
1600	16.00
1800	17.05

G. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES

GENERAL CORROSION RESISTANCE IN MILDLY CORROSIVE ATMOSPHERES IS SLIGHTLY INFERIOR, AND UNDER SEVERE CORROSIVE CONDITIONS GREATLY INFERIOR TO THAT OF TYPE 302. THIS STEEL RESISTS NITRIC ACID WELL, HALOGEN ACIDS POORLY, AND SULFURIC ACID MODERATELY.

TYPE 303 IS SUSCEPTIBLE TO STRESS CRACKING IF COLD WORKED.

TYPE 303 SE, THEREFORE, IS PREFERRED FOR APPLICATIONS INVOLVING COLD FORMING.

OXIDATION RESISTANCE IS SIMILAR TO THAT OF TYPE 302, BUT NON-UNIFORM SCALING MAY BE ENCOUNTERED IN STRONGLY OXIDIZING ATMOSPHERES ABOVE 1400°F.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

-423°F TO 750 °F

K. PROCESSING
SURFACE TREATMENT

SCALE MAY BE REMOVED BY A SOLUTION OF 15-20% NITRIC ACID AND 1-3% HYDROFLUORIC ACID AT 120-140°F, FOR 20-30 MINUTES. SCALE REMOVAL IS MORE EASILY ACCOMPLISHED WHEN PARTS HAVE BEEN HEATED IN AIR.

CHLORINATED HYDROCARBON CLEANERS, SUCH AS TRICHLOROETHYLENE, SHOULD BE AVOIDED SINCE THEY MAY CONTRIBUTE TO STRESS - CORROSION CRACKING.

THERMAL TREATMENT

ANNEAL OR SOLUTION TREAT:
1900° TO 2050°F, AIR COOL OR QUENCH, DEPENDING ON SECTION THICKNESS. COOLING TO 800°F MAXIMUM SHOULD BE WITHIN 3 MINUTES.

BAR AND FORGINGS:
1900 TO 1950°F, HOLD AT TEMPERATURE FOR 1/2 HOUR PER INCH OF THICKNESS. WATER QUENCH.

HARDENING:
ALLOY CAN ONLY BE HARDENED BY COLD WORK.

K. PROCESSING (CONTINUED)
JOINING

WELDING IS NOT GENERALLY RECOMMENDED.

FORMING

TYPE 303 SHOULD BE ANNEALED AFTER SEVERE FORMING TO PREVENT STRESS CRACKING.

MACHINABILITY

MACHINABILITY EXCEEDS 60% OF THAT OF MILD CARBON STEELS.

L. REFERENCES

NP-64-8

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

**REDUCTION OF AREA
ELONGATION**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

TYPES 304 AND 304 L ARE THE LOW CARBON GRADES OF THE AUSTENITIC STAINLESS STEELS. THESE MATERIALS HAVE HIGH CORROSION RESISTANCE, VERY GOOD FORMABILITY, AND ARE READILY WELDABLE BY ALL TECHNIQUES.

THE PROPERTIES GIVEN IN SECTION E ARE FOR AISI 304 AND ARE AVERAGE, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE LATTER PROPERTIES ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

WROUGHT: AISI 304, AISI 304 L
CAST: CF - 8, CF - 3

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP, AND PLATE (SOLUTION-TREATED)	MIL-S-5059 QQ-S-766, AMS 5513
TUBING, HYDRAULIC (COLD-DRAWN)	MIL-T-6845, AMS 5566
TUBING, SEAMLESS AND WELDED (SOL.-TREATED)	MIL-T-8506 AMS 5560, AMS 5565
BAR FORGINGS, TUBING (SOLUTION-TREATED)	MIL-S-7720, QQ-S-763 AMS 5639
WIRE (SOL. TREATED)	AMS 5697
SHEET, STRIP, AND PLATE (304L, SOL. TREATED)	MIL-S-4043

SUPPLIERS

ALLEGHENY - LUDLUM CO.
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
U. S. STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C*	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.08	2.00	1.00	.040	.030	20.0	11.0	0.50
MINIMUM	-	-	-	-	-	18.00	8.00	-
* FOR 304L, MAX. C CONTENT IS 0.030%						Cu 0.50	Fe BAL	
SOURCE NP-64-8								

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	ANNEALED	PLATE, BAR
	SHEET, STRIP	THICKNESS, INCHES
TENSILE ULTIMATE STRENGTH F_{TU}	68,000	68,000
TENSILE YIELD STRENGTH F_{TY}	28,000	24,000
COMP. YIELD STRENGTH F_{CY}		
ULTIMATE SHEAR STRENGTH F_{SU}		
SHEAR YIELD STRENGTH F_{SY}		
ULTIMATE BEARING STRENGTH F_{BRU}		
e/D = 1.5 e/D = 2.0		
YIELD BEARING STRENGTH F_{BRY}		
e/D = 1.5 e/D = 2.0		
ELONGATION e	40	53
REDUCTION OF AREA RA	50	
MODULUS OF ELASTICITY E	10^6 PSI	
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI	
MODULUS OF RIGIDITY G	10^6 PSI	
(DYNAMIC)	13	
POISSON'S RATIO	0.25	
HARDNESS R_B	80	
PLASTIC BENDING MODULUS	(SEE APPENDIX A)	

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.287
SPECIFIC HEAT C	BTU/LB - °F
	0.12
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
	8.9
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
(70-100°F)	8.7
ELECTRICAL RESISTIVITY R	MICROHM - IN.
	28
MAGNETIC PROPERTIES	
NON-MAGNETIC IN THE ANNEALED CONDITION, BUT BECOMES SLIGHTLY MAGNETIC WHEN COLD WORKED.	

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	2550 - 2650°F.
PHASE CHANGES	
SUBJECT TO CARBIDE PRECIPITATION AT 800° - 1600°F. (SEE SECTION G)	
THERMAL CONDUCTIVITY VS. TEMPERATURE	
TEMPERATURE °F	$k \left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
- 423	1.33
- 320	4.00
- 200	6.11
0	8.05
75	8.44
200	8.95
400	9.94
600	10.95
800	11.95
1000	13.21
1200	14.11
1350	15.06

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

GENERAL CORROSION RESISTANCE TO VARIOUS ATMOSPHERES, MOST ACIDS, STEAM, AND COMBUSTION GASES, IS VERY GOOD.

PASSIVATING IS NECESSARY TO DEVELOP BEST CORROSION RESISTANCE.

OXIDATION RESISTANCE IS GOOD UP TO 1700°F FOR CONTINUOUS SERVICE AND TO 1600°F FOR INTERMITTENT SERVICE.

INTERGRANULAR CORROSION AFTER WELDING OR HEATING MAY OCCUR IN TYPE 304. (SEE PHASE CHANGES, SECTION F).

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

AUSTENITIC STAINLESS STEELS RETAIN THEIR HIGH IMPACT STRENGTH AFTER IRRADIATION.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

R IN FATIGUE, THE ALGEBRAIC RATIO OF THE MINIMUM STRESS TO THE MAXIMUM STRESS IN ONE CYCLE, THAT IS, $R = \frac{S_{MIN}}{S_{MAX}}$

ELC - EXTRA LOW CARBON

J. SERVICE LIMITS
TYPE 304 L

-423°F TO 800°F (NOT RECOMMENDED ABOVE 800°F BECAUSE OF RELATIVELY LOW STRENGTH).

SEE SECTION G FOR OXIDATION RESISTANCE SERVICE LIMITS.

K. PROCESSING
SURFACE TREATMENT

SCALE MAY BE REMOVED BY A SOLUTION OF 15-20% NITRIC ACID AND 1-3% HYDROFLUORIC ACID AT 120° TO 140°F. FOR 20 TO 30 MINUTES. SCALE IS MORE READILY REMOVED WHEN PARTS HAVE BEEN HEATED IN AIR.

CHLORINATED CLEANERS, SUCH AS TRICHLOROETHYLENE, SHOULD BE AVOIDED, AS THESE MAY CONTRIBUTE TO STRESS-CORROSION CRACKING OF THE ALLOY.

THERMAL TREATMENT

FURNACE ATMOSPHERES SHOULD BE NEUTRAL OR SLIGHTLY OXIDIZING. HEATING WITH HIGH SULFUR FUELS SHOULD BE AVOIDED.

BRIGHT ANNEALING IS DONE IN A DRY HYDROGEN, CRACKED AMMONIA, OR ARCON ATMOSPHERE WITH A DEW POINT OF -80°F MAXIMUM.

SHEET AND TUBING

1900 TO 1950°F, 10 MINUTES HOLD AT TEMPERATURE, AIR COOL UP TO 0.064 INCH IN THICKNESS, WATER QUENCH 0.065 INCH AND THICKER.

K. PROCESSING (CONTINUED)
JOINING

CAN BE WELDED READILY BY ALL METHODS. TYPE 300 WELD WIRE GENERALLY USED.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

AISI 308/MIL-R-5031, CL. 1
AISI 308 ELC/MIL-R-5031, CL. 16
ER 308/ASTM-A-371, CL. ER308
ER 308L/ASTM-A-371, CL. ER308L

FORMING
FORMABILITY:

EXCELLENT FORMABILITY IN THE ANNEALED CONDITION. MAY REQUIRE INTERMEDIATE ANNEALING IN SEVERE FORMING OPERATIONS.

FORGING:

STARTING FORGING TEMPERATURE 2300°F MAXIMUM. FINISHING TEMPERATURE 1500°F MINIMUM. SEVERE REDUCTION BELOW 1700°F SHOULD BE AVOIDED.

CASTABILITY:

EXCELLENT

MACHINABILITY

MACHINABILITY IS ABOUT 35% OF BESSEMER STEEL SCREW STOCK.

L. REFERENCES

NP-64-0

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

**REDUCTION OF AREA
ELONGATION**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

0.16

0.12

0.08

0.04

0

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

POISSON'S RATIO

ELECTRICAL RESISTIVITY

ELECTRICAL RESISTIVITY
MICROHM-IN.

TEMPERATURES IN 100° F

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DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

AISI 310 IS MORE RESISTANT TO HIGH TEMPERATURE OXIDATION THAN OTHER STAINLESS STEELS. THE AISI 310 S GRADE CONTAINS SULFUR FOR IMPROVED MACHINABILITY. THESE STEELS ARE UN-STABILIZED.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGE, EXCEPT FOR ULTIMATE TENSILE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE LATTER PROPERTIES ARE GIVEN AS 80% OF AVERAGE.

THE VALUES FOR ANNEALED, 1-INCH DIAMETER BAR IN SECTION E RESULT FROM THE FOLLOWING TREATMENT: ANNEAL AT 2150°F AND WATER QUENCH (GRAIN SIZE 4-6). THIS APPLIES TO F_{TU} AND F_{TY} .

B. COMMERCIAL DESIGNATIONS

WROUGHT: TYPES 310 AND 310 S STAINLESS STEELS

CAST: CK-20 AND HK

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP AND PLATE (AISI 310)	QQ-S-766
SHEET, STRIP AND PLATE (AISI 310 S)	AMS 5521
BAR, FORGINGS (AISI 310)	QQ-S-763
BAR, FORGINGS, TUBE (AISI 310 S)	AMS 5651

SUPPLIERS

ALLEGHENY-LUDLUM STEEL CO.
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
U. S. STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C*	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.25	2.00	1.50	.045	.030	26.0	22.0	0.50
MINIMUM	-	-	-	-	-	24.0	19.0	-

*FOR TYPE 310S, CARBON CONTENT IN 0.08 MAX.
SOURCE NP-64-B

Cu Fe
0.50 BAL

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET AND STRIP PLATE
ANNEALED ANNEALED BAR 1.00-IN. DIA.
TENSILE ULTIMATE STRENGTH F_{TU} PSI
76,000 76,000 84,000

TENSILE YIELD STRENGTH F_{TY} PSI
36,000 36,000 28,000

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e %
36.0 40.0 43.0
(0.75-IN. DIA. BAR)

REDUCTION OF AREA RA %
52.0 54.0
(0.75-IN. DIA. BAR)

MODULUS OF ELASTICITY E 10^6 PSI
28.8

MODULUS OF RIGIDITY G 10^6 PSI

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

HARDNESS (ROCKWELL SCALE)
 R_B 85 R_B 87 R_B 89

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.29

SPECIFIC HEAT C BTU/LB - °F

0.12

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

7.6

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

8.0

ELECTRICAL RESISTIVITY R MICROHM - IN.

38.0

MAGNETIC PROPERTIES

THIS STEEL IS NON-MAGNETIC

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2550 - 2650°F.

PHASE CHANGES

THIS STEEL IS SUBJECT TO PRECIPITATION OF CARBIDES AT 800° - 1600°F.

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
200	7.25
400	8.00
600	8.75
800	9.50
1000	10.25
1200	11.04

F. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

GOOD CORROSION RESISTANCE IN GENERAL, BUT GENERALLY USED FOR HIGH TEMPERATURE APPLICATIONS DUE TO ITS RESISTANCE TO OXYGEN -, CARBON -, AND SULFUR - BEARING ATMOSPHERES.

ALLOY IS GOOD FOR CONTINUOUS SERVICE UP TO 2100°F MAXIMUM AND FOR INTERMITTENT SERVICE UP TO 1900°F. AT 1500°F OR HIGHER, IN AIR OR COMBUSTION ATMOSPHERES, THIS ALLOY IS SUPERIOR TO AISI TYPES 301, 302, 303, AND 304.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

AUSTENITIC STAINLESS STEELS RETAIN THEIR HIGH IMPACT STRENGTH AFTER IRRADIATION.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

AC = AIR COOLED
WQ = WATER QUENCHED
GS = ASTM GRAIN SIZE
ANN = ANNEALED

J. SERVICE LIMITS

-423°F TO 2100°F. (CONTINUOUS)
-423°F TO 1900°F. (INTERMITTENT)
(SEE SECTION G)

K. PROCESSING
SURFACE TREATMENT

CLEANING PRIOR TO HEATING AND WELDING SHOULD INCLUDE THOROUGH REMOVAL OF CARBONACEOUS MATERIAL AND OF ANY ZINC OR LEAD FROM DIES TO AVOID REDUCTION OF CORROSION RESISTANCE.

PASSIVATING IN NITRIC ACID IS REQUIRED TO ESTABLISH HIGHEST CORROSION RESISTANCE.

USE OF CHLORINATED HYDROCARBONS, SUCH AS TRICHLOROETHYLENE, SHOULD BE AVOIDED SINCE THEY MAY CONTRIBUTE TO STRESS CORROSION CRACKING.

THERMAL TREATMENT

ANNEAL OR SOLUTION TREAT:
2000° - 2150°F, 1/2 TO 1 HOUR PER INCH OF THICKNESS (PLATE 2 HOURS MINIMUM), WATER QUENCH OR SPRAY. THIS TREATMENT IS ALSO RECOMMENDED TO RESTORE DUCTILITY AFTER EACH 1000 HOURS OF SERVICE AT 1200° - 1950°F.

STRESS RELIEF:
400° - 750°F, 36 TO 8 HOURS RESPECTIVELY.

ALLOY CAN ONLY BE HARDENED BY COLD WORK.

K. PROCESSING (CONTINUED)
JOINING

CAN BE WELDED READILY BY EITHER ELECTRIC OR GAS FUSION METHODS. NO PRE-HEATING REQUIRED. OXY-ACETYLENE WELDING IS NOT RECOMMENDED BECAUSE OF POSSIBLE ADVERSE EFFECT ON CORROSION RESISTANCE BY CARBON PICKUP.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT THE FOLLOWING WELD ROD:
ER 310/ASTM-A-371, CL. ER310

FORMING

CAN BE FORMED INTO MOST DESIRED SHAPES. FAIRLY FREQUENT INTERSTAGE ANNEALING IS REQUIRED.

