April 1966

MATERIALS DATA HANDBOOK

Aluminum Alloy 2014

Edited by

John Sessler
Volker Weiss

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SYRACUSE UNIVERSITY RESEARCH INSTITUTE
DEPARTMENT OF CHEMICAL ENGINEERING AND METALLURGY

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DEPARTMENT OF CHEMICAL ENGINEERING AND METALLURGY
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PREFACE

This Materials Data Handbook on the aluminum alloy **2014** was prepared by personnel and associates of the Department of Chemical Engineering and Metallurgy, Syracuse University, as part of a program sponsored by the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama.

It is intended that this Handbook present, in the form of a single document, a comprehensive summary of the materials property information presently available on the 2014 alloy.

The scope of the information included herein includes physical and mechanical property data at cryogenic, ambient and elevated temperatures, supplemented with useful information in such areas as material procurement, metallurgy of the alloy, corrosion, environmental effects, fabrication and joining techniques. Design data are presented, where available, and these data are complemented with information on the typical behavior of the alloy. The major source for the design data used is the Department of Defense document, Military Handbook - 5.

The Handbook is divided into twelve **(12)** chapters as outlined below:

Chapter	**1**	General Information
	2	Procurement Information
	3	Metallurgy
	4	Production Practices
	5	Manufacturing Practices
	6	Space Environment Effects
	7	Static Mechanical Properties
	8	Dynamic and Time Dependent Properties
	9	Physical Properties
	10	Corrosion Resistance and Protection
	11	Surface Treatments
	12	Joining Techniques

Information on the alloy is given in the form of Tables and Illustrations supplemented with descriptive text where deemed useful by the authors. Source references for the information presented are listed at the end of each chapter.

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John G. Sessler, Editor
Volker Weiss, Associate Editor

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TABULAR ABSTRACT

Aluminum 2014

TYPE:

Wrought, heat treatable aluminum alloy

NOMINAL COMPOSITION:

Al-4.4Cu-0.8Mn-0.8Si-0.4Mg

AVAILABILITY:

Bare and clad sheet and plate, rod, bar, wire, tube, extruded shapes, forgings and forging stock.

TYPICAL PHYSICAL PROPERTIES:

Density	2.815 gr/cm^3 at RT
Thermal Conductivity	0.46 cal/cm sec C (O temper)
	0.37 cal/cm sec C (T6 temper)
Thermal Expansion	(20-100C), 22.5 x 10^{-6} in/in/C
Specific Heat	0.23 cal/gr cm at 100C
Electrical Resistivity	3.45 microhm-cm at RT (O temper)
	4.31 microhm-cm at RT (T6 temper)

TYPICAL MECHANICAL PROPERTIES:

F_{tu}	27,000 psi (O temper)
	70,000 psi (T6 temper)
F_{ty}	14,000 psi (O temper)
	60,000 psi (T6 temper)
e (2 inch)	18 percent (O temper)
	13 percent (T6 temper)
E (tension).	10.6 x 10^6 psi

FABRICATION CHARACTERISTICS:

Weldability	Good (fusion and resistance methods) if proper procedures are used
Formability	Good in the annealed condition
	Difficult to form in T6 temper
Machinability	Good in the T6 temper

COMMENTS:

A high strength aluminum alloy which is often used for heavy duty structures.

SYMBOLS

a	One-half notch section dimension
A	Area of cross section; "A" basis for mechanical property values (Mil-Hdbk-5)
Å	Angstrom unit
AC	Air cool
AMS	Aerospace Material Specifications
Ann	Annealed
AUS	Austenitize
Av or Avg	Average
B	"B" basis for mechanical property values (Mil-Hdbk-5)
b	Subscript "bending"
bcc	Body centered cubic
BHN	Brinell hardness number
br	Subscript "bearing"
Btu	British thermal unit (s)
C	Degree (s) Centigrade
c	Subscript "compression"
CD	Cold drawn
CF	Cold finished
cm	Centimeter
c_p	Specific heat
CR	Cold rolled
CW	Cold worked
CVM	Consumable vacuum melted
D or Dia	Diameter
DPH	Diamond pyramid hardness
e	Elongation in percent
E	Modulus of elasticity, tension Modulus of elasticity, compression
e/D	Ratio of edge distance to hole diameter
E_s	Secant modulus
E_t	Tangent modulus
ev	Electron volt (s)

F	Degree (s) Fahrenheit
f	Subscript "fatigue"
F_{bru}	Bearing ultimate strength
F_{bry}	Bearing yield strength
fcc	Face centered cubic
FC	Furnace cool
F_{cy}	Compressive yield stress
F_{su}	Shear stress; shear strength
F_{tu}	Tensile ultimate strength
F_{ty}	0.2% tensile yield strength (unless otherwise indicated)
G	Modulus of rigidity
HAZ	Heat affected zone in weldments
hcp	Hexagonal close pack
hr	hour (s)
HT	Heat treat
IACS	International annealed copper standards
in	inch
ipm	inches per minute
K	Stress intensity factor; thermal conductivity
K_c	Measure of fracture toughness (plane stress) at point of crack growth instability
K_{Ic}	Plane strain fracture toughness value
KSI or ksi	Thousand pounds per square inch
K_t	Theoretical elastic stress concentration factor
L	Longitudinal
lb	Pound
LT	Long transverse (same as transverse)
M	Bending moment
m	Subscript "mean"
Max	Maximum
MIL	Military
Min	Minimum
N	Cycles to failure
NSR	Notch strength ratio
NTS	Notch tensile strength

OQ	Oil quench
ppm	Parts per million
pt	Point
r	radius
RA	Reduction in area; Rockwell hardness A scale
RB	Rockwell hardness B scale
RC	Rockwell hardness C scale
ρ (rho)	Density
rpm	Revolutions per minute
RT	Room temperature
SA	Solution anneal
sec	second
S-N	S = stress; N = number of cycles
Spec	Specifications; specimen
ST	Solution treat; short transverse
T	Transverse
t	Thickness; Time, hour
Temp	Temperature
typ	Typical
Var	Variable
VHN	Vickers' hardness number
W	Width
WQ	Water quench

CHAPTER 1

GENERAL INFORMATION

1.1 Aluminum alloy 2014 is a heat treatable wrought alloy, developed by the Aluminum Company of America (Alcoa) in 1928. It was developed as a high strength alloy having good ductility and machinability for aircraft and other heavy-duty structural uses. The base alloy is similar to the commonly used 2024 (developed in 1931)in that copper is the primary alloyingaddition. Early in its history, 2014 was used mainly in the form of forging and extrusion products, but more recently the alloy has become available in various products including sheet and plate, (Refs. 1.1, 1.3, 1.6).

1.2 The alloy has good forming characteristics and can be welded satisfactorily using both fusion andresistance welding techniques. When used as sheet or plate, the alloy is frequently clad to provide improved corrosion resistance to a variety of environments. An advantage of 2014 is that it may be formed in the as-quenched temper and subsequently artificially aged to the T6 temper, (Ref. 1.1). Thus, forming operations of greater severity can be performed than would be possible in the T6 Condition.

1.3 Typical areas of application are use in heavy-duty structures, aircraft structures, bridges and truck frames. The alloy is also used for rivets, structural fittings and hardware. Alclad 2014 **is** used for high strength structural applications where high resistance to corrosion is required, (Ref. 1.3).

1.4 General Precautions

1.41 Overheated material exhibiting eutectic melting or high temperature oxidized material should not be used and cannot be salvaged by reheat treatment.

1.42 All quench operations should be performed as rapidly as possible because of possible precipitation and consequently reduced corresionresistance if cooling rate is slow.

CHAPTER 1 - REFERENCES

1.1 "Kaiser Aluminum Sheet and Hate Product Information", Second Edition, Kaiser Aluminum and Chemical Sales, Inc., Chicago, Illinois, (January 1958)

1.2 "Alcoa Structural Handbook", Aluminum Co. of America, (1960)

1.3 Alloy Digest, "Aluminum 2014", Filing Code A-17, Engineering Alloy Digest, Inc., (June 1954)

1.4 "Metals Handbook", Vol. I, Properties and Selection of Metals, 8th Edition, American Society for Metals, (1961)

1.5 Materials in Design Engineering, "Materials Selector Issue", Vol. 60, No. 5, (Mid-October 1964)

1.6 "Aerospace Structural Metals Handbook", V. Weiss and J. Sessler (Editors), ASD-TDR-63-741, Vol. II, (March 1963)

CHAPTER 2

PROCUREMENT INFORMATION

2.1 General. Aluminum 2014 alloy is available in the full commercial range of sizes for plate, rod, bar, wire, tube, pipe, shapes, forgings and forging stock. Products such as rod, bar and shapes are produced as extrusions or by rolling and drawing. Alclad 2014 is available as sheet and plate. Detailed tables of standard tolerances for the various products available are given in Ref. (2.1).

2.2 Procurement Specifications. Specifications that apply to the 2014 alloy as of May 31, 1965, are listed in Table 2.2 for various products and tempers.

2.21 NASA Specifications, Table 2.21.

2.211 MSFC-SPEC-104, "Aluminum Alloy, 2014 Bare, Plate and Sheet", (April 2, 1962), Amendment 1, (April 30, 1964). Prepared by George C. Marshall Space Flight Center. Custodian: NASA-MSFC.

2.212 MSFC-SPEC-144B, "Aluminum Alloy Forgings, Premium Quality, Heat Treated", (August 13, 1963), amendment 1, (September 8, 1964). Prepared by George C. Marshall Space Flight Center. Custodian: NASA-MSFC.

2.3 Comparison of Specifications. Federal procurement specifications are applicable to 2014 aluminum alloy extruded bar, rod and shapes; rolled or drawn bar, rod and shapes; forgings, and Alclad plate and sheet. Military specifications cover forgings, impact extrusions and standard structural shapes. ASTM specifications apply to all wrought products except forging stock and impact extrusions. AMS specifications cover all wrought products except Alclad sheet and plate. A sample comparison of the tensile properties specified for die forgings (tested in the direction parallel to forging flow lines) is given in Table 2.3. A detailed comparison of all of the specifications that apply to the 2014 alloy is beyond the scope of this handbook.

2.4 Major Producers of the Alloy. (United States only)

Aluminum Company of America
1501 Alcoa Building
Pittsburgh, Pennsylvania

Harvey Aluminum
General Offices
Torrance, California

Kaiser Aluminum and Chemical Sales, Inc.
919 North Michigan Avenue
Chicago, Illinois

Olin-Mathieson Chemical Corporation
460 Park Avenue
New York, New York

Reynolds Metals Co.
6601 West Broad Street
Richmond, Virginia

2.5 Available Forms, Sizes and Conditions

2.51 Commercial sizes and tempers available for sheet, sheet circles, plate and plate circles, Table **2.51.**

2.52 Range of sizes for wire, rod and bar, Table **2.52.**

PROCUREMENT SPECIFICATIONS(a)

TABLE 2.2

Source		Refs. 2.1, 2.3, 2.4, 2.5, 2.6, 2.7				
Product	Temper	Military	Federal	ASTM	SAE AMS	SAE HDBK
Bar, rod, shapes, and tube (extruded)	F	-	-	B221-64	-	-
	O	-	QQ-A-200/2b	B221-64	-	AA2014
	T4, T4510, T4511	-	QQ-A-200/2b	B221-64	-	AA2014
	T42, T62	-	QQ-A-200/2b	B221-64	-	-
	T6510, T6511	-	QQ-A-200/2b	B221-64	-	AA2014
	T6	-	QQ-A-200/2b	B221-64	4153B	AA2014
Bar, rod, wire, shapes (rolled, drawn or cold finished)	O	-	QQ-A-225/4b	B211-64	-	AA2014
	T4	-	QQ-A-225/4b	B211-64	-	AA2014
	T451	-	QQ-A-225/4b	-	-	AA2014
	T6	-	QQ-A-225/4b	B211-64	4121C	AA2014
	T651	-	QQ-A-225/4b	-	-	AA2014
Sheet and plate	O	-	-	B209-64	4028A	AA2014
	T3	-	-	B209-64	-	AA2014
	T6	-	-	B209-64	4029A	AA2014
	T62	-	-	B209-64	-	-
	T65	-	-	B209-64	4014	AA2014
Alclad sheet and plate	F	-	QQ-A-250/3c	-	-	-
	O, T3, T4	-	QQ-A-250/3c	B209-64	-	AA2014
	T42, T451	-	QQ-A-250/3c	B209-64	-	AA2014
	T6, T651	-	QQ-A-250/3c	B209-64	-	AA2014
	T62	-	-	B209-64	-	-
Forgings, stock	F	-	-	-	4134A 4135J	-
, die	T4	-	QQ-A-367f	B247-64	4134A	AA2014
, die	T6	MIL-A-22771B	QQ-A-367f	B247-64	4135J	AA2014
, die	T652	MIL-A-22771B	-	-	-	-
, rolled rings	T6	-	-	-	4135J	-
, hand	T6	MIL-A-22771B	QQ-A-367f	-	4135J	-
, hand	T652	MIL-A-22771B	QQ-A-367f	-	-	-
Impact extrusions	F, O, T4, T6	MIL-A-12545A	-	-	-	-
Structural shapes (rolled or extruded)	T4	MIL-A-25994	-	B308-64	-	-
	T6	MIL-A-25994	-	B308-64	-	-

(a) Current as of May 31, 1965

NASA SPECIFICATIONS

TABLE 2.21

Alloy	2014	
Specification	NASA-MSFC	
	Product	Tempers
MSFC-Spec-104 MSFC-Spec-144B	Bare plate and sheet Forgings, premium quality, heat treated	O, T3, T4, T6, F, T651, T451 T4, T6, T652

COMPARISON OF SPECIFIED TENSILE PROPERTIES FOR DIE FORGINGS

TABLE 2.3

Alloy	2014				
Data	Comparison of specified tensile properties				
Product	Die forgings - (parallel to forging flow lines)				
Specification	Temper	Section thickness max (in)	F_{tu}, min ksi	F_{ty}, min ksi	e(2 in or 4D) %
Federal (QQ-A-367f)	T4	4	55.0	30.0	16 (a)
	T6	4	65.0	55.0	10 (a)
Military (MIL-A-22771B)	T6	4	65.0	55.0	7 (b)
ASTM (B247-64)	T4	4	55.0	30.0	16 (a)
	T6	4	65.0	55.0	10 (a)
AMS (4134A) (4135J)	T4	4	55.0	30.0	16 (a)
	T6	4	65.0	55.0	10 (a)

(a) Tensile specimen separately forged as test coupon
(b) Tensile specimen taken from forging

TABLE 2. Si

Source	Ref. 2.2 (e) Size (maximum) (b)			
Product	Temper (c)	Thickness (inch)	Width, (in)	Length, (in)
Alclad sheet and sheet circles (flat, mill finish)(a)	0, T3, T6	0.010-0.014	36	120
		0.014-0.023	48	180
		0.023-0.030	60	180
		0.030-0.037	60	180
		0.037-0.060	84	200
		0.060-0.076	90	300
		0.076-0.096	90	300
		0.096-0.120	96	360
		0.120-0.250	102	360
Alclad sheet and sheet circles (coiled, mill finish)(d)	0, F	0.019-0.023	36	-
		0.024-0.029	36	-
		0.030-0.081	36	-
		0.082-0.102	36	-
	T4, T6	0.019-0.023	22	-
		0.024-0.029	22	-
		0.030-0.081	24	-
		0.082-0.102		-
Alclad and bare plate and plate circles (b) (mill finish)	0, F, T4, T451	0.250-0.625	120	480
		0.625-2.250	132	540
		2.250-3.001	120	480

(a) Maximum diameter of circle same as maximum width of sheet.
(b) Sizes greater than indicated can be supplied, subject to special inquiry.
(c) Available in 0 temper on special inquiry only.
(d) Maximum diameter of circle is 26 inches for coiled sheet.
(e) Consult producers of alloy for further information.

RANGE OF SIZES FOR WIRE, ROD AND BAR

TABLE 2.52

Source	Reference 2.2	
Form	Size range, in (a)	
	Diameter, distance across flats or dimensions	
	Min	Max
Round wire, drawn	0.010	0.374
Round rod, cold-finished	3/8	3.499
Round rod, rolled	19/16	8
Square wire, drawn	1/8 x 1/8	11/32 x 11/32
Square bar, cold-finished	3/8 x 3/8	1' 1/2 x 1 1/2
Square bar, rolled	15/8 x 1,5/8	4 x 4
Hex wire, drawn	3/16	11/32
Hex bar, cold-finished	3/8	2
Hex bar, rolled	19/16	3
Square edge rect. wire drawn	1/32 x 1/8	5/16 x 11/32
Square edge rect. bar, cold-finished	1/8 x 3/8	1 1/2 x 4
Square edge rect. bar, rolled	3/16 x 3/4	3 x 7
Round edge rect. bar, rolled	3/16 x 3/4	1/2 x 6

(a) This table indicates range of commercial sizes, Consult producers of the alloy for details.

CHAPTER 2 - REFERENCES

2.1 "Standards for Aluminum Mill Products", Seventh Edition, The Aluminum Association, (October 1964)

2.2 "Alcoa Aluminum Handbook", Aluminum Co. of America, (1962)

2.3 "Alcoa Product Data - Specifications", Section A12A, Aluminum Co. of America, (July 1963)

2.4 "1965 SAE Handbook", Society of Automotive Engineers, (1965)

2.5 "1963 Supplement to and Changes in Book of ASTM Standards, Part 2, Nonferrous Metals Specifications, Electron Tube Materials, Semiconductors", Am. Soc. Test Mets, (1963)

2.6 "SAE Aerospace Material Specifications", Soc. Automotive Eng., Inc., (Latest Index, February 15, 1965)

2.7 Department of Defense, "Index of Specifications and Standards", Part I, Alphabetical Listing, and Part II, Numerical Listing, (September 1964), Supplemented (March 31, 1965)

CHAPTER 3

METALLURGY

3.1 Chemical Composition

3.11 Nominal chemical composition of **2014** alloy, in percent, (Ref. **3.7, p. 42).**

Cu	**4.4**
Si	**0.8**
Mn	**0.8**
Mg	**0.4**
Al	Balance

3.181 Sheet and plate are available in Alclad condition. Cladding material is **6053** alloy; nominal composition, in percent:

Cr	**0.25**
Mg	**1.3**
Si	**0.7**
Al	Balance

Cladding is applied to both sides. The nominal cladding thickness per side is **10** percent of the total thickness of the composite if the latter is below 0.040 inch and **5** percent for total thickness of composite products 0.040 inch to **0.099** inch. For composite thicknesses of 0.100 inch and above, the nominal cladding thickness on each side is **2.5** percent.

3.12 Chemical composition limits, in percent, (Ref. **3.1, p. 44).**

Cu	**3.9 - 5.0**	
Si	**0.50 . 1.2**	
Mn	**0.40 - 1.2**	
Mg	**0.20 - 0.8**	
Fe	1.0	max
Cr	0.10	max
Zn	**0.25**	max
Ti	**0.15**	max
Other	**0.05**	max each, total not to exceed 0.05
Al	Balance	

Conformity with these composition limits are normally checked **by** spectrochemical analysis or in accordance with the procedure outlined in ASTM E **34,** "Standard Methods for Chemical Analysis of Aluminum and Aluminum Base Alloys", **(Ref. 3.2).**

3.13 Alloying Elements. The principal alloying elements are Cu, Mg, Mn and Si. The aluminum rich portions of the binary diagrams with each of these principal alloying elements are given in Figs. 3.131 (Al-Cu), 3.132 (Al-Mg), 3.133 (Al-Mn) and 3.134 (Al-Si), (Ref. 3.3). The effect of the additions of Cu, Mn and Mg is to render the alloy heat treatable by a precipitation hardening mechanism. The primary hardening agent is $CuAl_2$ modified by the presence of Mg. There also is a precipitation of metallic Si and both precipitates increase the attainable strength through artificial aging. The G. P. zones are responsible for the natural aging and artificial aging characteristics of the alloy, Mn is added to prevent the formation of the undesirable constituent Al-Cu-Fe-Si and acts together with Ti to cause grain refinement, (Ref. 3.9). Fe, Cr and Zn are present as undesirable impurities. Copper, and the other alloying elements, decrease the corrosion resistance of aluminum. The Al-Cu constituent is more cathodic than Al and more anodic than the solid solution containing more than 2.5 percent Cu, (Ref. 3.4, p. 918).

Since initial precipitation usually occurs along grain boundaries, zones lean in solutes will develop near the grain boundaries. These anodic zones will corrode selectively by an electrochemical process producing notches that cause stress concentrations. As the alloy structure (i.e. precipitate and solid solution relationship) is modified by heat treatment, its resistance to corrosion, stress corrosion, and weathering will be influenced.

The amount of protection provided by the cladding depends on the thickness and the purity of the cladding material, and also on the annealing and heat treatments, see Section 3.111.

3.2 Strengthening Mechanisms

3.21 General. The alloy can be strengthened by precipitation hardening and cold work, although cold work is not generally used. The precipitation hardening mechanisms are evident from the phase diagram relationship given in Figs. 3.131 to 3.134. Upon quenching from the solution temperature to room temperature, precipitation occurs in the form of submicroscopic particles which represent obstacles to plastic flow and thus cause hardening. Cold working also can produce a considerable amount of hardening in this alloy, This is a general property of most aluminum alloys and is related to the crystal structure (fcc) and the stacking fault energy. Various processing operations utilize the effects of both mechanisms i.e. cold working of the solution treated alloy at room temperature and subsequent aging at room or elevated temperatures producing the T3, T451, T452, and T651 tempers. However, cold work is not normally used to develop commercial tempers for this alloy, (Ref. 3.9).

3.22 Heat Treatment

3.221 Anneal (O Condition): All products; Heat to 400 to 426C, 2 to 3 hours, followed by furnace cooling at a rate of 10C/hour to at least 260C, (Refs. 3.1 and 3.5). Intermediate anneals during repeated cold working operations should be performed at 344C for no more than 30 minutes at a time.

3.222 Solution Treatment: All products; Heat to 496 to 507C, hold 10 minutes to 1 hour in salt bath (or longer in air) depending on thickness, quench in cold water. If held at room temperature, a naturally aged T4 Condition develops after 4 days. If the treatment is performed by the user, the proper designation is T42.

3.2221 It should be noted that the solution treat temperature should be closely controlled. If temperature is too high, it may cause solid solution grain boundary melting, high temperature oxidation and eutectic melting which cannot be corrected by subsequent heat treat operations. Low temperature may result in incomplete solution of the hardening constituents with a loss in hardening potential. Rapid quenching is also important because of possible precipitation and consequently reduced corrosion resistance on slow cooling from the solution treating temperature. The maximum allowable quench delay times are given below:

Nominal Thickness, in.	Maximum Time, s
≤ 0.016	5
0.017 to 0.031	7
0.032 to 0.090	10
≥ 0.091	15

3.223 _____

3.224 _____

3.2241 T3 Condition: 1 percent cold rolling of solution treated material.

3.2242 T451 Condition: Stress relieve T4 material by stretching 1.5 to 3 percent for plate or 1 to 3 percent for rod, bar and shapes.

3.2243 T452 Condition: Stress relieve T4 material by compression.

3.2244 T651 Condition: Artificially age T451 material at 172 to 182C for 7.5 to 8.5 hours.

3.3 Critical Temperatures. Melting range 580 to 638C. The oxidation resistance in atmosphere is generally good until the melting temperature is approached.

3.4 Crystal Structure. Face centered cubic. The lattice parameter depends primarily on the amount of Cu in solution. For pure aluminum, $a_o = 4.0413$Å; for 5.0% Cu, a, = 4.0290Å, (Ref. 3.6, p. 49).

3.5 Microstructure. Fig. 3.51 depicts the typical microstructure of the 2014 alloy in the (a) annealed, (b) naturally aged T4 Condition and (c) artificially aged T6 Condition, respectively. A structure showing an overheated condition by the presence of rosettes, grain boundary melting and grain boundary oxidation Is shown in Fig. 3-52 'for an extruded shape and in Fig. 3.53 for plate. Ref. 3.7 is recommended as an excellent source of information on the identification of constituents in aluminum alloys.

3.6 Metallographic Procedures: In general, mechanical polishing is preferred to electropolishing, especially where larger microconstituents are present and the material is relatively soft, as objectionable relief effects produced by the electrolytic polishing technique may cause a misinterpretation of the microstructure, (Ref. 3.8, p. 806). For homogeneous alloys, and for those conditions containing only finely dispersed particles, the electrolytic method is excellent. Preparatory polishing on metallographic polishing papers 0 to 000 should be performed wet with a solution of 50 g paraffin in 1 liter kerosene to keep the specimen bright and avoid imbedding of grinding compound particles into the soft specimen surface. Rough polishing on a "Kitten's Ear" broadcloth at 250 to 300 RPM with suspended 600 grade aluminum oxide and final polishing on a similar wheel at 150 to 200 RPM with heavy magnesium oxide powder is recommended, (Ref. 3.6 and 3.7).
An alternate and popular method consists of the following steps:

a) Wet polishing (flowing water with 240 grit silicon carbide paper at approximately 250 RPM.

b) Wet polishing with 600 grit silicon carbide paper at approximately 250 RPM.

c) Polishing with 9 micron diamond paste on nylon cloth at 150 to 200 RPM using a mild soap solution for lubrication.

d) Final polish on a vibratory polisher using a microcloth containing a slurry of methyl alcohol and 0.1 micron aluminum oxide powder. A slurry of 0.1

micron aluminum oxide powder in a 10% solution of glycerine in distilled water may also be used for this step.

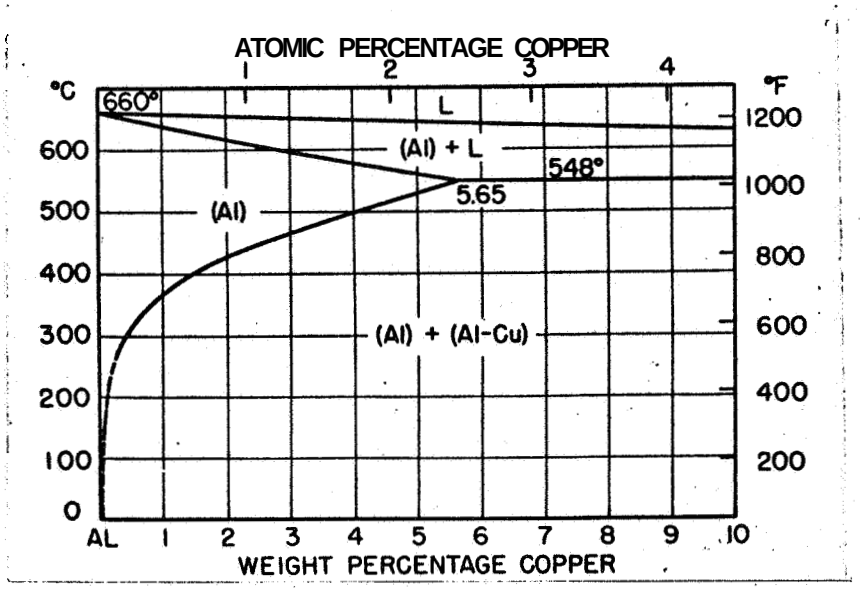
Etching reagents should be suited to the objective of the study. Keller's etch reveals microstructural details and grain boundaries satisfactorily. A 10% solution of NaOH gives better details of the microstructural constituents but does not delineate the grain boundaries. Study of the "as polished" surface prior to etching may also give valuable information on the types of constituents present, especially when attention is paid to the colors of the various particles. Macroscopic studies of cracks, gross defects, forging lines and grain structure should be made with the following etching solutions:

ETCHING SOLUTIONS FOR REVEALING MACROSTRUCTURE

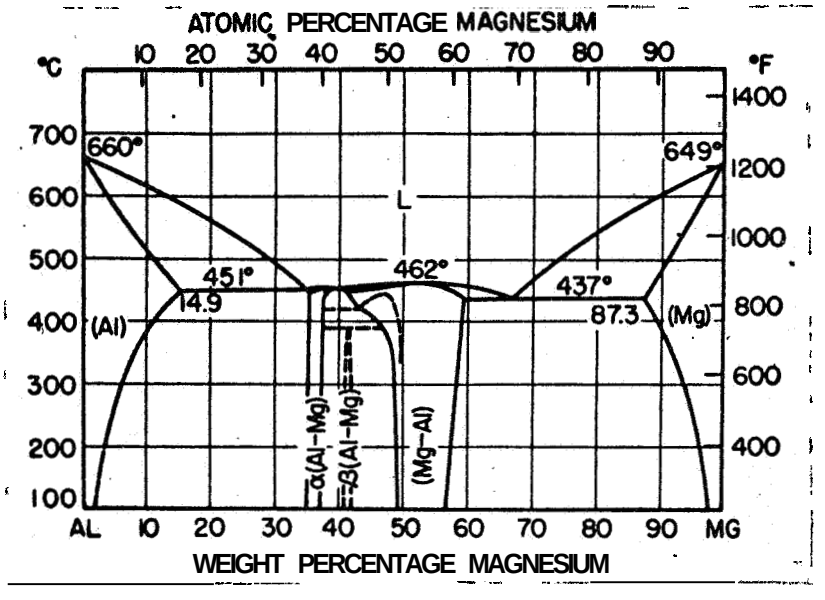
Solution	Concentration		Specific Use
Sodium Hydroxide	NaOH Water	10g 90ml	For cleaning surfaces, revealing unsoundness, cracks and gross defects
Tucker's	HCl (Conc.) HNO_3 (Conc.) HF (48%) Water	45ml 15ml 15ml 25ml	For revealing structure of castings, forgings, etc.
Modified Tucker's	HCl (Conc.) HNO_3 HF (48%) Water	10ml 10ml 5ml 75ml	For revealing structure of all castings and forgings except high-silicon alloys
Flick's	HCl (Conc.) HF (48%) Water	15ml 10ml 90ml	For revealing grain structure of duraluminum type of alloys. Surface should be machined or rough polished

All of these solutions are used at room temperature.

(Ref. ***3.6)***



.FIG. 3.131 BINARY PHASE DIAGRAM OF THE ALUMINUM RICH PORTION OF THE Al-Cu EQUILIBRIUM DIAGRAM



. FIG. 3.132 Al-Mg EQUILIBRIUM DIAGRAM

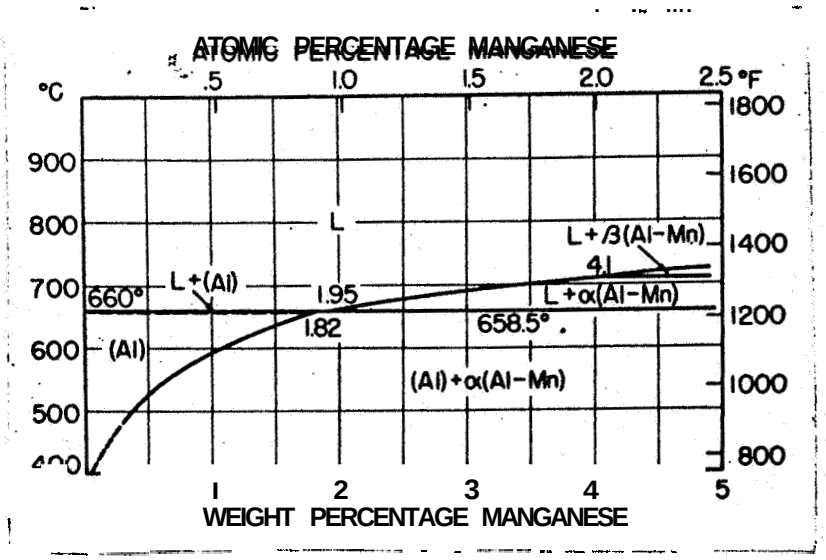


FIG. 3.133 BINARY PHASE DIAGRAM OF THE ALUMINUM RICH PORTION OF THE Al-Mn EQUILIBRIUM DIAGRAM.

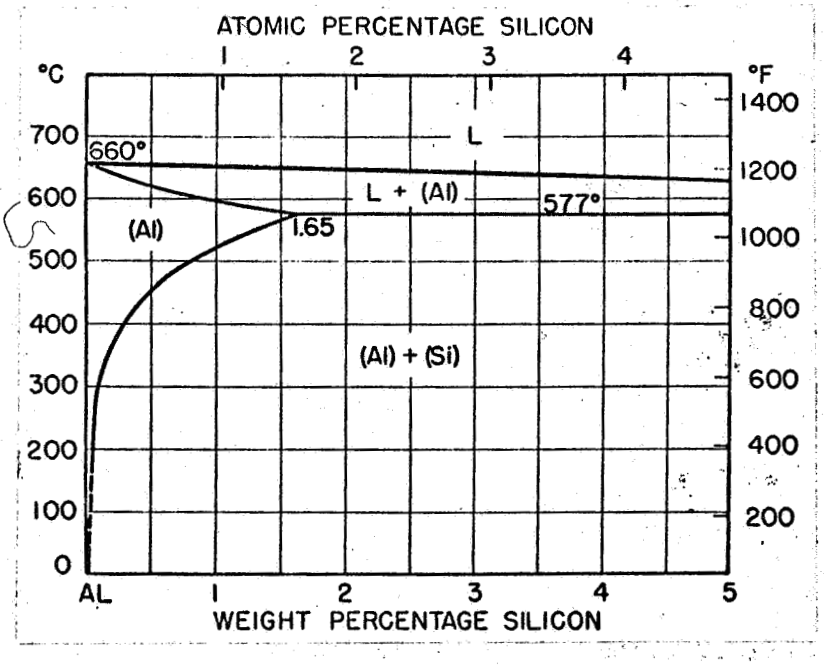


FIG. 3.134 BINARY PHASE DIAGRAM OF THE ALUMINUM RICH PORTION OF THE Al-Si EQUILIBRIUM DIAGRAM. (Ref. 3.3)

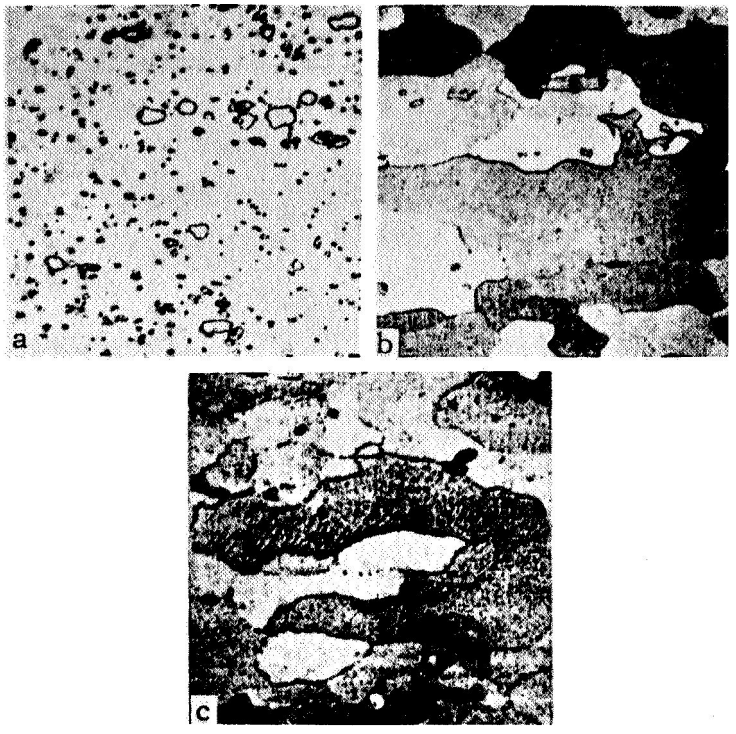
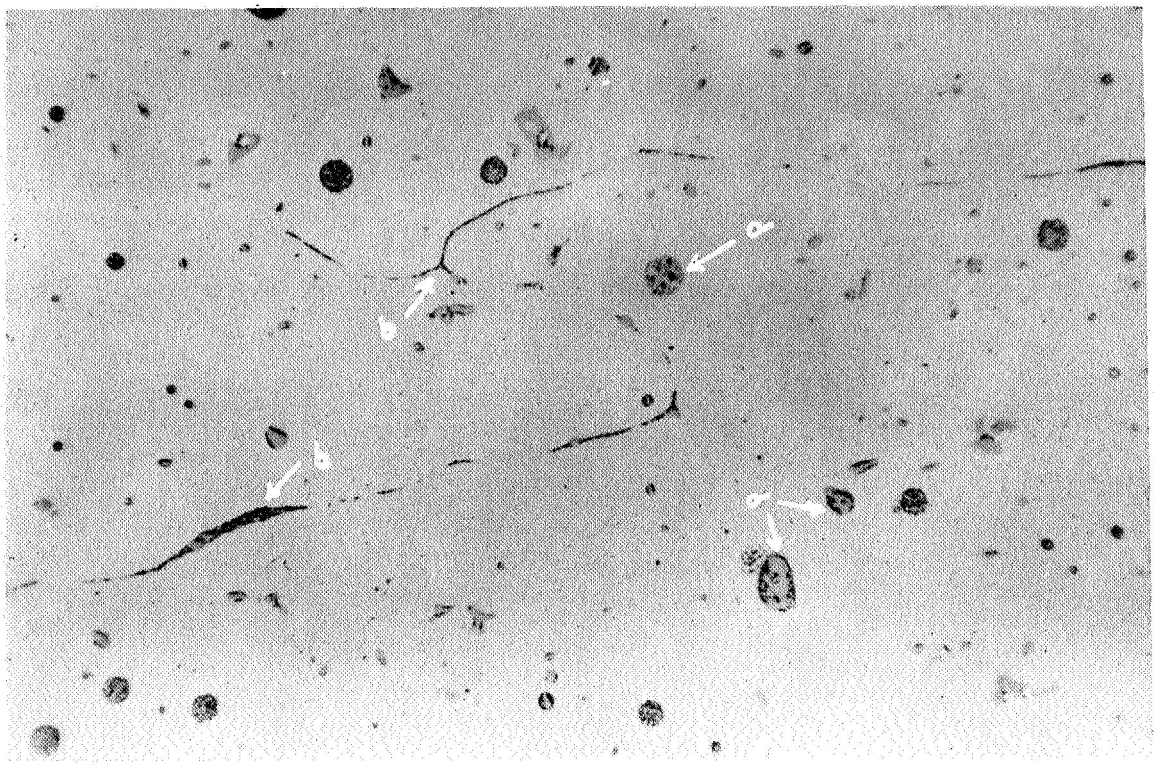


FIG. 3.51 TYPICAL MICROSTRUCTURE OF 2014 ALUMINUM ALLOY

a) Annealed
b) T4 Condition (Naturally aged)
c) T6 Condition (Artificially aged)
Keller's etch, 500X

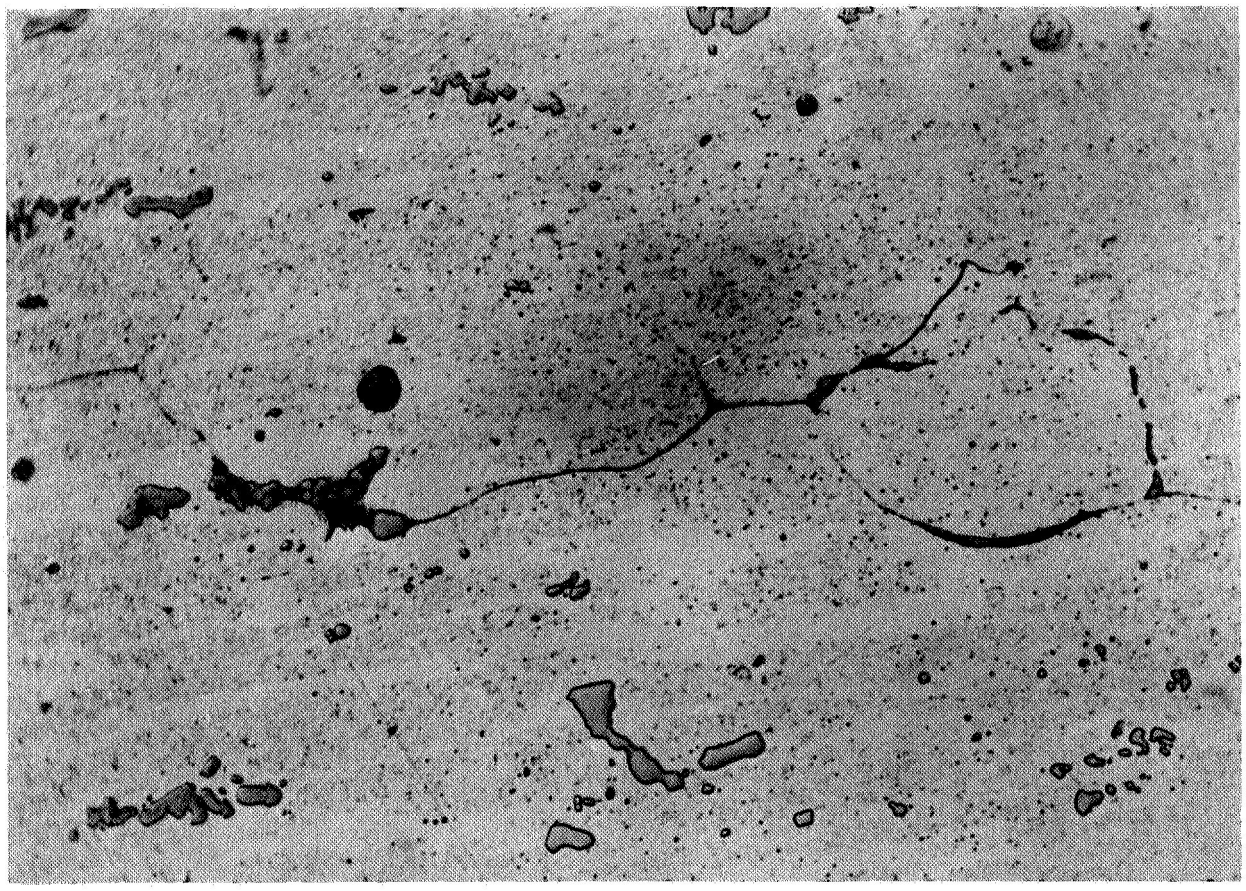
(Ref. 3.6)



500X
As Polished

FIG. **3.52** MICROSTRUCTURAL FEATURES ASSOCIATED WITH OVERHEATING OF EXTRUDED SHAPE. (a) ROSETTES INDICATING EUTECTIC MELTING. (b) GRAIN BOUNDARY STRINGERS DENOTING MELTING OF A COMPLEX PHASE ABOVE THE EUCTECTIC TEMPERATURE.

Courtesy of Mr. Dame Merrill
Martin Co., Baltimore, Md.



100 X
Etchant: 1% NaOH

FIG. **3.53** PHOTOMICROGRAPH OF AS RECEIVED PLATE AFTER SOLUTION HEAT TREATMENT AT 950F, SHOWING EUTECTIC AND GRAIN BOUNDARY MELTING

Courtesy **of** Mr. Dame Merrill
Martin Co., Baltimore, Md.

CHAPTER 3 - REFERENCES

3.1 Alcoa Aluminum Handbook, Aluminum Company of America, Pittsburgh, Pennsylvania, (1962)

3.2 Standards for Wrought Aluminum Mill Products, Fifth Edition, The Aluminum Association, New York, (October 1962)

3.3 E. H. Wright and L. A. Willey, "Aluminum Binary Equilibrium Diagrams", Technical Paper No. 15, Aluminum Company of America, (1960)

3.4 Metals Handbook,. Eighth Edition, Vol. 1, ASM, Metals Park, Novelty, Ohio, (1961)

3.5 Aerospace Structural Metals Handbook, Vol. II, V. Weiss and J. Sessler (Editors), ASD-TDR-63-741, (March 1963)

3.6 W. L. Fink, et al., "Physical Metallurgy of Aluminum Alloys", American Society for Metals, Cleveland, Ohio, (1958)

3.7 F. Keller and G. W. Wilcox, "Identification of Constituents of Aluminum Alloys", Technical Paper No. 7, Aluminum Company of America, (1942), Revised 1958

3.8 J. P. Vidosic, "Study of Phase identification in Steel and Aluminum Alloys", Georgia Institute of Technology, Final Report, Project No. A-641, NASA Contract NAS8-5117, (September 1963)

CHAPTER 4

PRODUCTION PRACTICES

4.1 General. In the United States, aluminum and its alloys are produced from an ore of impure hydrated aluminum oxide known as "bauxite". Important sources of bauxite are located in Arkansas, Dutch Guiana and Jamaica. The impure ore is converted into pure aluminum oxide (alumina) through a series of chemical processes. Oxygen is removed from the alumina by smelting in carbon-lined electric furnaces known as reduction pots. Pure molten aluminum is deposited at the bottom of the pot, and is periodically siphoned off and poured into molds to form "pigs" and "sows". A separate furnace operation is used to form "alloy pig" from the pure aluminum by the addition of alloying elements and this metal is cast into ingots for further processing, (Ref. **4.1).**

For the **2014** alloy, the additional alloying elements are copper, magnesium, silicon and manganese. Generally, this phase of production practice involves the melting, alloying and casting of large **20,000** to 50,000 pound ingots, carefully controlled. After the ingots are scalped and preheated in vertical electric soaking pits, they are ready for further processing to a particular form of product.

4.2 Manufacture of Wrought Products

4.21 Bar and rod are normally produced by hot rolling or extruding. Cold finished bar and rod are produced by hot working to a size slightly larger than specified and reducing to final dimensions by cold working. A better surface finish and closer dimensional tolerances are obtained in this manner, (Ref. **4.2).**

4.22 A similar process is used to produce rolled structural shapes; special rolls being required. Finishing operations include roller or stretch straightening, and heat treatment.

4.23 Roll form-shapes are produced by passing strip through a series of roller dies. Each successive pair of rolls cause the work to assume a cross-section shape more nearly approaching that desired. The final desired shape is produced at the last pair of rolls.

4.24 Plate is produced by hot rolling of ingots to slabs (approximately 60 percent reduction), usually in a **4** high reversible mill. The slabs are then further reduced 50 percent in a reversible **2** high mill. The last stage of hot rolling is done in a hot reversing mill, where the plate is progressively rolled to the final hot mill dimensions. Rate may be subjected to "stress relief" stretching (about **2** percent permanent set) to improve flatness and reduce warpage upon machining. Plate is then sheared or sawed to the required dimensions, (Ref. **4.2).**

4.25 Sheet is usually produced from plate by cold rolling to final sheet thickness; followed by trimming, tempering, heat treating, stretching and other finishing operations.

4.26 Wire is produced by drawing rod through a series of progressively smaller dies to obtain the desired dimensions.

4.27 Extrusions are produced by subjecting re-heated cast billets to enough pressure to force the metal to flow through a die orifice, forming a product whose cross-section shape and size conforms to that of the orifice. Speeds, pressures and temperatures must be closely controlled to insure uniform quality of extruded products.

4.28 Tube is produced by extruding, by drawing or by welding. Extruded tube is forced thru an orifice as described in **4.27.** A die and mandrel are used. Drawn tube is manufactured by a cold process which is similar to drawing bar and rod. A mandrel is used with one end fixed and a bulb attached to the other end. The tube is drawn over the mandrel bulb and through a die at the same time. Welded tube is produced by slitting coil stock into strips and passing the strips through a series of rolls to form tube. The longitudinal seam is welded as the tube leaves the last roll forming station.

4.29 Forgings are made by pressing (press forging) or hammering (drop forging). Relatively heavy equipment is required since aluminum is not as plastic at its forging temperature as steel. Aluminum forgings compare favorably with structural steel in unit strength at about me-third the weight. With comparable strength and with a lower elastic modulus, aluminum alloys have a much higher impact-energy-absorbing capacity than mild steel.

