1. GENERAL

This is a medium strength all alpha titanium alloy used only in the annealed condition, having very high fracture toughness at room and elevated temperatures. In common with other titanium alloys the tensile strength increases rapidly with decreasing temperature. At liquid hydrogen temperature yield strength to density ratios from 1,200,000 to 1,500,000 are obtained, depending on the interstitial element content. The yield strength and tensile strength increase and the fracture toughness decreases with increased content of the interstitial elements. The extra low interstitial grade (ELI) is particularly well suited to service at cryogenic temperatures and in sheet form has an excellent combination of toughness and strength at -423F. Information concerning the toughness of heavy sections at cryogenic temperatures is not available as yet. This alloy is readily fusion welded using the TIG or MIG process. The toughness and strength of properly made fusion welds is equal to that of the parent metal. The stress corrosion resistance of this alloy at elevated temperatures in the presence of solid salt is lower than that of other commonly used titanium alloys. A severe explosion hazard may exist if the alloy is used in contact with liquid oxygen or in contact with gaseous oxygen at pressures above about 50 psi, (see 1.09).

1.01 Commercial Designation
5Al-2.5Sn Titanium alloy.

1.02 Alternate Designations
A110-AT, HA-5137, MST-5Al-2.5Sn, RS-110C, 5Al-2.5Sn ELI.

1.021 Producers of the alloy:
- Crucible Steel
- Harvey Aluminum
- Reactive Metals
- Republic Steel
- Titanium Metals Corp. of America

1.03 Specifications

1.031 AMS Specifications, Table 1.031.

TABLE 1.031

AMS	Form	Military
4910A	Sheet, strip, plate	T9046 Class 3
4926	Bar	T9047 Class 2
4953	Weld wire	
4966	Forgings and forging stock	T9047 Class 2

1.04 Composition

1.041 Composition for standard grade, Table 1.041.

TABLE 1.041

Source	AMS (1)(2)(4)		AMS (5)		(15)	
Form	Sheet, strip, plate bar, forging and forging stock		Weld wire		Sheet, strip, plate, bar, billet, wire	
	Percent		Percent		Percent	
	Min	Max	Min	Max	Min	Max
Aluminum	4.0	6.0	4.0	6.0	4.0	6.0
Carbon	-	0.15	-	0.10	-	0.08
Hydrogen	0.003	0.020	-	0.015	-	(b)
Iron	-	0.50	-	0.50	-	0.50
Manganese	-	0.30	-	0.20	-	-
Nitrogen	-	0.07	-	0.07	-	0.05
Oxygen	-	0.20 (a)	-	0.0175(a)	-	-
Tin	2.0	3.0	2.0	3.0	2.0	3.0
Other elements	-	0.40	-	-	-	-
Titanium	Balance		Balance		Balance	

a) If determined (AMS 4926 and 4923)
b) Sheet, 0.0175 max; Bar, 0.0125 max; Billet, 0.0100 max.

1.042 Composition for ELI grade, Table 1.042.

TABLE 1.042

Source	(14)		(15)	
Form	Sheet		Sheet, strip, bar, billet and wire	
	Percent		Percent	
	Min	Max	Min	Max
Aluminum	5.0	5.8	4.7	5.6
Carbon	-	0.05	-	0.08
Chromium	-	0.10	-	--
Hydrogen	-	0.015	-	0.0175*
Iron	-	0.25	-	0.15
Manganese	-	0.10	-	-
Molybdenum	-	0.10	-	-
Nitrogen	-	0.04	-	0.05
Oxygen	-	0.12	-	0.12
Tin	2.2	2.8	2.0	3.0
Vanadium	-	0.10	-	-
Other elements	-	0.30	-	-
Titanium	Balance		Balance	

* 0.0125 on bar and billet

1.05 Heat Treatment

1.051 Anneal. 1325F to 1550F, 10 minutes to 4 hours, furnace cool or air cool. AMS 4910A and 4966 give 1475 to 1500F, 1 hour, air cool. Temperatures above 1400F appear to give somewhat improved tensile and impact properties (see Fig. 3.0331). Rapid cooling appears to increase fracture toughness as compared with slow cooling, (see Fig. 3.03722).

1.052 Stress relief 1000 to 1200F, 15 minutes to 1 hour, air cool.

1.06 Hardness
Annealed hardness approximately 36 RC.
As cast approximately 321 BHN.

1.07 Forms and Conditions Available

1.071 Alloy is available in the full commercial range of sizes for sheet, strip, plate, bar, forgings, wire and extrusions.

1.072 All wrought products are available in the annealed condition.

1.073 Castings are also available on a commercial basis.

1.08 Melting and Casting Practice
Consumable electrode double vacuum melt.

1.09 Special Considerations

1.091 Directionality. Depending on the rolling and annealing conditions, α Ti-Al alloys tend to develop a preferred orientation with the basal plane parallel to the sheet surface. This texture inhibits strain in the thickness direction when tensile stresses occur parallel to the sheet plane, (33). Since twinning is also able to produce deformation, factors which suppress this process such as a small grain size, also tend to inhibit thickness strain. The result of thickness strain inhibition is to raise the yield strength in a biaxial stress field beyond that for an isotropic material. This yield strength elevation can be calculated according to Hill, (31) as follows:

$$\frac{\sigma_1}{F_{TY}} = \left[1 + \frac{\sigma_2^2}{\sigma_1^2} - \frac{\sigma_2}{\sigma_1}\left(\frac{2R}{1+R}\right)\right]^{-1/2}$$

where σ_1 and σ_2 are the principal stresses and R is the ratio of natural strain in the width to that in the thickness direction in a tensile test:

$$R = \ln\frac{W_o}{W} \Big/ \ln\frac{t_o}{t}$$

where W and t are the instantaneous width and thickness and W_o and t_o are the corresponding initial values. An R value of one corresponds to istropic behavior, values as high as 3.0 are sometimes encountered in normally processed 5Al-2.5Sn sheet, (see Fig. 1.0911). By special rolling and annealing treatments values somewhat higher than four can be produced and give rise to considerable biaxial strengthening, (see Fig. 1.0912). Special compositions are under development which have higher R value than can be obtained with 5Al-2.5Sn, (32). It should be noted that the influence of texturing on properties other than the tensile strength have not been investigated at the time this chapter was prepared. In particular, the crack propagation resistance of texture strengthened sheet should be studied before applying it to critical applications.

1.0911 Directionality of tensile strength and plastic strain for three heats of annealed sheet, Fig. 1.0911.

1.0912 Effect of rolling temperature and annealing treatment on the uniaxial yield strength and the theoretical biaxial yield strength in a 2:1 stress field, Fig. 1.0912.

1.092 Interstitial embrittlement, (see 6Al-4V). Extra low interstitial grade(ELI)should be employed for cryogenic service. Reduction of the interstitial element content below that in present commercially produced ELI will give further improvements in toughness, (see Fig. 3.03714).

1.093 Embrittlement by β stabilizers. The toughness is reduced by β stabilizing elements. Iron is a common impurity and should be excluded as far as possible for alloy to be used at cryogenic temperatures, Fig. 1.0931.

1.0931 Effect of iron content on -423F tensile and mild notch properties of ELI sheet, Fig. 1.0931.

1.094 Reactivity. Under certain conditions titanium and its alloys exhibit extreme reactivity when exposed to oxygen environments. When in contact with liquid oxygen burning can occur in impact loading and violent explosive reactions have been observed when the metal is subjected to high velocity puncture or to shock waves from explosive charges. When in contact with gaseous oxygen at pressures as low as 50 psi and temperatures as low as -250F, fresh fracture surfaces will burn and the reaction may propagate, (30). Surface treatment has little or no effect in reducing the reactivity under the above conditions, (30).

