MATERIALS DATA HANDBOOK

Stainless Steel Type 301
(2nd Edition)

Revised by

R. F. Muraca
J. S. Whittick

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WESTERN APPLIED RESEARCH & DEVELOPMENT, INC.

1403-07 Industrial Road San Carlos, California 94070

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PREFACE

The revised edition of the Materials Data Handbook on stainless steel Type 301 was prepared by Western Applied Research & Development, Inc. under contract with the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama. It is a revised and updated version of the Handbook originally prepared by the Department of Chemical Engineering and Metallurgy at Syracuse University, June 1966.

It is intended that this Handbook present, in the form of a single document, a summary of the materials property information presently available on stainless steel Type 301.

The Handbook is divided into twelve (12) chapters. The scope of the information presented 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, as available, and these data are complemented with information on the typical behavior of the alloy. The major source used for the design data is the Department of Defense document, Military Handbook-5A.

Information on the alloy is given in the form of tables and figures, supplemented with descriptive text as appropriate. Source references for the information presented are listed at the end of each chapter.

Throughout the text, tables, and figures, common engineering units (with which measurements were made) are accompanied by conversions to International (SI) Units, except in the instances where double units would over-complicate data presentation, or where SI units are impractical (e.g., machine tools and machining). In these instances, conversion factors are noted. A primary exception to the use of SI units is the conversion of 1000 pounds per square inch to kilograms per square millimeter rather than newtons, in agreement with the ASTM that this unit is of a more practical nature for worldwide use.

ACKNOWLEDGMENTS

The second edition of "Materials Data Handbook: Stainless Steel Type 301" was prepared by Western Applied Research & Development, Inc. under Contract No. NAS8-26644 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Astronautics Laboratory, Materials Division of the George C. Marshall Space Flight Center with Mr. Wayne R. Morgan acting as Project Manager.

Sincere appreciation is tendered to the many commercial organizations and Government agencies who have assisted in the preparation of this document.

TABLE OF CONTENTS

TABULAR ABSTRACT

Stainless Steel Type 301

TYPE:

Austenitic stainless steel

NOMINAL COMPOSITION:

Fe-17Cr-7Ni

AVAILABILITY:

Full commercial ranges of sizes and product forms are available in annealed, 1/4 hard, 1/2 hard, 3/4 hard, full hard, and extra full hard conditions.

TYPICAL PHYSICAL PROPERTIES:

Density	7.91 g/cm^3 at room temperature
Thermal Conductivity	0.039 cal/cm^2/sec/$^\circ$C/cm at 100°C
Av. Coeff. of Thermal Expansion	16.9 x 10^{-6} μcm/cm/$^\circ$C (20–100°C)
Specific Heat	0.12 cal/g/$^\circ$C (0–100°C)
Electrical Resistivity	72 microhm-cm at 20°C

TYPICAL MECHANICAL PROPERTIES:

F_{tu}	(annealed)	105 ksi (74 kg/mm^2)
	(1/4 hard)	125 ksi (88 kg/mm^2)
	(1/2 hard)	150 ksi (105 kg/mm^2)
	(full hard)	185 ksi (130 kg/mm^2)
F_{ty}	(annealed)	40 ksi (28 kg/mm^2)
	(1/4 hard)	75 ksi (53 kg/mm^2)
	(1/2 hard)	110 ksi (77 kg/mm^2)
	(full hard)	140 ksi (98 kg/mm^2)
e(2 in, 50.8 mm)	(annealed)	55 percent
	(1/4 hard)	25 percent
	(1/2 hard)	18 percent
	(full hard)	9 percent
E (tension)		31 x 10^3 ksi (21.8 x 10^3 kg/mm^2)

FABRICATION CHARACTERISTICS:

Weldability	Excellent (fusion and resistance methods)
Formability	Good in annealed condition
Machinability	Good if proper tools and lubricants are employed

COMMENTS:

Alloy exhibits excellent corrosion and oxidation resistance and has good creep strength at elevated temperatures. High strengths are developed by cold working.

SYMBOLS

a	One-half notch section dimension
A	Area of cross section; "A" basis for mechanical property values (MIL-HDBK-5A)
Å	Angstrom unit
AC	Air cool
AMS	Aerospace Material Specifications
Ann	Annealed
ASTM	American Society for Testing Methods
Av or Avg	Average
B	"B" basis for mechanical property values (MIL-HDBK-5A)
b	Subscript "bending"
bcc	Body centered cubic
BHN	Brinell hardness number
br	Subscript "bearing"
Btu	British thermal unit(s)
$^{\circ}$C	Degree(s) Celsius
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
E_c	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)
$^{\circ}$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 strength
F_{su}	Shear stress; shear strength
F_{tu}	Ultimate tensile strength
F_{ty}	0.2% tensile yield strength (unless otherwise indicated)
g	Gram
G	Modulus of rigidity
HAZ	Heat affected zone in weldments
hcp	Hexagonal close pack
hr	Hour(s)
HT	Heat treat
IACS	International annealed copper standard
in	Inch
ipm	Inches per minute
°K	Degree(s) Kelvin
K	Stress intensity factor; thermal conductivity
K_c	Measure of fracture toughness (plane stress) at point of crack growth instability
kg	Kilogram
K_{Ic}	Plane strain fracture toughness value
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	Meter
M	Subscript "mean"
Max	Maximum
ml	Milliliter
MIL	Military
Min	Minimum
mm	Millimeter
N	Cycles to failure
NSR	Notch strength ratio
NTS	Notch tensile strength
OQ	Oil quench
ppm	Parts per million
pt	Point; part

r	Radius
RA	Reduction in area; Rockwell hardness A scale
RB	Rockwell hardness B scale
RC	Rockwell hardness C scale
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
STA	Solution treated and aged
T	Transverse
t	Thickness; time
Temp	Temperature
typ	Typical
Var	Variable
VHN	Vickers hardness number
W	Width
WQ	Water quench

CONVERSION FACTORS

To Convert	To	Multiply By
angstrom units	millimeters	1×10^{-7}
Btu/lb/°F	cal/g/°C	1
Btu/ft^2/sec/°F-inch	cal/g/cm^2/sec/°C-cm	1.2404
circular mil	square centimeters	$5.067\ 075 \times 10^{-6}$
cubic feet	cubic meters	0.028 317
cubic feet/minute	liters/second	0.4720
cubic inches	cubic centimeters	16.387 162
feet	meters	0.304 800 609
foot-pounds	kilogram-meters	0.138 255
gallons (U.S.)	liters	3.785 411 784
inches	millimeters	25.4
ksi (thousand pounds per square inch	kilograms/square millimeter	0.70307
microns	millimeters	0.001
mils	millimeters	0.0254
ounces (avoir.)	grams	28.349 527
ounces (U.S. fluid)	milliliters	29.5729
pounds (avoir.)	kilograms	0.453 592 37
pounds/foot	kilograms/meter	1.488 16
pounds/cubic foot	grams/cubic centimeter	0.016 018 463
square feet (U.S.)	square meters	0.092 903 41
square inches (U.S.)	square centimeters	6.451 625 8

Temperature in °C = (°F − 32) (5/9)

Temperature in °K = °C + 273.15

Chapter 1

GENERAL INFORMATION

1.1 Type 301 is the lowest alloyed member of the 18-percent chromium, 8-percent nickel series of steels, belonging to the larger family of austenitic stainless steels. The austenitic Fe-Cr-Ni alloys were developed in the Krupp Laboratories (Germany) by Benno Strauss and Edward Maurer during the years 1909-1912, and led to the 18-8 series of stainless steels which are widely used today (ref. 1.1). The austenitic alloys were developed as corrosion-resistant alloys for use in pyrometer tubes; however, they also possess excellent resistance to oxidation as well as good creep strength at elevated temperatures and good cold formability (ref. 1.2).

1.2 Of the austenitic stainless steels, Type 301 is the one used most frequently at high-strength levels in aircraft and missiles because of its greater work-hardening characteristics (ref. 1.2). Also, because of its high strength properties, Type 301 is used in the construction of bus, truck, trailer, and railroad-car bodies. It is used for automobile wheel discs, architectural trim, flashing, and roof drainage products (ref. 1.4).

1.3 The alloy cannot be hardened by heat treatment, but it hardens rapidly by cold working. It is possible to raise tensile strengths as high as 275 ksi (192 kg/mm^2) at room temperature. Wrought Type 301 is ordinarily used in either the annealed or cold-rolled condition. In the annealed condition, the mechanical properties are those of substantially stress-free austenite. Generally, the tensile strength will be between 85 and 110 ksi (60 and 77 kg/mm^2) with high ductility, comparatively low yield strength, high resistance to impact, relative insensitivity to notch effects, and low resistance to forming. Cold working increases hardness, strength, and elastic properties, but consequently reduces ductility and makes forming operations more difficult to a degree dependent upon the amount of cold work that has been applied (ref. 1.3).

1.4 Type 302 stainless steel has a slightly higher alloying composition than Type 301. Many of the specifications for Type 302 have a close enough range of composition for chromium and nickel to include Type 301 in its lower range. Their properties are only slightly different; while 302 is slightly inferior to 301 in strength, it has a better resistance to corrosion (ref. 1.4, 1.5).

1.5 General Precuations

1.51 Type 301 should not be used at temperatures of 750° to 1650° F (399° to 899° C) and should not be cooled slowly from higher temperatures through this range. Exposure to 900° F (482° C) or above reduces strength because of recrystallization (ref. 1.2, 1.5)

Chapter 1 - References

1.1 United States Steel, "Fabrication of USS Stainless Steels," ADUSS 03-1478-03, reprinted April 1971.

1.2 Military Handbook-5A, "Metallic Materials and Elements for Flight Vehicle Structures," Department of Defense, February 1966; latest change order January 1970.

1.3 The International Nickel Co., "Heat Treatment and Physical Properties of the Chromium-Nickel Stainless Steels," Nickel Alloy Steels, Section 7, Data Sheet A, 1947.

1.4 Republic Steel Corp., "Republic Enduro Stainless Steel," 1969.

1.5 Allegheny Ludlum Steel Corp., "Blue Sheet - Stainless Steel Type 301," 1971.

1.6 *Aerospace Structural Metals Handbook*, J.G. Sessler and V. Weiss, Eds., AFML-TR-68-115, 1971 Edition.

Chapter 2

PROCUREMENT INFORMATION

2.1 General. Type 301 is available in a full range of commercial sizes for sheet, strip, plate, wire, bar, and rod (ref. 2.1).

2.2 Procurement Specifications. AMS specifications that apply specifically to Type 301 as of May 1971 and equivalent Military and ASTM specifications are listed in table 2.2.

2.3 Comparison of Specifications. The three AMS specifications and ASTM A177-67 are specifically for Type 301 stainless steel. The other ASTM specification A167-63, and all the Federal and Military specifications are for a general classification of corrosion-resistant steels, or chromium-nickel steels, or sometimes (more specifically) the classification of 18-8 steels. For sheet and strip, the maximum mechanical properties for the various degrees of cold working correspond with AMS, ASTM, and Military specifications.

2.4 Major Producers of the Alloy (U.S.). Practically all alloy and stainless steel mills make this alloy under their own proprietary name or under AISI Type 301 specifications. Representative producers are:

Allegheny Metal 17-7, Type 301	Allegheny Ludlum Steel Corp. Pittsburgh, Pennsylvania
Carpenter Stainless No. 301	Carpenter Technology Corp. Reading, Pennsylvania
Crucible 301 Stainless Steel	Crucible Steel Co. of America Pittsburgh, Pennsylvania
Jessop Type 301	Jessop Steel Company Washington, Pennsylvania
Enduro Type 301	Republic Steel Corporation Cleveland, Ohio
USS 17-7, Type 301	United States Steel Corp. Pittsburgh, Pennsylvania
Stainless Steel Type 301	Universal-Cyclops Steel Corp. Bridgeville, Pennsylvania

2.5 Available Forms, Sizes, and Conditions. Type 301 is available in the full commercial range of sizes and forms in annealed, 1/4 hard, 1/2 hard, 3/4 hard, full hard, and extra-full hard conditions.

TABLE 2.2. — Procurement Specifications (a)

Source	Refs. 2.2, 2.3, 2.4			
Alloy	Type 301			
Product	Condition	AMS	ASTM	Military
Plate, sheet, and strip	Annealed	-	A167-63	-
Sheet and strip (b)	CR-125 ksi, 1/4 H	5517E	A177-67	MIL-S-5059C
Sheet and strip	CR-150 ksi, 1/2 H	5518D	A177-67	MIL-S-5059C
Sheet and strip	CR-175 ksi, 3/4 H	-	A177-67	MIL-S-5059C
Sheet and strip	CR-185 ksi, FH	5519F	A177-67	MIL-S-5059C

(a) As of May 1971.

(b) 1 ksi = 0.70307 kg/mm^2

Chapter 2 - References

2.1 Alloy Digest, "AISI Type 301," (Filing Code SS-54), Engineering Alloy Digest, April 1957.

2.2 SAE Aerospace Material Specifications, Society of Automotive Engineers, Inc., latest Index, May 1971.

2.3 ASTM Standards, Part 3, "Wrought Iron Bar and Sheet, Metallic Coated Products," 1968.

2.4 Index of Specifications and Standards, Dept. of Defense, Part I, Alphabetical Listing, Part II, Numerical Listing, July 1970, Supplement May 1971.

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Chapter 3

METALLURGY

3.1 Chemical Composition

3.11 The nominal chemical composition of Type 301 is:

Cr	17%
Ni	7%
Fe	Balance

3.12 There are some differences in the chemical composition ranges as listed by AMS and the steel producers. The chemical composition limits as specified by AMS and AISI are shown in table 3.1.

3.13 The principal alloying elements are chromium and nickel. Figure 3.1 illustrates the iron-chromium-nickel diagram at 18% chromium content. Figure 3.2 shows the iron-chromium-nickel diagram at 8% nickel content. The iron-chromium-nickel isothermal diagram at 1200° F (649° C) is presented in figure 3.3.

The chromium content gives the steel its passivity and resistance to oxidizing effects. The nickel content supplements the chromium in its resistance to oxidation to provide passivity where the chromium alone would not be sufficient for some corrodents. An increase in the chromium-nickel content improves the corrosion-resistance properties of the steel (ref. 3.4).

The mechanical properties of cold-worked Type 301 are influenced by its chemical composition. Not only do the individual percentages have an effect upon the mechanical properties, but also the ratios in which the elements are present in the steel influence its response to cold working. As the nickel content is increased, the steel becomes more stable and the rate of strengthening by cold working decreases. The effect of the chromium depends on the nickel and carbon contents. When the nickel is present in amounts greater than 9%, an increase of chromium will increase the rate of work hardening. However, if the nickel content is less than 7% an increase in chromium from 17% to 20% decreases the rate of work hardening.

Manganese and carbon also promote the stability of austenite. Carbon is very effective in this respect, while manganese is much less effective than nickel (ref. 3.5).

3.2 Strengthening Mechanisms

3.21 General. Austenitic chromium-nickel stainless steels cannot be hardened by heat treatment. Heat treatments are used, however, for purposes other than hardening. Full annealing maintains in the steel a fully austenitic structure (see figure 3.4); in this condition, the steel will be at its softest and most malleable state. Lower heat-treating temperatures may be employed to provide stress-relieving treatments or to improve yield strengths. Heat treatment may also be used to control carbide precipitation (ref. 3.5).

The austenite in Type 301 is not thermodynamically stable at room temperature. When the alloy is deformed plastically at or below room temperature, the metastable austenite undergoes a partial transformation to martensite (ref. 3.5).

3.22 Annealing. Light sections of the alloy may be annealed at 1950° to 2050° F (1065° to 1120° C) for 3 to 5 hours per 0.1 inch (2.54 mm) of thickness, followed by rapid cooling in air. Thicker sections are water quenched (ref. 3.6).

3.23 Stress Relief. To improve the elastic properties of cold-worked material, heat to 650° to 850° F (343° to 454° C) for 1/2 to 2 hours, and air cool (ref. 3.13). In order to minimize stress cracking in corrosive media (especially containing halogen compounds), full anneal after forming.

3.24 Surface oxide scale formed during thermal treatment must be removed from all material which has to serve in a corrosive environment (see Chapter 11, Surface Treatment).

3.25 Cold Working. The strength of sheet obtained by cold rolling depends largely upon the chemical composition, particularly the nickel and carbon contents. Figure 3.5 shows the effect of rolling reduction and composition on tensile properties of the alloy.

3.3 Critical Temperatures. The melting range of the alloy is 2550° to 2650° F (1399° to 1454° C). Carbon precipitation will take place when the alloy is exposed for a period of time to temperatures in the range of about 800° F to about 1650° F (427° to 899° C). The precipitation occurs during slow cooling, heating through this range, or while holding at temperatures within the range. The amount of carbide that will precipitate will depend upon the carbon content, time and temperature, and to some extent upon the chromium and nickel content. The carbides that precipitate in the grain boundaries are chromium-rich, reducing the chromium content in the grains adjacent to the boundaries. Due to this depletion of chromium, the alloy becomes susceptible to corrosion. Heating the alloy to the annealing temperature will put the carbides into solution and rapid cooling through the critical range will keep the carbides in solution. Thus, various fabricated parts or welded pieces that are subject to local heating, which may result in the precipitation of carbides, will require reannealing in order to prevent subsequent corrosion (ref. 3.5).

The effect of carbon on the constitution of stainless steel containing 18% chromium and 8% nickel is shown in figure 3.6.

3.4 Crystal Structure. The fully annealed alloy is face-centered-cubic, with a lattice constant of 3.56 x 10^{-7} mm (ref. 3.8).

3.5 Microstructure. The microstructure of a fully austenitic steel (18-8) is shown in figure 3.7. In materials plastically deformed at temperatures of 10°C and −188°C, the percentage of martensite obtained is shown to be related to the degree of working and to the temperature (ref. 3.10).

3.6 Metallographic Procedures. The specimens used for optical microscopy must be carefully polished, properly etched, and observed accurately at required magnifications. The choice of polishing methods, whether mechanical or electrolytic, depends upon the experience of the metallographer. While some metallographers have produced excellent results by mechanical polishing, it is believed by others that the polishing creates distortions causing slight changes in the properties of the surface. Also, chips (as well as abrasive particles) tend to collect on the surface and form material loosely adherent to the surface.

Electrolytic polishing eliminates these difficulties and, in general, is excellent for homogeneous alloys. However, where massive particles of microconstituent exist, this method leads to unsatisfactory relief effects. Mechanical polishing is ordinarily done wet on turn tables covered with a polishing cloth of velvet or silk sprinkled with a polishing abrasive such as the aluminum or magnesium oxides of 500- to 600-mesh grade or diamond dust. Electrolytic polishing is accomplished by using the ground specimen as an anode of a DC cell, using a proper cathode and an appropriate electrolytic solution. Conditions are best when a change in applied voltage produces no appreciable effect upon current density (ref. 3.11). Electropolishing information for austenitic stainless steel is given in table 3.2.

Etching is performed on specimens in order to isolate the constituents of the metal. Various etching agents are used to bring out the particular phase under examination. Etching may be accomplished by immersion, swabbing, or electrolytic techniques. Table 3.3 gives etching agent and use for austenitic stainless steels.

TABLE 3.1. – Chemical Composition Range

Alloy	Type 301			
Source	AMS (ref. 3.1)		AISI (ref. 3.2)	
Constituent	Percent Min	Max	Percent Min	Max
Carbon	-	0.15	-	0.15
Chromium	17.00	-	16.00	18.00
Copper	-	0.75	-	-
Manganese	-	2.00	-	2.00
Molybdenum	-	0.75	-	-
Nickel	7.00	-	6.00	8.00
Phosphorus	-	0.040	-	0.045
Silicon	-	1.00	-	1.00
Sulfur	-	0.030	-	0.030
Iron	Balance		Balance	

TABLE 3.2. – Electropolishing of Austenitic Stainless Steel

Source	Ref. 3.11					
Alloy	Type 301					
Electrolyte	Cathode	Current density, amp/ft^2 (a)	Power, volts	Max temp °F	°C	Time, min
Perchloric acid 30 ml Acetic anhydride 60 ml	Iron or aluminum	55	50*	85	29	4-5
Nitric acid 30 ml Alcohol (methyl) 60 ml	Any metal not attacked by electrolyte	-	-	-	-	-
Perchloric acid 5 ml Glacial acetic acid 100 ml		135-171	45	75	24	3-4
Water 7 ml Orthophosphoric 37 ml Glycerol 56 ml		720	-	212-248	100-120	5-10

* Externally applied. (a) 1 amp/ft^2 = 10.7 amp/m^2

TABLE 3.3. – Etching Agents and Uses

Source	Ref. 3.11	
Alloy	Type 301	
Electrolytic Etching Agent	Immersion Etching Agent	Uses
HCl (conc.) 10 ml Alcohol (ethyl) 90 ml 6V, 0.75 amp., 30 sec	$FeCl_3$ 5 g HCl (conc.) 50 ml H_2O 100 ml	Grain structure
Glacial acetic acid 20 ml HNO_3 (conc.) 40 ml 1 amp., 10 sec plus	Aqua Regia: HNO_3 (conc.) 40 ml HCl (conc.) 120 ml	
Oxalic acid 10 g H_2O 100 ml 1 amp., 10-15 sec	HNO_3 (conc.) 40 ml HCl (conc.) 120 ml Glycerin 160 ml	
$HClO_4$ (70-72% acid) 10 ml H_2O 90 ml 1 amp., 2 min	Alcoholic: Orthonitrophenol 20 ml HCl (50%) 40 ml $(NH_4)_2SO_4$ (15%) 40 ml	
CrO_3 10 g H_2O 100 ml 1 amp., 1 min		
CrO_3 10 g H_2O 100 ml 6V, 0.75 amp., 1 min	Murakami's (dilute): $K_3Fe(CN)_6$ 30 g KOH 30 g H_2O 100 ml	Sigma phase and carbide precipitation
	Murakami's (conc.): $K_3Fe(CN)_6$ 30 g KOH 30 g H_2O 60 ml	
	Vilella's: HNO_3 (conc.) 15 ml HCl (conc.) 30 ml Glycerin 45 ml	
	NaOH 1 g $KMnO_4$ 4 g H_2O 100 ml	
	Picric acid 5 g HCl 5 ml Alcohol (methyl) 90 ml	
NaCN 10 g H_2O 100 ml 1 amp., 5-10 sec		Carbide precipitation
NaCN 10 g H_2O 100 ml 1 am., 15 sec-2 min		Sigma phase
Oxalic acid 10 g H_2O 100 ml 6V-0.75 amp.		Sigma phase, then carbide precipitation

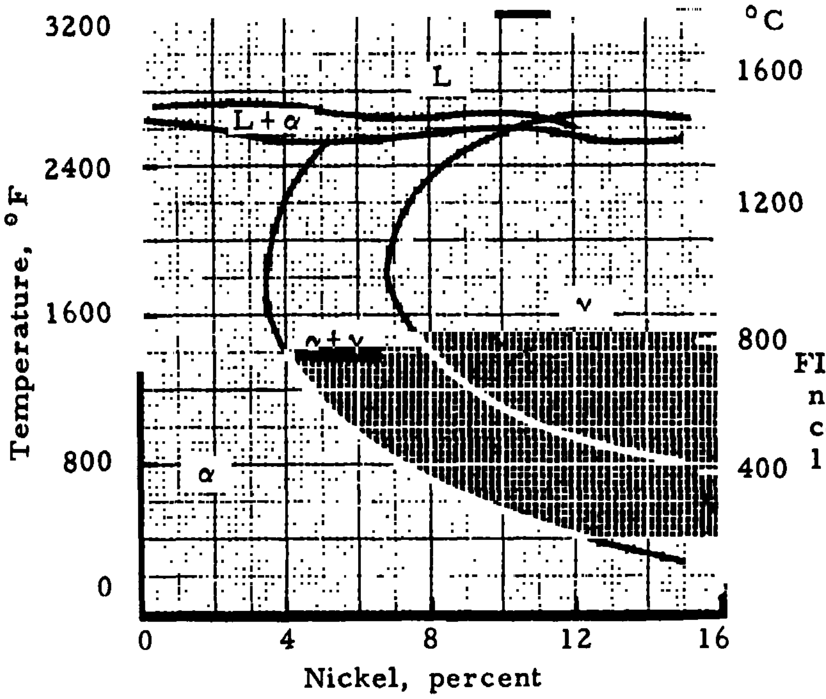

FIGURE 3.1.– Iron-chromium-nickel equilibrium diagram at constant chromium content of 18 percent. (Ref. 3.3)

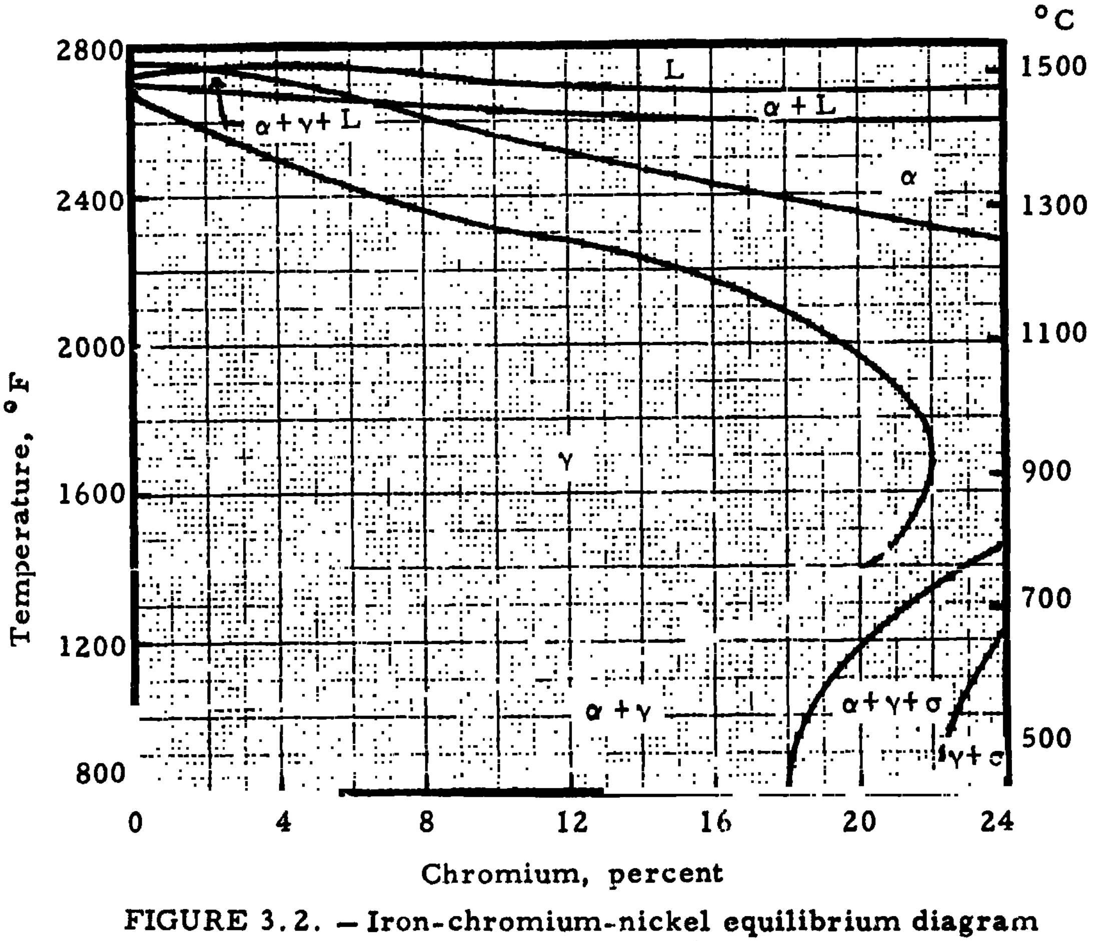

FIGURE 3.2. – Iron-chromium-nickel equilibrium diagram at constant nickel content of 8 percent. (Ref. 3.3)

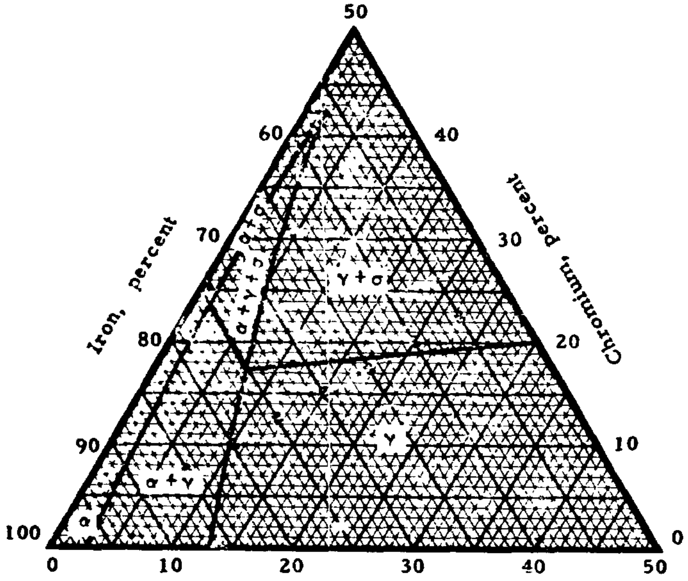

FIGURE 3.3. – Iron-chromium-nickel equilibrium diagram at 1200° F (649° C). (Ref. 3.2)

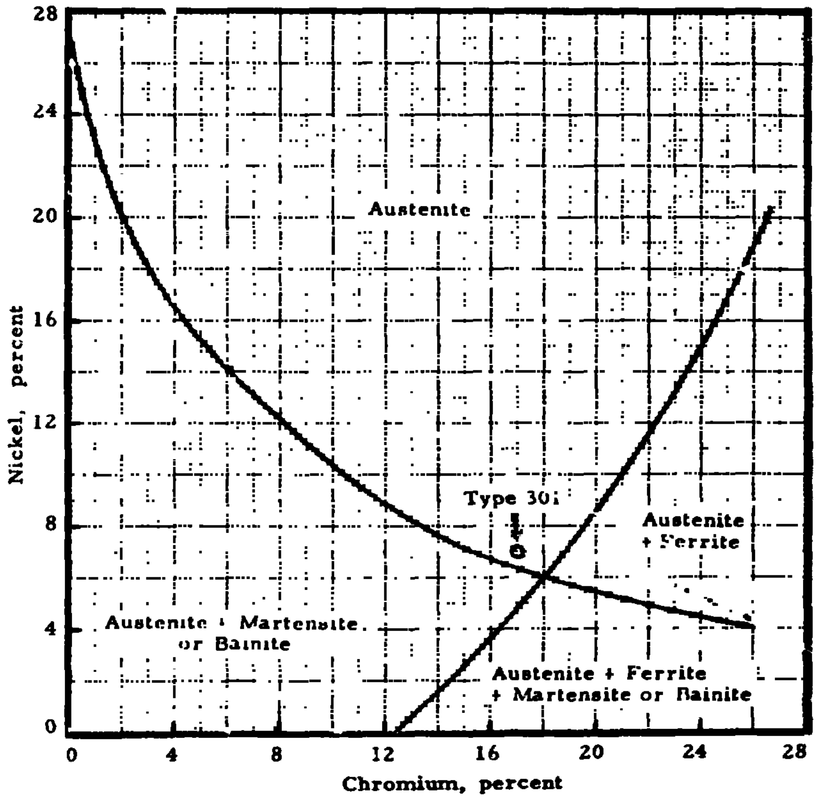

FIGURE 3.4. – Effect of variations in chromium and nickel in quenched-annealed Type 301 containing 0.10C, 0.40Mn, and 0.30Si. (Ref. 3.7)

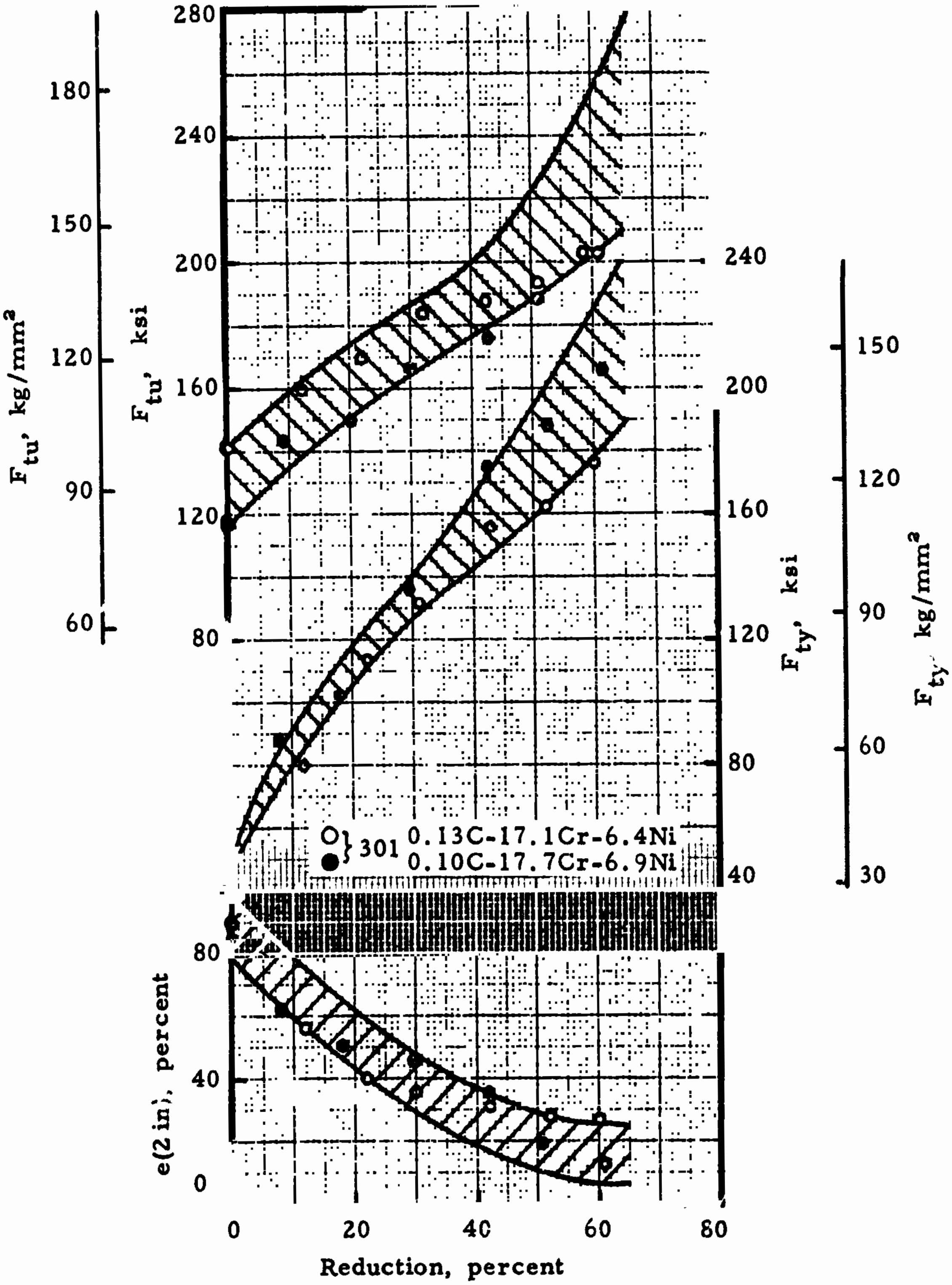

FIGURE 3.5. – Effect of rolling reduction and composition on tensile properties of 300 series steels.

