

REVISED: MARCH 1963

## NONFERROUS ALLOYS

COMMERCIALY  
PURE

1. **GENERAL**  
Commercially pure titanium is used where high ductility associated with moderate strength, high corrosion resistance and good weldability are desired. It is available in various degrees of purity, characterized mainly by different oxygen contents, and, consequently, with different mechanical properties. In 1959 three major grades were preferred with minimum yield strengths of 40 ksi, 55 ksi and 70 ksi, although other grades having yield strengths from 35 to 80 ksi are also widely used.
- 1.01 **Commercial Designations.** Commercially pure titanium, Ti-40, Ti-55, Ti-70.
- 1.02 **Alternate Designations.**  
F<sub>ty</sub>, min = 40 ksi. Ti (40,000 psi), A-40, MST-40, RS-40, Ti-55A.  
F<sub>ty</sub>, min = 55 ksi. 99 + Ti, Ti(55,000 psi), A-55, MST-55, RS-55, Ti-65A.  
F<sub>ty</sub>, min = 70 ksi. 99 Ti, Ti(70,000 psi), A-70, MST-70, RS-70, Ti-75A.  
F<sub>ty</sub>, min = 80 ksi. Ti-100A.
- 1.03 **Specifications.** Table 1.03.

TABLE 1.03

AMS	F <sub>ty</sub> , min	Form	Military
4902	40 ksi	Sheet, strip, plate	MIL-T-9046 Cl 5
4941		Tubing, welded	
4951		Wire, welding	
4900A	55 ksi	Sheet, strip, plate	MIL-T-9046 Cl 7
4901B	70 ksi	Sheet, strip, plate	MIL-T-9046 Cl 6
4921A		Bar, forgings, and forging stock	MIL-T-9047 Cl 1

- 1.04 **Composition.** Table 1.04.

TABLE 1.04

Source	AMS	AMS	AMS	AMS	AMS
	(1) (2)	(3)	(4)	(5)	(6)
F <sub>ty</sub> , min - ksi	40		55		70
	Percent Max	Percent Max	Percent Max	Percent Max	Percent Max
Carbon	0.20	0.10	0.20	0.20	0.20
Nitrogen	0.07 (b)	0.07	-	-	0.07
Oxygen (a)	-	0.15	-	-	0.40
Hydrogen	0.015	0.015	0.015	0.015	0.0125
Iron	-	0.30	-	-	-
Manganese	-	0.20	-	-	-
Other	0.60	-	0.60	0.80	0.80 (c)
Titanium	Balance	Balance	Balance	Balance	Balance

(a) If determined

(c) Need not be reported

(b) AMS 4941 only

- 1.05 **Heat Treatment**  
1.051 Anneal. 1000 F, 1 hr to 1300 F, 2 hr, depending upon degree of restoration of yield strength desired. Effect of annealing temperature on yield strength of cold rolled Ti-55, Fig. 1.051.
- 1.052 Stress relief to avoid distortions due to residual stresses. 1000 F, 1/2 hr to 1 hr, 900 F, 2 to 4 hr or 800 F, 8 hr.
- 1.06 **Hardenability.** All grades can be hardened only by cold work.
- 1.07 **Forms and Conditions Available**  
1.071 Alloy is available in the full commercial range of sizes for sheet, strip, plate, bar, billet, wire, forgings, extrusions and seamless and welded tubing, all in the annealed condition.
- 1.072 Special products which are available on a commercial basis are cold worked flat products and wire and castings.
- 1.08 **Melting and Casting Practice.** Consumable electrode double vacuum melt.

- 1.09 **Special Considerations**  
1.091 Hydrogen pickup during pickling or heating may lead to hydrogen embrittlement.  
1.092 Oxygen and nitrogen contamination during hot forming or heat treating may result in a brittle skin and difficulties on further forming operations.

## 2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 **Thermal Properties**  
2.011 Melting temperature. 3000 to 3040 F. Melting point of high purity (iodide) titanium is between 3020 and 3055 F.  
2.012 Phase changes. Alloy transforms from beta phase to alpha phase on cooling. Transformation temperature range (beta transus). Table 2.012.

TABLE 2.012

Grade	Iodide	Ti-55	Ti-70
Transformation range, F	1621	1650 to 1685	1665 to 1740

- 2.013 Thermal conductivity, Fig. 2.013.  
2.014 Thermal expansion, Fig. 2.014.  
2.015 Specific heat, Fig. 2.015.
- 2.02 **Other Physical Properties**  
2.021 Density. 0.163 lb per cu in. 4.51 gr per cu cm.  
2.022 Electrical resistivity, Fig. 2.022.  
2.023 Magnetic properties. Alloy is nonmagnetic. Permeability, 1.00005 to 1.0001 at 20 oersteds.
- 2.03 **Chemical Properties**  
2.031 Corrosion resistance  
2.0311 General. Titanium and its alloys possess outstanding corrosion resistance to most media, as summarized in Table 2.0311.

TABLE 2.0311

Medium	Corrosion Resistance
Nitric Acid	Excellent for all concentrations and to boiling point. Titanium has pyrophoric tendencies in red fuming nitric acid below 2 percent water and 10 to 20 percent nitrogen dioxide contents.
Sulfuric, Hydrochloric and Phosphoric Acids	Resists attack in dilute solutions at low temperatures. At higher temperatures and concentrations, inhibitors allow effective application.
Hydrofluoric Acid	Rapidly attacked.
Organic Salts	Generally good. Borderline passivity in formic and trichloroacetic acids.
Inorganic Salts	Outstanding, particularly to pitting attack of chloride solutions (see water), exception aluminum chloride.
Alkalies	Excellent for all concentrations and to boiling point, except boiling concentrated potassium hydroxide.