1.095 Stress corrosion. This alloy is more susceptible to elevated temperature solid salt corrosion than other commonly used titanium alloys, (see 2.032).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. 2800-3000F.

2.012 Phase changes. β transus on cooling is 1900 to 2000F, transus on heating 1700 to 1775F.

2.0121 Time-temperature-transformation diagrams

2.013 Thermal conductivity, Fig. 2.013.

2.014 Thermal expansion, Fig. 2.014.

2.015 Specific heat, Fig. 2.015.

2.016 Thermal diffusivity

2.02 Other Physical Properties

2.021 Density. 0.161 lb per cu in. 4.46 gr per cu cm.

2.022 Electrical resistivity, Fig. 2.022.

2.023 Magnetic properties. Alloy is nonmagnetic. Permeability at 20 oersteds, 1.00005.

2.024 Emissivity. See Ti-6Al-4V.

2.025 Damping capacity

2.03 Chemical Properties

See also Ti Commercially Pure and Ti-6Al-4V

2.031 Corrosion by gases. Appears to require a protective coating when used with gaseous flourine, (16).

2.032 Corrosion by solid salt.(see also Ti-6Al-4V). This alloy is more susceptible to solid salt corrosion at elevated temperatures than 6Al-4V or 8Al-1Mo-1V. Insufficient data is available to define the stress and temperature limits for stress corrosion for times above about 100 hours. Exposure to solid synthetic sea salt in heavy coatings will produce stress corrosion in 100 hours at 600F if the stress is above about 30 ksi (see Fig. 2.0321).

2.0321 Effect of stress and temperature on 100 hour salt stress corrosion of sheet, Fig. 2.0321.

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specified properties, Table 3.011.

TABLE 3.011

Source	(1)(2)(4) (c)	(3)
Alloy	Ti-5Al-2.5Sn	
Form	Sheet, strip, plate, bar, forgings and forging stock	Weld wire
Condition	1475 to 1525F, 1 hr, AC	-
F_{tu}, -min-ksi	115	115 to 150
F_{ty}, -min-ksi	110	-
e(4D) -min-percent(a)	10	-
RA, -min-percent(b)	25	-
Hardness, RC-max	36	-

a) e(2 in) for sheet ≤ 0.025 inch thick.
b) Not specified for sheet
c) For AMS 4926 and 4966. A tensile specimen with 60° V notch removing 50% of cross sectional area having 0.005 in tip radius shall have 5 hours, minimum rupture life at room temperature when loaded to 170 ksi.

3.012 Producer's specified mechanical properties, Table 3.012.

TABLE 3.012

Source	(15)	
Alloy	Ti-5Al-2.5Sn	
Form	Sheet, strip, plate, bar, billet	
Condition	Ann	
Grade	Standard	ELI
F_{tu}, -min-ksi	120	100
F_{ty}, -min-ksi	115	90
e(2 in) -min-percent(a)	10	10 (b)
RA, -min-percent	25	

(a) >0.025 in thick
(b) ≤ 0.020 in thick, 8 percent; determined by configuration of bar and forgings.

3.02 Mechanical Properties at Room Temperature

3.021 Tension

3.0211 Stress-strain diagrams, (see 3.0311).

3.0212 Effect of exposure in various mediums to elevated temperatures on tensile properties of sheet, Fig. 3.0212.

3.0213 Effect of stretching and stress relief on tensile and compressive yield strength of sheet, Fig. 3.0213.

3.022 Compression

3.0221 Stress-strain diagrams

3.023 Impact

3.024 Bending

3.025 Torsion and shear

3.026 Bearing

3.027 Stress concentration

3.0271 Notch properties

3.0272 Fracture toughness

3.028 Combined properties

3.03 Mechanical Properties at Various Temperatures

3.031 Tension

3.0311 Stress-strain diagrams

3.03111 Stress-strain curves for sheet, bar and forgings at room and elevated temperatures, Fig. 3.03111.

3.03112 Stress-strain curves for sheet at very high temperatures with various strain rates and holding times, Fig. 3.03112.

3.03113 Stress-strain curves for sheet at low temperatures, Fig. 3.03113.

3.0312 Effect of elevated test temperatures on the tensile properties of sheet, Fig. 3.0312.

3.0313 Effect of low test temperatures and interstitial element and Fe-content on tensile properties of sheet, Fig. 3.0313.

3.0314 Effect of low and elevated test temperature on tensile properties of bar, Fig. 3.0314.

3.0315 Effect of test temperature, strain rate and holding time on tensile properties of sheet, Fig. 3.0315.

3.0316 Effect of test temperature on the tensile properties of castings, Fig. 3.0316.

3.032 Compression

3.0321 Stress-strain curves in compression for sheet, bar and forgings at room and elevated temperatures, Fig. 3.0321.

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

3.033 Impact

3.0331 Effect of annealing temperature on the low temperature impact properties of ELI plate, Fig. 3.0331.

3.034 Bending

3.035 Torsion and shear

3.0351 Effect of test temperature on shear strength of bar, Fig. 3.0351.

3.036 Bearing

3.0361 Effect of test temperature on bearing properties of sheet, Fig. 3.0361.

3.037 Stress concentration

3.0371 Notch properties

3.03711 Effect of low test temperature, interstitial elements, and iron content on mild notch properties of sheet, Fig. 3.03711.

3.03712 Effect of test temperature on mild notch strength of sheet, Fig. 3.03712.

3.03713 Effect of test temperature on mild notch strength of bar, Fig. 3.03713.

3.03714 Effect of sheet thickness, interstitial element and iron content on sharp notch properties at -423F, Fig. 3.03714.

3.03715 Influence of cold rolling on -423F sharp notch strength of ELI sheet, Fig. 3.03715.

3.03716 Effect of stretching on the -423F sharp notch strength of ELI sheet, Fig. 3.03716.

3.0372 Fracture toughness

3.03721 General. The fracture toughness of this alloy is very high at room temperature and above. At cryogenic temperatures the toughness is highly dependent on the interstitial element content and the content of stabilizing elements. If the content of these elements is low (ELI grade) the alloy is very well suited to service at liquid hydrogen temperatures in sheet gages. Cooling rapidly from the annealing temperature appears to increase the toughness of sheet and this treatment should be used for critical applications. Fracture toughness values for plate are not yet available.

3.03722 Fracture toughness at -423F as function of thickness for ELI sheet cooled slowly and rapidly from annealing temperature, Fig. 3.03722.

3.038 Combined properties

3.04 Creep and Creep Rupture Properties

3.041 Creep deformation curves for sheet at 800F and 1000F, Fig. 3.041.

3.042 Creep deformation curves for sheet at 1100F, Fig. 3.042.

3.043 Isochronous stress-strain curves at 800F for annealed sheet, Fig. 3.043.

3.044 Isochronous stress-strain curves at 1000F for annealed sheet, Fig. 3.044.

3.05 Fatigue Properties

3.051 Rotating bending fatigue strength for smooth and notched sheet, Table 3.051.

TABLE 3.051

Source		(5, p. 6)					
Form		Sheet					
Condition		Ann					
Temp - F	Method	Stress Ratio		Stress Concentration	Fatigue Strength-ksi at cycles		
		A	R		10^5	10^6	10^7
RT	Rot beam	∞	-1	Smooth K = 1	77	64	62
				Notched K = 2.4	.56	45	43
				K = 3.2	40	30	27

3.052 Stress range diagram at 10^7 cycles for smooth and notched specimens of sheet, Fig. 3.052.

3.06 Elastic Properties

3.061 Poisson s ratio

3.062 Modulus of elasticity

3.0621 Static modulus of elasticity at low and elevated temperatures, Fig. 3.0621.

3.0622 Dynamic modulus of elasticity at low and elevated temperatures, Fig. 3.0622.

3.063 Modulus of rigidity

4. FABRICATION

4.01 Formability

See Titanium Commercially Pure

4.011 General. Formability of Ti-5Al-2.5Sn is inferior to that of Commercially Pure Titanium and Ti-8Mn. Short heating times are necessary when forming above 1000F.