4.3 Casting of Alloy Ingots

4.31 Metal for wrought products is alloyed in large 10 to 25 ton double hearth furnaces, carefully controlled and instrumented. The direct chill (DC) method is generally used for casting these ingots. Molten metal is poured into a mold and a hydraulic piston descends slowly as the metal solidifies. Water is sprayed on the outside of the mold to promote rapid solidification. Additional processing may include scalping (machining of outside surfaces) or homogenizing, (Refs. **4.2** and **4.3).**

CHAPTER 4 - REFERENCES

4.1 "Kaiser Aluminum Sheet and Rate Product Information", Second Edition, Kaiser Aluminum and Chemical Sales, Inc., (January 1958)

4.2 "The Aluminum Data Book, Aluminum Alloys and Mill Products", Reynolds Metals Co., (1958)

4.3 "Alcoa Aluminum Handbook", Aluminum Co. of America, **(1962)**

CHAPTER 5

MANUFACTURING PRACTICES

5.1 General. This heat-treatable alloy is available as the bare alloy and in the Alclad condition. The availability for the various standard forms of the material is shown in Table 5.1. The 2014 alloy is used typically as heavy-duty forgings, airplane fittings and structural members. The Alclad 2014 is used for bridges and heavy-duty structures.

5.2 Forming

5.21 Sheet and Plate. The general formability of sheet material compared to other heat-treatable aluminum alloys is listed in Table 5.21 and is indicative of its ease of manufacture for the many different techniques.

5.211 Cold Forming. The formability of this alloy as well as other aluminum alloys can be indexed on the basis of the mechanical properties. High elongation and a considerable spread between yield and ultimate strength will be indicative of good formability. The simplest and most widely used forming method is probably that of bending. The ease of bending is indicative of formability by most other forming operations. Table 5.2111 indicates the ease of forming in terms of recommended minimum bend radii, as a function of temper and sheet and plate thickness, using typical mechanical properties #or 0.100 inch sheet. It can be appreciated that forming should, wherever possible, be performed in the softest condition, the annealed ("O") temper. Material formed in this condition may be heat treated later. If the severity of the forming operation is modest, the sheet or plate may be formed in the heat treated state, such as the T3 or T4 Condition. It can also be appreciated that the T6 Condition is extremely restricting as to the deformation which can be tolerated. Forming in the "O" temper followed by heat treatment involving the quenching of the alloy from 940F into cold water may distort the part, requiring excessive straightening and processing difficulties. In this case the forming may be performed in the "W" or freshly quenched temper, since in this state it may be formed more readily than in the heat treated temper. It has maximum formability immediately after quenching. After forming, full strength is obtained by aging. For maximum formability the total time between quenching and forming should not exceed 20 minutes. If refrigeration is used, the times indicated in Table 5.2112 are suggested.

If operations are difficult in the fully aged (T6) Condition, but where annealing is not necessary to achieve the required degree of formability, the T4 temper is often satisfactory. The product can then be given maximum strength, by aging to the T6 temper. Aluminum sheet is normally formed using operations such as:

1. Bending
2. Flanging
3. Rolling
4. Drawing
5. Pressing
6. Stretching
7. Embossing
8. Coining
9. Stamping
10. Spinning
11. Contour Forming
12. Bulging and Expanding
13. Beading and Roll Flanging
14. Necking
15. Curling

The factors influencing bending of 2014 sheet as spelled out previously also influence the fourteen other forming operations in the same general manner. Because of the lower modulus of elasticity of aluminum compared with steel, a much greater "springback" is expected and indeed is encountered. Overforming is the common way of correcting the tendency. In addition reducing the bend radius, increasing sheet thickness, forming at elevated temperatures, and increasing the total amount of plastic deformation decrease the extent of springback. Alloy 2014 sheets can be formed to many shapes by drawing and this is the most extensively employed mass production method. Depending upon the desired shape, the part may be produced in one draw or in some cases the reduction is accomplished in successive draws using frequent annealing between successive draws to avoid exhausting the ductility and introducing cracks. Deep draws normally employ male and female metal dies. Forming in rubber (Guerin Process), for relatively shallow parts, is a method where several thin layers of rubber are confined in a pad holder or retainer made of steel or cast iron, A descending ram on Which this holder is mounted causes the aluminum sheet to be compressed against a form block to make the required part. If the aluminum is made to flow against a female die using fluid pressures behind a rubber diaphragm the method is known as "hydroforming".
Other techniques such as spinning and high energy rate methods have also been successful.

5.212 Hot Forming. When it is difficult to form heat treated 2014-T6 alloy by conventional methods, hot forming may be used. Maximum reheating periods which are recommended are as shown in Table 5.2121.
This treatment, in general, reduces the corrosion resistance of room-temperature-aged 2014, However, artificial aging after hot forming prevents this susceptibility to corrosion. Although formability at higher temperatures is easier, excessive heating should not be used due to strength loss. Under controlled conditions, however, strength loss will seldom exceed five

percent as the result of reheating in accordance with Table 5.2121.

5.22 Shapes, Tubes and Pipe. Aluminum shapes are generally produced as extrusions. However, many standard structural shapes may also be produced by rolling. Shapes may be formed by continuous roll forming. The relative formability of alloy 2014 as tubes or extrusions can be seen in Table 5.22. As has been pointed out in the section discussing sheet and plate material, better formability can be obtained in the softer tempers and again the precautions of the previous section apply. Sections in the O temper are bent and formed more easily than those in the T3, T4, T6 and T6 heat-treated tempers, the last generally being the most difficult.

Stretching, wiping or rolling are general methods used to form shapes and tubing. Draw bending is also used to form the contour for shapes and tubes. Sheets, shapes and tubes are stretch formed by clamping at one end and pulling or stretching over a single male die so as to exceed the elastic limit. The metal section takes the shape of the die by stretching or elongating more in the heavier curvature areas than in the shallower ones. When working exceptionally thin-wall round, square, or rectangular tube on small radii, it is necessary to add a wiper and a flexible mandrel to provide extra support for the tube at the point of bending. Rolls can also be used for the forming, using dies to form the contours.

5.23 Forging. The heat treatable aluminum alloy 2014 is widely used for high strength forgings exhibiting good ductility and machinability. Forgings are produced by either the open die or closed die methods, using pressure or impact or a combination of these two techniques. In "die forging:' steady hydraulic pressure forces the alloy metal to fill a closed-die cavity. Rough "hand forged" shapes are produced by forging between open flat dies using impact. Very large pieces weighing over two tons can be produced by the hand forging technique, Hand forgings are produced in the tempers which are defined in Table 5.231.

As in all forgings, there is grain flow in 2014 forgings which results in anisotropy of properties. This must be considered for the evalution of mechanical properties.

The forging process begins with the forging stock, which is usually produced by the rolling or extruding process and may be cold finished to obtain close tolerances. Forging stock is carefully conditioned and inspected to insure soundness and suitable surfaces for forging. Stock may vary in size from 3/8 to 8 inch diameter round stock; 3/8 to 4 inch square stock; and rectangles from 3/8 inch to as much as 10 inches on the maximum dimension.

The recommended maximum forging temperature is 875F with a minimum finishing temperature of 650F. The exact temperature is dependent upon the type of forging process employed. The stock may be shaped in one step or, in the case of complicated parts, in several operations involving several reheatings. In die forging, the flash resulting from excess metal overfilling the mold is removed by hot or cold trimming, sawing or grinding. Very close tolerances can be met in the standard forging by die coining (cold) to precise dimensions, usually within a few thousanths of an inch. Straightening after heat treatment is often required. Templates with indicators and gages are used to determine "out-of-tolerance". Straightening is accomplished by hand methods or by "cold restrike" operations. Forgings are inspected for grain flow, dimensions, mechanical properties and ultrasonic soundness.
The relative forgeability of 2014 as a function of forging temperature is shown in Fig. 5.232. Fig. 5.233 shows the test bar orientation as a function of principal directions for hand forgings.

5.3 Machining

5.31 Conventional Machining. The aluminum alloy 2014 is readily machined in all conventional machining operations. The highest machinability is obtained in the hardest temper. In the softer temper the alloy tends to be somewhat gummy and is not as machinable. Hand forgings of 2014 which require a large amount of metal removal by roughing out before heat treatment should be machined in the F ternper. In those cases where hand forgings are to be machined to very close dimensions with the additional requirement for a good surface condition, the T4 temper yields optimum results. Small hand forgings can be machined successfully in the T6 temper. It is difficult to produce a precise tabulation of machining parameters for each of the different types of operations. However, Table 5.31 is a compilation of typical factors for many common machining operations. Grinding typically uses a wheel speed of 6000 ft/minute and a table speed of 60 ft/minute. The down feed will produce a rough finish if it is kept about 0.001 inch per pass. A fine finish will be produced if the down feed is kept to a maximum of 0.0005 inch per pass. The crossfeed is approximately one-third of the wheel width. The wheel type is A 46 KV with a water base emulsion or chemical solution for the grinding fluid.

5.32 Electro-Chemical and Chemical Machining

5.321 General Remarks. In many cases the designer may wish to take advantage of the high strength-to-weight ratio inherent in the aluminum alloy by employing an integrally stiffened skin or bulkhead. The removal of adjacent pockets in thick aluminum alloy plates can be programed to leave a ribbed pattern in a thin, high-strength aluminum panel. For

example, the waffle pattern left in 1 1/4 inch plate by milling pockets 1 inch deep allows high strength designs. Machining pockets of these dimensions in large plates by conventional metal cutting techniques requires extremely heavy and fixed tooling which has many disadvantages because of equipment versatility limitations. Alternate methods employing chemical and electrochemical methods have been proposed and are being investigated.

5.322 Electro-Chemical Milling. Electrochemical machining for metal shaping subjects the chemically erodible workpiece to the action of anodic current flow in a suitable electrolyte. A second electrode which is the tool is provided for the cathodic action. The basic principles are the same as those generalized in Faraday's Law of Electrolysis. However, the electrochemical machining, or ECM, process is the reverse of electro-deposition or electroplating. An exception is that the cathodic process involves the evolution of hydrogen, in most cases, rather than the electro-deposition of a metal.

There are a number of tool workpiece configurations that may be employed in the ECM process depending upon the particular type of metal removal geometry desired. It is normally required that fresh electrolyte is supplied to the workpiece. The trepan-type tool is shown in Fig. 5.3221. In a device such as this the electrolyte under pressure is supplied and escapes through the clearance between the tool and the workpiece. The cutting action is between the end of the tool and the workpiece. Under the cutting action, a hole corresponding to the tool outline is produced and a plug matching the under-sized shape of the tool hole is formed. In the plunge-type tool shown in Fig. 5.3222, because the working end of the tool is nearly solid, a cavity rather than a plug is produced. The shape of the tool cross-sections can vary from the simple squares, ovals, rounds, and D-shapes to rather complicated design shapes.

Alloy 2014 is essentially a pure aluminum as far as the rate of the electrochemical process is concerned. Hence, from the Faraday Laws it is rather easily shown that 1.26 cubic inches of the metal can be removed per minute at P0, 000 amperes (assuming 100% efficiency). In practice efficiencies of 80 to 90% are encountered. An electrolyte of 5-10% NaCl solution has been found to yield excellent results and the process can be carried out using voltages of 10-15 Volts, The milling rate of the ECM process depends upon the current capacity of the power supply and the ability of the electrolyte system to provide fresh electrolyte. High electrolyte pressure requirements of 100-250 psi provide even electrolyte flow and satisfactory cutting conditions. Tool forces in the ECM process are appreciable due to these high pressures required in the electrolyte gap. Temperatures of about 120F produce good quality finishes. Cooling coils to keep the temperature below 212F for these aqueous solutions may be required.

5.323 Chemical Milling. The removal of metal stock by chemical dissolution or "chem-milling" in general has also many potential advantages over conventional milling methods. Uniform attack with an acid or alkaline solution, however, does not always take place.
It is difficult in chemical milling to maintain vertical sidewalls in cavities and holes. Preliminary experiments on 2014-T651 using 20% NaOH at 212F are not encouraging. Rough etched surface condition with very slow metal removal rates were encountered.

AVAILABILITY OF FORMS

TABLE 5.1

Source	Ref. 5.6, p. 12; 5.1 Code 3201, p. 1
Alloy	Forms
2014	Sheet, strip, plate, rod, bar, structural shapes, extruded shapes, tubes and forgings
Alclad 2014	Sheet, strip and plate

RELATIVE FORMABILITY OF HEAT-TREATABLE ALLOYS IN ORDER OF DECREASING FORMABILITY

TABLE 5.21

Source	Ref. 5.3, p.9
Rating	Alloy
1	No. 21 and No. 22 (Brazing sheet)
2	6061
3	6066
4	2024
5	2014
6	7075
7	7178

APPROXIMATE BEND RADII FOR 90 DEGREE COLD BEND (a)(c)

TABLE 5.2111

Source	Ref. 5.6, p. 31, p. 44												
Temper	F_{tu} - ksi min	max	F_{ty} - ksi min	max	e(b) min	Sheet 1/64	1/32	1/16	1/8	3/16	1/4	3/8	1/2
O	-	30	-	14	16	O	O	O	O	O - 1t	O - 1t	1.5-3t	3-5t
T3	57	-	36	-	15	1 - 2t	1.5-3t	2 - 4t	3 - 5t	4 - 6t	4 - 6t	5 -7t	5.5-8t
T4	57	-	34	-	15	1 - 2t	1.5-3t	2 - 4t	3 - 5t	4 - 6t	4 - 6t	5 -7t	5.5-8t
T6	64	-	57	-	8	2 -4t	3 -5t	3 - 5t	4 - 6t	5 - 7t	6 - 10t	7 - 12t	8 - 14t

(a) Radii for various thicknesses expressed in terms of thickness, t

(b) Elongation, percent in 2 in gage section

(c) Mechanical properties (F_{tu}, F_{ty} and e) are typical for 0.100 inch sheet

RECOMMENDED MAXIMUM HOLDING TIMES AFTER FRESHLY QUENCHED("W" TEMPER) PRIOR TO FORMING, AS A FUNCTION OF HOLDING TEMPERATURE

TABLE 5.2112

Source	Ref. 5.1 Code 3201, p. 3
Temperature of hold, F	Time in indicated units
Room	20 min
32F	24 hr
20F	3 days
0F	7 days

MAXIMUM REHEAT PERIOD FOR ALLOY 2014-T6

TABLE 5.2121

Source	Ref. 5.5, p. 133
Temp-F	Time
300	20 to 50 hr
325	8 to 10 hr
350	2 to 4 hr
375	30 to 60 min
400	5 to 15 min
425	Time to temperature
450	Time to temperature

RELATIVE FORMABILITY OF HEAT-TREATABLE EXTRUSION AND TUBE ALLOYS IN ORDER OF DECREASING FORMABILITY

TABLE 5.22

Source	Ref. 5.5, p. 133	
Rating	Extrusion	Tubing
1	6063, 6463	6063
2	6061, 6062	6061, 6062
3	2024	2024
4	2014	2014
5	7075, 7079	7075
6	7178	-

HEAT TREATMENT OF HAND FORGINGS

TABLE 5.231

Source	Ref. 5.2, p.56
Temper	Treatment
F	As forged, no thermal treatment following fabrication operation
W	Solution heat treated and quenched in water at 140F
T4	Solution heat treated, quenched in water at 140F and natural aged to a substantially stable condition
T41	Solution heat treated, quenched in water at 212F and naturally aged to a substantially stable condition
T6	Solution heat treated, quenched in water at 140F and artificially aged
T652	Solution heat treated, quenched in water at 140F, stress relieved by cold compression artificially aged

MACHINING RECOMMENDATIONS FOR SOLUTION TREATED AND AGED 2014 ALLOY

TABLE 5.31

Source	Ref. 5.7						
Operation	Cutting Conditions*	High Speed Tool			Carbide Tool		
		Speed fpm	Feed ipr	Tool mat'l	Speed fpm	Feed ipr	Tool mat'l
Single point Turning	0.250 inch depth of cut	600	0.015	T1, M1	1100	0.015	C-1
	0.050 inch depth of cut	800	0.008	T1, M1	1400	0.008	C-2
Form tool, turning	0.500 inch form tool width	450	0.0035	T1, M1,	1000	0.0035	C-2
	0.750 inch form tool width	450	0.0035	HSS	1000	0.0035	C-2
	1.000 inch form tool width	450	0.003	HSS	1000	0.003	C-2
	1.500 inch form tool width	450	0.0025	HSS	1000	0.002	C-2
	2.000 inch form tool width	450	0.002	HSS	1000	0.002	C-2
Boring	0.010 inch depth of cut	600	0.008	T1, M1,	1100	0.010	C-1, C-3
	0.050 inch depth of cut	570	0.010	HSS	1050	0.015	C-1, C-3
	0.100 inch depth of cut	540	0.015	HSS	1000	0.020	C-1, C-3
Planing	0.500 inch depth of cut	300	0.060	T1, M1	300	0.060*	C-2
	0.050 inch depth of cut	300	0.050	T1, M1	300	0.050	C-2
	0.010 inch depth of cut	300	3/4**	T1, M1	300	3/4**	C-2
Face milling	0.250 inch depth of cut	800	0.020*	T1, M1	max	0.018*	C-2
	0.050 inch depth of cut	1000	0.022*	T1, M1	max	0.020*	C-2
End milling (Profiling)	3/4 inch cutter diameter	700	0.006*	M1, M10	1200	0.005*	C-2
	1/2 inch cutter diameter	700	0.009*	M1, M10	1200	0.008*	C-2
	1/8 inch cutter diameter	1000	0.0007*	M1, M10	1800	0.0005*	C-2
	3/8 inch cutter diameter	1000	0.005*	M1, M10	1800	0.004*	C-2
	3/4 inch cutter diameter	1000	0.007*	M1, M10	1800	0.006*	C-2
	1 to 2 inch cutter diameter	1000	0.010*	M1, M10	1800	0.009*	C-2
Drilling	1/8 inch nominal hole diameter	250	0.003	M1, M10			
	1/4 inch nominal hole diameter	250	0.007	HSS			
	1/2 inch nominal hole diameter	250	0.012	HSS			
	3/4 inch nominal hole diameter	250	0.016	HSS			
	1 inch nominal hole diameter	250	0.020	HSS			
	1 1/2 inch nominal hole diameter	250	0.025	HSS			
	2 inch nominal hole diameter	250	0.030	HSS			
	3 inch nominal hole diameter	250	0.030	HSS			

* Feed - inches per tooth

* * Feed - 3/4 the width of square nose finishing tool

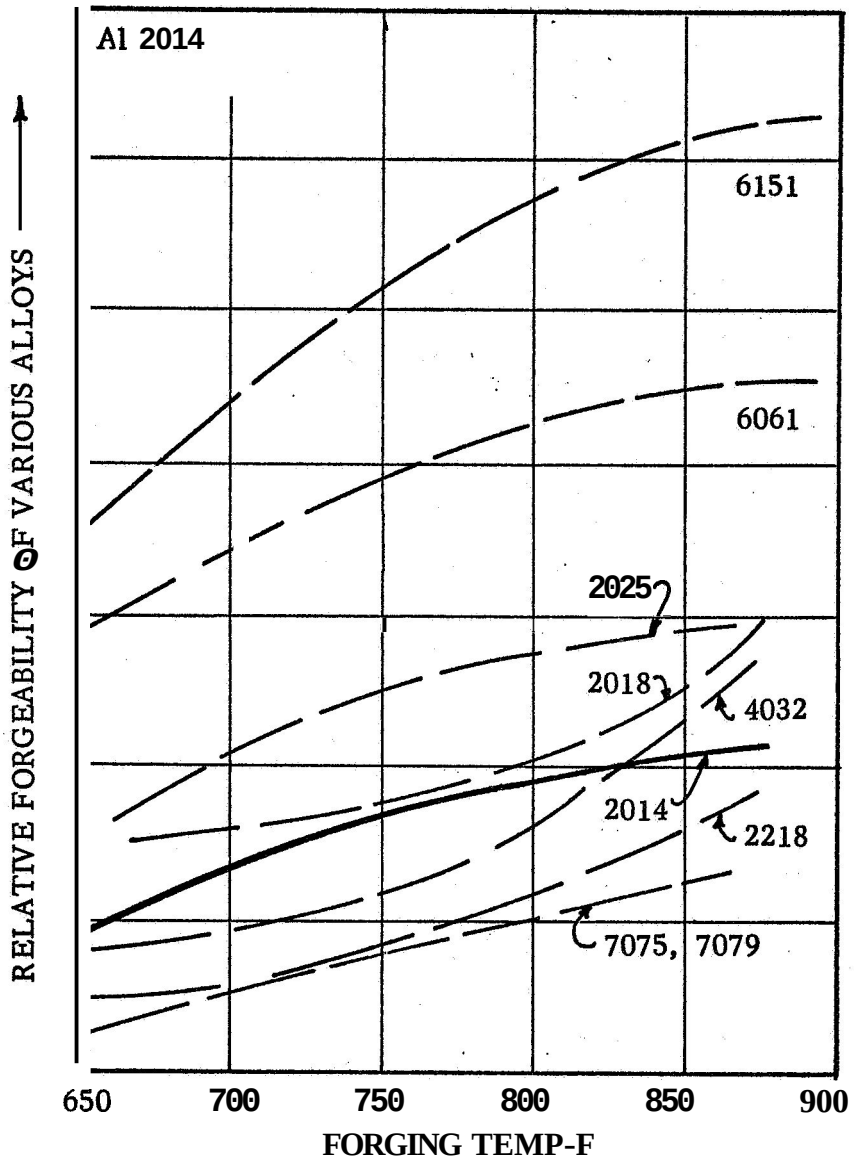


FIG. 5.232 RELATIVE FORGEABILITY OF VARIOUS ALUMINUM ALLOYS

(Ref. 5.2, p.264)

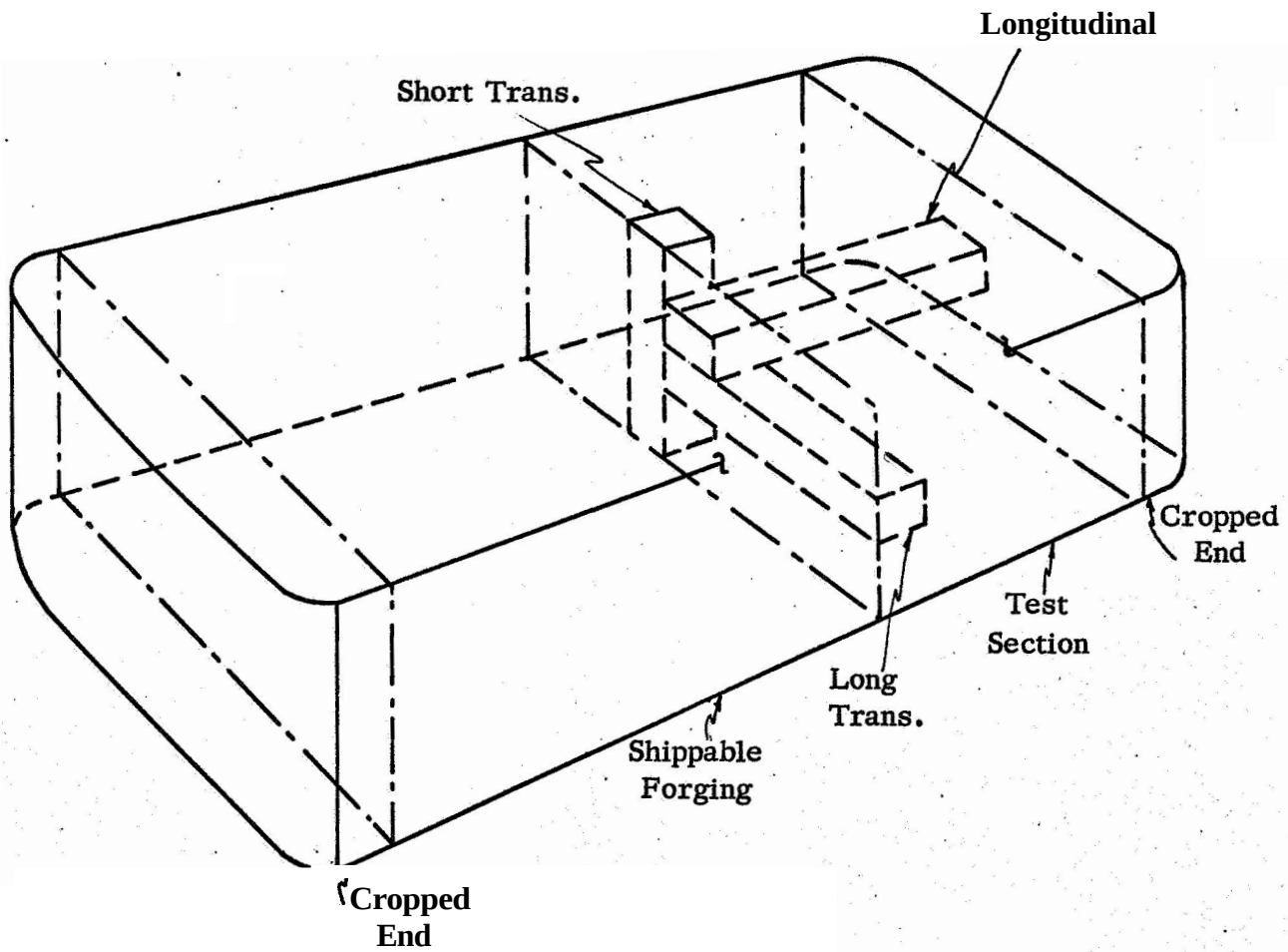
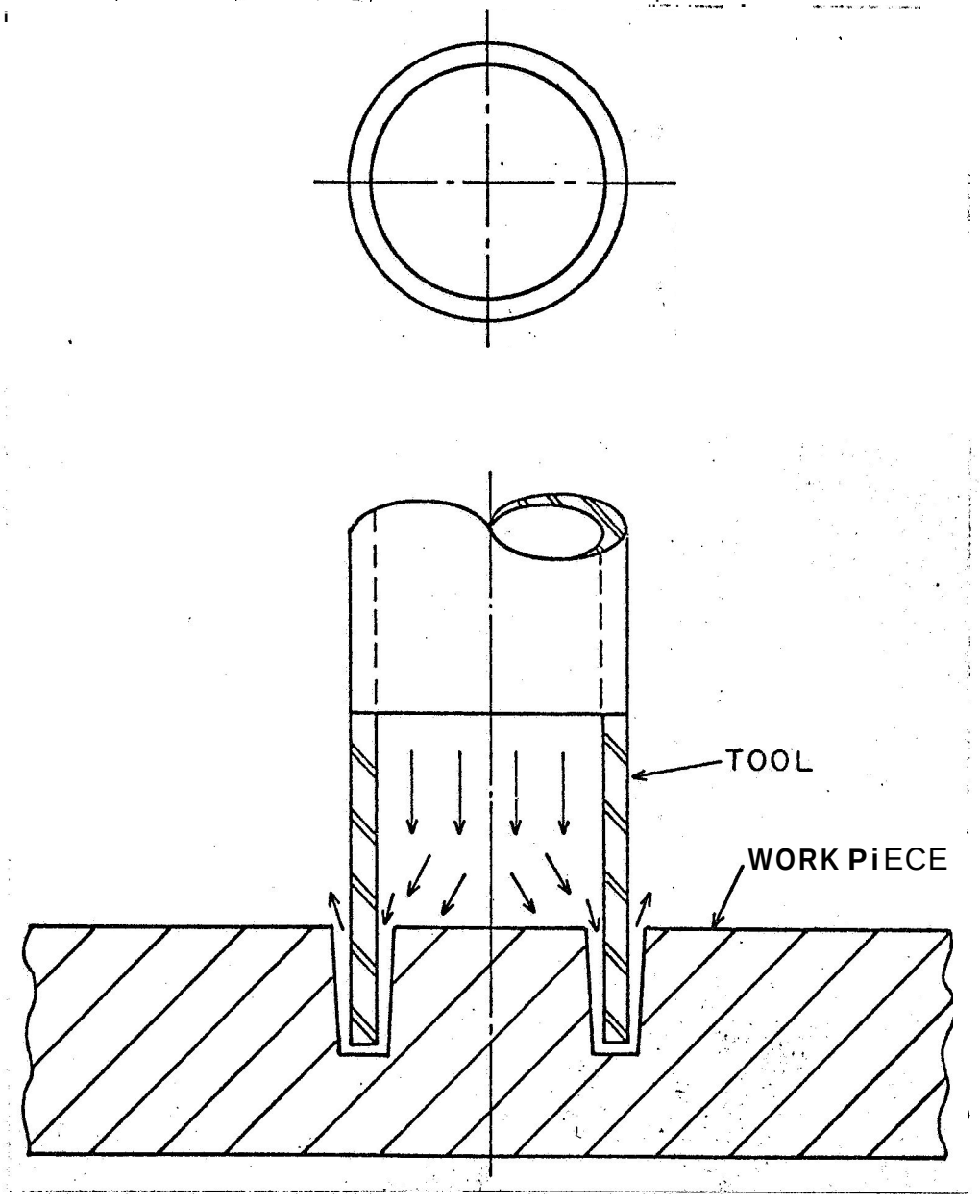


FIG. 5.233 LOCATIONS OF TEST BARS FOR TESTING HAND FORGINGS.OF RECTANGULAR OR SQUARE CROSS SECTIONS

(Ref. 5.2, p.59)



FIG, 5.3221 TREPAN-TYPE OF ECM TOOL
('Ref. 5.8)

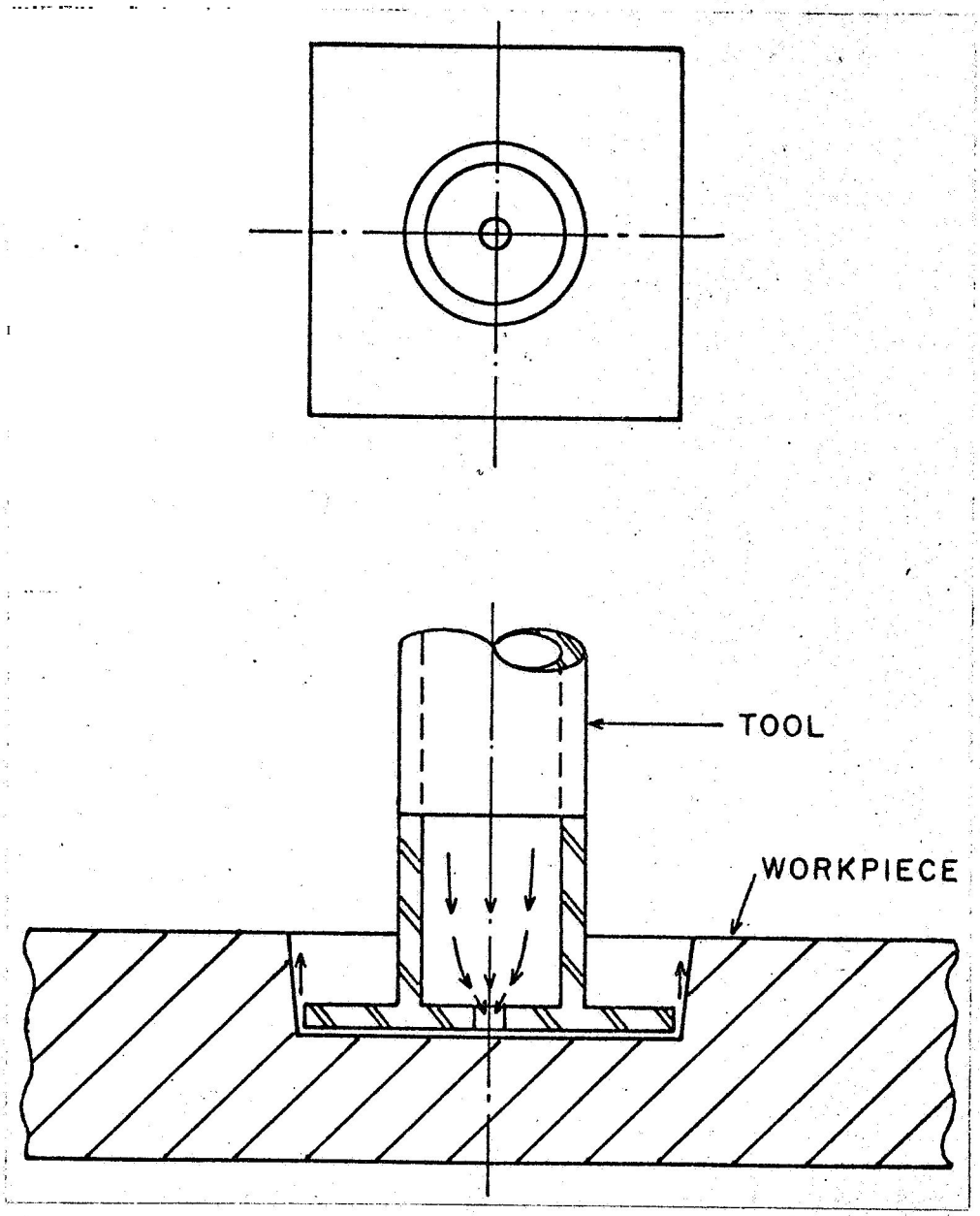


FIG. 5.3222 PLUNGE-TYPE OF ECM TOOL
(Ref. 5.8)

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CHAPTER 6

SPACE ENVIRONMENT EFFECTS

6.1 General. Aluminum alloys have been used in both structural and non-structural applications in launch vehicles and spacecraft with excellent success since, in general, the aluminum alloys are relatively insensitive to degradation in the typical space environmental conditions. The vapor pressures of the structural aluminum alloys are sufficiently high, (Fig. 6.1) so that the combined temperature-vacuum effects generally are negligible. Structural alloys such as 2014 are sufficiently hardened so that nuclear and space indigenous radiation induced defects do not significantly affect mechanical and physical properties, at room ambient and elevated temperatures, below accumulated doses of about 10^{22} particles/cm^2. When irradiated at cryogenic temperatures, the threshold may be lowered one or two decades, but the probabilities of experiencing doses on this order of magnitude are extremely remote except in the vicinity of nuclear reactors.

Elevated temperatures, hard vacuums, high energy radiations, and micrometeoroids can singularly and collectively influence surface characteristics of 2014 by desorption processes and erosion. These phenomena might be of great importance if optical properties, lubrication, certain electrical properties, etc., were critical design parameters.

Sputtering of the surface by atomic or molecular particles can deteriorate surface finishes in a relatively short period. A 300 A coating of aluminum (10^{-5} gm/cm^2) can be destroyed in one month during a period of low intensity solar wind or in several hours during a solar storm for example. Threshold energies for sputtering reactions are quite low, in the order of 6, 11, and 12 ev for O, N_2 and O_2 particles, respectively. Estimates of surface erosion by sputtering are given in Tables (6.1) and (6.2) for aluminum alloys.

Micrometeoroids can produce surface erosion similar to sputtering, although perhaps on a more macroscopic scale, as well as punctures. Micrometeoroids vary widely in mass, composition, velocity, and flux; generalizations about the rates of erosion and penetration, therefore, must be used with care. The predicted frequency of impact as a function of meteoroid mass is given in Fig. (6.2). Data are given in Figs. (6.3) and (6.4) on the penetration and cratering of aluminum alloy skins of various thicknesses.

The surface erosion of 2014 due to corpuscular radiation is probably insignificant, amounting to something on the order of 10 μ per year. Indigenous space radiation, however, will tend to accelerate the removal of surface films on the 2014. The removal of such films might result in loss of lubricity

and an increased propensity to "cold weld". The interaction of indigenous radiation with desorption gases might cause some spurious, transient electrical conditions when **2014** is used for electrical applications. The interaction of indigenous radiation with the **2014** will produce some internal heating that might be significant for small items and some induced radio-activity.

IMPACT FLUX, MASS FLUX, PARTICLE CONCENTRATION, AND DENSITY FOR THE PARTICLE BELT SURROUNDING THE EARTH

TABLE 6.1

Source		Ref. 6.3			
Zone	Altitude[a]	Flux Impact (m^{-2}-sec^{-1})	Flux Mass ($gm\text{-}cm^{-2}\text{-}sec^{-1}$)	Particle Concentration (cm^{-3})	Density ($gm\text{-}cm^{-3}$)
1	100km < h < 400km	10^{-1} to 10^{0}	10^{-13} to 10^{-12}	4×10^{-11} to 4×10^{-10}	4×10^{-19} to 4×10^{-18}
2	400km < h < $2R_E$	10^{-4} to 10^{-2}	10^{-16} to 10^{-14}	4×10^{-14} to 4×10^{-12}	4×10^{-22} to 4×10^{-20}
3	h > $2R_E$	5×10^{-6} to 10^{-4}	5×10^{-18} to 10^{-16}	2×10^{-15} to 4×10^{-14}	2×10^{-23} to 4×10^{-22}
	Zodiacal cloud	2×10^{-6} to 1.2×10^{-3}	10^{-17} to 10^{-15}	10^{-15} to 10^{-13}	3×10^{-23} to 3×10^{-21}

(a) h is distance from earth's surface in km unless given in R_E (earth radii),

ESTIMATE9 RATE OF REMOVAL AND TIME TO REMOVE 1 A OF ALUMINUM BY SPUTTERING

TABLE 6.2

Source	Ref. 6.2			
	Orbiting Vehicle		Escaping Vehicle	
Height (Km)	Rate (atom cm^{-2} sec^{-1})	Time (sec/Å)	Rate (atom cm^{-2} sec^{-1})	Time (sec/Å)
100	3.1×10^{16}	1.9×10^{-2}	3.4×10^{17}	1.8×10^{-3}
220	2.0×10^{13}	30	2.0×10^{17}	3.0×10^{-3}
700	2.2×10^{9}	2.7×10^{5}	3.4×10^{11}	1.8×10^{3}
2500	4.3×10^{5}	1.4×10^{9}	1.6×10^{8}	3.8×10^{6}

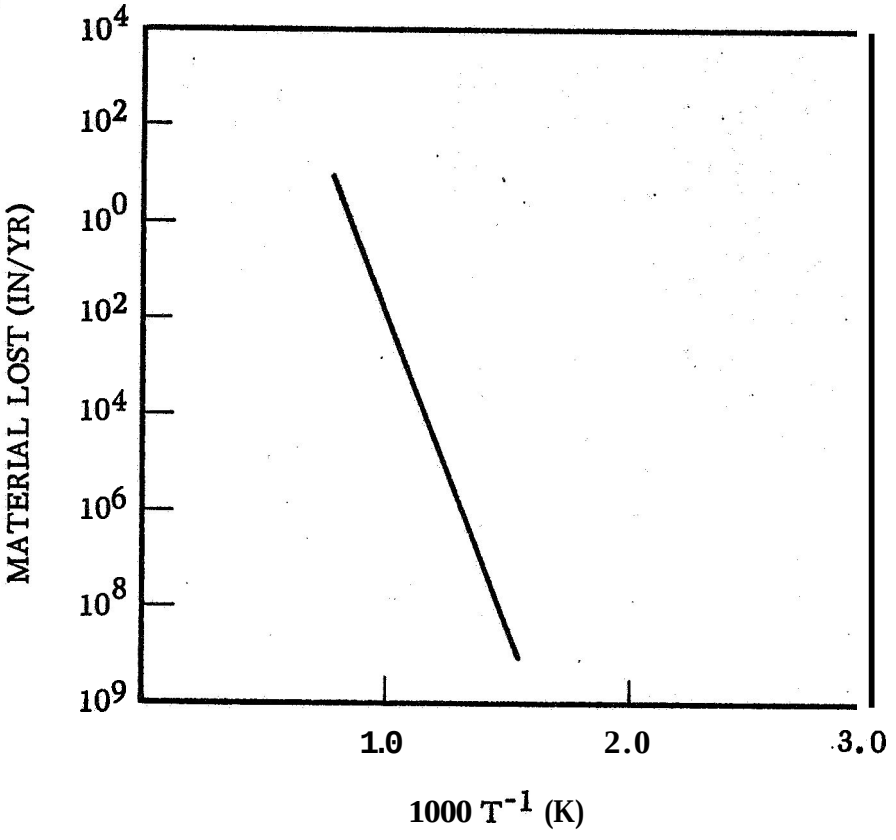


FIG. 6.1 EVAPORATION RATE FOR ALUMINUM (Ref. 6.1)

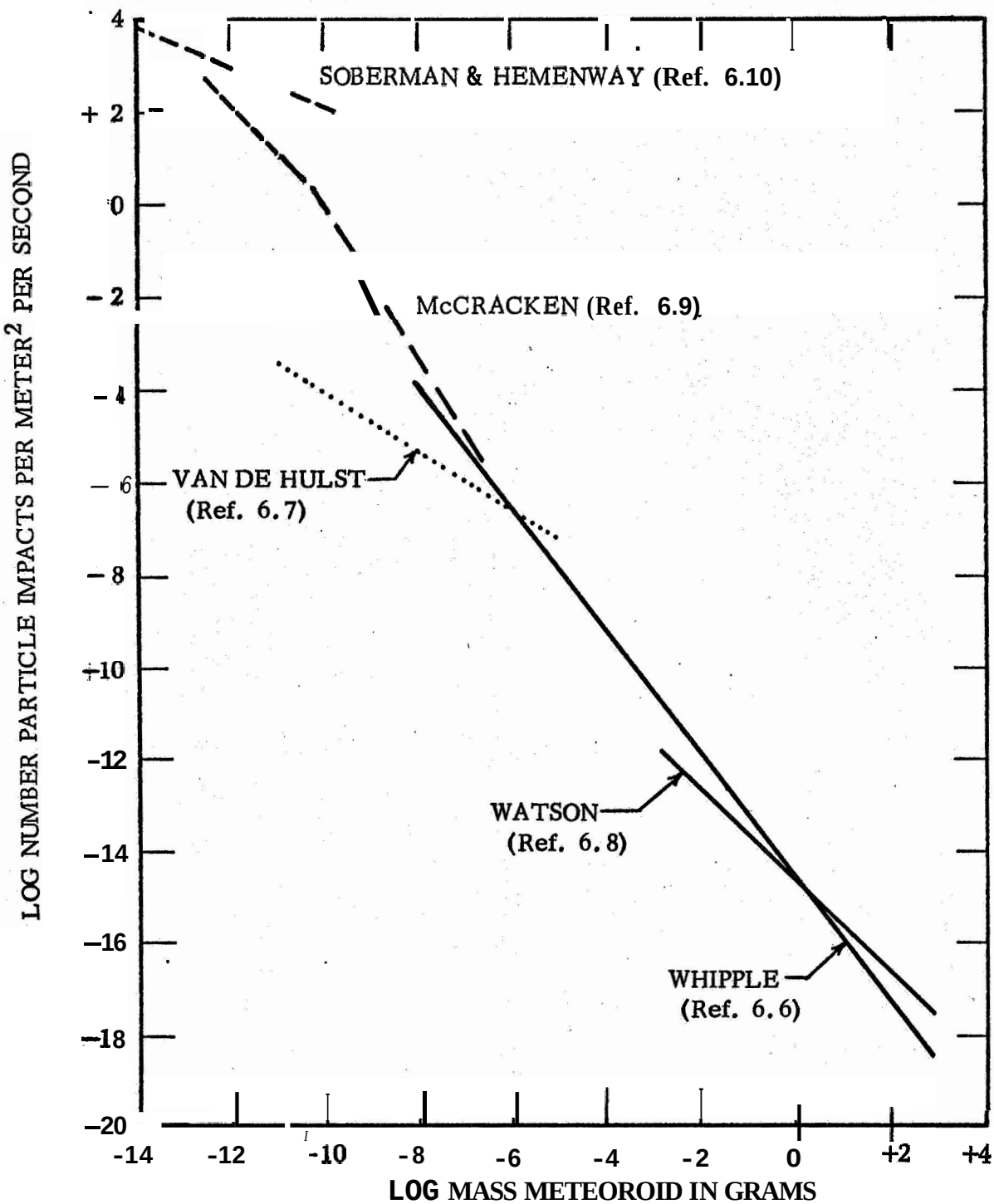


FIG. 6.2 CUMULATIVE METEOROID IMPACT RATES NEAR THE EARTH (Ref, 6.1)

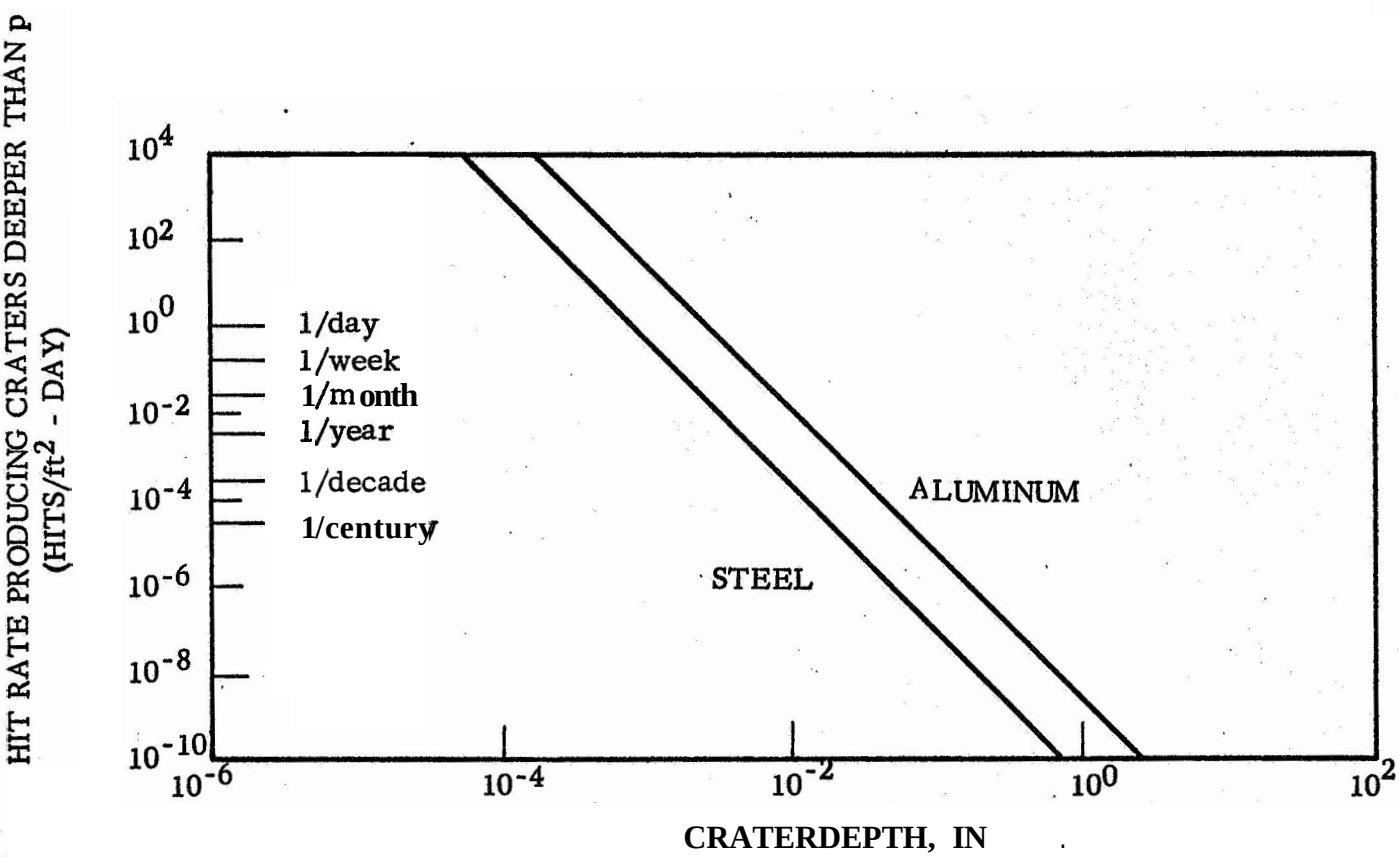


FIG. 6.3 HIT RATE vs CRATER DEPTH IN THE EARTH NEIGHBORHOOD BUT WITHOUT EARTH SHIELDING

(Ref. 6.4)

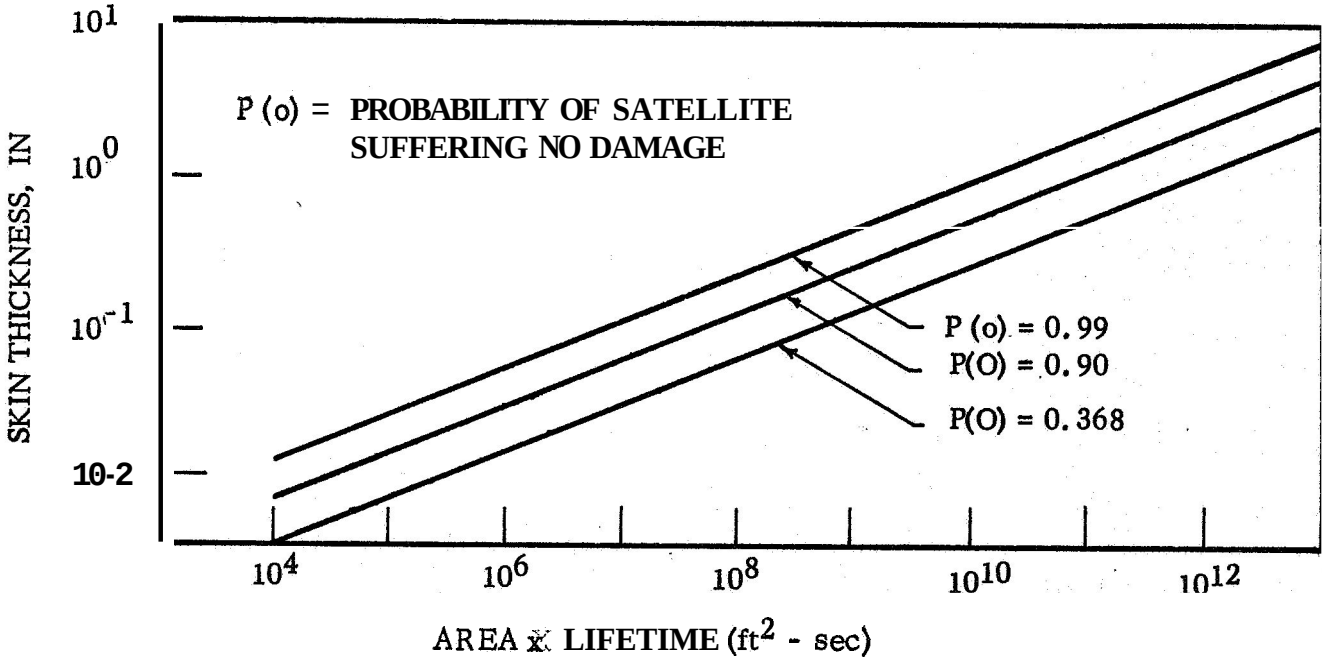


FIG. 6.4 ALUMINUM SKIN THICKNESS REQUIRED FOR METEOROID PROTECTION (Ref. 6.5)

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CHAPTER 7

STATIC MECHANICAL PROPERTIES

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7.22 Young's modulus of elasticity, E.