- 2.0312 Stress corrosion may occur in commercially pure titanium in dry red fuming acid. Stress corrosion may also occur in some titanium alloys, but not in pure titanium, if chloride salts have been deposited on the surface of stressed material which is then subjected to high temperatures.
- 2.0313 Galvanic corrosion of many metals is promoted by contact with titanium and its alloys, which are at the noble end of the galvanic series, next to nickel base alloys.
- 2.0314 Hydrogen embrittlement is a major problem with titanium and its alloys. Hydrogen is readily absorbed from hydrogenating solutions at room temperature and from the atmosphere at elevated temperatures. Hydrogen embrittlement of titanium alloys may assume one of two forms. First common for alpha alloys, is a reduction in ductility and slight increase in strength. This is associated with a decrease in impact strength at temperatures below 200 F and a shift in the temperature range where the change from duct-

CODE 3701

PAGE 1

tile to brittle behavior is observed. Second, similar to the embrittlement of steels, is an embrittlement at slow speeds of testing and under constant or "sustained" loads as usually demonstrated by such tests on notched specimens. This type of embrittlement generally becomes evident only above a certain strength level and it is observed particularly in alpha-beta type alloys at room and moderately elevated temperatures. In general, the hydrogen tolerance of titanium alloys is specified at 0.015 percent for bar products, but it may vary depending upon the alloy and its condition. If the tolerance limit is maintained, hydrogen embrittlement is practically absent.

2.032

Oxidation resistance

2.0321

Scaling of titanium and its alloys starts at about 900 F. Light scale formed during exposure at temperatures up to 1000 F for long times has no detrimental effect on the properties.

2.0322

Heating to temperatures above 1000 F under oxidizing conditions results in increasingly severe surface scaling as well as in diffusion of oxygen. Diffusion results in hard brittle surface layers difficult to distinguish from the base metal. This contaminated layer is brittle and must be removed, therefore, by mechanical or chemical means prior to forming parts or application in stressed components.

2.04

Nuclear Properties

2.041

The thermal neutron absorption cross section of titanium is 5.6 barns.

2.042

The mechanical properties of Ti-70 are affected by irradiation as follows.

2.0421

The hardness is increased by exposure at 3 to 20 x 10<sup>19</sup> nvt slow and 200 to 540 F from about 200 to 230 BHN.

2.0422

Irradiation at 180 F raises the yield strength considerably, the tensile strength to a lesser extent and reduces the ductility, both at room temperature and at 212 F. A yield point was observed when tested at 390 F.

2.0423

The impact strength appears unaffected by irradiation, according to limited data.

2.043

Physical properties of Ti-70 are affected by irradiation as follows.

2.0431

The density remained constant after irradiation.

2.0432

No dimensional changes were observed.

2.0433

The electrical resistivity decreased by exposure at 2 to 7 x 10<sup>20</sup> nvt slow and 180 F.

3.

MECHANICAL PROPERTIES

3.01

Specified Mechanical Properties

3.011

AMS specified mechanical properties, Table 3.011.

TABLE 3.011

Source	AMS (1)	AMS (2)	AMS (3)	AMS (4)	AMS (5)	AMS (6)
Alloy	Ti-40		Ti-55		Ti-70	
Form	Sheet, strip, plate	Tubing, welded	Wire, welding	Sheet, strip, plate	Sheet, strip, plate	Bar, forgings, stock
Condition	Ann					
F <sub>tu</sub> , min - ksi	50	50	50	65	80	80
max - ksi	-	-	80	-	-	-
F <sub>ty</sub> , min - ksi	40	40	-	55	70	70
max - ksi	65	65	-	80	95	-
e(2 in), min-percent	20	20	-	18	15	(4D) 15*
RA, min - percent	-	-	-	-	-	30*

\* Thickness ≤ 3 in

3.02

Mechanical Properties at Room Temperature. See 3.03 also.

3.021

Typical hardness values, Table 3.021.

TABLE 3.021

Alloy	Ti-40	Ti-55	Ti-70
Hardness			
RB, min	88	95	-
max	92	99	-
RC, min	-	-	23
max	-	-	29

3.022

Effect of exposure to elevated temperatures with load on tensile properties of Ti-70 bar, Table 3.022.

TABLE 3.022

Source (7, p. C-17)						
Alloy Ti-70						
Form Bar						
Condition Ann						
1100 hr exposure at			Tested at RT			
Temp F	Load ksi	Creep percent	F <sub>tu</sub> ksi	F <sub>ty</sub> ksi	e percent	RA percent
RT	65	10.6	107	97	15	45
400	40	3.6	97	89	20	53
600	35	5.8	106	98	20	33
800	12.5	6.5	93	76	20	33
1000	4	10.8	83	66	17	31

3.023

Effect of strain rate on tensile properties of Ti-55 and Ti-70 sheet, Fig. 3.023.

3.024

Compressive yield strength, F<sub>cy</sub> = 1.04 F<sub>ty</sub>.

3.025

Commercially pure titanium is not notch sensitive at room temperature, as evidenced for bar by a constant notch strength ratio over a wide range of stress concentrations or notch sharpnesses. Effect of notch sharpness on the notch strength ratio of bar at room temperature, Fig. 3.025.

3.026

Sheet specimens, provided with notches of various sharpnesses, also show lack of notch sensitivity at room temperature, evidenced by linear increase in notched strength ratio with notch depth. Effect of notch depth on the notch strength ratio of sheet, Fig. 3.026.

3.03

Mechanical Properties at Various Temperatures

3.031

Short time tension properties

3.0311

Stress strain curves for Ti-55 and Ti-70 sheet at room and elevated temperatures, Fig. 3.0311.

3.0312

Effect of test temperature on tensile properties of various grades of titanium bar and sheet, Fig. 3.0312.