(Ref. 3.12)

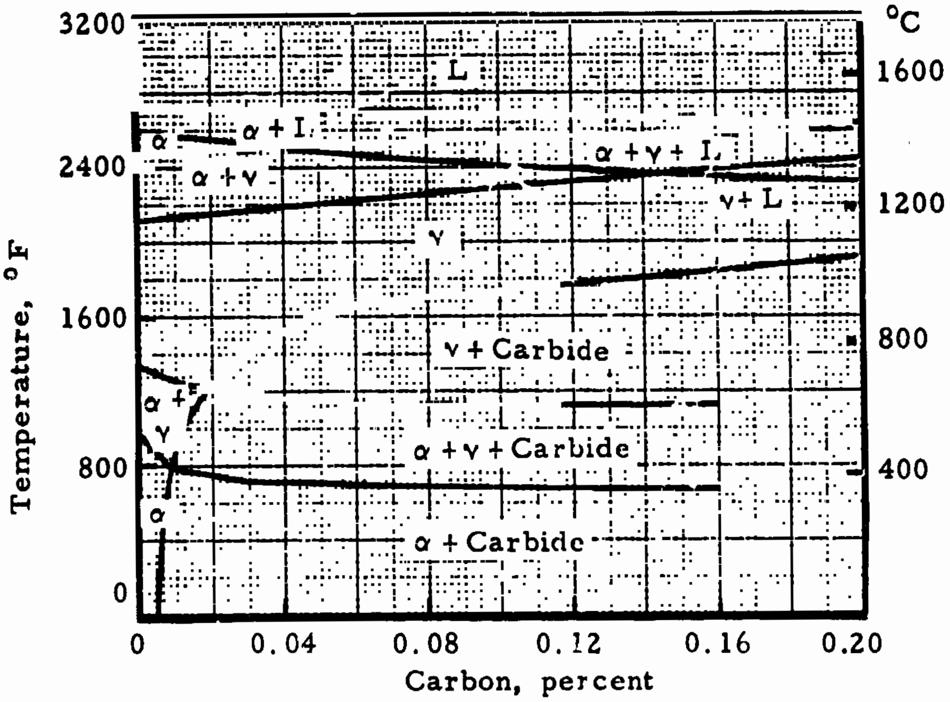

FIGURE 3.6. – Effect of carbon on the constitution of stainless steel containing 18 percent chromium and 8 percent nickel.

(Ref. 3.3)

FIGURE 3.7. – Structure of 18 percent chromium, 8 percent nickel steel, water-quenched from 1050°C; mag., 100X.

(Ref. 3.9)

Chapter 3 - References

3.1 *SAE Aerospace Material Specifications*, Society of Automotive Eng., Inc., 5517E, 5518D, and 5519F, Rev. 5-15-71.

3.2 American Iron and Steel Institute, "Stainless and Heat Resisting Steels," Steel Product Manual, June 1957.

3.3 United States Steel Company, J.M. Camp and C.B. Francis, "The Making, Shaping, and Treating of Steel," 6th Edition, 1951.

3.4 The International Nickel Co., "Corrosion Resisting Properties of the Chromium-Nickel Stainless Steels," Nickel Alloy Steels, Sec. 7, Data Sheet A, 1947.

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3.7 D.K. Bullens, *Steel and Its Heat Treatment*, Vol. III, 5th Edition, John Wiley & Sons, 1949.

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3.10 T. Angel, "Formation of Martensite in Austenitic Stainless Steels," *J. Iron & Steel Institute*, *177*, 165 (1954).

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Chapter 4

PRODUCTION PRACTICES

4.1 General. All austenitic stainless steels are produced by melting in either electric-arc or high-frequency induction furnaces. In each case, a cold charge is used. The necessity to maintain a low carbon content is aggravated by the high affinity for carbon and oxygen of the large quantity of chromium present in this class of steel. This is a special problem in the production of stainless steels. The composition of the charge, in normal steel production, has an excess of carbon, silicon, and manganese. The melt is then refined by controlling the oxidation of the carbon, silicon, and manganese by reaction with oxygen that comes from the furnace gases and from the oxides of iron from the added iron ore or mill-scale. During the refining operation the oxides (iron, silicon, and manganese) are removed in the slag and carbon monoxide escapes in the "boil." The removal of dissolved or entrained oxides in the melt is carried out by the addition of deoxidants of silicon and manganese in the appropriate quantities to assure the required excess of these elements. Any additional alloy elements are added at this stage. The bath is then heated to tapping temperature.

The production of austenitic stainless steel by the arc-furnace method is basically the same as for carbon steels. The high-frequency induction furnace employs a direct melt process. The arc-furnace method has a relatively new modification of direct application of oxygen into the melt in place of iron oxide (ref. 4.1).

4.11 The Arc Furnace Process. Normally, austenitic stainless steel is produced in this method by a two-slag process. The first charge consists of plain steel scrap and slag-making material. The melt is produced rapidly, oxidizing additions are made, and the carbon is restored to the desired low level. After the "boil" and removal of the first slag, a second slag is started by the addition of the alloy steel scrap. After melting, the bath composition is checked and alloy additions are made to the desired composition (ref. 4.1). Chromium is usually added to the bath after the steel has been deoxidized; it is added as ferrochromium containing 68% chromium, 6% carbon, and the balance iron.

4.12 The High Frequency Induction Process. This process is basically a melt process only. There is no significant oxidation, no oxidizing additions and no slag production. The charge is austenitic steel scrap which is rapidly melted; suitable alloy additions are made to adjust to the proper composition and the bath is tapped.

This process uses 100% scrap for the charge, permits savings in melting time, and close control of composition and quality may be maintained. The higher capital cost of the equipment prevents this method from more universal adoption (ref. 4.1).

4.13 Oxygen Lancing Modification. This method modifies the arc-furnace process by the injection of oxygen directly into the molten bath. The method rapidly oxidizes the carbon without excessive oxidation of the chromium. It provides greater speed and control in the refining stage. The addition of oxygen in this way increases the temperature of the bath by 360° F (182° C). At this higher temperature, the stability of carbon monoxide is increased while the stability of the oxides of chromium, manganese, silicon, and iron are decreased. The attack on the furnace refractories at the higher temperatures and the cost of the oxygen are the disadvantages to this modification in the arc furnace process (ref. 4.1).

4.14 Vacuum Melting. Induction and consumable electrode vacuum melts and remelts are available, but all or almost all Type 301 produced is produced by air melt methods. Comparisons of air-melted and vacuum-melted Type 302 tensile and notched tensile properties at cryogenic temperatures have been made. The results indicate higher tensile and yield strength, but greater notch sensitivity for the vacuum-melted heat as compared to the air-melted heat. For 70-percent cold reduction, the martensite present for the vacuum-melted heat was 91 percent, compared to 52 percent for the air-melted heat. Based on data available from this study, together with 140 similar tests performed on another austenitic stainless steel, it appears that the austenite is less stable for the vacuum-melted than for the air-melted material (ref. 4.3).

4.15 Casting Ingots. The bath of finished steel is cast into ingots for further processing to a particular form or product. Clean dry ladles are required and extremely clean ingot molds are necessary. Care must be taken to reduce to a minimum splashing in casting ingots. Splashing will increase oxidation and damage ingot surfaces. Badly damaged surfaces due to splashing will seriously increase manufacturing costs because of the necessity of heavy grinding required before deformation processes can be undertaken. Speed of casting is of great importance in order to minimize oxidation of the liquid steel. High chromium steels lose fluidity very rapidly if significant oxidation occurs (ref. 4.1).

4.2 Hot Working. The equipment that is used to heat and roll austenitic stainless steel ingots is the same as that used for carbon steel ingots. The austenitic stainless steels are generally stronger than ferritic steels at rolling temperatures and equire more power for deformations. The steel is susceptible to grain growth and overheating should be avoided. During the heating, special precautions should be taken to keep the sulfur content of the furnace or soaking pit atmospheres at a minimum because this steel after being heated in such atmospheres tends to tear and crack during rolling. The initial forging temperature range for Type 301 is 2100° to 2300° F (1149° to 1260° C) (ref. 4.2).

The ingots are rolled to blooms and slabs. The surfaces of bloom products are usually completely milled or planed to remove imperfections (conditioned). For slabs that are difficult to roll, there may be required an interruption in the process between ingot and slab for conditioning. The blooms used for the production of billet are also completely conditioned prior to heating for rolling (ref. 4.2).

Slabs are again conditioned prior to being rolled to plates. Ordinarily, the slabs are conditioned completely. Occasionally, the surface is satisfactory enough to condition only those areas surrounding defects. While the equipment for heating and rolling austenitic stainless steel plate is the same as for carbon steel plate, austenitic stainless steels require more power for rolling at elevated temperatures. Thus, the amount of reduction per pass is smaller for austenitic grades and the steel spreads less. After rolling, the plates are annealed and descaled by pickling (ref. 4.2).

Bars are rolled from conditioned billets.

Sheet and strip are usually rolled by the continuous method. Hot rolled coil is passed through a reversing mill to be cold rolled to sheet and strip and, depending on the finished thickness desired, an intermediate anneal and pickling may be used. A final anneal and pickling is performed (ref. 4.2).

4.3 Cold Working. Of the austenitic stainless steels, the Type 301 composition is best suited for the production of high strength steels by work hardening (see the discussion on cold working in Chapter 3).

Chapter 4 - References

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Chapter 5

MANUFACTURING PRACTICES

5.1 General. The various manufacturing processes of forming, cutting, and machining vary from that in plain carbon steel due to the special properties of austenitic stainless steels. With proper equipment and tools, the various manufacturing processes for Type 301 are not difficult to perform. Austenitic stainless steels in the annealed condition are tough rather than hard. They will tend to seize and gall in machining and require increased power in forming. The fundamental fact controlling the manufacturing processes of Type 301 is the instability of the austenite phase and its tendency to break down to hard martensite under cold work. As the material is drawn, rolled, machined, or cut, work hardening will take place, making it increasingly more difficult to carry on the process. Often a slower rate of working is desirable and annealing between operations may be more frequently required than for other metals.

Approximately 40-percent cold rolling produces the full hard temper which is used for high strength-to-weight ratio applications. The extra-hard temper is produced by a 50- to 60-percent cold reduction. Of course, when heavily cold worked, the formability is very limited. However, if the radii are reasonably generous, the parts can be formed.

5.2 Forming. The alloy may be formed by drawing, spinning, rolling, wiper forming, stretch forming, and press forming. Low yield strength and high ductility, which are characteristic of austenitic stainless steels in the annealed temper, permit successful forming of complex parts (ref. 5.10). As can be seen in table 5.1, this alloy is very formable in the annealed condition. Type 301 lends itself well to deep drawing. Reductions in one draw of 40 percent, producing a 4-inch deep cut (10.16 cm) from a 10-inch blank (25.4 cm), can be performed. Reduction as high as 50 percent is possible in one operation. Where multiple-step drawing is necessary, each individual draw should not be more than 34 to 40 percent. Intermediate annealing may be necessary between drawing steps. In all severe reductions, it is essential that strains be relieved immediately by annealing or the piece will crack within a few hours. Cracking may also occur following draws as a result of insufficient die clearance or improper lubrication (refs. 5.1, 5.2). Almost double the power used for equal drawing of ordinary carbon steels is required for this alloy. A speed of approximately one-half that used in regular draw work is appropriate. Clearance between punch and drawn die should be twice that used on carbon steels and a good lubricant must be applied uniformly over the surface to reduce friction (ref. 5.3).

For deep drawing, heavy-bodied lubricants and pigment-type lubricants must be used. For mild drawing, soluble oils or thinned pigment-type lubricants are satisfactory. The mill finish of the steel can greatly assist in retaining lubricants in deep drawing. Duller finishes assure better lubricant adhesion and thus minimize die wear and result in better finish of end products. Annealed and pickled finish is the appropriate mill finish for best results (ref. 5.1).

Proper die material is important in the successful drawing of stainless steel. Solid dies made from alloy tool steels of the nondeforming type (high carbon - high chromium) are most satisfactory for long wear. Cast iron dies may be used, but because of rapid wear are suitable only for short runs. Alloy cast iron, containing chromium and nickel, may also be used with good results (ref. 5.2).

While other austenitic stainless steels (such as Type 305) are preferred for spinforming, because of their slower rates of work hardening, Type 301 can be spun. In general, roller type tools are used and greater power and sturdier equipment is required for this operation (ref. 5.3). The lubricants recommended for drawing and spinning operations are:

1. Lithopane and boiled linseed oil in equal parts by volume and thinned with kerosene as necessary. Powdered sulfur or talc may be added for difficult work.
2. White lead thinned with linseed oil to about the consistency of 600 W oil.
3. Castor oil and emulsified soap.
4. Lithopane mixed with water and applied in an even coat of moderate thickness. This should be allowed to dry before beginning operations, although it may be difficult to remove during cleaning operations.
5. Corn oil of the highest quality.
6. Powdered graphite mixed to a thin paste with water. This is to be spread evenly over the work and allowed to dry before use. Thorough cleaning of the drawn parts is absolutely necessary before subsequent heating or annealing operations (ref. 5.2).

Roll or drawbench forming can be performed on Type 301 in the annealed condition up to full hard temper for bending and straight flange forming (ref. 5.4). Figure 5.1 shows recommended minimum bend radii for 301 stainless for the various tempers. (The smallest bend radius which can be formed without cracking is called the "minimum bend radius.") The radius increases in proportion to the sheet thickness and temper. High carbon or alloy steel are satisfactory roll materials. Dilute solutions of water soluble oils make adequate lubricants. Soap solutions and extreme pressure oils give greater roll protection and produce a finer finish. However, they are more difficult to remove (ref. 5.1).

Wipe or compression forming is used for forming contours of changing radii in a single plane. Form blocks of steel and cast iron are generally used. Form block surfaces must be highly polished to prevent marking the surface (ref. 5.1).

Small springback and the absence of wrinkling in stretch-forming make it an excellent method for forming Type 301. Form blocks may be made of wood, masonite, zinc, aluminum alloy, or steel, depending on the quantity of parts to be produced. A heavy lubricant should be used at the ends of the die; light lubricants may be used in the center. Mechanical or hydraulic equipment is used to apply stretching tension. The ends must be tightly gripped to prevent slipping and it is recommended that grips with knurled surfaces be used (ref. 5.1).

Rocket motor cases have been stretch-formed at cryogenic temperatures, yielding very high strength. Stretching to about 20 percent at –320°F(-196°C)has produced strengths of 275 ksi (193 kg/mm^2) in Type 301. Further strengthening of the material can be accomplished by age hardening at 800° F (427° C) for 20 hours, producing strengths of 300 ksi (211 kg/mm^2) (ref. 5.5).

Press or brake forming procedures that are used for carbon steel are applicable to Type 301. Because of the high strength of Type 301, heavier tools are needed. A good rule for the press-forming procedure is to use the same forming procedure that would be used for hot rolled carbon steel four gages heavier than Type 301. The tool stroke should be as short as possible on bending a part to avoid fouling or scoring of the tool. Clearance between die and punch should be almost 10 percent more than metal thickness to reduce the tendency for ironing. Dies should be well polished and free from all surface blemishes. A lubricant similar to that used in drawing or rolling can be applied to reduce friction and metal adhesion to the die. For bending of annealed Type 301, a minimum radius of 1/2 the metal thickness is possible. Mechanical press forming may be used for form parts with contoured flanges with tempers up to and including 1/4 hard (ref. 5.1).

5.3 Cutting. The methods used for mechanical cutting of carbon steels can be used for Type 301. However, greater power and slower cutting speed must be employed. Such mechanical methods as shearing, blanking and punching, perforating, abrasive cutting, and friction sawing are available for cutting stainless steel. Flame cutting, as practiced on carbon steel, is not suitable for stainless steel. However, modifications in the method have been developed to make flame cutting of stainless steel possible.

Shearing of Type 301 requires 30 to 50 percent more power than is needed to shear carbon steel of the same gage. The shear knives should be made of high speed steel or suitable tool steel and ground with a lip rake of about 2°. The blades should be sharp and maintain a very close adjustment to prevent dragging of the metal. Type 301 does not snap or break during shearing operation as do most metals. They must be cut all the way through. Clearances should be 1/20 of the metal thickness with a maximum of 0.003 inches (0.076 mm). It is better to make a long continuous cut rather than to chop off the metal. Hand snipping requires the same precautions as shearing. Blades must be kept sharp and closely adjusted to prevent dragging of the metal (ref. 5.1).

The best grade of tool steel should be used for blanking and punching dies. They should be kept sharp, rigidly backed, and clearance should be close. Suggested clearances are as for shearing, 1/20 of the metal thickness with a maximum of 0.003 inches (0.076 mm). The power for blanking or punching must be 50 percent higher and speed 2/3 of that for carbon steels (ref. 5.1).

Perforation of stainless steel can be done with little difficulty. Twice the power and half the speed that would be used for carbon steel is required. Top grade tool steels with sharp cutting edges and close clearances are necessary. The same clearances are required as for punching and blanking. Hole diameters twice the thickness of the material or more are recommended. For best results, a thin drawing or cutting lubricant should be used for punching minimum diameter holes (ref. 5.1). Abrasive wheel cutting speeds of 1/4 in^2 per second for dry cutting and 1/8 in^2 per second for wet cutting are obtainable. The recommended wheel speeds are 10,000 sfm for 12-inch diameter wheels and 16,000 sfm for 10-inch diameter wheels. Cutting with rubber-banded wheels is recommended to reduce heat-tinting or burning (ref. 5.1). [1 in^2 = 6.45 cm^2; 1 in = 2.54 cm]

Recommendations for friction sawing are given in table 5.2. The best feeds and speeds for an actual job should be determined by trial and error, using the table values on the first trial. The finish produced by friction sawing should be smooth and even with a 1/32-inch to 1/16-inch burr on the underside of the cut. The saw width is from 3/16 inch to 1 inch, depending upon the contour of the cut. In general, saws should be as wide as possible for the radius of the cut. Saw set ranges from 0.042 inch to 0.057 inch (depending on the saw width (ref. 5.1).

Flame cutting procedures used for carbon steels will produce refractory oxides so resistant to the heat of the torch that they will not burn away quickly. In this way, flame cutting becomes a melting process which is too inaccurate to be practiced. Two methods have been developed as a modification of the usual oxy-acetylene equipment that makes flame cutting of stainless steel possible. In the powder cutting method, metallic iron is introduced into the cutting zone. This oxidizes rapidly, liberating a great deal of local heat which is high enough to melt the refractory oxides rapidly; the oxides are then floated away as slag. In flux injection cutting, a flux is introduced to the cutting zone which combines with the refractory oxides chemically to produce a lower melting compound that is easily flushed away (ref. 5.1).

5.4 Machining. Because of the work hardening characteristics of Type 301, certain precautions and modifications of machining methods used for mild carbon steels must be employed. However, Type 301 will machine with little trouble as long as the proper tools and lubricants are selected. Rigidity is a necessary factor to prevent chatter and springing and consequently hard spots in the metal. Oversize motors are recommended for all equipment because they will permit heavy cuts without chattering. Precautions should be taken to prevent the tool from riding on or glazing the work. Tools should be kept sharp to prevent the surface from hardening due to rubbing action. Proper selection of the cutting tool may also be the deciding factor for successful machining. Table 5.3 shows recommended cutting speeds and feed speeds for various tool materials and machining operations. The procedures listed here can only act as a guide. Most production men who machine stainless steel will start with the average speeds recommended and feel their way to the proper cutting speeds and feed speeds for their own particular tools, equipment, and applications (refs. 5.1, 5.6).

In drilling Type 301, as short a drill as the job permits should be used. This will reduce whipping. When marking for drilling, a prick punch should not be used since this will work harden the metal and make starting of the drill difficult. A square or triangular punch should be used. The drill should not be allowed to ride in the hole. This will glaze the bottom, forming a hardened surface and make continued drilling more difficult. Drills should be kept sharp to reduce glazing. Backup plates of an easily machined metal should be used to reduce burring. To prevent chip packing, the drill should be backed out periodically. The depth of the first drill may be the drill diameter, then back out. Drill in successive bites, two diameters and one diameter. Where drill size permits, a chip breaker should be ground parallel to the cutting edge. Water soluble oils are generally satisfactory for cooling the drill. Sometimes it may be necessary to use sulfurized, chlorinated, mineral or fatty oils. Tap clearance should be 6° to 8°, point angle 135° to 140°. A high hook angle with two flute, gun-type taps are preferred. Hole tapping is relatively easy, particularly if the thread length is short. Hook angles from 15° to 20° are recommended. Spiral pointed taps will work well in open holes up to 3/8 inch (9.54 mm). Spiral fluted taps, with flutes having the opposite hand as the threads, is preferred in larger holes. Blind holes are more difficult. Room must be allowed for chips in deep holes. These chips are difficult to break when the tap reverses. Chamfer should be as long as possible and the chamfer angle should be greater than 9° with the tap axis.

Flutes with a spiral of the same hand will help in chip removal. The special angle should not be too large or tearing and oversize threads will result. Filling blind holes with heavy paste or grease helps in chip removal. Holes to be tapped must be properly sized. The taps should be as large as possible, especially when a fine pitched thread is used. Correct lubrication must be provided for successful tapping. A mixture of sulfur-chlorinated petroleum oils with active sulfur is recommended. The lubricants should be placed in the hole rather than on the tap and should be continuous if possible (ref. 5.1).

Self-opening dies are recommended for threading. Solid dies will cut satisfactory threads, but are more likely to tear them when they are backed-off. The standard thread chasers are used with a slightly modified grind. Die heat chasers for straight threads should be ground with almost a 15° hook angle. Tangent and circular type chasers require a rake angle of 20° to 25°. External pipe thread chasers should have a 10° hook angle. Tap chasers should have a 20° lip hook for straight threads and a 15° radial hole for tapered threads. A mixture of sulfur base and paraffin base oils is recommended as a proper lubricant for successful threading (ref. 5.1).

Sharp tools are very important in the turning operation. They should be as large as possible in order to dissipate heat away from the cutting area. Front and side clearance angles should be no more than 10°. Top rake should be 5° to 10° with slight nose radius. Chip breakers or curlers should be used where possible. Chip curlers are particularly important for making heavy cuts. The flat blade or circular parting tools may be used. They should provide 7° to 10° top rake and at least 3° side clearance. If parting is deep, a degree or two additional clearance may be necessary (ref. 5.1).

Milling cutters should have a positive rake as great as, or greater than, that used for carbon steels. This should be from 10° to 20° positive. The axial rake angle should be high to provide for smooth cutting. Saws and slotting cutters require a rake from 0° to 15°, and end and plain mills should have axial rake to 15° to 50° positive. The relief angle may vary from 5° to 10°; the larger the cutter, the smaller the angle. A lubricant must be used in milling (ref. 5.1).

Type 301 can be broached. The broach must be without nicks on the cutting edge. The back-off angle on internal broaches should range from 2° to 5°. Larger angles will shorten the life of the broach. The recommended lubricant for broaching is a sulfur-base paraffin-base oil mixture (ref. 5.1).

In reaming, enough metal should be allowed such that the tool can take a definite cut. A high speed spiral fluted reamer with a 30° to 35° chamfer angle and a 7° helix is suggested. Taper reaming may be performed on Type 301 and an ordinary finish can be obtained in this way. For precision work, a taper reaming attachment should be used. All reaming must be well lubricated with sulfurized oil (ref. 5.1).

TABLE 5.1. – Relative Formability of Annealed Austenitic Stainless * Steels in Order of Decreasing Formability

Source	Ref. 5.11				
180° Bend, 0.010 inch Min Radius or 10% Stretch (c)	Stretch Forming				
	10 - 20%	20 - 30%	30 - 35%(a)	30 - 35%(b)	>35%(a)
301	301	301	301	301	301
201	201	201	201	201	201
302	302	302	302	302	-
202	202	202	202	202	-
305	305	305	305	-	-
304	304	304	-	-	-
316	316	316	-	-	-
321	321	321	-	-	-
347	347	347	-	-	-
309	-	-	-	-	-
310	-	-	-	-	-

(a) Possible buckling (c) 0.010 inch = 0.254 mm
(b) No buckling
* Grades are listed in the order of decreasing ability to form parts having the indicated severity without intermediate annealing.

TABLE 5.2. – Friction Sawing Recommendations

Source	Ref. 5.1		
Alloy	Type 301		
Metal thickness, inches (a)	Saw pitch, feet per inch	Saw speed, feet per minute	Cutting rate, feet per minute
1/16	18	3,000-6,000	120
1/8	14	3,000-6,000	75
1/4	10	6,000-9,000	55
1/2	10	9,000-12,000	20
3/4	10	12,000-15,000	10
1	10	12,000-15,000	6

(a) 1 inch = 2.54 cm.

TABLE 5.3. – Machining Recommendations for Type 301 Stainless Steel

Source	Ref. 5.12							
Operation	Condition Hardness-BHN	Cutting Conditions	High Speed Tool			Carbide Tool		
			Speed fpm	Feed ipr	Tool mat'l	Speed fpm	Feed ipr	Tool mat'l
Turning, Single point and box tools	Annealed 135-185	0.150 in, depth of cut	80	0.015	T5, T15	275	0.015	C-2
		0.025 in, depth of cut	100	0.007	T5, T15	335	0.007	C-3
	Cold Drawn 225-275	0.150 in, depth of cut	75	0.015	T5, T15	250	0.015	C-2
		0.025 in, depth of cut	95	0.007	T5, T15	300	0.007	C-3
Turning, Form tool	Annealed 135-185	0.500in, form tool width	60	0.003	T5, T15	205	0.005	C-2
		0.750 in, form tool width	60	0.0025	T5, T15	205	0.004	C-2
		1.000 in, form tool width	60	0.0025	T5, T15	205	0.004	C-2
		1.500 in, form tool width	60	0.002	T5, T15	205	0.0035	C-2
		2.000 in, form tool width	60	0.002	T5, T15	205	0.0035	C-2
	Cold Drawn 225-275	0.500 in, form tool width	55	0.003	T5, T15	190	0.005	C-2
		0.750 in, form tool width	55	0.0025	T5, T15	190	0.004	C-2
		1.000 in, form tool width	55	0.0025	T5, T15	190	0.004	C-2
		1.500 in, form tool width	55	0.002	T5, T15	190	0.0035	C-2
		2.000 in, form tool width	55	0.002	T5, T15	190	0.0035	C-2
Boring	Annealed 135-185	0.010 in, depth of cut	80	0.004	T5, T15	275	0.005	C-3
		0.050 in, depth of cut	75	0.005	T5, T15	260	0.007	C-3
		0.100 in, depth of cut	70	0.007	T5, T15	250	0.009	C-3
	Cold Drawn 225-275	0.010 in, depth of cut	75	0.004	T5, T15	250	0.005	C-3
		0.050 in, depth of cut	70	0.005	T5, T15	240	0.007	C-3
		0.100 in, depth of cut	65	0.007	T5, T15	225	0.009	C-3
Face Milling	Annealed 135-185	0.150 in, depth of cut	95	0.006	M2	325	0.010	C-2
		0.025 in, depth of cut	125	0.005	M2	400	0.008	C-3
	Cold Drawn 225-275	0.150 in, depth of cut	85	0.006	M2	275	0.010	C-2
		0.025 in, depth of cut	100	0.005	M2	350	0.008	C-3
End Milling, Profiling	Annealed 135-185	1/4 in cutter diameter	90	0.001	M2, M6	225	0.001	C-2
	(0.050 in, depth cut)	1/2 in cutter diameter	90	0.002	M2, M6	225	0.002	C-2
		3/4 in cutter diameter	90	0.002	M2, M6	225	0.003	C-2
		1 to 2 in cutter diameter	90	0.003	M2, M6	225	0.005	C-2
	Cold Drawn 225-275	1/4 in cutter diameter	70	0.001	M2, M10	175	0.001	C-2
	(0.050 in, depth cut)	1/2 in cutter diameter	70	0.002	M2, M10	175	0.002	C-2
		3/4 in cutter diameter	70	0.002	M2, M10	175	0.003	C-2
		1 to 2 in cutter diameter	70	0.003	M2, M10	175	0.004	C-2
Drilling	Annealed 135-155	1/8 in nominal hole diam	50	0.003	(a)			
		1/4 in nominal hole diam		0.003				
		1/2 in nominal hole diam		0.005				
		1 in nominal hole diam		0.010				
		2 in nominal hole diam		0.016				
	Cold Drawn 225-275	1/8 in nominal hole diam	45	0.002	(a)			
		1/4 in nominal hole diam		0.003				
		1/2 in nominal hole diam		0.005				
		1 in nominal hole diam		0.011				
		2 in nominal hole diam		0.016				

(a) M10, M1, M7 Note: 1 inch = 25.4 mm.

