	Ti
8	Al
1	Mo
1	V

1. GENERAL

This alloy is designed primarily for use in elevated temperature applications and in the annealed condition. The room temperature tensile strength is about equal to 6Al-4V but at elevated temperatures the tensile strength and creep resistance are superior to other commonly available alpha or alpha + beta titanium alloys. Special duplex annealing treatments have been developed which yield high fracture toughness in sheet at temperatures as low as -200F. This alloy has the highest tensile modulus and lowest density of any commercial titanium alloy. Recent investigations have shown it to be more susceptible to elevated temperature solid salt corrosion than 6Al-4V or 4Al-3Mo-1V. Delayed failure of cracked specimens has been encountered in salt solutions and susceptibility to this effect increases with thickness.

1.01 Commercial Designation

8Al-1Mo-1V-Ti alloy.

1.02 Alternate Designation

None.

1.03 Specifications

1.031 AMS 4955, Welding wire, (50).

1.04 Composition

Table 1.04.

TABLE 1.04

Source	(1)(4)	
Alloy	Ti-8Al-1Mo-1V	
	Percent	
	Min	Max
Aluminum	7.5	8.5
Molybdenum	0.75	1.25
Vanadium	0.75	1.25
Iron	-	0.3
Carbon	-	0.08
Nitrogen	-	0.05
Oxygen*	-	0.10
Hydrogen	-	0.015
Titanium	Balance	

* Ref. 4

1.05 Heat Treatment

1.051 Alloy is used in annealed condition and solution treating and aging is not recommended. Either single anneal or duplex cycles are employed depending on the combination of properties desired. The duplex cycles follow normal mill annealing (furnace cool) and involve air cooling. Air cooling from the annealing temperature increases the toughness with some reduction in room temperature strength, (19). Special heat treating procedures are under development to improve the hot-salt stress corrosion resistance and to reduce the tendency to delayed failure in the presence of certain environments, (see 1.09 and 2.03).

1.052 Bar forgings and heavy sections. Duplex, 1650 to 1850, 1 hour, air cool + 1000 to 1100F, 8 to 24 hours, air cool. For minimum distortion 1650F, 1 hour, air cool + 1100F, 8 hours, air cool. For higher creep resistance 1850F, 1 hour, air cool + 1100F, 8 hours, air cool, (1).

1.053 Sheet

1.0531 Mill anneal. 1450F, 8 hour, furnace cool. Highest room temperature tensile strength. Good stability and creep strength to 700F.

1.0532 Duplex anneal. Mill anneal + 1450F, 15 minutes, air cool. Appears particularly suited to moderately elevated temperature applications and where high toughness is required. See Table 3.02712.

1.0533 Duplex anneal (also called Triplex). Mill anneal + 1850F, 5 minutes, air cool + 1375F, 15 minutes, air cool. For superior creep resistance combined with good toughness, (see Fig. 3.041) and Table 3.02712).

1.054 Stress relief

1.0541 Stress relief for mill annealed sheet, 1300F, 30 minutes, air cool.

1.0542 Stress relief for duplex annealed sheet 1350F to 1450F, 15 minutes, air cool, (5).

1.0543 Process anneal for sheet, 1450F, 15 to 30 minutes, air cool, (5).

1.06 Hardness

Alloy is used in annealed condition only.

1.07 Forms and Conditions Available

Alloy is available in all normal commercial forms except strip, (3).

1.08 Melting and Casting Practice

1.081 Melting. Double consumable electrode vacuum melt.

1.082 Casting. Alloys is not cast.

1.09 Special Considerations

This alloy is susceptible to hot salt corrosion at temperatures above about 400F and subject to delayed failure when tested with cracks in the presence of salt water, (see 2.03). Heating in or slow cooling through the temperature range from about 1000 to 1200F should be avoided, (see Fig. 3.02713) thus, slow cooling from the annealing temperature tends to decrease the toughness, (see Fig. 3.037110). Unfortunately the structure produced by air cooling from the annealing temperature is not stable if heated for long periods of time at moderately elevated temperatures and under the circumstances the yield strength increases and the toughness decreases, (see Figs. 3.03110, 3.0218 and 3.02714).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. Approximately 3100F, (3).