7.221 Bare products, Cond. O, T4 and T6; $E = 10.6 \times 10^3$ ksi
Clad products, Cond. O, T3, T4 and T6; $E = 10.5 \times 10^3$ ksi, (Ref. 7.13).

7.222 Effect of temperature on E and E_c, Fig. 7.222.

7.223 Design value of E at room temperature, $E = 10.5 \times 10^3$ ksi, (Ref. 7.1).

7.23 Compression modulus E_c.

7.231 Compression modulus is approximately 2 percent greater than the tension modulus, (Ref. 7.13).

7.232 Effect of temperature on E_c, see Fig. 7.222.

7.233 Design value of E_c at room temperature, $E_c = 10.7 \times 10^3$ ksi, (Ref. 7.1).

7.24 Modulus of rigidity (shear modulus), G.

7.241 Design value of G at room temperature, $G = 4.0 \times 10^3$ ksi, (Ref. 7.1).

7.25 Tangent modulus

7.251 Typical tangent modulus curves for clad sheet at room temperature, Fig. 7.251.

7.252 Typical tangent modulus curves for extrusions and rolled products at room temperature, Fig. 7.252.

7.253 Typical tangent modulus curves in compression for clad sheet at room and elevated temperatures, Fig.. 7.253.

7.26 Secant modulus

7.3 Hardness

7.31	Brinell scale	Cond O	45
		T4	105
		T6	135, (Ref. 7.13 and 7.14).
7.32	Rockwell scale	Cond O	H87-98
		T4	B65-73
		T6	B80-86, (Ref. 7.14).

7.33 Effect of cryogenic temperatures on Brinell hardness of forgings in T6 Condition, see Fig. 7.4134.

7.4 Strength Properties. See also 7.1.

7.41 Tension

7.411 Design tensile properties

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7.42 Compression

7.421 Design compression properties

7.4211 Design compression properties for sheet and plate, see Table **7.4111.**

7.4212 Design compression properties for clad sheet and plate, see Table **7.4112.**

7.4213 Design compression properties for die forgings and hand forgings in **T4** and T6 Conditions, see Table **7.4113.**

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7.422 Stress-strain diagrams (compression)

7.4221 Typical stress-strain curves in cornpression for clad sheet: in T6 Condition at room and elevated temperatures, Fig. **7.4221,**

7.43 Bending

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7.441 1 Design shear properties for sheet and plate, see Table **7,4111.**

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7.4413 Design shear properties for die forgings and hand forgings in **T4** and T6 Conditions, see Table **7.4113.**

7.4414 Design shear properties for bar, rod,: wire andshapes, see Table **7.4114.**

7.4415 Design shear properties for extruded bar, rod and shapes, see Table **7.4115.**

7.442 Effect of test temperature on F_{bru}, F_{bry} and F_{su} of clad sheet in T6 Condition, Fig. **7.442.**

7.443 Effect of low temperatures on shear strength of sheet in T6 Condition, Fig. **7.443.**

7.45 Bearing

7.451 Design bearing properties

7.4511 Design bearing properties for sheet and plate, see Table **7.4111.**

7.4512 Design bearing properties for clad sheet and plate, see Table **7.4112.**

7.4513 Design bearing properties for die forgings and hand forgings in **T4** and T6 Conditions, see Table **7.4113.**

7.4514 Design bearing properties for bar, rod, wire and shapes, see Table **7.4114.**

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7.4516 Bearing property reductions for thick plate, Table **7.4516.**

7.452 Effect of test temperature on F_{bru}, F_{bry} and F_{su} of clad sheet in **T6** Condition, see Fig. **7.442.**

7.46 Fracture

7.461 Notch strength, (see also Fig. 7.4135).

7.4611 Effect of cryogenic temperatures on tensile and sharp notch properties of sheet in **T6** Condition, Fig. 7.4611.

7.4612 Strength of sheet containing shallow cracks, Fig. **7.4612.**

NASA SPECIFIED MECHANICAL PROPERTIES FOR DIE FORGINGS AND SEPARATELY FORGED TEST BARS

TABLE 7.111

Alloy		2014 (b)		
Specification		NASA-MSFC-SPEC-144B		
Product		Die Forgings and Separately Forged Test Bars		
Max. sect, thick, in		4		
Temper	Orientation (A or B)	F_{tu}, ksi (min)(a)	F_{ty}, ksi (min)(a)	e(2 in or 4D) (min) percent
T4	A	55.0	30.0	11
T6	A	65.0	55.0	7
T6	B	64.0	56.0	3

(a) Tensile and yield strength test requirements may be waived for material in any direction in which the dimension is less than 2 inches because of the difficulty in obtaining a tension test specimen suitable for routine control testing.

(b) Die forgings in some configurations of this alloy can be purchased in the heat treated and mechanically stress relieved T652 temper conforming to the mechanical properties requirement specified for the T6 temper.

A Test specimen parallel to forging flow lines

B Test specimen not parallel to forging flow lines

NASA SPECIFIED MECHANICAL PROPERTIES FOR HAND FORGINGS

TABLE 7.112

Alloy		2014-T6			
Specification		NASA-MSFC-SPEC-144B			
Product		Hand Forgings (a)			
Temper	Thickness, in (b)	Axis of Test Specimen	F_{tu}, ksi (min)(c)	F_{ty}, ksi (min) (c)	e(2 in or 4D) (min) percent
T6	≤ 2.00	L	65.0	56.0	8
		LT	65.0	56.0	
	2.001 to 3,000	L	64.0	56.0	8
		LT	64.0	55.0	3
		ST	62.0	55.0	2
	3.001 to 4.000	L	63.0	55.0	8
		LT	63.0	55.0	3
		ST	61.0	54.0	2
	4.001 to 5.000	L	62.0	54.0	7
		LT	62.0	54.0	2
		ST	60.0	53.0	1
	5.001 to 6.000	L	61.0	53.0	7
		LT	61.0	53.0	2
		ST	59.0	53.0	1
	6.001 to 7.000	L	60.0	52.0	6
		LT	60.0	52.0	2
		ST	58.0	52.0	1
	7.001 to 8.000	L	59.0	51.0	6
		LT	59.0	51.0	2
		ST	57.0	51.0	1

(a) Maximum cross-sectional area is 256 square inches.

(b) Thickness is measured in the short transverse direction and applies to the "as forged" dimension before machining.

(c) Tensile property requirements may be waived for directions in which the dimension is less than 2 inches,

NASA SPECIFIED MECHANICAL PROPERTIES FOR T652 HAND FORGINGS

TABLE 7.113

Alloy		2014-T652			
Specification		NASA-MSFC-SPEC-144B			
Product		Hand Forgings (a)			
Temper	Thickness, in (b)	Axis of Test Specimen	F_{tu}, ksi (min)(c)	F_{ty}, ksi (min)(c)	e(2 in or 4D) (min) percent
T652	≤ 2.000	L	65.0	56.0	8
		LT	65.0	56.0	3
	2.001 to 3.000	L	64.0	56.0	8
		LT	64.0	55.0	3
		ST	62.0	55.0	2
	3.001 to 4.000	L	63.0	55.0	8
		LT	63.0	55.0	3
		ST	61.0	51.0	2
	4.001 to 5.000	L	62.0	54.0	7
		LT	62.0	54.0	2
		ST	60.0	50.0	1

(a) Maximum cross-sectional area is 256 square inches.
(b) Thickness is measured in the short transverse direction and applies to the "as forged" dimension before machining,
(c) Tensile property requirements may be waived for directions in which the dimension is less than 2 inches.

AMS SPECIFIED TENSILE PROPERTIES FOR SHEET AND PLATE

TABLE 7.121

Alloy	2014							
Property	Tensile (b)(c)(d)							
Form	Sheet and Plate							
Specification	AMS 4028A		AMS 4029A					
Condition	O		T6					
Thickness - in	0.020 to 0.499	0.500 to 1.000	0.020 to 0.039	0.040 to 0.499	0.500 to 1.000	1.001 to 1.500	1.501 to 2.000	2.001 to 3.000
F_{tu}, min-ksi	32.0 (a)	32.0 (a)	64.0	67.0	67.0	67.0	65.0	63.0
F_{ty}, min-ksi	16.0 (a)	-	57.0	59.0	59.0	59.0	59.0	57.0
e(2 in) min-percent	16 (a)	10 (a)	6	7	6	4	3	2

a) These values are maximum values.

b) Test specimens conforming to ASTM E8-57T except for material less than 0.75 inch wide, and shall be transverse to rolling direction except for material less than 9 inches wide.

c) Elongation requirements apply only to material 0.75 inch and over in width.

d) Tensile properties of plate over 3.000 inches in thickness shall be as agreed upon by vendor and purchaser.

AMS SPECIFIED TENSILE PROPERTIES FOR BAR, ROD, WIRE AND DIE FORGINGS

TABLE 7.122

Alloy	2014			
Property	Tensile			
Form	Bar, Rod, Wire (rolled, drawn, CF)	Die Forgings (b)(c)	Die Forgings (b)	Die Forgings (e)
Specificiation	AMS 4121C	AMS 4134A	AMS 4135J	AMS 4135J
Condition	T6	T4	T6	T6
Thickness - in	All except (a)	-	-	-
Area, in^2	All except (a)	-	-	-
F_{tu}, min-ksi	65.0	55.0	65.0	62.0
F_{ty}, min-ksi	55.0	30.0	55.0	52.0
e(2 in or 4D), min-percent	8	16 (c)	10 (d)	3

a) F_{ty} and e do not apply to material under 0.125 inch.
F_{tu} shall be agreed upon by purchaser and vendor on rounds over 8.000 inch diameter; on squares, hexagons and octagons over 4.000 inches;
and on rectangles thicker than 4.000 or maximum area over 36 square inches.

b) Specimens machined from separately forged coupons or from forging stock (representing the forgings; heat treated with the forgings.)

c) Specimens machined from forgings not over 4 inches thick (axis parallel to forging flow lines), than e may be as low as 11.0 percent).

d) Specimens machined from forgings not over 4 inches thick (axis parallel to forging flow lines), then e may be as low as 7.0 percent.

e) Specimens machined from die forgings not over 4 inches thick (axis not parallel to flow lines).

AMS SPECIFIED TENSILE PROPERTIES FOR ROLLED RINGS AND HAND FORGINGS

TABLE 7.123

Alloy	2014														
Property	Tensile														
Specification	AMS 4135J														
Condition	T6														
Form	Rolled Rings		Hand Forgings												
Thickness - in	< 4.0	< 4.0	< 6.0			< 6.0			< 6.0			< 6.0		
Area, in^2	-	-	≤ 16			16 to 36			36 to 144			144 to 256		
Orientation	Tang	Axial	L	LT	ST	L	LT	ST	L	LT	ST	L	LT	ST
F_{tu}, min-ksi	65.0	62.0	65.0	63.0	60.0	65.0	63.0	60.0	62.0	59.0	56.0	60.0	58.0	55.0
F_{ty}, min-ksi	55.0	55.0	55.0	55.0	55.0	53.0	53.0	53.0	53.0	52.0	52.0	52.0	50.0	50.0
e(4D),min-percent	7	3	8	4	3	7	3	2	5	2	1	5	2	1

L - Longitudinal
LT - Long transverse
ST - Short transverse

AMS SPECIFIED TENSILE PROPERTIES FOR EXTRUSIONS

TABLE 7.124

Alloy	2014				
Property	Tensile (a)				
Specificiation	AMS 4153B				
Condition	T6				
Form	Extrusions (bar, rod, shapes and tubing)				
Diameter or Thickness - in	≤ 0.124	0.125 to 0.499	0.500 to 0.749	> 0.749	> 0.749
Area, in^2	All	All	All	≤ 25	25 to 32
Orientation	L	L	L	L	L
F_{tu}, min-ksi	60.0	60.0	64.0	68.0	68.0
F_{ty}, min-ksi	53.0	53.0	58.0	60.0	58.0
e(2in)*min-percent	7	7	7	7	6

* or 4D

a) The tensile requirements for bar, rod and shapes are based on the thickness of the extrusion section from which specimen is taken. Specimens from sections > 1.5 inches are taken midway between center and surface,

AMS SPECIFIED TENSILE PROPERTIES FOR EXTRUSIONS

TABLE 7.125

Alloy	2014					
Property	Tensile					
Specification	AMS 4153B					
Condition	T6					
Form	Extrusions (bar, rod and shapes)					
Diameter or Thickness - in	0.125 to 0.499	0.500 to 0.749	0.750 to 1.499	0.750 to 4.499	1.500 to 2.999	3.000 to 4.499
Area, in^2	$\leq$ 25	$\leq$ 25	25 to 32	$\leq$ 25	$\leq$ 25	$\leq$ 25
Orientation	LT	LT	LT	LT	LT	LT
F_{tu}, min-ksi	60.0	64.0	63.0	56.0	61.0	58.0
F_{ty}, min-ksi	53.0	55.0	54.0	47.0	52.0	49.0
e(2in)*min-percent	5	5	2	1	2	1

* (or 4D)

AMS SPECIFIED BEND FACTORS. FOR SHEET AND PLATE

TABLE 7.126

Alloy	2014							
Property	Bend factor (a)							
Form	Sheet and Plate							
Specification	AMS 4028A			AMS 4029A				
Condition	O			T6				
Thickness - in	≤ 0.124	0.125 to 0.249	0.250 to 0.499	0.020 to 0.039	0.040 to 0.050	0.051 to 0.124	0.125 to 0.249	0.250 to 0.499
Bend factor	2T	4T	6T	5T	6T	8T	10T	12T

a) Axis of bend parallel to rolling direction,

ASTM SPECIFIED TENSILE PROPERTIES FOR SHEET AND PLATE

TABLE 7.151

Alloy	2014					
Source	Reference 7.8					
Property	Tensile (d)					
Form	Sheet and Plate					
Specification	ASTM B209-64					
Temper (a)	Thickness - in	F_{tu}, KSI		F_{ty}, KSI		e(2 in or 4D)
		Min	Max	Min	Max	Min - percent
O (b)	0.020 - 0.039	-	32.0	-	0	16
	0.500 - 1.000	-	32.0	-	-	10
T3	0.020 - 0.039	59.0	-	35.0	-	14
	0.040 - 0.249	59.0	-	36.0	-	14
T6, T62	0.020 - 0.039	64.0	-	57.0	-	6
	0.040 - 0.249	67.0	-	59.0	-	7
T6, T62, T652 (c)	0.250 - 0.499	67.0	-	59.0	-	7
	0.500 - 1.000	67.0	-	59.0	-	6
	1.002 - 1.500	67.0	-	59.0	-	4
	1.501 - 2.000	65.0	-	59.0	-	3
	2.001 - 3.000	63.0	-	57.0	-	2
	3.001 - 4.000	59.0	-	55.0	-	1

Footnotes, see page 7.

ASTM SPECIFIED TENSILE PROPERTIES FOR CLAD SHEET AND PLATE

TABLE 7.152

Alloy	2014					
Source	Reference 7.8					
Property	Tensile (d)					
Form	Alclad Sheet and Plate (e)					
Specification	ASTM B209-64					
Temper (a)	Thickness-in	F_{tu}, ksi		F_{ty}, ksi		e(2 in or 4D)
		Min	Max	Min	Max	Min - percent
O (b)	0.020 - 0.499	-	30.0	-	14.0	16
	0.500 - 1.000	-	32.0	-	-	10
T3	0.020 - 0.039	55.0	-	35.0	-	14
	0.040 - 0.249	57.0	-	36.0	-	15
T4 (f)	0.020 - 0.039	55.0	-	32.0	-	14
	0.040 - 0.249	57.0	-	34.0	-	15
T42 (g)	0.020 - 0.039	55.0	-	32.0	-	14
	0.040 - 0.499	57.0	-	34.0	-	15
	0.500 - 1.000	58.0	-	34.0	-	14
T4, T451	0.250 - 0.499	57.0	-	36.0	-	15
	0.500 - 1.000	58.0	-	36.0	-	14
T6	0.020 - 0.039	63.0	-	55.0	-	7
	0.040 - 0.249	64.0	-	57.0	-	8
T6, T62, T651 (c)	0.250 - 0.499	64.0	-	57.0	-	8
	0.500 - 1.000	67.0	-	59.0	-	6
	1.001 - 1.500	67.0	-	59.0	-	4
	1.501 - 2.000	65.0	-	59.0	-	3
	2.001 - 3.000	63.0	-	57.0	-	2
	3.001 - 4.000	59.0	-	55.0	-	1

Footnotes, see page 71

ASTM SPECIFIED TENSILE-PROPERTIES FOR BAR, ROD AM) WIRE-

TABLE 7.153

Alloy	2014					
Property	Tensile					
Form	Bar, Rod and Wire (rolled, drawn or cold finished)					
Specifications	ASTM B211-63					
Condition	O		T4 and T451 (a)		T6 and T651 (a)	
Diameter or Thickness - in	≥ 0.124	0.125 to 8.000	≥0.124	0.125 to 8.000 (b)	≥ 0.124	0.125 to 6.500 (b)
Orientation	L	L	L	L	L	L
F_{tu}, max-ksi	35.0	35.0	-	-	-	-
min-ksi	-	-	55.0	55.0	65.0	65.0
F_{ty}, min-ksi	-	-	-	32.0	-	55.0
e(2in)*min-percent	-	12	-	16	-	8

* (or 4D)

a) For stress relieved tempers, properties other than those specified may differ somewhat from properties in the basic temper.

b) For rounds, maximum diameter is 6.500 inch;
For square, rectangular, hexagonal or octagonal bar, maximum thickness is 4 inch and 36 square inch maximum cross section area.

ASTM SPECIFIED TENSILE PROPERTIES FOR EXTRUDED BAR, ROD, SHAPES, TUBING

TABLE 7.154

Alloy	2014							
Source	Reference 7.8							
Property	Tensile (m)							
Form	Bar, Rod, Shapes and Tubing (extruded)							
Specification	ASTM B221-64							
Temper	Section or Wall Thickness - in	Area, sq - in	F_{tu}, ksi		F_{ty}, ksi		Elongation, percent	
			Min	Max	Min	Max	Min	
O (h)	all	all	-	30.0	-			
T4, T4510, T4511	all	all	50.0	-	35.0	-	12	
T42 (k)	all	all	50.0	-	29.0	-	12	
T6, T6510, T6511 (j)	≤ 0.499	all	60.0	-	53.0	-	7	
	0.500 - 0.749	all	64.0	-	58.0	-	7	
	≥ 0.750	≤ 25	68.0	-	60.0	-	7	
	≥ 0.750	25 - 32	68.0	-	58.0	-	6	
T62 (k)	≤ 0.749	all	60.0	-	53.0	-	7	
	≥ 0.750	≤ 25	60.0	-	53.0	-	7	
	≥ 0.750	25 - 32	60.0	-	53.0	-	6	
F	all	all	Not required					

Footnotes, see page 71

ASTM SPECIFIED TENSILE AND HARDNESS PROPERTIES FOR DIE FORGINGS AND STRUCTURAL SHAPES'

TABLE 7.155

Alloy	2014			
Property	Tensile and Hardness			
Specification	ASTM B247-63		ASTM B308-63	
Form	Die Forgings (b) (d)		Structural Shapes*	
Thickness - in	≤ 4		Not given	
Orientation	(a)		(c)	
Condition	T4	T6	T4	T6
F_{tu}, min-ksi	55.0	65.0	50.0	60.0
F_{ty}, min-ksi	30.0	55.0	32.0	53.0
e(2 in), min-percent	-	-	12	7
(4D), min-percent	16	10	-	-
Brinell Hardness, min (500 Kg load-10mm ball)	100	125	-	-

a) Axis of test specimen should be as nearly parallel to direction of maximum flow of metal as possible.

b) If tension specimens are cut from forgings, the properties shall conform to the requirements of the above Table except the e shall be reduced to 70% of the value in Table.

c) Specimen axis parallel to the length of the structural shape.

d) Not applicable for forgings more than 4 inches thick.

* (rolled or extruded)

Footnotes for ASTM Specifications

(a) May also be supplied as plate in F temper. Tests for tensile properties not required, but after heat treatment the alloy shall develop properties required for T62 (or T6) temper.

(b) O temper sheet shall, after heat treatment, develop properties required for T62 (or T69 temper.

(c) T62 temper is heat treated and aged by the user.

(d) Strength values are rounded-off to nearest 100 psi and elongation to nearest 0.5 percent.

(e) Tension specimen for plate does not include clad material..

(f) Coiled sheet.

(g) Heat treated by the user.

(h) O temper material shall after heat treatment, develop properties required for T42 temper.

(j) For stress relieved tempers (T3510, T3511, T4510, T4511, T6510, T6511), properties other than those specified may differ somewhat from properties of alley in basic ternper.

(k) Material heat treated from any temper by the user should obtain the properties applicable to this temper.

(m) All specimens longitudinal (parallel to direction of extrusion).

ALUMINUM ASSOCIATION TENSILE PROPERTY LIMITS FOR SHEET AND PLATE

TABLE 7.161

Alloy	2014						
Source	Reference 7.4						
Property	Tensile						
Form	Sheet and Plate (a)						
Standards	Aluminum Association Mill Products						
Temper	Thickness - in	Width - in	F_{tu}, ksi		F_{ty}, ksi		e(2 in or 4D)
			Min	Max	Min	Max	Min - percent
O (c)	0.020 - 0.499	all	-	32.0	-	16.0	16
	0.500 - 1.000	all	-	32.0	-	-	10
T3	0.020 - 0.039	all	59.0	-	35.	-	14
	0.040 - 0.249	all	59.0	-	36.	-	14
T4	0.020 - 0.249	all	59.0	-	35.	-	14
T4, T451 (a)	0.250 - 0.499	all	58.0	-	36.	-	14
	0.500 - 1.000	all	58.0	-	36.	-	14
	1.001 - 2.000	all	58.0	-	36.	-	12
	2.001 - 3.000	all	57.0	-	36.	-	8
T42 (b)	0.020 - 1.000	all	58.0	-	34.	-	14
T6	0.020 - 0.039	all	64.0	-	57.	-	6
	0.040 - 0.249	all	66.0	-	58.	-	7
T6, T651 (a)	0.250 - 0.499	all	67.0	-	59.	-	7
	0.500 - 1.000	all	67.0	-	59.	-	6
	1.001 - 2.000	all	67.0	-	59.	-	4
	2.001 - 2.500	all	65.0	-	58.	-	2
	2.501 - 3.000	all	63.0	-	57.	-	2
	3.001 - 4.000	all	59.0	-	55.0	-	1

Footnotes, see page 79

ALUMINUM ASSOCIATION TENSILE PROPERTY LIMITS FOR ALCLAD SHEET AND PLATE

TABLE 7.162

Alloy	2014						
Source	Reference 7.4						
Property	Tensile						
Form	Alclad Sheet and Plate (a)(e)						
Standards	Aluminum Association Mill Products						
Temper	Thickness - in	Width - in	F_{tu}, ksi		F_{ty}, ksi		e(2 in or 4D)
			Min	Max	Min	Max	Min-percent
O (c)	0.020 - 0.499	all	-	30.0	-	14.0	16
	0.500 - 1.000	all	-	32.0	-	-	10
T3	0.020 - 0.039	all	55.0	-	34.0	-	14
	0.040 - 0.249	all	57.0	-	35.0	-	15
T4	0.020 - 0.039	all	55.0	-	32.0	-	14
	0.040 - 0.128	all	57.0	-	34.0	-	15
	0.129 - 0.249	all	57.0	-	34.0	-	15
T4, T451 (d)	0.250 - 0.499	all	57.0	-	36.0	-	15
	0.500 - 1.000	all	58.0	-	36.0	-	14
	1.001 - 2.000	all	58.0	-	36.0	-	12
	2.001 - 3.000	all	57.0	-	36.0	-	8
T42 (b)	0.020 - 0.039	all	55.0	-	32.0	-	14
	0.040 - 0.128	all	57.0	-	34.0	-	15
	0.129 - 0.249	all	57.0	-	34.0	-	15
	0.250 - 0.499	all	57.0	-	34.0	-	15
	0.500 - 1.000	all	58.0	-	34.0	-	14
T6	0.020 - 0.039	all	63.0	-	55.0	-	7
	0.040 - 0.249	all	64.0	-	57.0	-	8
T6, T651 (d)	0.250 - 0.499	all	64.0	-	57.0	-	8
	0.500 - 1.000	all	67.0	-	59.0	-	6
	1.001 - 2.000	all	67.0	-	59.0	-	4
	2.001 - 2.500	all	65.0	-	58.0	-	3
	2.501 - 3.000	all	63.0	-	57.0	-	2
	3.001 - 4.000	all	59.0	-	55.0	-	1

Footnotes, see page 79

ALUMIMJM ASSOCIATION TENSILE PROPERTY LIMITS FOR ROLLED OR COLD FINISHED BAR, ROD AND WIRE

TABLE 7.163

Alloy	2014					
Source	Reference 7.4					
Property	Tensile					
Form	Bar, Rod and Wire (rolled or cold finished) (f)					
Standards	Aluminum Association Mill Products					
Temper		F_{tu}, ksi		F_{ty}, ksi		e(2 in or 4D)
	Diameter, in*	Min	Max	Min	Max	Min-percent
O (g)	≤ 8.000	-	35.0	-	-	12
T4, T451 (d)	≤ 8.000 (h)	55.0	-	32.0	-	16
T6, T651 (d)	≤ 8.000 (h)	65.0	-	55.0	-	8

* 'Diameter or least distance between parallel faces'

'Footnotes, see page 79

ALUMINUM ASSOCIATION TENSILE PROPERTY LIMITS FOR EXTRUDED BAR, ROD, SHAPES AND TUBING

TABLE 7.164

Alloy	2014						
Source	Reference 7.4						
Property	Tensile						
Form	Bar, Rod, Shapes and Tubing (extruded) (f)						
Standards	Aluminum Association Mill Products						
Temper	Thickness - in	Area sq - in	F_{tu}, ksi		F_{ty}, ksi		e(2 in or 4D)
			Min	Max	Min	Max	Min - percent
O (c)	all	all	-	30.0	-	18.0	12
T4, T4510, T4511(d)	all	all	50.0	-	35.0	-	12
T42 (b)	all	all	50.0	-	29.0	-	12
T6, T6510, T6511(d)	≤ 0.499	all	60.0	-	53.0	-	7
	0.500 - 0.749	all	64.0	-	58.0	-	7
	≥ 0.750	≤ 25	68.0	-	60.0	-	7
	≥ 0.750	25 - 32	68.0	-	58.0	-	6
T62 (b)	≤ 0.749	all	60.0	-	53.0	-	7
	≥ 0.750	≤ 25	60.0	-	53.0	-	7
	≥ 0.750	25 - 32	60.0	-	53.0	-	6

Footnotes, see page 79

ALUMINUM ASSOCIATION TENSILE PROPERTY LIMITS FOR DRAWN TUBING

Alloy	2014					
Source	Reference 7.4					
Property	Tensile					
Form	Drawn Tubing (f)					
Standards	Aluminum Association Mill Products					
Temper	Wall Thickness-in	F_{tu}, ksi		F_{ty}, ksi		e(2in or 4D), min
		Min	Max	Min	Max	(j) (k)
O (g)	all	-	32.0	-	16.0	- -
T4	0.018 - 0.024	54.0	-	30.0	-	10 -
	0.025 - 0.049	54.0	-	30.0	-	12 10
	0.050 - 0.259	54.0	-	30.0	-	14 10
	0.260 - 0.500	54.0	-	30.0	-	16 12
T6	0.018 - 0.024	65.0	-	55.0	-	7 -
	0.025 - 0.049	65.0	-	55.0	-	7 6
	0.050 - 0.259	65.0	-	55.0	-	8 7
	0.260 - 0.500	65.0	-	55.0	-	9 8

Footnotes, see page 79

ALUMINUM ASSOCIATION TENSILE PROPERTY LIMITS FOR HAND FORGINGS

TABLE 7.166

Alloy	2014								
Source	Reference 7.4								
Property	Tensile								
Form	Hand Forgings (p)(q)								
Standards	Aluminum Association Mill Products								
Temper	Thickness - in (r)	F_{tu}, ksi			F_{ty}, ksi			e(2 in or 4D)		
		L	LT	ST	L	LT	ST	L	LT	ST
T6	T ≤ 2.000	65.0	65.0	-	56.0	56.0	-	8	3	-
	2.001 - 3.000	64.0	64.0	62.0	56.0	55.0	55.0	8	3	2
	3.001 - 4.000	63.0	63.0	61.0	55.0	55.0	54.0	8	3	2
	4.001 - 5.000	62.0	62.0	60.0	54.0	54.0	53.0	7	2	1
	5.001 - 6.000	61.0	61.0	59.0	53.0	53.0	53.0	7	2	1
	6.001 - 7.000	60.0	60.0	58.0	52.0	52.0	52.0	6	2	1
	7.001 - 8.000	59.0	59.0	57.0	51.0	51.0	51.0	6	2	1
T652	T ≤ 2.000	65.0	65.0	-	56.0	56.0	-	8	3	-
	2.001 - 3.000	64.0	64.0	62.0	56.0	55.0	52.0	8	3	2
	3.001 - 4.000	63.0	63.0	61.0	55.0	55.0	51.0	8	3	2
	4.001 - 5.000	62.0	62.0	60.0	54.0	54.0	50.0	7	2	1
	5.001 - 6.000	61.0	61.0	59.0	53.0	53.0	50.0	7	2	1
	6.001 - 7.000	60.0	60.0	58.0	52.0	52.0	49.0	6	2	1
	7.001 - 8.000	59.0	59.0	57.0	51.0	51.0	48.0	6	2	1

L - Longitudinal (m)
LT - Long Transverse
ST - Short Transverse

Footnotes, see page 79

ALUMINUM ASSOCIATION TENSILE PROPERTY AND HARDNESS LIMITS FOR DIE FORGINGS

TABLE 7.167

Alloy	2014					
Source	Reference 7.4					
Property	Tensile					
Form	Die Forgings (n)					
Standards	Aluminum Association Mill Products					
Temper	Brinell Hardness (500 Kg Load) min	F_{tu}, ksi		F_{ty}, ksi		e(2 in or 4D), Min - percent
		Min	Max	Min	Max	
T4	100	55.0	-	30.0	-	16
T6	125	65.0	-	55.0	-	10

Footnotes, see page 79

Footnotes for Aluminum Association Standards

(a) Test specimens taken transverse to rolling direction for widths $\geq$ 9 inches and parallel to rolling direction for widths < 9 inches,

(b) Material heat treated from any temper by the user should attain the properties applicable to this temper,

(c) O temper material shall be capable of developing properties for T42 temper after heat treatment.

(d) For stress relieved tempers, properties other than those specified may differ from the corresponding properties of the basic temper.

(e) For plate 0.500 inches or over in thickness, the listed properties apply to core material only. Strengths of composite (core plus clad) are slightly lower depending on thickness of cladding.

(f) Speciments taken parallel to direction of extrusion, rolling or drawing.

(g) O temper material within the size limitations specified for T4 temper, shall upon heat treatment be capable of developing properties applicable to T4 temper.

(h) For rounds (rod) maximum diameter is 8.000 inches; for square, rectangular, hexagonal or octagonal bar maximum thickness is 4 inches and 36 square inches cross section area.

(j) Round tube 2 inches or less in diameter and square tube 1.5 inches or less on a side are tested in full-section.

(k) For round tube over 2 inches diameter, for square tube over 1.5 inches on a side, for all sizes other than round or square or when full section cannot be used, a cut-out specimen is employed.

(m) Tensile *tests* are performed and properties guaranteed only when specifically required by purchase order or contract.

(n) These values apply to standard 0.5 inch diameter test specimens machined from separately forged coupons representative of the forgings. For specimens machined from forgings up to 4 inches In thickness or diameter with specimen axis substantially parallel to direction of grain flow, requirements apply except minimum *e* shall be 70 percent of values in the Table.

Footnotes for Aluminum Association Standards (Continued)

(p) Maximum cross-sectional area is 256 square inches.

(q) These properties are not applicable to upset biscuit forgings or to rolled or forged ring forgings.

(r) Thickness measured in short transverse direction.

TABLE 7.21

Source	Ref. 7.23	
Alloy	2014-T6	
Form	0.125 inch sheet (a)	
Property	Poisson's Ratio (elastic and plastic values)	
Grain Direction	μ, elastic	μ, plastic
Longitudinal	0.33	0.48
Transverse	0.27	0.52

(a) Purchased in the form of clad, heat treated sheet. Cladding removed prior to testing

DESIGN PROPERTIES FOR SHEET AND PLATE

TABLE 7.4111

Alloy	AMS-4029				AMS-4014 (2014)												AMS-4028								
Form	Sheet				Plate												Plate								
Condition	-T6				-T651												-T62								
Thickness, in.	0.020-0.039		0.040-0.249		0.250-0.499		0.500-1.000		1.001-2.000		2.001-2.500		2.501-3.000		3.001-4.000		0.250-0.499		0.500-1.000		1.001-2.000		2.001-2.500	2.501-3.000	3.001-4.000
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	S	S	S
Mechanical properties:																									
F_{tu}, ksi																									
L	65	67	67	69	66	68	66	67	66	67	65	66	63	64	60	61	68	70	68	70	67	68	65	63	59
LT	64	66	66	67	67	69	67	68	67	68	65	66	63	64	59	60	67	69	67	69	67	68	65	63	59
ST	....	....	....	....	....	....	....	....	....	....	60	61	58	59	54	55	....	....	....	....	....	....	60	58	54
F_{ty}, ksi																									
L	58	60	59	60	60	62	60	61	60	62	59	61	58	60	56	58	60	62	60	62	59	62	58	57	55
LT	57	59	58	59	59	61	59	60	59	61	58	60	57	59	55	57	59	61	59	61	59	62	58	57	55
ST	....	....	....	....	....	....	....	....	....	....	54	56	53	55	51	53	....	....	....	....	....	....	54	53	51
F_{cy}, ksi																									
L	58	60	59	60	58	60	58	59	58	60	57	59	56	58	54	56	60	62	60	62	61	64	60	59	57
LT	58	60	60	61	61	63	61	62	61	63	60	62	59	61	57	59	61	63	61	63	61	64	60	59	57
ST	....	....	....	....	....	....	....	....	....	....	60	62	59	61	57	59	....	....	....	....	....	....	60	59	57
F_{su}, ksi	39	40	40	41	40	41	40	41	40	41	39	40	38	39	36	36	41	42	41	42	41	41	40	39	37
F_{bru}, ksi [a]																									
(e/D=1.5)	97	100	100	103	106	109	106	107	106	107	103	104	99	101	93	95	102	105	102	105	101	102	98	94	88
(e/D=2.0)	123	127	127	131	135	139	135	137	135	137	131	133	127	129	119	121	129	133	129	133	127	129	124	120	112
F_{bry}, ksi [a]																									
(e/D=1.5)	81	84	83	84	90	93	90	92	90	93	89	92	87	90	84	87	84	87	84	87	83	87	81	80	77
(e/D=2.0)	93	96	94	96	107	110	107	109	107	110	105	109	103	107	100	103	96	99	96	99	94	99	93	91	88
e, percent																									
L	6	....	7	....	7	....	6	....	6	....	4	....	4	....	3	....	7	....	6	....	6	....	4	4	3
LT	6	....	7	....	7	....	6	....	4	....	2	....	2	....	1	....	7	....	6	....	4	....	2	2	1
ST	....	....	....	....	....	....	....	....	....	....	1	....	1	....	....	....	....	....	....	....	....	....	1	1	.....

(a) See Table 7.4516

(Ref. 7.1)

DESIGN PROPERTIES FOR CLAD SHEET AND PLATE

TABLE 7.4112

Alloy	QQ-A-250/3 (Clad 2014)																							
Form	Sheet				Plate																			
Condition	-T6				-T651												-T62							
Thickness, in	0.020–0.039		0.040–0.249		0.250–0.499		0.500–1.000 [b]		1.001–2.000 [b]		2.001–2.500 [b]		2.501–3.000 [b]		3.001–4.000 [b]		0.250–0.499		0.500–1.000 [b]		1.001–2.000 [b]	2.001–2.500 [b]	2.501–3.000 [b]	3.001–4.000 [b]
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	S	S	S	S
Mechanical Properties:																								
F_{tu}, ksi																								
L	64	66	65	67	63	65	63	64	63	64	62	63	60	61	57	58	65	67	65	67	64	62	60	56
T	63	65	64	66	64	66	64	65	64	65	62	63	60	61	56	57	64	66	64	66	64	62	60	56
ST	...	...	...	...	...	...	...	...	...	...	60	61	58	59	54	55	...	...	...	...	.....	60	58	54
F_{ty}, ksi																								
L	56	58	58	60	58	60	57	58	57	59	56	58	55	57	53	55	58	60	57	59	56	55	54	52
LT	55	57	57	59	57	59	56	57	56	58	55	57	54	56	52	54	57	59	56	58	56	55	54	52
ST	...	...	...	...	...	...	...	...	...	...	54	56	53	55	51	53	...	...	...	...	.....	54	53	51
F_{cy}, ksi																								
L	56	58	58	60	56	58	55	56	55	57	54	56	53	55	51	53	58	60	57	59	58	57	56	54
LT	57	59	59	61	59	61	58	59	58	60	57	59	56	58	54	56	59	61	58	60	58	57	56	54
ST	...	...	...	...	...	...	...	...	...	...	60	62	59	61	57	59	...	...	...	...	.....	60	59	57
F_{su}, ksi	39	40	39	40	39	40	39	39	39	39	37	38	36	37	34	34	39	40	39	40	39	38	37	35
F_{bru}, ksi [a]																								
$(e/D=1.5)$	96	99	98	101	101	104	101	103	101	103	98	99	95	96	88	90	98	101	98	101	96	93	90	84
$(e/D=2.0)$	122	125	124	127	129	133	129	131	129	131	125	127	121	123	113	115	124	127	124	127	122	118	114	106
F_{bry}, ksi [a]																								
$(e/D=1.5)$	78	81	81	84	87	90	86	87	86	89	84	87	83	86	80	83	81	84	80	82	79	77	76	73
$(e/D=2.0)$	90	93	93	96	103	107	101	103	101	105	100	103	98	101	94	98	93	96	91	95	90	88	86	83
e, percent																								
L	7	....	8	....	8	....	6	....	6	....	4	....	4	....	3	....	8	....	6	....	6	4	4	3
LT	7	....	8	....	8	....	6	....	4	....	2	....	2	....	1	....	8	....	6	....	4	2	2	1
ST	...	...	...	...	...	...	...	...	...	...	1	....	1	....	...	...	...	...	...	...	.....	1	1	.....

(a) See Table 7.4516

(b) These values, except in the ST direction, have been adjusted to represent the average properties across the whole section, including the 2 1/2 percent per side nominal clad thickness

(Ref. 7.1)

Table 7.4113

Design Properties for Die Forgings and Hand Forgings in T4 and T6 Conditions

Alloy	2014									
Form	Die forgings		Hand forgings Length 3 3 times width				Hand forgings Length >3 times width			
Condition	-T4		-T6							
Thickness, in	≤4 inches		≤6 inches							
Cross-sectional area, in.²			≤16	>16, ≤36	>36, 3144	>144, ≤256	≤16	>16, ≤36	>36, ≤144	>144, ≤256
Basis	A	A	A	A	A	A	A	A	A	A
Mechanical properties:										
F_{tu}, ksi										
L	55	65	65	65	62	60	65	65	62	60
T	62	62	63	63	59	58	63	63	59	58
ST	..	..	60	60	56	55	60	60	56	55
F_{ty}, ksi										
L	30	55	55	53	53	52	55	53	53	52
T	28	52	55	53	52	50	65	53	52	50
ST	..	..	55	53	52	50	55	53	52	50
F_{cy}, ksi										
L	30	55	55	53	53	52	55	53	53	52
T	28	52	55	53	52	50	55	53	..	..
ST	..	..	..	..	..	..	..	..	..	..
F_{su}, ksi	34	39	40	40	38	37	40	40	..	..
F_{bru}, ksi										
(e/D = 1.5)	..	..	91	91	87	84	91	91	87	84
(e/D = 2.0)	..	..	117	117	112	108	117	117	112	108
F_{bry}, ksi										
(e/D = 1.6)	..	..	77	74	74	73	77	74	74	73
(e/D = 2.0)	..	..	88	85	85	83	88	85	85	83
e percent										
L	11	7	10	9	7	5	10	9	7	5
T	..	a	6	5	3	2	4	3	2.5	2
ST			3	2	1	1	2	2	1	1

(Ref. 7.1)

. DESIGN PROPERTIES FOR BAR, ROD, WIRE AND SHAPES, ROLLED. DRAWN OR COLD FINISHED

TABLE 7.4114

Alloy..	QQ–A–22514 (2014)						
Form....	Bar, rod, wire and shapes; rolled, drawn or cold-finbhcd						
Condition	-T6 or -T651						
Thickness, in..	up to 1.000	1.001–2.000	2.001–3.000	3.001–4.000	4.001–5.000 [a]	5.001–6,000 [a]	6.001–8.000 [a]
Basis..	A	A	A	A	A	A	S
Mechanical properties:							
F_{tu}, ksi:							
L	65	65	65	65	65	65	65
LT	64	63	62	61	60	59	.....
F_{ty}, ksi:							
L	[b] 55	55	55	55	55	55	55
LT	[b] 53	52	51	60	49	48	.....
F_{cy}, ksi:							
L	[b] 53	53	53	53	53	53	53
LT	.....	.....	.....	.....	.....	.....	.....
F_{su}, ksi..	38	38	38	38	38	38	as
F_{bru}, ksi:							
$(e/D = 1.5)$	98	.....	.....	.....	.....	.....	.....
$(e/D = 2.0)$	124	.....	.....	.....	.....	.....	.....
F_{bry}, ksi:							
$(e/D = 1.5)$	[b] 77	.....	.....	.....	.....	.....	.....
$(e/D = 2.0)$	[b] 88	.....	.....	.....	.....	.....	.....
e, percent:							
L	[b] 8	8	a	8	8	8	8
LT	'4	3	2	1	1	1	.....

[a] For rounds (rod) maximum diameter is 8.000 in.; for square, rectangular, hexagonal, or octagonal bar, maximum thickness is 4 in., and maximum cross-sectional area is 36 Mi. In.

[b] Except for wire less than 0.125 in. in diameter, or for special shapes less than 0.062 in. thick.

(Ref. 7.1)

DESIGN PROPERTIES FOR EXTRUDED BAR, ROD AND SHAPES

TABLE 7.4115

Alloy	QQ-A-200/2 (2014)											
Form	Extruded rod, bar, and shapes											
Condition	-T6, -T6510, and -T6511											-T62
Cross-sectional area, in.[2]	≤25										>25, ≤3	≤32
Thickness, in.[a]	0.125–0.499		0.500–0.749		0.750–1.499		1.500–2.999		3.000–4.499		≤0.760	0.125–4.499
Basis	A	B	A	B	A	B	A	B	A	B	S	S
Mechanical properties:												
F_{tu}, ksi:												
L	60	61	64	68	68	73	68	73	68	73	68	60
T	60	61	64	67	63	66	61	63	68	61	66	66
F_{ty}, ksi:												
L	53	67	68	62	60	66	60	66	60	66	68	63
T	63	67	55	69	64	68	62	66	49	63	47	47
F_{cy}, ksi:												
L	55	69	b60	[b] 64	[b] 62	[b] 67	[b] 62	[b] 67	[b] 62	[b] 67	.....	63
T	63	66	68	62	67	61	67	61	67	61	.....	48
F_{cu}, ksi	36	36	37	39	39	42	39	42	39	42	39	35.
F_{bru}, ksi:												
$(e/D = 1.5)$	90	92	96	102	88	96	88	96	88	96	.....	.....
$(e/D = 2.0)$	114	116	122	129	109	117	109	117	109	117	.....	.....
F_{bry}, ksi:												
$(e/D = 1.5)$	74	80	81	87	78	86	78	86	78	86	.....	.....
$(e/D = 2.0)$	85	91	93	99	84	91	84	91	84	91	.....	.....
e, percent:												
L	7	...	7	....	7	...	7	.....	7	...	6	7
TO	6	...	6	....	2	...	2	.....	1	...	1	.....

[a] For extrusions with outstanding legs, the load carrying ability of such legs shall be determined on the basis of the properties in the appropriate column corresponding to the leg thickness.

[b] F_{cy} (*L*) for the -T6510 and -T6511 tempers may be lower than the values indicated.

[c] Not applicable to sections <3/4 in. thick. For cross-sectional area >25, *e* is 6.