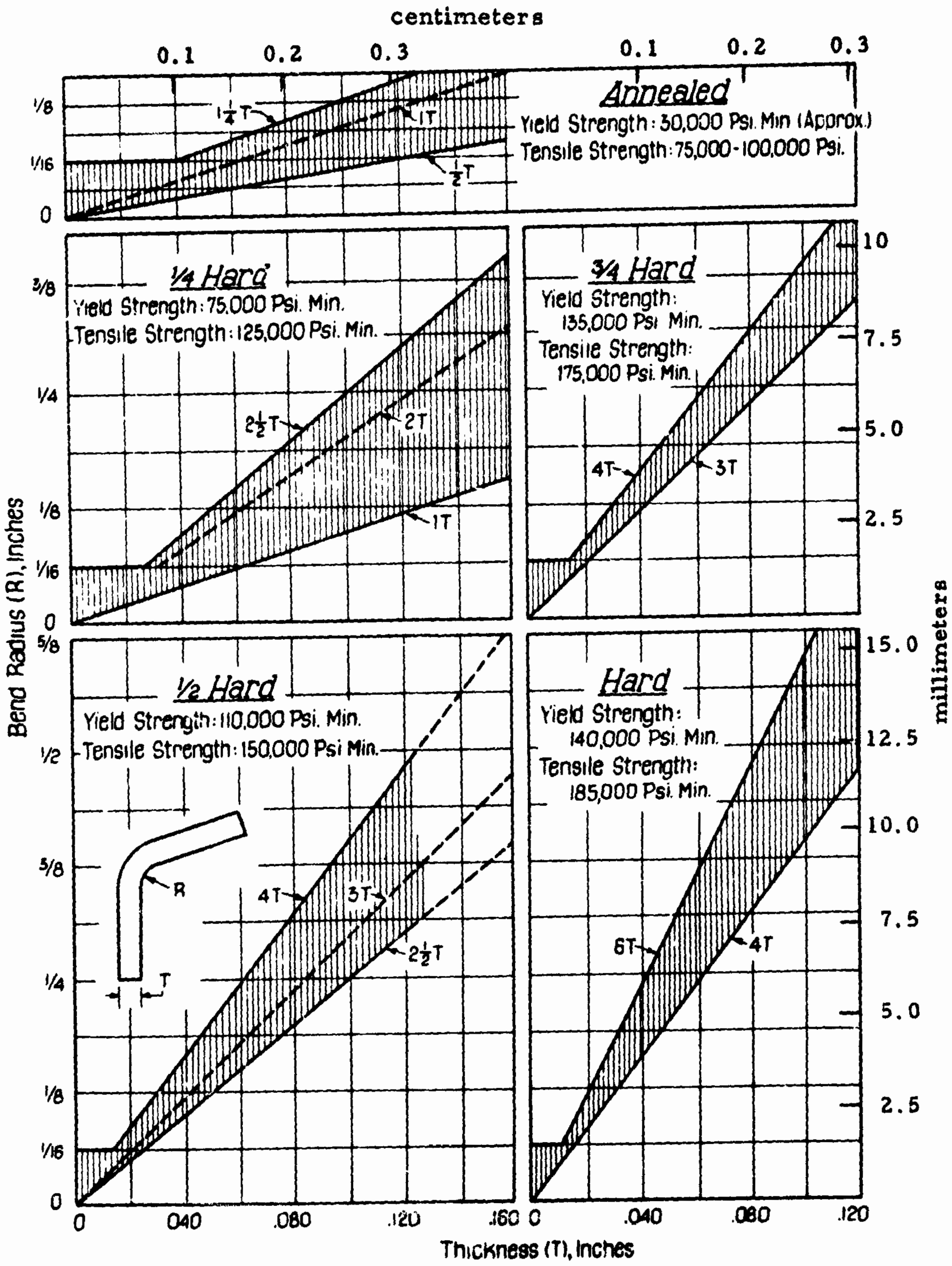

FIGURE 5.1. — Recommended minimum bend radii for Type 301 stainless steel for various tempers.
(1000 psi = 0.70307 kg/mm^2)

(Ref. 5.10)

Chapter 5 - References

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Chapter 6

SPACE ENVIRONMENT EFFECTS

6.1 General. The austenitic stainless steels are used successfully in both structural and nonstructural applications for launch vehicles and spacecraft. In general, these alloys are relatively insensitive to degradation under typical space environment conditions. The vapor pressures of stainless steels are sufficiently high (table 6.1). so that the combined temperature—vacuum effects are negligible. Nuclear and space indigenous radiation-induced defects do not appear to significantly affect mechanical and physical properties, at room ambient and elevated temperatures, below accumulated doses of about 1 x 10^{19} neutrons/cm^3 or greater (ref. 6.2). At these high doses, slight embrittlement takes place, resulting in increases in hardness and in some physical properties and a decrease in creep rate. Fatigue properties do not appear to be affected significantly. When irradiated at cryogenic temperatures, the dose threshold may be lowered by one or two decades, but the probabilities of encountering 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 individually and collectively influence the surface characteristics of stainless steels by desorption processes and erosion. These phenomena are of importance if optical properties, lubrication, certain electrical properties, etc. are critical design parameters.

Sputtering of the surface by atomic or molecular particles can deteriorate surface finishes in a relatively short period. The sputtering process is associated with a minimum threshold energy value for atomic or molecular particles striking a material surface. Typical values which have been obtained for this threshold energy are 6, 11, and 12 eV for O, N_2, and O_2 particles, respectively, to remove one or more atoms from the materials surface upon which they impinge (ref.6.11). Loss of metal by this mechanism can vary over a wide range and the greatest loss may be expected during solar storms (ref. 6.4). However, loss of metal by sputtering has little structural significance, although it may seriously affect optical and emissive properties of the material surface.

Micrometeoroids can produce surface erosion similar to sputtering but on a more macroscopic scale, and may also produce punctures They vary widely in mass, composition, velocity, and flux; generalizations about 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 figure 6.1. Data are given in figure 6.2 on the hit rate versus crater depth for steel and aluminum.

The surface erosion of stainless steels due to corpuscular radiation is probably insignificant, amounting to something of the order of 254 nm per year. Indigenous space radiation, however, will tend to accelerate the removal of surface films on stainless steels. The removal of such films might result in loss of lubricity and an increased propensity to "cold welds." The interaction of indigenous radiation with desorption gases might cause some spurious, transient electrical conditions if the alloy is used for electrical applications.

TABLE 6.1. — Evaporation Rates in Vacuum of Typical Elements Used in Aerospace Alloys (a, b)

Source	Ref. 6.14				
Element	Evaporation Rate, g/cm^2/sec				
	–100° C	0° C	100° C	250° C	500°C
Aluminum	1.2×10^{-81}	1.1×10^{-48}	2.0×10^{-33}	1.7×10^{-21}	6.5×10^{-12}
Titanium	$<10^{-99}$	2.5×10^{-60}	4.1×10^{-42}	7.4×10^{-28}	2.0×10^{-16}
Iron	$<10^{-99}$	6.8×10^{-64}	2.4×10^{-44}	4.8×10^{-29}	9.1×10^{-17}
Nickel	$<10^{-99}$	5.7×10^{-70}	1.3×10^{-48}	6.7×10^{-32}	1.7×10^{-18}
Copper	1.2×10^{-94}	1.4×10^{-56}	6.2×10^{-39}	4.0×10^{-25}	4.7×10^{-14}
Chromium	9.5×10^{-92}	1.0×10^{-54}	1.4×10^{-37}	3.8×10^{-24}	2.2×10^{-13}
Vanadium	$<10^{-99}$	1.9×10^{-87}	2.1×10^{-61}	5.0×10^{-41}	1.2×10^{-24}
Manganese	2.2×10^{-72}	1.1×10^{-42}	6.5×10^{-28}	3.8×10^{-18}	1.6×10^{-9}
Silicon	$<10^{-99}$	1.9×10^{-62}	3.6×10^{-43}	4.3×10^{-28}	5.5×10^{-16}
Magnesium	2.9×10^{-26}	5.3×10^{-20}	1.8×10^{-12}	1.3×10^{-6}	6.6×10^{-2}
Zinc	3.5×10^{-30}	5.1×10^{-16}	1.8×10^{-9}	2.3×10^{-4}	2.80

(a) The actual evaporation rate of each element in combination with others will be lower.

(b) The values may be in error by several orders of magnitude as they have been extrapolated from high-temperature data. The rates at low tempeatures will be considerably less than the values given in the table.

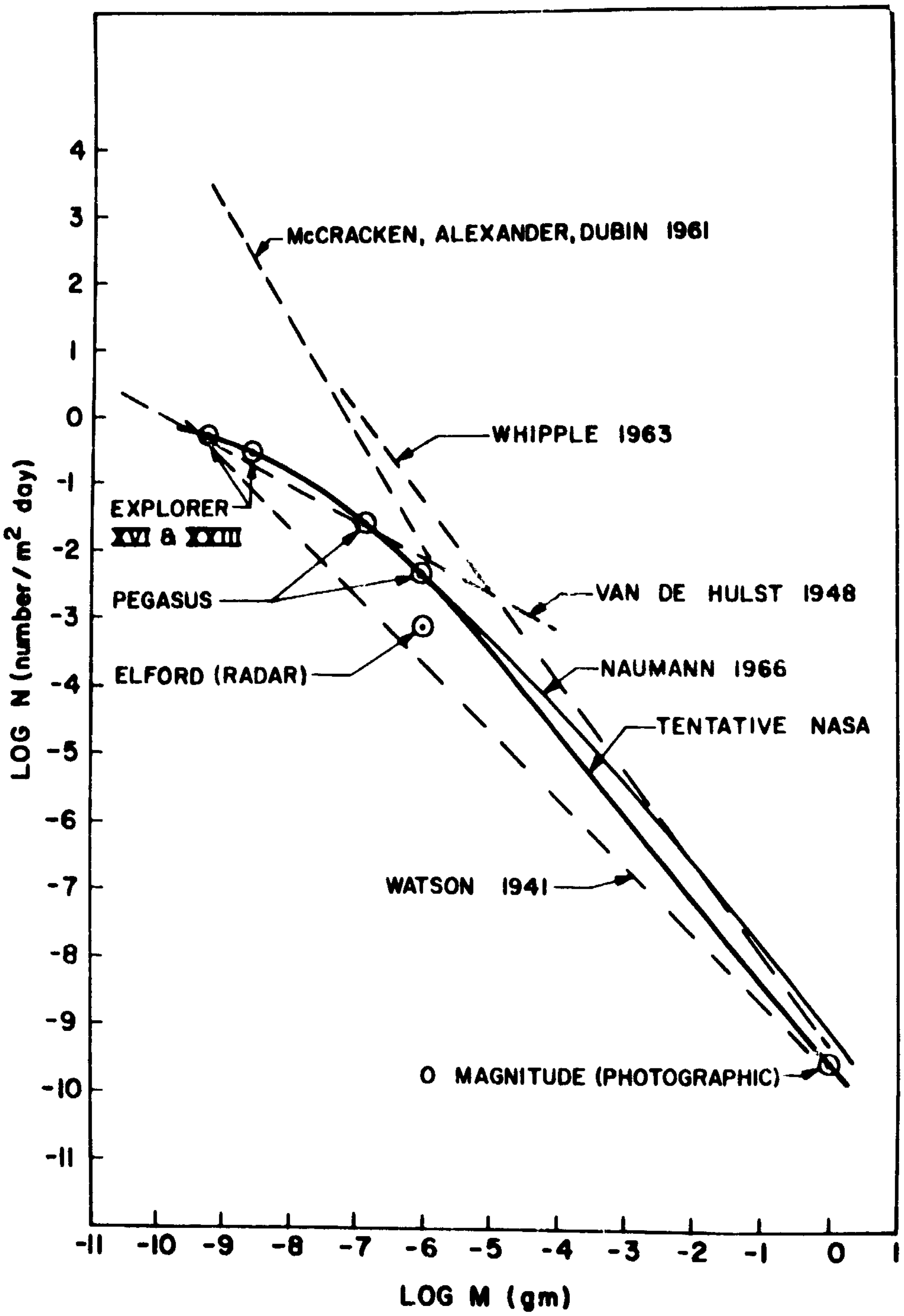

FIGURE 6.1. — Various estimates of meteoroid mass influx. (Ref. 6.3)

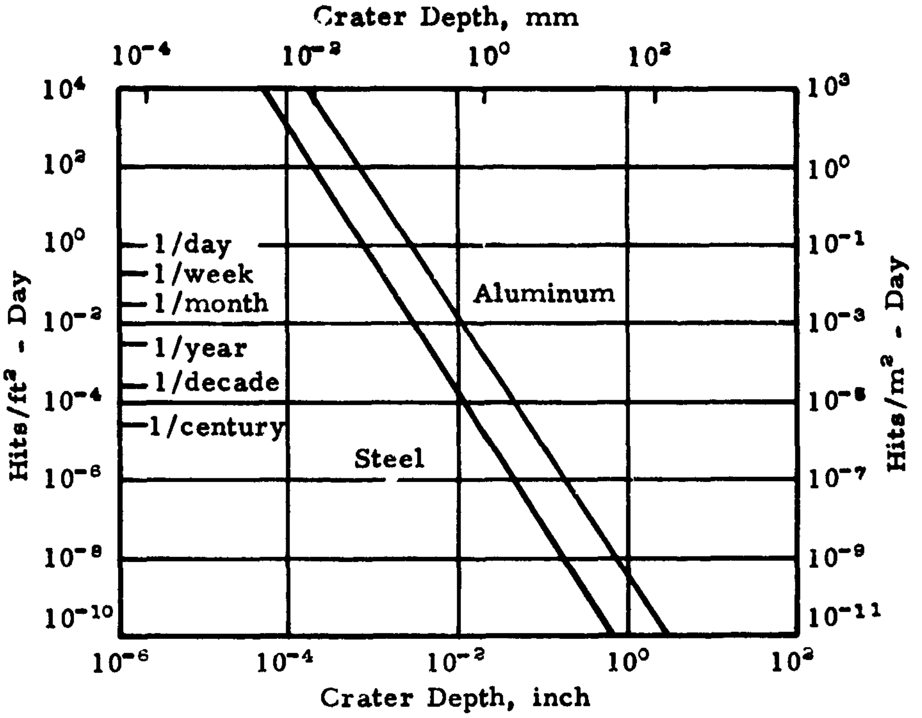

FIGURE 6.2. – Hit rate vs crater depth in the earth neighborhood but without earth shielding.

(Ref. 6.5)

Chapter 6 - References

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Chapter 7

STATIC MECHANICAL PROPERTIES

7.1 Specified Properties

7.11 NASA specified properties (none known)
7.12 AMS specified properties
7.121 AMS specified mechanical properties for sheet and strip, table 7.121.
7.13 Military specified properties
7.14 Federal specified properties
7.15 ASTM specified properties
7.151 ASTM specified properties for plate, sheet, and strip, table 7.151.

7.2 Elastic Properties and Moduli

7.21 Poisson's ratio
7.22 Young's modulus of elasticity, E.
7.221 Design values of E, E_c, and G, table 7.221.
7.222 Typical value of E: 28.0×10^3 ksi (19.7×10^3 kg/mm^2)(refs. 7.5, 7.6).
7.223 Modulus of elasticity of sheet and rod at low temperatures, figure 7.223.
7.224 Modulus of elasticity for 1/2-hard sheet at room and elevated temperatures, figure 7.224.
7.23 Compression modulus, E_c.
7.231 Design value of E_c, see table 7.221.
7.232 Effect of temperature on tensile and compressive modulus of 1/2-hard Type 301, figure 7.232.
7.233 Effect of temperature on tensile and compressive modulus of full-hard Type 301, figure 7.233.
7.24 Modulus of rigidity (shear modulus), G.
7.241 Design value of G, see table 7.221.
7.25 Tangent modulus
7.251 Typical tangent-modulus curves for Type 301 sheet and plate in tension (longitudinal) at room temperature, figure 7.251.
7.252 Typical tangent-modulus curves for Type 301 sheet and plate in tension (transverse) at room temperature, figure 7.252.
7.253 Typical tangent-modulus curves for Type 301 sheet and plate in compression (longitudinal) at room temperature, figure 7.253.
7.254 Typical tangent-modulus curves for Type 301 sheet and plate in compression (transverse) at room temperature, figure 7.254.
7.26 Secant modulus

7.3 Hardness

7.31 Effect of aging temperature on hardness of 67 percent cold rolled Type 301 sheet, figure 7.31.
7.32 Effect of hydrogen environment at elevated temperature on surface hardness of half-hard Type 301 sheet, figure 7.32.
7.33 AISI typical hardness values, table 7.33.

7.4 Strength Properties

7.41 Tension
7.411 Design tensile properties
7.4111 Design mechanical properties for plate, sheet, and strip, table 7.4111.
7.4112 Effect of cold reduction on tensile properties of sheet, figure 7.4112.
7.412 Stress-strain diagrams (tension)
7.4121 Stress-strain curves for sheet and strip cold-rolled to 1/4-hard and 1/2-hard conditions, figure 7.4121.
7.4122 Stress-strain curves for sheet and strip cold-rolled to 3/4-hard and full-hard conditions, figure 7.4122.
7.4123 Stress-strain curves for sheet and strip cold-rolled to extra-hard temper, figure 7.4123.
7.4124 Stress-strain curves for sheet in extra full hard condition at low temperatures, figure 7.4124.
7.4125 Typical tensile stress-strain curves at room and elevated temperatures for full-hard Type 301(longitudinal), figure 7.4125.
7.4126 Typical tensile stress-strain curves (transverse) at room and elevated temperatures for full-hard Type 301, figure 7.4126.
7.413 Effect of test temperature on tensile properties
7.4131 Effect of temperature on ultimate tensile strength of half-hard Type 301, figure 7.4131.
7.4132 Effect of temperature on tensile yield strength of half-hard Type 301, figure 7.4132.
7.4133 Effect of temperature on ultimate tensile strength of full-hard Type 301, figure 7.4133.
7.4134 Effect of temperature on tensile yield strength of full-hard Type 301, figure 7.4134.
7.4135 Tensile strength of sheet in various conditions at low temperatures, figure 7.4135.
7.4136 Yield strength of sheet in various conditions at low temperatures, figure 7.4136.
7.42 Compression
7.421 Design compression properties
7.4211 Design compression properties for plate, sheet, and strip, see table 7.4111.
7.422 Stress-strain diagrams (compression)
7.4221 Stress-strain curves in compression for Type 301 annealed sheet at elevated temperatures, figure 7.4221.
7.4222 Typical compressive stress-strain curves at room and elevated temperatures for full-hard Type 301 (longitudinal), figure 7.4222.
7.4223 Typical compressive stress-strain curves at room and elevated temperatures for full-hard Type 301 (transverse), figure 7.4223.
7.423 Typical compression properties
7.4231 Effect of temperature on compressive yield strength of half-hard Type 301, figure 7.4231.
7.4232 Effect of temperature on compressive yield strength of full-hard Type 301, figure 7.4232.
7.43 Bending
7.44 Shear and torsion
7.441 Design shear properties, see table 7.4111.
7.442 Effect of temperature on the ultimate shear strength of half-hard Type 301, figure 7.442
7.443 Effect of temperature on the ultimate shear strength of full-hard Type 301, figure 7.443

7.45 Bearing
7.451 Design bearing properties, see table 7.4111.
7.452 Effect on temperature on the ultimate bearing strength of Type 301 (half-hard), figure 7.452.
7.453 Effect of temperature on the bearing yield strength of Type 301 (half-hard), figure 7.453.
7.454 Effect of temperature on the ultimate bearing strength of Type 301 (full-hard), figure 7.454.
7.455 Effect of temperature on the bearing yield strength of Type 301 (full-hard), figure 7.455.
7.46 Fracture
7.461 Notch strength
7.4611 Effect of test temperature and exposure time on notch strength of 60 percent cold-reduced sheet, figure 7.4611.
7.4612 Effect of cold reduction and test direction on sharp notch strength of sheet, figure 7.4612.
7.4613 Effect of test temperature on net fracture stress of full-hard sheet, figure 7.4613.

TABLE 7.121. — AMS Specified Mechanical Properties for Sheet and Strip (a)

Alloy	Type 301				
Source	Ref. 7.1	Ref. 7.2		Ref. 7.3	
Condition	1/4 Hard	1/2 Hard		Full Hard	
Thickness, inch (b)	None Given	≤0.015	>0.015	≤0.015	>0.015
F_{tu}, ksi —min	125 (c)	150	150	185	185
—max	150	-	-	-	-
F_{ty}, ksi —min	75	110	110	140	140
—max	-	-	-	-	-
e(2 in), % —min	25	15	18	8	9

(a) For widths 9 inches and over, tensile specimens shall be taken with the axis perpendicular to the direction of rolling.
For widths less than 9 inches, tensile specimens shall be taken with the axis parallel to rolling direction.

(b) 0.015 in = 0.38 mm; 2 in = 50.8 mm.

(c) 1 ksi = 0.70307 kg/mm^2

TABLE 7.151. — ASTM Specified Properties for Plate, Sheet, and Strip

Source	Ref. 7.4				
Alloy	Type 301				
Form	Plate	Sheet and Strip			
Specification	A167-63		A177-67		
Condition	Ann	1/4 Hard	1/2 Hard	3/4 Hard	Full Hard
F_{tu}(min), ksi (a)	75.0	125.0	150.0	175.0	185.0
F_{ty}(min), ksi	30.0	75.0	110.0	135.0	140.0
e(2 in), min %					
≤0.015 in (b)	40	25	15	10	8
>0.015 in	40	25	18	12	9
Hardness, max					
Brinell	202	-	-	-	-
R B	94	-	-	-	-

(a) 1 ksi = 0.70307 kg/mm^2 (b) 0.015 in = 0.38 mm. 2 in = 25.4 mm.

TABLE 7.221. – Design Values of E, E_c and G for Sheet and Strip (a)

Source	Ref. 7.9				
Alloy	Type 301				
Condition	Ann	1/4 Hard	1/2 Hard	3/4 Hard	Full Hard
E, 10^3 ksi –L	29.0	27.0	26.0	26.0	26.0
–T	29.0	28.0	28.0	28.0	28.0
E_c, 10^3 ksi –L	28.0	26.0	26.0	26.0	26.0
–T	28.0	27.0	27.0	27.0	27.0
G, 10^3 ksi (b)	12.5	12.0	11.5	11.0	11.0

(a) Properties for annealed condition only are applicable to plate.
(b) 1 x 10^3 ksi = 0.70307 x 10^3 kg/mm^2

TABLE 7.33. – AISI Typical Hardness Values

Source	Ref. 7.14	
Alloy	Type 301	
Form	Condition	Hardness Value (av)
Sheet, strip	Annealed	85 RB
	1/4 hard	25 RC
	1/2 hard	32 RC
	3/4 hard	37 RC
	Full hard	41 RC
Plate	Annealed	165 BHN

TABLE 7.4111. – Design Mechanical Properties for Sheet and Plate

Source	Ref. 7.9								
Alloy	AISI 301 (a)								
Condition	Annealed	1/4 hard		1/2 hard		3/4 hard		Full hard	
Basis	S	A	B	A	B	A	B	A	B
F_{tu}, ksi (c)									
–L	75	124	129	141	151	157	168	174	185
–T	75	122	127	142	152	163	173	175	186
F_{ty}, ksi									
–L	30	69	83	93	110	118	135	137	153
–T	30	67	82	92	105	113	133	125	142
F_{cy}, ksi									
–L	27	46	56	63	72	78	91	86	98
–T	27	74	91	102	117	126	148	139	158
F_{su}, ksi	50	66	69	77	82	88	93	95	100
F_{bru}, ksi									
(e/D=1.5)	-	-	-	-	-	-	-	-	-
(e/D=2.0)	150	244	254	284	304	326	346	350	372
F_{bry}, ksi									
(e/D=1.5)	-	-	-	-	-	-	-	-	-
(e/D=2.0)	50	125	153	167	191	200	236	241	274
e, percent									
$\leq$0.015 in (c)	40	25		15		10		8	
>0.016 in	-	25		18		12		9	
0.016-0.030	45	-		-		-		-	
>0.030	50	-		-		-		-	

(a) Properties for annealed condition also applicable to plate.

(b) F_{tu} and F_{ty} values less than specification values.

(c) 1 inch = 25.4 mm; 1 ksi = 0.70307 kg/mm^2.

Note: Yield strength, particularly in compression may be raised appreciably by thermal stress-relieving treatment in the range 500° to 800° F (260° to 427° C).

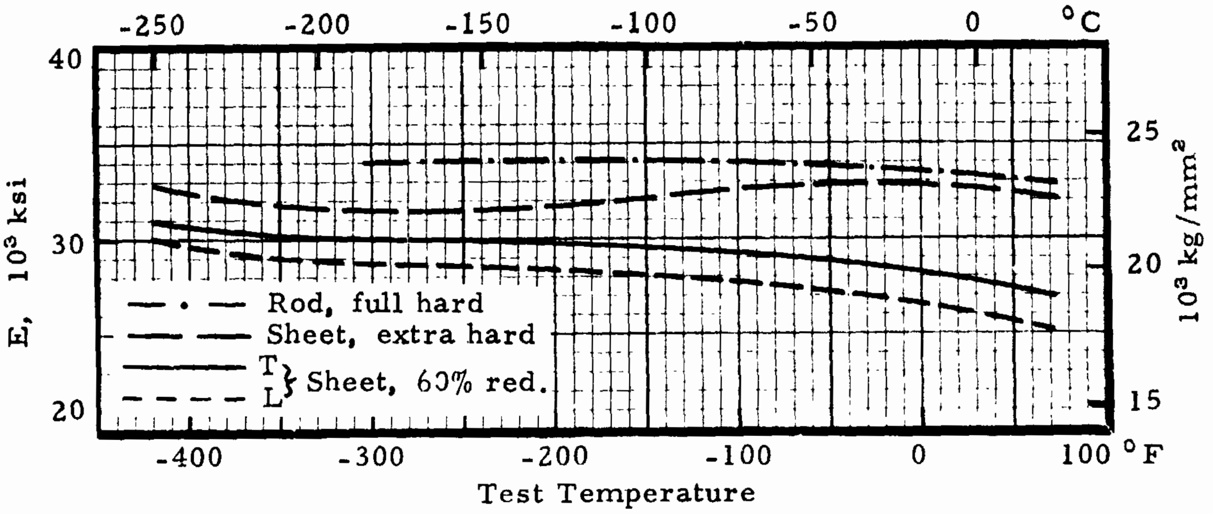

FIGURE 7.223. – Modulus of elasticity of Type 301 sheet and rod at low temperatures.

(Ref. 7.8)

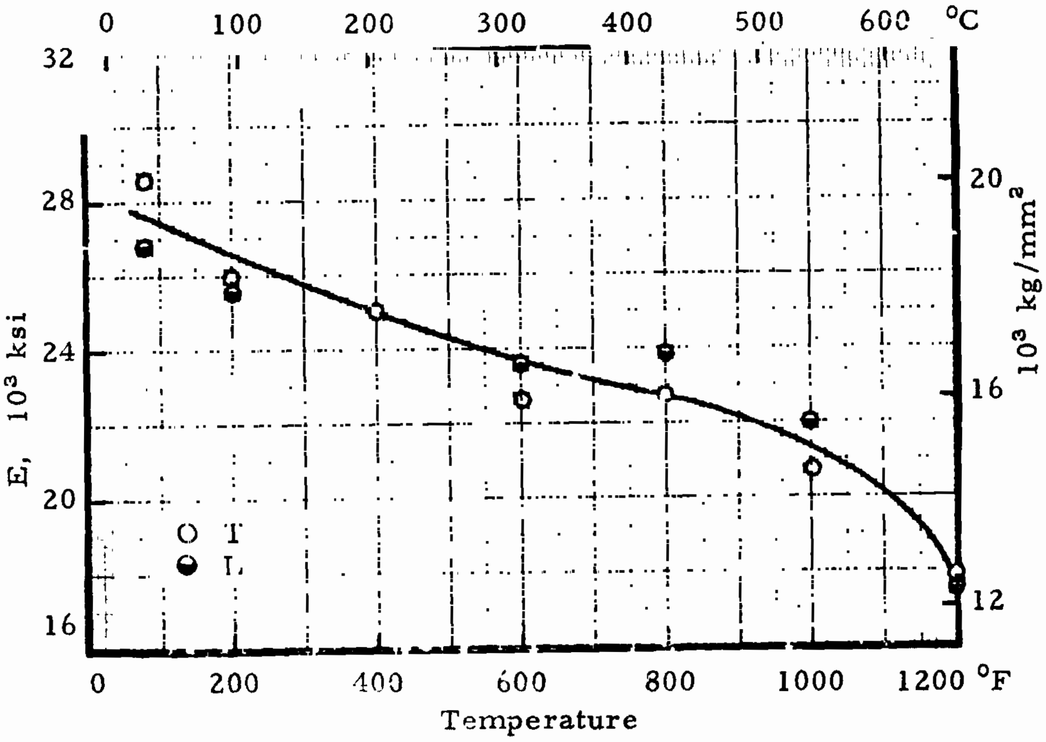

FIGURE 7.224. – Modulus of elasticity for Type 301 half-hard sheet at room and elevated temperatures.