3.0313

Effect of test temperature on tensile properties of Ti-70 sheet, Fig. 3.0313.

3.0314

Effect of test temperature on tensile properties of annealed and of cold worked 0.064 in Ti-55 sheet, Fig. 3.0314.

3.0315

Effect of test temperature on tensile strength of annealed and of cold worked 0.187 in Ti-55 sheet, Fig. 3.0315.

3.0316

Effects of test temperature, holding time and strain rate on tensile properties of Ti-70 sheet, Fig. 3.0316.

3.032

Short time properties other than tension

3.0321

Stress strain curves in compression for Ti-55 at room and elevated temperatures, Fig. 3.0321.

3.0322

Effect of test temperature on compressive yield strength of Ti-55 sheet, Fig. 3.0322.

3.0323

Effect of test temperature on bearing properties of Ti-55 sheet, Fig. 3.0323.

3.0324

Effect of test temperature on shear strength of Ti-55 sheet, Fig. 3.0324.

3.0325

Effects of test temperature and strain rate on torsion strength of Ti-70 bar, Fig. 3.0325.

3.0326

Effect of test temperature on impact strength of various grades of titanium, Fig. 3.0326.

3.033

Static stress concentration effects

3.0331

Effects of notch depth and low test temperatures on the notch strength ratio of Ti-70 bar, Fig. 3.0331.

3.04

Creep and Creep Rupture Properties

3.041

Total strain curves for Ti-70 sheet at 600 to 1200 F, Fig. 3.041.

3.042

Creep rupture curves for Ti-55 and Ti-70 at room temper-

REVISED MARCH 1963

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PURE

sure to 1000 F, Fig. 3.042.

- 3.05 Fatigue Properties  
3.051 Fatigue properties of Ti-55 bar, Table 3.051.

TABLE 3.051  
(8, p. 34)

Source		Ti-55					
Alloy		Bar					
Condition		Ann					
Temp F	Method	Stress Ratio		Stress Concen- tration	Fatigue Strength - ksi at Cycles		
		A	R		$10^6$	$10^7$	
-312	Rev bend	$\infty$	-1	Smooth K = 1	-	100	
				Notched K = 2.7	-	46	
RT				Smooth K = 1	42	41	
				Notched K = 2.7	-	35	
600				Smooth K = 1	22	21	

- 3.052 Fatigue properties of Ti-70 sheet and bar at room temperature, Table 3.052.

TABLE 3.052  
(7, p. C-15)

Source		Ti-70					
Alloy		Ann					
Form	Method	Stress Ratio		Stress Concen- tration	Fatigue Strength - ksi at Cycles		
		A	R		$10^5$	$10^6$	$10^7$
Bar	Rot beam	$\infty$	-1	Smooth K = 1	75	68	62
				Notched K = 2.7	42	38	36
Sheet	Direct Stress	0.25	0.6	Smooth K = 1	-	-	78

- 3.06 Elastic Properties  
3.061 Modulus of elasticity at various temperatures, Fig. 3.061.  
3.062 Modulus of rigidity at room and elevated temperatures, Fig. 3.062.  
3.063 Poisson's ratio, 0.34 to 0.405.  
3.064 Tangent modulus curves in compression at room and elevated temperatures, Fig. 3.064.

## FABRICATION

- 4.01 Forming and Casting  
4.011 Commercially pure titanium is formed only to a limited extent at room temperature. Many forming operations require heating to 400 to 1200 F. The ease of forming decreases as the strength increases. Burrs should be removed by filing to prevent edge cracking.  
4.012 Bend radii of 3.5t can be obtained at room temperatures using a lubricant. Smaller radii can be formed at temperatures above 300 F.  
4.013 Flanges can be rubber or die formed and sections can be contoured by stretch forming at room temperature. Preferably, the part is formed in two operations with an intermediate anneal.  
4.014 Elevated temperatures are used for various forming operations as follows: Drop hammer forming, 800 to 1000 F, spinning and deep drawing, about 800 F, rubber forming and die forming flanges, 400 to 800 F.  
4.015 Shearing and blanking require the same techniques and pressures as 1/4 hard austenitic stainless steels.  
4.016 Forging. Starting temperature 1700 F maximum, finishing temperature 1200 F minimum. To obtain optimum properties, forging equivalent to 25 to 40 percent reduction should be performed below the transformation temperature (beta to alpha + beta) in the final forging operation. Subsequent reheating such as required for sizing operations, should not exceed 1500 F or, generally, about 200 F below the beta to alpha plus beta temperature.  
4.017 Castings having properties comparable to those of wrought products can be produced in commercially pure titanium using consumable or nonconsumable electrode melting

techniques. The metal is poured in vacuum into special mold materials such as machined graphite.