(Ref. 7.1)

BEARING PROPERTY REDUCTIONS FOR THICK PLATE

TABLE 7.4516

Source	Ref. 7.1	
	Bearing Property Reduction, Percent	
Thickness, in	1.001-3.000	3.001-4.000
F_{bru} (e/D = 1.5)	20	15
F_{bru} (e/D = 2.0)	20	15
F_{bry} (e/D = 1.5)	5	0
F_{bry} (e/D = 2.0)	5	0

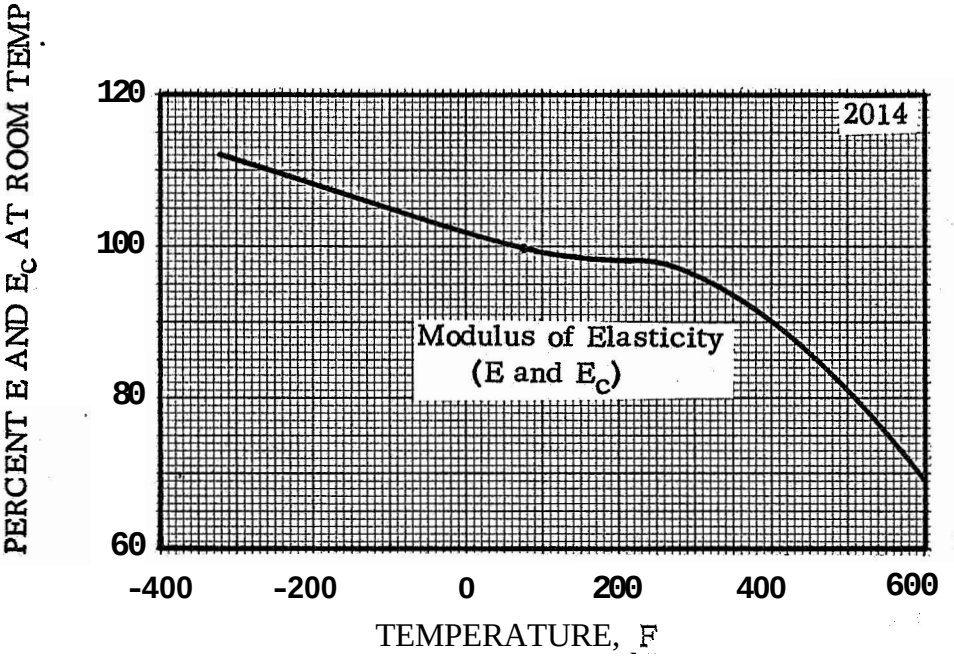


FIG. 7.222 EFFECT OF TEMPERATURE ON E AND E_c

(Ref. 7.1)

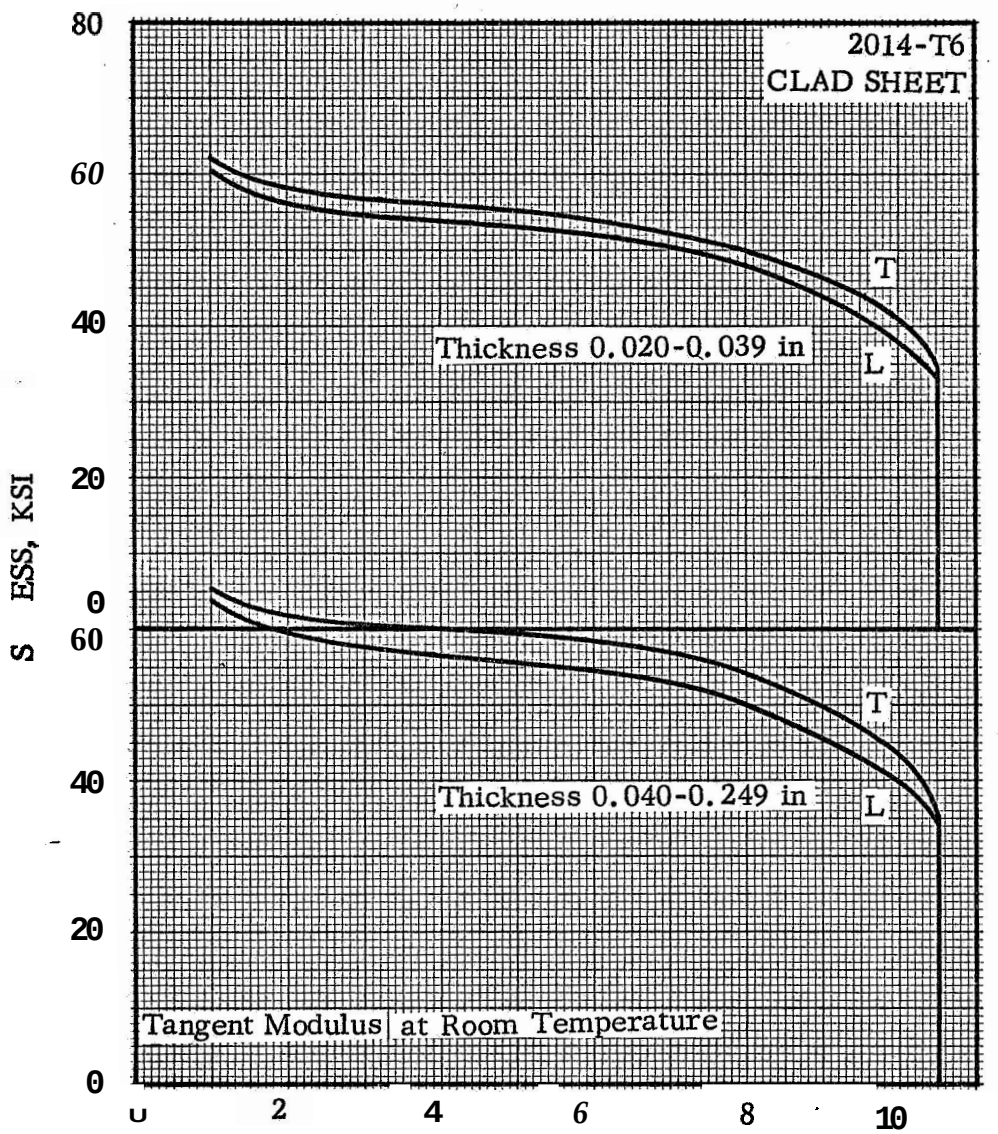


FIG. 7.251 TYPICAL TANGENT **MODULUS** CURVES FOR **CLAD** SHEET AT ROOM TEMPERATURE

(Ref. **7.1**)

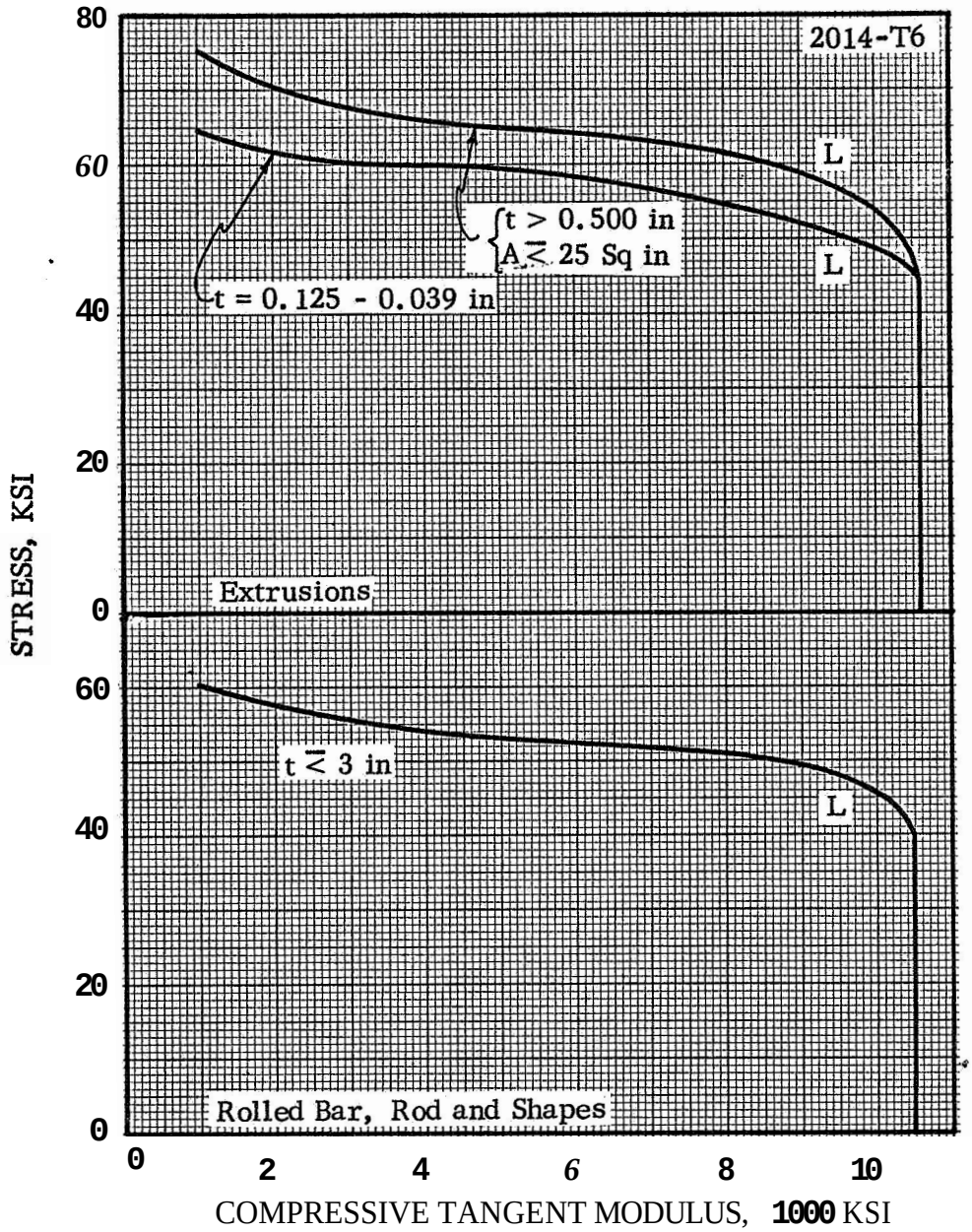
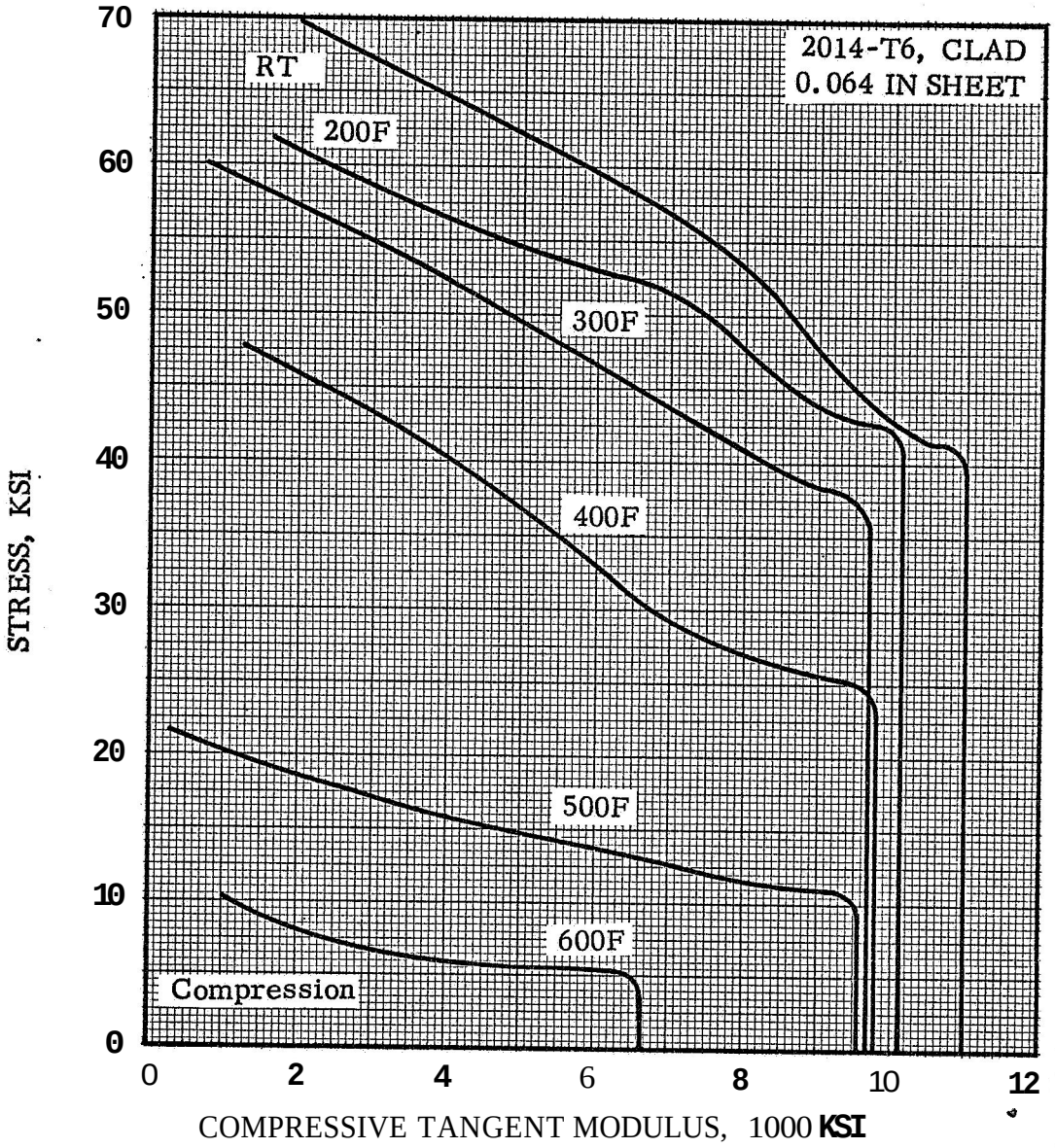


FIG. 7.252 TYPICAL TANGENT MODULUS CURVES FOR EXTRUSIONS AND ROLLED PRODUCTS AT ROOM TEMPERATURE

(Ref. 7.1)



FIG, 7.253 TYPICAL TANGENT MODULUS CURVES IN COMPRESSION FOR CLAD SHEET IN T6 CONDITION AT ROOM AND ELEVATED TEMPERATURES

(Ref. 7.10)

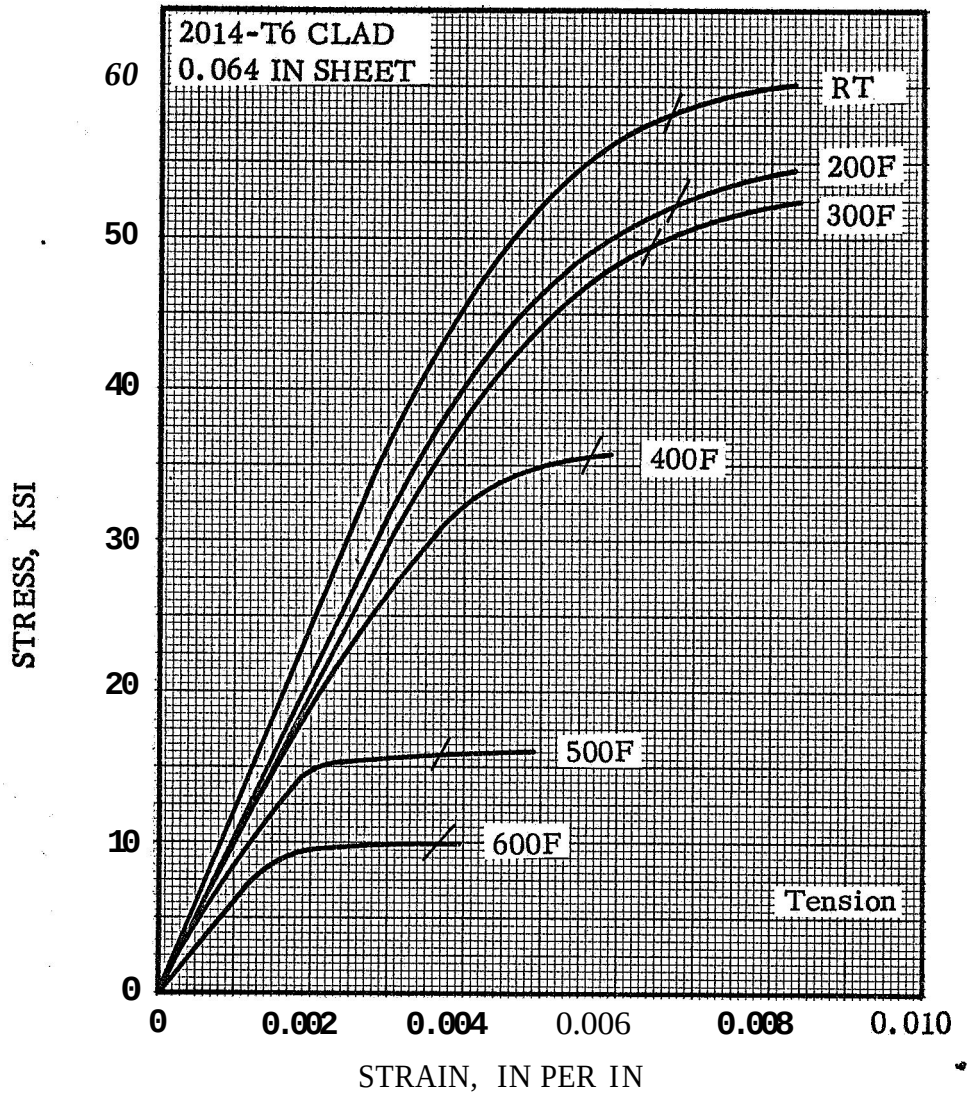


FIG. 7.4121 STRESS–STRAIN CURVES FOR CLAD SHEET IN T-6 CONDITION AT ROOM AND ELEVATED TEMPERATURES

(Ref. 7.10)

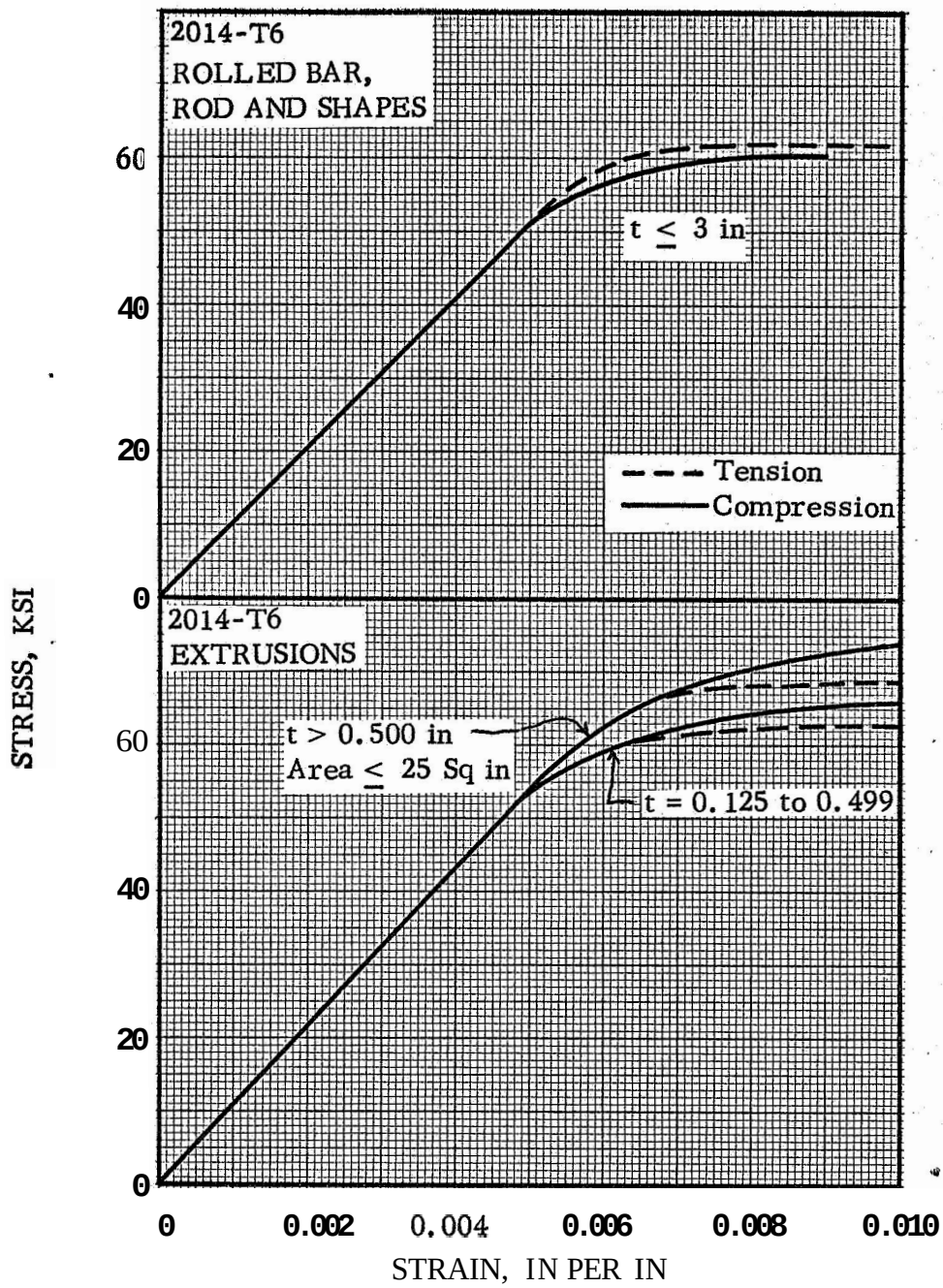


FIG. 7.4122 TYPICAL STRESS-STRAIN CURVES IN TENSION AND COMPRESSION FOR BAR, ROD, SHAPES AND EXTRUSIONS IN T6 CONDITION AT ROOM TEMPERATURE

(Ref, 7.1)

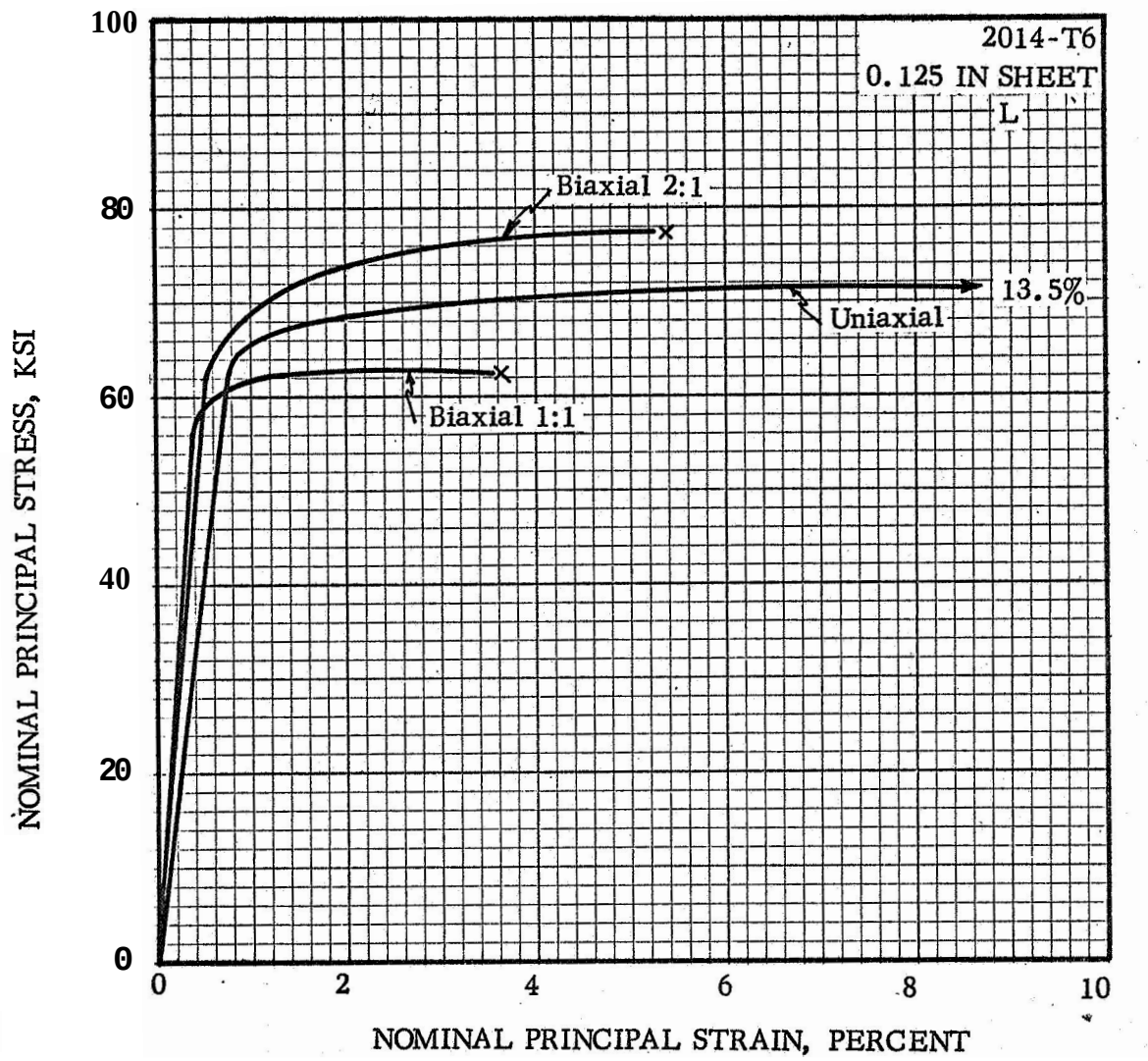
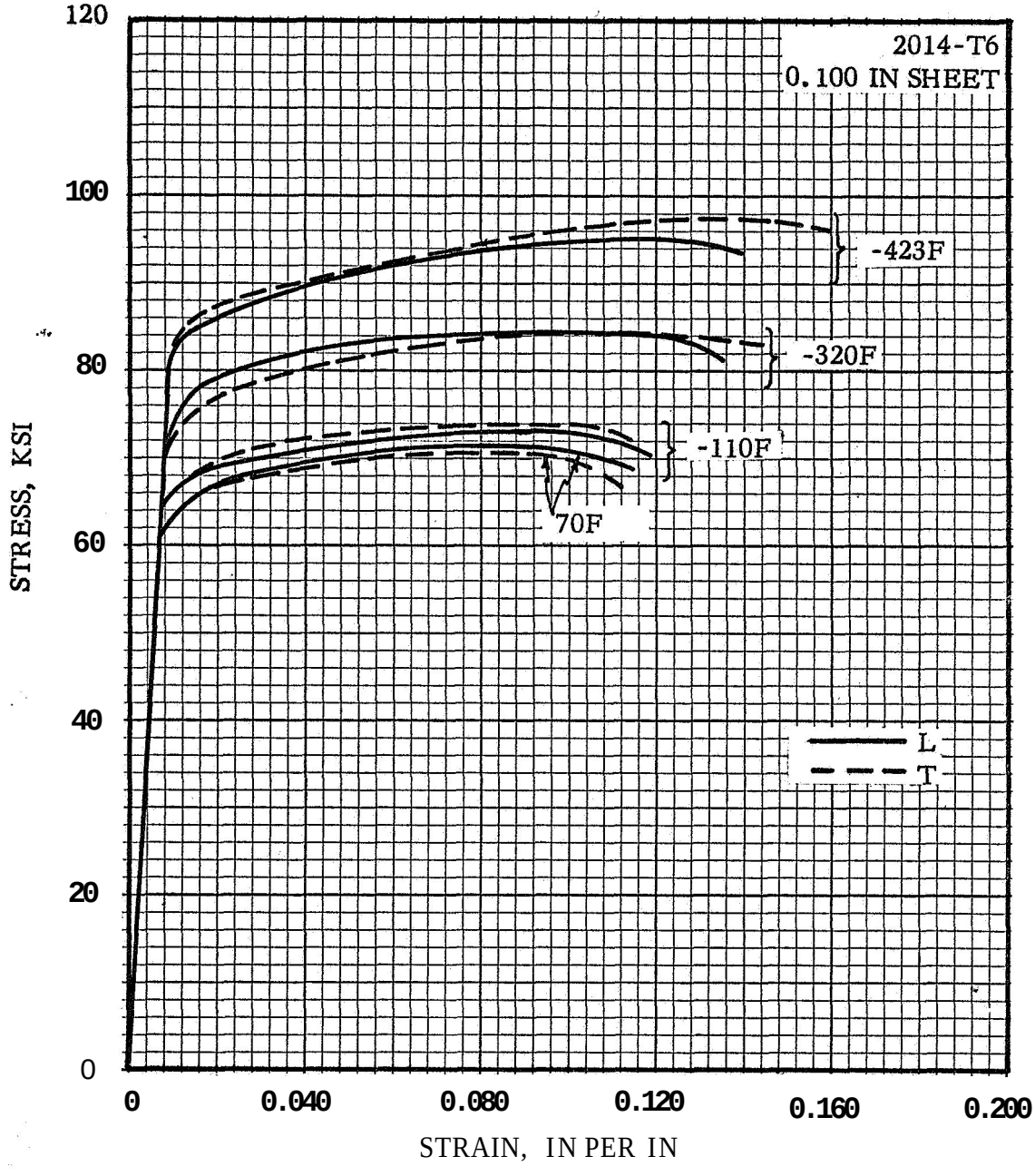


FIG. 7.4123 TYPICAL UNIAXIAL AND BIAXIAL STRESS-STRAIN CURVES FOR SHEET IN T6 CONDITION

(Ref. 7.23)



FIG, **7,4124** STRESS-STRAIN CURVES FOR SHEET IN T6 CONDITION AT LOW TEMPERATURES

(Ref. **7.25)**

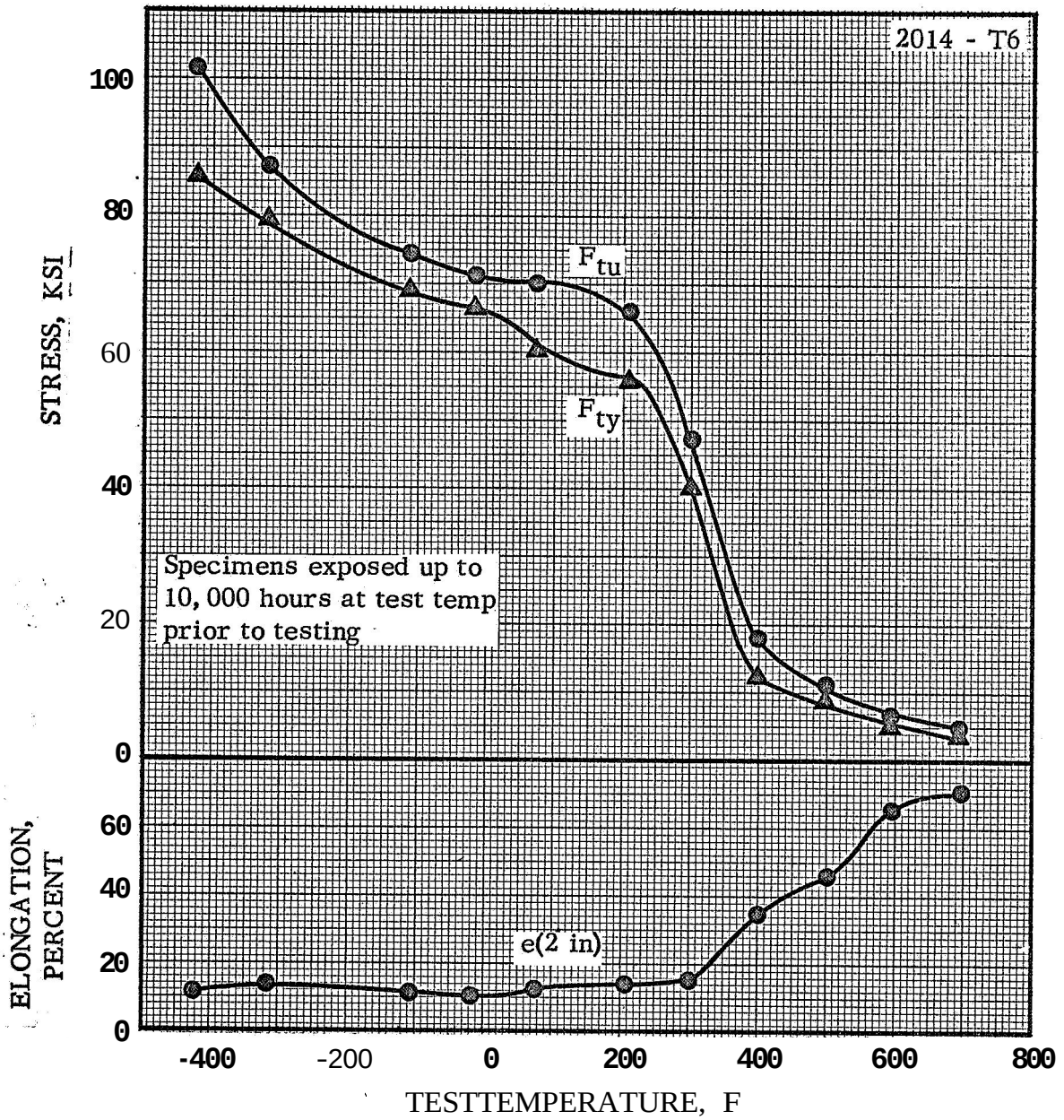


FIG. **7.4131** TYPICAL TENSILE PROPERTIES A T VARIOUS TEMPERATURES FOR ALLOY IN T6 CONDITION

(Ref. **7.26)**

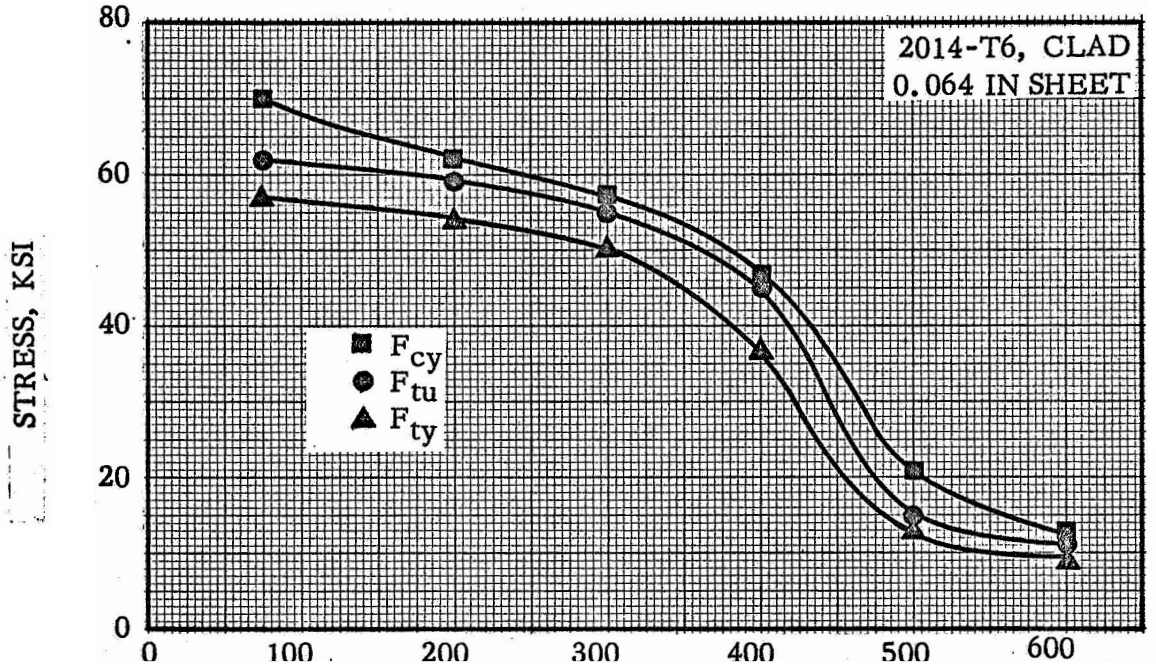


FIG. 7.4132 EFFECT OF TEST TEMPERATURE ON F_{TU}, F_{TY} AND F_{CY} OF CLAD SHEET IN T6 CONDITION

(Ref. 7.10)

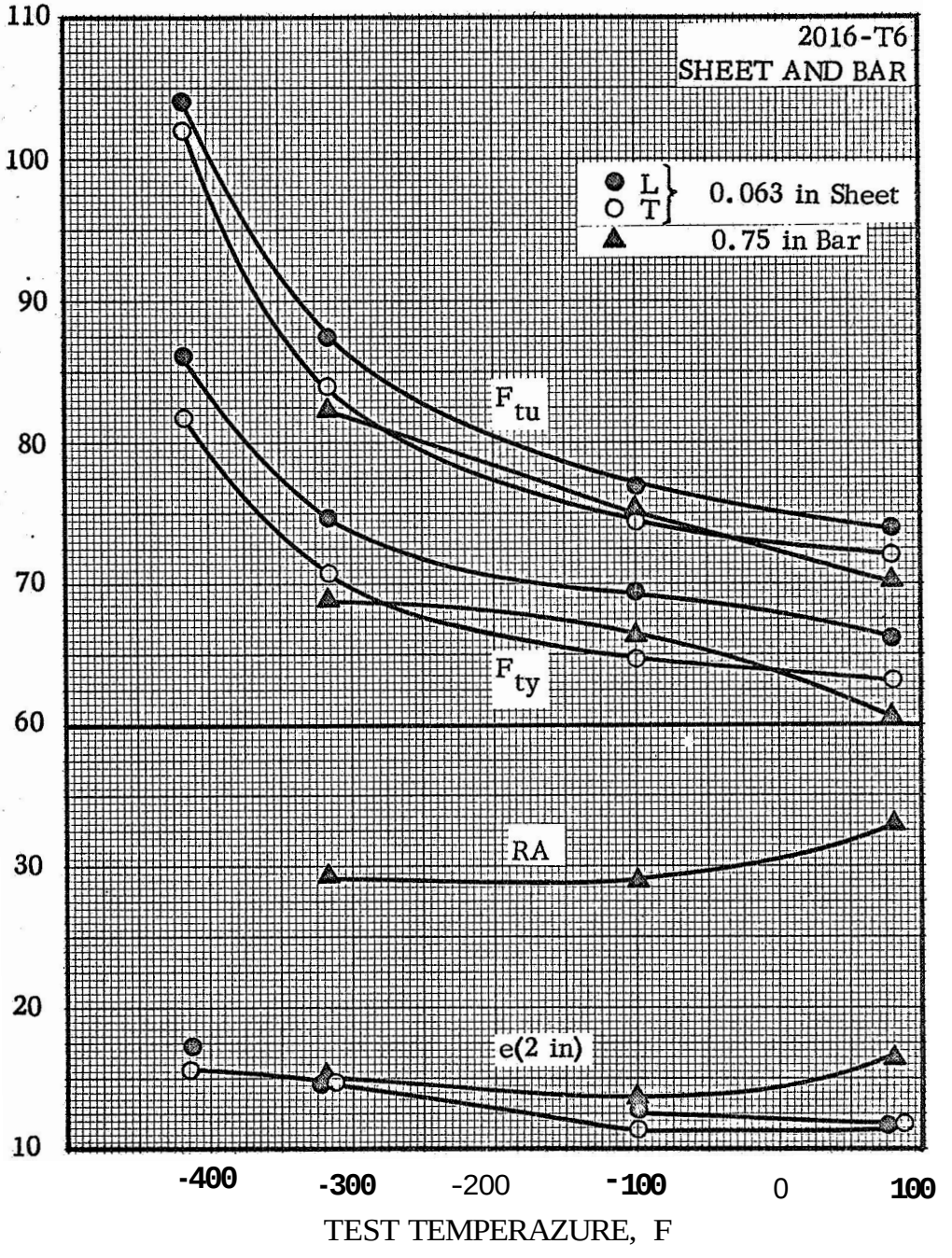


FIG. 7.4133 EFFECT OF CRYOGENIC TEMPERATURES ON TENSILE PROPERTIES OF SHEET AND BAR IN T6 CONDITION (Refs. 7.16 and 7.17)

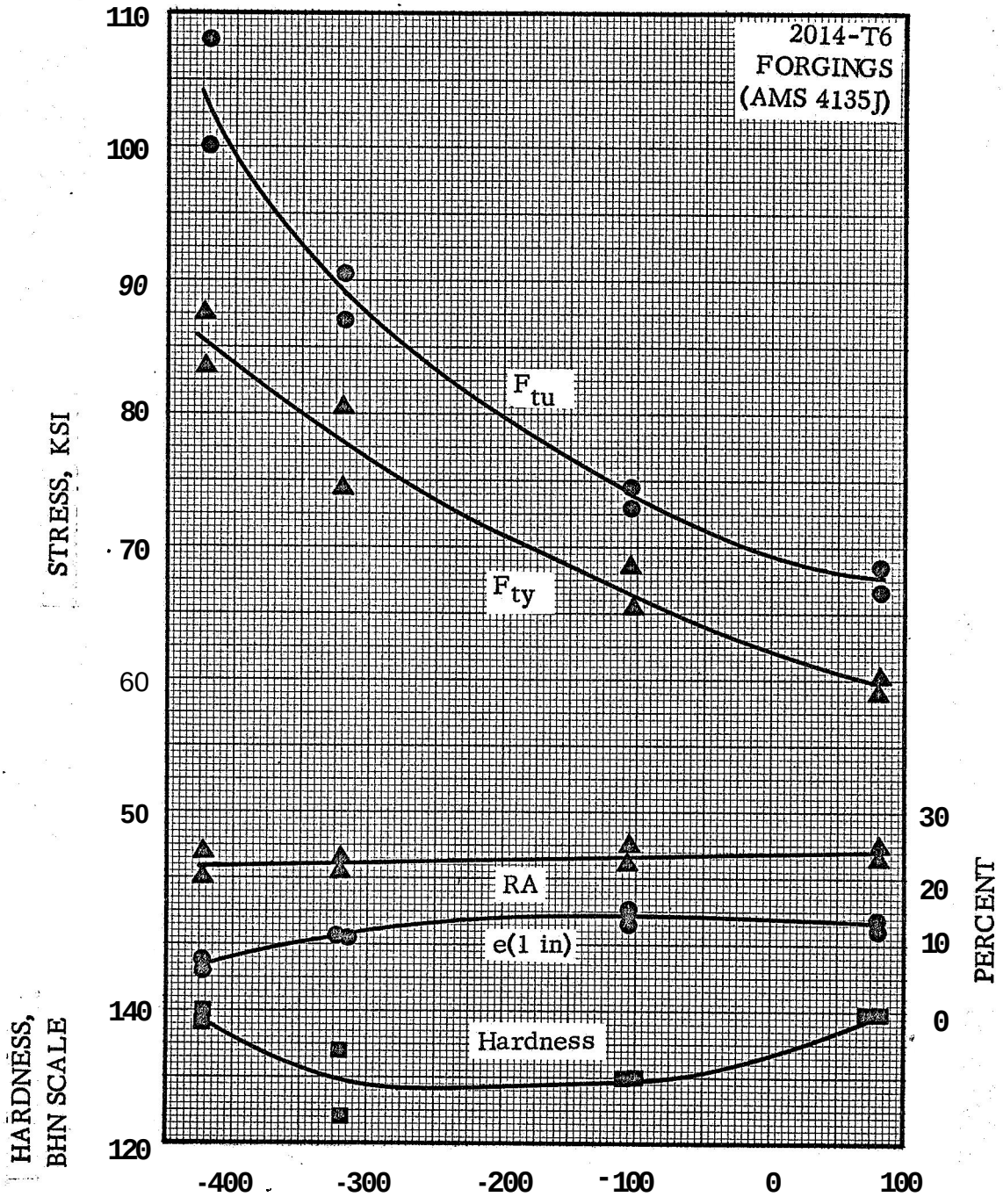


FIG. 7,4134 EFFECT OF CRYOGENIC TEMPERATURES ON TENSILE PROPERTIES AND HARDNESS OF FORGINGS IN THE T6 CONDITION'

(Ref. 7.20)

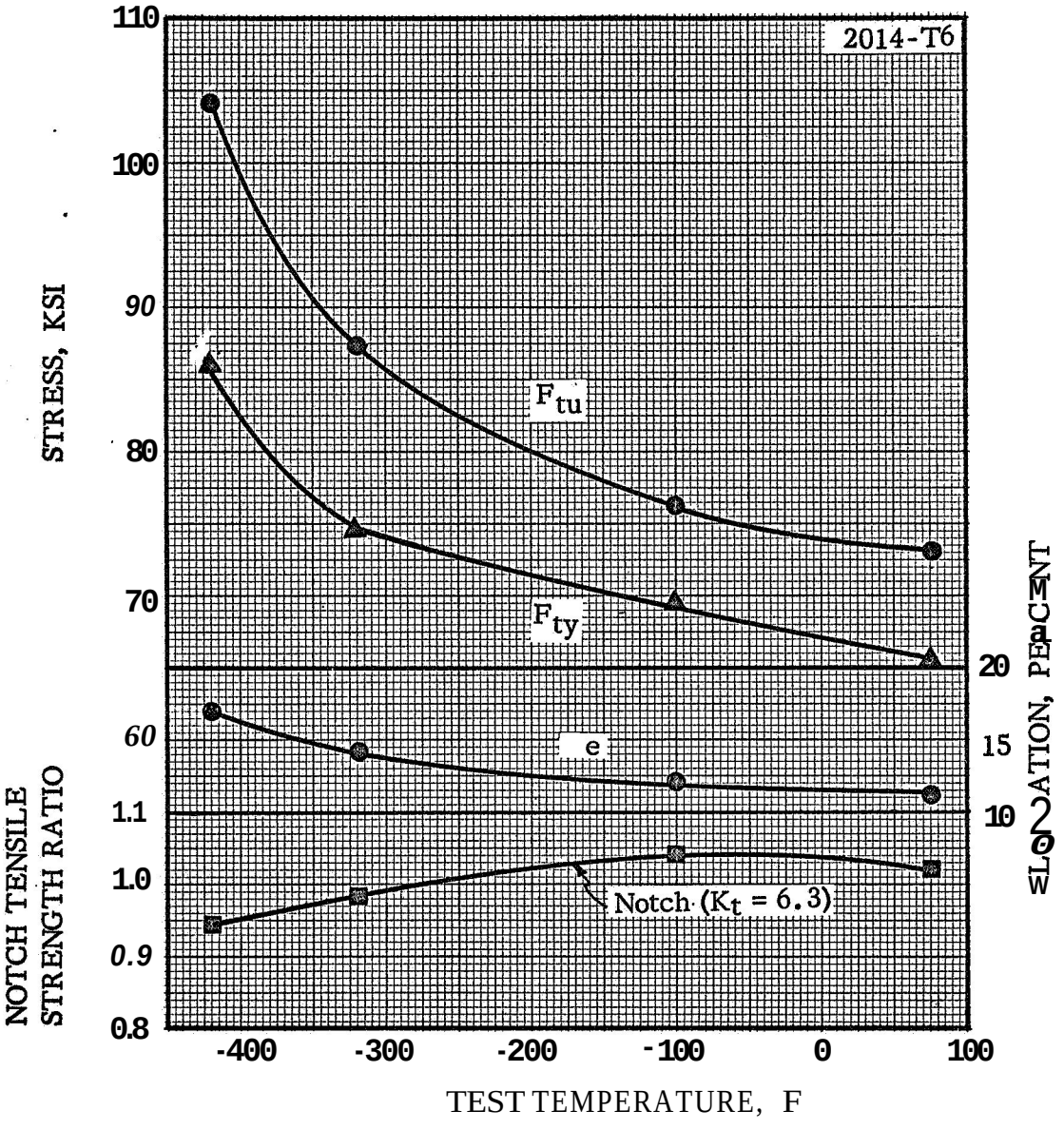
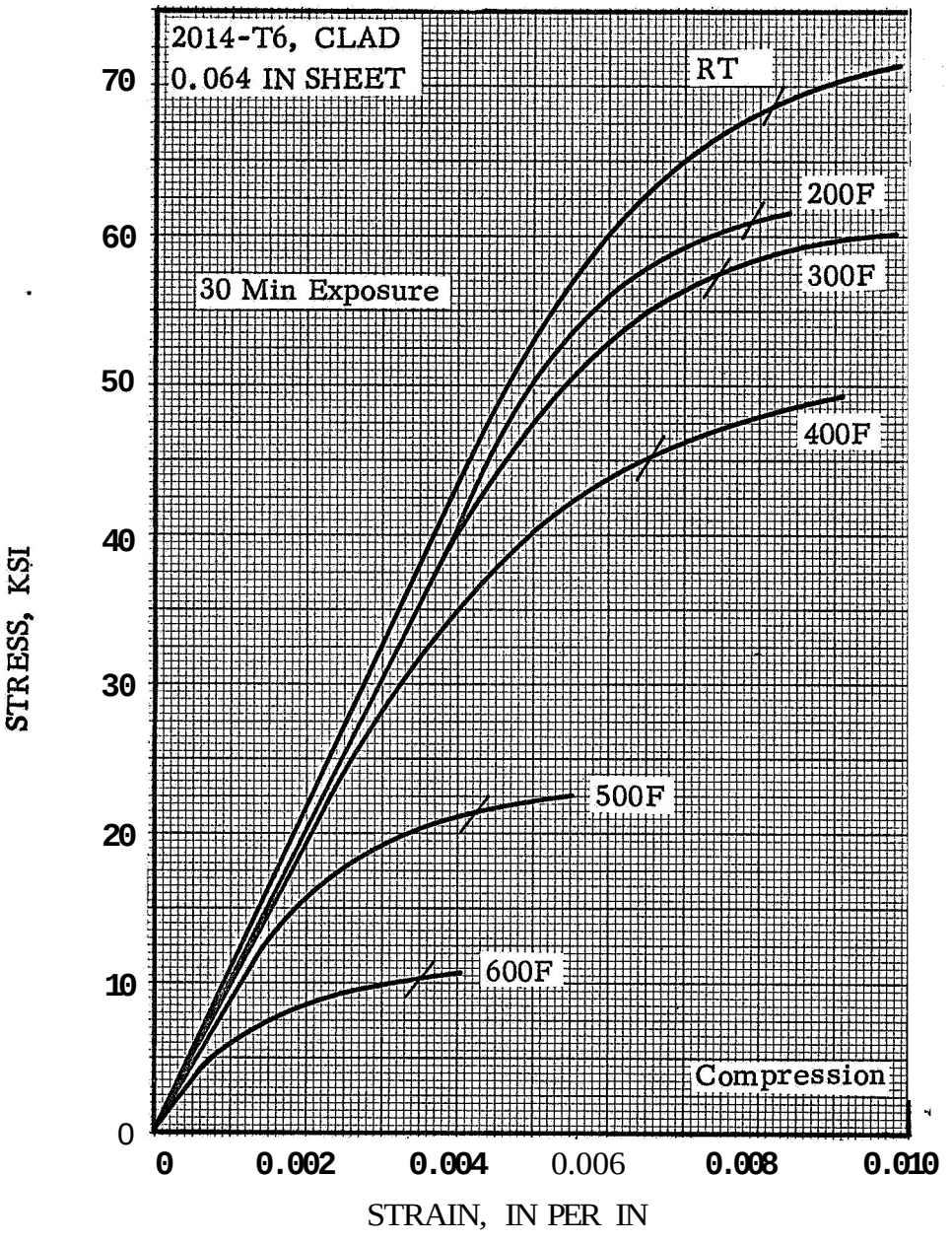