FORGING STARTING TEMPERATURE 2150 F MAXIMUM, FINISHING TEMPERATURE IS 1700°F MINIMUM.

MACHINABILITY

APPROXIMATELY 50% OF THAT OF MILD CARBON STEELS.

L. REFERENCES

NP-64-8

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

0.16
0.12
0.08
0.04
0

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

POISSON'S RATIO

ELECTRICAL RESISTIVITY

ELECTRICAL RESISTIVITY
MICROHM-IN.

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

SAISI 316 CONTAINS MOLYBDENUM. AS A RESULT, THIS ALLOY HAS A CORROSION RESISTANCE SUPERIOR TO THAT OF OTHER AUSTENITIC STEEL GRADES FOR CERTAIN APPLICATIONS.

THE PROPERTY VALUES GIVEN IN SECTION E ARE AVERAGES, EXCEPT FOR ULTIMATE TENSILE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA, WHICH ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

WROUGHT: 1B-8 Mo STAINLESS STEEL
CAST: CF3M, CF8M, CF12M (A.C.I. DESIGNATIONS)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP AND PLATE	MIL-S-5059 QQ-S-766 AMS 5524
BAR, FORGINGS, FORGING STOCK	MIL-S-7720 QQ-S-763 AMS 5648
SPRING WIRE	QQ-W-423
TUBING, SEAMLESS	AMS 5573

SUPPLIERS

ALLEGHENY LUDLUM STEEL CO.
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
U. S. STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.08	2.00	1.00	.045	.030	18.0	14.0	3.00
MINIMUM	-	-	-	-	-	16.0	10.0	2.00

SOURCE NP-64-8

Fe
BAL

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET, STRIP ANNEALED	PLATE ANNEALED	BAR
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	PSI
72,000	68,000	67,500 72,000

TENSILE YIELD STRENGTH		F_{TY}	PSI
32,000	28,000	30,000	48,000

COMP. YIELD STRENGTH F_{CY}	PSI
-------------------------------	-----

SHEAR STRENGTH F_{SU}	PSI
-------------------------	-----

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
-------------------------------------	-----

ELONGATION	<i>e</i>	%
40	44	40 36

REDUCTION OF AREA	RA	%
	66	

MODULUS OF ELASTICITY	E	10 ⁶ PSI
	26.3	

MODULUS OF RIGIDITY	G	10^6 PSI
---------------------	---	------------

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
-----------------------------------	------------

HARDNESS		ROCKWELL	
R _B 85	R _B 82	R _B 78	R _B 91

PLASTIC BENDING MODULUS (SEE APPENDIX A)

* COLD WORKED 13% BEFORE ANNEALING
** COLD DRAWN, 1-IN. DIA.

2. PHYSICAL PROPERTIES

DENSITY	ρ	LB/IN ³
<hr/>		
0.288		

SPECIFIC HEAT	C	BTU/LB - °F
	10.5	

THERMAL CONDUCTIVITY	k	$\frac{BTU - FT}{HR - FT^2 - ^\circ F}$
----------------------	-----	---

MEAN COEFF. LIN. THERMAL EXPANS. α	$\frac{10^{-6} \text{ IN.}}{\text{IN.} - ^\circ\text{F}}$
(75-100°F) 8.3	

ELECTRICAL RESISTIVITY	R	MICROHM - IN.
	32.0	

MAGNETIC PROPERTIES

NON-MAGNETIC IN ANNEALED CONDITION. FORMATION OF FERRITE IN SEVERELY COLD WORKED MATERIAL WILL RESULT IN VERY SMALL INCREASE IN PERMEABILITY.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2500 - 2550°F

PHASE CHANGES

SUBJECT TO PRECIPITATION OF CARBIDES, FORMATION OF SIGMA PHASE AND FERRITE ON HEATING AT 800° TO 1600°F. THIS CAN CAUSE EMBRITTLEMENT AND SUSCEPTIBILITY TO STRESS CORROSION.

THERMAL CONDUCTIVITY VS. TEMPERATURE *

TEMPERATURE °F	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
- 320	6.14
- 100	7.03
0	7.50
75	7.92
200	8.50
400	9.45
600	10.26
800	11.05
1000	11.85
1200	12.76
1400	13.55
1600	14.28

* FOLLOWS ANNEALED BAR CURVE, PAGE V-B-16/11

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

SUPERIOR CORROSION RESISTANCE, WHEN COMPARED TO OTHER AUSTENITIC STAINLESS STEELS, ON EXPOSURE TO SEA WATER AND CONDITIONS WHERE PARTICLES ARE DEPOSITED ON SURFACE.

OXIDATION RESISTANCE GOOD FOR CONTINUOUS SERVICE UP TO 1600°F AND FOR INTERMITTENT SERVICE UP TO 1500°F. SCALES SEVERELY AT APPROXIMATELY 1650°F. THIS TEMPERATURE VARYING WITH TYPE OF ATMOSPHERE AND OTHER CONDITIONS.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

AUSTENITIC STAINLESS STEELS RETAIN THEIR HIGH IMPACT STRENGTH AFTER IRRADIATION.

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

- 423°F TO 1600°F (CONTINUOUS)
- 423°F TO 1500°F (INTERMITTENT)
(SEE SECTION G)

K. PROCESSING

SURFACE TREATMENT

SCALE MAY BE REMOVED BY A SOLUTION OF 15 TO 20 PERCENT NITRIC ACID AND 1 TO 3 PERCENT HYDROFLUORIC ACID AT 120 TO 140 F. FOR 20 TO 30 MINUTES. SCALE REMOVAL IS MORE EASILY ACCOMPLISHED WHEN PARTS HAVE BEEN HEATED IN AIR.

CHLORINATED HYDROCARBON CLEANERS, SUCH AS TRICHLOROETHYLENE, SHOULD BE AVOIDED SINCE THEY MAY CONTRIBUTE TO STRESS-CORROSION CRACKING.

THERMAL TREATMENT

AVOID PROLONGED HEATING AT TEMPERATURES FROM 800° TO 1600°F (SEE SECTION F). ALL HEATING SHOULD BE CONDUCTED IN AIR OR INERT ATMOSPHERES SUCH AS HELIUM, ARGON, OR DISSOCIATED AMMONIA.

ANNEALING

WROUGHT PRODUCTS:

1850-2150°F, AIR COOL OR QUENCH DEPENDING ON SECTION SIZE. 1950°F MINIMUM FOR SHEET.

CASTING:

1950-2100°F, AIR COOL OR QUENCH, USE LOW SIDE OF TEMPERATURE RANGE FOR CF-8M; HIGH SIDE (ABOVE 2000°F) FOR CF-12M.

STABILIZING FOR HIGH-TEMPERATURE SERVICE
1625-1675°F, 2-4 HR. FURNACE OR AIR COOL

STRESS RELIEF
400-750°F, 1/2 TO 2 HR

ALLOY CAN ONLY BE HARDENED BY COLD WORK

K. PROCESSING (CONTINUED)

JOINING

MAY BE WELDED BY CONVENTIONAL TECHNIQUES. OXY-ACETYLENE WELDING IS NOT ADVISABLE FOR CASTINGS BECAUSE OF POSSIBLE IMPAIRMENT OF CORROSION RESISTANCE DUE TO CARBON PICK-UP.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

AISI 316/MIL-R-5031, CL. 4
AISI 316 ELC/MIL-R-5031, CL. 17
ER 316/ASTM-A-371, CL. ER316
ER 316L/ASTM-A-371, CL. ER316L

FORMING

FORMING SHOULD BE DONE AT ROOM OR FORGING TEMPERATURES, BUT NOT IN THE CARBIDE PRECIPITATION RANGE.

MACHINABILITY

ABOUT 50% OF THAT OF MILD CARBON STEELS.

L. REFERENCES

NP-64-8

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

AISI 321 IS A STABILIZED STAINLESS STEEL. TITANIUM IS ADDED TO COMBINE WITH CARBON AND TO PREVENT THE FORMATION OF CHROMIUM CARBIDES WHICH WOULD LOWER THE CORROSION RESISTANCE.

THE PROPERTIES IN SECTION E ARE AVERAGES EXCEPT FOR ULTIMATE TENSILE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION IN AREA, WHICH ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

18-8 Ti STAINLESS STEEL

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP AND PLATE	MIL-S-6721 QQ-S-766 AMS 5510
BAR, FORGINGS	QQ-S-763 AMS 5645
TUBING, SEAMLESS	MIL-T-8606 AMS 5570
TUBING, WELDED	MIL-T-6737

SUPPLIERS

ALLEGHENY-LUDLUM STEEL CO.
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
U. S. STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.08	2.00	1.00	.040	.030	19.0	11.0	0.50
MINIMUM	-	-	0.40	-	-	17.0	8.0	-

	Ti	Cu	Fe
MAX.	0.70	0.50	BAL
MIN.	6XC	-	-

SOURCE NP-64-8

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SHEET, STRIP	PLATE	BAR	1.0-IN. BAR
ANNEALED	ANNEALED	ANNEALED	ANN. & CD
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	PSI	PSI
72,000	68,000	68,000	76,000

TENSILE YIELD STRENGTH F_{TY}	PSI
28,000	24,000
28,000	48,000

COMP. YIELD STRENGTH F_{CY}	PSI
45,000	

SHEAR STRENGTH F_{SU}	PSI
74,000	

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
77,000	

ELONGATION e	%
40	44
44	32

REDUCTION OF AREA RA	%
52	48

MODULUS OF ELASTICITY E	10^6 PSI
ANNEALED	27

MODULUS OF RIGIDITY G	10^6 PSI
-------------------------	------------

COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
-----------------------------------	------------

HARDNESS	ROCKWELL
$R_B 85$	$R_B 84$
$R_B 84$	$R_B 96$

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
0.29	

SPECIFIC HEAT C	BTU/LB - °F
0.12	

THERMAL CONDUCTIVITY k	$\frac{BTU - FT}{HR - FT^2 - °F}$
--------------------------	-----------------------------------

ANNEALED (32°F)	7.74
-----------------	------

MEAN COEFF. LIN. THERMAL EXPANS. α	$\frac{10^{-6} IN.}{IN. - °F}$
---	--------------------------------

ANNEALED (70° TO 200°F)	9.2
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ELECTRICAL RESISTIVITY R	MICROHM - IN.
27.5	

MAGNETIC PROPERTIES

NON-MAGNETIC IN ANNEALED CONDITION, BECOMES SLIGHTLY MAGNETIC WHEN SEVERELY COLD WORKED.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2550 - 2600°F.

PHASE CHANGES

SUBJECT TO CARBIDE PRECIPITATION AFTER HEATING TO ABOVE 1900°F, FOLLOWED BY HEATING AT 800° - 1500°F. COLD WORK WILL CAUSE TRANSFORMATION OF A SMALL AMOUNT OF AUSTENITE TO FERRITE.

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k ($\frac{BTU - FT}{HR - FT^2 - °F}$)
-250	7.1
-200	7.3
-100	7.7
68	8.4
200	9.0
400	9.8
600	10.7
800	11.5
1000	12.4
1200	13.2
1400	14.1
1600	14.9
1640	15.0
1790	15.0
1790	15.6
1990	16.4
2165	17.0
2315	17.6

F. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

GENERAL GOOD CORROSION RESISTANCE. INTERGRANULAR CORROSION IS ABSENT IN THIS STEEL, UNLESS OVER-HEATED ABOVE 1900°F. AT THIS TEMPERATURE TITANIUM CARBIDES ARE GOING INTO SOLID SOLUTION, AND SUBSEQUENT RAPID COOLING, FOLLOWED BY HEATING AT ABOUT 1200°F WILL CAUSE PRECIPITATION AND REDUCE RESISTANCE TO INTERGRANULAR ATTACK. FULL ANNEALING OR A STABILIZING ANNEAL WILL ELIMINATE THE CONDITION.

STRESS CRACKING MAY OCCUR IN WATER CONTAINING SMALL AMOUNTS OF CHLORIDES.

PASSIVATING IMPROVES THE CORROSION RESISTANCE.

OXIDATION RESISTANCE IS GOOD UP TO 1600°F FOR CONTINUOUS SERVICE, AND TO 1700°F FOR INTERMITTENT SERVICE.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

AUSTENITIC STAINLESS STEELS RETAIN THEIR HIGH IMPACT STRENGTH AFTER IRRADIATION.

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

-423°F TO 1500°F

K. PROCESSING

SURFACE TREATMENT

SCALE MAY BE REMOVED BY A SOLUTION OF 15 - 20 OF NITRIC ACID AND 1 - 3% HYDROFLUORIC ACID, AT 120 - 140°F FOR 20 - 30 MINUTES. SCALE REMOVAL IS EASIER WHEN PARTS HAVE BEEN HEATED IN AIR.

THE USE OF CHLORINATED HYDROCARBONS SUCH AS TRICHLOROETHYLENE, SHOULD BE AVOIDED SINCE THEY MAY CONTRIBUTE TO STRESS-CORROSION CRACKING.

THERMAL TREATMENT

FULL ANNEAL:
1750° - 1900°F (1750° TO 1850°F PREFERRED, SEE SECTION G) 1 HOUR PER INCH OF THICKNESS, 2 HOURS MINIMUM FOR PLATE. FURNACE OR AIR COOL.

STABILIZING ANNEAL:
(FOR SERVICE AT 800° - 1500°F) 1500° - 1650°F, 1 HOUR PER INCH AT THICKNESS, 2 HOURS MINIMUM FOR PLATE.

STRESS RELIEF AFTER FABRICATION:
1300°F.

ALLOY CAN ONLY BE HARDENED BY COLD WORK.

K. PROCESSING (CONTINUED)

JOINING

FUSION WELDING THIS ALLOY WITHOUT IMPAIRING THE STABILIZATION IS OBTAINED ONLY IF TYPE 347 WELDING ROD IS USED.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

AISI 347/MIL-R-5031, CL. 5A
AISI 349/MIL-R-5031, CL. 6
ER 349/ASTM-A-371, CL. ER349

FORMING

FORMABILITY IS GOOD AND IS COMPARABLE TO THAT OF AISI 301.

MACHINABILITY

ABOUT 50% OF MILD CARBON STEEL.

L. REFERENCES

NP-64-B

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

IMPACT STRENGTH
ROCKWELL HARDNESS

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

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DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

AISI 347 IS A STABILIZED STAINLESS STEEL. THE ELEMENT COLUMBIUM IS ADDED FOR STABILIZATION. BECAUSE TANTALUM IS USUALLY IN COMBINATION AND SIMILAR CHEMICALLY, THE STABILIZING ELEMENT CONTENT IS SPECIFIED AS THE TOTAL OF COLUMBIUM AND TANTALUM FOR NUCLEAR APPLICATIONS, TANTALUM CAN BE LIMITED TO 0.1% MAXIMUM, AND THE ALLOY IS THEN DESIGNATED AS TYPE 348. A FREE-MACHINING VARIETY CONTAINING SELENIUM IS ALSO AVAILABLE.

THIS MATERIAL IS AVAILABLE IN ALL WROUGHT FORMS AND AS CASTINGS.