- 4.02 Machining  
4.021 Commercially pure titanium has machining characteristics similar to those of austenitic stainless steels. Titanium alloys, because of their higher hardness, are somewhat more difficult to machine, but the same general rules apply. Sharp tools, rigid setups, heavy feeds slow speeds and an abundance of soluble oil coolant are the basic rules for successful machining. Titanium requires low forces and demonstrates a complete absence of "built up edge" it can be machined to very high surface finishes.  
4.022 Sawing is best performed with high speed friction saws running at a linear speed of 4000 to 4500 fpm. The feed should be positive. Hack and hand sawing is also possible. High speed steel blades, heavy feeds and slow speeds should be used. Surface scale and contaminated surfaces will result in excessive blade wear if not removed.  
4.023 Grinding should be performed only as a finishing operation. Light feed rates should be maintained. Silicon carbide wheels are satisfactory for conventional speed grinding. Maximum grinding ratios are maintained at 3,000 to 5,000 feet per minute surface speed. Parts should be stress relieved after grinding to remove residual stresses.  
4.03 Welding  
4.031 General. Commercially pure titanium is readily welded by suitable techniques. Welds possess excellent flow characteristics, high strength and ductility and a corrosion resistance equal to that of the parent metal.  
4.032 Fusion welding to 100 percent efficiency is accomplished by using gas shielded arc welding techniques. In open fusion welding, shielding can be effected by a sufficient supply of helium or argon, or preferably a 50/50 mixture of both, whereby any air contact with surface areas heated to 1800 F or higher is prevented. Alternatively, inert gas filled chambers are used. Back up support is essential. The edges must be deburred by filing and the metal must be very clean where welded. Stress relief at 800 to 1000 F in a furnace, or at about 1200 F with a gas torch is recommended after welding.  
4.033 Resistance welding. Spot and seam welding is done without protective atmosphere, using electrode pressures welding currents and time cycles similar to those used with austenitic stainless steels.  
4.04 Heating and Heat Treating  
4.041 Electric furnaces are preferred for heating and heat treating. If gas fired furnaces are used, these should be of the muffle type and the atmosphere should be oxidizing. Direct flame impingement should be avoided to prevent severe localized oxidation and contamination.  
4.042 Contact with scale or dirt should be prevented.  
4.043 The heating and heat treating time should be kept at a minimum, after uniform temperature is reached.  
4.044 Direct resistance heating of sheet or other thin sections may alternately be used where extremely short heat up and total heating times are desired on nearly finished surfaces to minimize surface oxidation.  
4.05 Surface Treating  
4.051 Cleaning. Oxidation at temperatures in excess of 1100 F is detrimental to forming and machining operations and can rarely be tolerated in finished parts. Scale may be removed preferably in oxidizing molten salt baths although under certain conditions sodium hydride type baths can be used if hydrogen pickup is minimized. It may also be removed mechanically by grit or vapor blasting or by grinding. Grinding should be followed by stress relief. After scale removal, the subsurface high oxygen layer should be removed by pickling in a 20 to 35 percent nitric acid - 2 to 5 percent hydrofluoric acid solution at 130 to 160 F. A nitric to hydrofluoric acid ratio of 10:1 or greater should be maintained to prevent hydrogen pickup.  
4.052 Light discolorations obtained by heating at 1000 to 1100 F may be removed by pickling in the nitric acid-hydrofluoric acid solution.

- 4.053 Surface hardening, to minimize wear of reciprocating parts can be accomplished by nitriding to surface hardnesses in excess of 600 KHN.
- 4.054 Galling of bolts or in forming of parts, can be eliminated by anodic or phosphate base chemical conversion type coatings. Oxides developed at 1200 to 1400 F also prevent galling and serve as a base for lubricants.
- 4.055 Electroplating with copper or nickel can be applied to titanium.

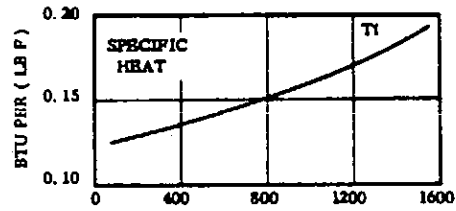


FIG. 2.015 SPECIFIC HEAT (10, p. 4)

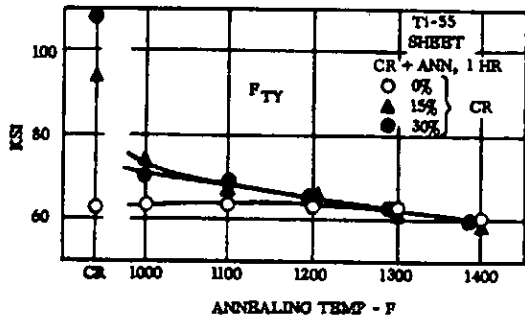


FIG. 1.051 EFFECT OF ANNEALING TEMPERATURE ON YIELD STRENGTH OF COLD ROLLED TI-55 SHEET (9, p. 108)

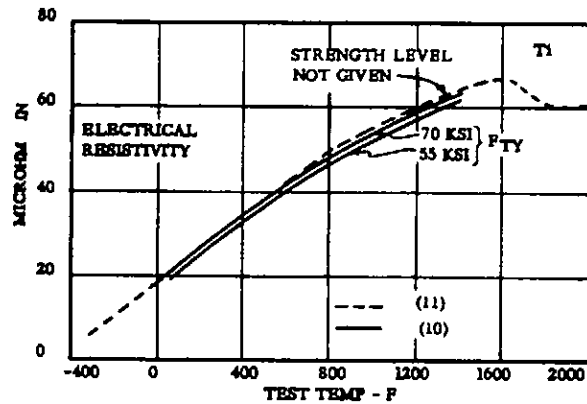


FIG. 2.022 ELECTRICAL RESISTIVITY (10, p. 3)(11, p. 44)

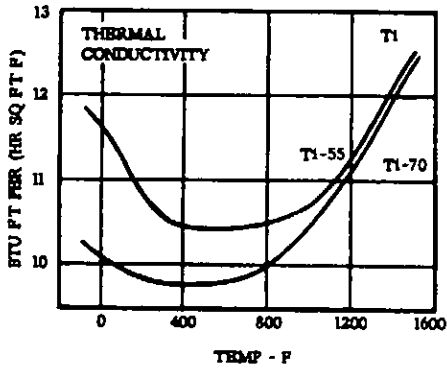


FIG. 2.013 THERMAL CONDUCTIVITY (10, p. 3)

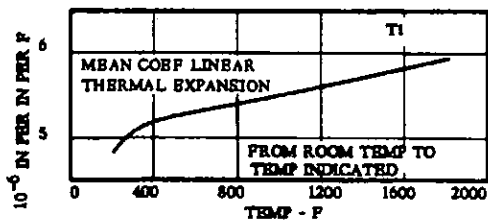


FIG. 2.014 THERMAL EXPANSION (10, p. 3)