FIG. 7.4135 EFFECT OF LOW TEST TEMPERATURES ON TENSILE AND NOTCH PROPERTIES

(Ref. 7.21)



FIG, 7.4221 TYPICAL STRESS-STRAIN CURVES IN COMPRESSION FOR CLAD SHEET IN T6 CONDITION AT ROOM AND ELEVATED TEMPERATURES

(Ref. **7.10)**

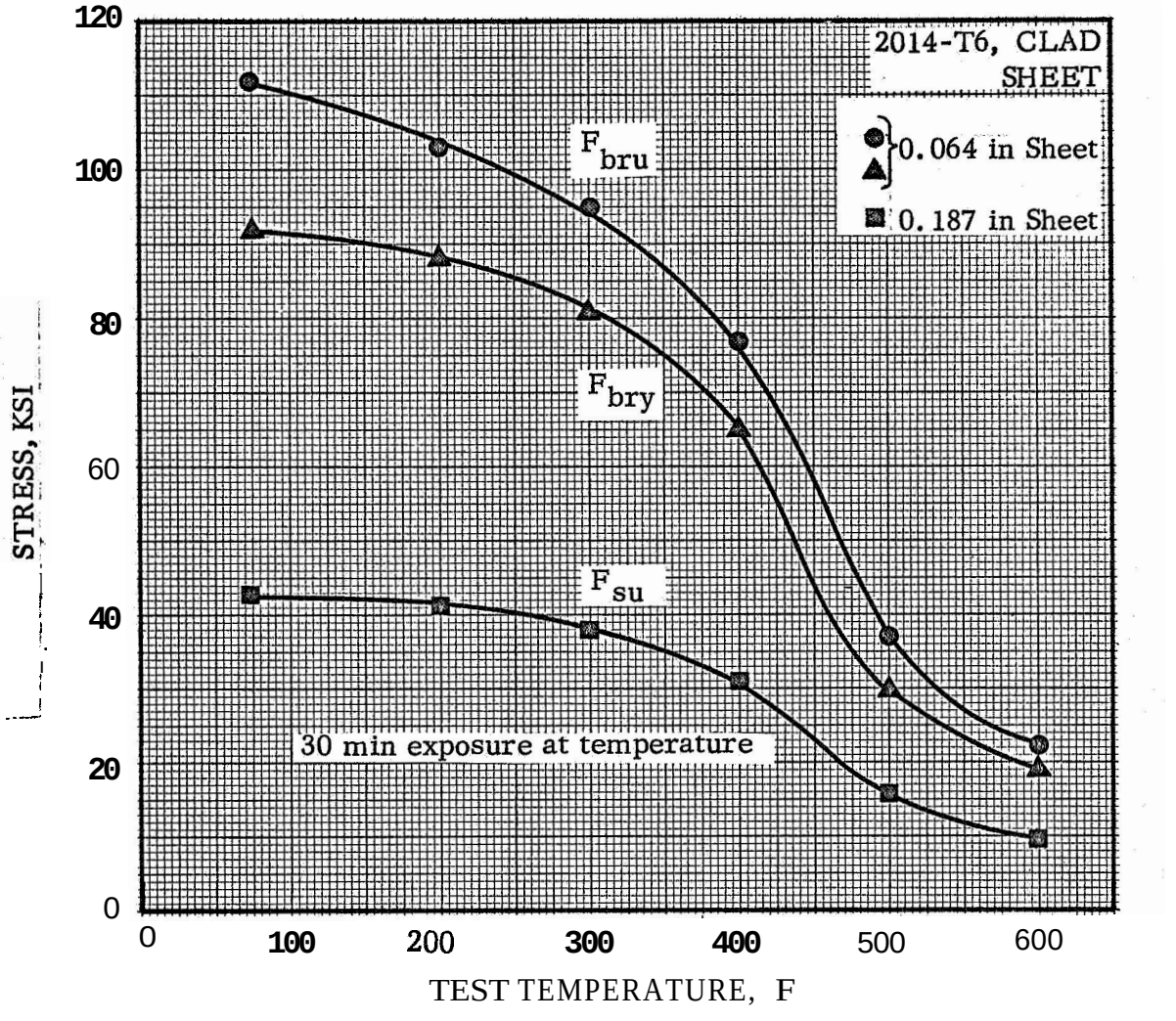


FIG. 7.442 EFFECT OF TEST TEMPERATURE ON F_{BRU}, F_{BRY} AND F_{SU} OF **CLAD** SHEET IN T6 CONDITION

(Ref. 7.10)

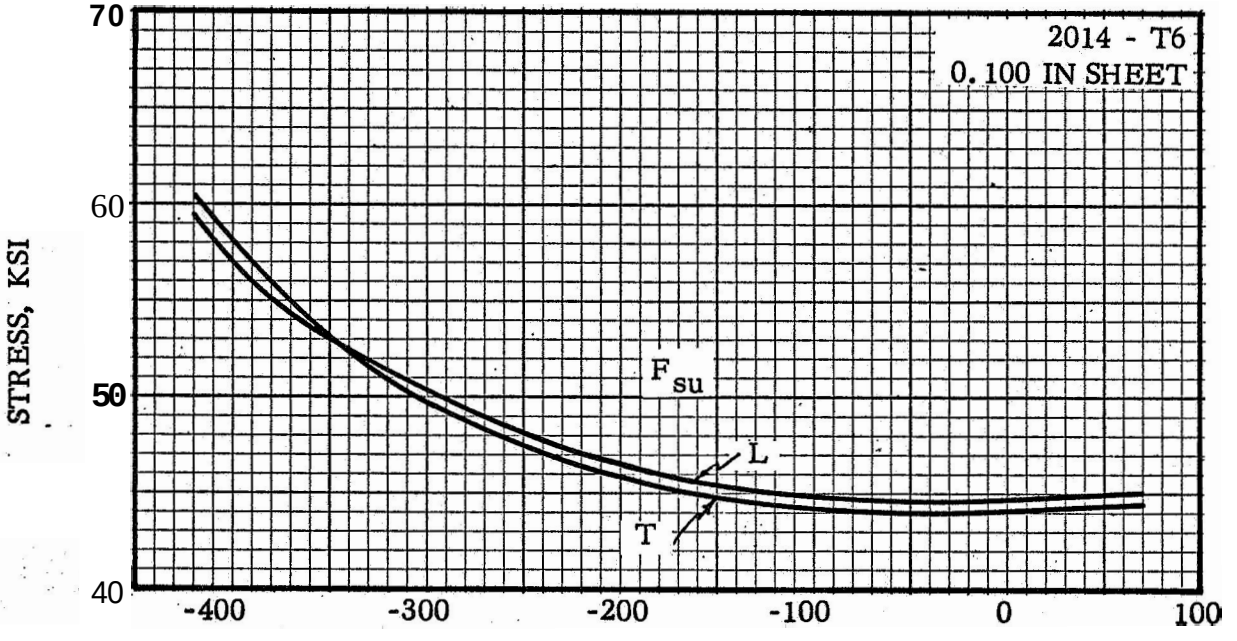


FIG. **7.443** EFFECT OF LOW TEMPERATURES ON SHEAR STRENGTH OF SHEET IN T6 **CONDITION**

(Ref. **7.24)**

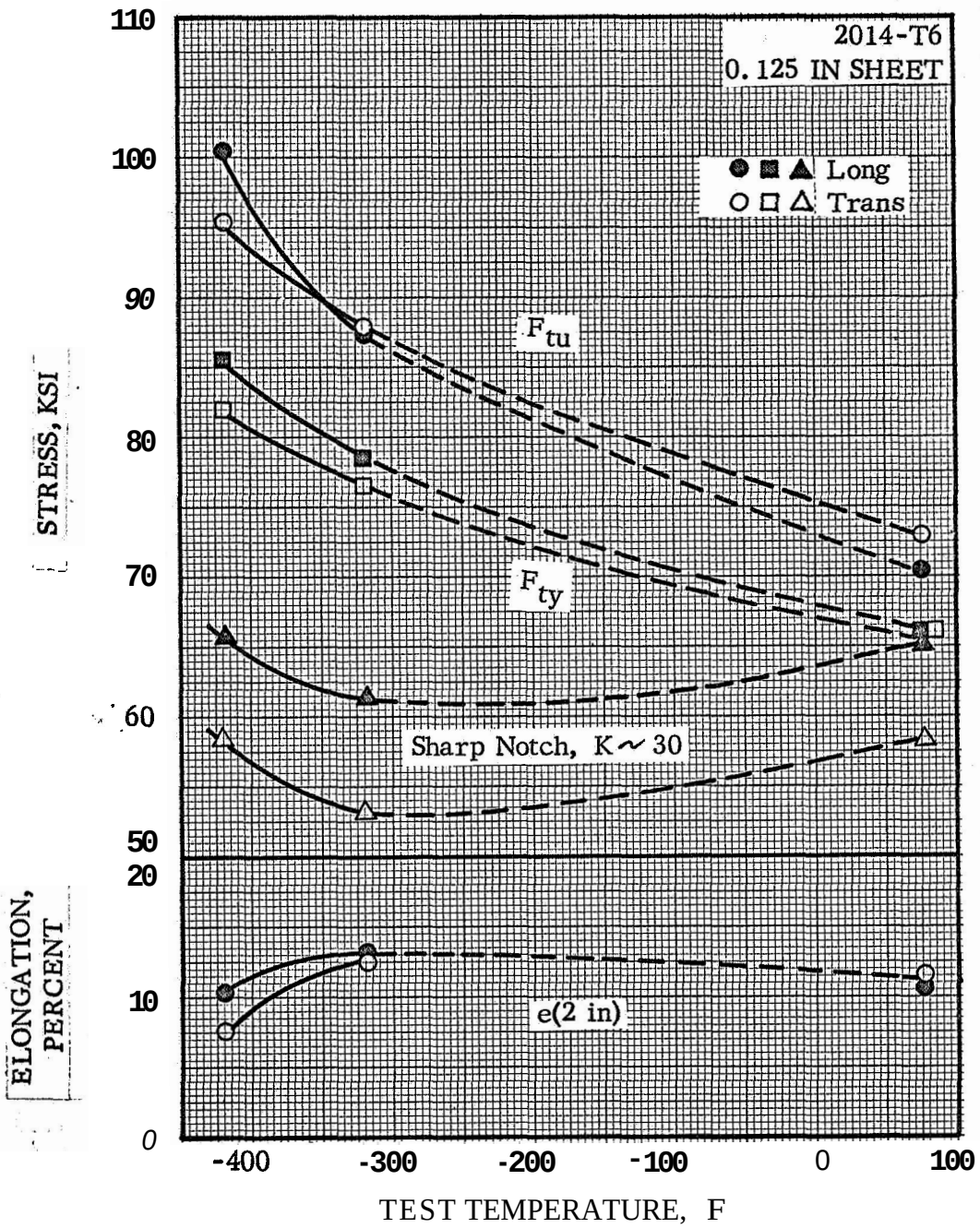


FIG. 7.4611 EFFECT OF CRYOGENIC TEMPERATURES ON TENSILE **AND** SHARP NOTCH PROPERTIES OF SHEET IN T6 CONDITION

(Ref. 7.18)

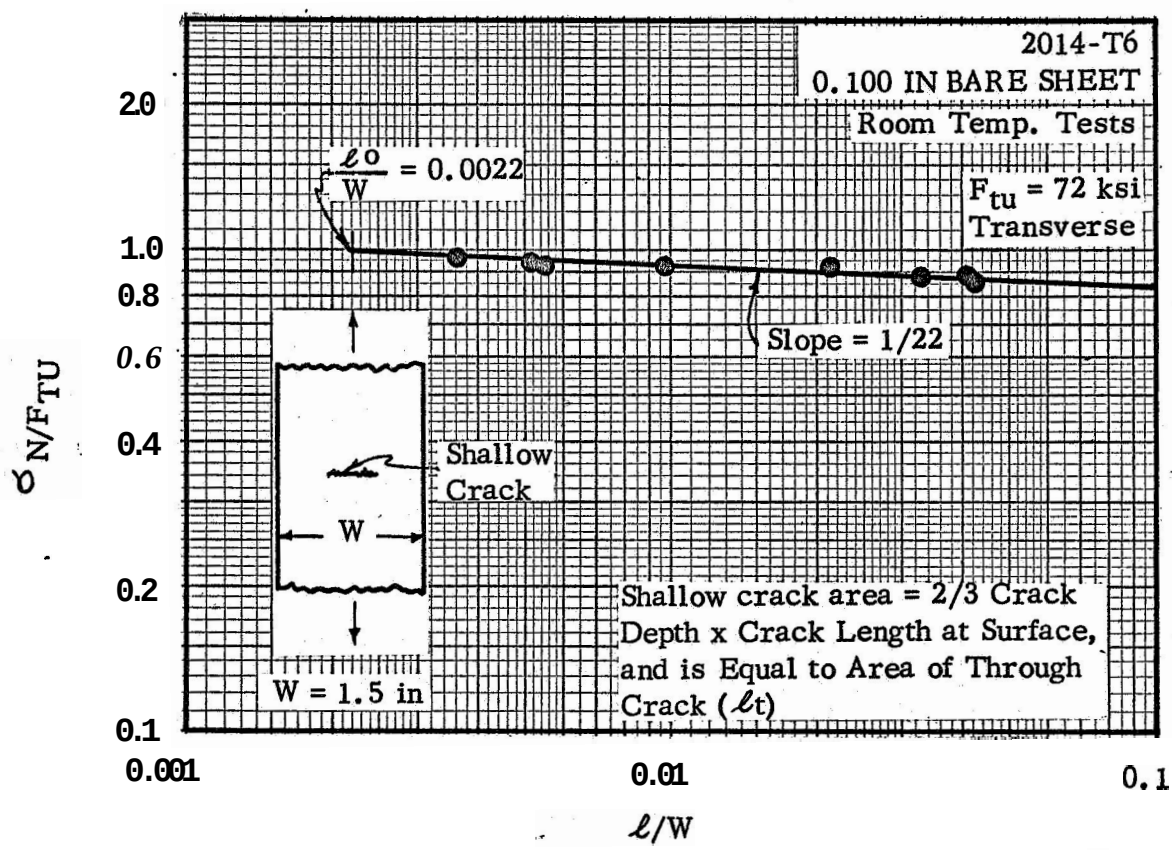


FIG. 7.4612 STRENGTH OF SHEET CONTAINING SHALLOW CRACKS

(Ref. 7.22)

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CHAPTER 8

DYNAMIC AND TIME DEPENDENT PROPERTIES

8.1 General

8.2 Specified Properties

8.3 Impact
8.31 Effect of cryogenic temperatures on Charpy V impact strength, Fig. 8.31.

8.4 Creep
8.41 Creep and creep rupture
8.411 Creep and creep rupture curves for alloy in T6 Condition at 212 to 600F, Fig. 8.411.
8.42 Creep deformation, see also 8.411.
8.421 Short time total strain curves for clad sheet in T6 Condition at 300 to 600F, Fig. 8.421.
8.43 Time-temperature-parameters
8.44 Isochronous stress-strain diagrams
8.441 Isochronous stress-strain curves in tension at 400F, Fig. 8.441.

8.5 Stability
8.51 Exposure effects
8.511 Effect of exposure and test temperature on tensile properties of clad sheet, Fig. 8.511.
8.512 Effect of exposure on room temperature tensile properties of 2014-T6 aluminum rod, Fig. 8.512.
8.513 Effect of exposure and elevated temperature on tensile properties of 2014-T6 aluminum rod, Fig. 8.513.
8.514 Effect of exposure on room temperature tensile properties of 2014-T6 aluminum rod, Fig. 8.514.
8.515 Effect of exposure and elevated temperature on tensile properties of 2014-T6 aluminum rod, Fig. 8.515.

8.6 Fatigue
8.61 Controlled stress cycling
8.611 Typical fatigue strength of alloy in T4 and T6 Conditions, Table 8.611.
8.612 Stress range diagram for smooth and notched bar in T6 Condition, Fig. 8.612.
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8.614 Scatter band of fatigue data for smooth and notched hand forged bar in T6 Condition, Fig. 8.614.

8.615 S-N curves for alloy tested in air and in simulated sea water, Fig. 8.615.
8.62 Controlled strain cycling
8.621 Effect of strain cycling on fatigue life of bar stock, Fig. 8.621.
8.63 Damping
8.64 Thermal cycling
8.65 Stress concentration effects
8.651 See Table 8.611 and Fig. 8.618, 8.614.
8.66 Environmental effects
8.67 Surface effects

. Typical Fatigue Strength **of Alloys** in T4 and T6 Conditions

TABLE 8.611

Source	Ref. 8.6								
Form	All								
Temp RT	Method	Stress Ratio		Stress Concen-	Fatigue Strength - ksi at Cycles				
Condition		A	R	tration	10^5	10^6	10^7	10^8	$5x10^8$
T4	Rot Beam	∞	-1	Smooth K = 1	42	34	27	22	20
T6				Smooth K = 1	39	30	24	19	18
				Notched K = 8	21	14	10	9	9

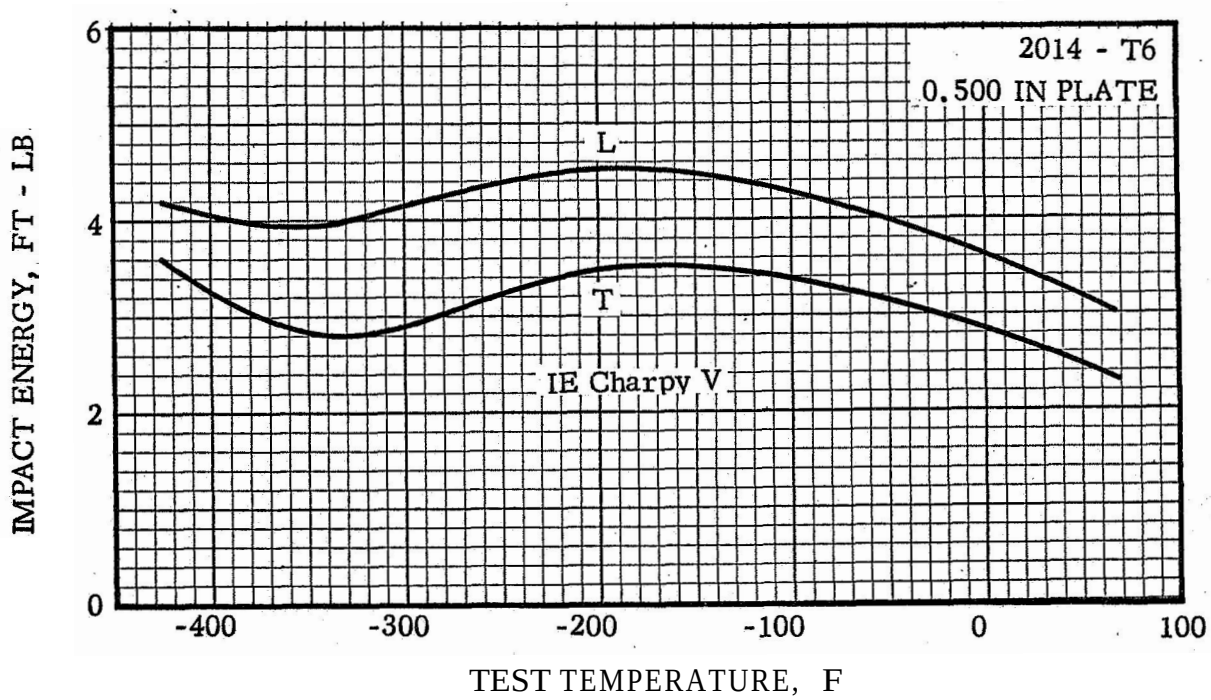
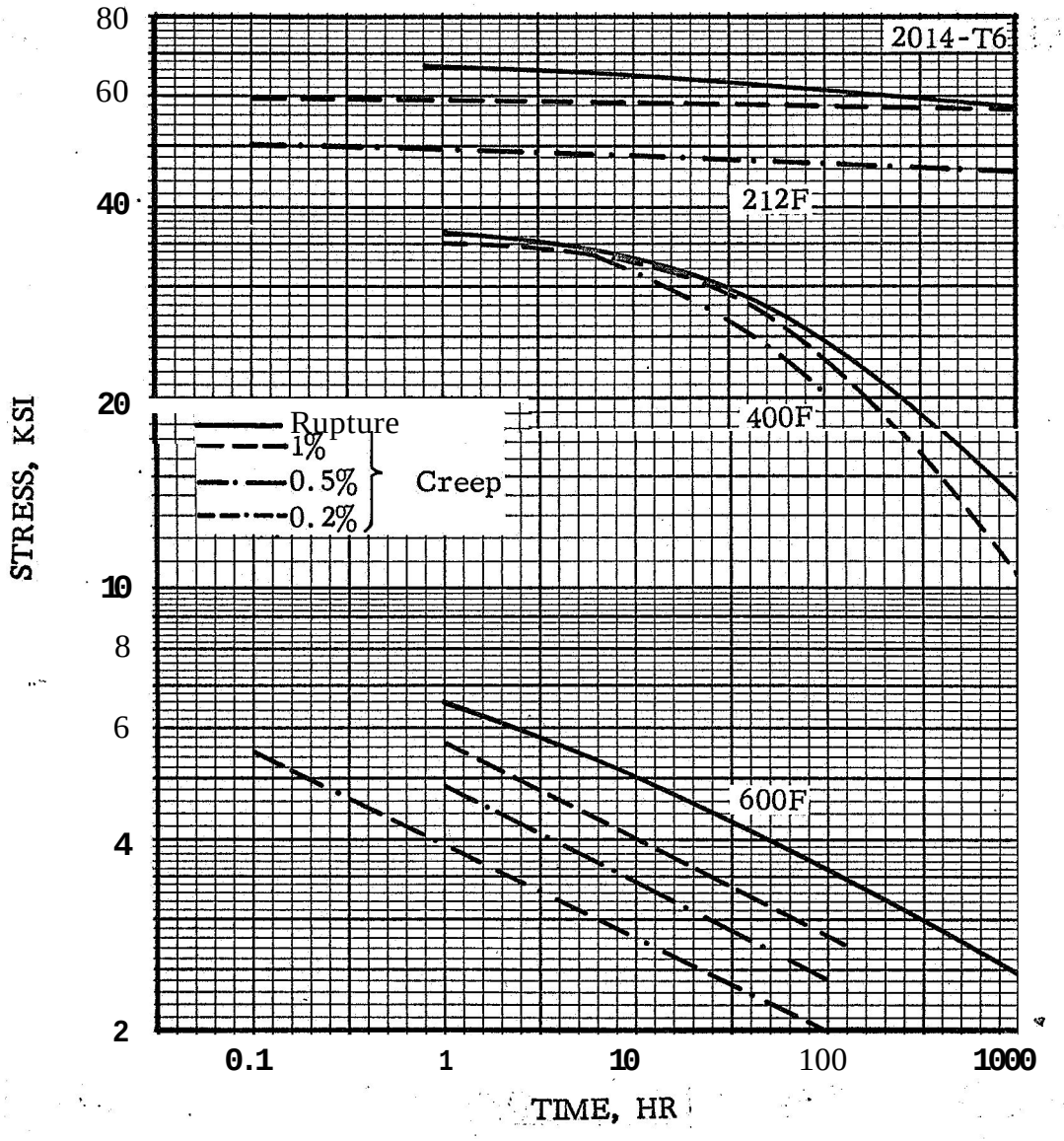


FIG. 8.31 EFFECT OF CRYOGENIC TEMPERATURES ON CHARPY V IMPACT STRENGTH

(Ref. **8.12**)



FIG, 8,411 CREEP AND CREEP RUPTURE CURVES FOR ALLOY IN T6 CONDITION AT 212 TO 600F

(Ref. 8.1)

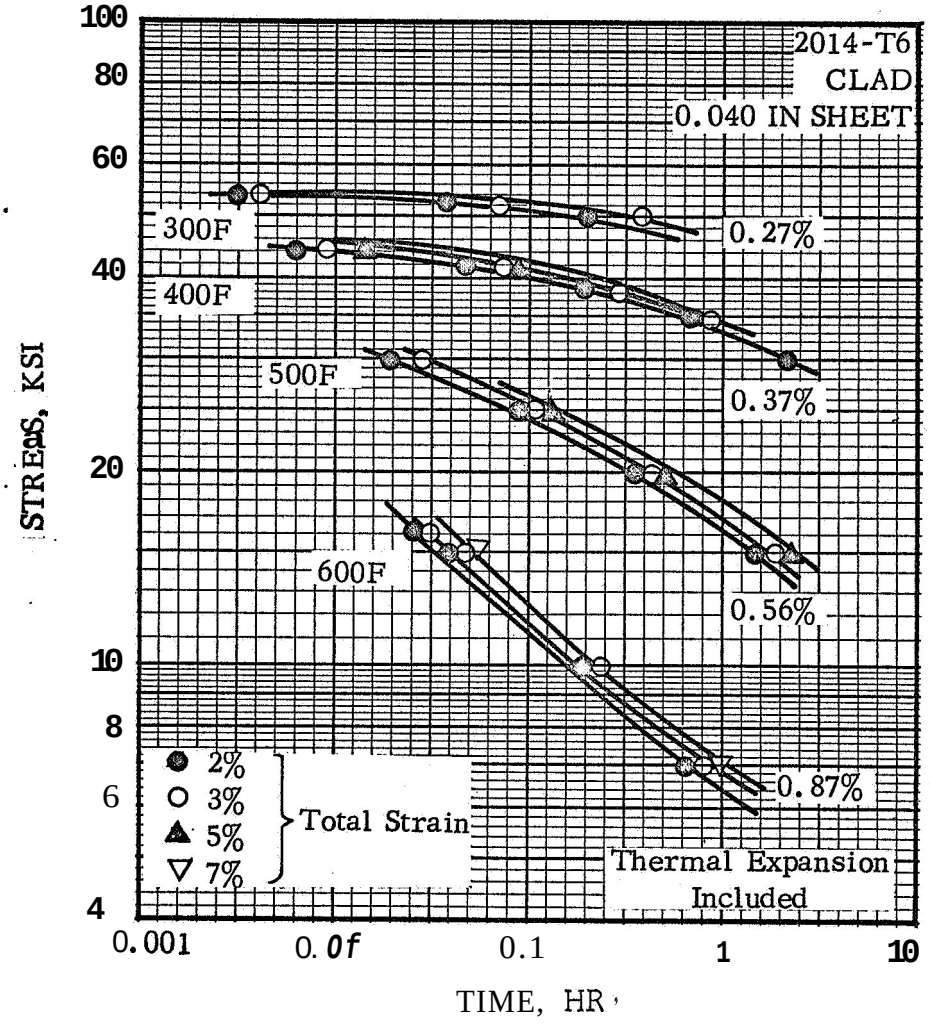


FIG. 8.421 SHORT TIME TOTAL STRAIN CURVES FOR CLAD SHEET IN T6 CONDITION AT 300 TO 600F

(Ref. 8.2)

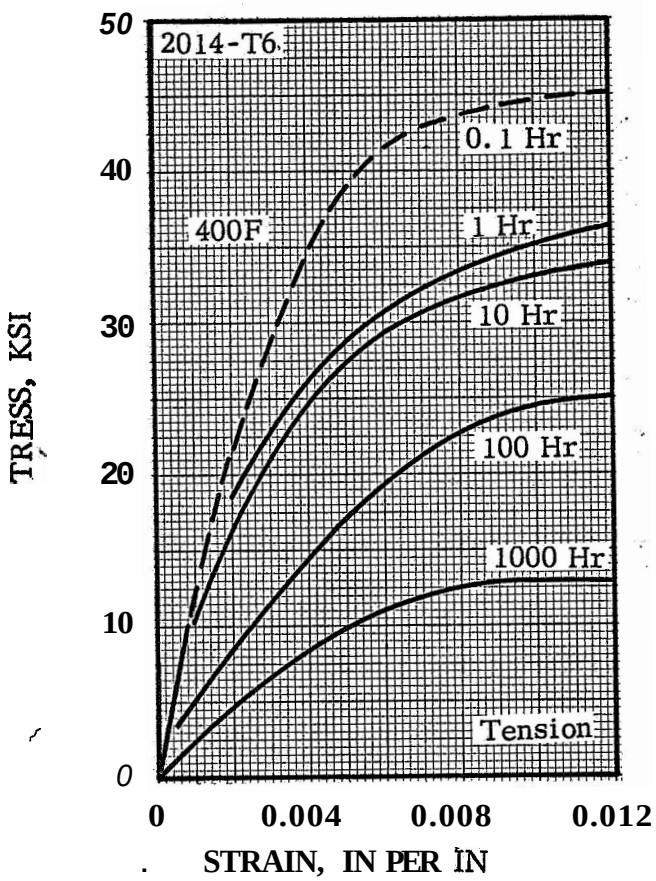


FIG. 8.441 ISOCHRONOUS STRESS-STRAIN CURVES IN TENSION AT 400F (Ref. 8.3)

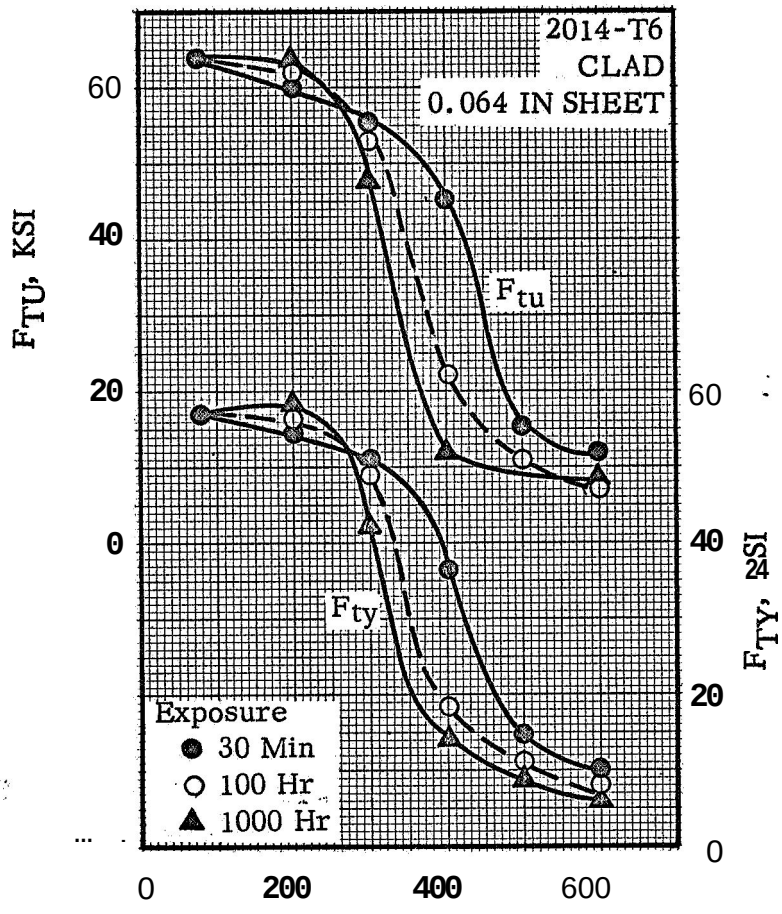


FIG. 8,511 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF CLAD SHEET (Ref. **8.4)**

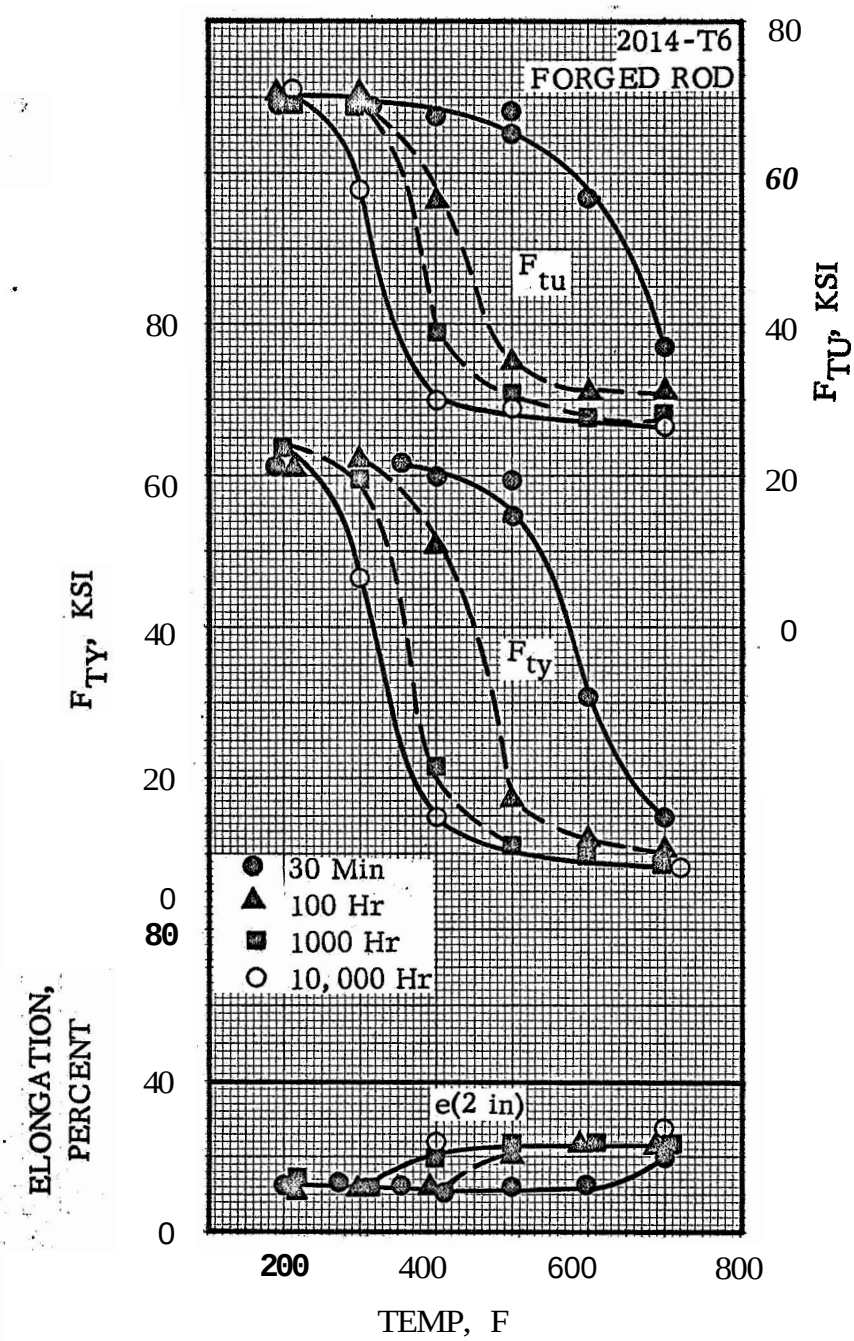


FIG. 8.512 EFFECT OF EXPOSURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF 2014-T6 ALUMINUM **ROD**

(Ref. 8.5)

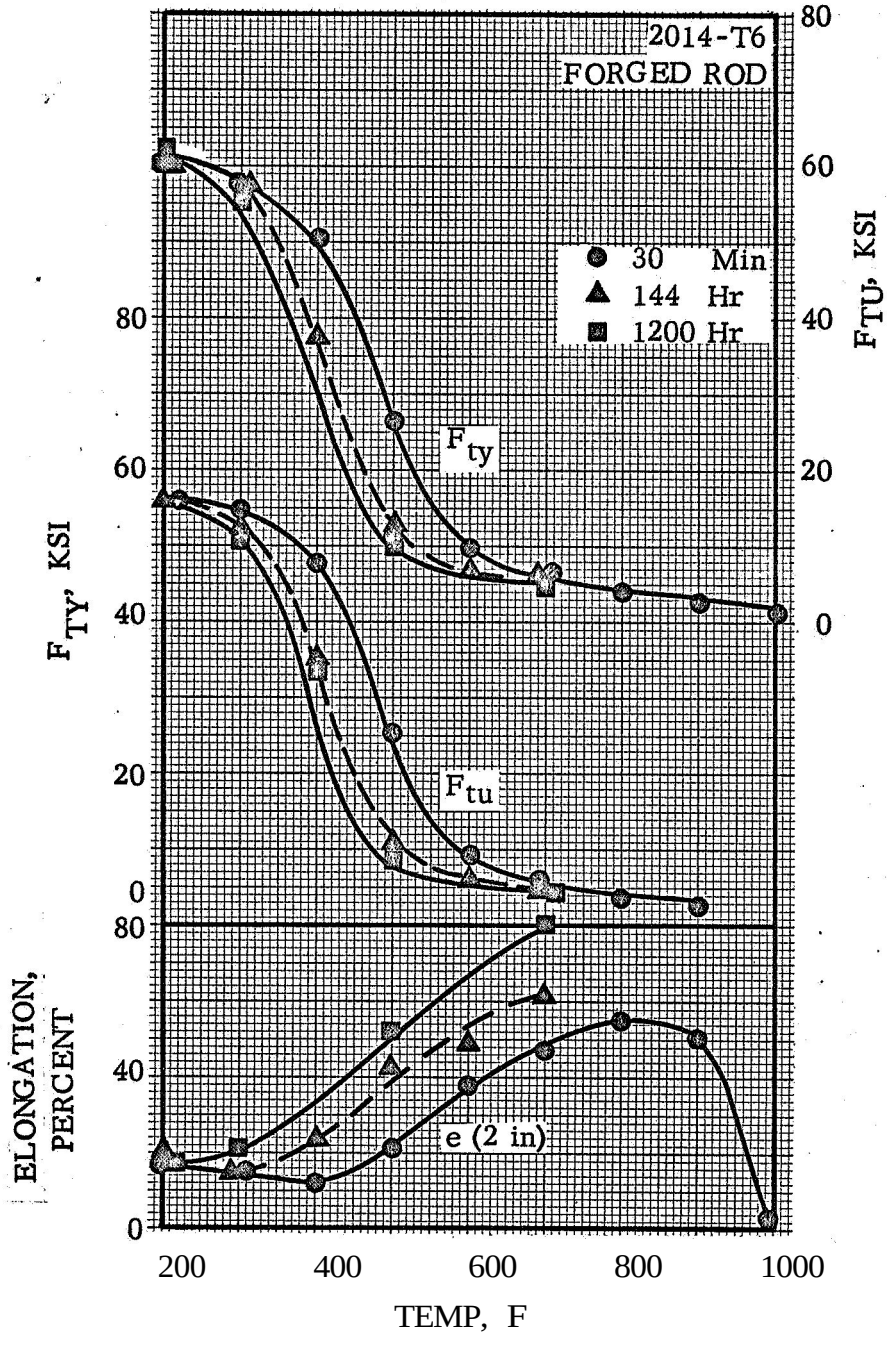


FIG. **8,513** EFFECT OF EXPOSURE **AND** ELEVATED TEMPERAZURE ON TENSILE PROPERTIES OF 2014-T6 ALUMINUM **ROD**

(Ref. 8.5)

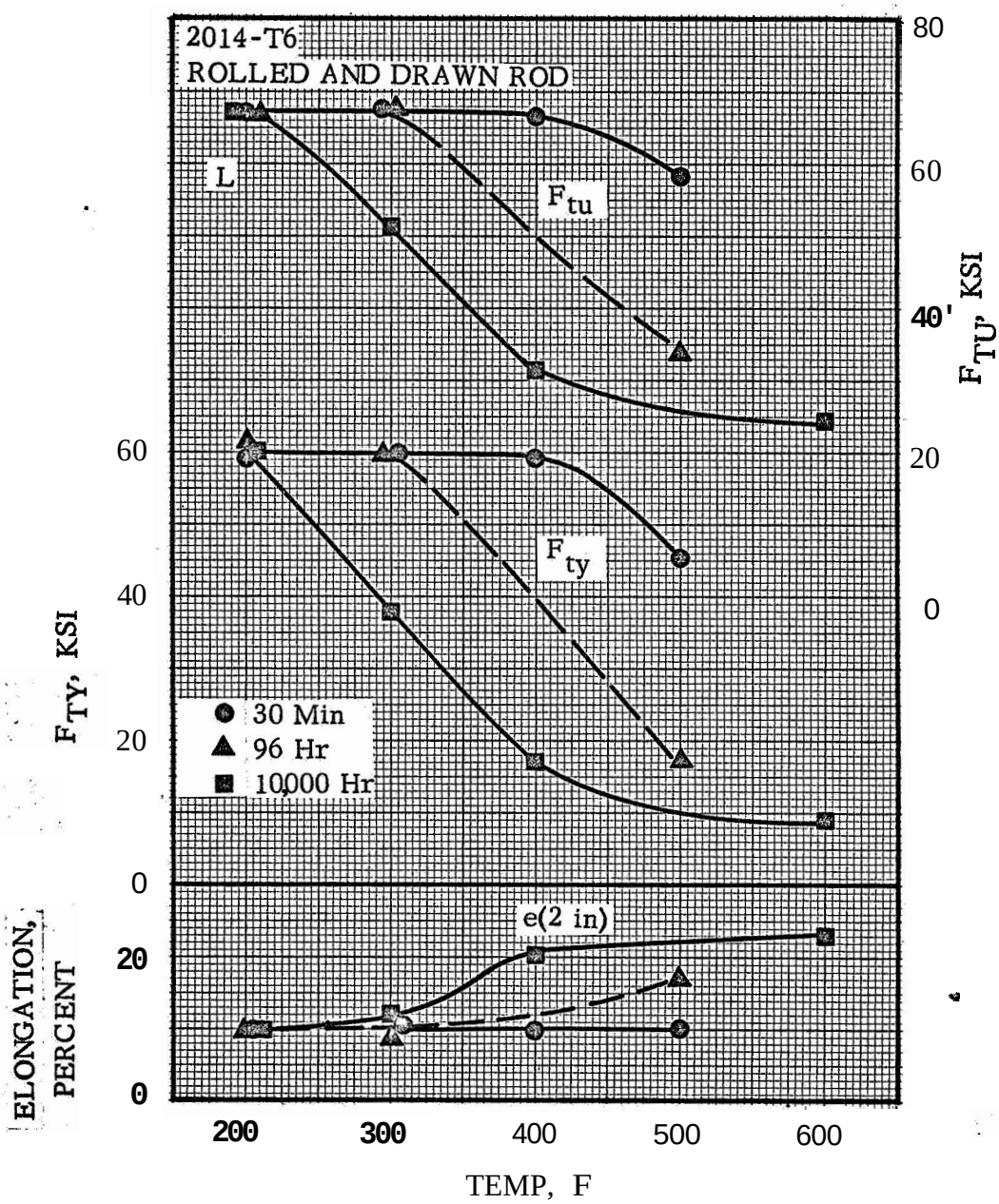


FIG. 8.514 EFFECT OF EXPOSURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF 2014-T6 ALUMINUM ROD (Ref. **8.5)**

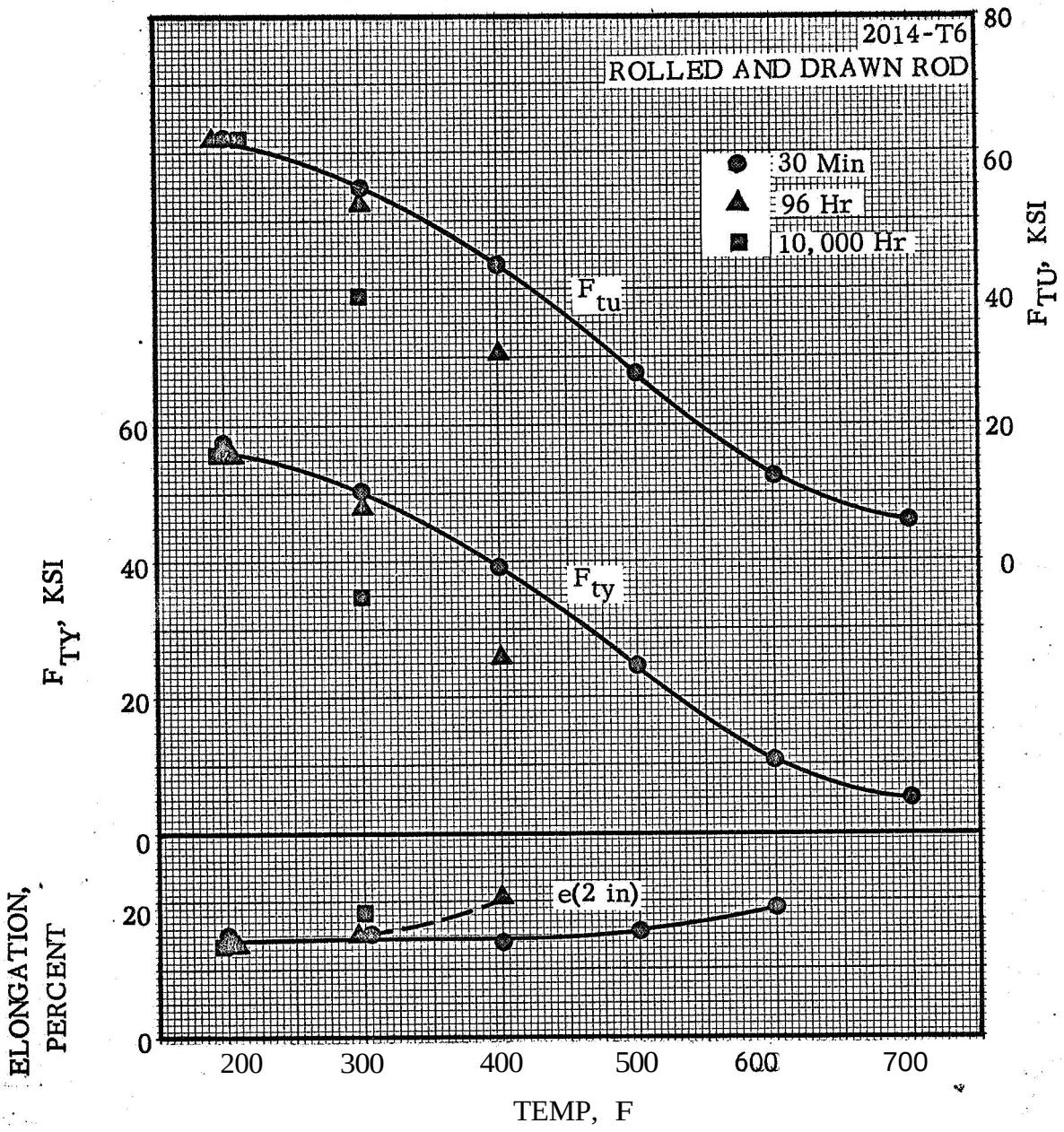


FIG. **8.515** EFFECT OF EXPOSURE **AND** ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF 2014-T6 ALUMINUM ROD (Ref. **8.5)**