B. COMMERCIAL DESIGNATIONS

AISI 347, COLUMBIUM-STABILIZED 18-8 STEEL
CAST: CF-8C, 347C

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP AND PLATE	MIL-S-6721 QQ-S-766 AMS 5512
TUBING, SEAMLESS	MIL-T-8606 AMS 5571
TUBING, WELDED	MIL-T-6737 AMS 5575
BAR, FORGINGS	QQ-S-763 AMS 5646
WELDING WIRE	MIL-R-5031 AMS 5680
ELECTRODE, COATED, WELDING	MIL-E-6844 AMS 5681

SUPPLIERS

ALLEGHENY-LUDLUM STEEL CO.
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
U. S. STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.08	2.0	1.0	.040	.030	19.5	14.0	0.50
MINIMUM	-	-	-	-	-	17.0	9.0	-

SOURCE	NP-64-8	MAX.	1.50	0.50	Fe
		MIN.	10XC	-	-

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

BAR AND SHEET	
TENSILE ULTIMATE STRENGTH F_{TU}	PSI
	74,000
TENSILE YIELD STRENGTH F_{TY}	PSI
	32,000
COMP. YIELD STRENGTH F_{CY}	PSI
SHEAR STRENGTH F_{SU}	PSI
ULTIMATE BEARING STRENGTH F_{BRU}	PSI
ELONGATION e	%
	SHEET 36 BAR 38
REDUCTION OF AREA RA	%
	(SHEET) 35 (BAR) 54
MODULUS OF ELASTICITY E	10^6 PSI
	29.3
MODULUS OF RIGIDITY G	10^6 PSI
	10.8
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
PLASTIC BENDING MODULUS	(SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.29
SPECIFIC HEAT C	BTU/LB - °F
	0.115
THERMAL CONDUCTIVITY k	$\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$
	16.0
MEAN COEFF. LIN. THERMAL EXPANS. α	$\frac{10^{-6}}{IN. \cdot ^\circ F}$
(75°-150°F)	9.1
ELECTRICAL RESISTIVITY R	MICROHM - IN.
	30.8
MAGNETIC PROPERTIES	

NON-MAGNETIC IN THE ANNEALED CONDITION. BECOMES SLIGHTLY MAGNETIC WHEN SEVERELY COLD WORKED. 20% COLD WORK RAISES PERMEABILITY FROM LESS THAN 1.02 TO 1.5.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2550° - 2650°F.

PHASE CHANGES

SUBJECT TO CARBIDE PRECIPITATION AFTER HEATING ABOVE 2150°F, FOLLOWED BY HEATING AT ABOUT 1200°F (SEE SECTION G).

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	$k \left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$
-250	7.1
-200	7.3
-100	7.7
68	8.4
200	9.0
400	9.8
600	10.7
800	11.5
1000	12.4
1200	13.2
1400	14.1
1600	14.9
1640	15.0
1790	15.6
1990	16.4
2165	17.0
2315	17.6

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

GENERAL CORROSION RESISTANCE OF THIS STEEL IS SIMILAR TO THAT OF TYPE 302, BUT IT HAS A GREATER TENDENCY TO PITTING CORROSION AND ATTACK IN STREAKS.

INTERGRANULAR CORROSION IS ABSENT IN THIS STEEL, UNLESS IT IS OVERHEATED TO ABOVE 2150 F. AT THIS TEMPERATURE COLUMBIUM CARBIDES ARE GOING INTO SOLID SOLUTION AND SUBSEQUENT RAPID COOLING, FOLLOWED BY HEATING TO 1200 F, WILL CAUSE PRECIPITATION AND REDUCE THE RESISTANCE TO INTERGRANULAR ATTACK. A STABILIZING ANNEAL WILL RESTORE THE CORROSION RESISTANCE.

STRESS CRACKING MAY OCCUR IN WATER CONTAINING SMALL AMOUNTS OF CHLORIDES.

PASSIVATING WILL IMPROVE THE CORROSION RESISTANCE.

OXIDATION RESISTANCE IS GOOD UP TO 1700°F FOR CONTINUING SERVICE AND 1600°F FOR INTERMITTENT SERVICE.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

THERMAL NEUTRON CROSS-SECTION IS 2.72 BARNS AT A MINIMUM CONTENT OF NICKEL, CHROMIUM, AND MANGANESE, AND 2.96 BARNS AT MAXIMUM CONTENT OF THESE ELEMENTS.

AUSTENITIC STAINLESS STEELS RETAIN THEIR HIGH IMPACT STRENGTH AFTER IRRADIATION, IN CONTRAST TO FERRITIC STEELS WHICH MAY BECOME EMBRITTLED.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

-423° TO 1800°F.

K. PROCESSING
SURFACE TREATMENT

SCALE MAY BE REMOVED BY A SOLUTION OF 15-20% NITRIC ACID AND 1-3% OF HYDROFLUORIC ACID, AT 120°-140°F FOR 20 - 30 MINUTES. SCALE REMOVAL IS EASIER WHEN PARTS HAVE BEEN HEATED IN AIR.

THE USE OF CHLORINATED HYDROCARBONS, SUCH AS TRICHLOROETHYLENE, SHOULD BE AVOIDED SINCE THEY MAY CONTRIBUTE TO STRESS-CORROSION CRACKING.

THERMAL TREATMENT
ANNEALING:

WROUGHT PRODUCTS, 1800° - 2000°F (1800° - 1900°F PREFERRED), 1 HOUR PER INCH OF THICKNESS, 2 HOURS MINIMUM FOR PLATE, FURNACE COOL, OR AIR COOL.

CASTINGS:

1950° - 2050°F 30 MINUTES AT TEMPERATURE QUENCH OR AIR COOL.

STABILIZATION FOR SERVICE:

AT 800° - 1500°F, HEAT TO 1500° - 1650°F, HOLD ONE HOUR PER INCH OF THICKNESS, 2 HOURS MINIMUM FOR PLATE.

STRESS RELIEF:

AFTER FABRICATION 1300°F.

ALLOY CAN BE HARDENED ONLY BY COLD-WORKING.

K. PROCESSING (CONTINUED)
JOINING

FUSION WELDING OF THIS ALLOY IS MORE DIFFICULT THAN THAT OF OTHER 18-8 GRADES. POSTWELD ANNEALING IS NOT REQUIRED ALTHOUGH A STRESS-RELIEF IS RECOMMENDED. TYPES 347 OR 349 FILLERS ARE USED.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

AISI 347/MIL-R-5031, CL. 5A

AISI 349/MIL-R-5031, CL. 6

ER 349/ASTM-A-371, CL. ER349

FORMING

FORMABILITY IS GOOD. A STRESS RELIEF OR ANNEALING IS RECOMMENDED AFTER FABRICATION.

MACHINABILITY
L. REFERENCES

NP-60-2

NP-61-3

NP-64-8

NP-65-1

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

FERROUS ALLOYS

MATERIALS DATA

V

FERROUS ALLOYS

C.

MARTENSITIC STAINLESS STEELS

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DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

ASI 440C IS A HIGH CHROMIUM, HIGH-CARBON, STAINLESS STEEL, WHICH MAY BE HARDENED BY HEAT TREATMENT. HARDNESSES ARE HIGH AND MAY EXCEED $R_C 60$. THIS MATERIAL IS USED WHERE WEAR RESISTANCE AND DIMENSIONAL STABILITY ARE REQUIRED.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGES, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE PROPERTIES ARE GIVEN AS 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

ASI 440C

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, FORGINGS AND FORGING STOCK	QQ-S-763 AMS 5630
CASTINGS, PRECISION INVESTMENT	AMS 5352

SUPPLIERS

ALLEGHENY-LUDLUM STEEL CO.
CRUCIBLE STEEL CO.
REPUBLIC STEEL CO.
U. S. STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	1.20	1.00	1.00	.040	.030	18.0	0.75	0.75
MINIMUM	0.95	-	-	-	-	16.0	-	0.35

SOURCE NP-64-8

MAX. Fe BAL.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ALL FORMS ANNEALED
TENSILE ULTIMATE STRENGTH F_{TU} PSI
88,000 228,000

TENSILE YIELD STRENGTH F_{TY} PSI
52,000 220,000

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e %
13 2

REDUCTION OF AREA RA %
20 8

MODULUS OF ELASTICITY E 10^6 PSI
29.0

MODULUS OF RIGIDITY G 10^6 PSI

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

HARDNESS ROCKWELL
 $R_B 97$ $R_C 57$

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³
0.28

SPECIFIC HEAT C BTU/LB - °F
0.11

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F

(212°F.) 14.0
MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN. / IN. - °F

(32° - 212°F) 5.6

ELECTRICAL RESISTIVITY R MICROHM - IN.
23.6

MAGNETIC PROPERTIES
FERROMAGNETIC

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2500° - 2700°F.

PHASE CHANGES
ALLOY TRANSFORMS FROM AUSTENITE TO MARTENSITE ON RAPID COOLING. SEE SECTION K.

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

TYPE 440C IS RESISTANT TO ATMOSPHERIC AND FRESH WATER CORROSION, AND TO A VARIETY OF MILD ACIDS AND ALKALINES. HOWEVER, IT IS INFERIOR TO THE 300 SERIES STAINLESS STEELS IN CORROSION RESISTANCE. CORROSION PROTECTION IS FREQUENTLY REQUIRED. THE SURFACE MUST BE FREE FROM SCALE AND FOREIGN PARTICLES IN ORDER TO PREVENT GALVANIC CORROSION. CORROSION RESISTANCE IS BEST IN THE FULLY HARDENED CONDITION WITH A POLISHED SURFACE.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

IRRADIATION TENDS TO INCREASE THE HARDNESS, TENSILE STRENGTH, AND YIELD STRENGTH. THIS EFFECT INCREASES WITH INCREASING IRRADIATION.

DUCTILITY AND IMPACT STRENGTH DECREASE WITH INCREASING IRRADIATION, WHILE DENSITY IS UNCHANGED.

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

OXIDATION RESISTANCE IS GOOD UP TO 1400°F FOR CONTINUOUS SERVICE AND UP TO 1500°F FOR INTERMITTENT SERVICE.

MATERIAL IS USEFUL IN BEARING APPLICATIONS TO -423°F.

K. PROCESSING

SURFACE TREATMENT

PICKLING IS PERFORMED AS FOLLOWS: (ALTERNATE TREATMENTS)

- (A) 8 TO 12% H_2SO_4 AT 150 TO 170°F.
 - (B) 6 TO 10% HCl + 10% H_2SO_4 AT 130 TO 140°F.
 - (C) 10% HNO_3 + 2% HF AT 120 TO 130°F.
- THE MATERIAL SHOULD BE ANNEALED OR STRESS RELIEVED TO PREVENT CRACKING ON PICKLING.

CLEANING BY SANDBLASTING OR MECHANICAL BREAKING OF HEAVY SCALE IS RECOMMENDED PRIOR TO PICKLING TO AVOID LOCALIZED OVERPICKLING.

THERMAL TREATMENT

FULL ANNEAL

BAR AND FORGINGS. 1550 TO 1650°F, FURNACE COOL. PRECISION INVESTMENT CASTINGS. 1625 TO 1675°F, 1 HOUR MINIMUM, FURNACE COOL AT 25°F PER HOUR MAXIMUM TO 1200°F MAXIMUM.

SUBCRITICAL ANNEAL. 1250 TO 1450°F.

SPHEROIDIZING ANNEAL FOR BEST MACHINABILITY OF PRECISION INVESTMENT CASTINGS. 1875°F, 1 HOUR AIR COOL + 1350°F, 32 HOURS.

STRESS RELIEF AFTER FORGING TYPE 440C 1200°F.

AUSTENITIZE

1850 TO 1950°F, RAPID AIR COOL OR OIL QUENCH. TYPE 440C SHOULD BE PREHEATED AT 1450 TO 1500°F.

TEMPER

300° TO 800°F, PREFERABLY 400° TO 500°F

THIS STEEL IS ESPECIALLY SUSCEPTIBLE TO DE-CARBURIZATION BECAUSE OF ITS HIGH CARBON CONTENT. FOR THIS REASON NEUTRAL ATMOSPHERES OR SALT BATHS SHOULD BE USED FOR HEAT TREATING THIS STEEL.

CARE SHOULD BE TAKEN IN HEATING AND COOLING TO AVOID CRACKING.

K. PROCESSING (CONTINUED)

JOINING

FOR FUSION WELDING THIS ALLOY, ELECTRODES OF SIMILAR COMPOSITION CAN BE USED. IF A SOFTER WELD CAN BE TOLERATED, AUSTENITIC STAINLESS STEEL ELECTRODES, TYPES 309 OR 310, CAN BE USED. PREHEAT AT 450°F AND POSTHEAT AT 1300°F, AIR COOL.

CARE IN HEATING, WELDING, OR COOLING SHOULD BE TAKEN TO PREVENT POST-TREATING CRACKING.

WELDING NOT RECOMMENDED

FORMING

FORGING

STARTING TEMPERATURE 2050°F MAXIMUM, FINISHING TEMPERATURE 1700°F MINIMUM. HEATING TIME IS ABOUT TWICE THAT FOR CARBON STEELS. PREHEATING AT 1400 TO 1500°F IS RECOMMENDED. FURNACE COOL AFTER FORGING TO 1200°F OR COOL UNDER INSULATING COVER. ALTERNATIVELY, STRESS RELIEVE TYPE 440C BY PLACING, AFTER FORGING, IN FURNACE HELD AT 1200°F.

MACHINABILITY

THIS ALLOY IS DIFFICULT TO MACHINE. MACHINING IS GENERALLY PERFORMED IN THE FULLY ANNEALED CONDITION FOR BAR AND FORGINGS, AND IN THE SPHEROIDIZED CONDITION FOR CASTINGS. THE MACHINABILITY RATING IS ABOUT 40% OF THAT OF MILD STEEL.

L. REFERENCES

NP-64-8

DATE 1 MAY 1966
SUPERSEDES

IMPACT STRENGTH
ROCKWELL HARDNESS

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

FERROUS ALLOYS

MATERIALS DATA

**V
FERROUS METALS**

**D.
PRECIPITATION-HARDENING STAINLESS STEELS**

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

AIN 630 IS AN AGE-HARDENING STAINLESS STEEL. IT IS AVAILABLE IN MANY WROUGHT FORMS AND AS CASTINGS.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGES, EXCEPT FOR F_{TU} , F_{TY} , e , AND RA . F_{TU} , F_{TY} , AND e ARE MANUFACTURER-GUARANTEED VALUES; RA IS 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

17-4 PH STAINLESS STEEL

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR, FORGINGS	AMS 5643
CASTINGS, PRECISION INVESTMENT	AMS 5355
CASTINGS, SAND AND CENTRIFUGAL	AMS 5398

SUPPLIERS

ARMCO STEEL CORP.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	P	S	SI	Cr	Ni	Cu
MAXIMUM	0.07	1.00	.040	.030	1.00	17.5	5.00	5.00
MINIMUM	-	-	-	-	-	15.5	3.00	3.00
SOURCE	NP-64-8				MAX. 0.45 BAL. MIN. 0.15 -			

E. ROOM TEMPERATURE PROPERTIES

I. MECHANICAL PROPERTIES

	CONDITION A*	CONDITION H900 *
* SEE SECTION K		
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	
MAX. 185,000		
MIN. 190,000		
TENSILE YIELD STRENGTH F_{TY}	PSI	
MAX. 160,000		
MIN. 170,000		
COMP. YIELD STRENGTH F_{CY}	PSI	
178,000		
ULTIMATE SHEAR STRENGTH F_{SU}	PSI	
130,000		
SHEAR YIELD STRENGTH F_{SY}	PSI	
ULTIMATE BEARING STRENGTH F_{BRU}	PSI	
$e/D = 1.5$		
$e/D = 2.0$		
YIELD BEARING STRENGTH F_{BRY}	PSI	
$e/D = 1.5$		
$e/D = 2.0$		
ELONGATION e	%	
MAX. 3		
MIN. 5		
REDUCTION OF AREA RA	%	
28		
MODULUS OF ELASTICITY E	10^6 PSI	
29		
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI	
MODULUS OF RIGIDITY G	10^6 PSI	
POISSON'S RATIO		
HARDNESS R_C		
MAX. 38		
MIN. 40		
PLASTIC BENDING MODULUS	(SEE APPENDIX A)	

2. PHYSICAL PROPERTIES

	COND. A	COND. H900
DENSITY P	LB/IN ³	
0.280		
SPECIFIC HEAT C	BTU/LB - °F	
(CONDITION H900)	0.11	
THERMAL CONDUCTIVITY k	BTU - FT / HR - FT ² - °F	
9.2		
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. / IN. - °F	
(70° - 200°F)	6.0	
ELECTRICAL RESISTIVITY R	MICROHM - IN.	
0.11		
30.3		
MAGNETIC PROPERTIES		

THE MAGNETIC PERMEABILITY IN CONDITION A IS 74 AT 100 OERSTEDS AND 48 AT 200 OERSTEDS. THE MAXIMUM PERMEABILITY IN THIS CONDITION IS 95. IN THE H900 CONDITION, PERMEABILITY IS 100 AT 100 OERSTEDS, AND 60 AT 200 OERSTEDS. THE MAXIMUM PERMEABILITY FOR THE H900 CONDITION IS 151.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	2560° - 2625°F.
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PHASE CHANGES

ALLOY IS AUSTENITIC AT ELEVATED TEMPERATURES, BUT TRANSFORMS TO MARTENSITE ON COOLING. M_s POINT ON COOLING IS 300°F, APPROXIMATELY. THE MARTENSITE IS COMPLETELY TRANSFORMED BELOW 90°F. AGING CAUSES PRECIPITATION OF COMPLEX INTERMETALLIC COMPOUNDS WHICH PRODUCE HARDENING.