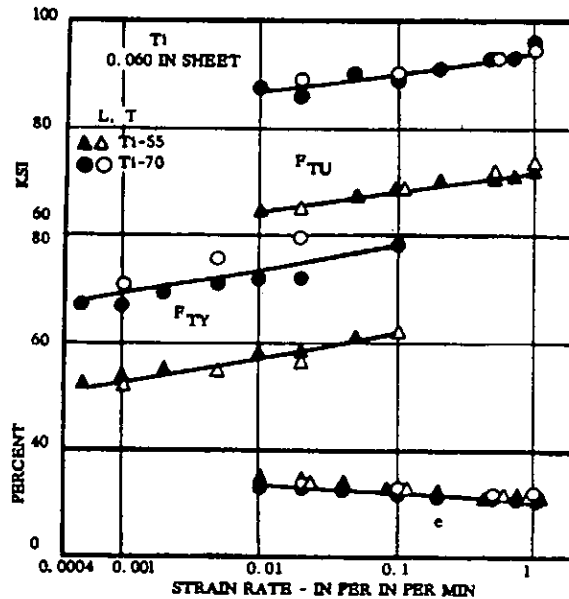


Fig. 3.023 EFFECT OF STRAIN RATES ON TENSILE PROPERTIES OF TI-55 AND TI-70 SHEET (9, p. 100, 101)

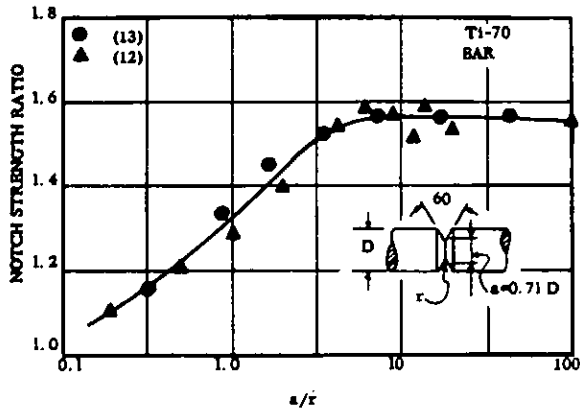


FIG. 3.025 EFFECT OF NOTCH SHARPNESS ON THE NOTCH STRENGTH RATIO OF BAR AT ROOM TEMPERATURE (12, p. 15)(13, p. 17)

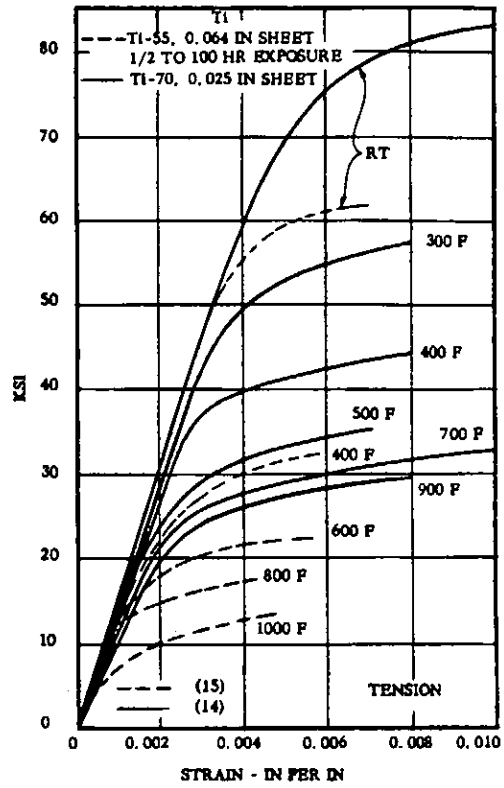


FIG. 3.0311 STRESS STRAIN CURVES FOR TI-55 AND TI-70 SHEET AT ROOM AND ELEVATED TEMPERATURES (14)(15, p. 67, 68)

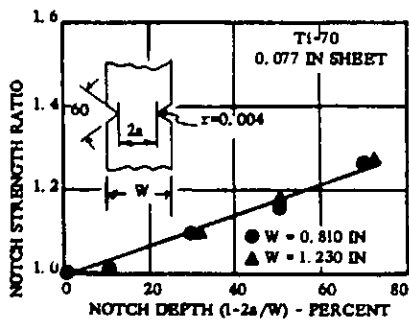


FIG. 3.026 EFFECT OF NOTCH DEPTH ON THE NOTCH STRENGTH RATIO OF SHEET (21)

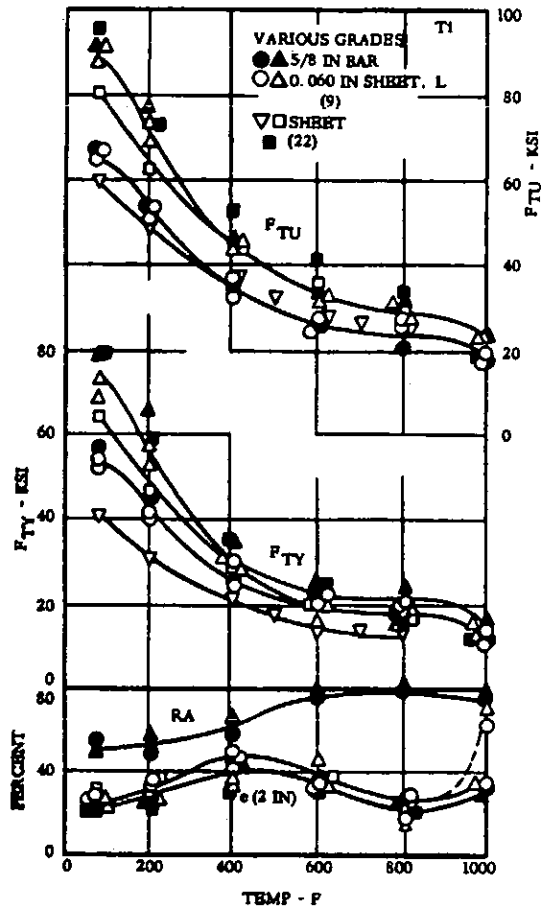


FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF VARIOUS GRADES OF TITANIUM BAR AND SHEET (9, p. 102-107) (22, p. 4-6)