4.012 Forging. Starting temperature. 1925F maximum, finishing temperature, 1650F minimum. To obtain optimum properties, reductions equivalent to 25 to 40 percent should be performed below the beta to alpha + beta transformation temperature in the final forging operation. Subsequent reheating, such as required for sizing operations, should not exceed a temperature of about 200F below the beta to alpha + beta transformation temperature.

4.02 Machining and Grinding

See Titanium Commercially Pure

4.03 Welding

4.031 General. This alloy is readily weldable by the same processes used for Commercially Pure Titanium. Fusion welds using the TIG or MIG process are preferred for high toughness at cryogenic temperatures. The fracture toughness at -425F of TIG fusion welds made in sheet is as high as the fracture toughness of parent metal provided that contamination is avoided, (24). Brazing is not recommended at this time due to brittleness associated with the formation of intermetallic compounds.

4.032 Effect of test temperature on impact strength of plate MIG welded with various fillers, Fig. 4.032.

4.04 Heat Treatment

4.05 Surface Treatment

See Titanium Commercially Pure

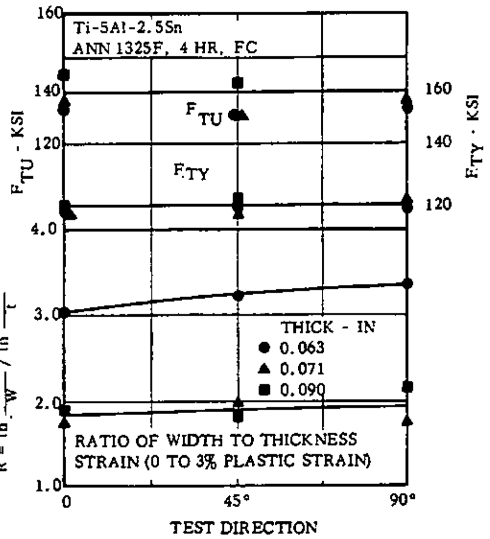


FIG. 1.0911 DIRECTIONALITY OF TENSILE STRENGTH AND PLASTIC STRAIN FOR THREE HEATS OF ANNEALED SHEET (29, p. 12)

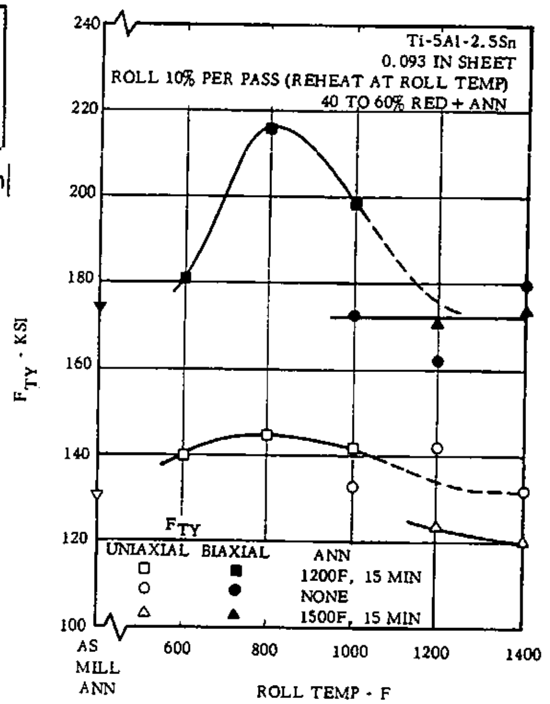
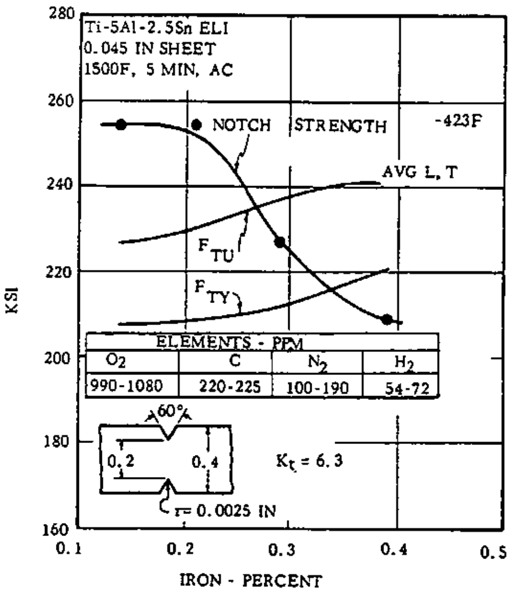


FIG. 1.0912 EFFECT OF ROLLING TEMPERATURE AND ANNEALING TREATMENT ON THE UNAXIAL YIELD STRENGTH AND THE THEORETICAL BIAXIAL YIELD STRENGTH IN A 2:1 STRESS FIELD (28, p. 5)



ELEMENTS - PPM			
O_2	C	N_2	H_2
990-1080	220-225	100-190	54-72

FIG. 1.0931 EFFECT OF IRON CONTENT ON -423F TENSILE AND MILD NOTCH PROPERTIES OF ELI SHEET (27)

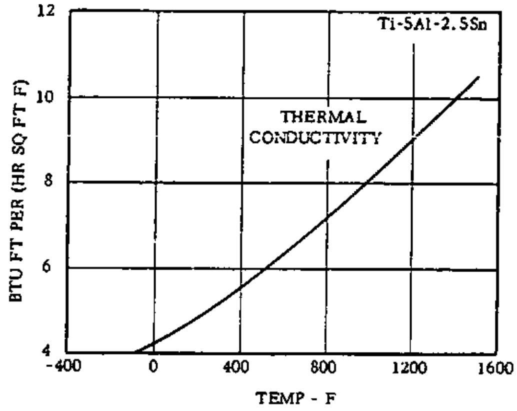


FIG. 2.013 THERMAL CONDUCTIVITY (5, p. 3)

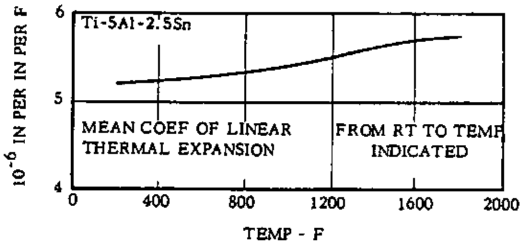


FIG. 2.014 THERMAL EXPANSION (5, p. 2)

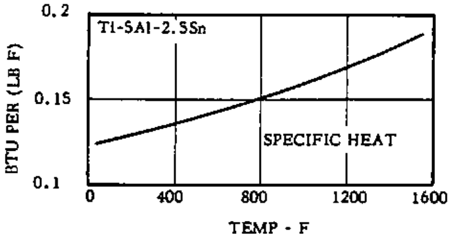


FIG. 2.015 SPECIFIC HEAT (5, p. 3)