2.012 Phase changes. Alloy transforms on heating to all-beta at approximately 1900F. Slow cooling from above the beta transus results in a predominately alpha structure with approximately ten percent beta, (3).

2.0121 Time-temperature-transformation diagrams

2.013 Thermal conductivity, Fig. 2.013.

2.014 Thermal expansion, Fig. 2.014.

2.015 Specific heat

2.016 Thermal diffusivity

2.02 Other Physical Properties

2.021 Density. 0.156 lbs per cu in. 4.37 gr per cu cm.

2.022 Electrical resistivity, Fig. 2.022.

2.023 Magnetic properties

2.024 Emissivity

2.025 Damping capacity

2.03 Chemical Properties

See also 6Al-4V.

2.031 Corrosion resistance. General. Recent intensive investigations of several commercial titanium alloys including 8Al-1Mo-1V have served to characterize the elevated temperature solid salt stress corrosion behavior in considerable detail and have shown that delayed failure of cracked specimens may be encountered at room temperature in both air and aqueous environments. Only a brief summary of these investigations can be given here and the reader should refer to the references for further details. In general, the results indicated that this alloy in its conventionally processed and heat treated conditions is more susceptible to solid salt stress corrosion than is annealed 6Al-4V or 4Al-3Mo-1V but probably less so than 5Al-2.5Sn. It appears to be more susceptible to delayed failure in aqueous salt solutions than 6Al-4V. Preliminary results indicate that by special processing and heat treatment the delayed failure resistance of this alloy may be improved.

2.032 Solid salt corrosion. The rate of corrosion in the presence of salt is very rapid above 900F without stress while the rate at lower temperatures depends strongly on the stress. Sodium chloride coated sheet tensile

	Ti
8	Al
1	Mo
1	V

specimens stressed at 40 ksi exhibit losses in retained room temperature tensile strength after exposures of 5000 hours at 500F and 1000 hours at 500F, (31), (see Fig. 2.0321). Exposure at 650F and 10 ksi for 100 hours results in a large loss in tensile elongation, (44). Tension-tension fatigue tests (19) at 800F and 60 ksi show pronounced loss in the fatigue life of sheet specimens provided with a small hole (K_t = 2.3) while no effect on the fatigue life of these specimens was observed at 600F and below. The stress and temperature limits below which solid salt stress corrosion does not occur are not definitely established. As might be expected, the sensitivity of the test is a factor which must be considered when attempting to establish these limits, and different tests can have widely different sensitivities. For example a self stressed specimen (see Fig. 2.0321) has been developed (29) which appears to be more sensitive than the commonly used tensile specimen. The self stressed specimen is formed of a pair of oppositely bowed strips fastened at their ends to preserve the bow. The amount of bowing determines the exposure stress.

Following exposure the specimen is placed in longitudinal compression and the end deflection or shortening to fracture determined. On the basis of the data thus far available it would appear that at temperatures below 400F salt stress corrosion of this alloy would not be an important consideration for most applications.

A wide variety of halogen salts have been found to produce stress corrosion in this alloy at 650F and above, (32)(35). Pure sodium chloride appears to be among the most damaging and is more severe than ASTM artificial sea salt, (29)(32).

Stressed specimens (120 ksi) placed in a non-industrial atmosphere two miles from the sea for 18,000 hours showed appreciable stress corrosion when subsequently exposed 2,600 hours at 550F in air, (29) and tested using the self stressed specimen shown in Fig. 2.0321. Various metals used for bearing or for surface protection readily form chlorides in the presence of even a few ppm of chlorine at temperatures above 750F. These chloride coated metals, if in contact with a titanium alloy susceptible to salt stress corrosion, can produce premature failures of the titanium alloy, (33). Silver is a bad actor in this respect and precautions should be taken to avoid contact between silver and titanium if elevated temperatures are encountered in the service application. Other metals which may have a damaging effect include cadmium, lead and palladium, (33).

Reducing the thickness of sodium chloride coatings decreases the time at temperature necessary to initiate stress corrosion but does not appreciably affect the amount of damage produced by very long times at temperature, (30)(31).

The amount of stress corrosion produced by a given total time at elevated temperature during cyclic heating decreases the cycle dwell time at elevated temperature, (30)(31). In certain types of tests this beneficial effect of cycling begins to disappear as the cycle dwell time exceeds about 8 hours, (see Fig. 2.0322).