THERMAL CONDUCTIVITY VS. TEMPERATURE*

TEMPERATURE °F	k (BTU - FT / HR - FT ² - °F)
80	9.33
200	9.92
400	10.82
600	11.75
800	12.75
917	13.33

* FOR CONDITION H-900

F. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE
GENERAL CORROSION RESISTANCE TO ATMOSPHERIC AND ACID ATTACKS IS CONSIDERABLY SUPERIOR TO THAT OF MARTENSITIC STAINLESS STEELS AND COMPARES FAVORABLY WITH THAT OF AUSTENITIC STAINLESS STEELS.

ALLOY IS NOT SUSCEPTIBLE TO HYDROGEN EMBRITTLEMENT.

STRESS CORROSION OF THE HIGH STRENGTH CONDITIONS MAY OCCUR IN CERTAIN MEDIA.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

PROPERTIES

EFFECTS OF IRRADIATION ON PHYSICAL AND MECHANICAL PROPERTIES UNDER THE FOLLOWING EXPOSURE CONDITIONS (GE): WATER LOOP AT 540°F, 3 MONTHS AT 4×10^{19} NVT (THERMAL).

DENSITY AND DIMENSIONAL PROPERTIES. NO SIGNIFICANT CHANGES.

MAGNETIC SUSCEPTIBILITY. 4% INCREASE ON HARDENED ALLOY.

HARDNESS

CONDITION A, PRE-IRRADIATION R_C 33-35;
POST-IRRADIATION, R_C 48-52

CONDITION H 900, PRE-IRRADIATION, R_C 43-44;
POST-IRRADIATION, R_C 44-48

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
J. SERVICE LIMITS

-423°F to 800°F. DUCTILITY AND IMPACT STRENGTH APPROACH ZERO BELOW -320°F AND LIMIT APPLICABILITY.

K. PROCESSING
SURFACE TREATMENT

PICKLING AFTER SOLUTION TREATING OR FORGING IS PERFORMED BY THE SAME METHODS AS FOR STANDARD STEELS. WET PICKLING MAY LEAVE A SMUT WHICH CAN BE REMOVED WITH HIGH PRESSURE WATER OR BY BRUSH SCRUBBING.

DESCALING BY SALT BATH METHODS RESULTS IN AN AGED CONDITION.

PASSIVATING IS DONE IN A 10% NITRIC, 2% HYDROFLUORIC ACID SOLUTION AT 110 TO 140°F, FOR A FEW MINUTES. THIS TREATMENT ALSO REMOVES THE HEAT TINT RESULTING FROM AGING. ALTERNATIVELY THE HEAT TINT MAY BE REMOVED BY ELECTROPOLISHING.

THERMAL TREATMENT

ALLOY DEVELOPS FULL HARDENING IN ALL SECTION SIZES ON AIR COOLING.

SOLUTION TREATING (CONDITION A):

BAR, FORGINGS AND WIRE 1875° - 1925°F, HOLD 30 MINUTES, COOL TO 90°F MAXIMUM. OIL QUENCH THICKNESSES UNDER 3 IN., AIR COOL THICKNESSES OF 3 - 6 INCHES, USE RETARDED AIR COOL UNDER SHEET COVER FOR THICKNESSES GREATER THAN 6 INCHES.

PRECIPITATION HARDENING (AGING):

CONDITION	TEMPERATURE (°F)	HOLDING TIME (HR.)
H 900	890 - 910	1
H 925	915 - 935	4
H 1025	1015 - 1035	4
H 1075	1065 - 1085	4
H 1150	1140 - 1160	4

RECOMMENDED PRACTICE FOR HEATING AND HEAT TREATING IS TO USE ELECTRIC MUFFLE TYPE FURNACE, EITHER OF THE CONVECTION OR THE RADIANT HEAT TYPE.

BRIGHT HEAT TREATING IS POSSIBLE IN HYDROGEN WITH A DEW POINT BELOW -50°F. DISSOCIATED AMMONIA ANNEALING MAY CONTAMINATE THE METAL.

ON EITHER HEATING OR COOLING THICKNESSES OVER 4 INCH, AVOID SLOW TEMPERATURE CHANGES BETWEEN 1750 TO 1850°F. HEAVY SECTIONS SHOULD BE PRE-HEATED, SUCH AS AT 1200°F.

K. PROCESSING (CONTINUED)
JOINING

ANY OF THE ARC AND RESISTANCE WELDING PROCESSES USED ON AUSTENITIC STAINLESS STEELS MAY BE USED ON THIS ALLOY. SOUND JOINTS WITH PROPERTIES COMPARABLE TO THOSE OF THE PARENT METAL CAN BE OBTAINED BY USING WELD METAL OF SAME COMPOSITION AND POST-WELD ANNEALING OR HEAT TREATING. PREHEATING IS NOT REQUIRED. BECAUSE OF ITS HIGH STRENGTH, STRESS CONCENTRATIONS SHOULD BE MINIMIZED.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

AISI 630 (17-4PH)/AMS 5825
AISI 630 (17-4PH)/AMS 5827
AISI 308 ELC/MIL-R-5031, CL. 16
ER 308L/ASTM-A-371, CL. ER308L
AISI 347/MIL-R-5031, CL. 5A
ER 347/ASTM-A-371, CL. ER347

FORMING
FORGING

STARTING TEMPERATURE 2150°F MAXIMUM, FINISHING TEMPERATURE 1850°F MINIMUM. THICKNESSES OVER 3 INCH MUST BE INSERTED INTO FURNACE AT REDUCED TEMPERATURE, SUCH AS 1200°F, HEATED TO FORGING TEMPERATURE, HELD AT THIS TEMPERATURE FOR 1/2 HOUR PER INCH OF THICKNESS PLUS 1 HOUR. AFTER FORGING AND BEFORE COOLING, INSERT INTO FURNACE AND EQUALIZE AT SOME TEMPERATURE BETWEEN 1900°F AND FORGING TEMPERATURE.

MACHINABILITY

TOOL LIFE IN MACHINING THIS ALLOY IS APPROXIMATELY THE SAME AS THAT FOR TYPE 416 STAINLESS STEEL OF EQUAL HARDNESS. FOR OBTAINING CLOSE TOLERANCES ON MACHINING CONDITION A, THE CONTRACTION ON AGING MAY HAVE TO BE CONSIDERED.

COLD SAWING IS RECOMMENDED, AS HOT CUTTING OR WHEEL CUTTING MAY CAUSE CRACKING. TORCH CUTTING IS POSSIBLE WITH METHODS SUITABLE FOR AUSTENITIC STAINLESS STEELS.

L. REFERENCES

NP-64-8
NP-65-34
NP-65-37

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

AISI 631 IS A PRECIPITATION-HARDENING STAINLESS STEEL. ITS CORROSION RESISTANCE IS SUPERIOR TO THAT OF THE CHROMIUM STAINLESS STEELS (AISI 400 SERIES).

DIMENSIONAL CHANGES DURING HEAT TREATING TO CONDITIONS TH 1050 OR RH 950 NEED CONSIDERATION AND SPECIAL PROVISIONS MUST BE MADE WHEN MACHINING AND TOOLING (SEE SECTION K).

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGES, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. OF THESE LATTER PROPERTIES, TENSILE ULTIMATE STRENGTH AND TENSILE YIELD STRENGTH ARE DESIGN MINIMA FROM REFERENCE NP-61-2. ELONGATION AND REDUCTION OF AREA ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

17-7 PH STAINLESS STEEL.

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP AND PLATE (COND. A & TH 1050)	MIL-S-25043 AMS 5528
SHEET, STRIP AND PLATE (COND. A & CH 900)	AMS 5529
BAR, FORGINGS (COND. A & TH 1050)	AMS 5644
TUBING, WELDED	AMS 5568
WIRE, SPRING TEMPER	AMS 5673

SUPPLIERS

ARMCO STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Al
MAXIMUM	0.09	1.00	1.00	.040	.030	18.0	7.75	1.50
MINIMUM	-	-	-	-	-	16.0	6.50	0.75

SOURCE NP-64-8

Fe
MAX. BAL.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	ALL FORMS * TH 1050	ALL FORMS * RH 950
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	
	170,000	185,000
TENSILE YIELD STRENGTH F_{TY}	PSI	
	140,000	150,000
COMP. YIELD STRENGTH F_{CY}	PSI	
.050-0.060-IN. SHEET	199,000	230,000 (100°F)
SHEAR STRENGTH F_{SU}	PSI	
0.050-IN.- SHEET	135,000	148,000
ULTIMATE BEARING STRENGTH F_{BRU}	PSI	
ELONGATION e	%	
	8	6
REDUCTION OF AREA RA	%	
	20	14
MODULUS OF ELASTICITY E	10^6 PSI	
	29	
MODULUS OF RIGIDITY G	10^6 PSI	
	11.7	
COMP. MODULUS OF ELASTICITY E_c	10^6 PSI	
PLASTIC BENDING MODULUS (SEE APPENDIX A)		

* SEE SECTION K

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.28
SPECIFIC HEAT C	BTU/LB - °F
	0.11
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
(EXTRAPOLATED)	8.5
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN./IN. - °F
(75-100°F) RH 950	5.8
(70-300°F) TH 1050	5.5
ELECTRICAL RESISTIVITY R	MICROHM - IN.
CONDITION A	31.5
CONDITION TH1050	32.5
CONDITION RH950	32.7
MAGNETIC PROPERTIES	MAX. PERMEABILITY
CONDITION A	1.4-3.6
CONDITION TH1050	134-208
CONDITION RH950	119-135
CONDITION CH125	125

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2580° - 2640°F.

PHASE CHANGES

IN CONDITION A THIS ALLOY IS MOSTLY AUSTENITIC. CONTAINING 5 TO 20% FERRITE. AUSTENITE CONDITIONING CAUSES CARBIDES TO PRECIPITATE. M_s POINT IS 55°F IF AUSTENITE IS CONDITIONED AT 1750°F, 200°F IF AUSTENITE IS CONDITIONED AT 1400°F. HEAT TREATED CONDITIONS ARE MARTENSITIC WITH SOME AUSTENITE.

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE °F	k $\left(\frac{\text{BTU} - \text{FT}}{\text{HR} - \text{FT}^2 - ^\circ\text{F}} \right)$
300	9.41
400	10.0
500	10.56
600	11.05
700	11.48
800	12.0
900	12.53

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

GENERAL CORROSION RESISTANCE IS SUPERIOR TO THAT OF MARTENSITIC STAINLESS STEELS.

OXIDATION RESISTANCE IS COMPARABLE TO THAT OF AUSTENITIC STAINLESS STEELS.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

-423°F to 800°F. DUCTILITY AND IMPACT STRENGTH ARE VERY LOW AT CRYOGENIC TEMPERATURES, ACTUAL VALUES DEPEND ON FORM AND CONDITION. THIS REDUCES THE UTILITY OF THIS ALLOY IN THE LOWER PORTION OF THE TEMPERATURE RANGE GIVEN ABOVE.

K. PROCESSING
SURFACE TREATMENT

CLEANING PRIOR TO HEATING CONSISTS FIRST OF REMOVAL OF OIL, ETC., BY VAPOR OR SOLVENT DEGREASERS, AND SECOND OF REMOVAL OF DIRT BY SCRUBBING WITH MILD ABRASIVE CLEANERS AND RINSING WITH WARM WATER.

SCALE REMOVAL IS PREFERABLY ACHIEVED BY WET OR DRY GRIT BLASTING OR VAPOR BLASTING.

ACID PICKLING MAY CAUSE INTERGRANULAR ATTACK EXCEPT IN CONDITIONS A AND CH 900.

THERMAL TREATMENT

THOROUGH CLEANING PRIOR TO THERMAL TREATMENTS IS RECOMMENDED IN ORDER TO AVOID CARBURIZATION AND TO MINIMIZE DIFFICULTIES IN DE-SCALING.

DIMENSIONAL CHANGES ON HEAT TREATING: HEAT TREATING TO CONDITION RH 950 OR TH 1050 INCREASES DIMENSIONS BY 0.004 TO 0.005-IN. PER INCH.

HEATING AND HEAT TREATING

FOR HEATING THIS ALLOY, EITHER ELECTRIC OR RADIANT TUBE GAS FURNACE SHOULD BE USED TO PREVENT CONTACT WITH THE FLAME AND COMBUSTION PRODUCTS. SALT BATHS ARE NOT RECOMMENDED FOR HEATING WITHIN THE RANGE OF 1375° TO 1975°F BECAUSE CARBURIZING AND INTERGRANULAR ATTACK WILL OCCUR. SALTS OF THE HYDRIDE OR NITRIDE TYPE MAY BE USED FOR HEATING TO 900°F TO 1200°F.

FURNACE ATMOSPHERES SUITABLE FOR HEATING AND HEAT TREATING AT 1725°F TO 1975°F ARE AIR, DRY HYDROGEN, ARGON, OR HELIUM. AT 1400°F A SCALE-FREE PRODUCT CAN BE OBTAINED ONLY IN VACUUM.

TEMPERATURE CONTROL MUST BE ADEQUATE TO AVOID MAJOR VARIATIONS IN FINAL MECHANICAL PROPERTIES.

MATERIAL TO BE HEAT TREATED MUST BE THOROUGHLY CLEANED TO PREVENT CARBURIZING AND AN UNEVEN SCALE, WHERE SUCH CLEANING IS IMPRACTICAL, SPECIAL COATINGS MAY BE USED TO REDUCE SCALING.

K. PROCESSING (CONTINUED)
THERMAL TREATMENT (CONTINUED)

CONDITION A (SOLUTION-TREATED OR ANNEALED)
HEAT TO 1875°-1925°F, HOLD AT TEMPERATURE 30 MIN. PER INCH OF THICKNESS OR DIAMETER, AIR COOL TO ROOM TEMPERATURE.

CONDITION TH1050 (PRECIPITATION, OR AGE HARDENED)
START WITH MATERIAL IN CONDITION A. HEAT TO 1375°-1425°F, HOLD FOR 90 MINUTES. WITHIN 1 HOUR OF REMOVAL FROM FURNACE COOL TO 50°-60°F; HOLD AT TEMPERATURE 30 MIN. THIS GIVES CONDITION T. HEAT TO 1040°-1060°F FOR 90 MINUTES, AIR COOL TO ROOM TEMPERATURE.