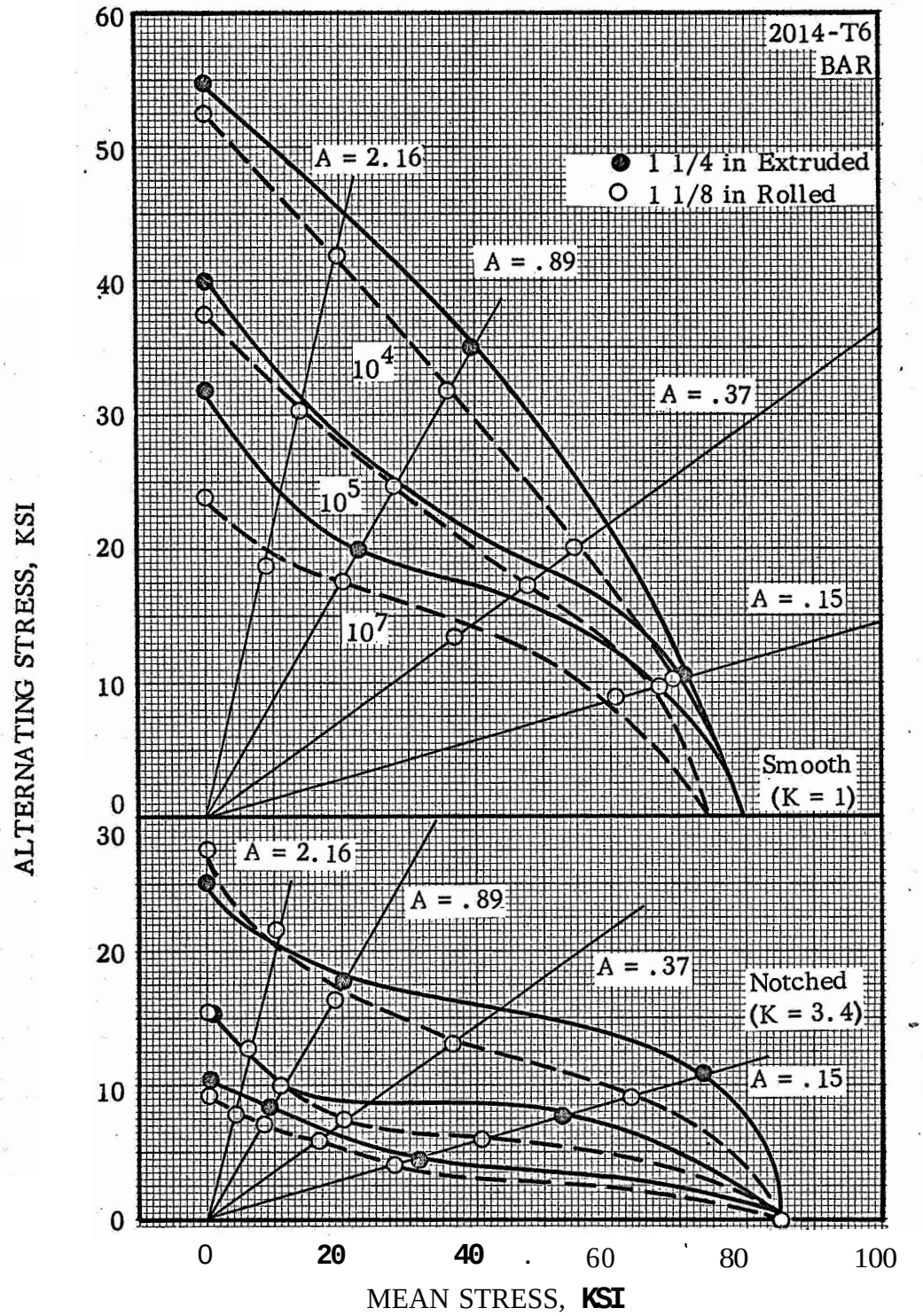


FIG. 8.612 STRESS RANGE DIAGRAMS FOR SMOOTH AND NOTCHED BAR IN T6 CONDITION (Ref. 8.7)

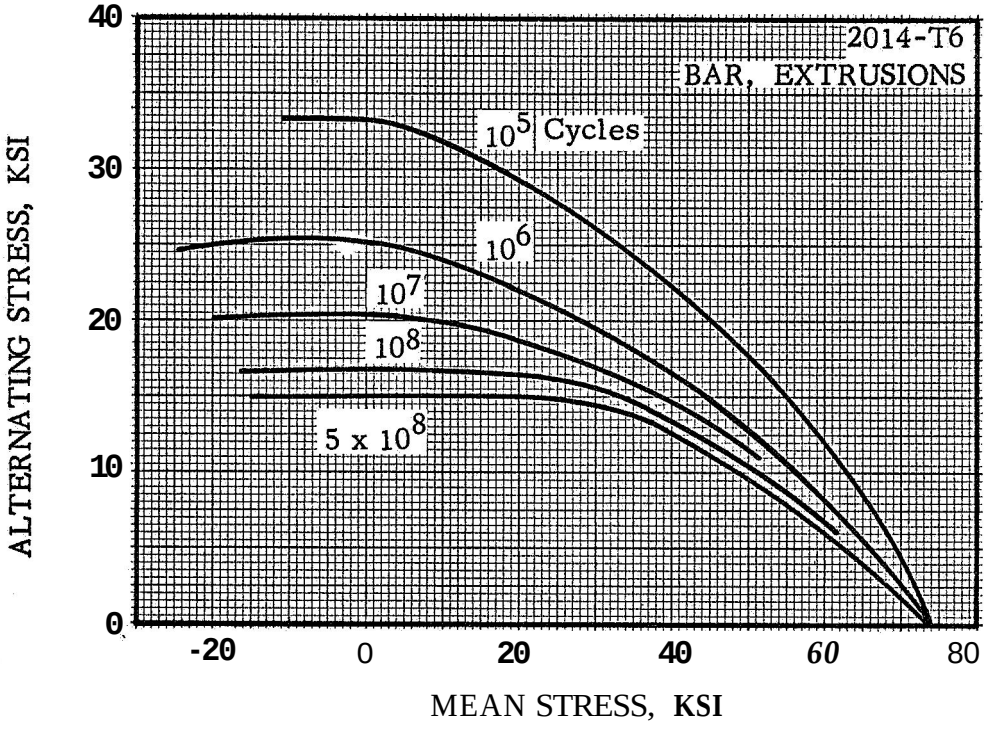


FIG. 8.613 AVERAGE STRESS-RANGE DIAGRAM FOR BAR AND EXTRUSIONS

(Ref. 8.8)

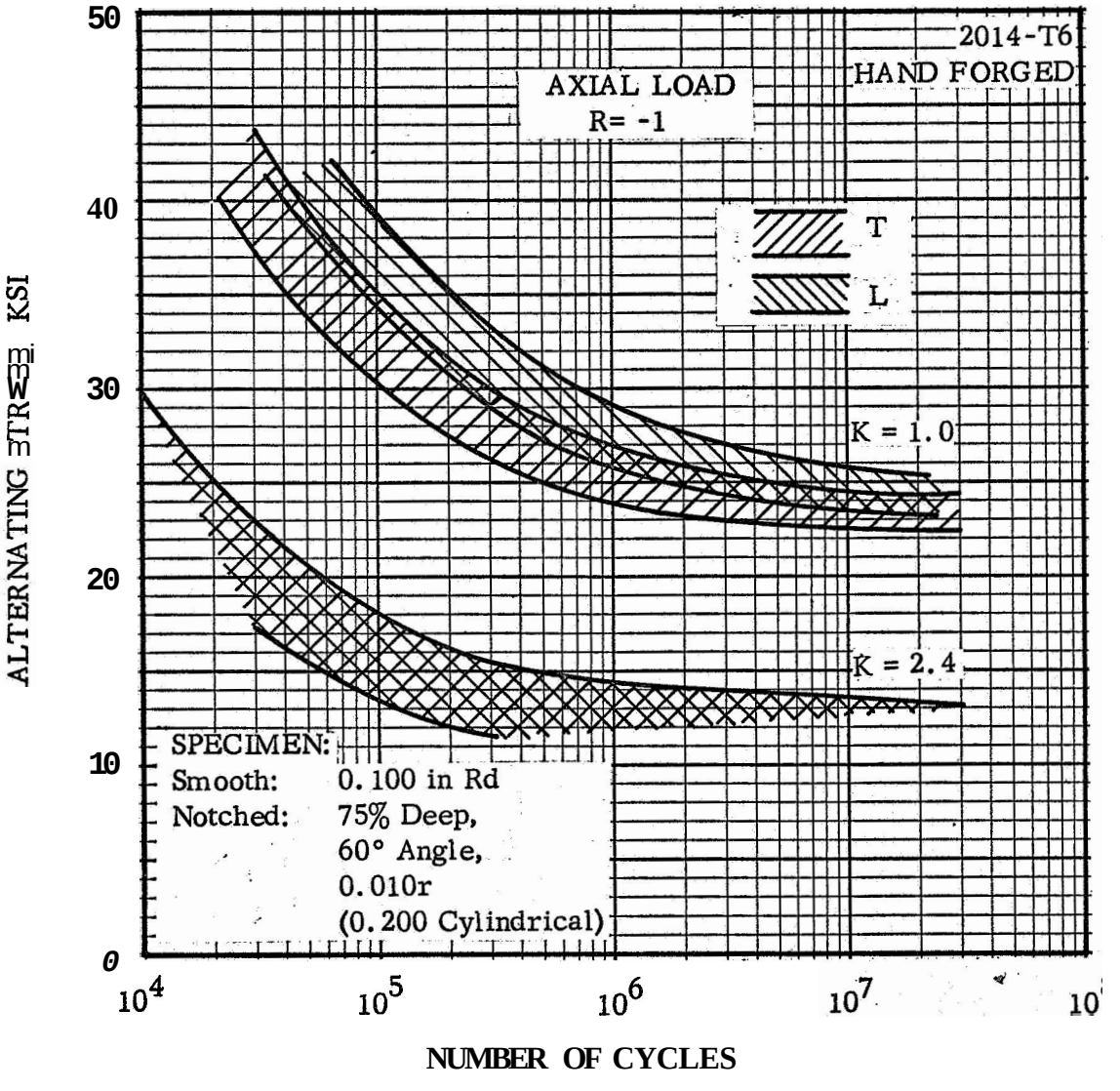


FIG. 8.614 SCATTER BAND OF FATIGUE DATA FOR SMOOTH AND NOTCHED HAND FORGED BAR IN T6 CONDITION

(Ref. 8.9)

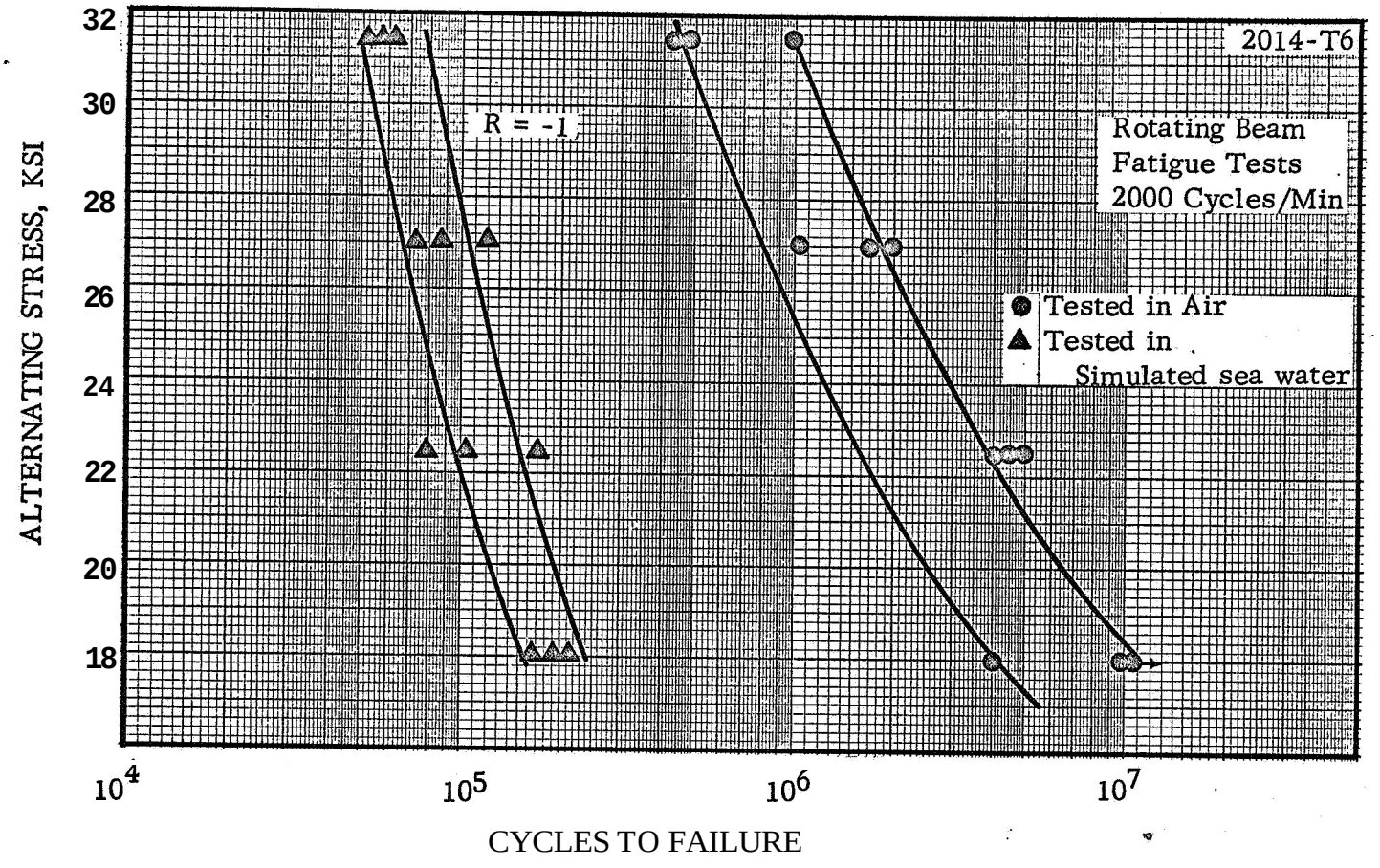


FIG. **8.615** S-N CURVES FOR ALLOY TESTED IN AIR AND IN SIMULATED SEA WATER **(Ref. 8.11)**

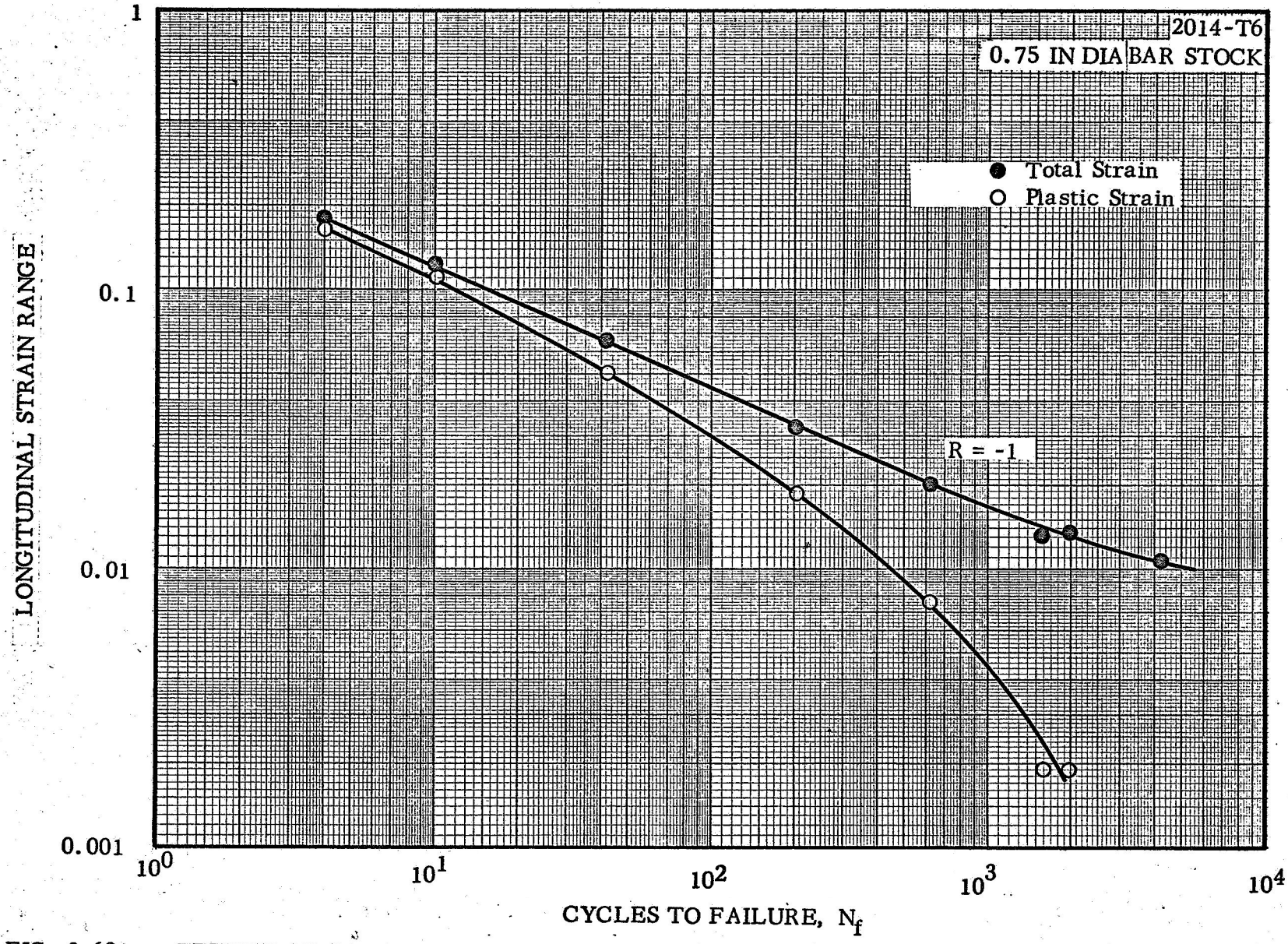


FIG. 8.621 EFFECT OF STRAIN CYCLING ON FATIGUE LIFE OF BAR STOCK

(Ref. 8.10)

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8.11 C. W. Austin, "Rotating Beam Fatigue and Corrosion Fatigue Properties of Aluminum and Magnesium Alloys", Report No. DS-TN-169, Army Ballistic Missile Agency, (February 1958)

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CHAPTER 9

PHYSICAL PROPERTIES

9.1 Density (ρ)

0.101 lb/in^3 at 68F

2.815 gr/cm^3 at 20C, (Ref. 9.1, 9.2, 9.3)

9.2 Thermal Properties

9.21 Thermal conductivity (K), Table 9.21

9.211 Critical appraisal of data. The thermal conductivity of 2014 aluminum is, at room temperature, up to 30 percent lower than that of electrical conductor grade aluminum. This indicates that the heat transfer depends markedly on temper and composition, or concentration and distribution of secondary elements. The allowed composition range for these secondary elements is rather large, (Ref. 9.3). It is for copper 3.9 to 5.0 percent, manganese 0.40 to 1.20 percent and magnesium 0.20 to 0.80 percent. The resistance to heat flow due to impurities will therefore change noticeably from heat to heat of material, even with identical heat treatments.

9.22 Thermal expansion (α), Fig. 9.22.

9.221 Thermal expansion of plate at low temperatures, Fig. 9.221.

9.23 Specific heat (c_p),

0.23 cal/C gr at 100C,

0.23 Btu/lbF at 212F, (Ref. 9.5).

9.24 Thermal diffusivity

0.57 cm^2/sec at 25C,

2.28 ft^2/hr at 77F.

9.241 Critical appraisal of data. Data was calculated according to the equation: Diffusivity = $K/\rho c_p$. Therefore, one should expect similar deviations from the normal value as for the thermal conductivity, (see 9.211)

9.3 Electrical Properties

9.31 Electrical resistivity, Table 9.31.

9.311 The electrical resistivity depends even more strongly than does the thermal conductivity, (see 9.21) on impurity concentration and distribution. Therefore, the resistivity differs even more drastically in 2014 alloy from electrical conductor grade aluminum than the thermal conductivity. This means that changes in composition and variations in heat treatment will influence the resistivity values markedly, (variations in the order of 10 percent may be expected).

9.4 Magnetic Properties

9.41 Permeability. The alloy is not ferromagnetic.

9.42 Susceptibility. The susceptibility changes strongly with heat treatment. Reversible and irreversible structure changes can be determined from susceptibility measurements, This makes it possible to use these measurements for studies on the kinetics of precipitation processes in aluminum-copper alloy systems.

9.5 Nuclear Properties

9.51 General. Aluminum and its alloys have been used extensively in the construction of research and test nuclear reactors. However, its low melting point and high chemical reactivity, leading to relatively poor corrosion resistance in nuclear environments, make it of doubtful value for power reactors operating at temperatures above 400 to 450F, (Ref. 9.8).

9.52 Radiation damage in aluminum alloys has not been studied extensively. However, data available indicate that exposure of aluminum alloys to high-flux neutron irradiation (10^9 nvt or greater) results in increases in hardness, tensile strength and sometimes in corrosion rate. Increases in electrical resistivity have also been observed, Ductility usually is decreased. Changes in density, thermal expansion or in dimensions appears to be negligible. No changes in microstructure have been observed unless the temperature exceeds the recrystallization temperature, (Ref. 9.9).

9.6 Other Physical Properties

9.61 Emissivity

In air: 0,035 to 0.07 at 77F, (Ref. 9.5).

9.62 Damping capacity. (No data found).

TABLE 9.21

Source	Ref. 9.1			Ref. 9.2	
Alloy	2014				
Property	Thermal Conductivity				
Temper	T6			0	T4, T5, T6
Thermal Conductivity,					
BTU in/ft^{2}F Hr	1075	1330	1344	1340	840
Cal/cm C sec	0.37	0.458	0.644	0.46	0.29,
Temperature,					
F	77	396	572	77	77
C	25	206	300	25	25

TAB. E 9.31

Source	Ref. 9.5		Ref. 9.3		
Alloy	2014				
Property	Electrical Resistivity				
Temper	0	T6	0	T4	T6
Electrical Resistivity,					
microhm - in	1.3	1.7	1.34	2.24	1.69
microhm - cm	3.3	4.3	3.4	5.7	4.3
Temperature,					
F	68	68	68	68	68
C	20	20	20	20	20

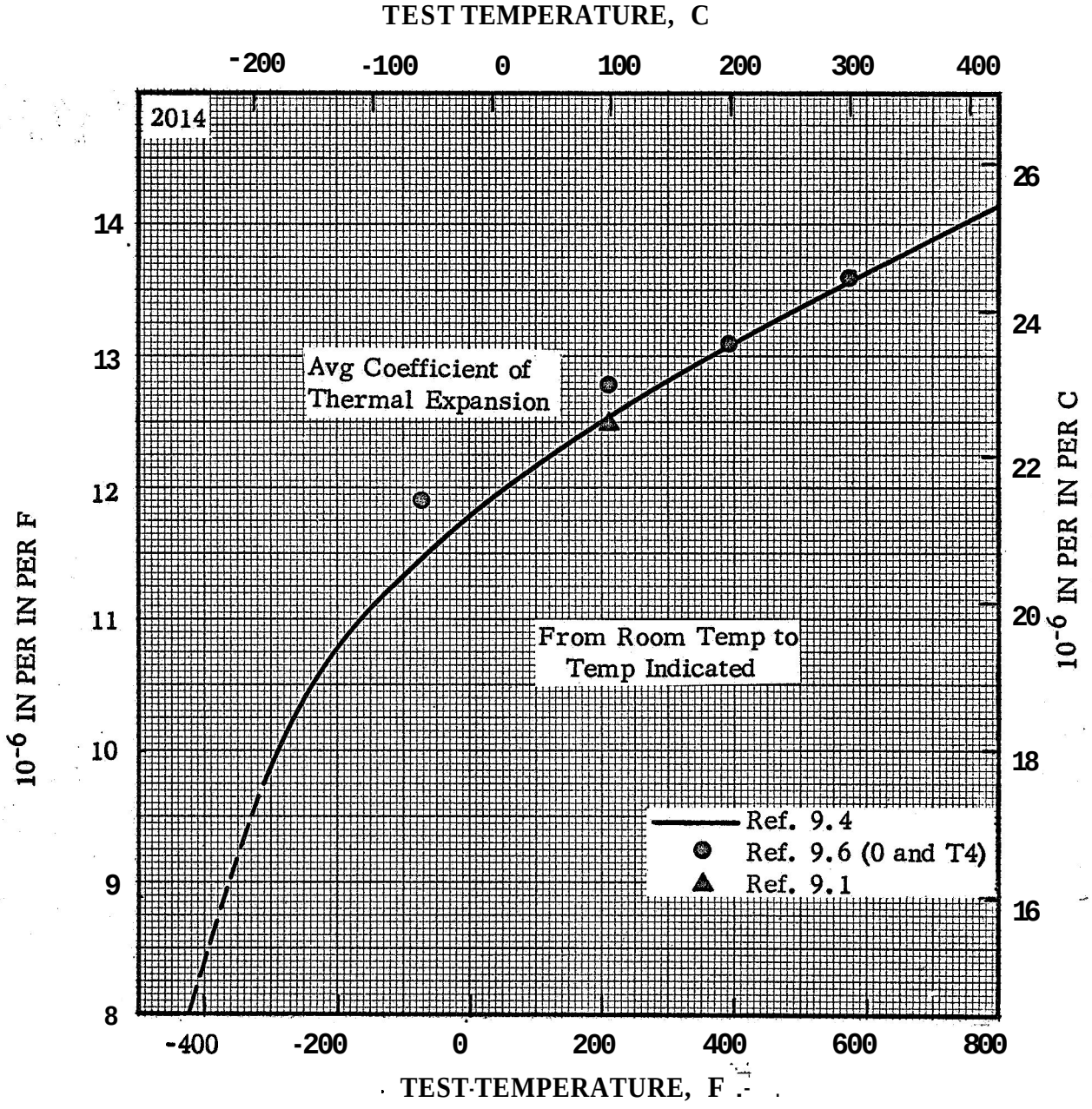


FIG. 9.22 THERMAL EXPANSION

(Refs. 9.1, 9.4, 9.6)

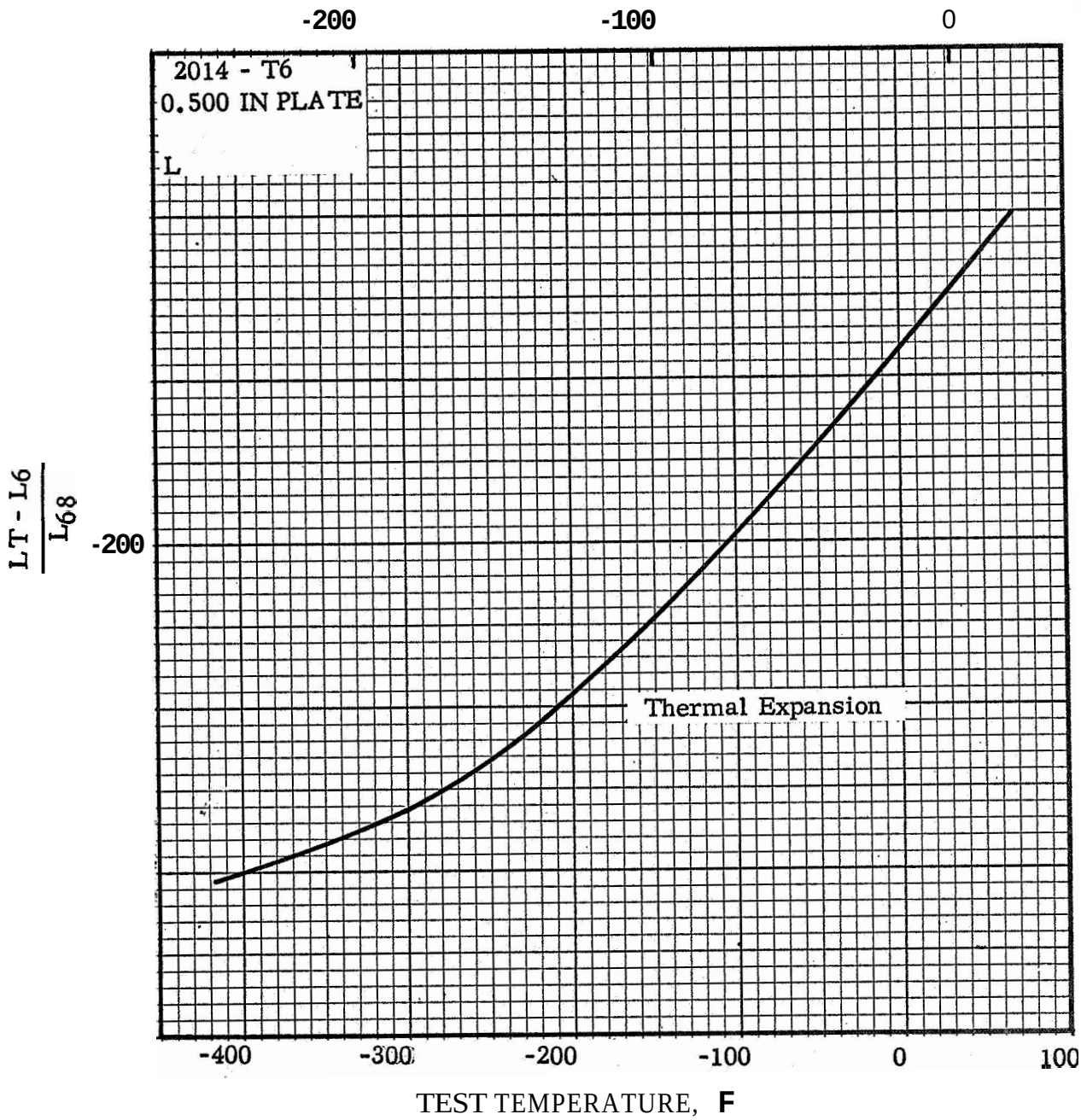


Fig. 9.221 THERMAL EXPANSION OF PLATE AT LOW TEMPERATURE (Ref. *9.7)*

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CHAPTER 10

CORROSIQN RESISTANCE AND PROTECTION

10.1 General. Despite its high chemical reactivity and affinity for oxygen, aluminum exhibits excellent corrosion resistance in most common environments, because it passivates spontaneously and very rapidly under normal oxidizing conditions. The passive film is a hard, strongly adhering layer of aluminum oxide, estimated as 20-100 Å thick on aluminum exposed to air, (Ref. 10.1), which protects the metal from direct attack. Thus the corrosion rate of aluminum generally decreases with time, except under severe or specific exposure conditions which tend to disrupt the passive film.

Outdoors, aluminum and its alloys weather to a pleasant gray color, with some initial superficial pitting which gradually ceases, (Ref. 10.2). Industrial soot, sulfur dioxide, sulfur trioxide and marine spray tend to increase atmospheric corrosion, but hydrogen sulfide and carbon dioxide do not, (Ref. 10.3). Twenty-year tests at several marine, industrial and rural sites have shown that atmospheric attack on aluminum takes place principally in the first year and progresses very slowly beyond the second year, (Ref. 10.4). Even at high temperatures in dry atmospheres, aluminum is highly resistant to most common gases, except the halogens, (Ref. 10.2).

In aqueous environments, corrosion resistance of aluminum is greatest under neutral or slightly acid condition, where the protective oxide film is most stable (pH 5.5-8.5 at room temperature, 4.5-7 at 95C), (Ref. 10.1 and 10.5). Strong alkalies and strong-non oxidizing acids destroy the oxide and greatly accelerate corrosion. Pitting attack occurs in waters containing chloride or other halogen ions, particularly at crevices or stagnant areas where passivity breakdown is accelerated by differential aerative effects. Traces of copper, iron and mercury ions are also effective in promoting localized attack via galvanic cells formed between aluminum and metal deposited by replacement reactions, (Ref. 10.1). Since aluminum is strongly anodic to most other common metals, galvanic coupling with them generally produces severe attack on the aluminum, especially in sea water, (Ref. 10.2).

Aluminum and its alloys are rather resistant to most molten salts. However, molten metals generally attack aluminum, particularly zinc and tin, which form alloys, (Ref. 10.2). Even a small amount of mercury is especially harmful, since it breaks down passivity and amalgamates, causing rapid perforation of aluminum piping or sheet, (Ref. 10.1). Aluminum exhibits very poor resistance to uninhibited chlorinated solvents and may even react explosively with them, (Ref. 10.6).

Aluminum purity significantly affects its corrosion resistance. High purity metal is more resistant than commercially pure aluminum, which in turn is generally more resistant than most alloys, (Ref. 10.1). Corrosion resistance of specific alloys is affected by composition, heat treatment and stress conditions, as discussed further below.

10.2 Aluminum - Copper Alloys. To maximize its corrosion resistance, the composition of an alloy should be maintained as homogeneous as possible since non-homogenieties frequently initiate localized attack. This principle applies clearly to the aluminum - copper alloys, of which alloy **2014** is a typical example. Copper generally depresses the electrode potential of aluminum in the cathodic (noble) direction, but its concentration and distribution are significant, as shown in Table 10.21.

For optimum corrosion resistance of Al-Cu alloys, copper should be maintained in solution by rapid quenching from above the homogenizing temperature (about 900F). If the cooling rate is not rapid enough, the compound $CuAl_2$ forms preferentially along the grain boundaries. This results in copper depletion adjacent to the intermetallic compound, making the grain boundaries anodic to the grains and susceptible to intergranular corrosion, (Refs. 10.1 and PO. 7). Fig. **10.22** shows the effect of aging duration on electrode potentials of grains and grain boundaries of an aluminum alloy containing **4.1%** Cu. This suggests that prolonged aging can restore uniformity and reduce intergranular corrosion susceptibility. From data such as these, it may be concluded that corrosion resistance of the **2014** alloy in the **T4** Condition improves with increased rate of cooling, whereas in the **T6** Condition it improves with decreased rate of cooling, (Ref. 10.8). Thus in the **T4** Condition thin sections exhibit better corrosion resistance than thick sections, and vice-versa in the T6 Condition.

Tensile stress in the presence of moisture further reduces corrosion resistance of aluminum-copper alloys, leading to intergranular stress corrosion cracking. Susceptibility toward this type of attack is heightened by the presence of grain boundry precipitates, although authorities disagree on the details of the mechanism involved, (Refs. **PO.** 1, 10.7 and 10.9). Attack is particularly severe in the presence of chloride ions, which weaken protective oxide films. Extensive research on stressed **2024** alloy in aqueous solutions containing 5% NaCl and 0.3% H_2O_2 showed that on aging at **160** -200C, maximum susceptibility to stress corrosion cracking occurred before maximum tensile strength was attained, (Ref. **PO. 10).**

10.3 Behavior of Aluminum Alloy **2014.** Extensive information on the corrosion beha'vior of **2014** under a variety of exposure conditions is not available. However, some data has been published on stress corrosion in the atmosphere and in chloride environments, (Refs. PO. 11 and **10.12).** These are summarized in the following figures and tables, which also include comparable information on other common aluminum alloys. The data indicate that stress corrosion resistance of **2014** is comparable to **2024** and 7079, but inferior to **2219.**

10.31 Stress corrosion performance of **2014** and other aluminum alloys (Short transverse specimens from plate, extrusions and forgings), Fig. **10.31.**

10.32 Stress corrosion performance of **2014** and other aluminum alloys. Alternate immersion in 3.5 percent NaCl solution **(0.125-0.437** inch bar, except as noted), Fig. **10.32.**

10.33 Comparative stress corrosion performance of aluminum alloy forgings. Alternate immersion in **3.5** percent NaCl solution, Fig. **10.33.**

10.34 Loss in tensile strength of stressed specimens exposed to various environments, Table **10.34.**

10.35 Comparative stress corrosion resistance of heat treated aluminum-copper alloys, Table **10.35.**

10.4 Protective Measures. Anodizing, which thickens the surface oxide film, is widely used for corrosion protection of aluminum and its alloys. Cathodic protection has also proved effective in retarding both general dissolution and localized attack, although overprotection by this method should be avoided to insure against harmful accumulation of alkali at the cathode surface, (Ref. **10.1).** Painting and inorganic inhibitors have also been applied with some success in specific cases, (Ref. **10.2).**

Cladding with commercially pure aluminum or a more resistant alloy is the traditional method used for many applications. Alloys **6003** and **6053** are common cladding materials for **2014,** (Ref. **10.8).** Careful heat treatment and proper fabrication to avoid localized tensile stresses and structural crevices are desirable to minimize localized attack and stress corrosion cracking.

Surface treatments are discussed in greater detail in Chapter **11.**

TABLE 10.21

Source	Ref. 10.7	
Property	Electrode Potentials vs 0.1N Calomel at 25°C	
(Aqueous solution of 53 gr NaCl and 3 gr H_2O_2 per liter)		
Al(99.95 + %)	-	0.85 volt
Alclad 201	-	0.83 volt
2014-T6	-	0.78 volt
Al + 2% Cu (solid solution)	-	0.75 volt
$CuAl_2$	-	0.73 volt
Al + 4% Cu (solid solution)	-	0.69 volt
2014-T	-	0.69 volt

LOSS IN TENSILE STRENGTH OF STRESSED SPECIMENS
EXPOSED TO VARIOUS ENVIRONMENTS
(0.063 inch production sheet)

Source				
Alloy	Environment	Exposure (days)	Average loss in tensile strength	
			Unstressed %	Stressed 75% of yield strength
2014-T6	A	365	7	7
	B	365	18	28
	C	84	42	55
2024-T3	A	365	6	9
	B	365	16	20
	C	84	33	40
2219-T81	A	300	-	-
	B	365	6	8
	C	84	21	26
7075-T6	A	365	2	5
	B	365	7	10
	C	84	13	22

Environments: A - Inland Industrial
B - Sea Coast
C - 3.5% NaCl, alternate immersion

COMPARATIVE STRESS CORROSION RESISTANCE OF HEAT-TREATED ALUMINUM-COPPER ALLOYS

TABLE 10.35

Source (Ref. 10.12. p. 82)

Alloy	Test Direction	Highest sustained tensile stress without failure (ksi)				
		Plate	Bar	Extruded shapes 0.25 - 1in	Extruded shapes 1.25-2in	Hand forgings
2014-T6	L	45	45	50	45	30
	LT	30	-	27	22	25
	ST	7	15	-	7	7
2024-T3, T4	L	35	30	>50	>50	-
	LT	20	-	37	18	-
	ST	7	10	-	7	-
2024-T6, T8	L	>50	>47	>60	>60	-
	LT	>50	-	50	50	-
	ST	43	>43	-	16	-

Test environment: 3.5%.NaCl, alternate immersion, 12 weeks.
> indicates no failure at highest *stress* employed.

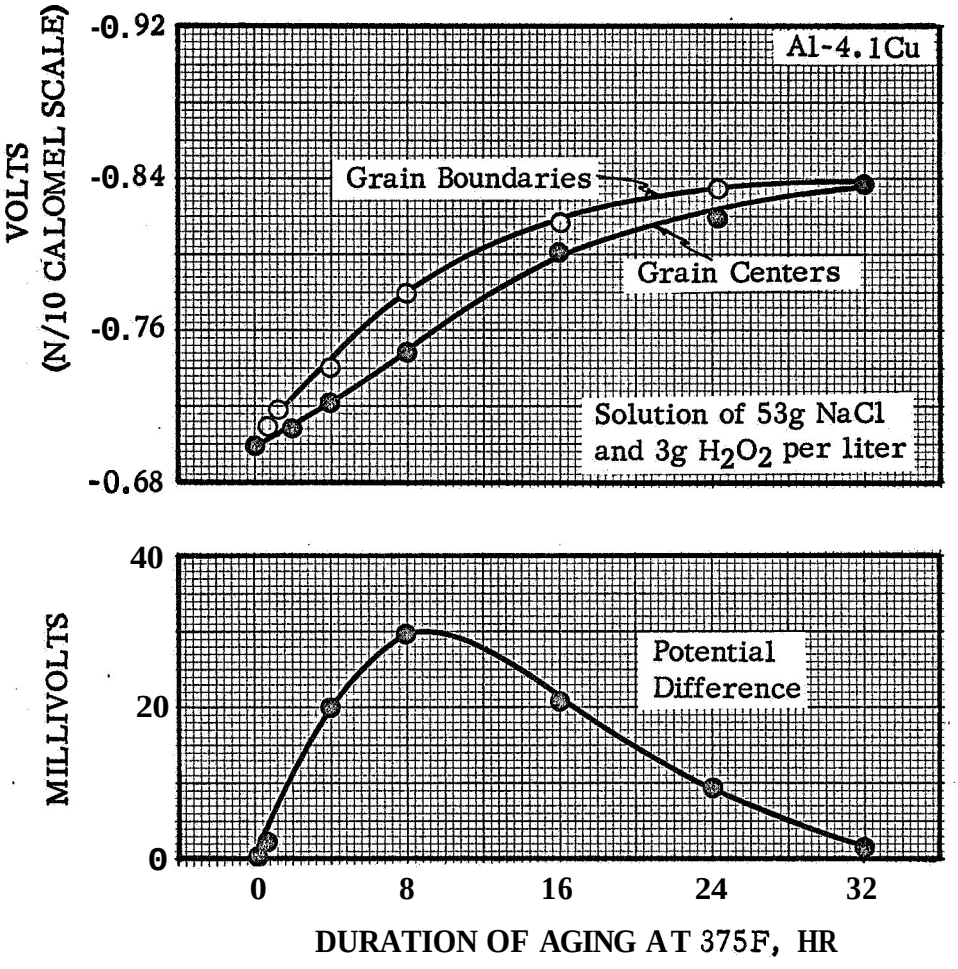
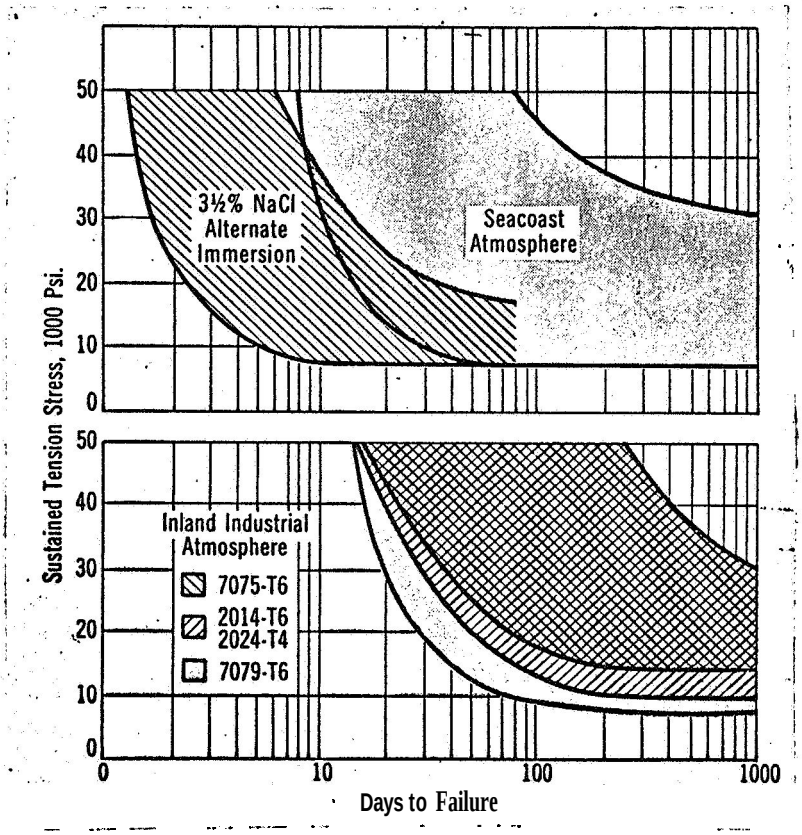


FIG. 10.22 EFFECT OF DURATION OF AGING AT 375F ON THE ELECTRODE POTENTIALS OF GRAINS AND BOUNDARIES OF A HIGH PURITY AL-4.1Cu ALLOY (Ref. 10.7)



FIG, **10.31** STRESS CORROSION PERFORMANCE OF **2014** AND OTHER ALUMINUM ALLOYS (SHORT TRANSVERSE SPECIMENS FROM PLATE, EXTRUSIONS **AND** FORGINGS)

(Ref, 10.12, p. 85)

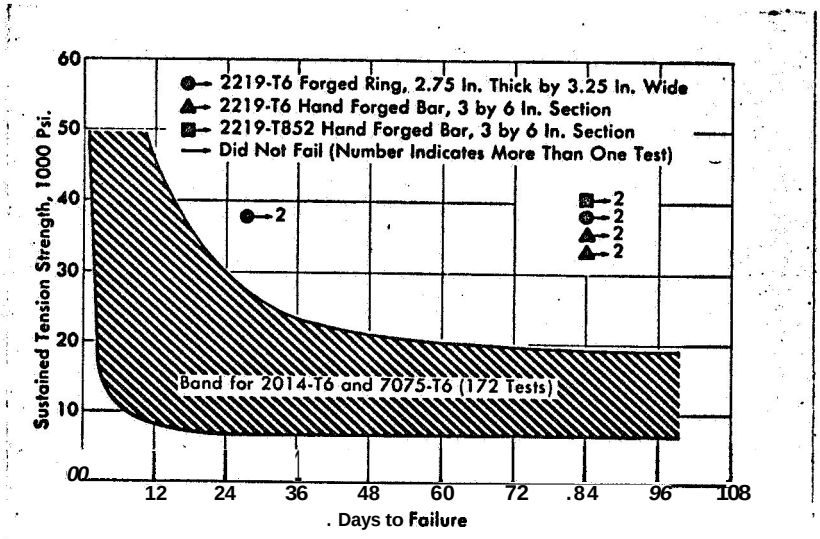


FIG. 10.32 STRESS CORROSION PERFORMANCE OF 2014 AND OTHER Al ALLOYS. ALTERNATE IMMERSION IN 3.5% NaCl SOLUTION (0.125 to 0.437 IN BAR EXCEPT AS NOTED) (Ref. 10.11, p. 89)

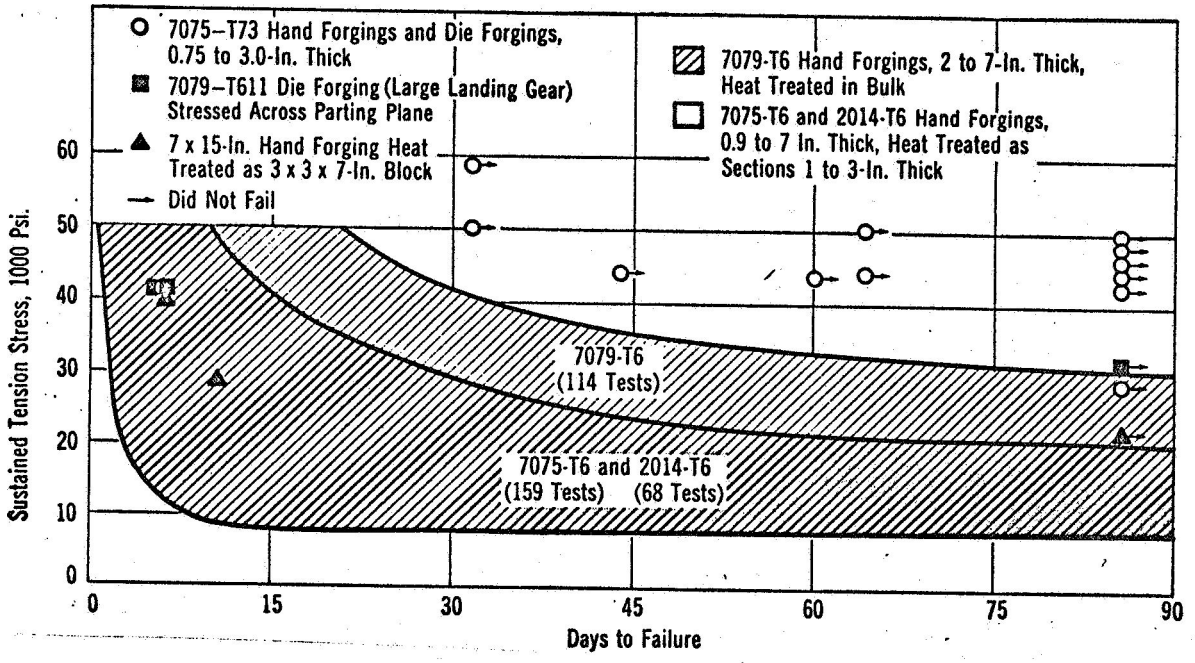


FIG. 10.33 COMPARATIVE STRESS CORROSION PERFORMANCE OF ALUMINUM ALLOY FORGINGS. ALTERNATE IMMERSION IN 3.5% NaCl SOLUTION (Ref. 10.12, p. 83)

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CHAPTER 11

SURFACE TREATMENTS

11.1 General. A wide variety of surface treatments can be applied to the 2014 alloy (and other aluminum alloys) to protect and improve the appearance of the surface. These include mechanical, chemical and electrochemical finishes and organic, porcelain and paint coatings. Alclad forms of aluminum alloys have a very high inherent resistance to corrosion and may be used without benefit of protective coatings, (Ref. 11.1).