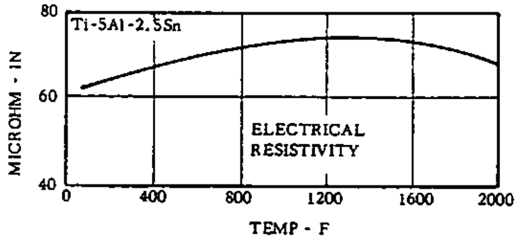


FIG. 2.022 ELECTRICAL RESISTIVITY (5, p. 2)

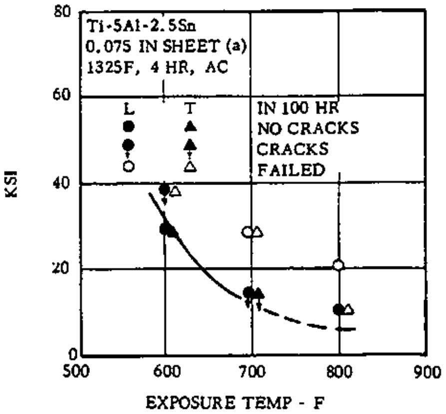


FIG. 2.0321 EFFECT OF STRESS AND TEMPERATURE ON 100 HOURS SALT STRESS CORROSION OF SHEET (17)

(a) 1/4 in wide smooth specimen coated 1/16 inch thick with ASTM sea salt.

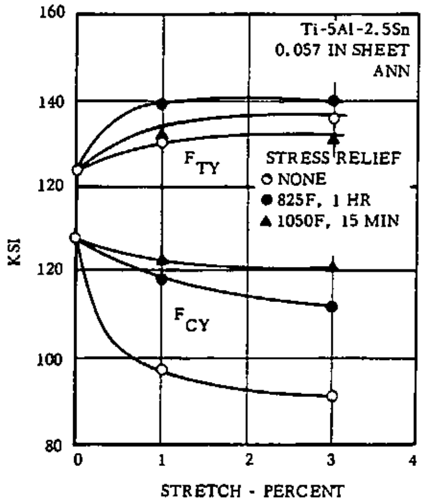


FIG. 3.0213 EFFECT OF STRETCHING AND STRESS RELIEF ON TENSILE AND COMPRESSIVE YIELD STRENGTH OF SHEET (13)

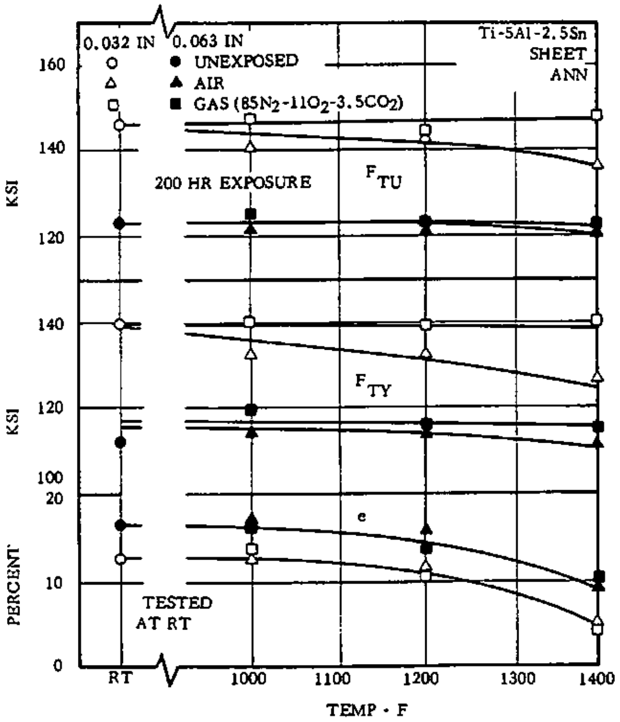


FIG. 3.0212 EFFECT OF EXPOSURE IN VARIOUS MEDIUMS TO ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF SHEET (12)

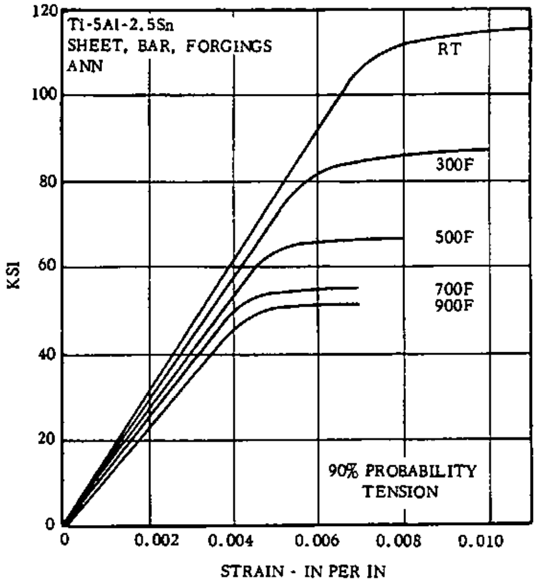


FIG. 3.03111 STRESS-STRAIN CURVES FOR SHEET, BAR AND FORGINGS AT ROOM AND ELEVATED TEMPERATURES (10, p. 31)

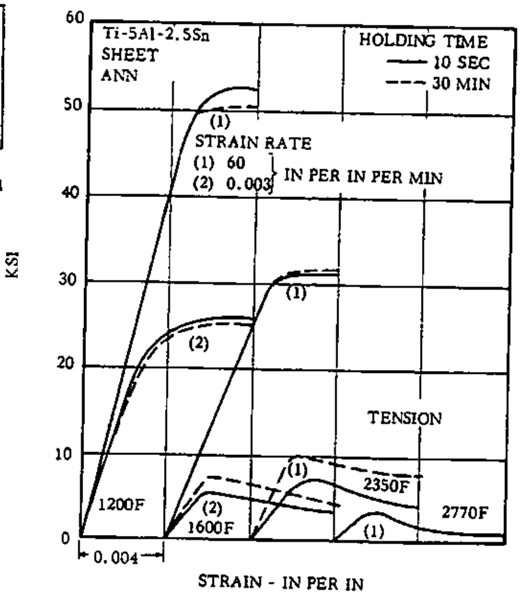


FIG. 3.03112 STRESS-STRAIN CURVES FOR SHEET AT VERY HIGH TEMPERATURES WITH VARIOUS STRAIN RATES AND HOLDING TIMES (9, p. 54)

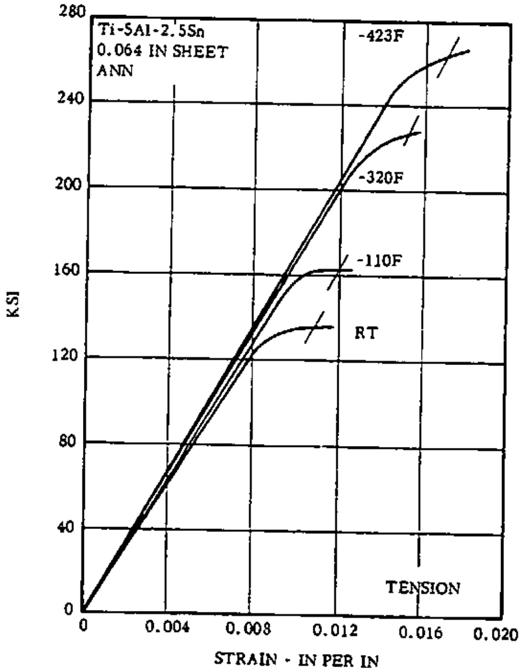


FIG. 3.03113 STRESS-STRAIN CURVES FOR SHEET AT LOW TEMPERATURES (8, p. 43)