CONDITION RH950 (TRANSFORMED AT -100°F BEFORE AGE HARDENING). START WITH MATERIAL IN CONDITION A. HEAT TO 1725°-1775°F. HOLD FOR TEN MINUTES, AIR COOL TO ROOM TEMPERATURE. COOL TO -90° TO -110°F, HOLD FOR 8 HR. THIS GIVES CONDITION R-100. HEAT TO 940°-960°F, HOLD FOR 60 MINUTES, AIR COOL TO ROOM TEMPERATURE.

JOINING
WELDING

BOTH FUSION WELDING AND SPOT WELDING OF 17-7 PH IS READILY PERFORMED. THE SURFACES SUBJECT TO WELDING MUST BE CLEANED BY SAND OR VAPOR BLASTING TO AVOID POROUS WELD METAL.

INERT-GAS TUNGSTEN-ARC FUSION WELDING OF ANNEALED AND SUBSEQUENTLY HEAT TREATED METAL YIELDS A WELD EFFICIENCY OF 95 TO 100%. WELDING OF CONDITION TH 1050 YIELDS A WELD EFFICIENCY OF ABOUT 65%. HELIUM OR COPPER CHILL BLOCKS WITH GROOVES FOR THE GAS MAY BE USED TO BACK UP THE WELD. EXCESSIVE TEMPERATURES LEADING TO LOSS OF ALUMINUM MUST BE AVOIDED.

FUSION WELDED JOINTS OF 17-7 PH IN CONDITION A WITH 17-4 PH ELECTRODES CAN BE HEAT TREATED TO F_{TU} OF 170,000 PSI MINIMUM BY AUSTENITE CONDITIONING AT 1400°F FOLLOWED BY AGE HARDENING AT 950°F. SLIGHTLY HIGHER STRENGTH MAY BE OBTAINED BY AUSTENITE CONDITIONING AT 1600°F AND AGE HARDENING AT 900°F.

SPOT WELDING AND SEAM WELDING ARE READILY PERFORMED BY TECHNIQUES SIMILAR TO THOSE USED FOR AUSTENITIC STAINLESS STEELS. BEST RESULTS ARE OBTAINED BY WELDING IN PARTLY OR FULLY HEAT TREATED CONDITIONS.

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

AIISI 630 (17-4PH)/AMS 5825
AIISI 630 (17-4PH)/AMS 5827
AIISI 308/MIL-R-5031, CL. 1
AIISI 308 ELC/MIL-R-5031, CL. 16
ER 308/ASTM-A-371, CL. ER308
ER 308L/ASTM-A-371, CL. ER308L
AGC 44039

K. PROCESSING (CONTINUED)
FORMING

SHEET PARTS ARE NORMALLY FORMED IN THE ANNEALED CONDITION A WHICH POSSESSES FORMING CHARACTERISTICS SIMILAR TO ANNEALED AUSTENITIC STAINLESS STEELS. IN DRAWING AND SEVERE FORMING OPERATIONS, CONSIDERABLE COLD WORK HARDENING WILL OCCUR IN LOCALIZED AREAS. THIS CAUSES A NON-UNIFORM CONDITION WHICH MAY NOT BE COMPLETELY ELIMINATED BY HEAT TREATMENT. HOWEVER, THIS HAS NOT BEEN FOUND OBJECTIONABLE BY MOST USERS. IF COMPLETE UNIFORMITY IS REQUIRED IN CRITICAL PARTS WHICH HAVE BEEN SEVERELY COLD WORKED, ANNEALING TO CONDITION A AFTER FABRICATING AND BEFORE HEAT TREATMENT TO CONDITION TH 1050 IS RECOMMENDED. WHEN THE RH 950 HEAT TREATMENT IS USED, THE 1750°F AUSTENITE CONDITIONING ACTS LIKE A FULL ANNEAL.

PARTS FORMED IN CONDITION A WILL FREQUENTLY REQUIRE SIZING IN THE FULL OR PARTLY AGE HARDENED CONDITION.

SIZING DURING COOLING FROM 1400°F IS ALSO FOUND TO BE USEFUL. WHERE DIMENSIONAL OR OTHER REQUIREMENTS CANNOT BE MET AFTER FULL HEAT TREATMENT, FORMING CAN BE PERFORMED IN SOME INTERMEDIATE CONDITION FOLLOWED BY SPECIAL AGE HARDENING TREATMENTS WITH ALLOWANCE FOR REDUCED STRENGTH.

FORGING. STARTING TEMPERATURE 2200°F MAXIMUM, FINISHING TEMPERATURE 1700°F MINIMUM.

MACHINABILITY

MATERIAL IS USUALLY MACHINED IN CONDITION T* OR R-100* BY TECHNIQUES SUITABLE FOR ANNEALED AUSTENITIC STAINLESS STEELS. FURTHER THERMAL PROCESSING OF THESE CONDITIONS RESULTS IN MINIMAL DIMENSIONAL CHANGES. MACHINING OF CONDITION A IS DONE USING THE SAME TECHNIQUES. LARGE CUTS SHOULD BE TAKEN.

* SEE SECTION K, THERMAL PROCESSING.

L. REFERENCES

NP-64-8

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

IMPACT STRENGTH
ROCKWELL HARDNESS

REDUCTION OF AREA
ELONGATION

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

AISI 632 IS A PRECIPITATION-HARDENABLE STAINLESS STEEL. IT HAS HIGHER STRENGTH AT ROOM AND ELEVATED TEMPERATURES THAN AISI 631.

DIMENSIONAL CHANGES DURING HEAT TREATING TO CONDITIONS TH 1050 OR RH 950 NEED CONSIDERATION AND SPECIAL PROVISIONS MUST BE MADE FOR MACHINING AND TOOLING. SEE SECTION K.

THE PROPERTIES GIVEN IN SECTION E-I ARE DESIGN MINIMA FROM REFERENCE NP-64-3, EXCEPT FOR ULTIMATE BEARING STRENGTH AND BEARING YIELD STRENGTH, WHICH ARE AVERAGES.

B. COMMERCIAL DESIGNATIONS

PH 15-7 MO STAINLESS STEEL

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP AND PLATE	AMS 5520
BARS AND FORGINGS	AMS 5657
WIRE, WELDING	AMS 5812 AMS 5813

SUPPLIERS

ARMCO STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Al	C	Cr	Mn	Mo	Ni	P	Si
MAXIMUM	1.50	0.09	16.0	1.00	3.00	7.75	0.04	1.00
MINIMUM	0.75	-	14.0	-	2.00	6.50	-	-

SOURCE NP-64-8

MAX. 0.03 BAL.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

COND. RH 950 * SHEET 0.005 TO 0.125-IN.	COND. TH 1050 * SHEET & PLATE 0.015 TO 0.5-IN.
TENSILE ULTIMATE STRENGTH F_{TU}	PSI
225,000	190,000

TENSILE YIELD STRENGTH F_{TY}	PSI
200,000	170,000

COMP. YIELD STRENGTH F_{CY}	PSI
220,000	185,000

SHEAR STRENGTH F_{SU}	PSI
135,000	120,000

ULTIMATE BEARING STRENGTH F_{BRU}	PSI
(e/d = 1.5) (0.050-IN. SHEET)	318,000
(e/d = 2.0) (0.050-IN. SHEET)	400,000

BEARING YIELD STRENGTH F_{BRY}	PSI
(e/d = 1.5) (0.050-IN. SHEET)	270,000
(e/d = 2.0) (0.050-IN. SHEET)	322,000

ELONGATION e	%
5.0	6.0

REDUCTION OF AREA RA	%
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MODULUS OF ELASTICITY E	10^6 PSI
29.0	

MODULUS OF RIGIDITY G	10^6 PSI
11.7	

COMP. MODULUS OF ELASTICITY E_c	10^6 PSI
30.0	

PLASTIC BENDING MODULUS	(SEE APPENDIX A)
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2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
0.28	

SPECIFIC HEAT C	BTU/LB - °F
0.11	

THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
8.75	

MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN./IN. - °F
(75-200°F) (CONDITION TH 1050) 6.1	
(75-200°F) (CONDITION RH 950) 4.5	

ELECTRICAL RESISTIVITY R	MICROHM - IN.
32.2	

MAGNETIC PROPERTIES - MAXIMUM PERMEABILITY

CONDITION A	5.3
CONDITION TH 1050	150
CONDITION RH 950	119

POISSON'S RATIO	
CONDITION RH 950	0.30

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
2580° - 2640°F.	

PHASE CHANGES

IN CONDITION A, THIS MATERIAL IS MOSTLY AUSTENITIC, CONTAINING 5 TO 20% FERRITE. AUSTENITE CONDITIONING CAUSES CARBIDES TO PRECIPITATE. M_s POINT IS 55°F, IF AUSTENITE IS CONDITIONED AT 1750°F, 200°F IF AUSTENITE IS CONDITIONED AT 1400°F. HEAT TREATED CONDITIONS ARE MARTENSITIC WITH SOME AUSTENITE.

THERMAL CONDUCTIVITY VS TEMPERATURE		
TEMPERATURE (°F)	k $\left(\frac{\text{BTU} \cdot \text{FT}}{\text{HR} \cdot \text{FT}^2 \cdot ^\circ\text{F}} \right)$	
	TH 1050	RH 950
70	8.7	8.7
200	9.3	9.3
400	10.3	10.2
600	11.3	11.1
800	12.2	12.0
900	-	12.5
1000	13.2	-

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE.

GENERAL CORROSION RESISTANCE OF THIS ALLOY IS SUPERIOR TO THAT OF MARTENSITIC STAINLESS STEELS AND, IN CONDITION CH 900, IT IS COMPARABLE TO THAT OF AUSTENITIC STAINLESS STEELS.

SALT SPRAY TESTS ON 0.051-INCH SHEET IN CONDITIONS TH 1050 AND RH 950 INDICATE NO LOSS IN STRENGTH AND LONGITUDINAL ELONGATION, BUT SHOW REDUCTION IN TRANSVERSE ELONGATION TO ABOUT 1% AFTER 250 AND 1000 HOUR EXPOSURE.

STRESS CORROSION CRACKING

AT HIGH STRESS LEVELS AND HIGH STRENGTH, THIS MATERIAL SHOWS A TENDENCY TO CRACK IN STRESS CORROSION. EACH SITUATION REQUIRES AN INDIVIDUAL EVALUATION.

INTERGRANULAR CORROSION MAY OCCUR DURING ACID PICKLING, EXCEPT IN CONDITIONS A AND CH 900. HYDROGEN EMBRITTLEMENT MAY OCCUR DURING PLATING AND RECOMMENDED PROCEDURES FOR PREVENTING SAME MUST BE FOLLOWED.

OXIDATION RESISTANCE IS COMPARABLE TO THAT OF THE AUSTENITIC STAINLESS STEELS.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

J. SERVICE LIMITS

RT TO 1000°F FOR ALL CONDITIONS.

CONDITION RH 950 SHOWS GOOD TENSILE ULTIMATE STRENGTH AND TENSILE YIELD STRENGTH AT -423°F. NOTCHED TENSILE STRENGTH - TENSILE STRENGTH RATIO, HOWEVER, IS LOW, BEING ONLY 0.53. IMPACT STRENGTH IS ALSO VERY LOW AT -423°F, BEING 3 FT-LBS.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
K. PROCESSING
SURFACE TREATMENT
TREATING

CLEANING PRIOR TO HEATING CONSISTS FIRST OF REMOVAL OF OIL, ETC., BY VAPOR OR SOLVENT DEGREASERS, AND SECOND OF REMOVAL OF DIRT BY SCRUBBING WITH MILD ABRASIVE CLEANERS AND RINSING WITH WARM WATER.

SCALE REMOVAL IS PREFERABLY ACHIEVED BY WET OR DRY GRIT BLASTING OR VAPOR BLASTING.

ACID PICKLING MAY CAUSE INTERGRANULAR ATTACK EXCEPT IN CONDITIONS A AND CH 900.

THERMAL TREATMENT

FOR HEATING THIS ALLOY, EITHER ELECTRIC OR RADIANT TUBE GAS FURNACE SHOULD BE USED TO PREVENT CONTACT WITH THE FLAME AND COMBUSTION PRODUCTS. SALT BATHS ARE NOT RECOMMENDED FOR HEATING WITHIN THE RANGE OF 1375° TO 1975°F BECAUSE CARBURIZING AND INTERGRANULAR ATTACK WILL OCCUR. SALTS OF THE HYDRIDE OR NITRIDE TYPE MAY BE USED FOR HEATING TO 900 TO 1200°F.

FURNACE ATMOSPHERES SUITABLE FOR HEATING AND HEAT TREATING AT 1725° TO 1975°F ARE AIR, DRY HYDROGEN, ARGON, OR HELIUM. AT 1400°F, A SCALE-FREE PRODUCT CAN BE OBTAINED ONLY IN VACUUM.

SOLUTION TREAT TO CONDITION A.

SHEET AND STRIP. 1925 TO 1975°F, 3 MINUTES PER 0.1 INCH THICKNESS, AIR COOL.

BAR AND FORGINGS. 1925° TO 1975°F, WATER QUENCH.

AGE CONDITION A TO CONDITION TH 1050

1375° TO 1425°F, 1-1/2 HR (AUSTENITE CONDITIONING), AIR COOL TO 50° TO 60°F WITHIN 1 HR, HOLD AT 50° TO 60°F, 1/2 HR (CONDITION T) + 1040° TO 1060°F, 1-1/2 HR, AIR COOL.

AGE CONDITION A TO CONDITION RH 950.

1735° TO 1765°F, TEN MINUTES (AUSTENITE CONDITIONING), AIR COOL (CONDITION A 1750) AT -90° TO 110°F, 8 HOURS (CONDITION R-100) AT 940° TO 960°F, ONE HOUR, AIR COOL.

AGE CONDITION C OF SHEET (COLD ROLLED) OR WIRE (COLD DRAWN) TO CONDITION CH 900. 890° TO 910°F, ONE HOUR, AIR COOL.

TH AND RH CONDITIONS ARE ALSO USED WITH DIFFERENT FINAL AGE HARDENING TEMPERATURES, E.G., TH 1150, RH 1050, ETC.

DIMENSIONAL CHANGES ON HEAT TREATING.

HEAT TREATING TO CONDITION RH 950 OR TH 1050 INCREASES DIMENSIONS BY 0.004 - 0.005-IN. PER INCH.

K. PROCESSING (CONTINUED)
JOINING

MOST WELDING IS PERFORMED WITH THE INERT-GAS TUNGSTEN-ARC PROCESS OR THE RESISTANCE SPOT AND SEAM WELDING PROCESSES. RESISTANCE FLASH BUTT WELDING IS NOT RECOMMENDED FOR JOINTS TO BE PLACED IN HIGH STRENGTH CONDITIONS.

SPOT WELDING AND SEAM WELDING ARE READILY PERFORMED BY TECHNIQUES SIMILAR TO THOSE USED FOR AUSTENITIC STAINLESS STEELS. BEST RESULTS ARE OBTAINED BY WELDING IN PARTLY OR FULLY HEAT TREATED CONDITIONS. THE SURFACES SUBJECT TO WELDING MUST BE CLEANED BY SAND OR VAPOR BLASTING TO AVOID POROUS WELD METAL.

INERT-GAS TUNGSTEN-ARC FUSION WELDING OF ANNEALED AND SUBSEQUENTLY HEAT TREATED METAL YIELDS A WELD EFFICIENCY OF 80 TO 100%.