(Ref. 7.7)

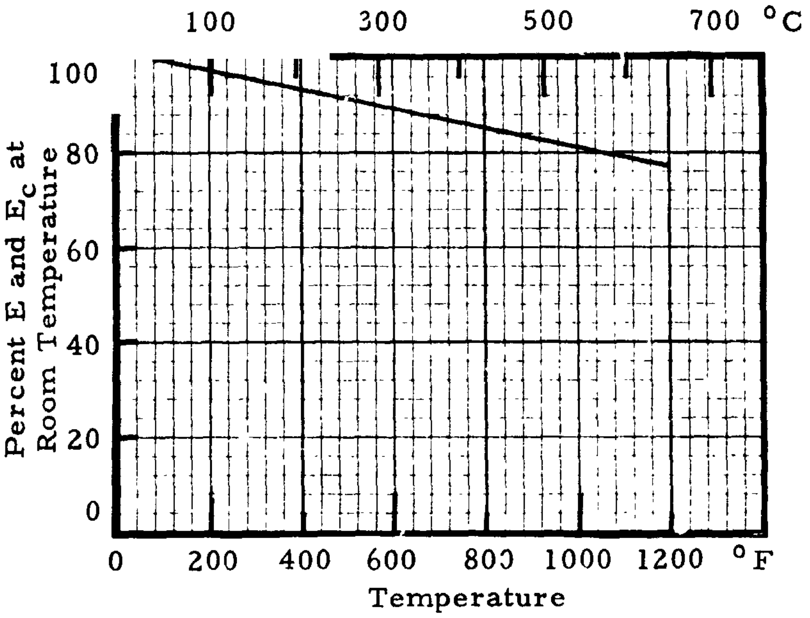

FIGURE 7.232. – Effect of temperature on the tensile and compressive modulus of Type 301 (half-hard). (Ref. 7.9)

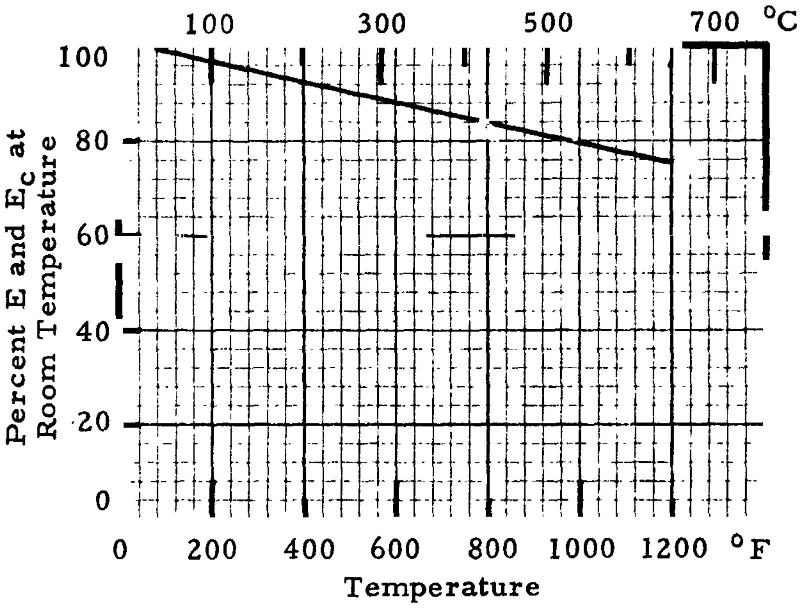

FIGURE 7.233. – Effect of temperature on the tensile and compressive modulus of Type 301 (full hard). (Ref. 7.9)

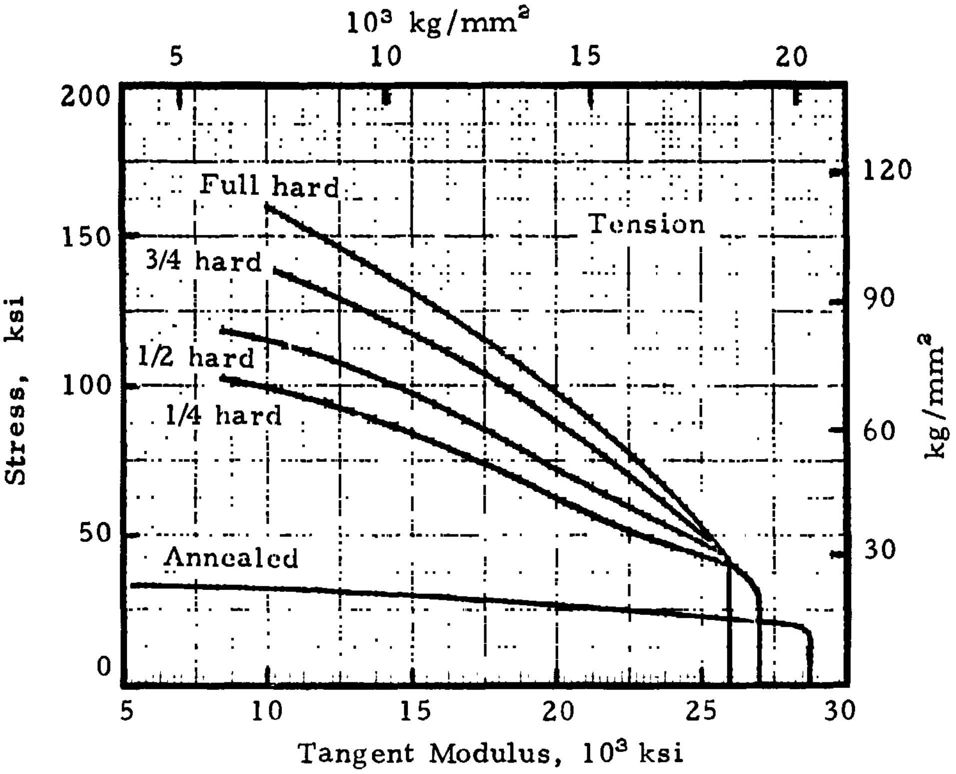

FIGURE 7.251. – Typical tangent-modulus curves (longitudinal) for Type 301 sheet and plate at room temperature. (Ref. 7.9)

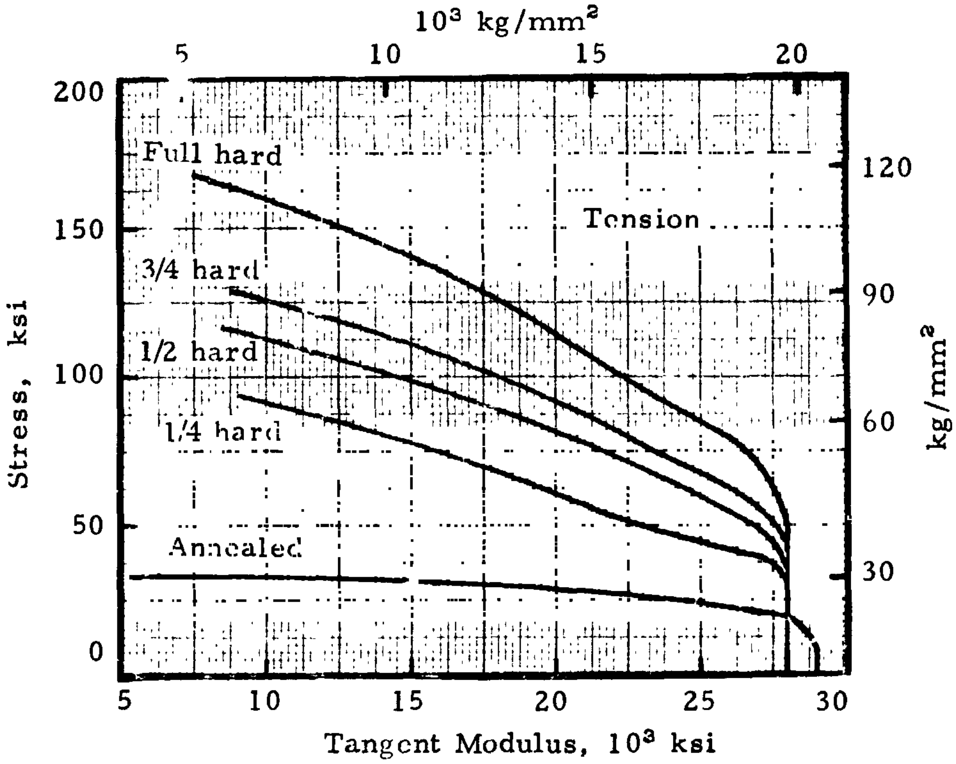

FIGURE 7.252. – Typical tangent-modulus curves (transverse) for Type 301 sheet and plate at room temperature. (Ref. 7.9)

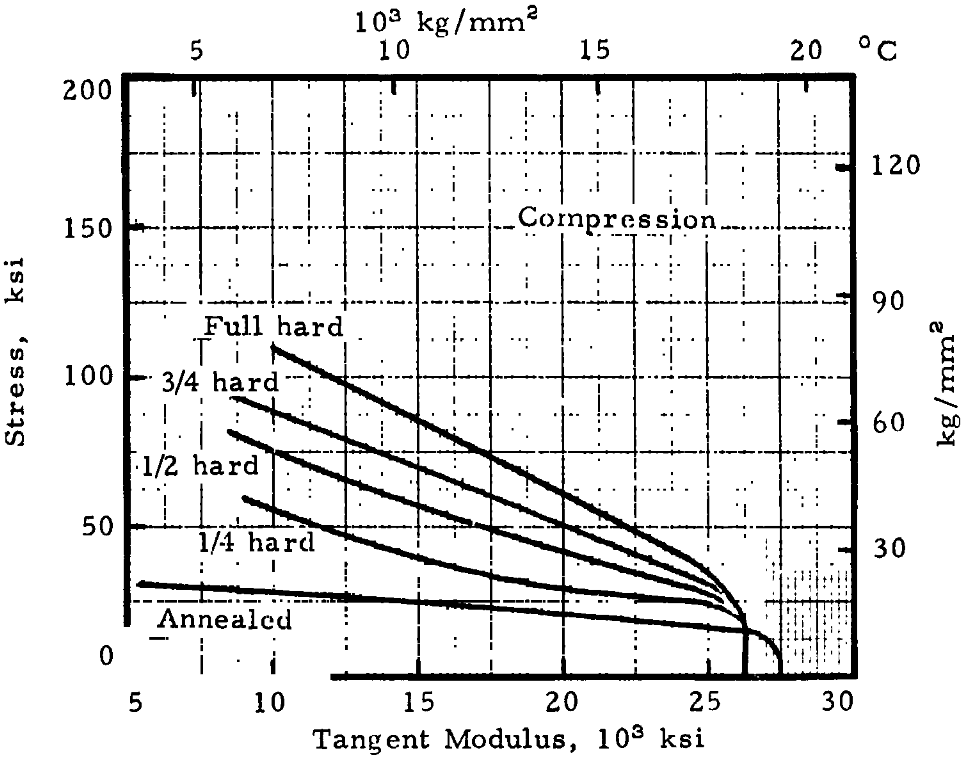

FIGURE 7.253. – Typical tangent-modulus curves (longitudinal) for Type 301 sheet and plate at room temperature.
(Ref. 7.9)

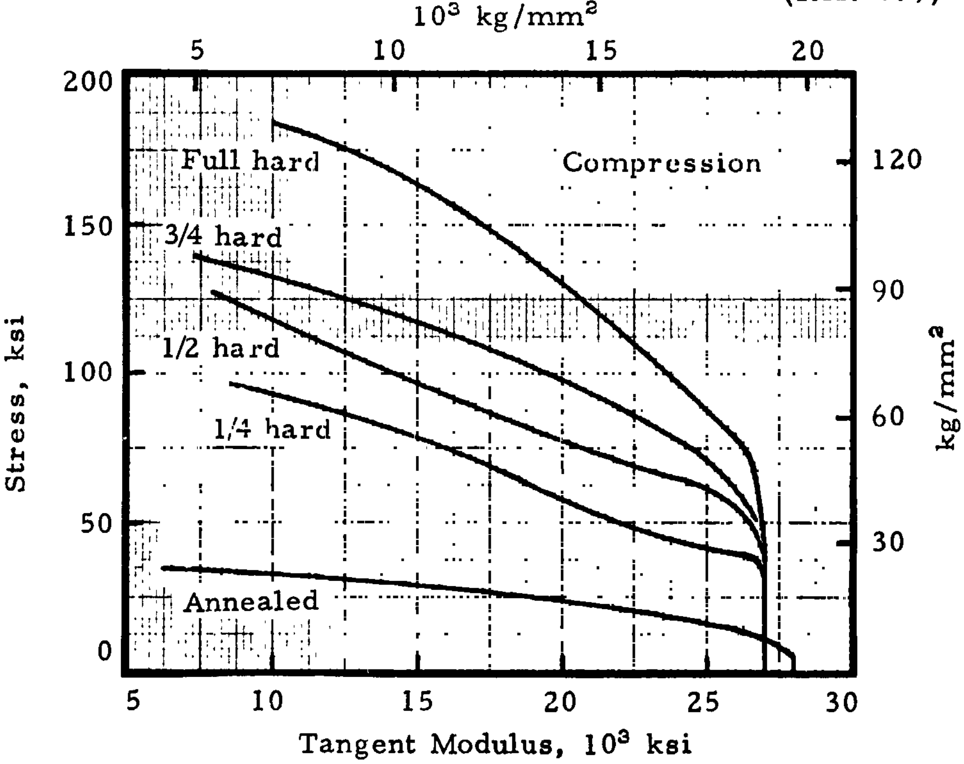

FIGURE 7.254. – Typical tangent-modulus curves (transverse) for Type 301 sheet and plate at room temperature.
(Ref. 7.9)

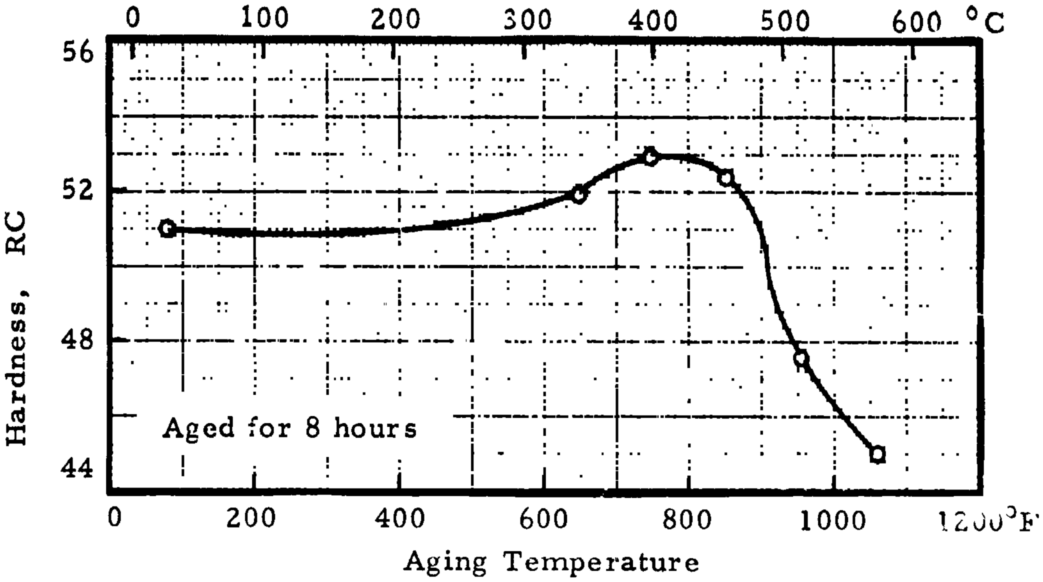

FIGURE 7.31. – Effect of aging temperature on hardness of 67-percent cold-rolled Type 301 sheet. (Ref. 7.11)

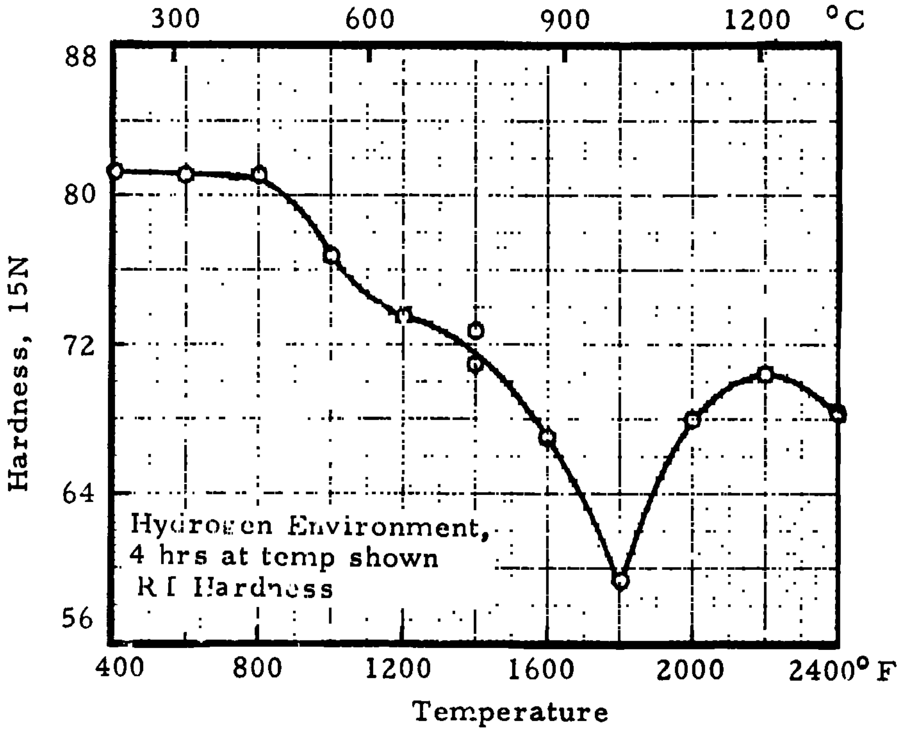

FIGURE 7.32. – Effect of hydrogen environment at elevated temperature on surface hardness of Type 301 half-hard sheet; thickness, 0.012 inch (0.305 mm). (Ref. 7.12)

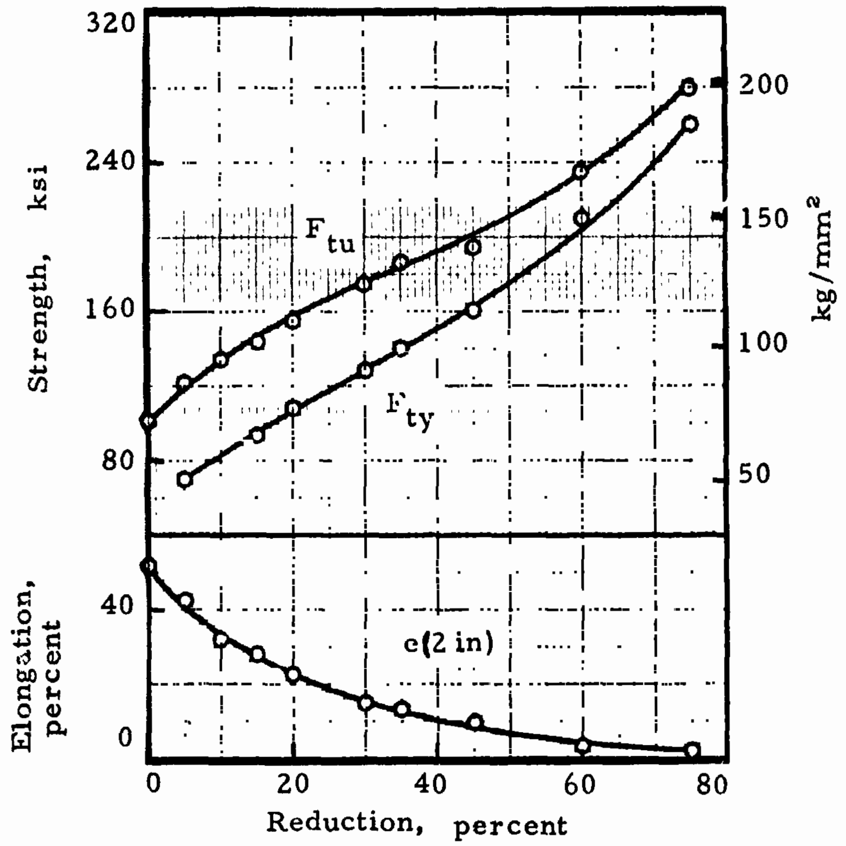

FIGURE 7.4112. – Effect of cold reduction on tensile properties of Type 301 sheet.
(Ref. 7.13)

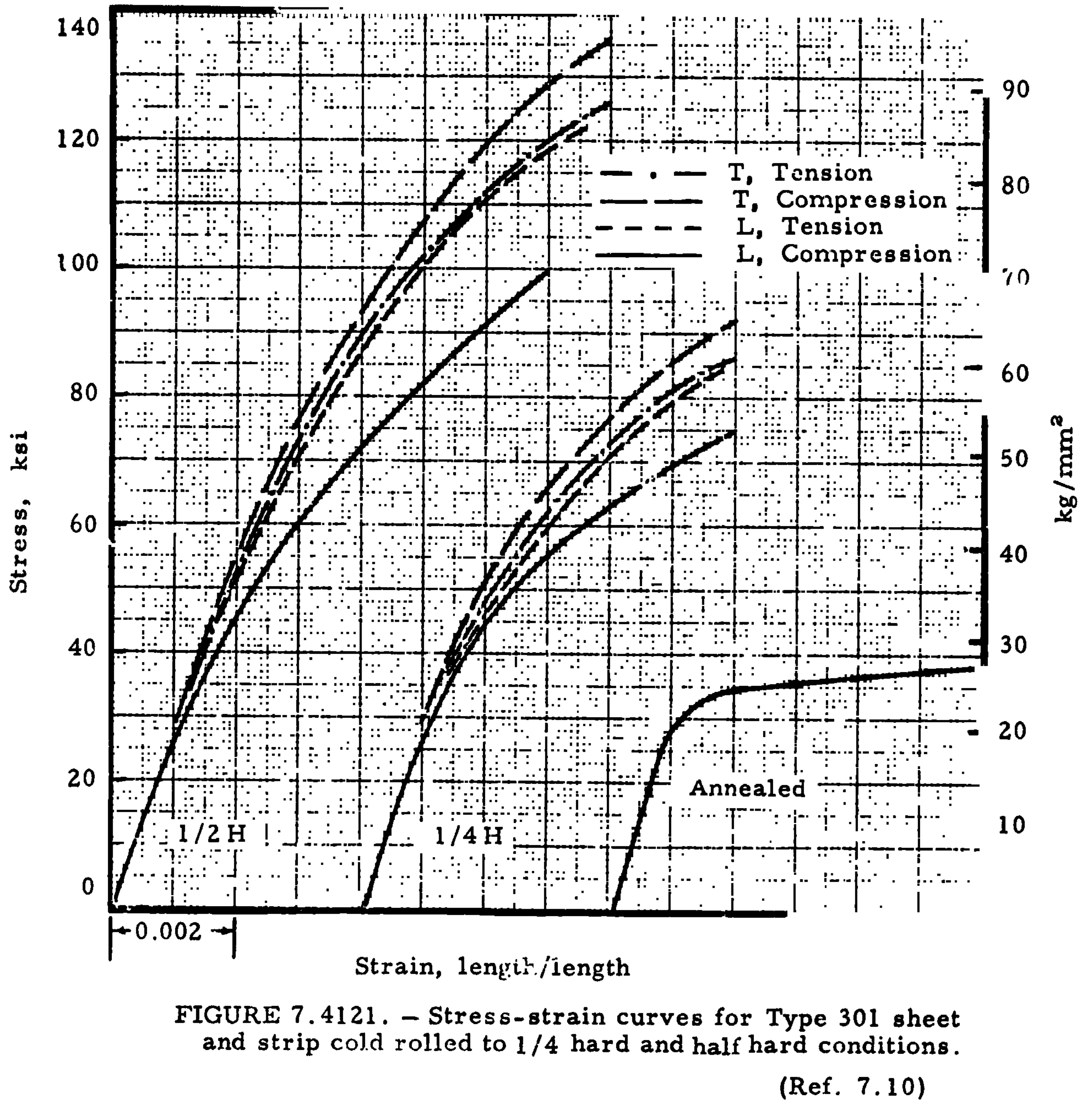

FIGURE 7.4121. – Stress-strain curves for Type 301 sheet and strip cold rolled to 1/4 hard and half hard conditions.

(Ref. 7.10)

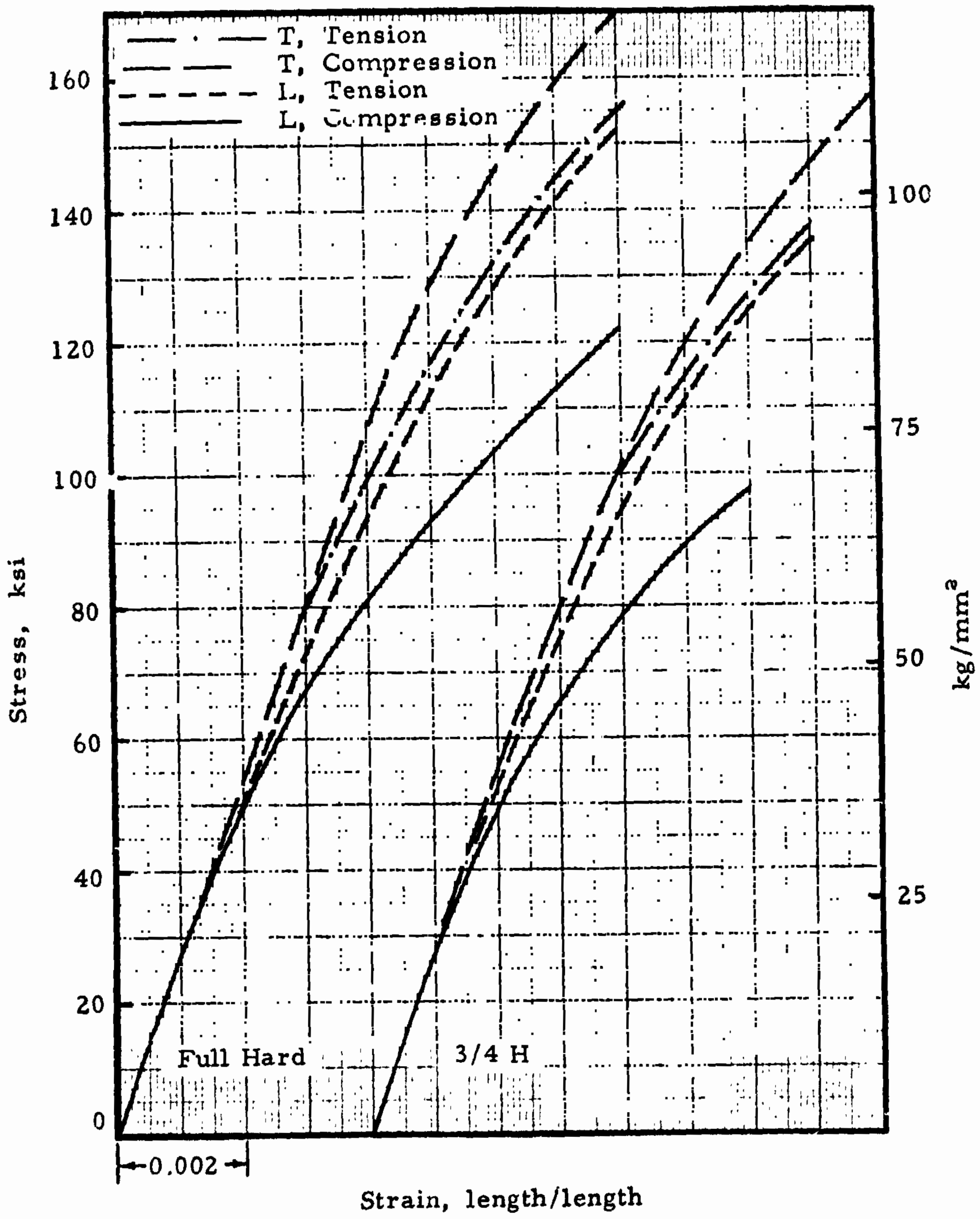

FIGURE 7.4122. – Stress-strain curves for Type 301 sheet and strip cold rolled to 3/4 hard and full hard conditions.

(Ref. 7.10)

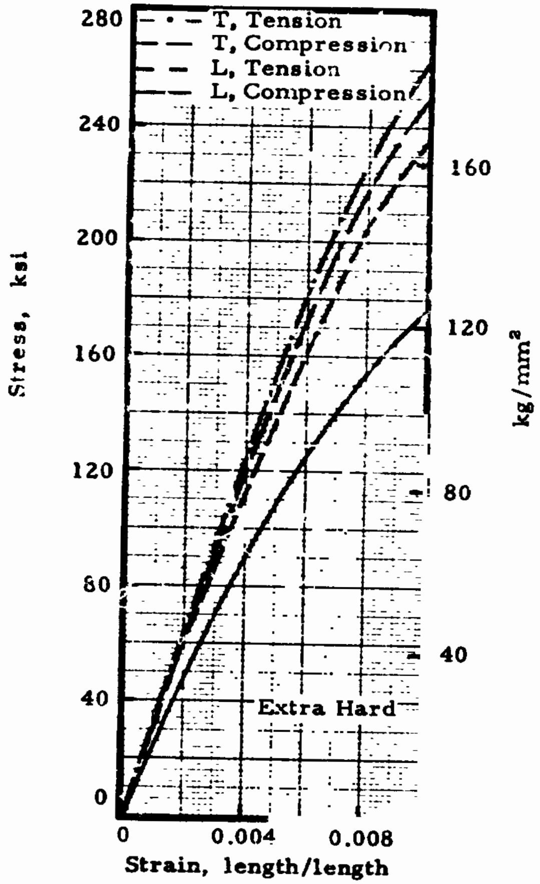

FIGURE 7.4123. — Stress-strain curves for Type 301 sheet and strip cold rolled to extra hard temper. (Ref. 7.7)

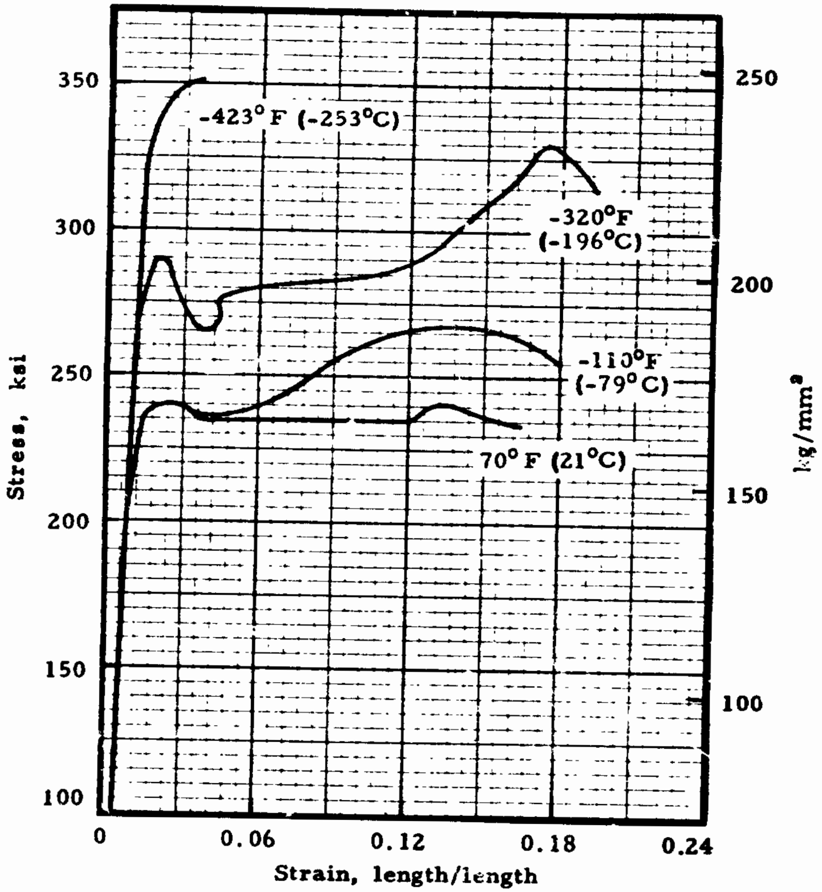

FIGURE 7.4124. — Stress-strain curves for Type 301 sheet in extra full hard condition at low temperatures. (Ref. 7.8)

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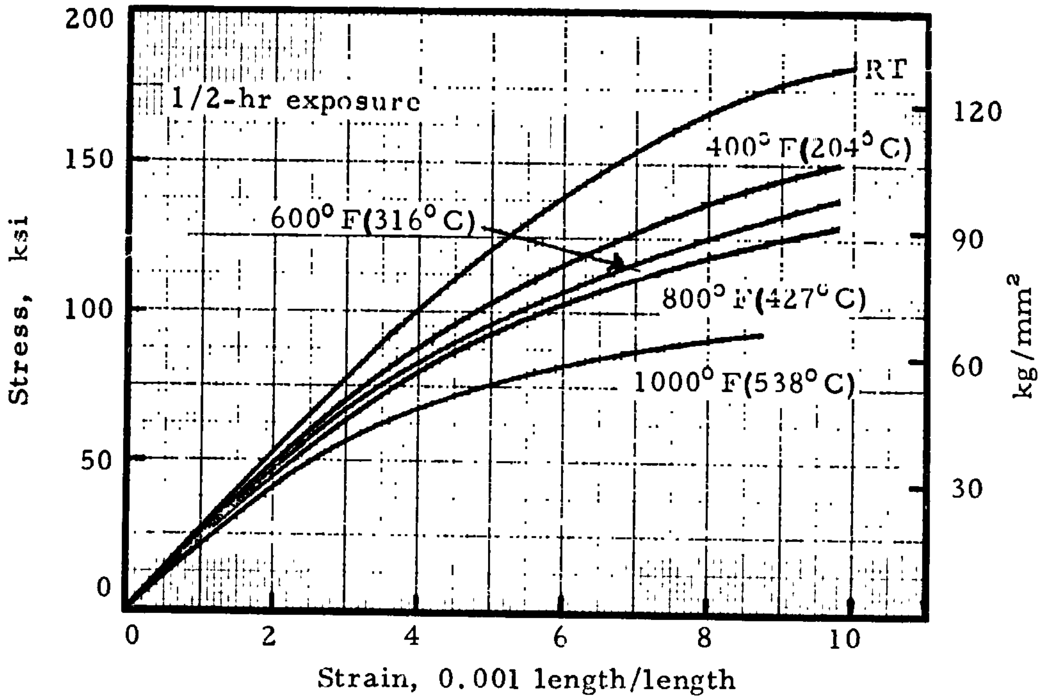