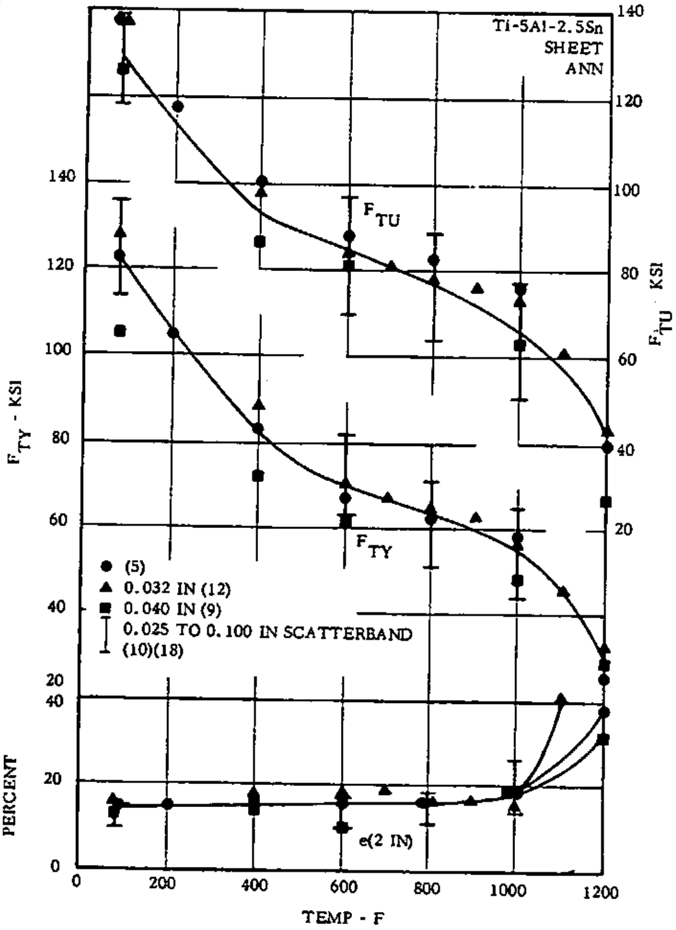
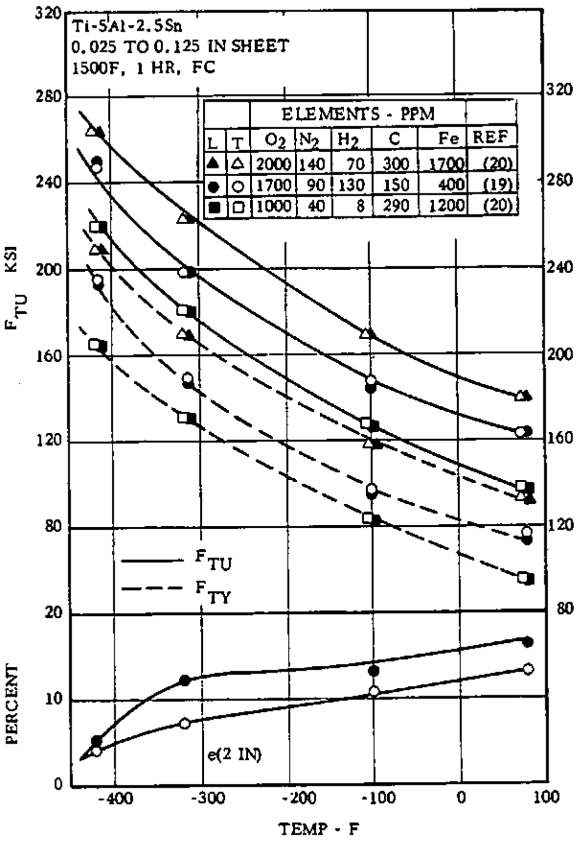


FIG. 3.0312 EFFECT OF ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF SHEET (5, p.5)(9)(10, p.15, 16)(12)(18, p.5)



		ELEMENTS - PPM					
L	T	O_2	N_2	H_2	C	Fe	REF
▲	△	2000	140	70	300	1700	(20)
●	○	1700	90	130	150	400	(19)
■	□	1000	40	8	290	1200	(20)

FIG. 3.0313 EFFECT OF LOW TEST TEMPERATURES AND INTERSTITIAL ELEMENT AND Fe-CONTENT ON TENSILE PROPERTIES OF SHEET (19, p. 204)(20)

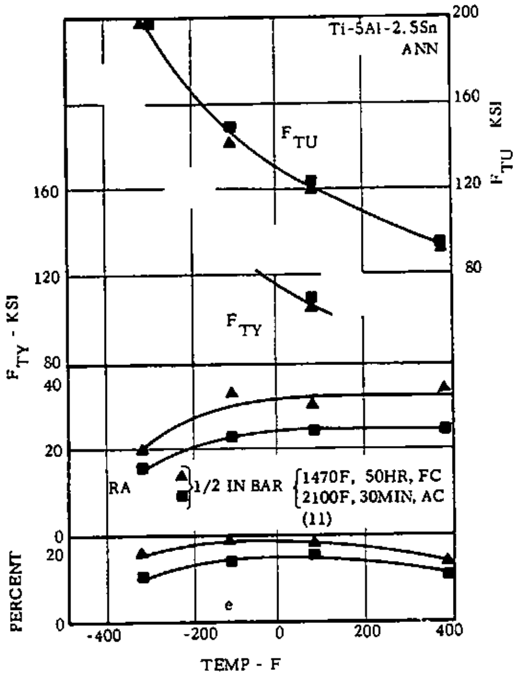


FIG. 3.0314 EFFECT OF LOW AND ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF BAR (11, p. 13, Tbl. 4)

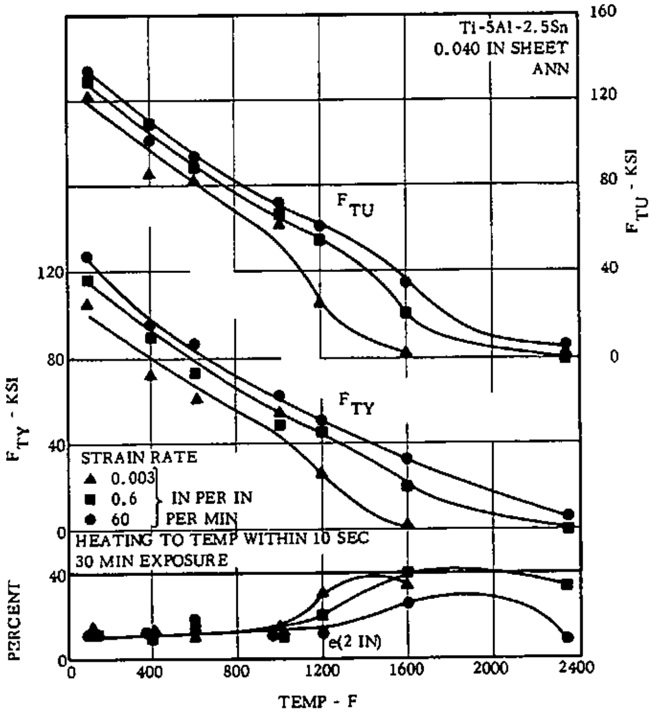


FIG. 3.0315 EFFECT OF TEST TEMPERATURE, STRAIN RATE AND HOLDING TIME ON TENSILE PROPERTIES OF SHEET (9, Tbl. VI)