THE MOLYBDENUM ADDITION IN THIS ALLOY CAUSES LARGER AMOUNTS OF DELTA FERRITE OR FREE FERRITE TO FORM IN WELD DEPOSITS UPON SOLIDIFICATION. THE AMOUNTS OF FERRITE REQUIRES SOME CONTROL IN ORDER TO MAINTAIN GOOD DUCTILITY IN THE HIGHEST STRENGTH CONDITIONS. THE CONTROL IS EFFECTED THROUGH THE USE OF FILLER METAL OF APPROPRIATE CHEMICAL COMPOSITION OR THROUGH HEAT TREATMENT.

WELDING

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:

WPH 15-7 Mo-VM/AMS 5812

WPH 15-7 Mo/AMS 5813

FORMING
GENERAL

SHEET PARTS ARE NORMALLY FORMED IN THE ANNEALED CONDITION A WHICH POSSESSES FORMING CHARACTERISTICS SIMILAR TO ANNEALED AUSTENITIC STAINLESS STEELS. IN DRAWING AND SEVERE FORMING OPERATIONS, CONSIDERABLE COLD WORK HARDENING WILL OCCUR IN LOCALIZED AREAS. THIS CAUSES A NON-UNIFORM CONDITION WHICH MAY NOT BE COMPLETELY ELIMINATED BY HEAT TREATMENT, HOWEVER, THIS HAS NOT BEEN FOUND OBJECTIONABLE BY MOST USERS. IF COMPLETE UNIFORMITY IS REQUIRED IN CRITICAL PARTS WHICH HAVE BEEN SEVERELY COLD WORKED, ANNEALING TO CONDITION A AFTER FABRICATING AND BEFORE HEAT TREATMENT TO CONDITION TH 1050 IS RECOMMENDED. WHEN THE RH 950 HEAT TREATMENT IS USED, THE 1750°F AUSTENITE CONDITIONING ACTS LIKE A FULL ANNEAL.

IN LAYING OUT DIMENSIONS OF PARTS TO BE FABRICATED IN CONDITION A AND SUBSEQUENTLY HARDENED BY HEAT TREATMENT, ALLOWANCE SHOULD BE MADE FOR THE DIMENSIONAL CHANGES THAT OCCUR IN THE HEAT TREATING OPERATIONS. DIES AND FIXTURES MUST BE UNDERSIZE FOR PARTS FORMED IN THE ANNEALED CONDITION.

K. PROCESSING (CONTINUED)
FORMING (CONTINUED)

PARTS FORMED IN CONDITION A WILL FREQUENTLY REQUIRE SIZING IN THE FULL OR PARTLY AGE HARDENED CONDITION.

SIZING DURING COOLING FROM 1400°F IS ALSO FOUND TO BE USEFUL. WHERE DIMENSIONAL OR OTHER REQUIREMENTS CANNOT BE MET AFTER FULL HEAT TREATMENT, FORMING CAN BE PERFORMED IN SOME INTERMEDIATE CONDITION FOLLOWED BY SPECIAL AGE HARDENING TREATMENTS WITH ALLOWANCE FOR REDUCED STRENGTH.

FORGING. STARTING TEMPERATURE 2200°F MAXIMUM, FINISHING TEMPERATURE 1700°F MINIMUM.

MACHINABILITY

MATERIAL IS USUALLY MACHINED IN CONDITION T OR R-100 BY TECHNIQUES SUITABLE FOR ANNEALED AUSTENITIC STAINLESS STEELS. IN THESE CONDITIONS DIMENSIONAL CHANGES ARE MINIMIZED ON HEAT TREATING. CONDITION A IS ALSO MACHINED BY THE SAME TECHNIQUES. LARGE CUTS SHOULD BE TAKEN.

L. REFERENCES

NP-57-7
NP-64-3
NP-64-8

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

0.16

0.12

0.08

0.04

0

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

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DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

AISS 633 IS A PRECIPITATION-HARDENING STAINLESS STEEL. IT IS USED FOR ELEVATED TEMPERATURE SERVICE, IN WHICH IT DISPLAYS THE CORROSION RESISTANCE OF AUSTENITIC STAINLESS STEELS.

THE PROPERTIES FOR F_{TU} , F_{TY} , e , AND RA IN SECTION E-1 ARE DESIGN MINIMA FROM MIL-HDBK-5.

DIMENSIONAL CHANGES ON HEAT TREATMENT REQUIRE SPECIAL CONSIDERATION; SEE SECTION K.

B. COMMERCIAL DESIGNATIONS

AM-350 STAINLESS STEEL

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET AND STRIP	MIL-S-8840
TUBING, SEAMLESS	AMS 5554
BARS, FORGINGS	AMS 5745
WIRE, WELDING	AMS 5774
ELECTRODE, COATED, WELDING	AMS 5775

SUPPLIERS

ALLEGHENY-LUDLUM STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.12	1.25	0.50	.040	.030	17.0	5.00	3.25
MINIMUM	0.08	0.50	-	-	-	16.0	4.00	2.50

SOURCE NP-64-8

MAX. 0.13 BAL.
MIN. 0.07

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

SHEET AND STRIP 0.187-IN. THICK MAX. DOUBLE AGED * COND SCT *	
TENSILE ULTIMATE STRENGTH F_{TU}	PSI
165,000	185,000
TENSILE YIELD STRENGTH F_{TY}	PSI
135,000	150,000
COMP. YIELD STRENGTH F_{CY}	PSI
145,000	162,000
SHEAR STRENGTH F_{SU}	PSI
105,000	120,000
ULTIMATE BEARING STRENGTH F_{BRU}	PSI
ELONGATION e	%
10.0	10.0
REDUCTION OF AREA RA	%
MODULUS OF ELASTICITY E	10^6 PSI
29.5	
MODULUS OF RIGIDITY G	10^6 PSI
11.5	
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
29.5	
PLASTIC BENDING MODULUS	(SEE APPENDIX A)

* SEE SECTION K

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
0.28	
SPECIFIC HEAT C	BTU/LB - °F
0.12	
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
8.3	
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
CONDITION SCT 850 (RT TO 200°F)	6.3
ELECTRICAL RESISTIVITY R	MICROHM - IN.
CONDITION H *	28.0
CONDITION SCT *	32.0
CONDITION DA *	33.0
MAGNETIC PROPERTIES	

ALLOY IS FERROMAGNETIC. IN CONDITION SCT, MAXIMUM PERMEABILITY IS 76. INDUCTION IN A FIELD OF 200 OERSTEDS IS 8600 GAUSSSES.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	
2500° - 2550°F	
PHASE CHANGES	
ON HEATING, AUSTENITE STARTS TO FORM AT 1100°F. MATERIAL IS COMPLETELY AUSTENITIC AT 1600°F. RAPID COOLING FROM 1710°F RESULTS IN MARTENSITE FORMATION AT A TEMPERATURE BETWEEN 80° AND 200°F (M_S). MARTENSITE FORMATION IS ESSENTIALLY COMPLETE AT -110°F (M_F). HOLDING FOR 3 HOURS AT -110°F IS RECOMMENDED TO OBTAIN OPTIMUM FORMATION OF MARTENSITE. IF COOLED FROM 1375°F, MARTENSITE BEGINS TO FORM BETWEEN 250° AND 400°F (M_S). COOLING TO ROOM TEMPERATURES PRODUCES SUBSTANTIAL TRANSFORMATION TO MARTENSITE. APPROXIMATELY 10 TO 20% AUSTENITE REMAINS IN BOTH TREATMENTS. THE RETAINED AUSTENITE IS THERMALLY STABLE.	

F. THERMOPHYSICAL EFFECTS

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE (°F)	k (BTU - FT HR - FT ² - °F)
100	8.38
200	8.87
300	9.37
400	9.81
500	10.3
600	10.8
700	11.3
800	11.7
900	12.2

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE
GENERAL CORROSION RESISTANCE APPROACHES THAT OF AUSTENITIC STAINLESS STEELS. INTERGRANULAR ATTACK MAY OCCUR IN CONDITION DA.

OXIDATION RESISTANCE
COMPARABLE TO THAT OF AUSTENITIC STAINLESS STEELS.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

-320° to 800°F (FOR CONDITIONS SCT 850 AND DA).
-320° to 900°F (FOR CONDITION SCT 1000).

DUCTILITY, NOTCH TENSILE STRENGTH, AND RATIO OF NOTCHED TENSILE STRENGTH TO TENSILE STRENGTH DROP OFF RAPIDLY FROM -320°F TO -423°F.

K. PROCESSING

SURFACE TREATMENT

DEGREASING AND CLEANING SHOULD BE THOROUGH TO AVOID HARMFUL SURFACE EFFECTS ON HEATING SUCH AS CARBURIZATION, AND TO FACILITATE PICKLING. IRON PARTICLES FROM FINISHING OPERATIONS SHOULD BE REMOVED BY A FINAL CLEANING IN A 20% NITRIC ACID SOLUTION TO PREVENT A REDUCTION IN CORROSION RESISTANCE.

PICKLING TO REMOVE SCALE AFTER ANNEALING IS BEST EFFECTED BY USING A 15% NITRIC ACID, 2 TO 4% HYDROFLUORIC ACID SOLUTION AT 130°F. IF THE SCALE IS VERY HEAVY, A SOLUTION WITH A SLIGHTLY INCREASED HYDROFLUORIC ACID CONTENT OR AN INCREASED BATH TEMPERATURE, 140°F MAXIMUM, CAN BE USED.

ACID PICKLING OF HEAT TREATED MATERIAL SHOULD BE AVOIDED. MECHANICAL DESCALING FOLLOWED BY CLEANING WITH WARM 20 TO 40% NITRIC ACID IS SUGGESTED. IF ACID PICKLING MUST BE USED, THE NITRIC HYDROFLUORIC ACID SOLUTION NOTED ABOVE IS SATISFACTORY FOR MATERIAL IN CONDITION SCT. THE LIGHT OXIDE FORMED DURING THE TEMPERING TREATMENT CAN BE REMOVED IN THIS BATH AT SLIGHTLY LOWER TEMPERATURES AND CONCENTRATIONS THAN PREVIOUSLY STATED.

THE DA AND EQUALIZED CONDITIONS WHICH CONTAIN PRECIPITATED CARBIDE CAN BE PICKLED IN A 50% HYDROCHLORIC ACID SOLUTION AT 160°F MAXIMUM.

THERMAL TREATMENT

ALLOY HARDENS FULLY IN ALL SECTION SIZES AFTER HEAT TREATING TO EITHER CONDITION SCT OR DA.

PRIOR TO ANNEALING, MATERIAL SHOULD BE THOROUGHLY DEGREASED AND CLEANED TO AVOID HARMFUL SURFACE REACTIONS AND TO FACILITATE SUBSEQUENT PICKLING.

ANNEALING ATMOSPHERE SHOULD BE SUCH THAT SURFACE REACTIONS RESULTING IN DECARBURIZATION, CARBURIZATION, OR NITRIDING WHICH AFFECT THE STABILITY OF AUSTENITE ARE AVOIDED.

GROWTH OCCURS IN HEAT TREATING, AND ALLOWANCE MUST BE MADE FOR IT IN MACHINING AND FORMING. THE EXPANSION ON AGING CONDITION H TO CONDITION SCT AMOUNTS TO ABOUT 0.004-0.0045 IN./IN. IF CONDITION H IS COLD-WORKED 5%, THE GROWTH REDUCES TO ABOUT 0.002 IN./IN.

K. PROCESSING (CONTINUED)

HEATING TO TEMPERATURES ABOVE THOSE SPECIFIED FOR CONDITION H SHOULD BE AVOIDED BECAUSE OF GRAIN COARSENING AND LOSS OF RESPONSE TO HARDENING. ANNEALING OF HEAVY BAR AND FORGINGS TO CONDITION H MAY RESULT IN LOSS OF RESPONSE TO HEAT TREATING.

HEAT TREATMENT

ANNEAL TO CONDITION H FOR MAXIMUM FORMABILITY AND STABILITY. 1900° TO 1950°F.
SHEET AND STRIP. 3/4 HOUR MINIMUM PER INCH THICKNESS, RAPID AIR COOL TO 80°F MAXIMUM.
FORGING STOCK. 1 HOUR MINIMUM PER INCH THICKNESS, OIL OR WATER QUENCH TO 80°F MAXIMUM.
BAR AND FORGINGS SHOULD NOT BE ANNEALED TO CONDITION H, BECAUSE OF RESULTING LACK OF RESPONSE TO HEAT TREATMENT IN LARGER SIZES.

ANNEAL TO CONDITION L FOR MAXIMUM RESPONSE TO HARDENING. 1685° TO 1735°F.
SHEET AND STRIP. 3/4 HOUR MINIMUM PER INCH THICKNESS, RAPID AIR COOL TO 80°F MAXIMUM.
BAR AND FORGINGS. 1 HOUR MINIMUM PER INCH THICKNESS, OIL OR WATER QUENCH TO 80°F MAXIMUM. EQUALIZE AND AGE BAR FOR BEST MACHINING. 1350° TO 1450°F, 3 HOURS, AIR COOL TO 80°F MAXIMUM + 1000° TO 1050°F, 3 HOURS. HARDNESS SHOULD BE ABOUT 38 RC.

SUBZERO COOL AND AGE CONDITION L TO CONDITIONS SCT. COOL TO -100°F, HOLD 3 HOURS MINIMUM + 850° TO 1050°F, 3 HOURS MINIMUM.

AGE TO CONDITION SCT 850. 825° TO 875°F.
AGE TO CONDITION SCT 1000. 975° TO 1025°F.

DOUBLE AGE EITHER CONDITION H OR CONDITION L TO CONDITION DA. 1350° TO 1400°F, 2 HOURS, AIR COOL TO 80°F MAXIMUM + 825° TO 875°F, 3 HOURS. CONDITION L YIELDS SLIGHTLY HIGHER TENSILE PROPERTIES THAN CONDITION H.

0.039 TO 0.062-IN. SHEET, L & T,
(AVERAGE OF 4 HEATS)

CONDITION OR TREATMENT	DIMENSIONAL CHANGE IN. PER IN.
H + 1375°F, 2 HR, AC	+ 0.0045
+ 850°F, 3 HR, AC	- 0.0002
H TO DA	+ 0.0043
H TO L	+ 0.0015
L + 1375°F, 2 HR, AC	+ 0.0036
+ 850°F, 3 HR, AC	- 0.0002
L TO DA	+ 0.0034
H TO L TO DA	+ 0.0049
L + -100°F, 3 HR	+ 0.0034
+ 850°F, 3 HR, AC	- 0.0002
L TO SCT	+ 0.003
H TO L TO SCT	+ 0.0047

K. PROCESSING (CONTINUED)

JOINING

WELDING

WELDING OF AM-350 CAN BE PERFORMED BY USING THE SAME WELDING TECHNIQUES AS THOSE USED ON AUSTENITIC STAINLESS STEELS. IT IS EASIER TO WELD THAN FERRITIC OR MARTENSITIC STEELS AND DOES NOT REQUIRE EITHER PREHEATING OR POSTHEATING TO MINIMIZE CRACKING. THIS IS EXPLAINED BY THE FACT THAT THE ALLOY REMAINS DUCTILE DURING COOLING, ALTHOUGH ITS STRUCTURE CHANGES FROM AUSTENITE TO A STRUCTURE CONTAINING UPWARDS OF 15% MARTENSITE.

WELDING CAN BE PERFORMED IN ALL CONDITIONS. TO WELD THE PRINCIPAL FORMS AVAILABLE (SHEET, STRIP, BAR, AND WIRE), ELECTRIC RESISTANCE, TUNGSTEN ELECTRODE, AND CONSUMABLE ELECTRODE INERT GAS WELDING TECHNIQUES ARE RECOMMENDED.

FUSION WELDING CAN BE PERFORMED BY ALL CONVENTIONAL METHODS. ANY AUSTENITIC STEEL FILLER ROD OR ELECTRODE MAY BE USED, UNLESS HIGH STRENGTH IN THE JOINT IS REQUIRED.