FIGURE 7.4125. – Typical stress-strain curves (longitudinal) at room and elevated temperatures for Type 301 (full-hard). (Ref. 7.9)

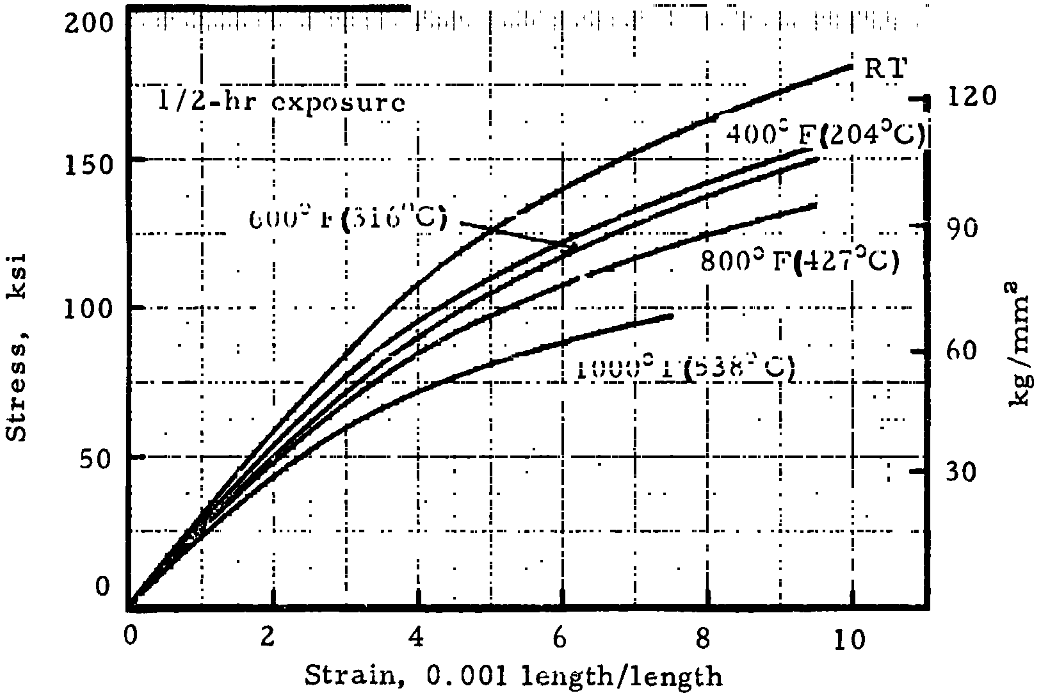

FIGURE 7.4126. – Typical stress-strain curves (transverse) at room and elevated temperatures for Type 301 (full-hard). (Ref. 7.9)

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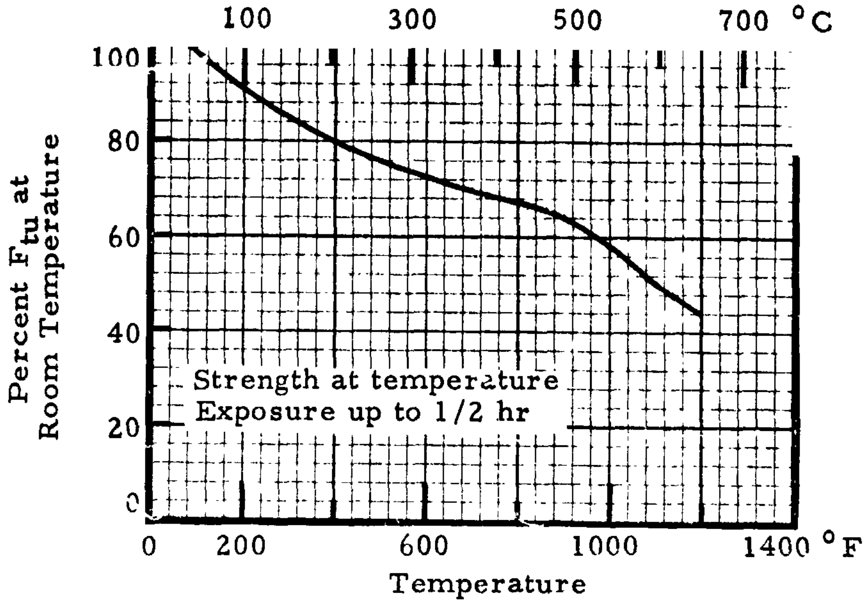


FIGURE 7.4131. – Effect of temperature on the ultimate tensile strength of Type 301 (half-hard).
(Ref. 7.9)

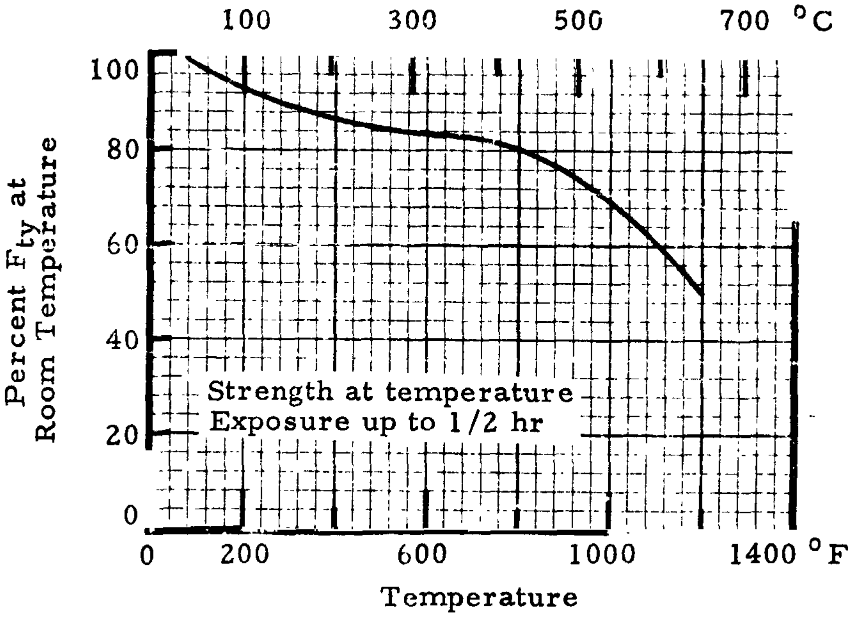


FIGURE 7.4132. – Effect of temperature on the tensile yield strength of Type 301 (half-hard).
(Ref. 7.9)

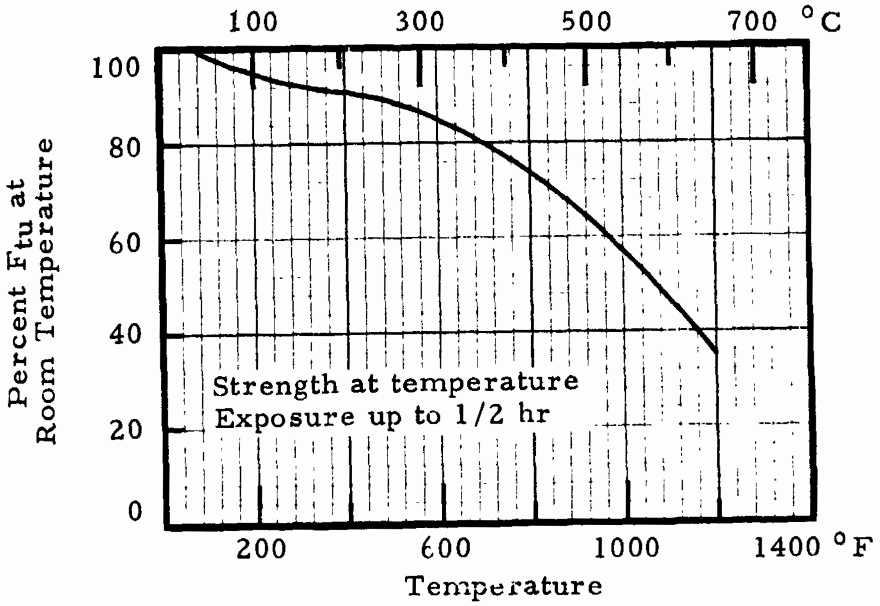


FIGURE 7.4133. — Effect of temperature on the ultimate tensile strength of Type 301 (full-hard). (Ref. 7.9)

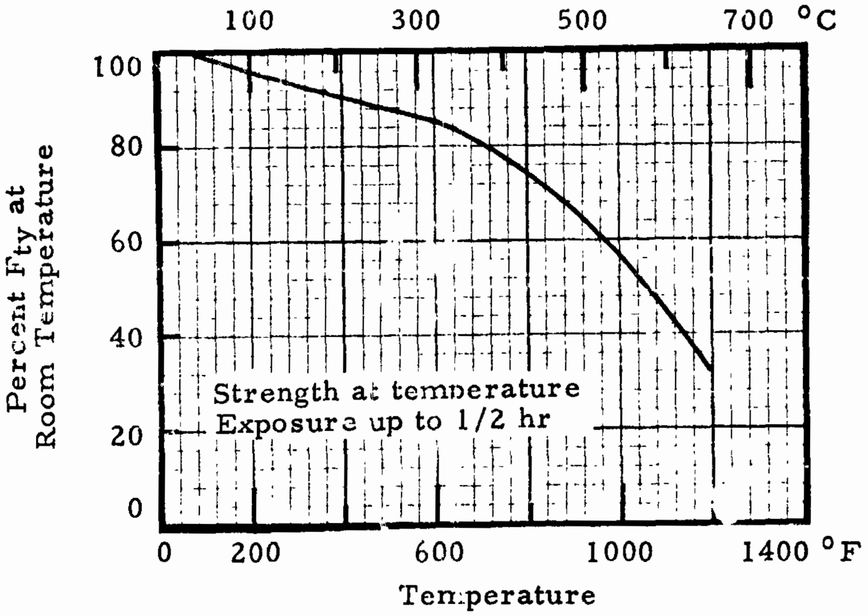


FIGURE 7.4134. — Effect of temperature on the tensile yield strength of Type 301 (full-hard). (Ref. 7.9)

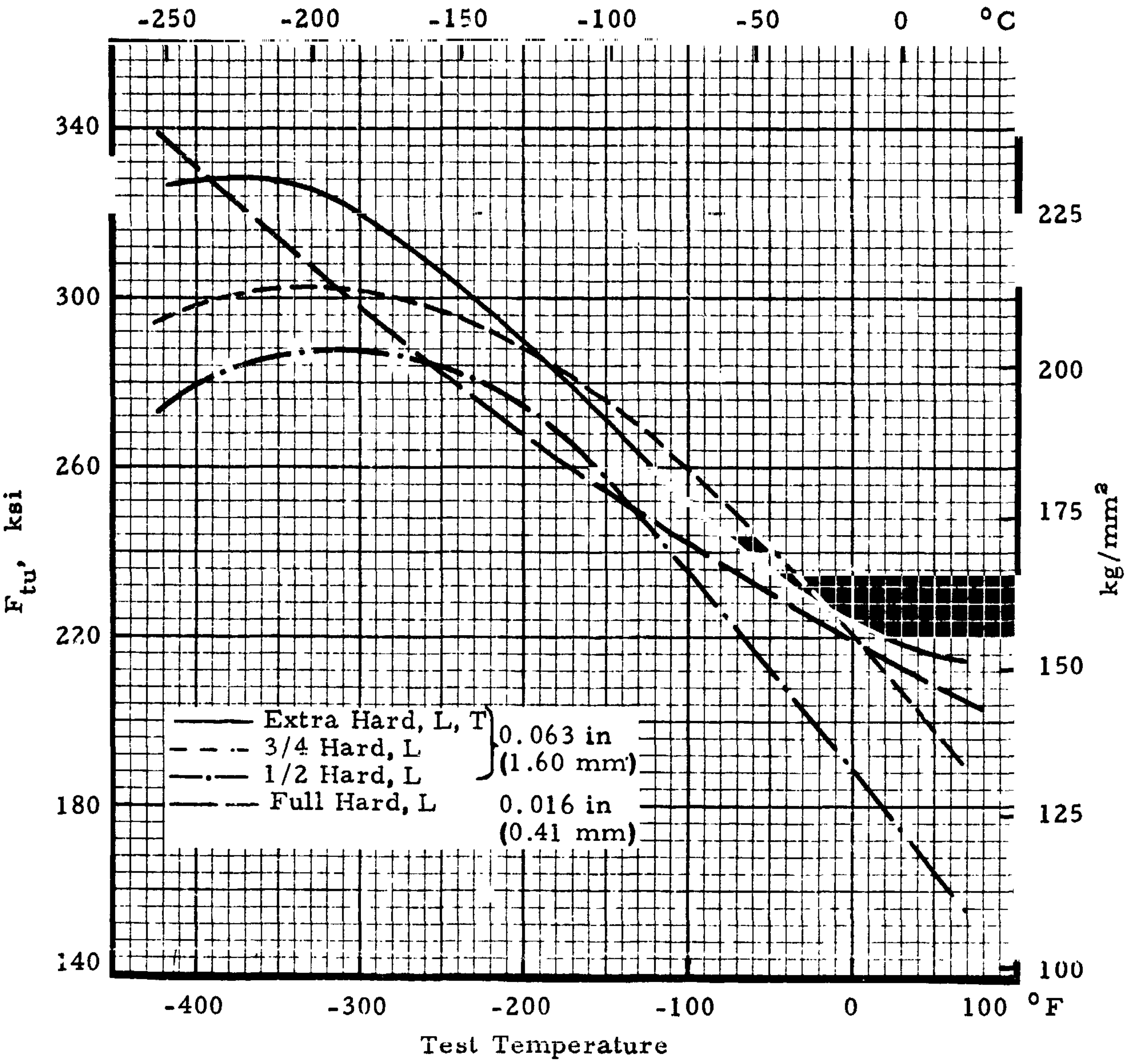


FIGURE 7.4135. -- Tensile strength of Type 301 sheet in various conditions at low temperatures.

(Ref. 7.8)

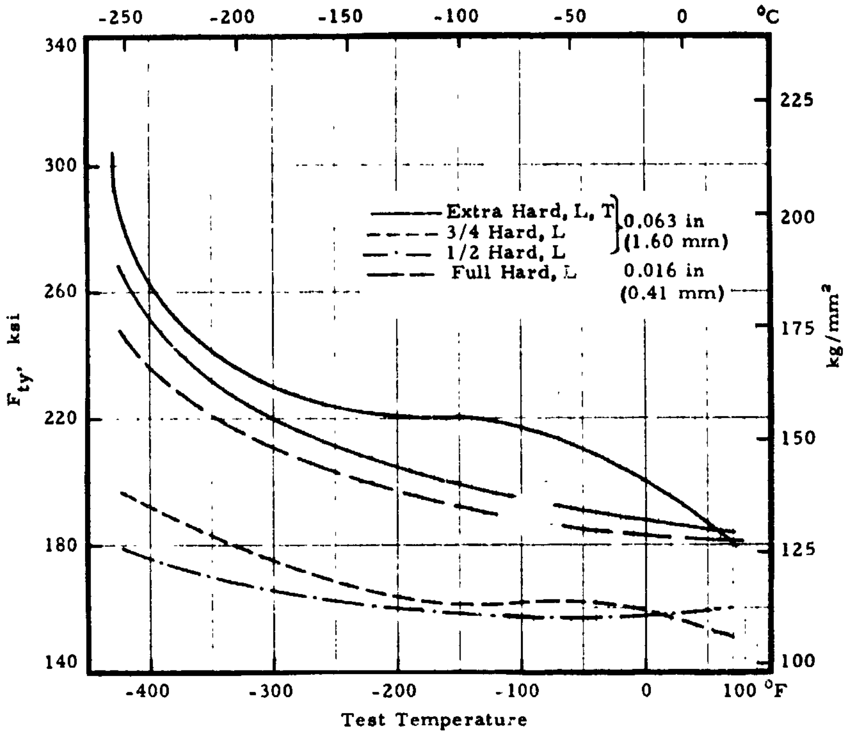


FIGURE 7.4136. – Yield strength of Type 301 sheet in various conditions at low temperatures.
(Ref. 7.8)

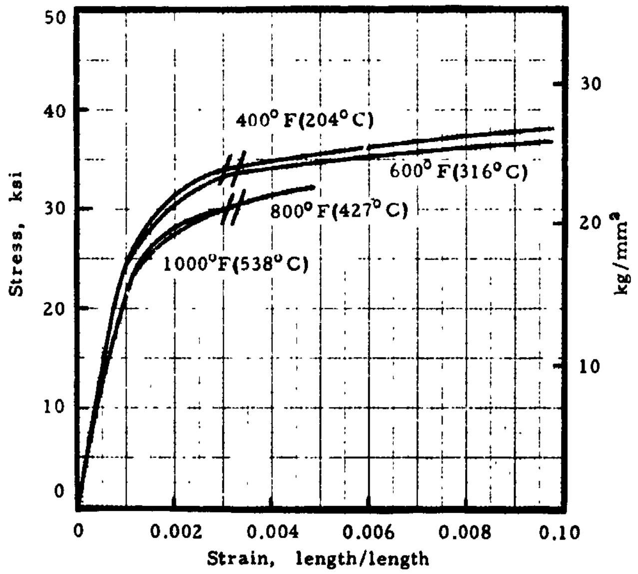


FIGURE 7.4221. – Stress-strain curves in compression for Type 301 annealed sheet at elevated temperatures; thickness, 0.063 inch (1.60 mm).
(Ref. 7.15)

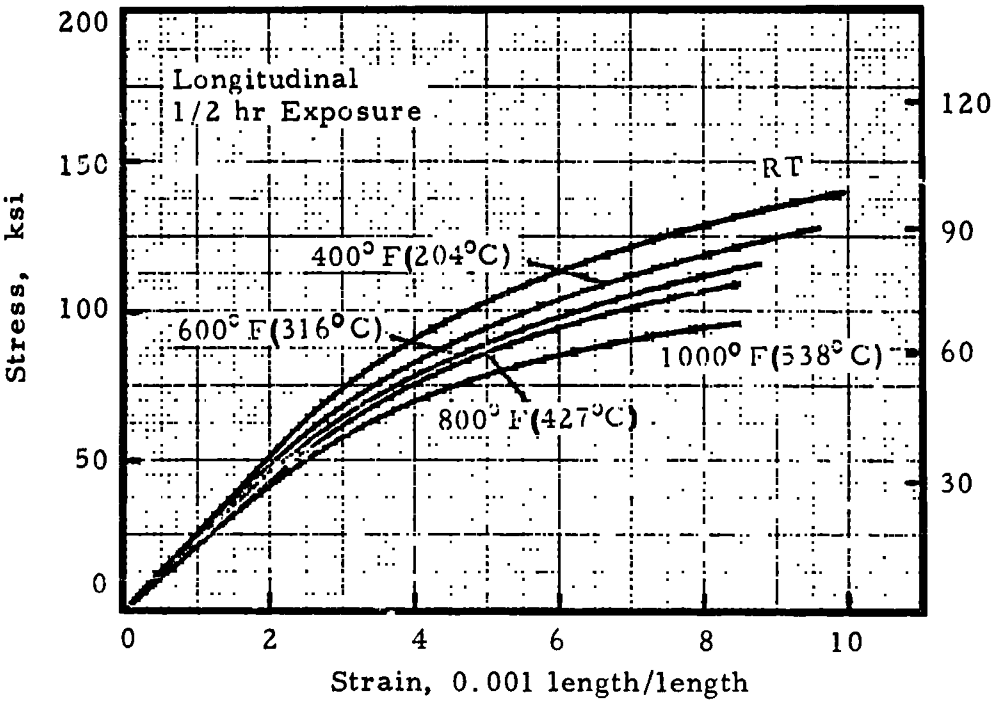


FIGURE 7.4222. – Typical compressive stress-strain curves at room and elevated temperatures for Type 301 (full-hard). (Ref. 7.9)

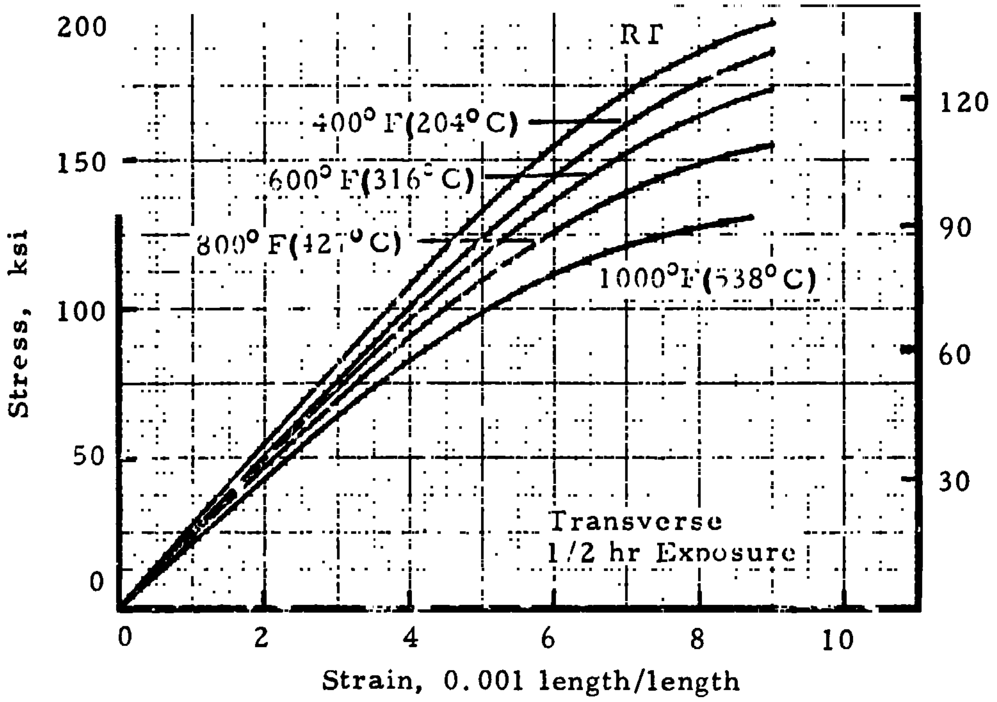


FIGURE 7.4223. – Typical compressive stress-strain curves at room and elevated temperatures for Type 301 (full-hard). (Ref. 7.9)

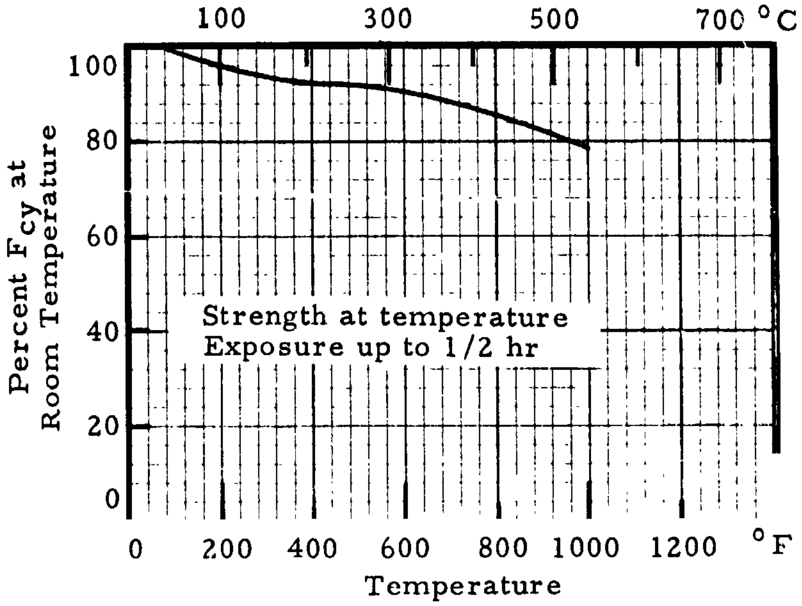
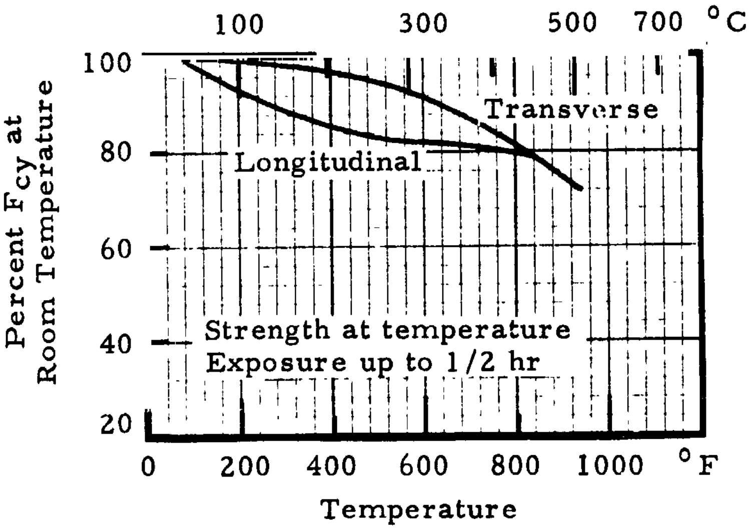


FIGURE 7.4231. – Effect of temperature on the compressive yield strength of Type 301 (half-hard). (Ref. 7.9)



URE 7.4232. – Effect of temperature on the compressive yield strength of Type 301 (full-hard). (Ref. 7.9)

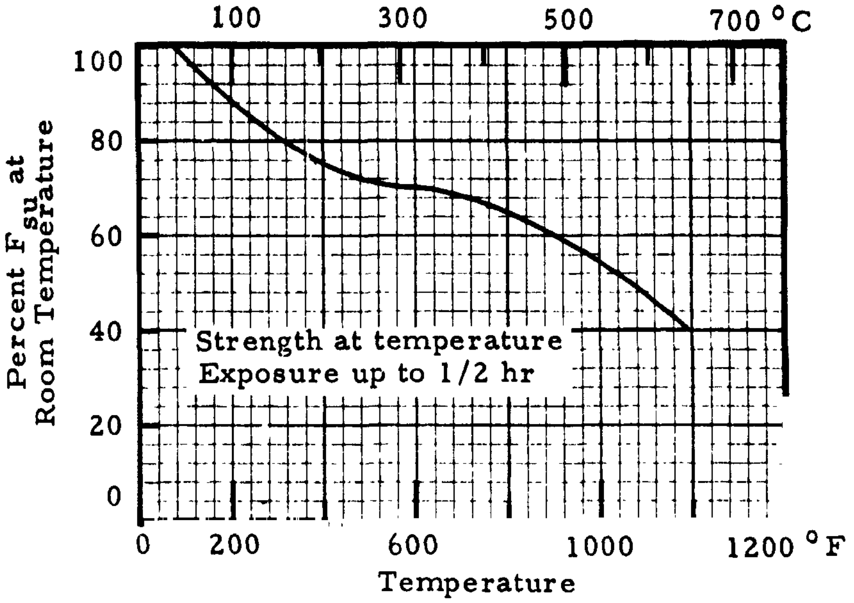


FIGURE 7.442. – Effect of temperature on the ultimate shear strength of Type 301 (half-hard).
(Ref. 7.9)

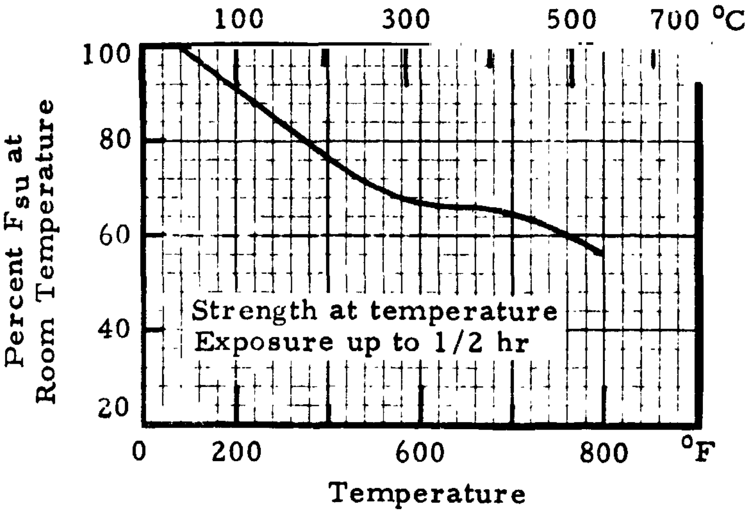


FIGURE 7.443. – Effect of temperature on the ultimate shear strength of Type 301 (full-hard).
(Ref. 7.9)

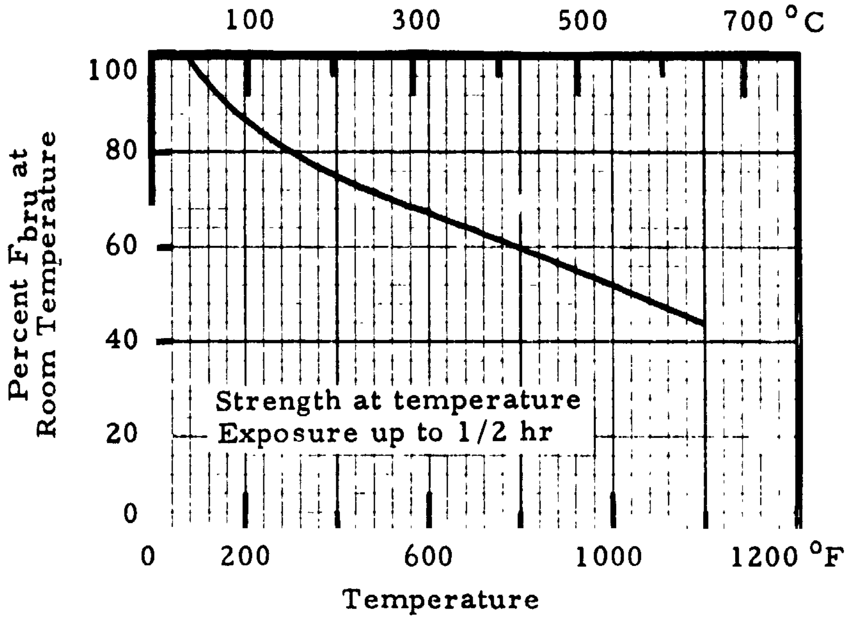


FIGURE 7.452. – Effect of temperature on the ultimate bearing strength of Type 301 (half-hard).
(Ref. 7.9)

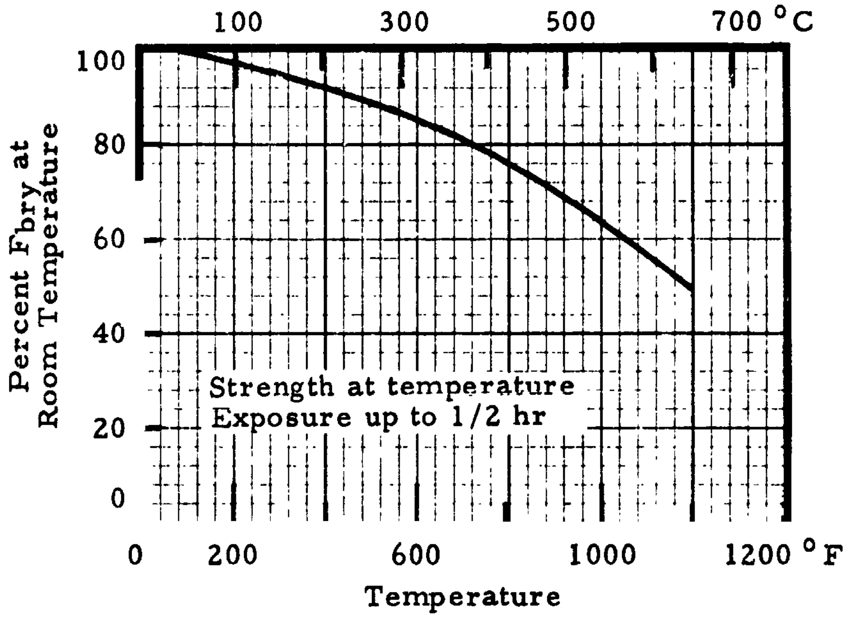


FIGURE 7.453. – Effect of temperature on the bearing yield strength of Type 301 (half-hard).
(Ref. 7.9)

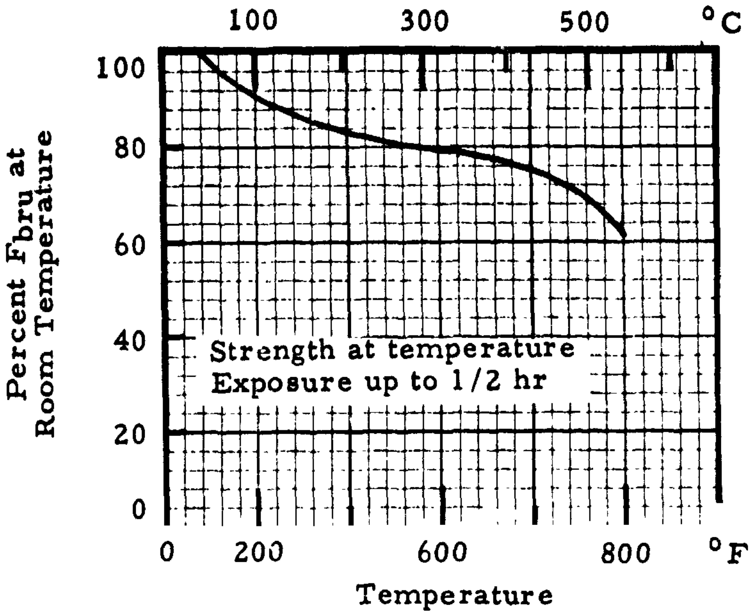


FIGURE 7.454. – Effect of temperature on the ultimate bearing strength of Type 301 (full-hard).