The mechanism of solid salt corrosion of titanium alloys is not clearly understood and appears to be complex, involving as yet unidentified intermediate reaction products. There is general agreement that oxygen in some form, (e.g. as a titanium oxide) must be present and that corrosion is more rapid in moist than in dry environments. The electrochemical nature of the reaction can be readily demonstrated, (38) and involves an oxygen differential cell with the cracks occurring at the cathode. Some investigators propose a gas reaction product is directly or indirectly involved in the cracking. Thus, it has been suggested chlorine could be formed from the intermediate corrosion products and cause cracking directly, (29)(35). Another suggested mechanism involves the production of HCl (from a reaction between NaCl and water) which then reacts with Ti, Al, and V to form chlorides and hydrogen. The hydrogen then diffuses into the titanium alloy to produce the observed cracking, (32). Experiments conducted using hot stage microscopy have been interpreted to show that a gas is not responsible for the cracks but that a solid state reaction occurs producing hydrogen ions that diffuse into and embrittle the metal, (37).

2.0321 Effect of exposure temperature and time on solid salt stress corrosion of duplex annealed sheet, Fig. 2.0321.

2.0322 Effect of cyclic heating on solid salt corrosion susceptibility of duplex annealed sheet, Fig. 2.0322.

2.033 Delayed failure. Titanium alloys are considered to be exceptionally resistant to attack by aqueous environments including most inorganic salt solutions. Recent investigations, however, have shown that cracked specimens of this and several other titanium alloys exhibit delayed failure in aqueous sodium chloride solutions and in certain cases also in distilled water, (36)(42)(43)(45). The mill annealed condition of this alloy appears to be considerably more susceptible to this than the duplex annealed condition, (see Fig. 2.0331). Sufficiently thin duplex annealed sheet exhibits essentially no susceptibility to delayed failure in the presence of a 3 1/2 percent sodium chloride solution while this alloy condition in the 0.045 inch gage shows large reductions in strength when tested in the same environment, (see Fig. 2.0331). Additional information is necessary to properly delineate this thickness effect and the influence of metallurgical structure. Preliminary results (36) indicate that significant improvement in the resistance to delayed failure may be obtained by producing microstructures having substantial amounts of transformed beta so that the primary alpha exists in the form of discontinuous islands. Suitable structure may be obtained by modified rolling techniques followed by 1850F, 5 minutes, AC + 1375F, 15 minutes, AC, heat treatment, (41). The possible influence of mill processing and heat treatment variables on solid salt stress corrosion of this or other titanium alloys has received little attention. There is some indication that rapid cooling from the 1450F annealing temperature appears to produce a less susceptible condition than a very slow cooling rate, (34). However, additional tests would be necessary to prove this. Investigations of protective coatings show that aluminum modified silicone provides useful protection from solid salt corrosion at 550F for 3000 hours, (39). Data for longer exposure times is not yet available. Preliminary results indicate that flame sprayed or zinc dipped coatings should be further investigated, (35).

2.0331 Delayed failure curves in 3 1/2 percent salt solution for mill and duplex annealed sheet, Fig. 2.0331.

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specifications. Welding wire; AMS 4955, (50).

3.012 Producer's guaranteed minimum tensile properties for annealed bar and forgings, Table 3.012.

TABLE 3.012

Source	(1)	
Alloy	Ti-8Al-1Mo-1V	
Form	Forgings[a]	Rolled Bar[a]
Condition	Single or Duplex anneal	
F_{tu}, min -ksi	130	130
F_{ty}, min -ksi	120	120
e(4D)min - percent	10	10
RA, min - percent	20	25

(a) Sections up to and including 4 sq in.