HEAT TREATED WELDS HAVING 90 TO 100% JOINT EFFICIENCY IN LIGHT GAGE MATERIAL CAN BE OBTAINED WITHOUT FILLER METAL. AM-350 OR AM-355 WELDING WIRE AND COATED AM-355 ELECTRODES SHOULD BE USED FOR HEAVIER GAGES.

IN ORDER TO HEAT TREAT TO CONDITION SCT, THE SAME FULL HEAT TREATMENTS AS FOR UNWELDED MATERIAL ARE USED. AGE HARDENING TO CONDITION DA REQUIRES NO ANNEAL TO CONDITION L, IF AM-350 WELD METAL IS USED. IF AM-355 IS USED HOWEVER, SUCH AN ANNEAL SHOULD PRECEDE THE DA AGING TREATMENT.

SPOT WELDING OF AGE HARDENED SHEET CAN BE PERFORMED BY PROPER SELECTION OF CURRENT AND ELECTRODE SIZE TO GIVE TENSION SHEAR VALUES EQUAL TO, AND TENSION IMPACT AND FATIGUE STRENGTH VALUES HIGHER THAN, THOSE OF WELDED AND SUBSEQUENTLY AGE HARDENED MATERIAL.

FOR PARENT METAL WELDED TO ITSELF, SELECT ONE OF THE FOLLOWING WELD RODS:
AM 350/AMS 5774
AM 350/AMS 5775
AM 355/AMS 5780
AM 355/AMS 5781

K. PROCESSING (CONTINUED)

FORMING

CONDITION H HAS A FORMABILITY SIMILAR TO THAT OF AUSTENITIC STEELS EXCEPT FOR A HIGHER RATE OF STRAIN HARDENING DUE TO MARTENSITE FORMATION. CONDITION L IS EVEN LESS STABLE. IT STRAIN-HARDENS MORE RAPIDLY AND THEREFORE POSSESSES INFERIOR FORMING CHARACTERISTICS.

ALLOY IN CONDITIONS H AND L CAN BE FORMED WITH ADVANTAGE AT 300°F OR HIGHER DUE TO ABSENCE OF MARTENSITE FORMATION AND CORRESPONDINGLY DECREASED RATE OF STRAIN HARDENING. THE HEAT TREATED CONDITION SCT PERMITS MINOR FORMING OPERATIONS, INCLUDING BENDING, STRAIGHTENING, AND DIMPLING, WHILE CONDITION DA IS STILL MORE DIFFICULT TO FORM.

BENDING. BEND FACTOR FOR CONDITION SCT = 3T, FOR CONDITION DA = 5T.

SHEET FORMED IN CONDITION H NEEDS SUBSEQUENT FULL HEAT TREATMENT. IF IT IS POSSIBLE TO FORM THE ALLOY IN CONDITION L, SUBSEQUENT AGING TO CONDITION SCT WILL PRODUCE ABOUT THE SAME PROPERTIES AS OBTAINED WITHOUT THE STRAIN HARDENING DUE TO FORMING.

STRAIGHTENING OF PARTS TO BE HEAT TREATED TO CONDITION SCT IS PERFORMED PREFERABLY AFTER COOLING TO -100°F TO REDUCE THE DIMENSIONAL CHANGES OCCURRING DURING HEAT TREATING. STRETCHED PARTS SHOW LITTLE DIMENSIONAL CHANGES.

FORGING. STARTING TEMPERATURE 2100°F MAXIMUM. FINISHING TEMPERATURE SHOULD BE ABOUT 1750°F TO INSURE ADEQUATE RESPONSE TO HEAT TREATING. BEFORE HEAT TREATING, FORGINGS SHOULD BE EQUALIZED AT 1375°F.

MACHINABILITY

MACHINING PROPERTIES OF AM-350 ARE SIMILAR TO THOSE OF AUSTENITIC STAINLESS STEELS. RIGID SUPPORTS, POSITIVE CUTS, AND ADEQUATE COOLING ARE REQUIRED. CONDITIONS H AND L DO NOT MACHINE WELL BECAUSE OF THEIR INITIAL SOFTNESS AND THEIR HIGH RATE OF STRAIN HARDENING. FOR BEST MACHINING, IT IS RECOMMENDED THAT THE ALLOY BE SUBJECTED TO AN EQUALIZING TREATMENT CONSISTING OF 1375°F, 3 HOURS, AIR COOL TO ROOM TEMPERATURE PLUS TEMPER AT 1000° TO 1050°F, 3 HOURS, WITH A RESULTING HARDNESS OF ABOUT 35 RC.

ALLOWANCE MUST BE MADE FOR GROWTH ON SUBSEQUENT HEAT TREATMENT. FOR EXTREME DIMENSIONAL ACCURACY, FINISH MACHINING SHOULD BE DONE ON MATERIAL IN CONDITION SCT OR DA, WHICH MACHINE IN A MANNER SIMILAR TO LOW ALLOY STEELS OF EQUAL HARDNESS.

L. REFERENCES

NP-64-3 NP-64-8 NP-61-3

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

0.16

0.12

0.08

0.04

0

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

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DATE 1 MAY 1966

SUPERSEDES

FERROUS ALLOYS

MATERIALS DATA

V

FERROUS ALLOYS

E.

IRON-NICKEL-CHROMIUM ALLOYS

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DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

THIS ALLOY IS ONE OF THE FIRST AND MOST POPULAR, AGE-HARDENABLE, AUSTENITIC, NICKEL-CHROMIUM STEELS WHICH HAS PIONEERED THE SUCCESSFUL APPLICATION OF THIS TYPE OF SUPER ALLOYS FOR HIGH TEMPERATURES. IT IS SIMILAR TO, AND A DEVELOPMENT OF, THE GERMAN ALLOY TINIUR. IT IS USED PRIMARILY AT TEMPERATURES UP TO 1300°F. THE ALLOY IS AVAILABLE IN FORM OF SHEET, PLATE, BAR, TUBING, WIRE, EXTRUSIONS, AND FORGINGS. INVESTMENT CASTINGS ARE ALSO PRODUCED IN THIS ALLOY. IT CAN BE FORMED AND WELDED.

THE VALUES FOR THE PROPERTIES GIVEN IN SECTION E-1, ARE AVERAGE, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE LAST FOUR PROPERTIES ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

A-286

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP, PLATE	AMS 5525 AMS 5734
BAR, FORGINGS, TUBING (ST + AGED)	AMS 5735
BAR, FORGINGS, TUBING (ST AND ST + AGED)	AMS 5736
BAR, FORGINGS, TUBING (ST + AGED) (CONS. ELECT. MELT)	AMS 5737

SUPPLIERS

ALLEGHENY-LUDLUM STEEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.08	2.00	1.00	.040	.030	16.0	27.0	1.50
MINIMUM	--	1.00	0.40	--	--	13.5	24.0	1.00
SOURCE								
NP-64-B	MAX	0.50	2.30	0.35	.010	Fe		
	MIN	0.10	1.90	--	.0010			

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI
ALL FORMS, AGE-HARDENED 152,000

TENSILE YIELD STRENGTH F_{TY} PSI
ALL FORMS, AGE-HARDENED 93,000

COMP. YIELD STRENGTH F_{CY} PSI
7/8-IN. DIA. BAR* 117,000

0.062-IN. SHEET* 100,000

SHEAR STRENGTH F_{SU} PSI
7/8-IN. DIA. BAR (SAME AS ABOVE) 110,000
0.062-IN. SHEET (SAME AS ABOVE) 95,000

ULTIMATE BEARING STRENGTH F_{BRU} PSI
e/D = 1.5 215,000
e/D = 2.0 295,000

BEARING YIELD STRENGTH F_{BRY} PSI
e/D = 1.5 167,000
e/D = 2.0 193,000

ELONGATION e %
26.0

REDUCTION OF AREA RA %
44.0

MODULUS OF ELASTICITY E 10^6 PSI
29.1

MODULUS OF RIGIDITY G 10^6 PSI
10.4

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI
29.1

PLASTIC BENDING MODULUS (SEE APPENDIX A)

* HEAT TREATMENT 1800°F, 1 HR., OIL QUENCHED, AGED AT 1325°F, 16 HR.

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³
0.29

SPECIFIC HEAT C BTU/LB - °F
0.11

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F
(AT 100°F) 7.5

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN. / IN. - °F
(80 - 200°F) 9.2

ELECTRICAL RESISTIVITY R MICROHM - IN.
36.0

MAGNETIC PROPERTIES

ALLOY IS NON-MAGNETIC AT ROOM AND ELEVATED TEMPERATURES. IT MAY HAVE A CURIE POINT AT LOW TEMPERATURES.
POISSON'S RATIO 0.306

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
2500° - 2600°F

PHASE CHANGES

PRECIPITATION OF Ni₃Ti OCCURS BETWEEN 1200° & 1500°F

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{\text{BTU} - \text{FT}}{\text{HR} - \text{FT}^2 - ^\circ\text{F}} \right)$
200	8.1
400	9.3
600	10.5
800	11.7
1000	13.0
1200	14.3

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE

THIS ALLOY IS BASICALLY AN AUSTENITIC NICKEL CHROMIUM STEEL AND POSSESSES A CORROSION RESISTANCE COMPARABLE TO THAT OF THESE STEELS. IT HAS EXCELLENT RESISTANCE AGAINST ALL ATMOSPHERES ENCOUNTERED IN APPLICATIONS AT TEMPERATURES UP TO 1300°F.

OXIDATION RESISTANCE

OXIDATION RESISTANCE IS HIGH FOR CONTINUOUS SERVICE UP TO 1500°F AND FOR INTERMITTENT SERVICE UP TO 1800°F. IT PERFORMS IN A MANNER SIMILAR TO TYPE 310 STAINLESS STEEL.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

-423°F TO 1800°F (INTERMITTENT SERVICE AT ELEVATED TEMPERATURES IN OXIDIZING ATMOSPHERES)

-423°F TO 1500°F (CONTINUOUS SERVICE AT ELEVATED TEMPERATURES IN OXIDIZING ATMOSPHERES)

K. PROCESSING
SURFACE TREATMENT
CLEANING:

THESE STEELS EXHIBIT MAXIMUM CORROSION RESISTANCE ONLY WHEN THOROUGHLY CLEAN. REMOVAL OF FOREIGN MATTER FROM THE SURFACES BY CONVENTIONAL CLEANING METHODS PRIOR TO ANY HEATING IS PARTICULARLY IMPORTANT.

DESCALING:

GENERALLY DONE IN SOLUTIONS OF NITRIC AND HYDROFLUORIC ACIDS. MOLTEN CAUSTIC SODA BATHS ARE ALSO WIDELY USED FOR DESCALING. FOR REMOVING HEAVY SCALE, SAND OR VAPOR BLASTING SHOULD PRECEDE PICKLE.

K. PROCESSING (CONTINUED)
THERMAL TREATMENT

ALLOY SHOULD BE RAPIDLY COOLED FROM SOLUTION TREATING TO INSURE FULL AGING RESPONSE IN ALL SECTION SIZES.

ALLOY CAN ALSO BE HARDENED BY COLD WORK AND BY COMBINATIONS OF HEAT TREATING AND COLD WORK.

USE NEUTRAL OR SLIGHTLY OXIDIZING ATMOSPHERE TO PREVENT CARBURIZING.

ANNEAL OR SOLUTION TREAT:

1650° TO 1800°F, 1650°F YIELDS HIGHER TENSILE PROPERTIES, WHILE 1800°F PRODUCES SUPERIOR CREEP AND CREEP RUPTURE PROPERTIES.

SHEET, STRIP, PLATE (AMS 5525)

1775° TO 1825°F, 1 HR MINIMUM PER INCH THICKNESS, AIR BLAST OR OIL QUENCH.

BAR, FORGINGS, TUBING (AMS 5735 AND 5736)

1775° TO 1825°F 1 HR., OIL OR WATER QUENCH.

BAR, FORGINGS, TUBING (CONSUMABLE ELECTRODE MELT), (AMS 5737)

1625° TO 1675°F, 2 HR., OIL OR WATER QUENCH.

AGE SOLUTION TREATED CONDITION

1300° TO 1400°F, 16 HR. MINIMUM

SHEET, STRIP, PLATE

1310° TO 1340°F., 16 HR

BAR, FORGINGS, TUBING

1300° TO 1400°F 16 HR., OR PREFERABLY 1310 TO 1340°F 16 HR

BAR, FORGINGS, TUBING (CONSUMABLE ELECTRODE MELT,)

1300° TO 1350°F, 16 HR.

GENERAL COMMENTS

AFTER COLD WORKING SHEET OR BAR, THESE FORMS NEED NOT BE SOLUTION TREATED AGAIN, BUT CAN BE AGED DIRECTLY. THE RESULTING HARDNESS AND STRENGTH AFTER REGULAR AGING WILL INCREASE BY THE COLD WORK.

A MORE UNIFORM CONDITION CAN BE OBTAINED BY DOUBLE AGING AT 1400°F, 16 HR + 1300°F, 16 HR. THIS CONDITION IS SLIGHTLY MORE DUCTILE, BUT POSSESSES LOWER CREEP RUPTURE STRENGTH THAN THE CONVENTIONALLY HEAT TREATED CONDITION.

BAR AND WIRE COLD DRAWN 80% AND AGED AT 1100° TO 1200°F, 16 HR DEVELOP $F_{TU} = 240$ TO 250 KSI.

K. PROCESSING (CONTINUED)
JOINING
WELDING

WELDING OF THIS ALLOY IS PREFERABLY PERFORMED IN THE SOLUTION TREATED CONDITION. THE ALLOY IS SUSCEPTIBLE TO HOT CRACKING, PARTICULARLY IN THE AGED CONDITION. CRACKING CAN BE MINIMIZED BY KEEPING WELDING CONDITIONS CLOSELY CONTROLLED, AVOIDING RESTRAINTS, AND KEEPING THE WELD AFFECTED ZONE TO A MINIMUM.

FUSION WELDING

IS PERFORMED BY THE INERT-GAS-SHIELDING METHOD OR BY THE ARC-METHOD USING COATED ELECTRODES. AUSTENITIC WELDING WIRE AND COATED ELECTRODES OR VARIOUS COMPOSITIONS, PREFERABLY NICKEL BASE, CAN BE USED. A-286 WIRE AND ELECTRODES ARE AVAILABLE FOR HIGH WELD STRENGTH WHICH IS OBTAINED BY AGING AFTER WELDING. THE INERT-GAS METHOD MUST BE USED TO PREVENT LOSS OF TITANIUM AND HARDENABILITY. HEAVY SECTIONS ARE PARTICULARLY DIFFICULT TO FUSION WELD BECAUSE OF THE HOT SHORT PHASE WHICH IS RESPONSIBLE FOR CRACKING.

FLASH WELDING

CAN BE SUCCESSFULLY PERFORMED ON NEARLY ALL SECTION SIZES FOR WHICH EQUIPMENT EXISTS. RESISTANCE SEAM AND SPOT WELDS CAN BE MADE USING HIGH CURRENT AND HIGH ELECTRODE PRESSURES. A-286 MAY BE JOINED TO OTHER AUSTENITIC OR MARTENSITIC ALLOYS BY WELDING.

BRAZING:

MAY BE PERFORMED IN VACUUM OR DRY HYDROGEN. WHEN THE BRAZING CYCLE GOES ABOVE 1800°F, IT IS NECESSARY TO RESOLUTION TREAT AT 1650°F TO IMPROVE DUCTILITY.

K. PROCESSING (CONTINUED)
FORMING
FORMABILITY:

FORMABILITY OF SHEET IN THE ANNEALED CONDITION IS SIMILAR TO THAT OF AUSTENITIC STAINLESS STEELS, ALTHOUGH A-286 IS STRONGER AND SOMEWHAT LESS DUCTILE.