(Ref. 7.9)

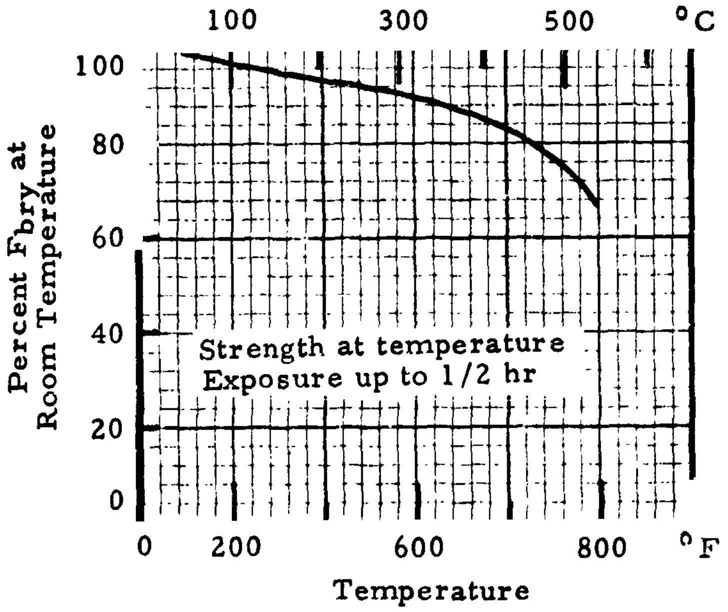


FIGURE 7.455. – Effect of temperature on the bearing yield strength of Type 301 (full-hard.)

(Ref. 7.9)

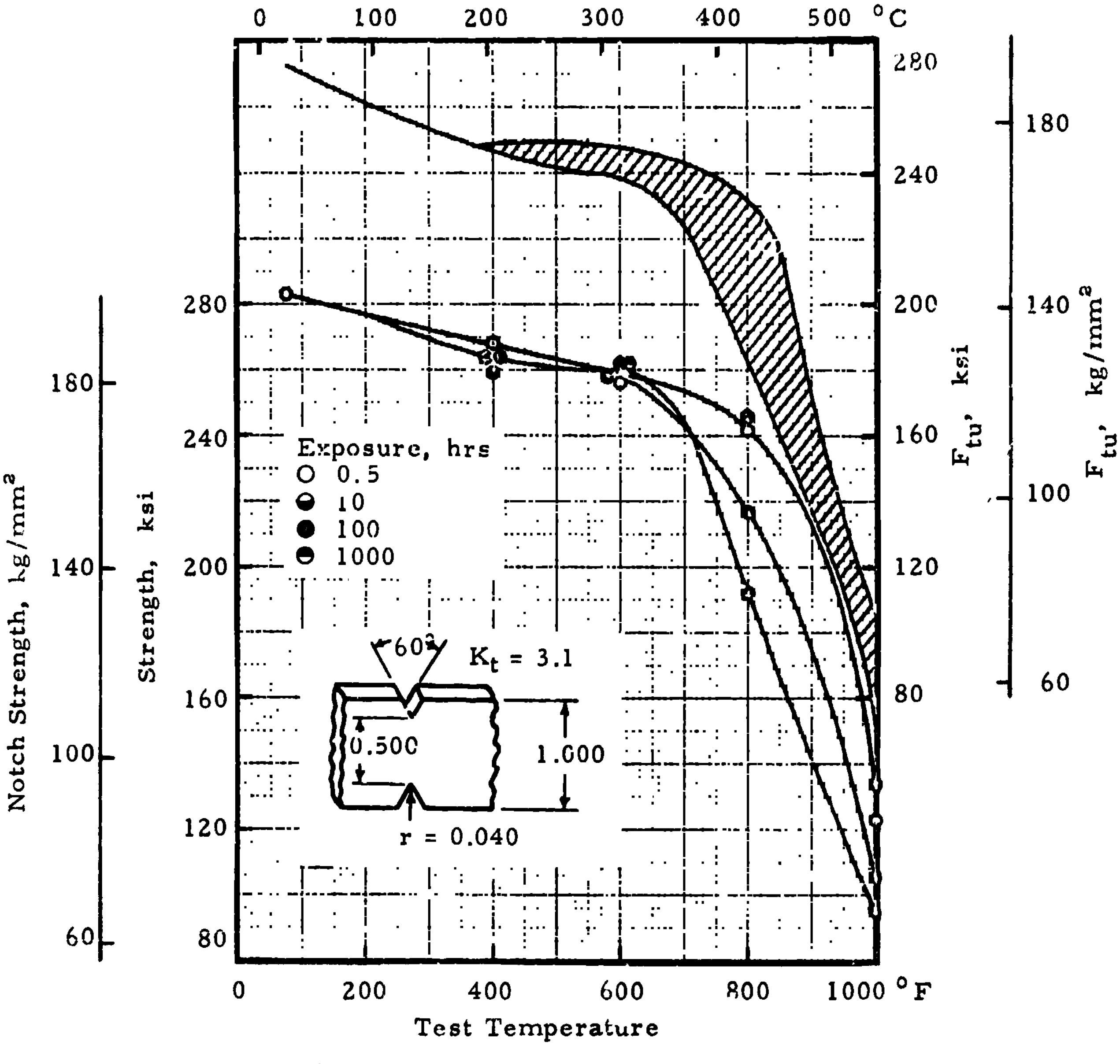


FIGURE 7.4611. – Effect of test temperature and exposure time on notch strength of 60 percent cold reduced Type 301 sheet; thickness, 0.050 inch(0.127 mm).

(Ref. 7.16)

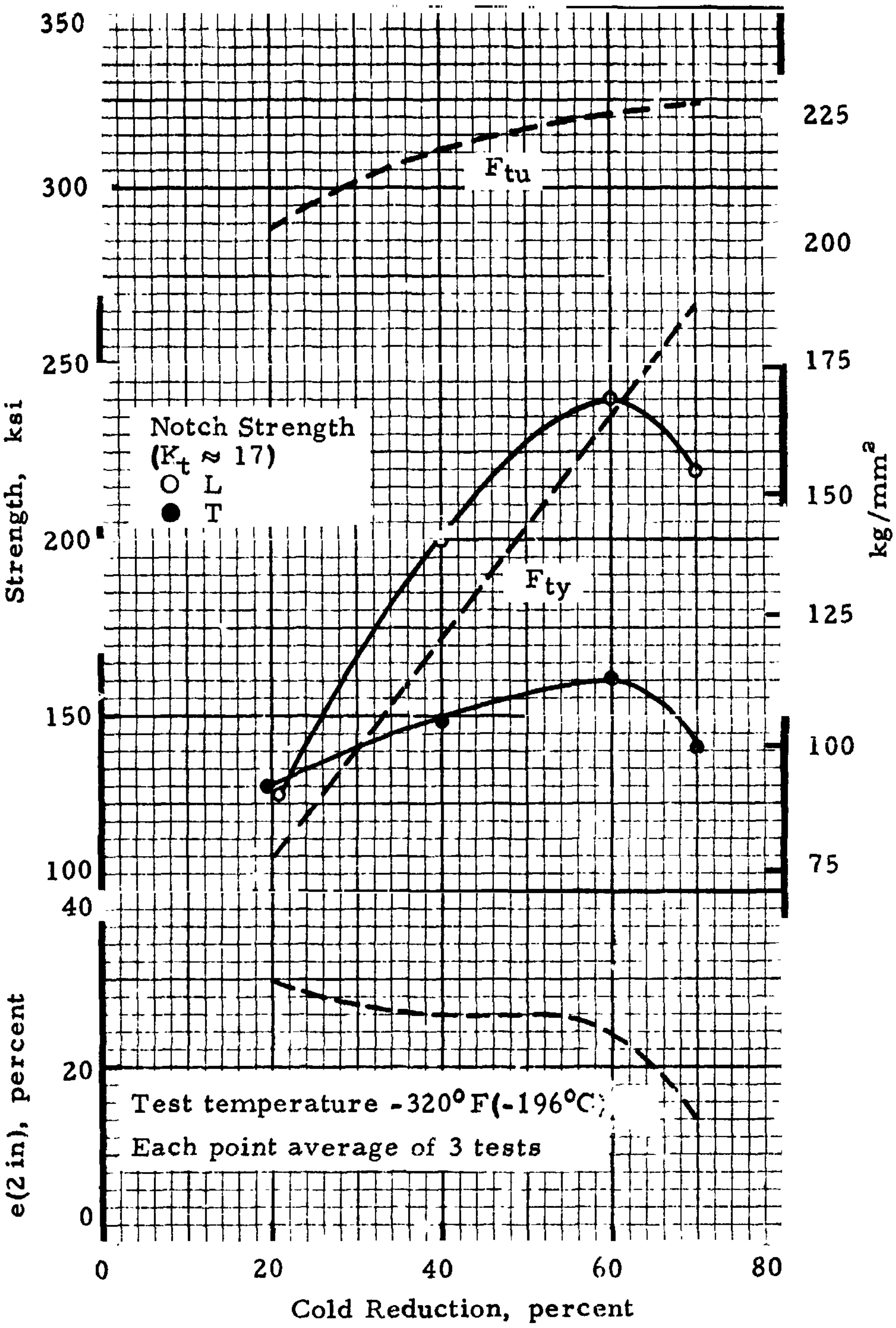


FIGURE 7.4612. – Effect of cold reduction and test direction on sharp notch strength of Type 301 sheet; thickness, 0.063 inch (1.60 mm).

(Ref. 7.17)

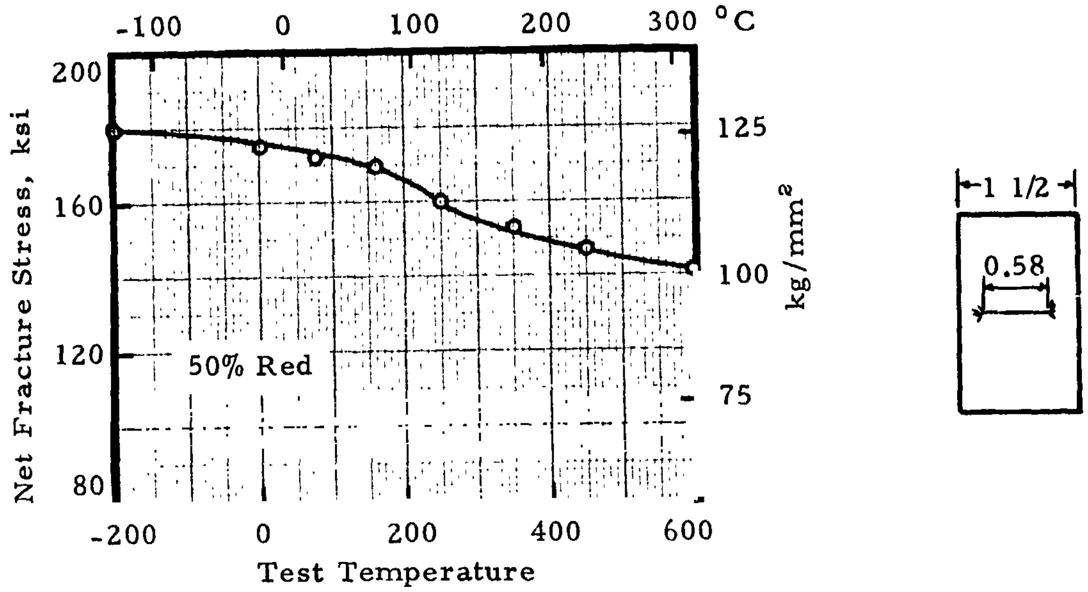


FIGURE 7.4613. – Effect of test temperature on net fracture stress of Type 301 full-hard sheet; thickness, 0.046 inch (1.17 mm).

(Ref. 7.18)

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7.13 United States Steel, "USS 301, A Standard AISI Type Stainless Steel Cold Reduced to Higher Properties for Aircraft and Missiles," June 1959.

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7.18 J. D. Morrison and J. R. Kattus, "An Investigation of Methods for Determining Crack Propagation Resistance of High Strength Alloys," Southern Research Institute, January 1961.

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Chapter 8

DYNAMIC AND TIME DEPENDENT PROPERTIES

8.1 General. Type 301 has good dynamic and time dependent properties. In the annealed condition, the alloy exhibits good impact strength down to cryogenic temperatures. The alloy can be used at moderately elevated temperatures because of its excellent creep and rupture properties. It has good structural stability for long time use at temperatures up to 800° F (427° C). When held in the temperature range from 800° to 1600° F (427° to 871° C), however, carbides are precipitated which may lower the resistance of the alloy to corrosion. Exposure of cold-reduced material to temperatures above 900° F (482° C) results in a reduction in room temperature properties (refs. 8.1, 8.2, 8.3).

8.2 Specified Properties

8.3 Impact

8.31 Izod impact strength of annealed sheet, 110 ft-lbs (15.2 kg-m) (ref. 8.4).
8.32 Effect of low temperature on impact strength of annealed plate, figure 8.32.
8.33 Effect of room and low temperature on impact strength of annealed and 1/2-hard bar, figure 8.33.

8.4 Creep

8.41 Creep and creep rupture curves for Type 301 half-hard sheet at elevated temperatures, figure 8.41.
8.42 Creep rupture curves for Type 301 full-hard and stress relieved sheet at elevated temperatures, figure 8.42.
8.43 Creep and creep rupture curves at 800° F (427° C) for Type 301 full-hard sheet, figure 8.43.
8.44 Time—temperature parameters
8.45 Isochronous stress-strain diagrams

8.5 Stability

8.51 Effect of exposure at low temperatures on room temperature tensile properties of extra hard sheet, figure 8.51.
8.52 Effect of temperature and exposure time on tensile properties of 60-percent reduced sheet, figure 8.52.
8.53 Effect of test temperature and exposure time on shear strength of Type 301, see figure 7.442 and 7.443.
8.54 Effect of temperature and exposure on bearing properties of Type 301, see figures 7.452 and 7.453.

8.55 Effect of test temperature and exposure time on notch strength of 60-percent cold reduced sheet, see figure 7.4611.

8.6 Fatigue

8.61 S-N curves in flexure for extra full hard sheet at low temperatures, figure 8.61.

8.62 Results of fatigue tests before and after exposure for 26,300 hours at 288° C, table 8.62.

TABLE 8.62. -- Results of Fatigue Tests Before and After Exposure for 23,600 Hours at 288° C (550° F)

Source	Ref. 8.11										
Alloy	Type 301, 50 percent cold rolled										
Before Exposure						After Exposure					
K_T = 1 (a)			K_T = 4 (a)			K_T = 1 (a)			K_T = 4 (a)		
S_{max}		Fatigue life, kilocycles	S_{max}		Fatigue life, kilocycles	S_{max}		Fatigue life, kilocycles	S_{max}		Fatigue life, kilocycles
kg/mm²	ksi		kg/mm²	ksi		kg/mm²	ksi		kg/mm²	ksi	
98.4	140	18	49.2	70	17	94.9	135	35	52.7	75	11.1
		21			18			37			11.4
		23			21			213			13.0
		36	45.7	65	20	87.9	125	43	45.7	65	20
		37			28			60			21
		51			30			231			33
91.4	130	32	42.2	60	43			>10,000	42.2	60	36
		33			52			>10,000			40
		37			59			>10,000			6,313
85.8	122	1,741			>10,000						
84.4	120	47	40.1	57	62	80.8	115	83	38.7	55	53
		51			103			88			1,187
		63			7,529			3,486			4,464
		68			>10,000	77.3	110	196	35.2	50	>10,000
		73			>10,000			>10,000			
		81			>10,000			>10,000			
		87	38.7	55	94	66.8	95	16			
		167			108			23			
		425			271	52.7	75	397			
		841			425						
		>10,000									
70.7	100	75	35.2	50	2,018						
		106			7,904						
		176			>10,000						
		210									
		1,720									
		6,770									
		>10,000									

(a) K_T = 1, unnotched specimens; K_T = 4, edge-notched specimens

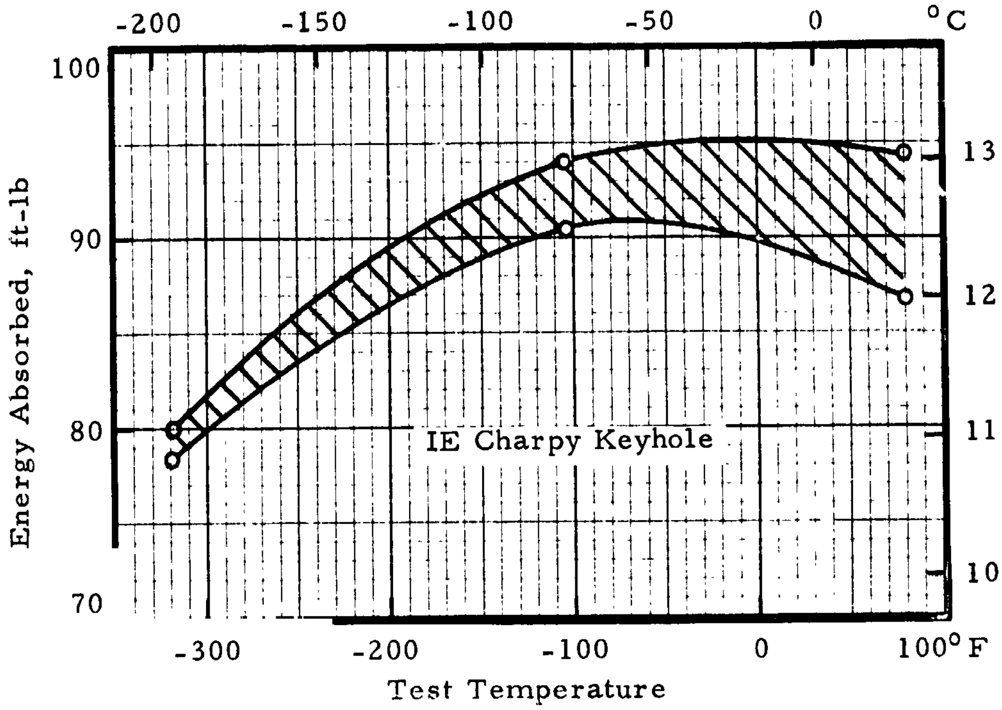


FIGURE 8.32. — Effect of low temperature on impact strength of Type 301 annealed plate; thickness, 0.50 inch (12.7 mm). (Ref. 8.5)

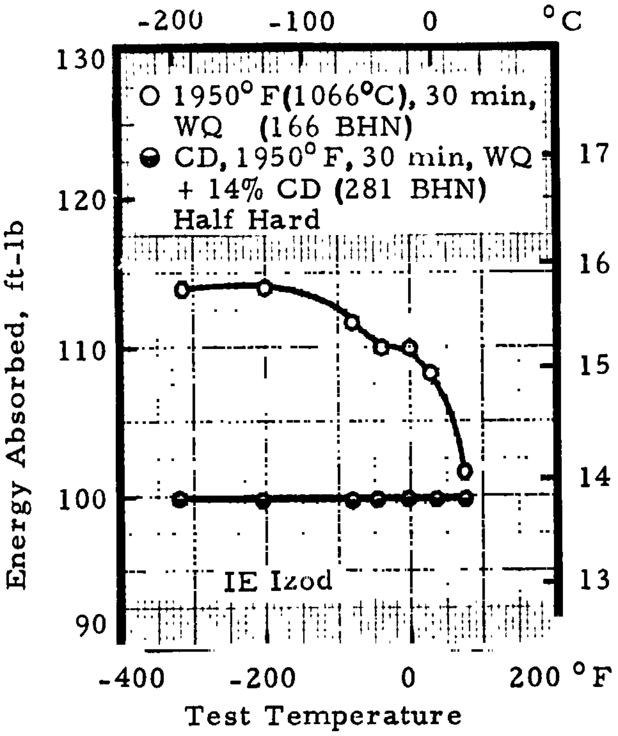


FIGURE 8.33. — Effect of room and low temperature on impact strength of Type 301 annealed and half-hard bar. (Ref. 8.1)

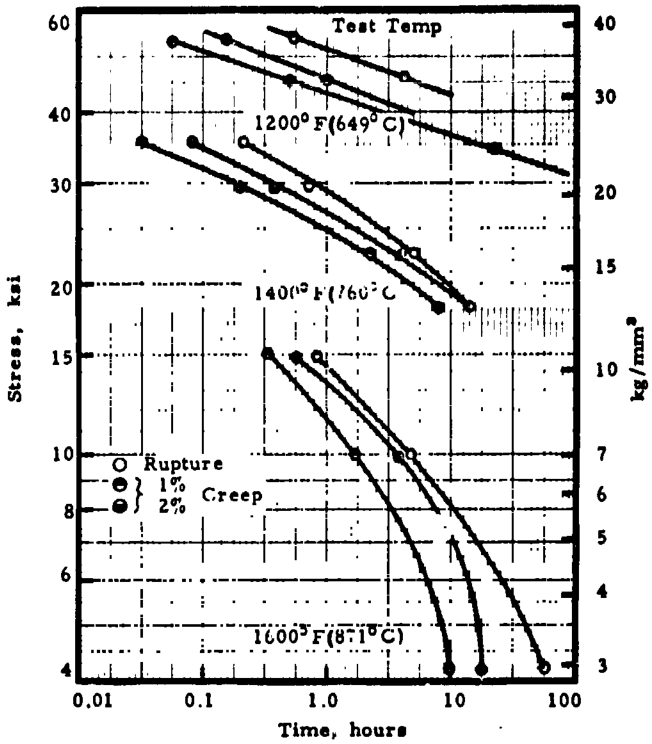


FIGURE 8.41. – Creep and creep rupture curves for Type 301 half-hard sheet at elevated temperatures; thickness, 0.050 inch (1.27 mm). (Ref. 8.6)

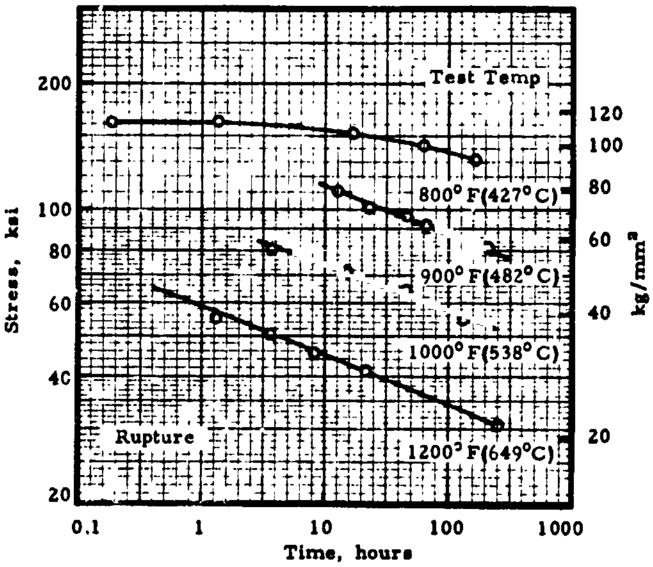


FIGURE 8.42. – Creep rupture curves for Type 301 full-hard and stress-relieved sheet at elevated temperatures; thickness, 0.032 inch (0.81 mm). (Ref. 8.7)

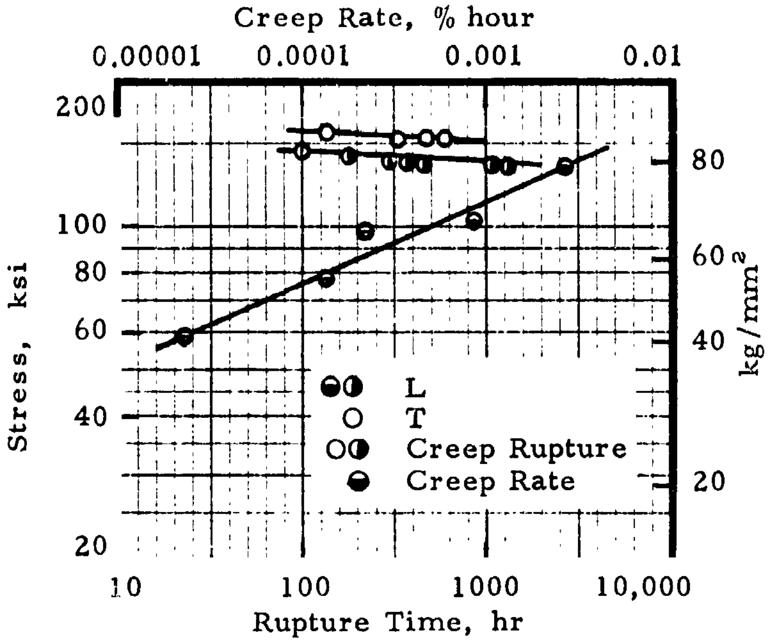


FIGURE 8.43. – Creep and creep rupture curves at 800° F (427° C) for Type 301 full-hard sheet.

(Ref. 8.1)

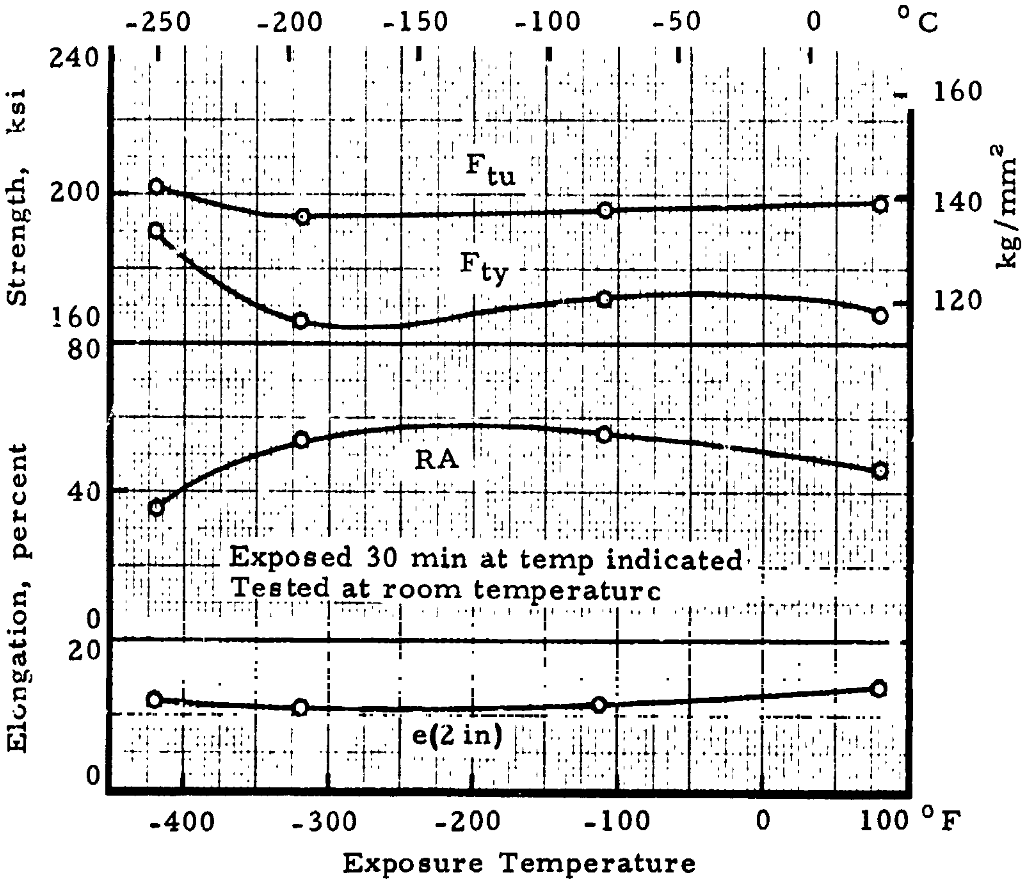


FIGURE 8.51. – Effect of exposure at low temperature on room temperature tensile properties of Type 301 extra-hard cold rolled sheet; thickness, 0.060 inch (1.52 mm).