11.2 Alclad Products. The 2014 alloy is available as Alclad sheet and plate which consists of bare 2084 core material clad with a thin coating of 6003 or 6053 alloy on both sides. The clad material is metallurgically bonded to the core material. It is chosen to provide a surface having a high resistance to corrosion and sufficiently anodic ts the 2014 core to afford electrochemical protection to it in corrosive environments. Consequently, any spot of attack can penetrate only as deep as the core alloy where further progress is stopped by cathodic protection. Corrosion is thus confined to the clad material only. The life of cladding is a function of its thickness and the severity of the environment. Alclad products, therefore, limit corrosion to a relatively thin clad surface layer, (Ref. 11.2).

11.3 Mechanical Finishes. Mechanical finishes are used to alter the texture of the alloy surface to provide a more decorative appearance or as a treatment prior to other finishing such as painting. Grinding, polishing and buffing result in smoother reflective surfaces. Abrasive blasting (sand or grit) gives a rough matte finish which is often used as a base for organic coatings. Scratch finishing, satin finishing, Butler finishing and skin finishes are scratched Bine finishes which remove minor surface defects and provide a decorative effect. The possibility of generating an explosive mixture of fine powder and air during mechanical finish operations should be recognized, (Ref. 11.3).

11.4 Anodizing. Anodic coatings are hard, abrasion and corrosion resistant oxide coatings. The alloys can be anodically coated in a number of electrolytes, but most commercial anodizing is done by either the sulfuric acid or chromic acid process. The thickness of the coating is dependent upon the anodizing time. Coatings produced by the sulfuric acid process vary in thickness from 0.0001 to 0.001 inch. Coatings produced in chromic acid vary from 0.00001 to 0.00009 inch. Anodic coatings provide good protection against corrosion and are excellent bases for paint coatings, (Ref. 11.1). However, the chromic acid process does not provide as corrosion resistant a coating as does the sulfuric acid process, (Ref. 11.9).

11.41 In recent years a number of new methods have been developed for producing heavier anodic coatings of from 0.001 to 0.010 inch. These methods require electrolytes which enable the oxide growth process to continue until the desired coating thickness is obtained.
Another recent development in coatings is that of hard anodizing, designated as "hardcoatings". Processes most suitable for a wide range of applications are Alumilite 226 (oxide coatings, 0.002 inch thick) and Martin Hardcoat (coating thicknesses up to 0.004 inch). A flash hardcoat of a very thin film can also be applied by these methods by shortening the normal time cycle. The operating conditions for the two baths employed for these processes are given in Table 11.1. The Martin process should be specified where maximum hardness and corrosion resistance are required along with thickness buildups to 0.004 inch. Alumilite 226 is selected where hardness and corrosion resistance are required and 0.002 inch is the acceptable maximum buildup. Further details of these processes are presented in Ref. 11.9.

11.5 Chemical Finishes. Chemical finishes are of three main types. Finishes used for decorative effects include caustic etching, acid etching and chemical polishing. Etched surfaces have a matte appearance while chemically polished surfaces are highly reflective and require protection by anodizing or lacquering.
Conversion coatings can be oxide, phosphate or chromate types and are used primarily as base coatings prior to application of organic coatings. Miscellaneous special-purpose finishes includes those produced by the Alrok process, Modified Bauer-Vogel process and processes for staining aluminum alloys.

11.6 Electropolishing. This process produces a highly reflective surface and is often used for surface preparation prior to microscopic examination of metallurgical structure, see Chapter 3.

11.7 Electroplating of aluminum alloys has gained increased commercial use in recent years. A commonly used finish consists of successive deposits of copper, nickel and chromium. Other metals may be applied over the copper. A satisfactory base surface for electroplating is provided by immersing the aluminum part in a solution of sodium zincate of controlled composition. Brass, iron, silver or chromium can be applied directly over this zinc immersion coating, (Ref. 11.4).

11.8 Painting. When severe conditions of exposure are to be encountered, it is frequently desirable to protect aluminum alloy surfaces with paint. Prior to painting, the surface should be properly prepared

before priming. Dirt may be removed by brushing and grease or oil may be removed by means of solvent or degreasing techniques. The parts are then immersed in (or swabbed with) a solution of phosphoric acid and organic grease solvents diluted with water. A number of proprietary solutions of this type are available commercially. Solution temperature should be between 50 and 90F and contact with the metal part should not be for less than 5 minutes. The part is then rinsed with water and dried thoroughly. Where chemical treatment is impractical, mild sandblasting methods may be employed. A chemical conversion coating per MIL-C-5541 or an anodize coating is necessary prior to priming with zinc chromate primer per MIL-P-8585.

For severe conditions of exposure, both primer and joint compound should be used at joints.

All surfaces except contacting surfaces may be given a second coat of paint consisting of two pounds of aluminum paste pigment (ASTM Spec: D 962, Type II, Glass B.) per gallon of varnish which meets Federal Spec. TT-V-86b, Type II or equivalent. The final assembled structure may be finished with one coat of aluminum paint. One or more coats of alkyd base enamel (pigmented to desired color) may be substituted for aluminum paint, (Ref. 11.5).

11.81 To minimize stress-corrosion cracking when the alloy is subjected to sustained surface stresses and corrosive environments, certain surface treatments and protective coatings are effective. The most effective protection is obtained by applying a topcoat of epoxy-polyamide paint to shot-peened or metallized surfaces of the alloy. Satisfactory temporary protection is obtained by an electroplated galvanic coating (3 to 4 mils thick), or a topcoat of paint containing epoxy-polyamide or polyurethane resins. The former is preferred and can be used on unprimed surfaces. Care is necessary to prevent breaking or scratching the paint film. Shot peening alone will provide good surface protection (if all surfaces are treated) when corrosive environment is not severe. Anodic films and zinc-rich paints are the least effective coatings for preventing stress-corrosion cracking, (Ref. 11.6).

11.9 Porcelain Enameling. The principal difference between porcelain enameling of aluminum alloys and other metals is the use of porcelain frits, which melt at lower temperatures. High lead frits are commonly used and they can be formulated in a wide variety of colors and surface finishes. The enamel slip is sprayed onto chemically cleaned and treated surfaces and then fired at temperatures of 950 to 1050F for a period of 4 to 8 minutes, (Ref. 11.7).

TABLE 11.1

Source	Ref. 11.9	
Alloy	Aluminum Wrought Alloys	
Data	Baths for Hard Anodized Coatings	
	Process	
	Martin (a)	Alumilite (b)
Composition	15% H_2SO_4	12% H_2SO_4 1% $H_2C_2O_4$
Electrolyte Temp, F	25 to 32	48 to 52
Current Density	25 asf	36 asf

(a) Developed by the Martin Co.
(b) Developed by the Aluminum Co. of America

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CHAPTER 12

JOINING TECHNIQUES

12.1 General. The 2014 aluminum alloy can be joined satisfactorily by fusion and resistance welding techniques and by riveting (or bolting). Brazing and soldering are not recommended, as satisfactory materials and methods have not been developed for this alloy. Specifications for the welding of aluminum alloys are presented in Table 12.1.

12.2 Welding. Reliable, sound, high quality welds have been made in aluminum alloys for many years. Although aluminum is one of the most readily weldable of all metals, it has individual characteristics which must be well understood for successful welding of the metal or its alloys. Four important factors that must be considered are the low melting point, the presence of an oxide film, low strength at elevated temperatures, and the fact that aluminum exhibits no characteristic color changes even at temperatures up to the melting point. The welding of aluminum alloys requires care to prevent excessive melting of the material. The oxide film must be removed and prevented from reforming by some inhibiting technique before a good bond can be obtained. Parts should be well supported during welding to prevent distortion, (Ref. 12.1).
The 2014 alloy is slightly more difficult to weld than the non-heat-treatable alloys. However, with proper precautions, refined techniques and close control of variables, the alloy is welded satisfactorily by fusion welding and electric-resistance welding techniques. Considerable progress has been made in recent years in overcoming difficulties with cracking, brittleness and loss of desirable mechanical properties in many of the heat treatable alloys. New equipment and better techniques are continually being developed which should lead to further progress in the welding of high strength aluminum alloys, (Ref. 12.1).

12.21 Fusion Welding. Although the 2014 alloy was developed by Alcoa in 1928, it was not considered to be weldable by fusion techniques until about a decade ago. The main problems in the welding of 2014 were inconsistent strength and ductility and the occurrence of a fine porosity. The search for stronger aluminum alloys, however, has enticed several aircraft companies and government agencies to investigate the fusion weldability of 2014 (and other aluminum-copper alloys), and to develop the refined technqiues and close control of variables required for successful welding of these alloys by fusion methods. Customarily the alloy, when fusion welded, is used as the "as-welded" condition and designers usually arrange to have the welded joint about twice the thickness of the parent metal to compensate for the lower strength in this condition, (Ref. 12.3).

12.211 Fusion Welding Methods. One of the most important advances in aluminum welding has been the development of inert-gas shielded methods that do not require a flux. The "tungsten-inert-gas" (TIG) method and the "metal-arc consumable electrode" (MIG) method have both contributed significantly to the advancement of the "state of the art" of aluminum welding. TIG and MIG techniques each have inherent advantages and disadvantages and these are discussed in greater detail in Ref. 12.2. A study was made in conjunction with the Saturn space vehicle program, (Ref. 12.6) to determine whether MIG or TIG welding processes are the most advantageous for joining 0. B00 inch thick 2014-T6 sheet. Comparison was made of the mechanical and corrosion properties of both MIG and TIG welds made in the laboratory and on production welding fixtures. The specimens were subjected to various service conditions and test temperatures. The effects of adhesive bonding cures, weld repairs, back-up bars, weld wire and stress corrosion were evaluated in this program. The results of these studies on 2014-T6 sheet indicated the following:

1) THG welds exhibited equal or slightly Mgher mechanical properties than MIG welds for most welding conditions and test temperatures studied, as shown in Tables 12.2, 12.3 and 12.4.

2) TIG welds made on a copper back-up bar generally had higher tensile properties and higher bend ductility than TIG welds made on a titanium back-up bar, Tables 12.2, 12.3 and 12.4.

3) TIG welds made on a copper back-up bas with a small groove (0.187 x 0.025 inch) had the highest tensile strength, but the loss in strength with larger grooves was generally less than 10 percent.

4) An adhesive cure cycle, performed after welding (see footnote, Table 12.5) lowered the bend ductility of both MIG and TIG welds by 50 to 75 percent. TIG welds, made on a copper back-up bar, had higher bend ductility (both before and after the cure cycles) than MIG welds made on a titanium back-up bar, Tables 12.5 and 12.6.

5) Ultimate and yield strengths of all welds were increased by the cure cycle and decreased by repair welding. Elongation was reduced by the cure cycle and unaffected by repair welding, Tables 12.3 and 12.4.

6) In the "as-welded" condition, the single pass welds made with 2319 wire generally exhibited slightly better tensile properties than welds made with 4043 filler wire. The 2319 wire welds; however, were adversely affected to a greater degree than 4043 wire welds by the "double cure" cycle.

7) MIG and TIG welded specimens both exhibited similar notch sensitivity in the presence of shallow surface cracks, Fig. 12.1,

Stress corrosion tests, consisting of alternate immersion in simulated ocean water, indicated that TIG welds made on a copper back-up bar had greater corrosion resistance than MIG welds made on a titanium back-up bar. Bend specimens were employed for these studies.

An investigation has been made of TIG welded 0.125 inch Alclad 2014 sheet material to examine the effects of preweld and post-weld treatments, welding speed and stress corrosion, (Ref. 12.3). Single-pass square butt-welds, with 0 to 0.010 inch gap, were made mechanically using Linde HQ shaved 4043 filler wire. The weld fixture had water-cooled copper hold-downs and a mild steel back-up bar. Welds were made parallel to the rolling direction of the sheet and specimens were taken from the sheet transverse to the weld bead. Cleaning before welding consisted of a caustic dip followed by nitric acid and a water rinse. Abutting edges were filed with a clean vixen file. Tensile specimens had a 0.5 x 2.5 inch gage section with weld beam transverse at the center. Bend specimens were 6 inches long, bent around a 5T radius mandrel. Welds were ground flush on both tensile and bend specimens.

It was found that no problems were encountered in making sound welds in Alclad 2014 alloy sheet under laboratory conditions.

The inferior weldability of 2014 alloy (as compared to the 6061 alloy) was attributed largely to its wide melting range of 230F (950 to 1180F), which results in delay solidification of the base metal at the edge of the weld zone. While in this partially-melted condition, the joint has low strength and ductility and is subject to cracking from shrinkage stresses. All joints failed in the weld metal in both tensile and bend tests. On fully heat treated joints, the weld metal hardened to 80 percent of the base metal strength of 70 ksi. Hardness surveys across the welded joints were useful in determining the relative strengths of welds and heat affected zones as shown in Fig. 12.2.

Increase in welding speed improved the strength of 2014-T4 alloy, welded then aged, by improvement in the response to aging in the heat affected zone (HAZ). However, it appeared that speeds above 15 ipm did not result in significantly greater improvement, Fig. 12.3.

The effect of post-weld treatment on tensile and bend properties is presented in Table 12.6. Base metal properties are also given in this Table for comparison.

Stress corrosion tests, in sodium chloride at 100F, indicated that the "as-welded" joints had superior stress corrosion resistance to the joints which were aged after welding.

The effect of test temperature on butt-welded 0.063 inch sheet, welded by the TIG method, is shown in Fig. 12.4. Values obtained for the base metal are also included in this graph. The strength of welds made with 2319 filler wire is compared to that of welds made with 4043 wire, and it can be seen that the 2319 wire gave slighlyhigher tensile values and weld joint efficiencies in this particular study. However, weld ductility was low for both filler wires (0.9 to 2.6 percent average elongation of 2319 wire welds and 0.6 to 1.8 percent average elongation for 4043 wire). Base on these results, 2319 filler wire would be preferred.

The effect of test temperature on TIG welded sheet specimens is shown in Figs. 12.5 and 12.6 for 2014-T3 and 2014-T6, respectively. F_{tu} and F_{ty} for the parent metal is also given in these graphs for comparison. Fatigue curves for TIG butt-welded sheet specimens are given in Fig. 12.7 for both room temperature and cryogenic (low) temperatures. An increase in strength is observed at low temperatures, but this increase is not as large as the static strength increase. This may signify some degree of embrittlement of the weld at -423F.

The problem of cracking in 2014 alloy fusion weld zones has been attributed to the composition of the base metal and the filler metal used. Cracking that occurs above the solidus temperature (hot cracking) was observed to be intergranular in nature. Cracking below the solidus temperature may be either transgranular or intergranular. Large heat affected zones and repeated rewelding (such as sometimes is done in repair welding) has frequently produced HAZ cracks. A precaution *to* prevent this type of cracking is to weld as rapidly as possible, using a minimum amount of heat. Rewelding should be avoided whenever possible, (Ref. 12.8).

The occurrence of porosity in 2014 alloy fusion welds is a problem that apparently is still not completely solved. Studies have indicated that gases (notably hydrogen) trapped in the weld zones are the principal, if not the sole cause of porosity in 2014 alloy weldments, (Ref. 12.5). Hydrogen is soluble in liquid aluminum, but is nearly insoluble in the solid state. Thus any hydrogen present at solidification is rejected in the form of porosity as the alloy solidifies. Hydrogen normally comes from water vapor. At temperatures above 920F, aluminum reacts with water to produce nascent hydrogen plus oxygen. The hydrogen dissolves in molten aluminum and the oxygen

combines to form aluminum oxide, (Ref. **12.7).** The solubility of hydrogen in aluminum is shown in Fig. **12.8.** Control **of** humidity and cleaning of filler wire to remove the oxide surface layer have helped to reduce porosity in **2014** alloy welds. However, hydrogen in the interior of the base metal or filler wire is more difficult to eliminate, (Ref, **12.9).** The combined effect of porosity and mismatch has also been investigated for TIG welded **2014-T6** sheet, (Ref. **12.15).** These studies have led to the conclusion that both porosity and mismatch are factors that contribute to the lowering of strength as each increases in magnitude, as shown in Fig. **12.9.** Mismatch is somewhat the greater of the two factors. **A** project was conducted to produce high quality weldments in **2014** plate, in thicknesses from **1/4** to 1 1/2 inches, using the most advanced type of welding equipment, (Ref. **12.16).** Both TIG and MIG welds were made in the flat, vertical and horizontal positions. It was concluded from this study that to assure quality welds in thick plate, the following items are essential:

1) Welding equipment must have self-contained contamination control, (e.g. cathodic cleaning of filler wire just ahead of torch).

2) Weld schedule parameters must be precisely controlled.

3) Gases, filler wires, and base material must be controlled by adequate quality control procedures.

Manual welding of chemically milled sheet requires a land area of approximately twice the sheet thickness to dissipate weld heat and prevent loss in base metal properties. Studies at the Martin Co., (Ref. **12.24)** were conducted on **T6** sheet to determine the land width necessary to retain the **HAZ,** and also to determine the tensile strength of repair welds for various land widths. It was found that based on hardness data, a **2** inch wide land, **0.100** inch thick, will fully retain the weld HAZ of repaired welds. It was also determined that base metal tensile properties are only slightly affected by weld heat when widths of **1.5** to **2.0** inch lands are used, as shown in Fig. **12.10.** Values of **59.1** ksi can be expected with **90** percent confidence for **1.5** inch lands, (based on **58** tests). If **95** and **99** percent confidence is required, expected values for repairs are **57.8** and **55.4** ksi, respectively. Studies at the Alcoa Research Laboratories, (Ref. **12.25)** have led to notable gains in the strength and ductility of MIG welds in **2014-T6** sheet by producing weld beads with pronounced papillary depressions. Direct current-reversed polarity (DCRP) was employed for these studies. Weld contour was controlled by proper balance of energy

input, heat extraction and shielding gas flow during welding. Narrow heat affected zones that followed bead contour were obtained by positioning hold-down plates close to the sheet edges being welded. A 5 to 20 percent argon (balance helium) shielding gas mixture flowing at 75 cfh produced shallower root bead angles that increased tensile strengths 2 to 4 ksi. Welds up to 10 ksi stronger than those normally obtained prior to the study were achieved. Fig. 12.11 shows the tensile and bulge test properties of the MIG welded sheet for various argon-helium gas mixtures. The effect of weld travel speed on these properties is presented in Fig. 12.12.

12.212 Gas Metal-Arc Spot Welding (or inert-gas spot welding) is used to make high strength localized welds with light equipment and from one side only. It is a quick and reliable method to join sheet, extrusions and tubing. The localized spot welding is accomplished by using very high automatically controlled welding current for a short period of time with the addition of small quantities of filler metal, (Ref. 12.26). Filler metal alloys commonly used in the gas metal arc spot welding of the 2014 alloy are 2319 and 4043 alloys. Gas tungsten-arc spot welding is similar to gas metal-arc spotwelding in that satisfactory spot welds can be made from one side of the joint. The use of the gas tungsten-arc spot weld process has become widespread, in recent years, for the assembly of products made from sheet metals, (Ref. 12.27).

12.22 Electrical Resistance Welding. Resistance welding (spot welding and seam welding) is a most useful, practical and economic method of joining aluminum alloys. The welding process is almost entirely automatic and standard welding machines are capable of handling a wide variety of operations. Resistance welding heats only a small area of metal. Thus there is only a minimum of metallurgical disturbance for a minimum length of time which is important in the welding of aluminum alloys.

Mechanical or chemical cleaning of the contact surfaces is necessary to obtain good spot welds in aluminum as no fluxes are used during spot welding. In aircraft construction, it is recommended that the contact resistance of the elements to be joined be continually checked as a measure of surface cleanliness. Surface contact resistance should not exceed 50 microhms for best results. Details on surface cleaning are given in Ref. 12.2, p. 48.

The 2014 alloy, in heat treated tempers, is successfully spotwelded but special practices are required, and the range of machine settings is rather narrow for this alloy. In the annealed temper the alloy is difficult to weld and spot welding in this condition is not recommended. Spot-welded Clad 2014 has good resistance to corrosion in all tempers, but the resistance of bare 2014-T4 is poor and 2014-T6 is only fair, (Ref. 12.2). Clad 2014 may be joined by spot welding to 1100, 3003, 5052,

6061, Clad 2014, Clad 2024 and Clad 7075. Bare 2014 may be joined to all of the above alloys except Clad 2014. According to federal specifications QQ-A-261 and QQ-A-266, bare material may be spotwelded to clad material only with the specific approval of the procuring or certificating agency, (Ref. 12.12).

The choice of the type of resistance welding machine for spot or seam welding of aluminum alloys depends partly on the power supply, it voltage drop characteristics, demand limitations and other similar factors. A more detailed discussion of resistance-welding equipment is given in Ref. 12.2, p. 44.

12.221 Mechanical Properties of Spot Welds. The use of spot welds on military structural parts is governed by the requirements of the procuring or certificating agency, (Ref. 12.12). The requirements for equipment, materials and production control of spot and seam welds in aluminum alloys is covered by military specification MIL-W-6858B-1, see Table 12.1. The minimum distance suggested by Alcoa for joint overlap and spot-weld spacing is given in Table 12.7 for a number of sheet thicknesses. Minimum allowable edge distance for spot weld joints is presented in Table 12.8. Table 12.9 gives design shear strength allowables for spot welds in bare and clad aluminum alloys; the thickness ratio of the thickest sheet to the thinnest outer sheet in the combination should not exceed 4:1. In applications of spot welding where ribs, intercostals or doublers are attached to sheet, either at splices or at other points on the sheet panels, the allowable ultimate strength of the spot welded sheet should be determined by multiplying the ultimate tensile sheet strength (MIL-HDBK-5 "A" values where available) by the appropriate efficiency factor as given in Fig. 12.13. The minimum values of the basic sheet efficiency in tension should not be applied to seam welds. Allowable ultimate tensile strengths for spot welded sheet less than 0.020 inch should be established on the basis of tests acceptable to the procuring or certificating agency, (Ref. 12.12).

The effect of cryogenic temperatures on the cross-tension and tensile-shear strength of single spot welds in 2014-T6 sheet is shown in Fig. 12.14.

12.3 Brazing. Brazing of the 2014 alloy is not recommended. The melting point of 2014 is lower than that of the commercially available brazing alloys, (Ref. 12.19).

12.4 Riveting. Riveting is a commonly used method for joining aluminum, particularly the heat treatable alloys. It is reliable because riveting is a method that is well understood and highly developed. Also, modern riveting methods are largely independent of the operator's skill and thus uniformity of riveted joints can be readily attained, (Ref. 12.1).

Specifications for aluminum riveting are presented in Table **12.10.**

12.41 Aluminum alloy rivets are preferred for the fabrication of aluminum alloy structures, although cold-driven annealed steel rivets have been used successfully for some applications. To determine the strength of riveted joints, it is necessary to know the strength of the individual rivet. In most cases, failure of such joints occurs by shearing, by bearing or tearing of the sheet or plate. Table **12.11** gives the average shear strengths of driven rivets of various aluminum alloys. These values may be considered representative of properly driven rivets although occasional driven rivets may fall below the average **by** about **5** to **10** percent. It is customary to use a slightly larger factor of safety for the shear strength of rivets than is employed for other parts of an assembly. The design of joints where rivets are subjected to tensile loads should be avoided. Bolted connections may be used where high tensile stresses preclude the use of riveting. Information in greater detail on the riveting of aluminum alloys is given in Refs. **12.20** and **12.21.** Design data on mechanical joints using rivets or bolts may be found in MIL HDBK-5, (Ref. **12.12).**

TABLE 12.1

Source	Refs. 12.14, 12.22, 12.23			
Item	Welding specifications			
Product or process	Federal	Military	ASTM	AMS
Weldments (aluminum and aluminum alloys)	-	MIL-W-22248	-	-
Welding of aluminum alloys	-	MIL-W-8604	-	-
Welding (aluminum alloy armor)	-	MIL-W-45206	-	-
TIG welding, aluminum alloy for structures	-	MIL-W-45205	-	-
Welding; resistance, aluminum alloys	-	MIL-W-45210A	-	-
Welding; spot, seam or stitch (Al, steel, Mg and Ti)	-	MIL-W-6858B	-	-
Welding rods (aluminum)	QQ-R-566-2	-	B285-61T	4190A 4191A
Welding electrodes (flux coated)	-	MIL-E-15597C	B184-43T	-
Welding electrode wire	-	MIL-E-16053J	B285-61T	-
Flash welds (rings, flanges)	-	-	-	7488A

TABLE 12.2

Source	Ref. 12.6							
Alloy	2014-T6, 0.100 inch sheet, "as-welded"							
Property	Tensile data on single pass, square butt-welded specimens							
Weld Method	L or T	Back-up bar used	Weld wire	Test Temp (F)	F_{tu} ksi (aver)	F_{ty} ksi (aver)	e-% (1 in) (aver)	No. of specs. tested
MIG	T	Ti	4043	RT	45.0	32.5	4.0	2
TIG	T	Ti	4043	RT	48.0	30.8	4.8	3
TIG	T	cu	4043	RT	50.3	35.0	3.8	3
TIG	T	cu	2319	RT	52.5	37.6	3.2	5
MIG	T	Ti	4043	-423	55.5	46.1	1.7	3
TIG	T	Ti	4043	-423	64.0	46.8	1.7	3
TIG	T	cu	4043	-423	71.0	53.3	2.0	3
TIG	T	cu	2319	-423	69.4	55.3	2.0	3
MIG	L	Ti	4043	RT	60.0	40.0	9.4	4
TIG	L	Ti	4043	RT	63.5	44.7	10.3	3
TIG	L	cu	4043	RT	66.8	54.6	12.9	3
TIG	L	cu	2319	RT	66.9	56.8	12.0	3
MIG	L	Ti	4043	-321	72.0	50.6	7.0	3
TIG	L	Ti	4043	-321	76.6	60.3	6.1	3
TIG	L	cu	4043	-321	79.7	65.7	7.3	3
TIG	L	cu	2319	-321	78.7	62.1	7.3	3
MIG	L	Ti	4043	-423	79.2	61.2	5.0	3
TIG	L	Ti	4043	-423	80.1	66.1	5.4	4
TIG	L	cu	4043	-423	86.0	73.3	5.1	4
TIG	L	cu	2319	-423	88.5	72.2	6.0	3
MIG		Ti	4043	RT	40.9	23.4	8.6	5
TIG	AWM	Ti	4043	RT	42.8	23.3	10.0	3
TIG	AWM	cu	4043	RT	44.2	23.5	11.3	3
TIG	AWM	cu	2319	RT	43.7	26.4	7.0	3
MIG	AWM	Ti	4043	-423	49.4	34.9	1.5	4
TIG	AWM	Ti	4043	-423	58.1	40.5	2.5	3
TIG	AWM	cu	4043	-423	56.3	37.0	3.0	3
TIG	AWM	cu	2319	-423	61.1	45.9	2.7	3

(a) **All** weld metal (for specimen, see Table 12.3)

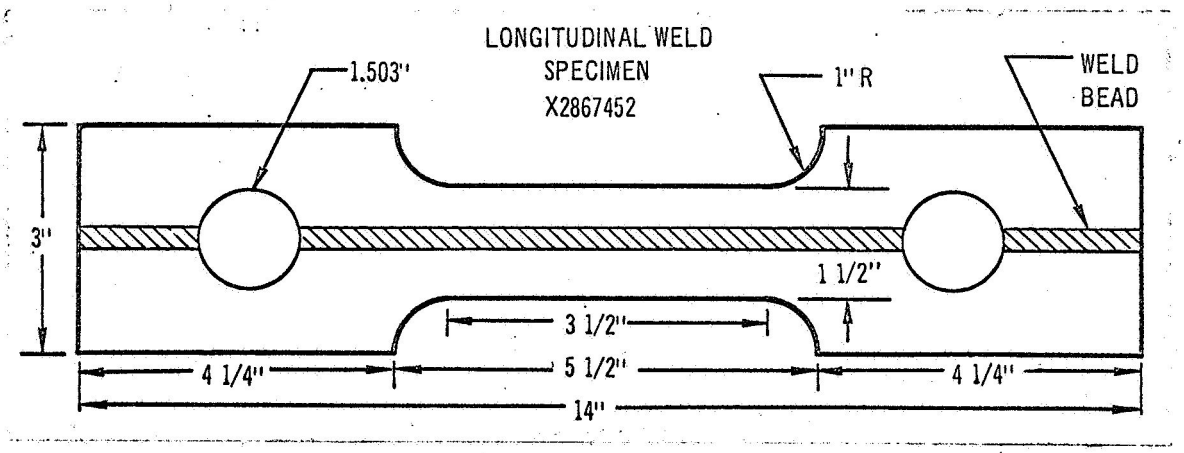
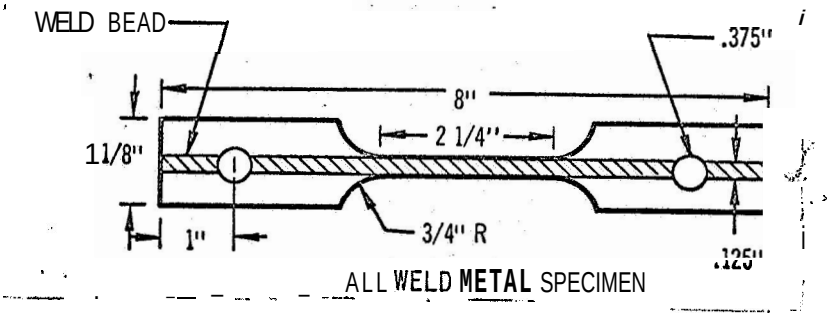


TABLE 12.3

Source	Ref. 12.6							
Alloy	2014-T6, 0.100 inch sheet, welded - 2 "cures"							
Property	Tensile data on single pass square butt-welded specimens							
Weld Method	L or T	Back-up bar used	Weld wire	Test Temp (F)	Ftu ksi (aver)	Fty ksi (aver)	e-% (1 in) (aver)	No. of specs tested
MIG	T	Ti	4043	RT	51.3	44.3	1.7	3
TIG	T	Ti	4043	RT	52.3	44.9	3.0	3
TIG	T	cu	4043	RT	58.2	49.8	2.4	5
TIG	T	cu	2319	RT	51.4	45.1	2.0	3
MIG	T	Ti	4043	-423	61.5	53.3	1.3	3
TIG	T	Ti	4043	-423	64.8	56.0	1.7	3
TIG	T	Cu	4043	-423	73.3	63.4	1.7	5
TIG	T	cu	2319	-423	68.5	58.3	1.4	5
MIG	L	Ti	4043	RT	63.1	53.3	3.5	3
TIG	L	Ti	4043	RT	66.0	60.0	4.3	3
TIG	L	cu	4043	RT	70.3	56.9	9.3	3
TIG	L	cu	2319	RT	68.5	58.1	6.8	4
MIG	L	Ti	4043	-321	71.8	65.3	2.0	3
TIG	L	Ti	4043	-321	77.1	70.1	2.7	3
TIG	L	cu	4043	-321	81.5	73.7	3.5	4
TIG	L	cu	2319	-321	83.7	73.0	5.3	3
MIG	L	Ti	4043	-423	79.6	72.3	1.3	3
TIG	L	Ti	4043	-423	82.8	77.4	1.5	2
TIG	L	cu	4043	-423	89.9	83.1	2.7	3
TIG	L	cu	2319	-423	85.3	79.3	2.9	4
MIG	AWM(a)	Ti	4043	RT	44.9	31.6	1.1	4
TIG	AWM	Ti	4043	RT	45.6	39.0	2.3	3
TIG	AWM	Cu	4043	RT	47.8	35.8	3.5	5
TIG	AWM	cu	2319	RT	46.3	32.0	5.5	2
MIG	AWM	Ti	4043	-423	55.8	46.5	1.1	5
TIG	AWM	Ti	4043	-423	65.8	53.6	2.0	3
TIG	AWM	cu	4043	-423	61.4	50.3	1.3	5
TIG	AWM	cu	2319	-423	61.0	53.0	1.3	3

(a) **All** weld metal



ALL WELD METAL SPECIMEN

TABLE 12.4

Source	Ref. 12.6							
Alloy	2014-T6, 0.100 inch sheet, double repair weld + 2 "cures"							
Property	Tensile data on square butt-welded specimens							
Weld Method	L or T	Back-up bar used	Weld wire	Test Temp (F)	F_{tu}, ksi (aver)	F_{ty}, ksi (aver)	e-% (1 in) (aver)	No. of specs tested
MIG	T	Ti	4043	RT	41.5	39.2	1.3	3
TIG	T	Ti	4043	RT	49.2	38.4	2.8	4
TIG	T	Cu	4043	RT	51.8	41.8	2.6	5
TIG	T	cu	2319	RT	55.2	45.5	3.4	5
MIG	T	Ti	4043	-423	43.8	-	0.13	3
TIG	T	Ti	4043	-423	61.1	47.6	1.7	3
TIG	T	Cu	4043	-423	72.1	51.9	1.8	5
TIG	T	cu	2319	-423	68.2	56.4	1.8	5
MIG	L	Ti	4043	RT	58.9	53.8	2.7	3
TIG	L	Ti	4043	RT	62.8	55.0	3.7	3
TIG	L	cu	4043	RT	67.7	60.4	5.7	4
TIG	L	cu	2319	RT	68.9	60.9	7.7	3
MIG	L	Ti	4043	-321	69.4	61.7	2.0	3
TIG	L	Ti	4043	-321	72.0	63.1	1.7	3
TIG	L	cu	4043	-321	79.8	67.6	3.7	3
TIG	L	cu	2319	-321	80.8	70.1	3.3	3
MIG	L	Ti	4043	-423	73.4	71.8	1.3	3
TIG	L	Ti	4043	-423	77.4	69.1	1.2	3
TIG	L	cu	4043	-423	81.1	69.8	1.7	4
TIG	L	cu	2319	-423	84.9	76.3	2.7	3
MIG	AWM(a)	Ti	4043	RT	41.1	29.7	3.0	4
TIG	AWM	Ti	4043	RT	45.0	32.3	4.1	5
TIG	AWM	cu	4043	RT	45.5	30.5	5.6	5
TIG	AWM	cu	2319	RT	46.1	35.6	2.0	3
MIG	AWM	Ti	4043	-423	46.7	38.2	1.0	4
TIG	AWM	Ti	4043	-423	60.4	44.8	2.0	5
TIG	AWM	cu	4043	-423	56.5	40.5	1.8	4
TIG	AWM	cu	2319	-423	56.3	46.1	1.2	3

(a) All weld **metal**

TABLE 12.5

Source	Ref. 12.6					
Alloy	2014-T6, 0.100 inch sheet					
Property	Bend test data on single pass, square butt-welded specimens					
Weld Method	Condition of weld	Back-up bar used	Weld wire	Test temp (F)	Bend deflection, inches(a) Top in Tension	Bend deflection, inches(a) Bottom in Tension
MIG	As welded	Ti	4043	-321	0.28	0.28
TIG	As welded	Ti	4043	-321	0.18	0.19
TIG	As welded	Cu	4043	-321	0.56	0.39
TIG	As welded	Cu	2319	-321	0.56	0.62
MIG	Weld + 2 cures(b)	Ti	4043	-321	0.07	0.07
TIG	Weld + 2 cures(b)	Ti	4043	-321	0.09	0.09
TIG	Weld + 2 cures(b)	Cu	4043	-321	0.15	0.14
TIG	Weld + 2 cures(b)	Cu	2319	-321	0.17	0.16
MIG	Double repair welds(c)	Ti	4043	-321	0.07	0.10
TIG	Double repair welds(c)	Ti	4043	-321	0.08	0.08
TIG	Double repair welds(c)	Cu	4043	-321	0.13	0.14
TIG	Double repair welds(c)	Cu	2319	-321	0.14	0.15

(a) Each point average of 7 to 10 tests.

(b) Simulated postweld adhesive "cure": Heat rapidly to 230F, heat 5F/hr from 230F to 330F, hold at 330F for 2.5 hours, cool at 4.5F/hr from 330F to 180F.

(c) Double repair welds:

1) Weld panels cleaned and welded
2) Penetration and reinforcement weld beads shaved to within 0.010 inch of parent metal surface
3) Panel rewelded entire length, using original weld parameters
4) Repeat item 2
5) Repeat item 3
6) Double "cure" as per (b)
7) Inspect

TABLE 12.6 (a)

Source	Ref. 12.3					
Alloy	Alclad 2014, 0.125 inch sheet					
Property	Tensile and Bend Properties of TIG Welded Sheet					
Condition before Welding	Treatment after Welding	Weld Speed (ipm)	F_{tu} (ksi)	F_{ty} (ksi)	e - % (in 2 in)	Bend angle (deg)
T6	As welded	20	41.0	29.1	2.3	40, 55
T6	Aged	20	45.6	40.5	2	25, 20
T6	Heat treat and age	20	62.0	56.7	2	24, 25
T4	As welded	20	36.7	23.0	3	57, 59
T4	Aged	20	48.4	44.1	1	23, 27
T4	Aged	5	42.6	39.3	1	20, 20
T4	Aged	10	44.3	41.6	1	27, 32
T4	Aged	15	49.7	42.2	2	32, 32
T4	Aged	25	48.7	43.4	1	32, 31
T6	As welded	Manual	35.8	23.6	2	35, 32
T6	Aged	Manual	44.9	36.4	2	23, 26
T6	Heat treat and age	Manual	52.9	52.3	1	24, 25

TABLE 12.6 (b)

Source	Ref. 12.3			
Alloy	Alclad 2014, 0.125 inch sheet			
Property	Tensile Properties of Base Metal			
Condition	L or T	F_{tu} (ksi)	F_{ty} (ksi)	e-% (in 2 in)
T6, as received	T	68.9	61.7	10
	L	69.2	64.1	10
T6, Sol treat to T4	T	62.4	36.0	22
	L	62.8	37.3	24
T6, Sol treat to T4, age to T6	T	71.6	63.7	11
	L	72.3	64.3	11

TABLE 12.7

Source	Ref. 12.2	
Alloy	Aluminum Alloys	
Data	Suggested minimum joint overlap and spacing of spot welds	
Thinnest sheet in joint, inch	Minimum joint overlap, inch	Minimum weld spacing, in
0.016	5/16	3/8
0.020	3/8	3/8
0.025	3/8	3/8
0.032	1/2	1/2
0.040	9/16	1/2
0,051	5/8	5/8
0.064	3/4	5/8
0,072	13/16	3/4
0.081	7/8	3/4
0.091	15/16	7/8
0.102	1	1
0.125	1 1/8	1 1/4

TABLE 12.8

Source	Ref. 12.12
Alloy	Aluminum Alloys
Property	Minimum allowable edge distances for spot-welded joints (a)(b)(c)
Nominal thickness of the thinner sheet, in	Edge distance, E, in
0.016	3/16
0.020	3/16
0.025	7/32
0.032	1/4
0.036	1/4
0.040	9/32
0.045	5/16
0.050	5/16
0.063	3/8
0.071	3/8
0.080	13/32
0.090	7/16
0.100	7/16
0.125	9/16
0.160	5/8

(a) Intermediate gages will conform to the requirement for the next thinner gage shown.

(b) Edge distances less than those specified above may be used provided there is no expulsion of weld metal or bulging of the edge of the sheet or damage to bend radii by electrode.

(c) Values may be reduced for non-structural applications or applications not depended on to develop full weld strength.

TABLE 12.9

Source	Ref. 12.12			
Alloy	Aluminum Alloys, (bare and clad)			
Property	Spot weld maximum shear strength standards (a)			
Nominal thickness of thinner sheet, inch	Material ultimate tensile strength, lb.			
	Above 56 (ksi)	28 to 56 (ksi),	20 to 27.5 (ksi)	19.5 ksi and below
0.012	60	52	24	16
0.016	86	78	56	40
0.020	112	106	80	62
0.025	148	140	116	88
0.032	208	188	168	132
0.040	276	248	240	180
0.050	374	344	321	234
0.063	539	489	442	314
0.071	662	578	515	358
0.080	824	680	609	417
0.090	1002	798	695	478
0.100	1192	933	750	536
0.112	1426	1064	796	584
0.125	1698	1300	840	629
0.160	2490	-	-	-
0.190	3230	-	-	-

(a) The reduction in strength of spotwelds due to cumulative effects of the-temperature-stress factors is not greater than the reduction in strength of the parent metal.

TABLE 12.10

Source	Ref. 12.14		
Item	Specifications for Rivets (Aluminum)		
Products	Specifications		
	Federal	Military	AMS
Rivets	FF-R-556a	MIL-R-1150A-1	7220C
	-	MIL-R-5674B-1	7222C
	-	MIL-R-12221B	7223
Rivets, blind	-	MIL-R-7885A-1	-
	-	MIL-R-8814-1	-
	-	MIL-R-27384	-
Rivet, wire	QQ-A-430-1	-	-

TABLE 12.11

Source	Ref. 12.20		
Data	F_{su} (Average) for Driven Rivets (c)		
Alloy and Temper before Driving (a)	Driving Procedure	Alloy and Temper after Driving	F_{su} (Aver) (ksi)
1100-H14	Cold, as received	1100-F	11
2017-T4	Cold, as received	2017-T3	39
2017-T4	Cold, immediately after quenching	2017-T31	34(b)
2024-T4	Cold, immediately after quenching	2024-T31	42(b)
2117-T4	Cold, as received	2117-T3	33
5056-H32	Cold, as received	5056-H321	30
6053-T61	Cold, as received	6053-T61	23
6061-T4	Cold, immediately after quenching	6061-T31	24(b)
6061-T4	Hot, 990 to 1050F	6061-T43	24(b)
6061-T6	Cold, as received	6061-T6	30
7277-T4	Hot, 850 to 975F	7277-T41	38

(a) These designations should be used when ordering rivets.

(b) Immediately after driving, the shear strengths of these rivets are about 75% of the values shown. On standing at ambient temperatures, they age harden to develop full shear strength. This action takes about 4 days for 2017-T31 and 2024-T31 rivets. Values shown for 6061-T31 and 6061-T43 rivets are attained in about 2 weeks. Values of 26 ksi are attained by 6061-T31 rivets about 4 months after driving. Values shown for 7277-T41 rivets are attained in about one week.

(c) These values are for rivets driven with core point heads. Rivets driven with heads requiring more pressure may be expected to develop slightly higher strengths.