	Ti
5	Al
2.5	Sn

Ti-5Al-2.5Sn

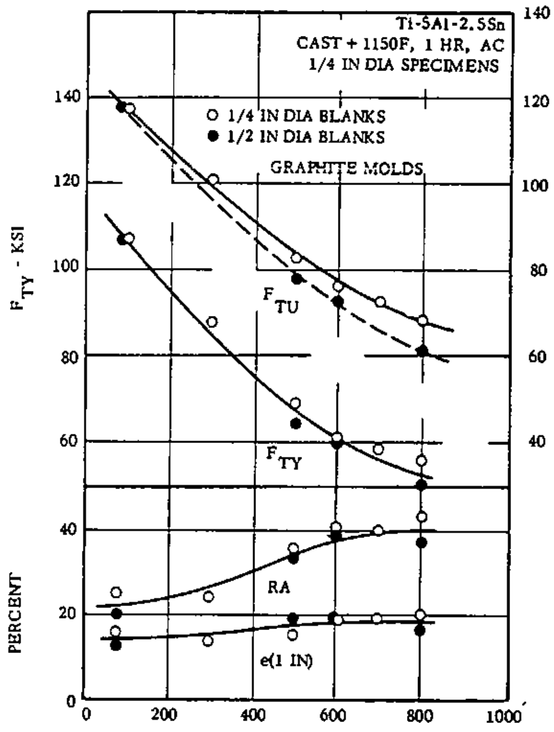


FIG. 3.0316 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF CASTINGS (21, p. A 4.2)

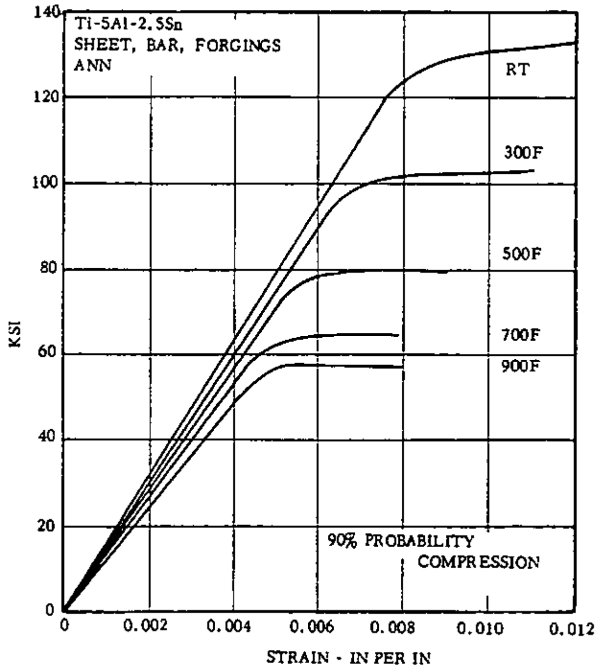


FIG. 3.0321 STRESS-STRAIN CURVES IN COMPRESSION FOR SHEET, BAR AND FORGINGS AT ROOM AND ELEVATED TEMPERATURES (10, p. 32)

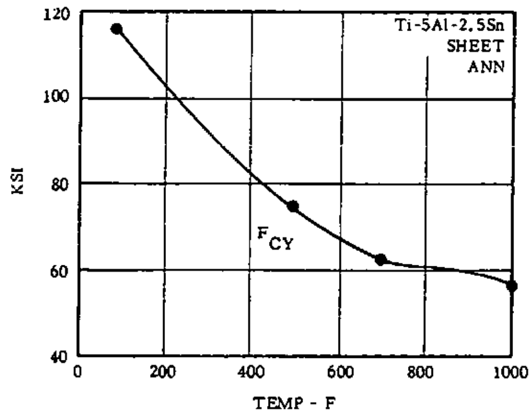


FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF SHEET (6, p. 89)

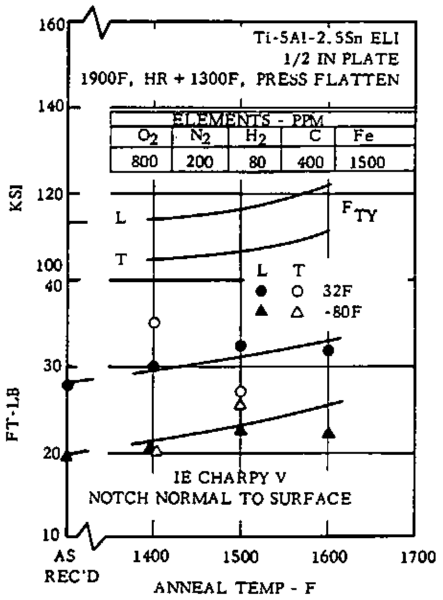


FIG. 3.0331 EFFECT OF ANNEALING TEMPERATURE ON THE LOW TEMPERATURE IMPACT PROPERTIES OF ELI PLATE (22)

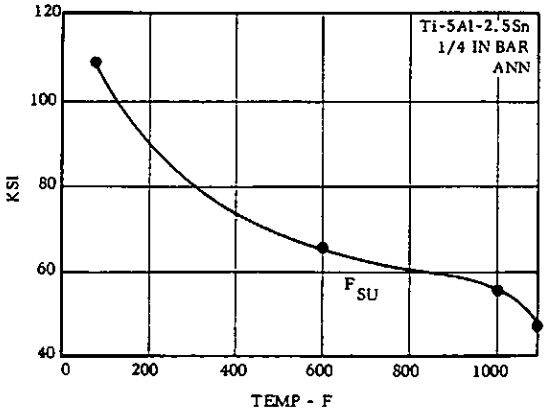


FIG. 3.0351 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF BAR (10, p. 37)

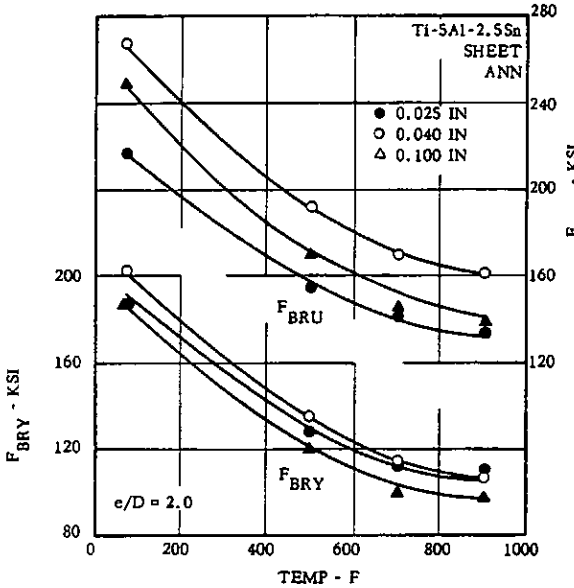


FIG. 3.0361 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF SHEET (7, p. D-4)

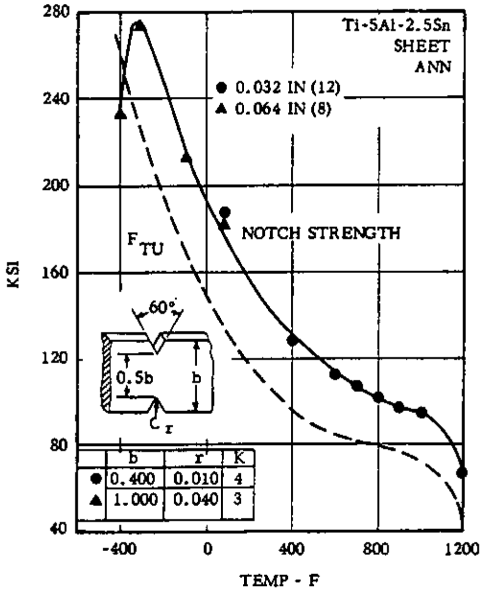


FIG. 3.03712 EFFECT OF TEST TEMPERATURE ON MILD NOTCH STRENGTH OF SHEET (8, p. 37)(12)