(Ref. 8.10)

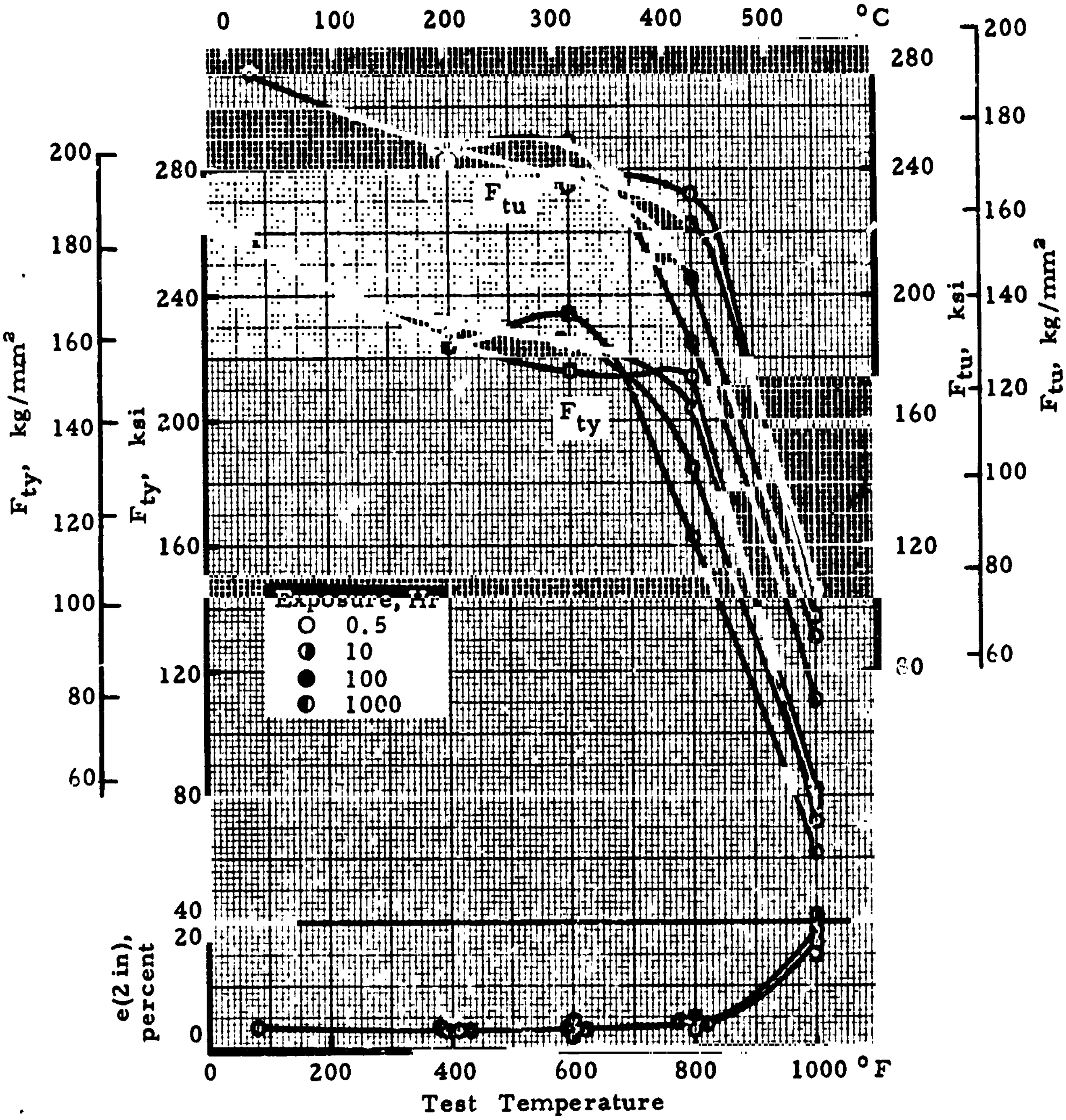


FIGURE 8.52. – Effect of test temperature and exposure time on tensile properties of Type 301 60-percent cold reduced sheet; thickness, 0.050 inch (1.27 mm).

(Ref. 8.9)

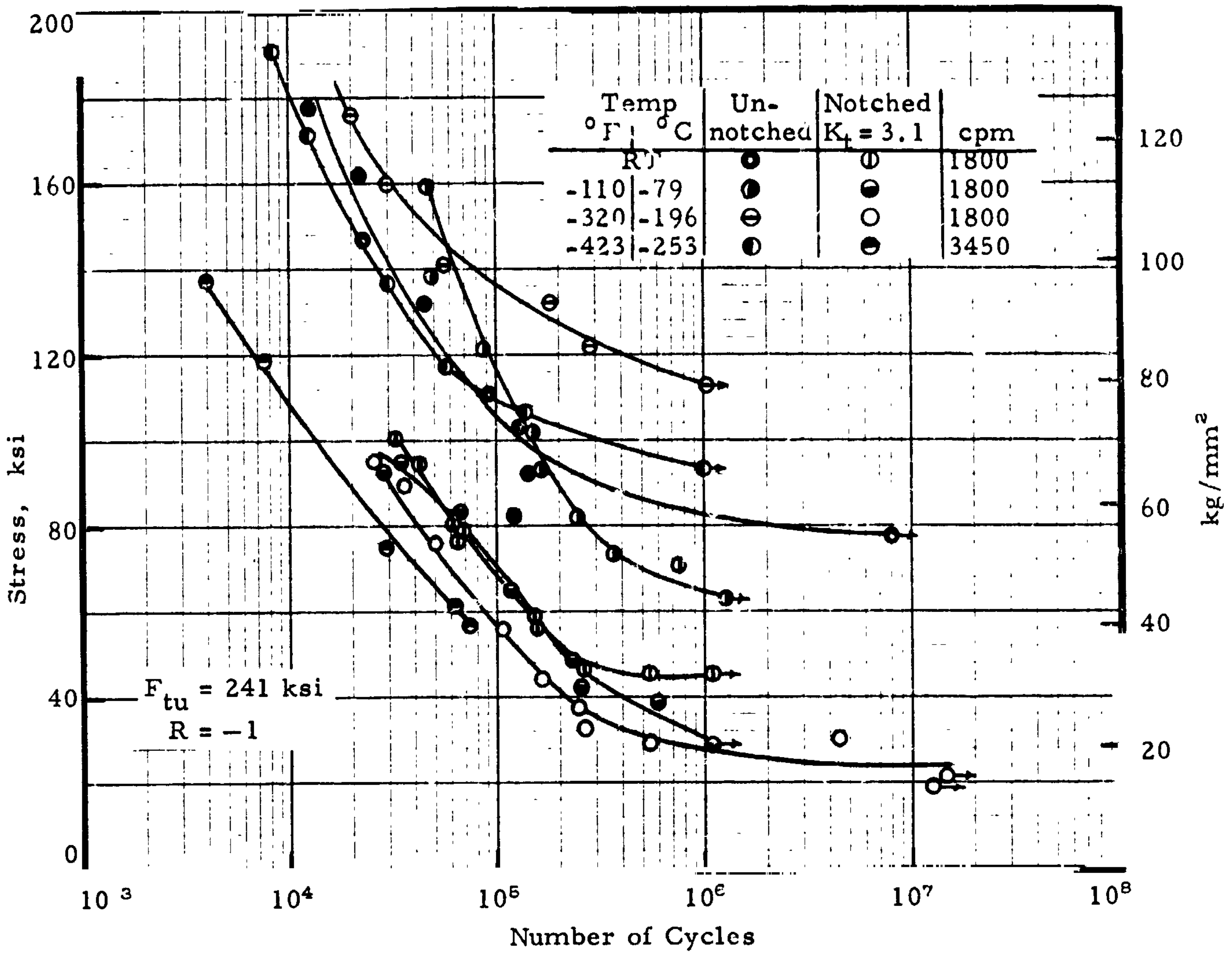
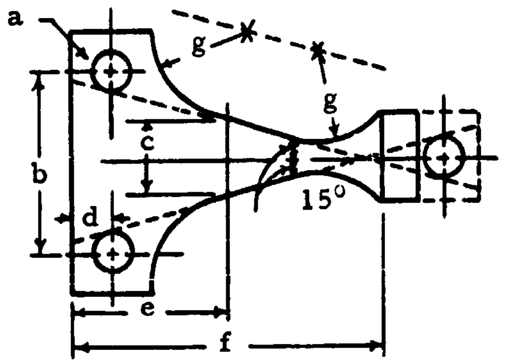


FIGURE 8.61. — S-N curves in flexure for Type 301 extra-fully-hard sheet at low temperatures; thickness, 0.039 inch (0.99 mm). (Ref. 8.8)



a = 0.187 - 0.188 in dia (3 holes)
b = 0.808 ± 0.002 in
c = 0.378 ± 0.002 in
d = 0.47 ± 0.002 in
e = 0.700 ± 0.002 in
f = 1.400 ± 0.002 in
g = 0.40
(Note: 1 in = 25.4 mm)

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Chapter 9

PHYSICAL PROPERTIES

9.1 Density at room temperature
0.286 - 0.292 lb/in^3 (refs. 9.1, 9.2)
9.11 Specific gravity, 7.86 - 7.94 (ref. 2)

9.2 Thermal Properties

9.21 Thermal conductivity (K), figure 9.21.
9.22 Thermal expansion (α), see figure 9.21.
9.23 Specific heat (c_p), see figure 9.21.
9.24 Thermal diffusivity, figure 9.24.

9.3 Electrical Properties

9.31 Electrical resistivity, figure 9.31.

9.4 Magnetic Properties. This alloy is nonmagnetic in the annealed condition, but becomes increasingly magnetic when cold worked (ref. 9.2).

9.41 Magnetic permeability (at 200 oersteds)
Annealed, 1.003
10% CW, 1.10
60% CW, 20.0 (approx).

9.5 Nuclear Properties. The effects of exposure to high intensity nuclear radiation is generally as follows:

a) Magnetic susceptibility is increased, depending on material condition and irradiation variables such as total flux and temperature.

b) Tensile strength, yield strength, and hardness of annealed alloy are increased; elongation is usually decreased.

c) Austenitic stainless steels retain their high impact strength after irradiation.

9.51 Effect of high intensity nuclear radiation on tensile properties and hardness, table 9.51.
9.52 Effect of irradiation below 100°C (212°F) on yield strength, figure 9.52.

9.6 Other Physical Properties
9.61 Emissivity, figure 9.61
9.62 Damping capacity

TABLE 9.51. – Effect of High Intensity Nuclear Radiation on Tensile Properties and Hardness

Source	Ref. 9.9			
Alloy	Type 301			
Condition	Annealed		60% CW	
Irradiation temperature	200° F (99° C)	-	-416°F(-249°C)	-
Irradiation exposure, n(m^{-2})	3.9 x 10^9	Control	2.0 x 10^{17}	Control
Test temperature	RT		-423° F (-253° C)	
F_{tu}, ksi (kg/mm^2)	113.2 (79.6)	98.7 (69.4)	284 (200)	391 (275)
F_{ty}, ksi (kg/mm^2)	87.0 (61.2)	38.4 (27.0)	284 (200)	300 (211)
e, percent	50.0	56.0	8	13
RA, percent	81.0	83.0	-	-
Hardness, R_B	94	94		

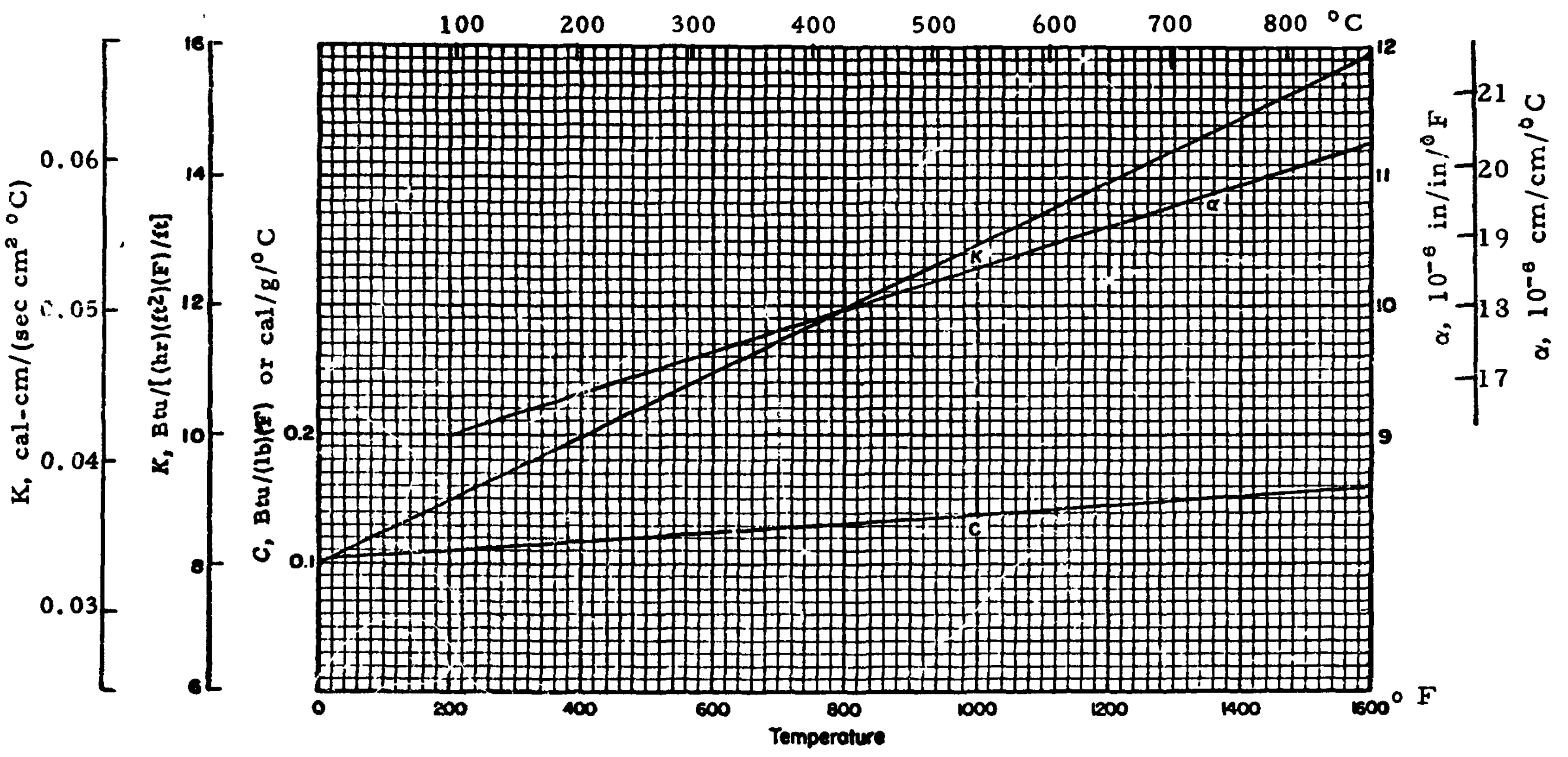


FIGURE 9.21. — Effect of temperature on physical properties of Type 301. (Ref. 9.1)

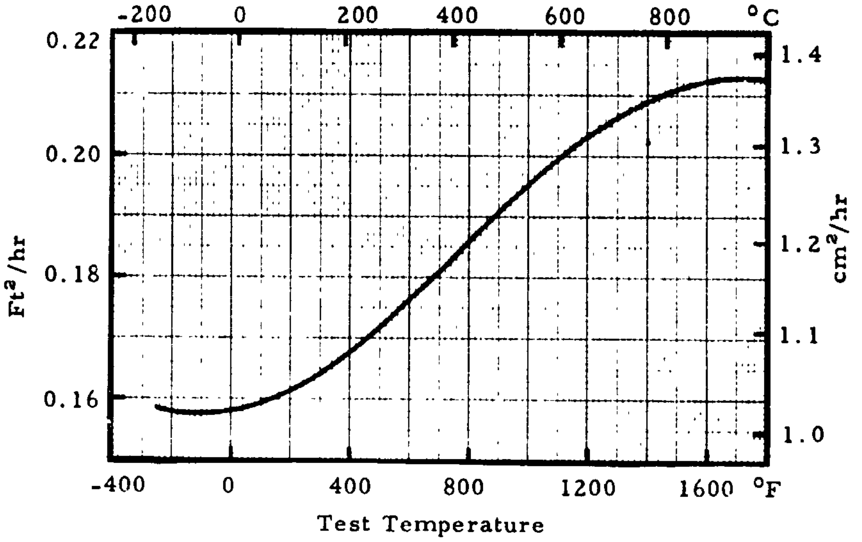


FIGURE 9.24. – Effect of temperature on thermal diffusivity of Type 301 (annealed).

(Ref. 9.5)

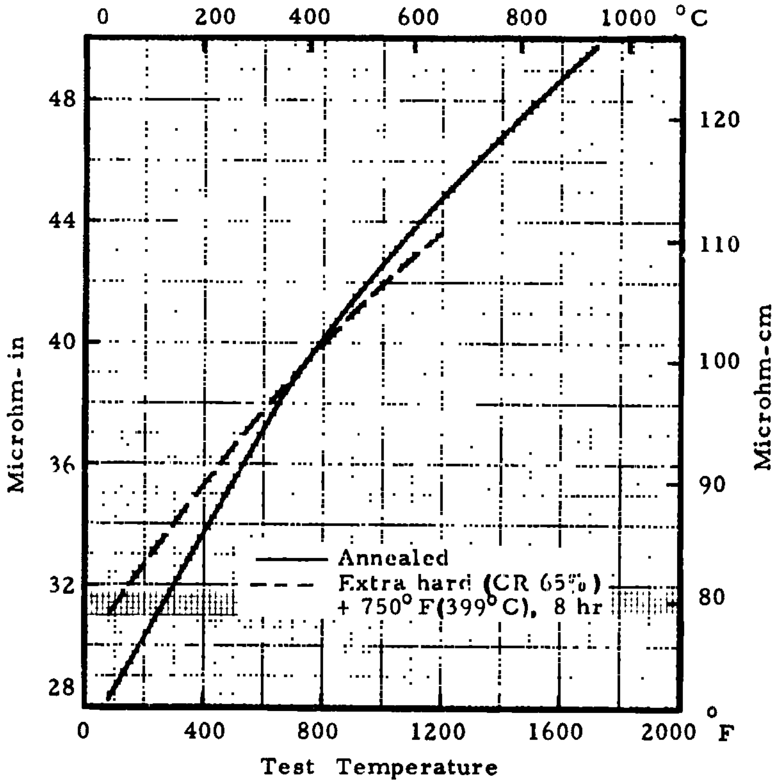
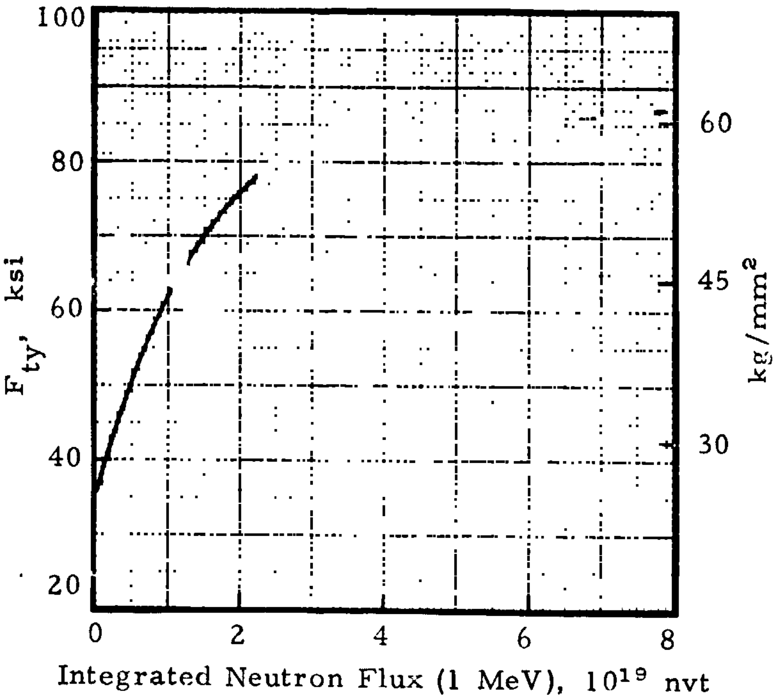


FIGURE 9.31. – Effect of temperature on electrical resistivity of Type 301.

(Refs. 9.7, 9.8)

FIGURE 9.52. – Effect of irradiation below 100°C (212°F) on yield strength of Type 301 (annealed).

(Ref. 9.11)



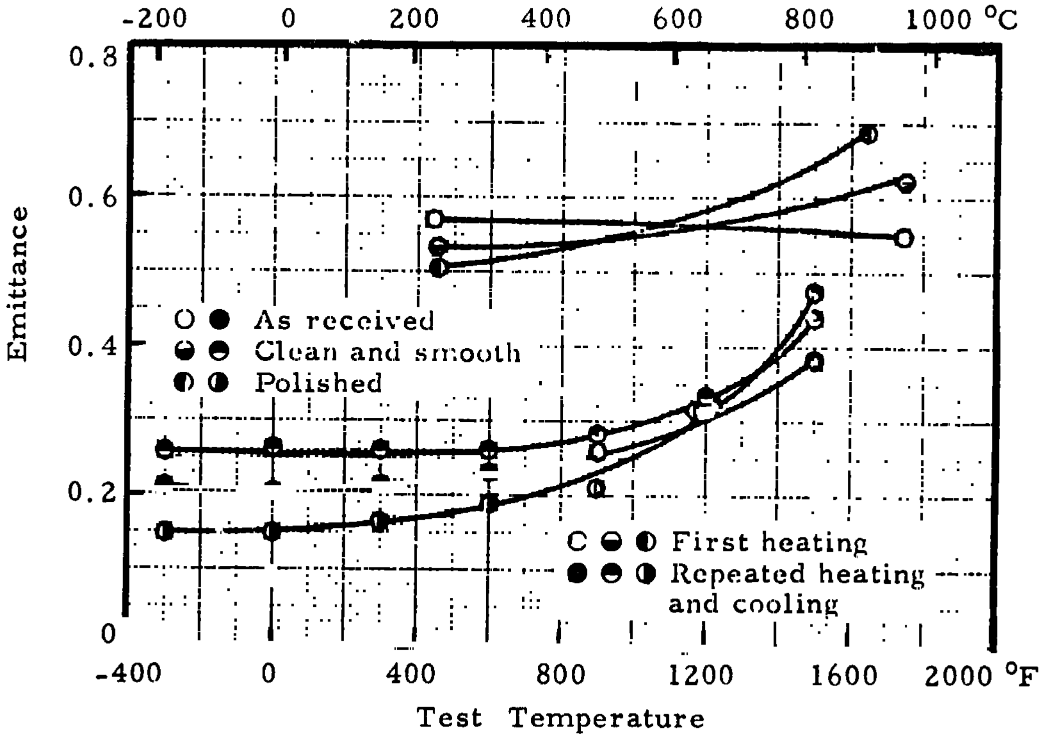


FIGURE 9.61. – Effect of temperature and surface treatment on emissivity of Type 301.

(Ref. 9.10)

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Chapter 10

CORROSION RESISTANCE AND PROTECTION

10.1 General. While the primary characteristic of Type 301 that is essential to its applications in missiles and aircraft is that it may be work hardened to very high strengths, this material also exhibits good resistance to corrosion in a variety of media. However, of all the steels in the 18-8 family of stainless steels, Type 301 is the least resistant to corrosion. Type 302, with a chemistry very close to Type 302 (except for the slight increase of chromium and nickel), exhibits slightly better corrosion resistance. Information will be given for Type 302 in this chapter where the same information is not known or available for Type 301.

The corrosion resistance of austenitic stainless steel is due primarily to its passivity which is due to an air-formed oxide film on the surface of the metal. The oxide film is mostly chromic oxide which is increased in content by polishing. Films from highly polished specimens have been found to contain as much as 90 percent Cr_2O_3 (ref. 10.1).

An oxide film will form on most metals that are exposed to air. This film will be so thin that it is invisible unless it is thickened by heating or chemical treatment. These oxides, which are insoluble in a corroding agent, are difficult to reduce electrochemically. They adhere well to the metal, do not crack or form pores, and are effective barriers against corrosion. No oxide film is actually free from cracks or pores arising from stresses which occur in the film; however, any exposed metal is automatically sealed with fresh oxide (ref. 10.2).

Chromic oxide forms the passivating film on stainless steel. In an oxidizing environment, the film is strengthened, self-generating, and stable. A reducing environment tends to break down the film and causes the steel to corrode (ref. 10.3). The addition of 11.5 percent or more of chromium produces high passivity in stainless steel. The passivity not only depends on the amount of chromium, but to a great extent on the amount and condition of the carbon and its relation to the amount of chromium (ref. 10.4).

10.2 Atmospheric Corrosion. Austenitic stainless steels are highly resistant to atmospheric corrosion. Tests of 18-8 stainless steel exposed to the industrial atmosphere of New York City for 15 years showed a weight loss of 1.4 and 1.9 mg/in^2 ($\approx$0.2 and 0.3 mg/cm^2) and an appearance described as very slight discoloration, mostly dirt (ref. 10.5). Atmospheric corrosion resistance can be improved by periodic cleaning of any dirt deposits that form. The dirt deposits prevent oxygen from getting to the metal surface and also bring corrosive matter, particularly chlorides, into contact with the metal (ref. 10.1). Tests were also performed over a period of three years in a marine atmosphere. In the first months, a thin superficial but adherent rust appeared and uniformly covered the surface and then became thicker with prolonged exposure. This rust was in greater quantity on the bottom side of the test sheets. After three years, the rust was relatively thin on those panels that were initially polished and could be removed with an appropriate metal cleaner. Panels that were cleaned every 6 months showed a lower rate of rust formation (ref. 10.6). Type 301 sheet tensile specimens in various conditions were exposed to the atmosphere at Niagara Falls, New York, for five years. After cleaning off an appreciable quantity of deposited dirt, an examination showed a mild pitting in some cases but not enough to mar the surface appearance. The exposure indicated no effect on the strength and ductility of the specimens (ref. 10.7).

10.3 Corrosion in Water. The 18-8 stainless steels remain practically unattacked by distilled water. Exposure to long periods of time in tap water, kept at about 140° F (60° C) at seven locations, has shown this steel to be highly resistant to corrosion. Some river waters, particularly those rivers near highly industrial cities, can be quite corrosive to many metals, but 18-8 stainless steels show almost complete resistance to corrosion (<0.00005-mm penetration/year) in river waters (ref. 10.8).

The behavior of stainless steel in marine waters will depend upon the conditions of exposure. If the water velocity is low, marine organisms or other solid materials will become attached to the metal and thus screen out oxygen and concentrate corrodents on the metal. Where the water velocity is high and matter cannot attach itself to the metal, corrosion is negligible (ref. 10.8). Galvanic corrosion may occur in sea water if a material more electropositive than Type 301 is in contact with the metal (see Section 10.5, Galvanic Corrosion).

10.4 Intergranular Corrosion. When austenitic stainless steel is heated for a length of time between 800° and 1650° F (427° and 899° C), chromium carbides will precipitate at the grain boundaries. This will reduce the chromium content of the adjacent material and reduce its resistance to corrosion. Corrosion then may occur along the grain boundaries. Welding operations may leave the area adjacent to the welds in this sensitive condition, which is then vulnerable to attack by corrosive media that would not ordinarily affect the steel. Common methods for eliminating this chromium carbide precipitation in Type 301 are: (a) Maintain a very low carbon content; (b) Anneal after any carbide precipitation has occurred (ref. 10.8).

10.5 Galvanic Corrosion. Galvanic action may take place if two dissimilar metals are in contact in the presence of an electrolyte. The metal that is more electropositive will dissolve or corrode, while the other material will not be affected. The metal more electropositive will become the anode, and the metal less electropositive will become the cathode in a galvanic cell. Ordinarily, stainless steel will act as the cathode with most materials and not be affected by galvanic action. Under some special conditions, stainless steel may become activated; the current will reverse and the stainless steel will be attacked. Stainless steel may be activated by passing an electric current in a manner to make it anodic. This may be done intentionally when electrolytic etching or pickling is performed or unintentionally by accident or stray currents. If corrosion occurs because stray currents are rendering the stainless steel active, it can be stopped by grounding or shunting the current, by proper insulation, or by providing a counter current to neutralize the effect of the stray electric current (ref. 10.4). Table 10.1 shows the position of Type 301 in the galvanic series when active or passive.

10.6 Chemical Corrodents. Corrosion in the form of pitting usually occurs during continuous exposures to relatively weak corroding media where the steel otherwise would be resistant. Pitting occurs in certain vulnerable spots where the passivity is continuously destroyed. Compounds or their acid radicals that are capable of causing pitting are some fluorides, chlorides, bromides, iodides, sulfides, sulfites, thiocyanates, and chlorites or hypochlorites. Pitting action will be accelerated in an acidic medium. Corrosive solutions should not be permitted to stand for long periods of time in stainless steel equipment, particularly if the solutions are acidic. Making the solution alkaline will retard corrosion. Periodic cleaning and aerating of equipment is recommended as a procedure for retarding corrosion of equipment subject to chemical corrodents. An increase in temperature, pressure, and concentration will increase the rate of corrosion. Alternate wetting and drying of the steel with a corrodent solution will create a concentration of the corrodent on the surface of the metal that may enhance the rate of corrosion. Similarly, a partial immersion of the steel in a corrodent will create concentration of the corrodent because of evaporation at the surface of the solution, thus resulting in a more rapid rate of corrosion (ref. 10.4).

The 18-8 types of austenitic steels have excellent resistance to most types of atmospheric corrosion and are highly resistant to organic acids such as acetic acid and oxidizing acids such as nitric acid. However, they are not generally resistant to mineral acids such as sulfuric acid or the the halogen acids such as hydrochloric. Detailed tables of the corrosion resistance of the alloy in various chemical media, as determined in the laboratory, are given in references 10.4 and 10.10; however, it must be recognized that service conditions cannot be duplicated in the laboratory, for example, impurities or combinations of chemicals, and such lists are to be used only as guides. Cold working, stress, fabrication, and surface finish all may have effects on the corrosion resistance.

10.7 Stress Corrosion. Residual stresses will be left in any metal after cold forming. The stressed metal may be slightly anodic compared to adjacent unstressed metal and, when subject to a corrosive media, stress corrosion may take place. The characteristic failure that takes place as a result of the stress corrosion is a brittle failure. Chemical environments that are conducive to stress-corrosion cracking in stainless steel include caustic and chloride solutions. Tensile stresses, either external or residual, must be present on the surface of the metal for stress corrosion to occur (ref. 10.9).

Stress cracking may be pronounced in Type 301 steel in the formed condition if high residual stresses are present. The tendency for stress cracking depends primarily on the value of tensile strength developed. Severely formed parts, particularly in the harder tempers of Type 301, should be immediately annealed or stress relieved to prevent cracking. Stress-corrosion cracking may occur in certain media, primarily hot chlorides, if residual stresses are present. Under normal atmospheric conditions, stress corrosion does not normally occur even in extra hard sheet (ref. 10.10).

Results of tests on stress-corrosion cracking under a variety of applied stresses and conditions show that, in general, Type 301 steel is very resistant to stress-corrosion cracking in the environments tested. These stress corrosion tests were performed on both longitudinal and transverse sheet specimens of full-hard, full-hard and stress-relieved, and extra-hard and stress-relieved conditions. The specimens were subjected to an applied stress of 10–70 percent of their tensile strength in a series of test environments. The natural environments were exposure at 80 feet and 800 feet (24 to 240 meters) from the ocean at Kure Beach, North Carolina and laboratory environments of 20-percent neutral salt spray and 3-1/2 percent NaCl solution (10 minutes immersion and 50-minutes air-dry cycle). Except for three specimens, all others were exposed about a year and more without any evidence of stress-corrosion cracking (ref. 10.11).

Basic and fundamental information on corrosion and corrosion protection of metals for guidance in the design of military components is presented in reference 10.12.

TABLE 10.1 – Position of Type 301 Stainless Steel in the Galvanic Series

Source	Ref. 10.5

ANODIC END

(electropositive)

Magnesium
Magnesium alloys
Zinc
Aluminum 2S
Cadmium
Aluminum 175ST
Iron and carbon steel
Copper steel
4–6% Cr steel
Stainless Type 410
Stainless Type 430
Stainless Type 446
Stainless Type 301 Active
Stainless Type 302
Stainless Type 309
Stainless Type 310
Stainless Type 316
Lead-tin solder
Lead
Tin
Nickel (active)
Inconel (active)
Brasses
Copper
Bronzes
Copper-nickel alloys
Monel
Silver solder
Nickel (passive)
Inconel (passive)
Stainless Type 410
Stainless Type 430
Stainless Type 446
Passive Stainless Type 301
Stainless Type 302
Stainless Type 309
Stainless Type 310
Stainless Type 316
Silver
Graphite
Gold
Platinum

CATHODIC END

(Electronegative)

Chapter 10 - References

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10.5 I.V. Williams and K.G. Compton, "Results of 15 Years Exposure Tests on Corrosion Resistant Steels," *Proc. ASTM*, *46*, 673 (1946).

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10.8 The International Nickel Co., Inc., "Corrosion Resisting Properties of the Chromium Nickel Stainless Steels," Nickel Alloy Steels, Sec.7, Data Sheet B, 1949.