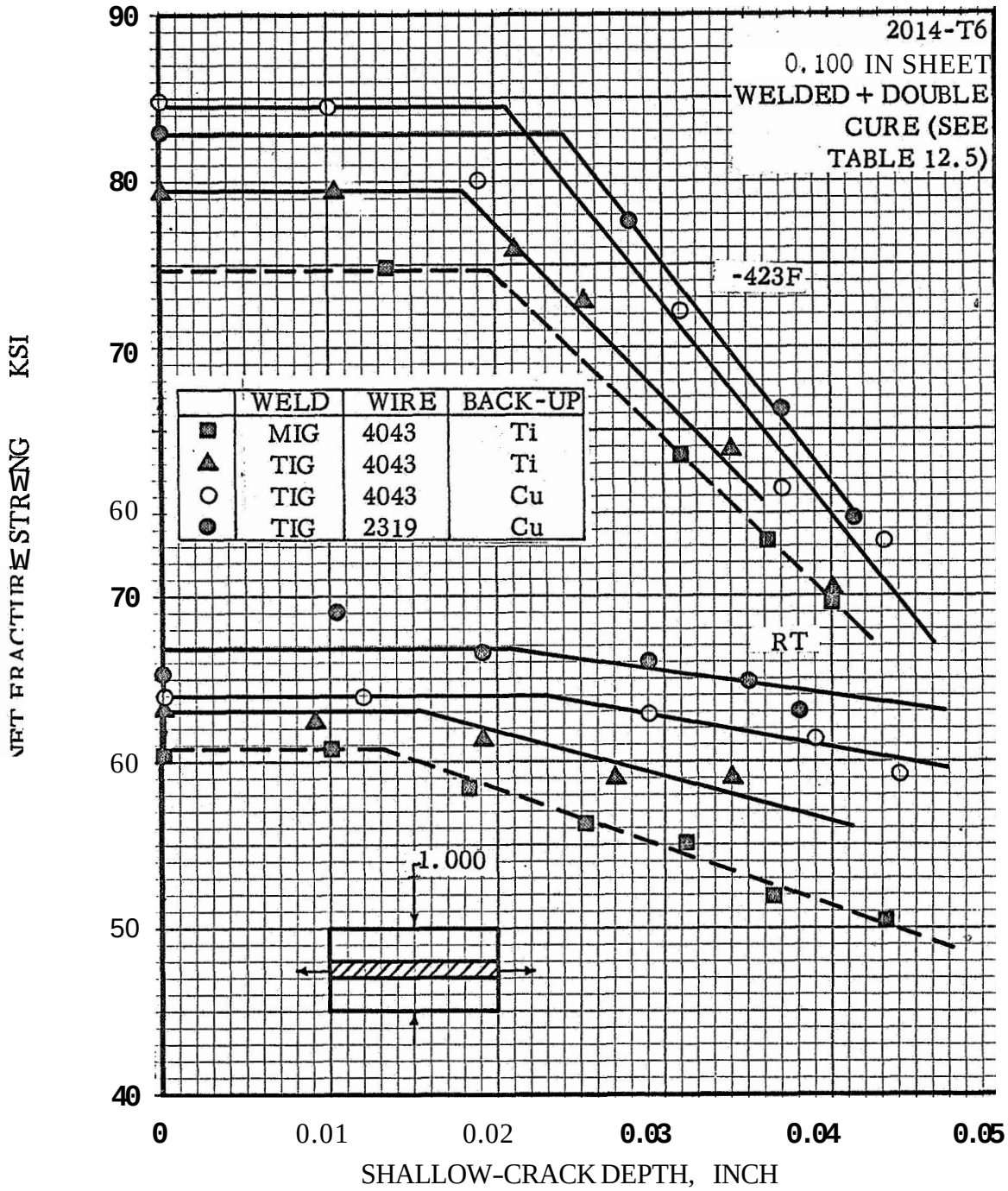


FIG. 12.1 EFFECT OF SHALLOW-CRACK DEPTH ON THE FRACTURE STRENGTH OF MIG AND TIG WELDED SPECIMENS

(Ref. 12.6)

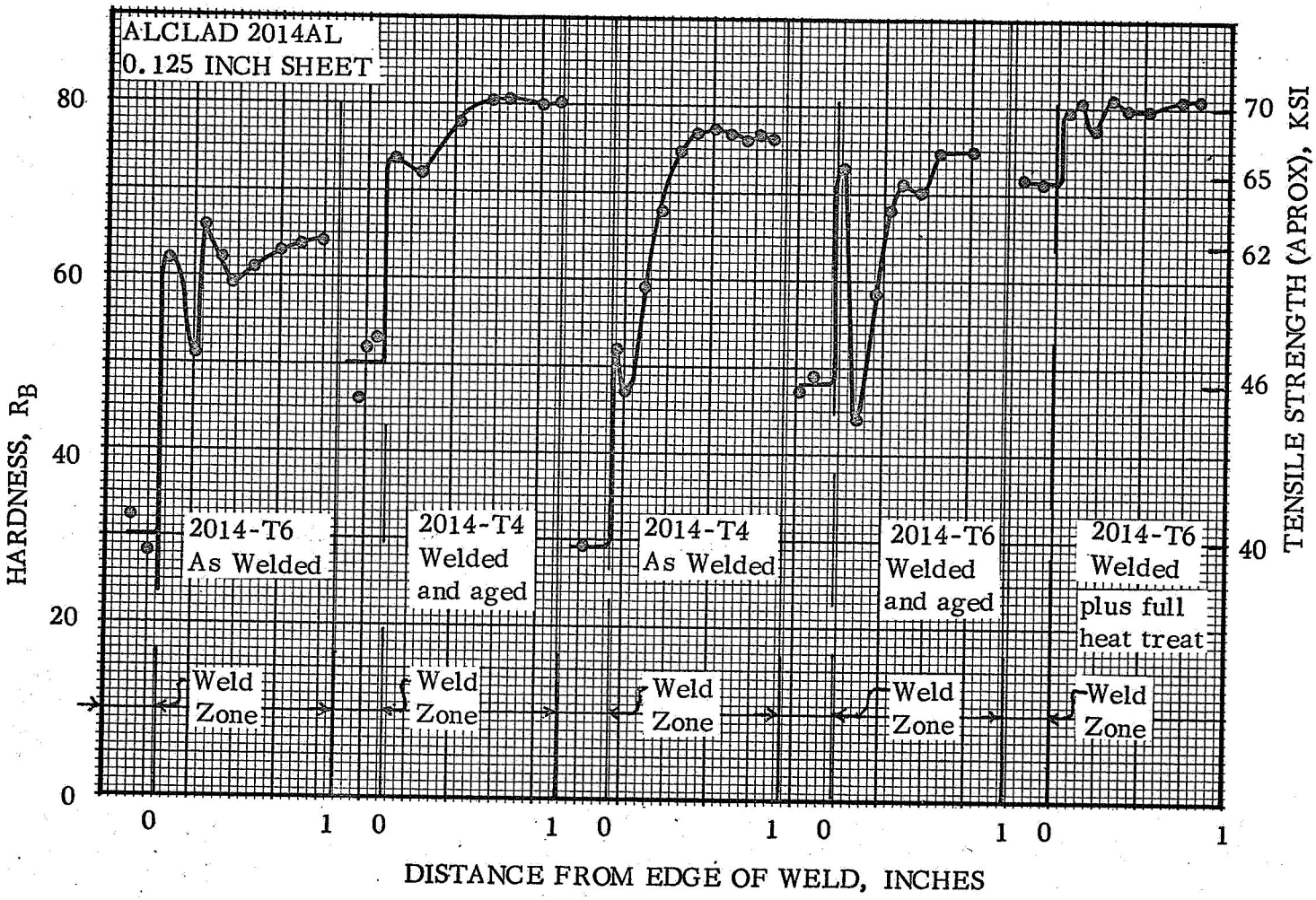


FIG. 12.2 HARDNESS SURVEY ON 2014-T4 AND 2014-T6 WELDMENTS, WELDED AT 20 IPM AND TREATED AS SHOWN (TIG WELDED, SINGLE PASS, 4043 WIRE) (Ref. 12.3)

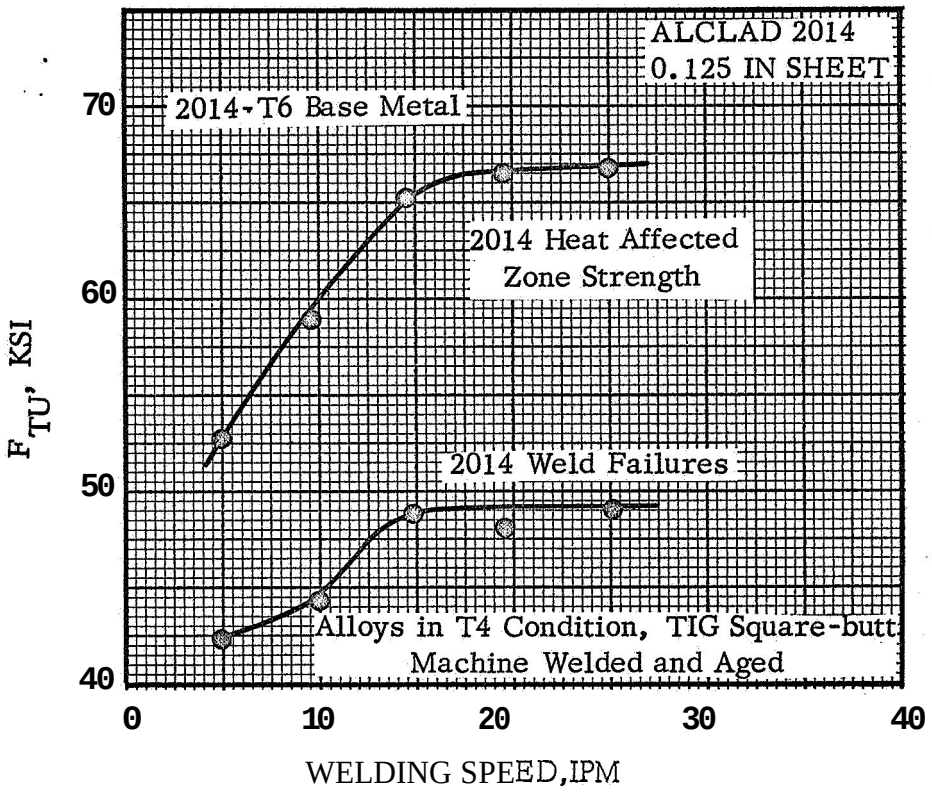


FIG. 12.3 EFFECT OF WELDING SPEED ON ULTIMATE TENSILE STRENGTH OF TIG WELDS

(Ref. 12.3)"

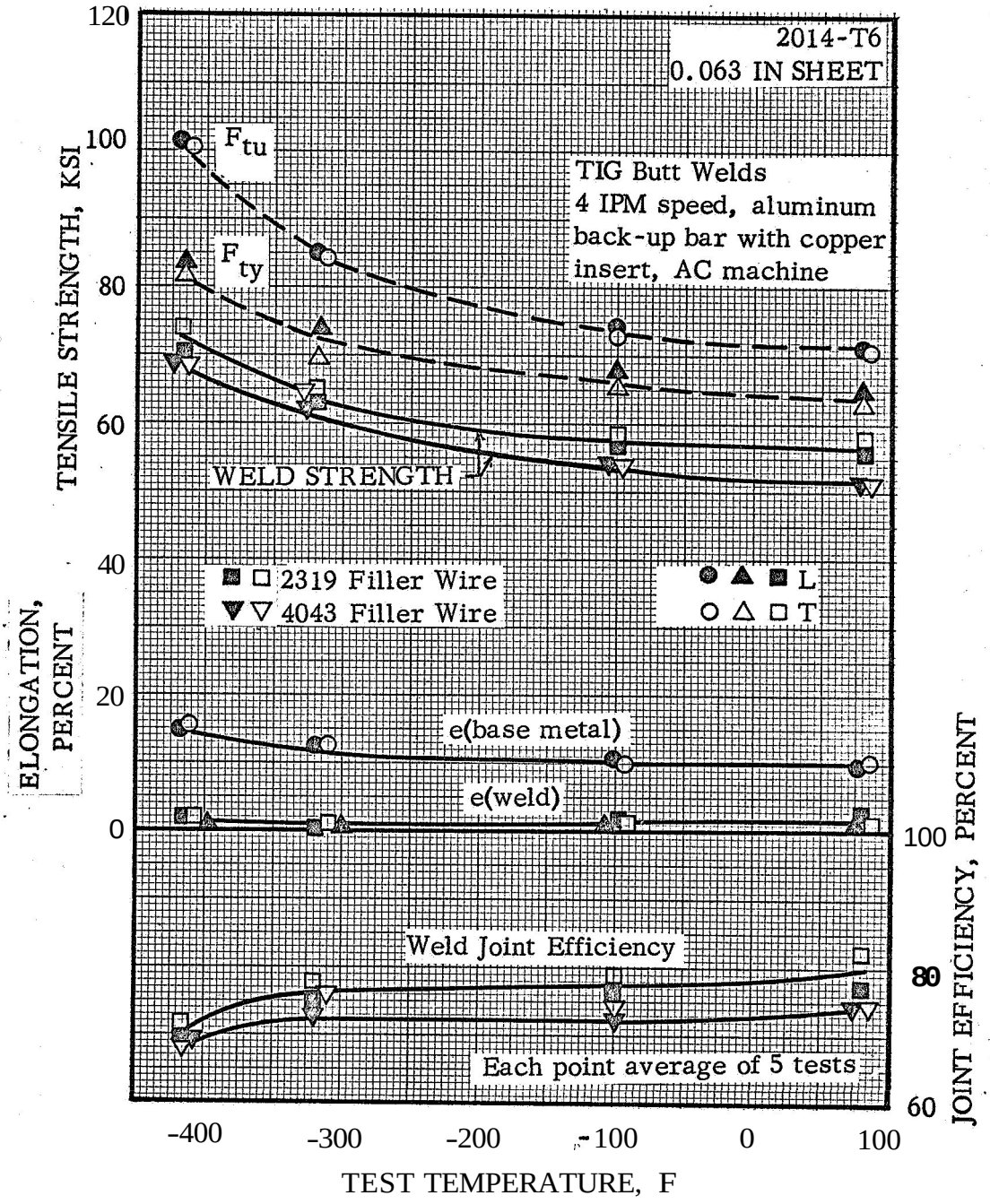


FIG. 12.4 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF BASE METAL **AND** BUTT-WELDED 2014-T6 SHEET

(Refs. 12.10 **and** 12.11)

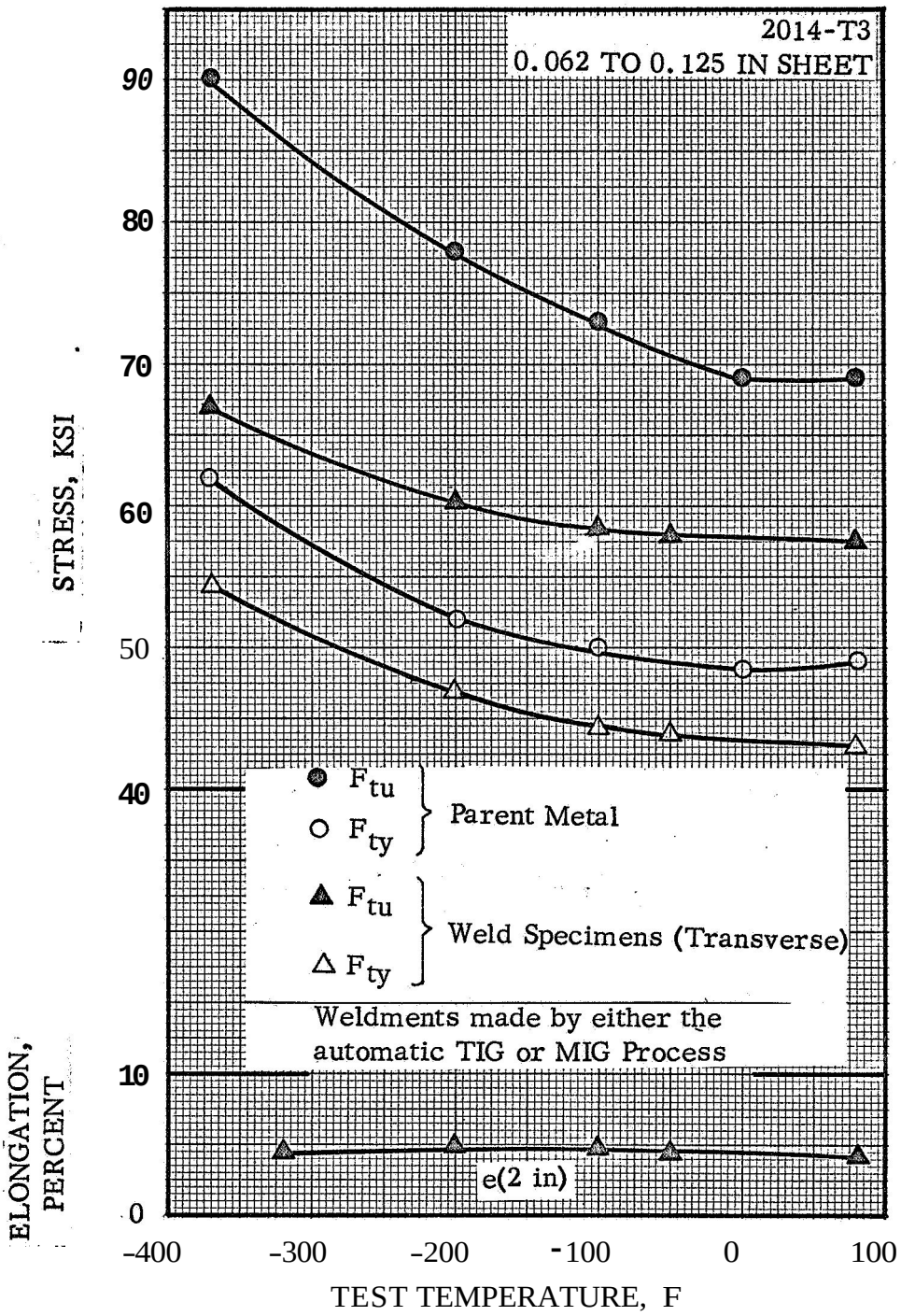


FIG. 12.5' EFFECT OF CRYOGENIC TEMPERATURES ON TENSILE PROPERTIES OF WELDMENTS AND PARENT METAL SHEET IN T3 CONDITION (Ref. 12.13)

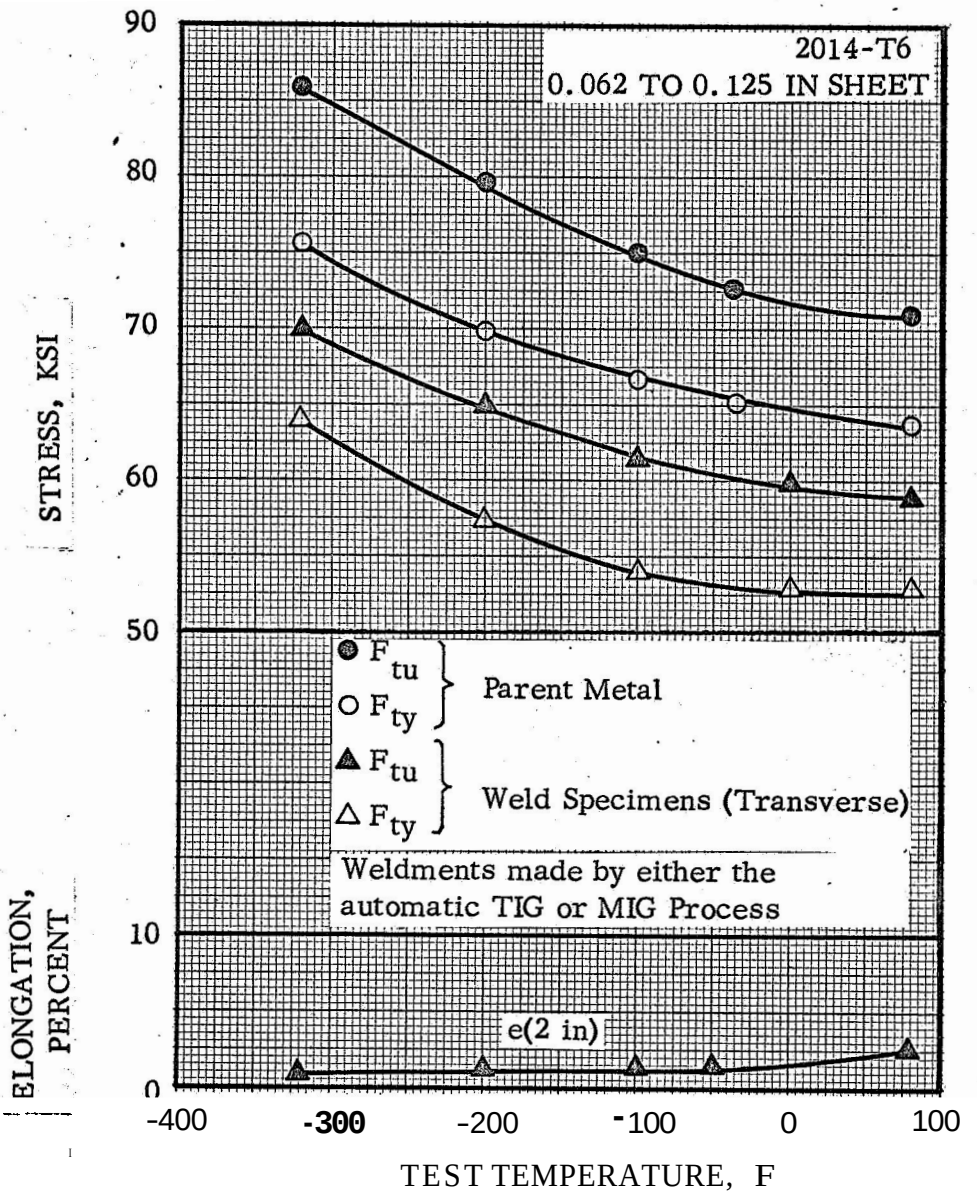


FIG. 12.6 EFFECT OF CRYOGENIC TEMPERATURES ON TENSILE PROPERTIES OF WELDMENTS AND PARENT METAL SHEET IN T6 CONDITION (Ref. 12.13)

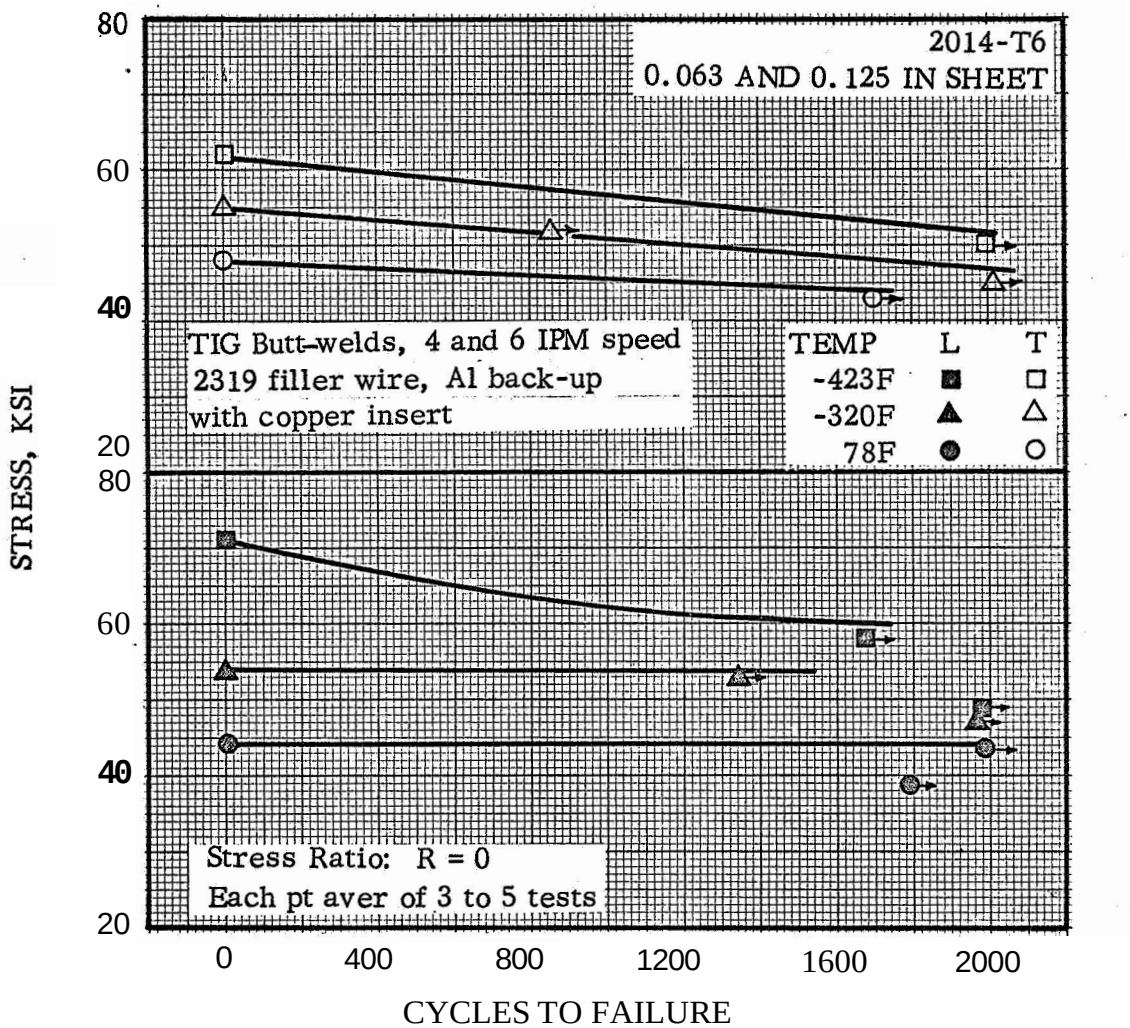


FIG. 12.7 S-N FATIGUE CURVES FOR TIG BUTT-WELDED SHEET AT ROOM AND CRYOGENIC TEMPERATURES (Ref. 12.10)

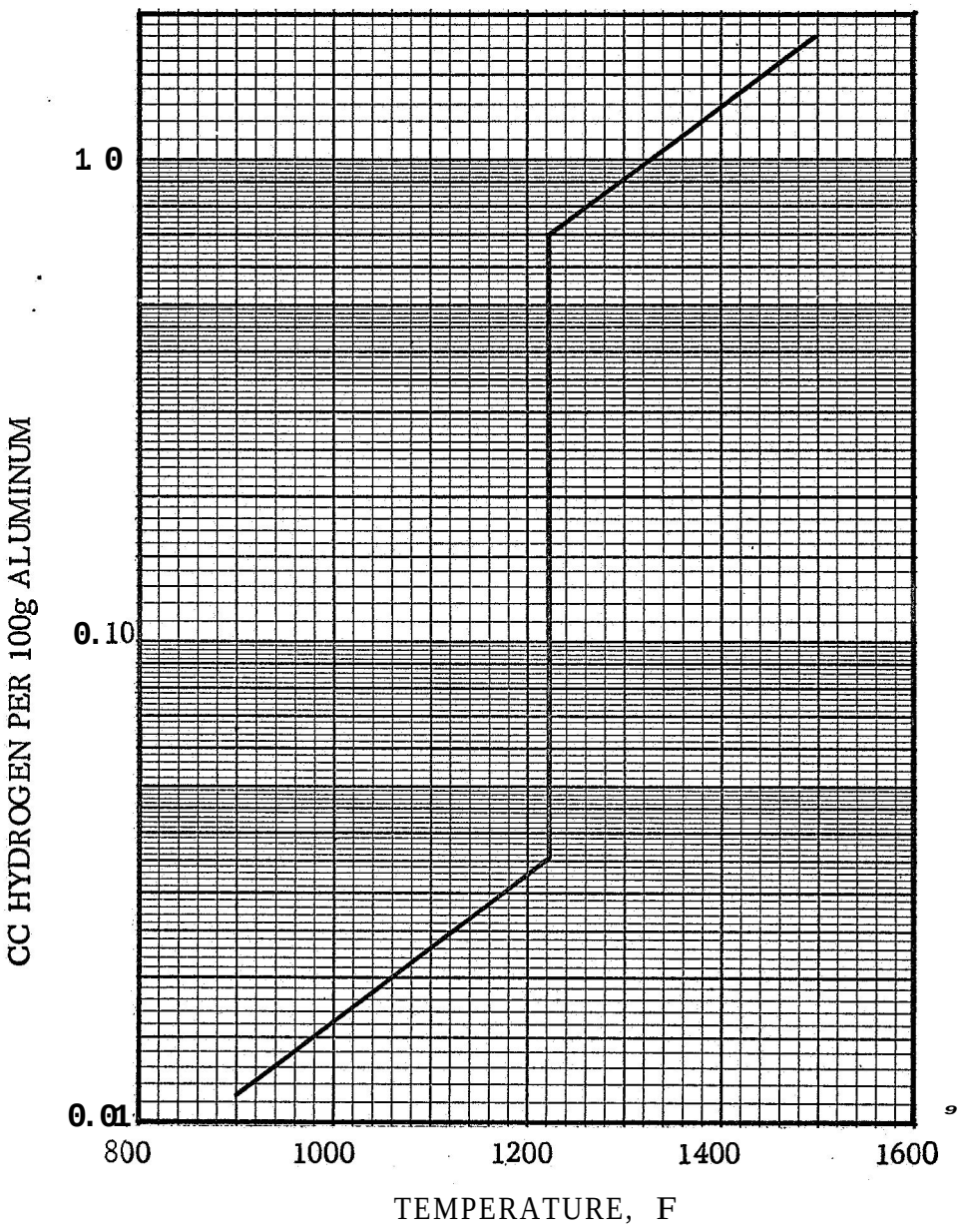


FIG. 12.8 SOLUBILITY OF HYDROGEN IN ALUMINUM
(Ref. 12.9)

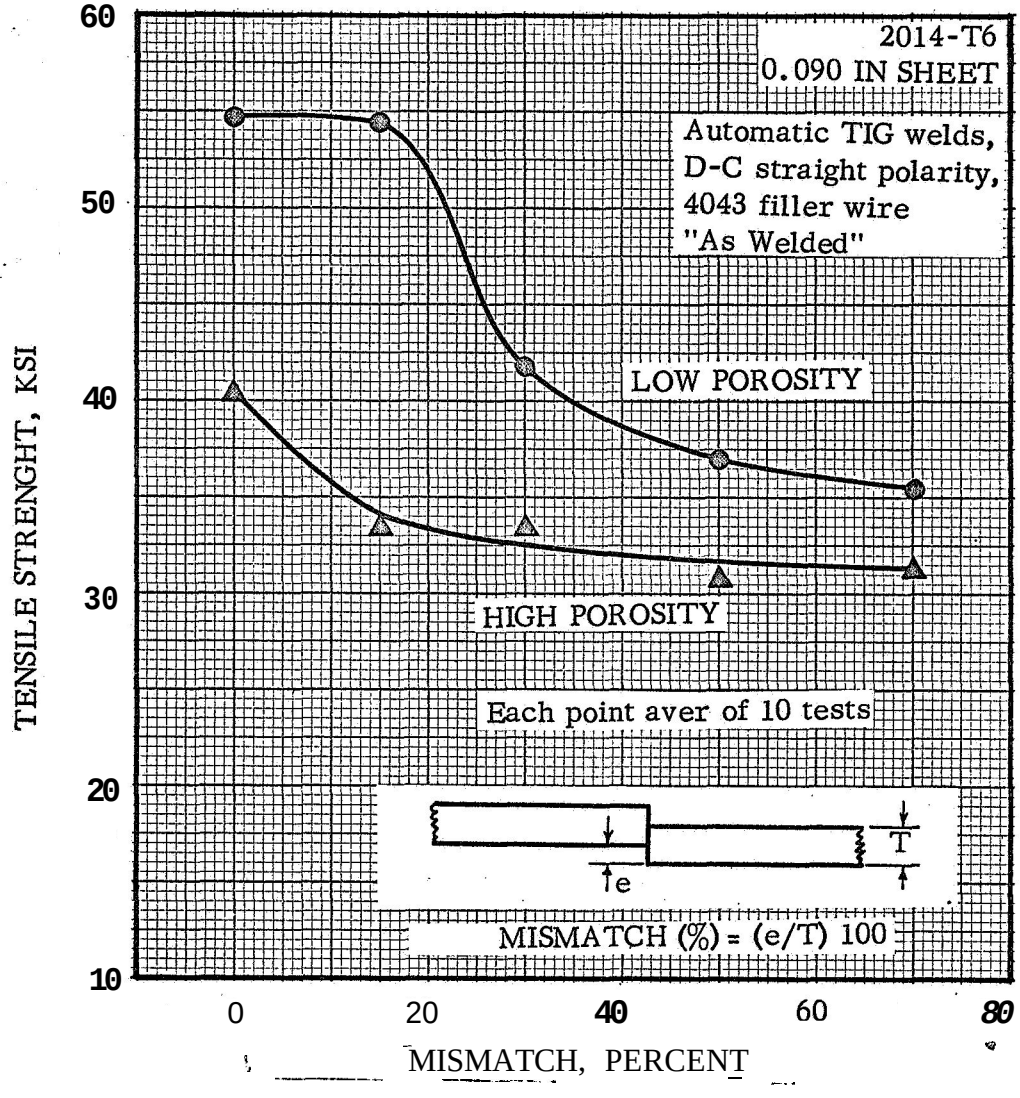


FIG. 12.9 COMBINED EFFECT OF POROSITY AND MISMATCH FOR TIG WELDED SHEET

(Ref. 12.15)

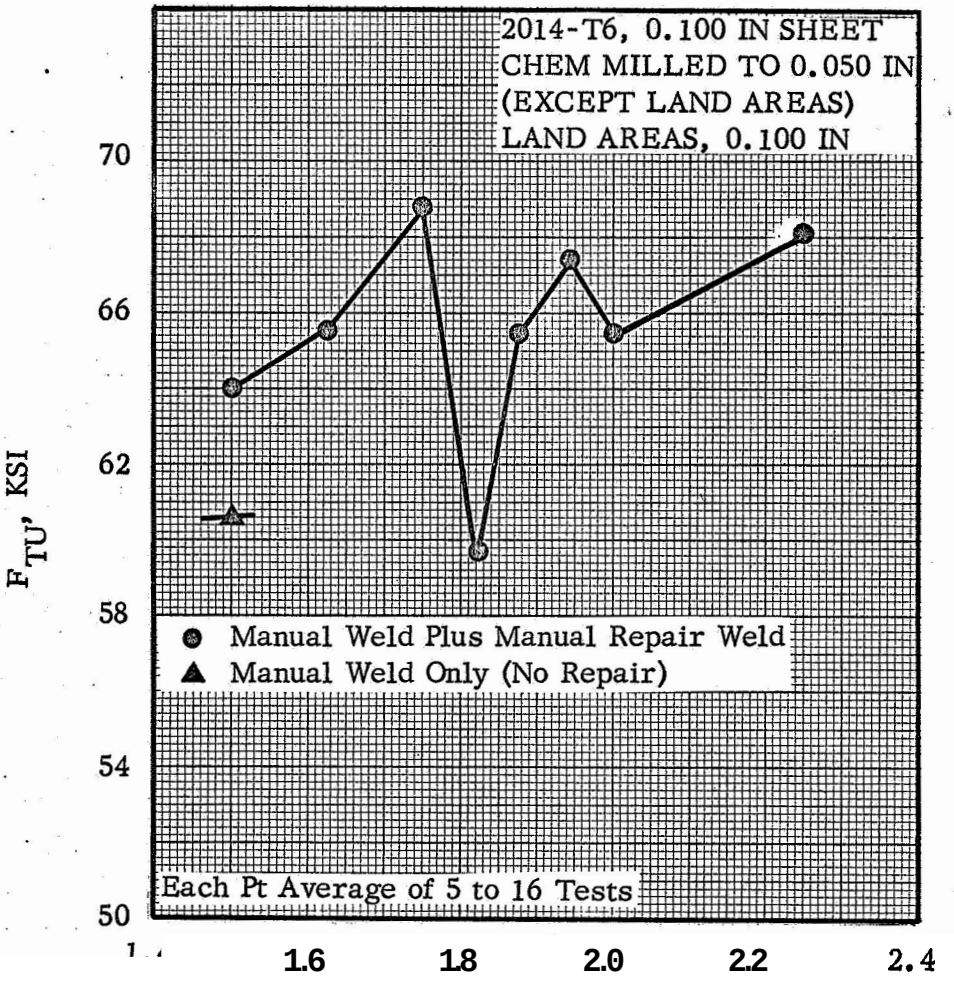


FIG. **12.10** EFFECT OF LAND WIDTH ON TENSILE STRENGTH OF MANUAL WELDED CHEM-MILLED SHEET

(Ref. **12.24**)

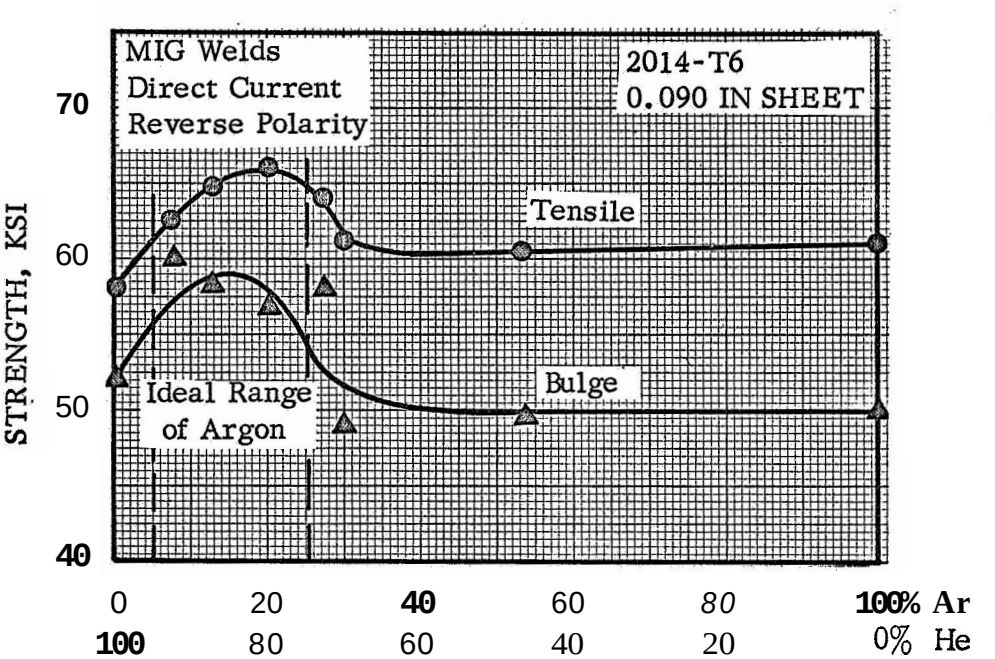


FIG. 12.11 TENSILE AND BULGE PROPERTIES OF MIG WELDED SHEET FOR VARIOUS ARGON-HELIUM GAS MIXTURES (Ref. 12.25)

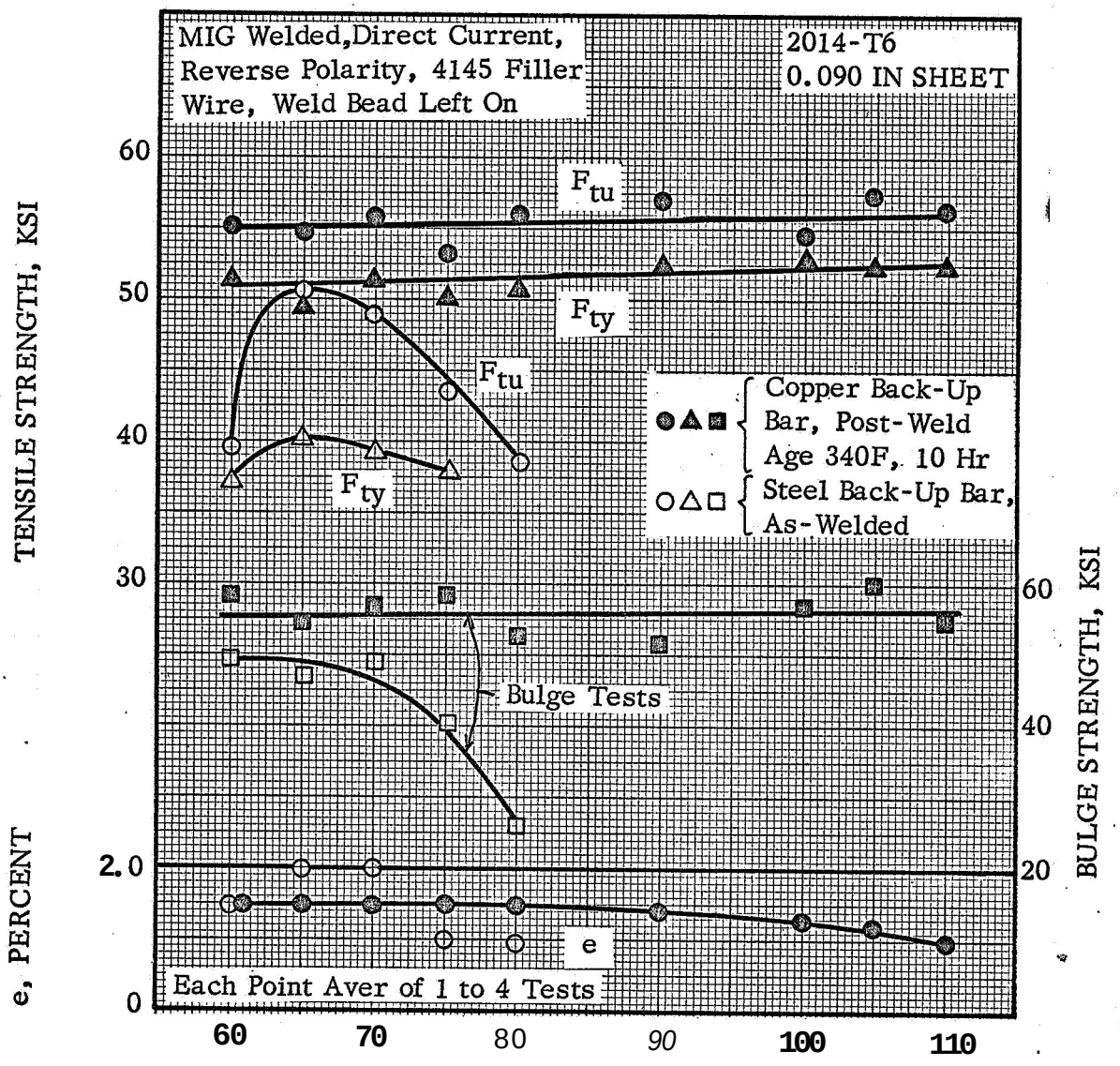


FIG. 12.12 EFFECT OF WELD TRAVEL SPEED ON TENSILE PROPERTIES AND BULGE STRENGTH OF MIG WELDED SHEET

(Ref. **12.25**)

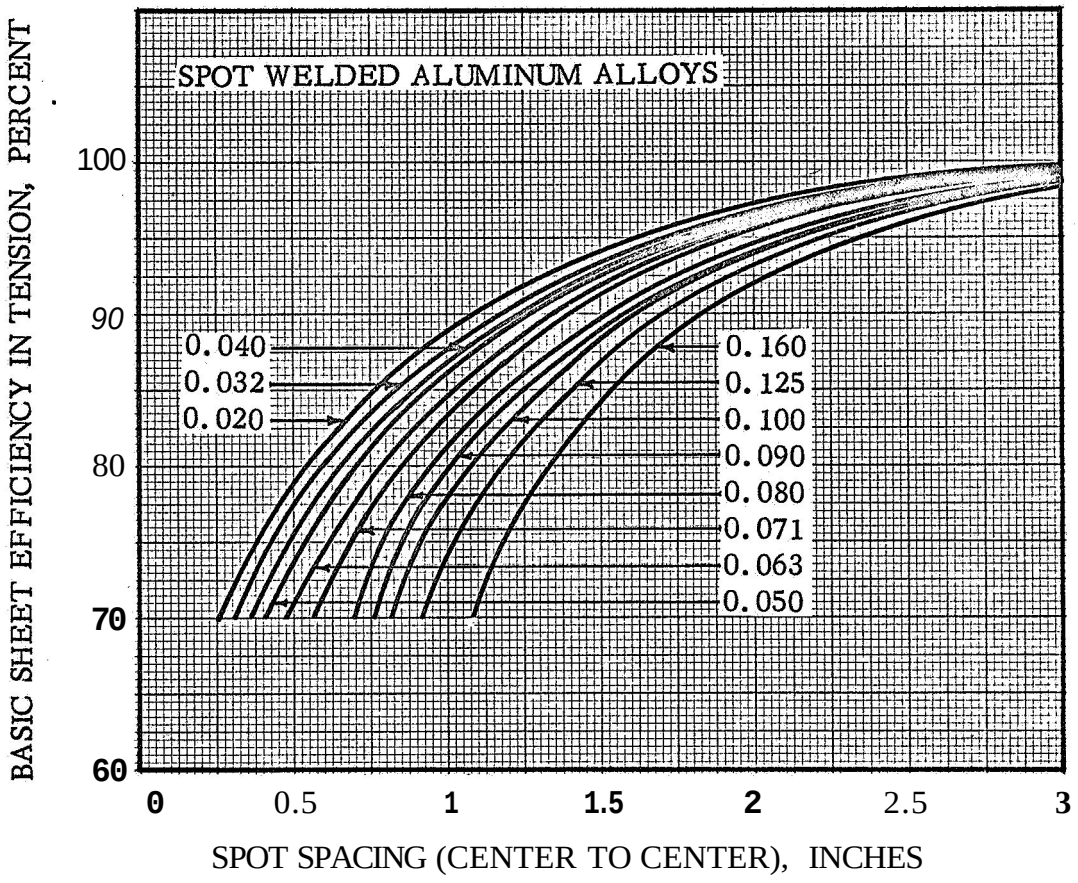


FIG. 12.13 EFFICIENCY OF THE PARENT METAL IN TENSION FOR SPOT WELDED ALUMINUM ALLOYS

(Ref. 12.12)

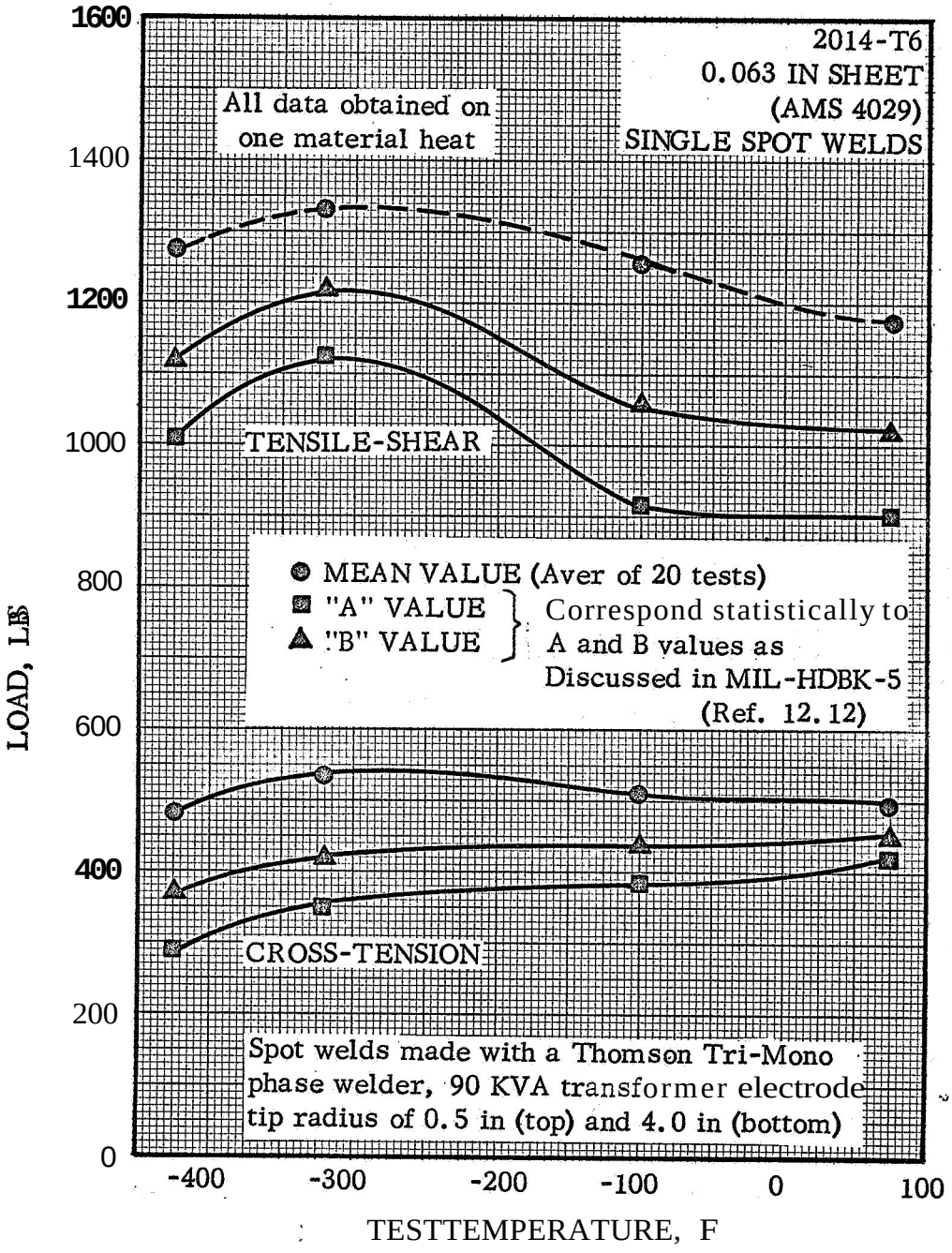


FIG. 12.14 EFFECT OF LOW TEST TEMPERATURES ON CROSS-TENSION AND TENSILE-SHEAR STRENGTH OF SINGLE SPOT WELDS

(Ref. 12.11)

CHAPTER 12 - REFERENCES

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