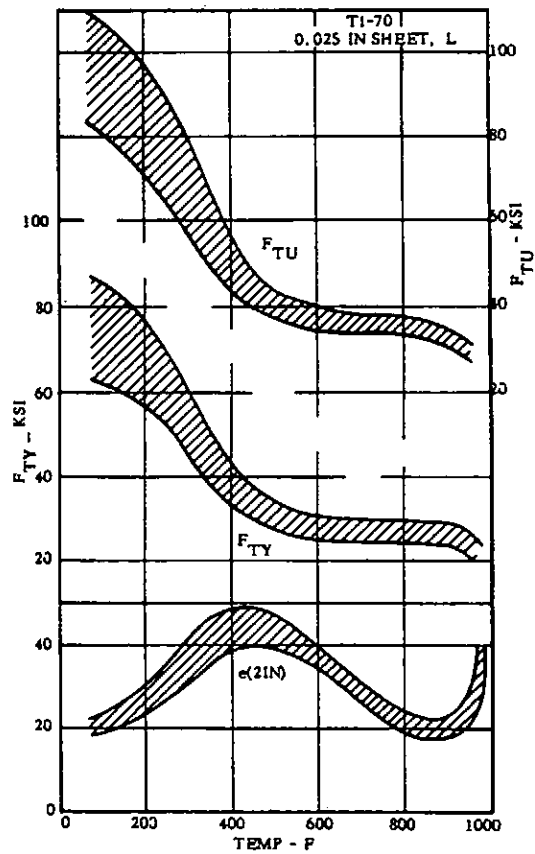


FIG. 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF TI-70 SHEET (14)

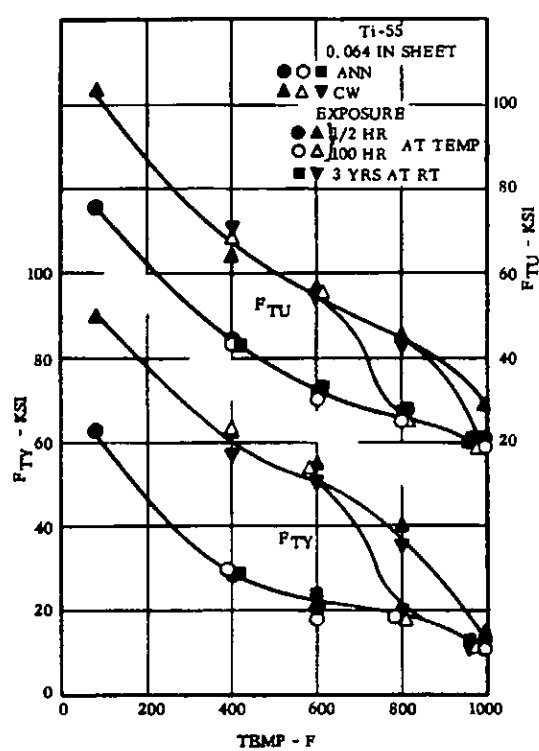


FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF ANNEALED AND OF COLD WORKED 0.064 IN TI-55 SHEET

(17), (19, p. 31)

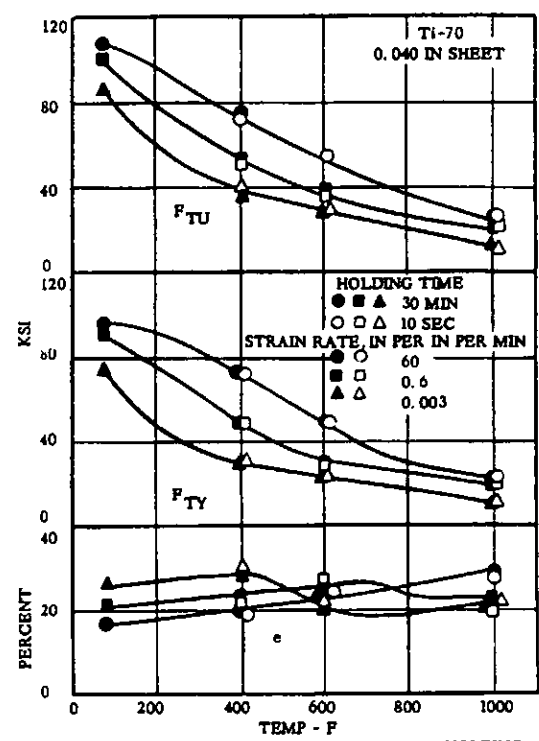


FIG. 3.0316 EFFECTS OF TEST TEMPERATURE, HOLDING TIME AND STRAIN RATE ON TENSILE PROPERTIES OF TI-70 SHEET

(16, p. 102-107)

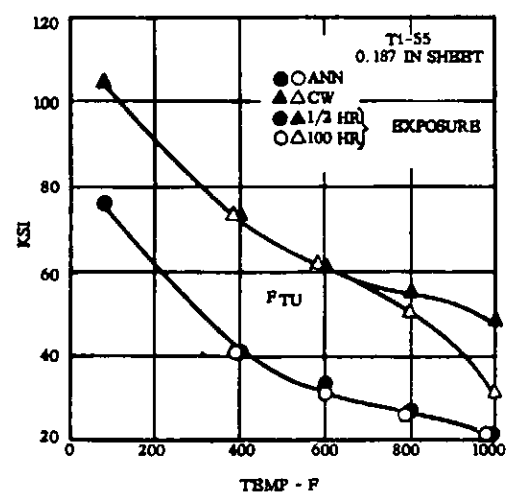


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE STRENGTH OF ANNEALED AND OF COLD WORKED 0.187 IN TI-55 SHEET

(17, p. 168, 177)