FORGING:

FORGING CHARACTERISTICS ARE SIMILAR TO THOSE OF AUSTENITIC STAINLESS STEELS. HOWEVER, THIS ALLOY REQUIRES MORE POWER AND MORE FREQUENT REHEATING. REDUCTIONS OF AT LEAST 15% MUST BE USED UNDER 1800°F TO PREVENT FORMATION OF COARSE GRAINS ON SOLUTION TREATING.

CASTING:

INVESTMENT CASTINGS ARE MADE BY VACUUM MELTING.

MELTING AND CASTING PRACTICE

AIR MELTED
ELECTRIC FURNACE AIR MELT
OTHER FURNACE
INDUCTION VACUUM MELTED

VACUUM MELTING IMPROVES HOMOGENEITY AND INCREASES THE EFFECTIVE TITANIUM FOR HARDENING. A DECREASED SCATTER BAND OF PROPERTIES AT THE HIGH END OF THE COMPOSITION RANGE AND BETTER FORGEABILITY ARE TYPICAL ADVANTAGES OF THE VACUUM MELTING PRODUCT. VACUUM MELTING ALSO IMPROVES ROOM AND ELEVATED TEMPERATURE PROPERTIES.

CONSUMABLE ELECTRODE MELTED.

MACHINABILITY

THIS ALLOY DOES NOT MACHINE WELL IN THE SOLUTION TREATED CONDITION, SINCE IT IS GUMMY LIKE ALL SOFT AUSTENITIC STEELS, IT CAN BE MACHINED EITHER IN THE FULLY HEAT TREATED CONDITION OR IN A CONDITION WHICH IS PARTLY AGED AT 1325°F, 1 HR, OR OVERAGED AT 1500°F, SEVERAL HOURS, TO A HARDNESS OF ABOUT 210 BHN. MATERIAL COLD WORKED AFTER SOLUTION TREATING ALSO EXHIBITS GOOD MACHINING CHARACTERISTICS.

L. REFERENCES

NP-64-3
NP-64-8

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

STRENGTHS
COMPRESSIVE, SHEAR,
BEARING

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

THIS MATERIAL IS HEAT TREATABLE, AND IS USEFUL FOR STRUCTURAL PURPOSES TO 1600°F. IT IS GENERALLY PRODUCED BY CONSUMABLE-ELECTRODE, VACUUM WELDING.

THE VALUES GIVEN FOR THE PROPERTIES IN SECTION E ARE AVERAGES, EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THESE LATTER PROPERTIES ARE 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

D-979

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SHEET, STRIP & PLATE	AMS 5509
BAR, ROD, FORGING & HEADING STOCK	AMS 5746

SUPPLIERS

ALLEGHENY-LUDLUM STEEL CORP.
PITTSBURGH, PENNA.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	Si	P	S	Cr	Ni	Mo
MAXIMUM	0.08	0.75	0.75	0.040	0.040	16.0	48.0	4.50
MINIMUM	-	-	-	-	-	14.0	42.0	3.00
SOURCE								
NP-60-24	MAX	W	Ti	Al	B	Fe		
	MIN	4.50	3.30	1.30	.016	Bal.		
		3.00	2.70	0.75	.0080			

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

SOLUTION TREATED AND AGED *			
SHEET AND PLATE		BAR	
HT"A"	HT"B"	HT"A"	HT"B"
TENSILE ULTIMATE STRENGTH	F _{TU}	PSI	
156,000	-	164,000	140,000
TENSILE YIELD STRENGTH	F _{TY}	PSI	
116,000	-	116,000	80,000
COMP. YIELD STRENGTH	F _{CY}	PSI	
ULTIMATE SHEAR STRENGTH	F _{SU}	PSI	
ANNEALED SHEET, 0.060-IN. THICK	82,000	-	-
SHEAR YIELD STRENGTH	F _{SY}	PSI	

ULTIMATE BEARING STRENGTH F_{BRU} PSI
e/D = 1.5
e/D = 2.0

YIELD BEARING STRENGTH F_{BRV} PSI
e/D = 1.5
e/D = 2.0

ELONGATION e %

FORM NOT GIVEN 9.5 -

REDUCTION OF AREA RA %

FORM NOT GIVEN 42 10

MODULUS OF ELASTICITY E 10⁶ PSI

DYNAMIC 30
STATIC 28

COMP. MODULUS OF ELASTICITY E_C 10⁶ PSI

MODULUS OF RIGIDITY G 10⁶ PSI

DYNAMIC 11.6

POISSON'S RATIO 0.29

HARDNESS

PLASTIC BENDING MODULUS (SEE APPENDIX A)

* FOR HEAT TREATMENT, SEE SECTION K.

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³
0.295

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$

7.2

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$

(70-212°F) 7.6

ELECTRICAL RESISTIVITY R MICROHM - IN.

MAGNETIC PROPERTIES

ALLOY IS NON-MAGNETIC AT ROOM AND ELEVATED TEMPERATURES. IT MAY HAVE A CURIE POINT AT LOW TEMPERATURES.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2225° - 2550°F

PHASE CHANGES

ALLOY IS SUBJECT TO PRECIPITATION OF HARDENING CONSTITUENTS

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$
75	7.2
200	7.62
400	8.42
600	9.17
800	9.92
1100	10.70
1200	11.5
1400	12.2

G. THERMOPHYSICAL EFFECTS (CONTINUED)

G. CHEMICAL PROPERTIES

OXIDATION RESISTANCE OF D-979 HAS BEEN EVALUATED TO 1600°F IN STILL-AIR FURNACES, AND FOUND TO BE SIMILAR TO A-286 ALLOY AT 1200°F, BUT SUPERIOR TO THAT ALLOY ABOVE 1200°F. RESULTS OF TESTS ON SPECIMENS 0.50-IN. DIA. BY 0.50-IN. LONG ARE:

TEMPERATURE (°F)	% WT. LOSS IN 100 HRS
1200	0.020
1500	0.085
1800	0.367

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

HT = HEAT TREATMENT
OQ = OIL QUENCH
AC = AIR COOLED

J. SERVICE LIMITS

-423° TO 1600°F (SEE SECTION G)

K. PROCESSING
SURFACE TREATMENT
CLEANING:

VAPOR DEGREASING, SOLVENT WIPING.

DE-SCALING:

NITRIC-HYDROFLUORIC ACID BATH, MOLTEN CAUSTIC SODA BATH

THERMAL TREATMENT

OIL QUENCHING FOLLOWED BY AGING WILL RESULT IN FULL HARDENING OF ALL COMMERCIAL SIZES.

SOLUTION TREAT:

1850 TO 2050°F, 1/4 HR TO 1 HR., OIL QUENCH, RAPID AIR COOLING APPEARS SATISFACTORY FOR SHEET AND STRIP. AGE 1550°F, 6 TO 10 HR + 1300°F, 16 HR, AIR COOLED.

RECOMMENDED HEAT TREATMENTS
HEAT TREATMENT A

1850°F, 1 HR, OIL QUENCH + 1550°F, 6 HR + 1300°F, 16 HR, AIR COOL. THIS TREATMENT RESULTS IN HIGH TENSILE AND FATIGUE STRENGTH BUT SLIGHTLY LOWER CREEP RUPTURE STRENGTH THEN DOES HEAT TREATMENT B

HEAT TREATMENT B

2050°F, 1 HR, OIL QUENCH + 1550°F, 8 TO 10 HR + 1330°F, 16 HR, AIR COOL. THIS TREATMENT PRODUCES OPTIMUM COMBINATION OF CREEP AND CREEP RUPTURE PROPERTIES, BUT LOWER YIELD STRENGTHS.

HEAT TREATMENT FOR OPTIMUM HI-TEMP NOTCH TOUGHNESS

1900°F, 4 HR, WQ; 1550°F, 12 HR, AC; 1300°F, 16 HR, AC (DEVELOPED BY ALLEGHENY-LUDLUM AND LYCOMING DIVISION, AVCO CORP., FOR GAS-TURBINE APPLICATIONS)

JOINING
WELDING

THE ALLOY CAN BE READILY FUSION AND RESISTANCE WELDED.

FUSION WELDING OF SHEET AND PLATE USING THE INERT GAS SHIELDED TUNGSTEN ARC METHOD AND D-979 FILLER ROD CAN BE PERFORMED WITH A HIGH WELD EFFICIENCY. VARIOUS OTHER NICKEL BASE WELDING RODS ARE ALSO SUITABLE. THE SURFACES OF THE WELD MUST BE THOROUGHLY CLEANED AFTER EACH PASS, IF FILLER MATERIAL CONTAINS TITANIUM OR ALUMINUM, TO AVOID OXIDE INCLUSIONS.

K. PROCESSING (CONTINUED)
FORMING
GENERAL:

SHEET AND OTHER PRODUCTS ARE BEST FORMED AFTER SOLUTION TREATING AT 2050°F. SHEET CAN BE AIR COOLED FROM THE SOLUTION TEMPERATURE TO TYPICAL TENSILE PROPERTIES OF $F_{TU} = 104$ KSI, $F_{TY} = 42$ KSI, AND $e = 68\%$ WHICH ARE SIMILAR TO THOSE OF AUSTENITIC STAINLESS STEELS. THE STRAIN HARDENING OF THE ALLOY DURING COLD FORMING IS ALSO SIMILAR TO THAT OF STAINLESS STEELS.

FORGING

STARTING TEMPERATURE 2050°F MAXIMUM, FINISHING TEMPERATURE 1750°F MINIMUM. THE ALLOY IS HOT SHORT IF THE METAL TEMPERATURE DURING FORGING EXCEEDS 2050°F, AND BELOW 1750°F ITS RESISTANCE TO DEFORMATION RAPIDLY INCREASES. IN THE FORGING RANGE GIVEN ABOVE, D-979 REQUIRES A POWER CONSUMPTION INTERMEDIATE BETWEEN THAT OF IRON BASE AND OTHER SUPER ALLOYS. REDUCTIONS IN EXCESS OF 10% ARE RECOMMENDED TO PREVENT EXCESSIVE GRAIN GROWTH.

MACHINABILITY

EXPERIENCE TO DATE INDICATES THAT THE ALLOY HAS A MACHINABILITY SIMILAR TO THAT OF AUSTENITIC STEELS. THE SOLUTION TREATED CONDITIONS ARE DIFFICULT TO MACHINE. IT IS EXPECTED THAT MATERIAL AFTER THE FIRST AGING AT 1550°F WILL MACHINE BEST, AND IT WILL THEN ALSO CHANGE ITS DIMENSIONS ONLY SLIGHTLY AFTER AGING AT 1300°F. FINISH MACHINING CAN BE PERFORMED IN THE FULLY AGED CONDITIONS.

L. REFERENCES

NP-60-24
P-63-1
NP-64-8
NP-64-32

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

STRENGTHS
COMPRESSIVE, SHEAR,
BEARING

DATE 1 MAY 1966
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 1 MAY 1966

SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

**REDUCTION OF AREA
ELONGATION**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

THERMAL EXPANSION
SPECIFIC HEAT

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

TEMPERATURES IN 100° F

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DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

NI-SPAN-C-902 IS AN IRON-NICKEL-CHROMIUM ALLOY WHICH IS USED PRIMARILY FOR ITS CONSTANT MODULUS OF ELASTICITY FROM -50° TO + 150°F. THIS ALLOY IS AGE HARDENABLE.

THE PROPERTIES GIVEN IN SECTION E-I ARE AVERAGES EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA. THE PROPERTIES OF F_{TU} , F_{TY} , e , AND RA ARE BASED UPON 30% CW BAR, SOLUTION ANNEALED AT 1750°F FOR 1 HOUR, WQ, AND AGED AT 1350°F FOR 3 HOURS AND THEN AIR COOLED. THE PROPERTY OF G IS BASED UPON SOLUTION TREATED AND AGED 0.750-IN. BAR, AGED AT 1200°F/5 HOURS, AIR COOLED; THE PROPERTY OF e IS BASED UPON AGED BAR. THE VALUES FOR F_{TU} , F_{TY} , RA , AND e ARE $\pm 3\sigma$ LIMITS.

B. COMMERCIAL DESIGNATIONS

NI-SPAN-C-902

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
STRIP (SOLUTION-TREATED)	AMS 5221
STRIP (COLD ROLLED, 10% REDUCTION)	AMS 5223
STRIP (COLD ROLLED, 50% REDUCTION)	AMS 5225

SUPPLIERS

HUNTINGTON ALLOY PRODUCTS DIV.
INTERNATIONAL NICKEL CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	Ni	Cr	Ti	Al	C	Mn	Si	S
MAXIMUM	43.5	5.75	2.75	0.80	0.06	0.80	1.0	0.04
MINIMUM	41.0	4.90	2.20	0.30	-	-	-	-
SOURCE	NP-65-32				MAX.	0.04	P	Fe
					MIN.	-	BAL.	

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI
170,000

TENSILE YIELD STRENGTH F_{TY} PSI
108,000

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e %
17.0

REDUCTION OF AREA RA %
23.0

MODULUS OF ELASTICITY E 10^6 PSI
25.2

MODULUS OF RIGIDITY G 10^6 PSI
10.2

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

HARDNESS (ROCKWELL)
(COLD-WORKED) R_C 37

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.293

SPECIFIC HEAT C BTU/LB - °F

0.12

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

7.0

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

(75-125°F) 3.8

ELECTRICAL RESISTIVITY R MICROHM - IN.

40.0

MAGNETIC PROPERTIES

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2650 - 2700°F.

PHASE CHANGES

SUBJECT TO PRECIPITATION OF HARDENING CONSTITUENTS.

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
- 250	4.74
- 100	6.11
0	6.87
200	8.00
400	9.05
600	10.11
800	11.18
1000	12.11

F. THERMOPHYSICAL EFFECTS (CONTINUED)
G. CHEMICAL PROPERTIES

CORROSION RESISTANCE

LESS THAN 0.001 IN. PER YEAR IN INDUSTRIAL AND MARINE ENVIRONMENTS.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

- 50° TO + 150°F IN CONSTANT MODULUS OF ELASTICITY.

K. PROCESSING
SURFACE TREATMENT

CLEANING:
VAPOR DEGREASING, ULTRASONIC, SOLVENT WIPING.

DE-SCALING:
NITRIC-HYDROFLUORIC ACID BATH, MOLTEN CAUSTIC SODA BATH.

THERMAL TREATMENT

ANNEALING TEMPERATURE, 1850°F
USE REDUCING ATMOSPHERE, FREE OF SULPHUR, QUENCH RAPIDLY.

AGE HARDENING
1350°F (+ 15°F), 3 HR, AC (PER AMS 5221)

K. PROCESSING (CONTINUED)
JOINING

WELDING:
INERT-GAS FUSION WELDABLE (MIG OR TIG). FILLER MATERIAL IS OF PARENT METAL COMPOSITION.

FORMING
MACHINABILITY

BEST IN HOT-WORKED OR SOLUTION-TREATED CONDITION.

L. REFERENCES

P-56-1	NP-64-2
NP-60-4	NP-64-16
NP-62-29	NP-65-1
NP-62-34	NP-65-31
NP-63-31	NP-65-32
NP-63-32	

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

FATIGUE STRENGTH

DATE 1 MAY 1966
SUPERSEDES

STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE

DATE 1 MAY 1966
SUPERSEDES

IMPACT STRENGTH
ROCKWELL HARDNESS

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

THERMAL EXPANSION
SPECIFIC HEAT

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966

SUPERSEDES

FERROUS ALLOYS

MATERIALS DATA

**V
FERROUS METALS**

**F.
OTHER FERROUS ALLOYS**