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Chapter 11

SURFACE TREATMENT

11.1 General. The surface of Type 301 may be treated mechanically, chemically, and electrochemically. The purpose of surface treatment for Type 301 is to:

a. Remove scale developed during heat treatment.

b. Improve resistance to corrosion.

c. Provide an attractive decorative finish.

11.2 Scale Removal. The very high temperatures that are attained during welding, annealing, and forging will produce sufficient scale on Type 301 to make its removal necessary. Such a scale will impair the metal's appearance and resistance to corrosion. If the alloy is to be fabricated by cold working or welding, it must be scale-free. Scale left on a surface that is to be cold worked may lead to tearing and induced corrosion attack. Descaling may be carried out by various pickling solutions, sand blasting, or electropolishing (ref. 11.1). Scale-removing processes must be controlled with great care; otherwise, fabrication is hindered and impairment of anticorrosion properties may result (ref. 11.2).

The scale or oxide formed on stainless steel under very high temperatures may be heavy and difficult to remove. In such cases it may be necessary to employ more than one pickling bath to remove the scale. An initial bath is used to soften the scale and a second bath to remove the scale. For more tenacious scales, an intermediate bath may be necessary to assist in the softening of the scale. Under a number of annealing conditions, the scale may be light enough to be removed by a one bath process (ref. 11.3). The acids most commonly used in making up pickling solutions for descaling stainless steel are nitric, hydrofluoric, sulfuric, and hydrochloric (ref. 11.5). Nitric acid is an oxidizing agent whereas the other acids are reducing. An oxidizer will promote and preserve the passivity of stainless steel; reducers will descale by reducing the oxide, but will also reduce the protective oxide film (ref. 11.5).

Reducing agents are used to soften the oxide scale and are followed by a nitric acid bath to remove the softened scale and preserve the passivity. When nitric acid is used alone, it will not act to dissolve and remove oxide scale from stainless steel; thus, for single-bath pickling, hydrofluoric acid is usually added to nitric acid.

A recommended two-bath pickling process utilizes the following solutions:

Solution A

15 to 20 percent sulfuric acid (Sp. G. 1.84) by volume
Balance water, maintain at 140° to 150° F (60° to 66° C).

Solution B

15 to 20 percent nitric acid (Sp. G. 1/42) by volume
Balance water, maintain at 150° F (66° C).

Immerse in Solution A for not more than 5 minutes or until scale is loose, rinse in water, then follow with a 5-minute immersion in Solution B, rinse in water, and dry. If this pickling process is the last step and a bright finish is desired, 1 to 3 percent by volume of hydrofluoric acid can be added to Solution B (ref. 11.3).

When small parts are produced manually, the anneal may produce a brittle dark scale; this is the least difficult to remove of all scales, and can be removed by a single bath. Solution B, with hydrofluoric acid, is used in this case. The parts should then be flushed in water and possible brushed with soft brushes to remove scale (refs. 11.3 and 11.5).

Additional pickling solutions may be used:

Solution C

10 to 14 percent sodium hydroxide, by weight
3 to 6 percent potassium permanganate, by weight
Balance water, maintain at or near boiling.

This solution may be used as an intermediate bath between Solution A and B, where the scale is very difficult to remove. The usual immersion time is 20 to 30 minutes (ref. 11.3).

Solution D

5 to 10 percent sulfuric acid (Sp. G. 1.84) by volume
2 to 4 percent hydrochloric acid (Sp. G. 1.19) by volume
Balance water, maintain at 160° F (71° C).

This solution may be substituted for Solution A. Very close control must be maintained with the use of this solution because, when exhausted, it tends to cause pitting and become very corrosive (ref. 11.3). Solutions containing sulfuric and/or hydrochloric acids tend to cause pitting. There are several commercially available inhibitors that will minimize this effect. Nitric acid when used above 150° F (66° C) will fume badly, which is dangerous to those working with it and which will exhaust the strength of the bath; commercially available foaming agents will minimize this effect (ref. 11.3)

Molten baths of caustic or alkali are used to change the composition of the scale and make its removal relatively easy in the subsequent acid bath (ref. 11.3). One type of bath uses molten sodium hydroxide to which about 2 percent sodium hydride has been added This bath is maintained at 750° F (399° C) or higher. This will reduce the oxide of the scale. The steel is then removed from the bath and water quenched. The steam generated usually blasts off most of the scale. The steel is then immersed in a acid bath of almost 10-percent sulfuric acid, and the balance of the scale is removed. After a water rinse, a solution similar to Solution B is used to brighten the finish (ref. 11.3).

11.21 Sandblasting is a common and well known method to remove the scale from ordinary carbon steels. It is, however, not in common practice for stainless steel. If used, the sand should be clean and free from iron and if hardened steel grit is used, the metal surface should be acid-cleaned to remove all traces of free iron. Pickling follows to make sure that the scale is completely removed. Electrolytic polishing processes have been developed that provide a fine high finish on parts after fabrication and assembly. In electropolishing, the stainless steel is made the anode and metal is removed into solution (ref. 11.2).

11.3 Passivation. Passivation is usually recommended as a final surface treatment for stainless steel before it is ready to be put into service. The treatment will produce a stronger and more resistant oxide film than simple exposure to air. In the drawing, forming, machining, and other fabrication of stainless steels, the steel must come in contact with other steels and may pick up on their surface small amounts of free iron or "tramp iron." If this free iron is allowed to remain on the surface, it will soon rust, marking the stainless steel surface and, more significantly, leading to localized pitting and eventual corrosion.

Nitric acid is the recommended solution for passivation. The steel is heated in a 30-percent solution (by volume) of nitric acid at 120° to 140° F (49° to 60° C) for 15 to 30 minutes, and then rinsed well in water (ref. 11.3).

11.4 Standard Finishes. For flat rolled stock, the mill finishes are divided into two categories: unpolished and polished finishes. Table 11.1 shows the finishes available for flat rolled material and for bar and wire.

The bright and dull finishes for mill rolled sheet are produced by applying a light cold rolled pass on either polished or dull rolls. The various polished finishes are accomplished with abrasives and buffing processes to produce the finish desired.

11.5 Protection of Finish. Stainless steel should be properly protected during the various fabrication processes to avoid unnecessary scratches and contaminations. Not only do such scratches and contaminations score the surface of the stainless steel, but they also form a nucleus for pitting and corrosion. Protection of the material can be made by the use of plastic coatings or adhesive paper which can be peeled off later. Ample lubrication should be used during drawing operations; paper under hold-down pads and adhesive paper on the edges of brakes will avoid excessive marking and scoring.

Areas adjacent to welds may turn brown under some alternating wet and dry conditions. This is an oxide film that should be removed. Stainless steels are tougher than ordinary carbon steels and they tend to drag and wear out wheels more rapidly in the grinding, polishing, and buffing processes. Since they conduct heat away more slowly, they will overheat and warp more easily. It is therefore recommended that a lubricant be used on all finish-grinding operations. All wheels, buffs, dies, etc. should be checked constantly to see that they are not contaminated with other metals. These metals, when imbedded in the surface of the stainless steel, may cause galvanic corrosion under moist conditions. Buffing and greasing components should be free of iron or iron oxide.

TABLE 11.1 — Finishes Available for Type 301 Steel

Source	Ref. 11.4
Flat Rolled Material	**Bar and Wire**
Mill Rolled Finishes Cold Rolled Strip No. 1 finish - cold rolled annealed and pickled No. 2 finish - bright cold rolled No. 2 finish - bright annealed Sheets No. 1 finish - hot rolled annealed and pickled No. 2B finish - bright cold rolled No. 2D finish - dull cold rolled Hot Rolled Plates Hot rolled Hot rolled and annealed Hot rolled annealed and pickled	Hot Rolled Bar Hot rolled Hot rolled and annealed Hot rolled annealed and pickled Hot rolled and rough turned Hot rolled annealed and rough turned Hot Rolled Wire Hot rolled Hot rolled and annealed Hot rolled annealed and pickled
Mill Polished Finishes (on one or both sides) Sheets and Plates No. 3 finish - intermediate polish No. 4 finish - standard polish No. 6 finish - Tampico brushed polish No. 7 finish - high luster polish No. 8 finish - mirror polish	Cold Finished Bar Annealed and cold drawn Heat treated and cold drawn Annealed and centerless ground Annealed centerless ground and polished Heat treated centerless ground and polished Cold Finished Wire Annealed and cold drawn Heat treated and cold drawn

Chapter 11 - References

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Chapter 12

JOINING TECHNIQUES

12.1 General. Type 301 stainless steel is readily welded by all fusion and resistance welding methods. Both soft and hard soldering can also be performed on this alloy. Copper brazing can be accomplished under controlled conditions. Stainless steel can be riveted, but requires techniques different from the usual methods for carbon steels. Welding techniques have been made sufficiently adaptable to stainless steel so that riveting is employed only in those applications where welding is not suitable because of structural requirements.

12.2 Welding. All methods of welding applicable to carbon steel, except hammer or forge welding, can be readily used for Type 301. Austenitic stainless steels are not normally preheated. Because of carbide precipitation (see Section 10.4), the areas adjacent to welds are more sensitive to corrosion than the parent material. The forming of chromium carbides at the grain boundary during welding does not affect the structural strength, but may lead to failure if subjected to severe corrosive conditions. When parts are left as-welded and subsequently exposed to severe corrosive conditions and when the parts are to be operated at 800° to 1650° F (427° to 899° C), a stabilized type of stainless steel such as Types 321 or 347 should be specified. When exposure is below 800° F (427° C), the stabilized types are unnecessary and the low-carbon stainless steel types such as 304L and 316L are normally satisfactory (ref. 12.14).

Where use requires the same corrosion resistance for the welded joint and the parent material, the welded parts should be fully annealed and then rapidly quenched to dissolve the carbides. Because of the rapid heating and cooling possible with resistance welding, carbide precipitation along grain boundaries is minimal. Consequently, corrosion resistance is usually not adversely affected when the material thickness is less than 1/8 inch (3.17 mm). When thickness is greater than 1/8 inch and the welded structure is to be subjected to a corrosive exposure, a low-carbon or stabilized grade of stainless steel should be used (ref. 12.15). Great care must be taken in cleaning the welded area of any carbonaceous materials that may be picked up in earlier stages of fabrication. The carbonaceous material raises the carbon content of the weld and will reduce its resistance to corrosion. The coefficient of thermal expansion of austenitic stainless steel is about 60 percent greater than that of mild steel. Warpage or distortion at the weld will result if these thermal properties are not properly accounted for in the design of welded equipment and welding fixtures (refs. 1?.1, 12.3). The most effective means to prevent fissuring or cracking of the weld metal is to adjust the composition of the weld deposit to include small amounts of ferrite. This can be accomplished by proper selection of filler metal composition. Ordinarily, 3 to 4 percent ferrite is adequate. If the welds are in heavy sections, 6 to 7 percent ferrite may be required. The amount of ferrite in a weld is basically a function of its chemical composition and can be predicted from the Schaeffler Diagram (see figure 12.1). Cooling rate and subsequent heat treatment also influence the amount of ferrite in the weld (ref. 12.1).

The heat of welding will reduce the mechanical properties of strain hardened material to those of annealed Type 301. Planishing will improve the tensile strength of weld metal by cold working, but will have little effect on the mechanical properties of the heat-affected zone (ref. 12.4).

The strengthening of the weld joints may also be accomplished by using reinforcing plates or thickened joints (ref. 12.5). A comprehensive review of weldment evaluation methods is given in reference 12.20.

12.21 Fusion Welding. For material less than 1/8-inch (3.17-mm) thick, fusion welding is ordinarily performed without filler metal. For heavier material, the filler metal alloying composition should be at least that of Type 301 or higher. For corrosion application, the carbon content should be restricted to low levels, about 0.03 to 0.04 percent or even lower. The most widely used methods of fusion welding are by electric arc processes. Flame welding, such as with an oxy-acetylene torch, is not generally recommended. Where used (and only by sheer necessity), it is used for thin material and the flame adjustment should be strictly neutral in order to prevent carburization. It is difficult to make a satisfactory weld with an oxidizing flame (ref. 12.2).

Electron- and laser-beam welding are two relatively new nonarc procedures that have some application in the welding of stainless steel (refs. 12.5, 12.6).

Metal arc welding with flux-coated filler rods is the most widely-used process for welding heavier stock material. Either AC or DC current may be used, although DC is ordinarily preferred. A coating of AC-DC titania flux or DC lime-base flux may be used as a rod coating. For welds thicker than 1/4 inch (6.36 mm), multiple beads should be used. The slag must be thoroughly cleaned from each preceding weld bead before starting the next weld. The recommended current ranges for AC or DC metal are shown in table 12.1.

Austenitic stainless steels have physical properties that are different from those of carbon steels and their welding procedures are accordingly altered. The electrical resistance of austenitic stainless steel is about six times greater than carbon steel, the melting point about 200° F (93° C) lower, and the thermal conductivity about 50 percent less. For these reasons, the welding-current requirements for stainless steel are lower than for carbon steels (ref. 12.16).

The submerged-arc process and atomic hydrogen welding are also used for stainless steel (ref. 12.7). Atomic-hydrogen fusion welding has its chief use for thin sheets and strip from 0.010 inch to 0.140 inch (0.254 to 3.36 mm), although it is also suitable for heavier gage work. It is adaptable to butt, lap, filler, and raised edge-joints. The fusion and bonding take place under a constant protective shield of hydrogen which, because of its reducing action, protects against oxidation from the surrounding atmosphere as well as burning away of the edges and holing-through on light work. The welds exhibit a surface smoothness that reduces the amount of subsequent finishing (ref. 12.14). Submerged-arc welding employs a continuous electrode which makes possible uninterrupted depositing of filler metal under protection of flux separately applied (ref. 12.14).

The most widely used process for producing welds of high quality are the two inert-gas arc-welding processes, TIG and MIG. The TIG method is performed on this metal with a single nonconsumable tungsten electrode with an opening in the welding torch for the inert gas (usually argon) to be introduced around the arc. The MIG method is generally used for 1/8-inch thick (3.17 mm) steel or heavier and employs a filler metal as the electrode fed from a reel of wire through the welding gun into an inert gas atmosphere. The gas mixture used is 98 percent argon and 2 percent oxygen. These methods provide excellent quality welds at high speeds with no flux removal problems (ref. 12.2).

The effects of low temperatures on TIG-weld tensile properties of cold rolled sheet are shown in figure 12.2. The effects of exposure at elevated temperature on fusion and spot welds are indicated in table 12.2.

12.22 Resistance Welding. The high electrical resistance of austenitic stainless steels permits rapid heating, limited to a small area, and allows electrical resistance welding to be an efficient, highly recommended joining procedure for this steel. Resistance welding is done under water or a stream of water directed at the weld or, more commonly, the electrodes are cooled with water circulating through the hollow portion. This cooling minimizes warpage and carbide precipitation (ref. 12.10). The primary requirements for resistance welding are: clean metal surface, sufficient pressure, correct joint and electrode design, sufficient power, and accurate timing (ref. 12.2). Spot, seam, and stitch welding, or butt and flash resistance welding are ordinarily performed on Type 301. More recent applications of high-frequency resistance welding have also been made on this stainless steel.

Resistance welding is sometimes used in conjunction with fusion welding. A sheet welded together by the TIG process can be reinforced at the joint by a backup sheet joined by spot welds. Low cycle fatigue data for such a complex joint is given in figure 12.3. Efficiency of parent metal in tension for spot-welded sheet of various tempers are given in figure 12.4 for various sheet gages.

12.3 Brazing. Copper brazing requires protective atmospheres and high purity copper. Temperature of 2050° to 2100° F (1121° to 1149° C) are needed to melt and flow the copper (ref. 12.14). Corrosion due to galvanic action may occur if a brazed part is subjected to wet corrosive conditions. Silver-alloy brazing (also called "silver soldering" or "hard soldering") is discussed in Section 12.4.

12.4 Soldering. Both soft and hard soldering may be performed successfully on Type 301 stainless steel; 50 percent tin and 50 percent lead solder is most commonly used for soft soldering. Higher tin percentages up to 100 percent may be used to create better color match and a stronger joint. Roughening the steel surface helps the solder to adhere, for it is difficult to make solder adhere to a bright or highly polished stainless surface (ref. 12.3).

Fluxes especially prepared for stainless steel should be used. Improper fluxing is often the cause of joint failures. Fluxes should be neutralized immediately after the joint is made, then flushed away with water. Soft soldered joints cannot be depended upon for their mechanical strength and are used primarily as a seal. If strength is required in addition to a seal, the soldered joint should be used in conjunction with another joining device, such as spot welding, riveting, or lock steaming (ref. 12.3).

A very satisfactory joint may be obtained by silver soldering. This method is often used to join stainless steel to copper, bronze, another steel, stainless steel, or many nonferrous metals. A sound, strong, gas-tight and liquid-tight joint is made if proper procedures are followed. Good silver-alloy joints have tensile strengths greater than 40 ksi (28.1 kg/mm^2) (ref. 12.3).

12.5 Riveting. Rivets are available in this grade of stainless steel and no trouble should be experienced in driving sizes 3/16 inches (4.8 mm) and smaller. Larger size rivets should be hot driven. The rivets should not be heated more than 10 minutes and to the temperature range of 2000° to 2200° F (1019° to 1204° C). In no case should the rivets be driven at temperatures below 1800° F (982° C) (ref. 12.3).

12.6 Mechanical Joints. A number of lock joints and edge reinforcements may be used on stainless steel sheets not thicker than 0.062 inch 1.575 mm). Some of these joints are designed to be filled with soft solder. The lock joint will provide mechanical strength while the solder will provide a seal (ref. 12.2).

TABLE 12.1. – Current Ranges for AC-DC Metal Arc Welding

Source	Ref. 12.2					
Alloy	Type 301					
Electrode diameter, in	Material Gage U.S. Std.	 Equiv inches	Volts	Flat amp.	Vert up amp.	Overhead amp.
1/16	24-20	0.025-0.037	20	20-35	20-25	20-30
5/64	22-16	0.030-0.062	21	30-45	30-33	30-40
3/32	18-12	0.050-0.109	22	50-70	45-55	50-60
1/8	12-7	0.109-0.187	23	90-110	75-85	90-100
5/32	7-7 o's	0.087-0.500	24-25	125-150	95-110	125-140
3/16	3- o's	0.375-0.750	25-27	155-195	105-120	155-185
1/4	-	>0.375	26-28	240-290	-	-
5/16	-	-	27-30	325-375	-	-

*AC current recommended; if DC used, employ procedures to avoid arc blow.
1 inch = 25.4 mm.

TABLE 12.2. — Results of Fatigue Tests Before and After Exposure for 23,600 Hours at 288°C (550° F)

Source	Ref. 12.20										
Alloy	Type 301, 50-percent cold rolled										
Before Exposure						After Exposure					
Spot Welded			Fusion Welded			Spot Welded			Fusion Welded		
S_{max}		Fatigue life, kilocycles	S_{max}		Fatigue life, kilocycles	S_{max}		Fatigue life, kilocycles	S_{max}		Fatigue life, kilocycles
kg/mm²	ksi		kg/mm²	ksi		kg/mm²	ksi		kg/mm²	ksi	
49.2	70	18	61.2	87	61	49.2	70	17	66.8	95	19
		19			66			18	61.2	87	44
		19			115			23			44
45.7	65	30	59.8	85	39	45.7	65	34			44
		32			48			34	59.8	82	74
		36			103			38			76
		54	58.4	83	309	42.2	60	69			108
42.2	60	71			312			73	54.1	77	147
		71			573			79			206
		76	57.8	82	86	38.7	55	137			>10,000
		125			108			165	52.7	75	>10,000
38.7	55	137			9,991			179			>10,000
		167			>10,000	36.6	52	295			
		186	56.2	80	114			311			
		332			198			314			
36.6	52	290			10,000	33.7	48	1,110			
		387			>10,000			1,560			
		437	54.8	78	>10,000	33.0	47	>10,000			
		>10,000			>10,000						
33.7	48	>10,000	52.7	75	10,000	31.6	45	>10,000			
		>10,000			10,000			>10,000			

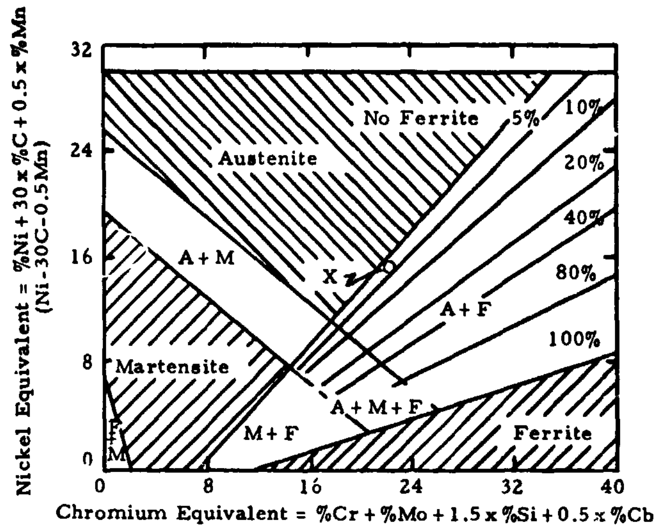


FIGURE 12.1. — Schaeffler diagram; ferrite as determined from chemical composition of austenitic stainless steel. (Ref. 12.8)

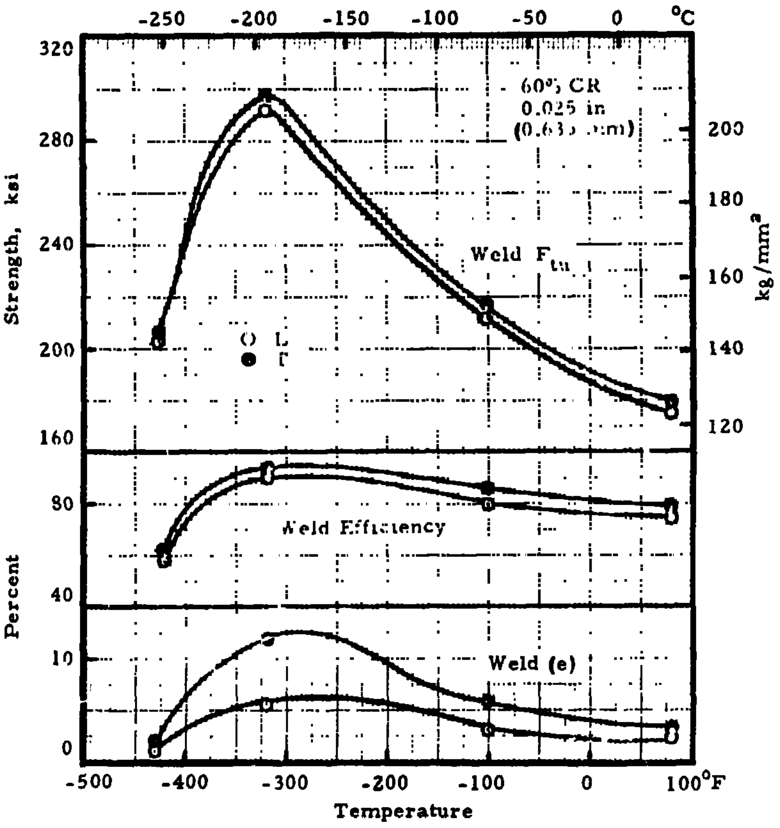


FIGURE 12.2. — Effect of low temperatures on tensile properties and efficiency of Type 301 TIG butt-welded sheet. (Ref. 12.9)

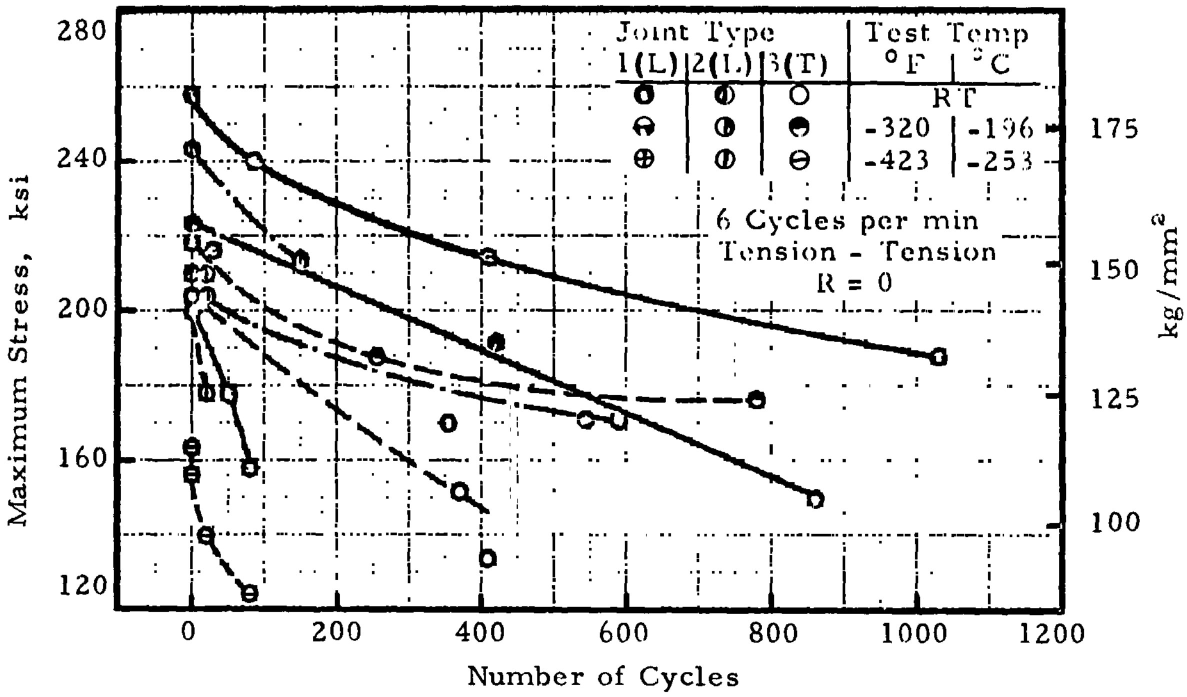
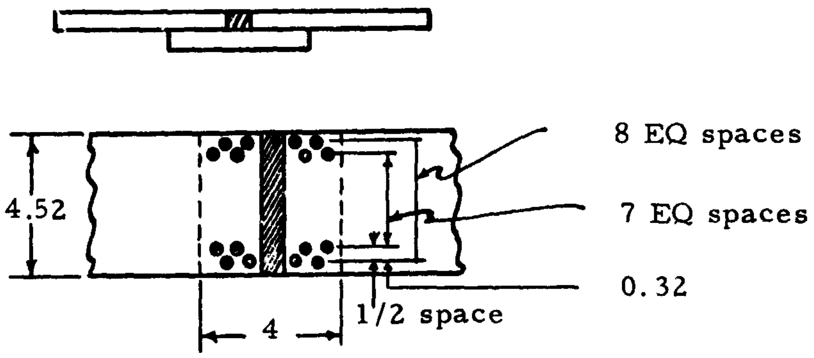
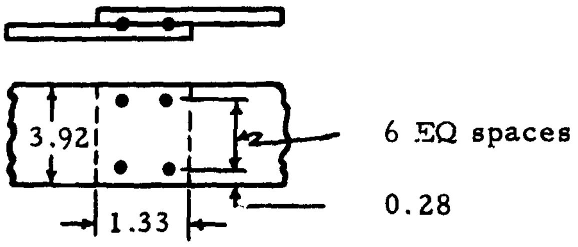


FIGURE 12.3. – Low-cycle S-N curves for complex welded joints of Type 301 60 percent cold-rolled sheet; thickness, 0.025 inch (0.635 mm). (Ref. 12.9)



Joint 1 (L): Heliarc buttweld plus spotweld doubler

Joint 2 (L): Same as 1(L) except 2 rows of spotweld on each side of buttweld instead of 4.



Joint 3(T): Resistance spotweld

(Note: 1 in = 25.4 mm)

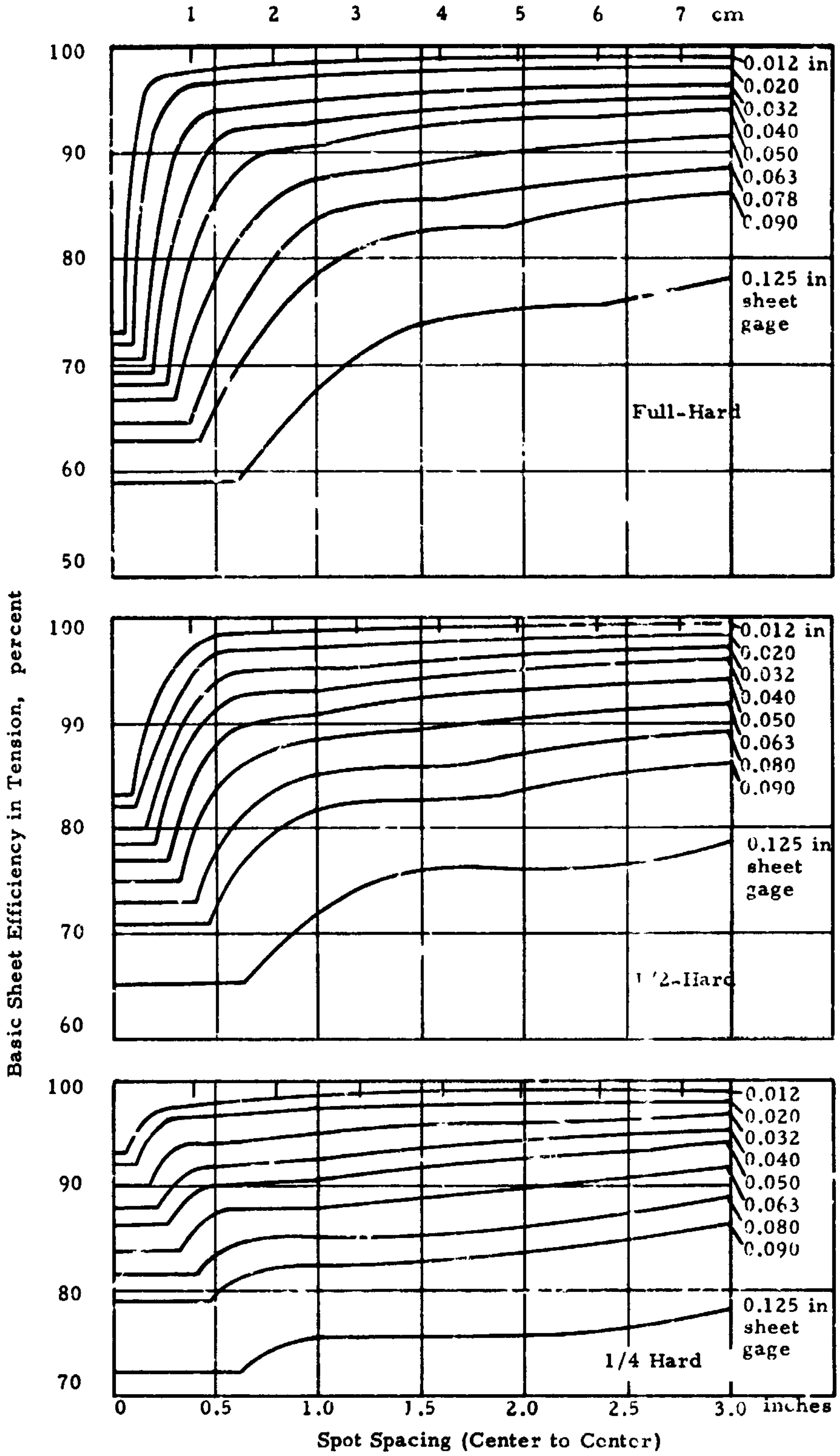


FIGURE 12.4. — Efficiency of the parent metal in tension for spot-welded Type 301 sheet in various conditions. (Ref. 12.13)

Chapter 12 - References

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