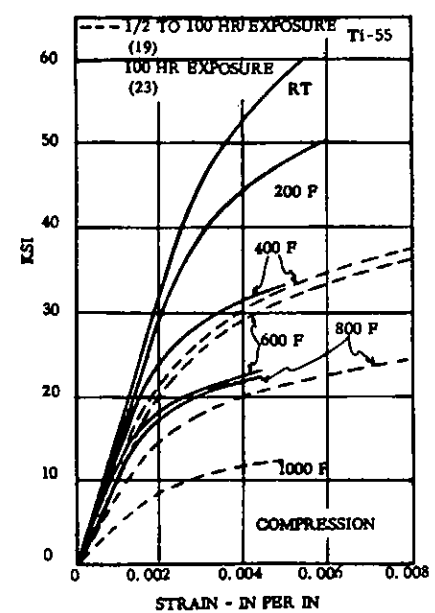


FIG. 3.0321 STRESS STRAIN CURVES IN COMPRESSION FOR TI-55 AT ROOM AND ELEVATED TEMPERATURES

(19, p. 55) (23)

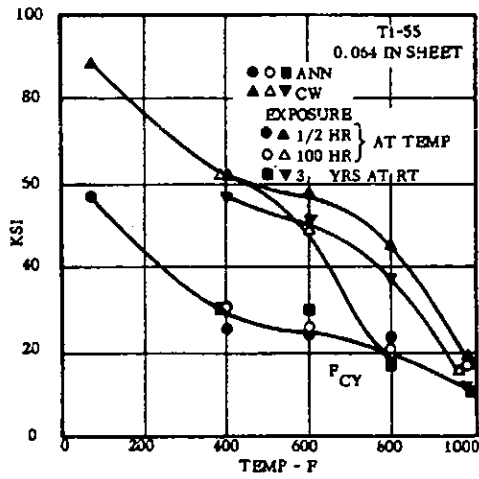


FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF TI-55 SHEET (17, p. 163, 172) (19, p. 28)

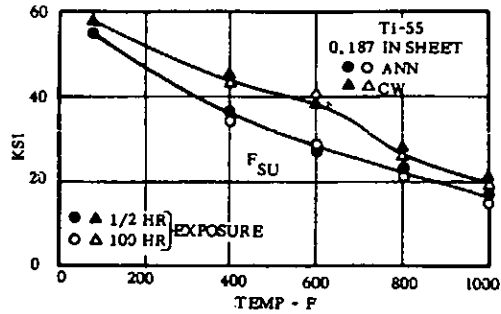


FIG. 3.0324 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF TI-55 SHEET (17, p. 167, 176)

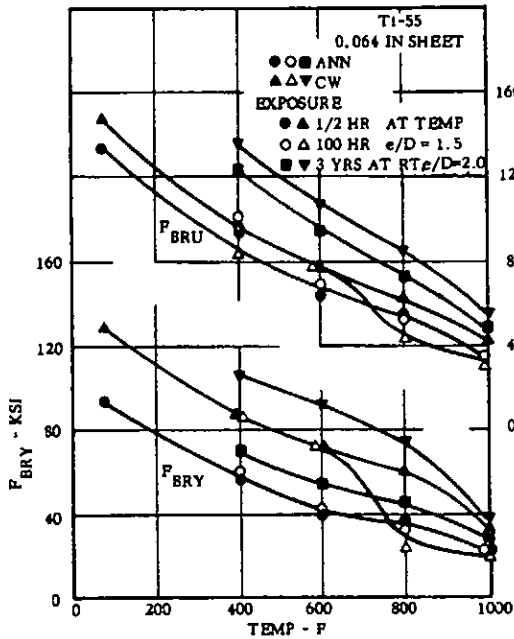


FIG. 3.0323 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF TI-55 SHEET (17) (19, p. 26)

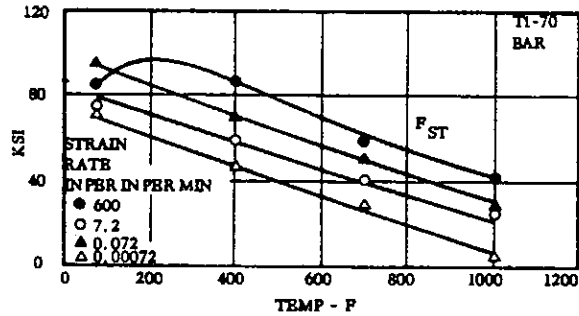


FIG. 3.0325 EFFECTS OF TEST TEMPERATURE AND STRAIN RATE ON TORSION STRENGTH OF TI-70 BAR (18, p. 103)

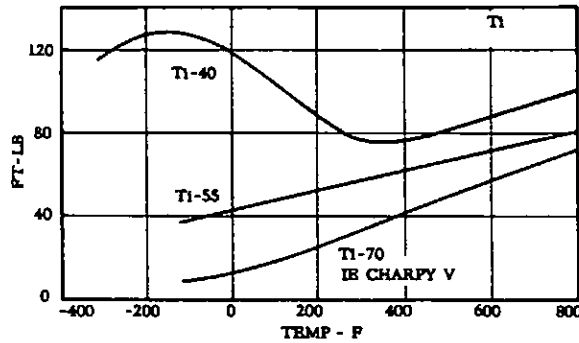


FIG. 3.0326 EFFECT OF TEST TEMPERATURE ON IMPACT STRENGTH OF VARIOUS GRADES OF TITANIUM (22)