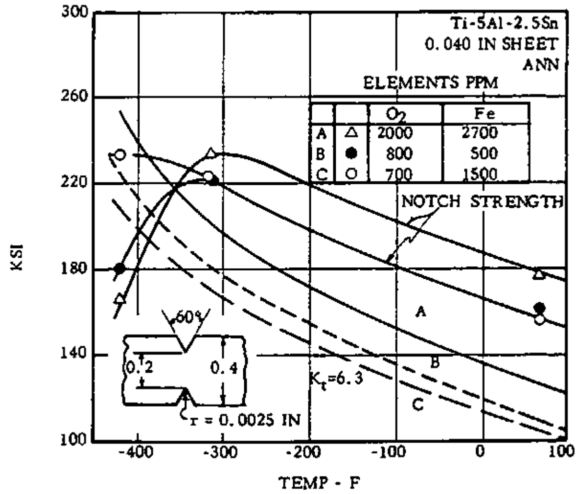


FIG. 3.03711 EFFECT OF LOW TEST TEMPERATURES, INTERSTITIAL ELEMENT AND IRON CONTENT ON MILD NOTCH PROPERTIES OF SHEET (23)

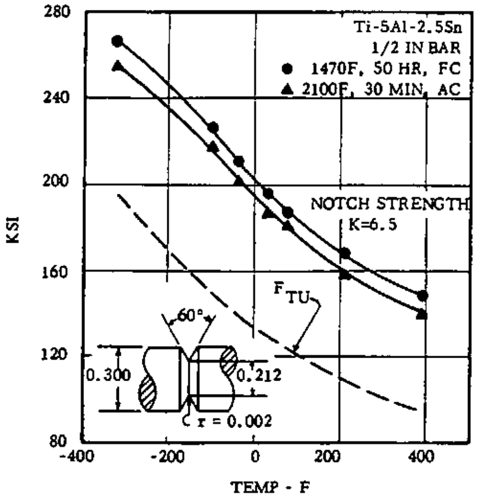
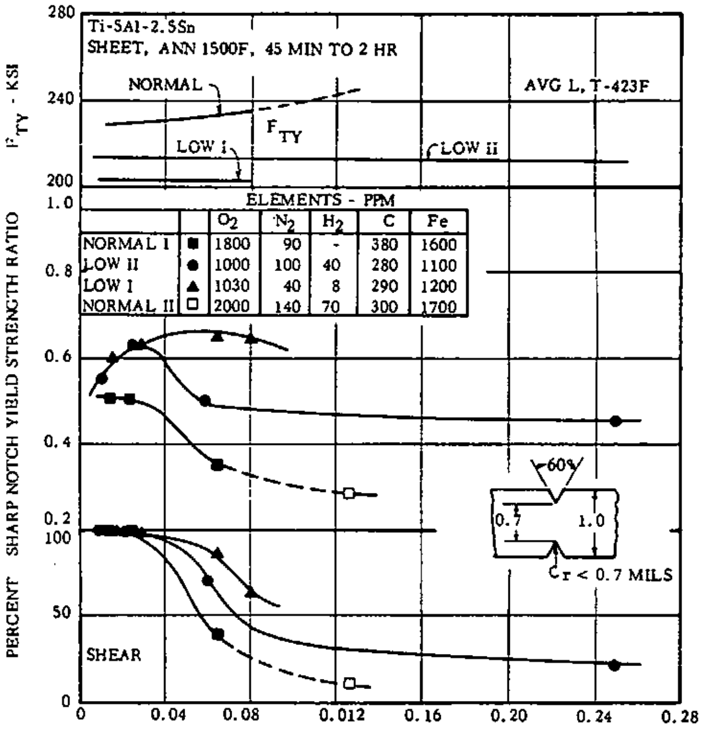


FIG. 3.03713 EFFECT OF TEST TEMPERATURE ON MILD NOTCH STRENGTH OF BAR (11)



ELEMENTS - PPM

		O_2	N_2	H_2	C	Fe
NORMAL I	■	1800	90	-	380	1600
LOW II	●	1000	100	40	280	1100
LOW I	▲	1030	40	8	290	1200
NORMAL II	□	2000	140	70	300	1700

FIG. 3.03714 EFFECT OF SHEET THICKNESS, INTERSTITIAL ELEMENT AND IRON CONTENT ON SHARP NOTCH PROPERTIES AT -423F (24)

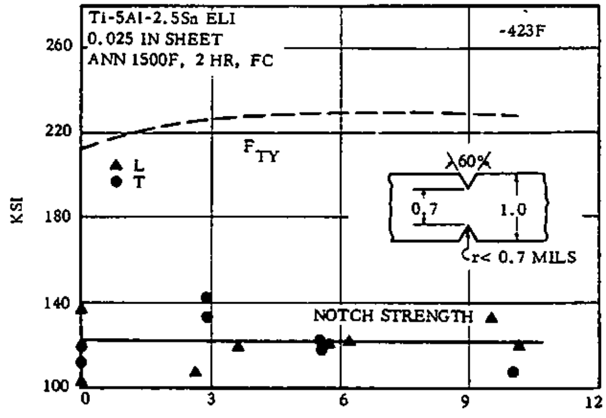


FIG. 3.03715 INFLUENCE OF COLD ROLLING ON -423F SHARP NOTCH STRENGTH OF ELI SHEET (24)

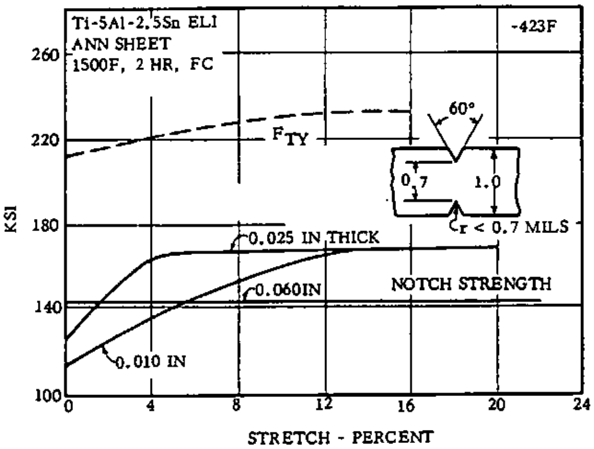


FIG. 3.03716 EFFECT OF STRETCHING ON -423F SHARP NOTCH STRENGTH OF ELI SHEET (24)

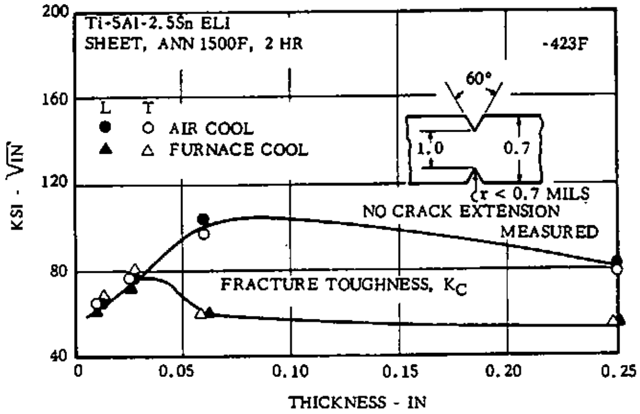


FIG. 3.03722 FRACTURE TOUGHNESS AT -423F AS FUNCTION OF THICKNESS FOR ELI SHEET COOLED SLOWLY AND RAPIDLY FROM ANNEALING TEMPERATURE (24)