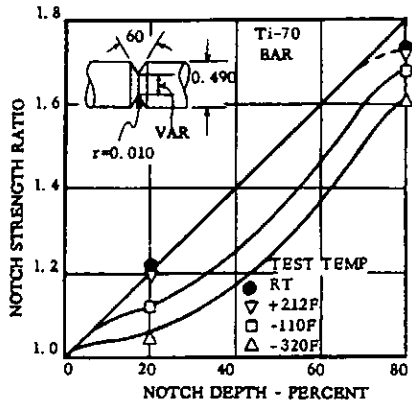


FIG. 3.0331 EFFECTS OF NOTCH DEPTH AND LOW TEST TEMPERATURES ON THE NOTCH STRENGTH RATIO OF Ti-70 BAR (13, TBL. B-7)

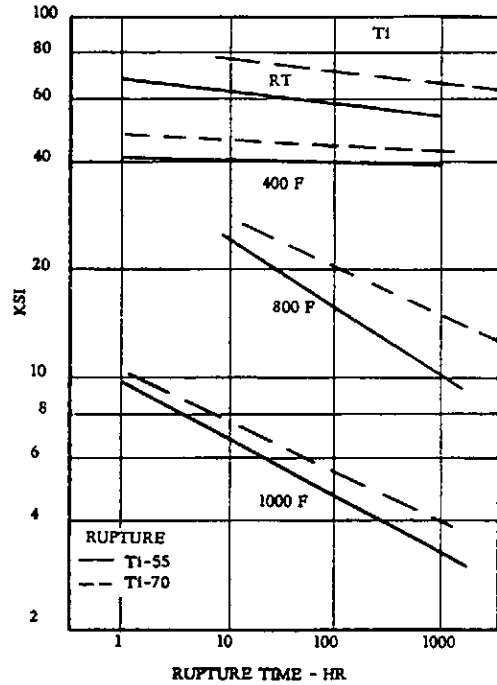


FIG. 3.042 CREEP RUPTURE CURVES FOR Ti-55 AND Ti-70 AT RT TO 1000 F (7)

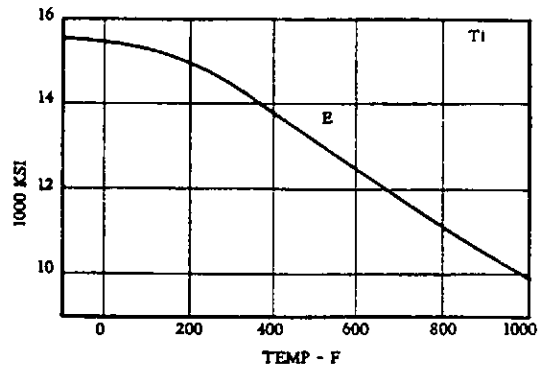


FIG. 3.061 MODULUS OF ELASTICITY AT VARIOUS TEMPERATURES (7)

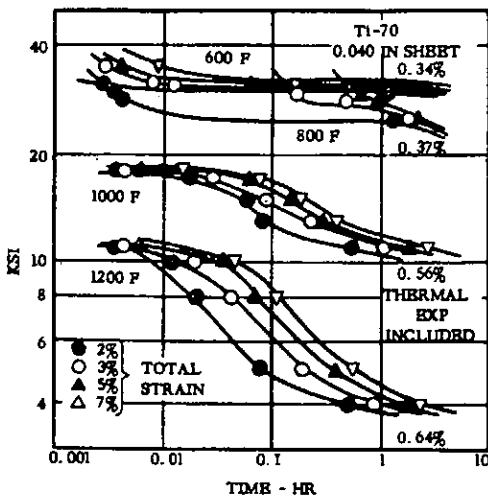


FIG. 3.041 TOTAL STRAIN CURVES FOR Ti-70 SHEET AT 600 TO 1200 F (20, p. 34, 35)

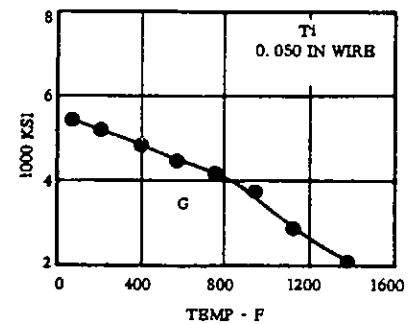


FIG. 3.062 MODULUS OF RIGIDITY AT ROOM AND ELBVATED TEMPERATURES (23)

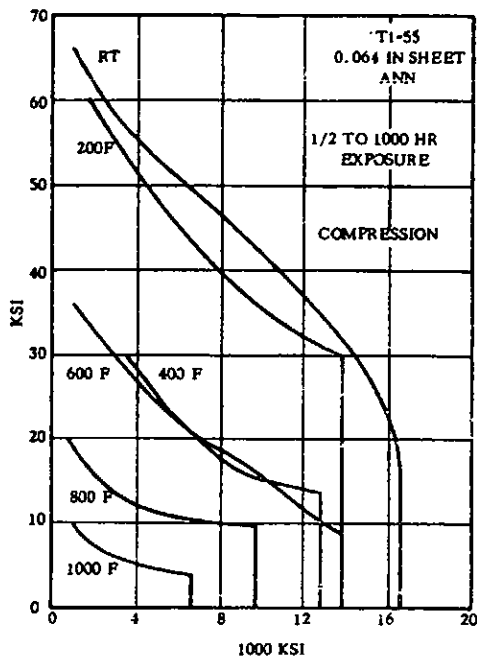


FIG. 3.064 TANGENT MODULUS CURVES IN COMPRESSION AT ROOM AND ELEVATED TEMPERATURES (19, p. 86, 87)

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