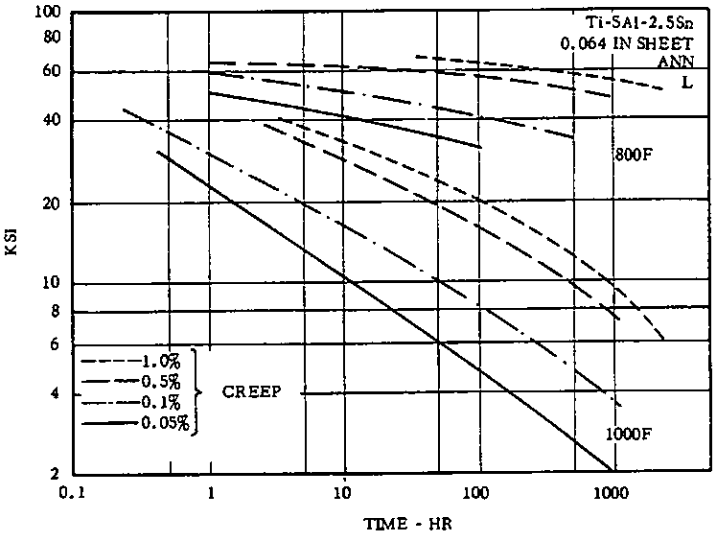


FIG. 3.041 CREEP DEFORMATION CURVES FOR SHEET AT 800 AND 1000F (18, p. 23)

	Ti
5	Al
2.5	Sn

Ti-5Al-2.5Sn

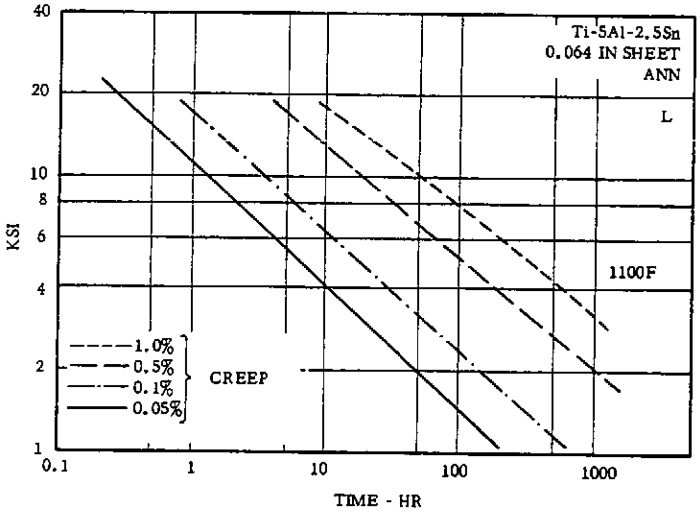


FIG. 3.042 CREEP DEFORMATION CURVES FOR SHEET AT 1100F (18, p. 23)

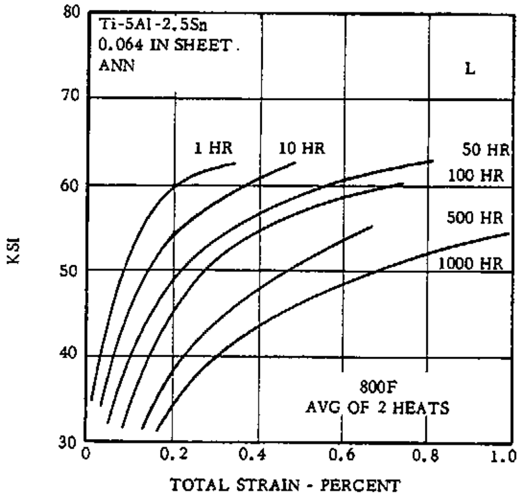


FIG. 3.043 ISOCHRONOUS STRESS-STRAIN CURVES AT 800F FOR ANNEALED SHEET (18, p. 17)

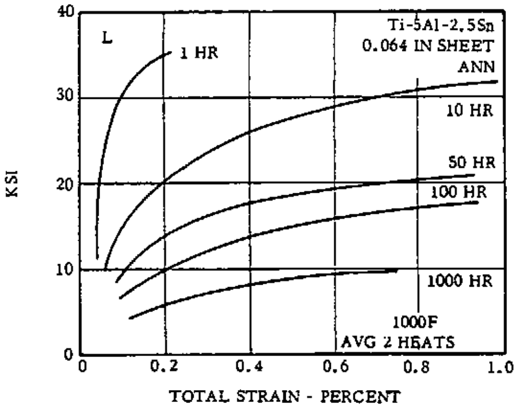


FIG. 3.044 ISOCHRONOUS STRESS-STRAIN CURVES AT 1000F FOR ANNEALED SHEET (18, p. 17)

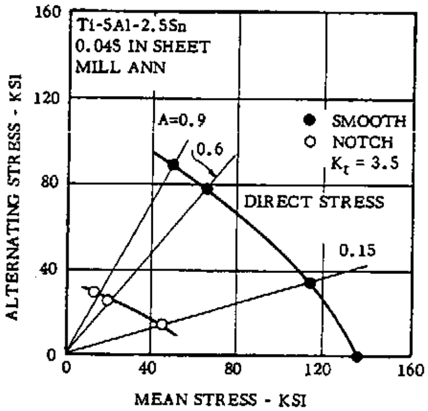


FIG. 3.052 STRESS RANGE DIAGRAM AT 10^7 CYCLES FOR SMOOTH AND NOTCHED SPECIMENS OF SHEET (25)

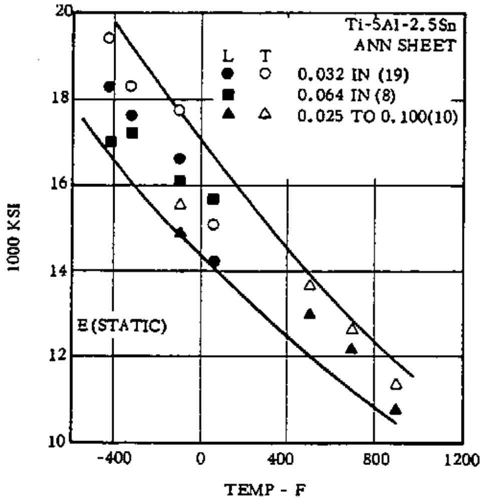


FIG. 3.0621 STATIC MODULUS OF ELASTICITY AT LOW AND ELEVATED TEMPERATURES (8)(10)(19)

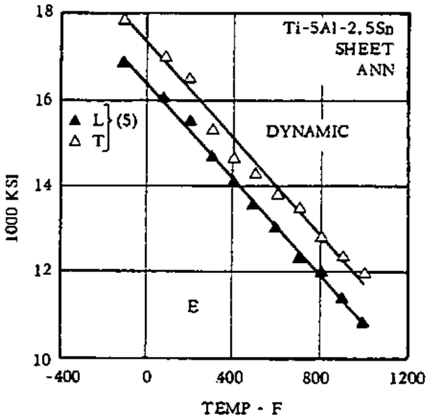


FIG. 3.0622 DYNAMIC MODULUS OF ELASTICITY AT LOW AND ELEVATED TEMPERATURES (5, p. 2)