Ti
8 Al
1 Mo
1 V

3.013 Producer's guaranteed minimum tensile properties for annealed sheet, Table 3.013.

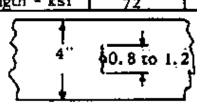
TABLE 3.013

Source	TMCA (20)		
Alloy	Ti-8Al-1Mo-1V		
Form	Sheet		
Condition	Mill ann, 1450F, 8hr, FC	1450F 15 min, AC	1850F, 5 min, AC + 1375F, 15 min, AC
F_{tu} min-ksi	145	135	135
F_{ty} min-ksi	135	125	125
e(2in)-percent:			
< 0.025 in	8	8	6
≥ 0.025 in	10	10	8

3.02 Mechanical Properties at Room Temperature
3.021 Tension. See also 3.03.
3.0211 Stress-strain diagrams. See 3.0311.
3.0212 Average and spread of longitudinal tensile properties for mill annealed sheet of various thicknesses, Fig. 3.0212.
3.0213 Average and spread of transverse tensile properties for mill annealed sheet of various thicknesses, Fig. 3.0213.
3.0214 Influence of various reannealing cycles on tensile properties of 1350F mill annealed sheet, Fig. 3.0214.
3.0215 Influence of various reannealing cycles on tensile properties of 1450F mill annealed sheet, Fig. 3.0215.
3.0216 Influence of aging temperature and solution treating temperature on tensile properties of sheet, Fig. 3.0216.
3.0217 Effect of elevated temperature air exposure on tensile properties of duplex annealed bar, Fig. 3.0217.
3.0218 Effect of elevated temperature exposure with and without stress on tensile properties of duplex annealed sheet, Fig. 3.0218.
3.022 Compression. See 3.0322.
3.0221 Stress-strain diagrams
3.023 Impact. See 3.033.
3.024 Bending
3.025 Torsion and shear
3.026 Bearing. See 3.036.
3.027 Stress concentration
3.0271 Notch properties. See also 3.0371.
3.02711 Sharp notch properties of mill annealed sheet, Table 3.02711.

TABLE 3.02711

Source	(4)			
Alloy	Ti-8Al-1Mo-1V			
Form	0.020 in Sheet			
Condition	Mill ann 1350 F, 8 hr		Mill ann 1425 F, 8 hr	
	L	T	L	T
F_{ty}, -ksi	157	153	142	140
Notch strength - ksi	72	54	96	71



Fatigue center crack
Slow crack extension by ink stain
Anneal before cracking

3.02712 Sharp notch properties of mill and duplex annealed sheet, Table 3.02712.

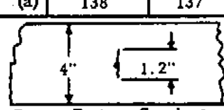
3.02713 Effect of stress relief temperature and time on sharp notch properties of duplex annealed sheet, Fig. 3.02713.
3.02714 Effect of elevated temperature exposure on sharp notch properties of duplex annealed sheet, Fig. 3.02714.
3.0272 Fracture toughness. See 3.0327.
3.02721 Nominal fracture toughness of mill annealed and duplex annealed sheet, (see Table 3.02712).
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 mill annealed sheet at elevated temperatures, Fig. 3.03111.
3.03112 Stress-strain curves at elevated temperature for duplex annealed sheet, Fig. 3.03112.
3.0312 Effect of test temperature on tensile properties of forgings annealed at two temperatures, Fig. 3.0312.
3.0313 Effect of test temperature and annealing temperature on tensile properties of duplex annealed bar stock, Fig. 3.0313.
3.0314 Effect of test temperature on tensile properties of 1450F mill annealed sheet, Fig. 3.0314
3.0315 Effect of test temperature on tensile properties of duplex annealed sheet from five heats, Fig. 3.0315.
3.0316 Effect of test temperature on two heats of triplex annealed sheet, Fig. 3.0316.
3.0317 Effect of low temperatures on tensile properties of 1350F mill annealed sheet, Fig. 3.0317.
3.0318 Effect of exposure and test temperature on tensile properties of 1450F mill annealed sheet, Fig. 3.0318.
3.0319 Effect of elevated temperature exposure time under stress on tensile properties and mill annealed sheet at room temperature and 550F, Fig. 3.03719.
3.03191 Effect of eleevated temperature exposure under stress on tensile properties of duplex annealed sheet at several temperatures, Fig. 3.03191.
3.032 Compression
3.0321 Stress-strain diagrams
3.0322 Effect of test temperature on compressive yield strength of mill annealed sheet, Fig. 3.0322.
3.033 Impact
3.0331 Effect of test temperature and hot rolling temperature on impact strength of hot rolled bar, Fig. 3.0331.
3.034 Bending
3.035 Torsion and shear
3.0351 Effect of test temperature on shear strength of bar duplex annealed at various temperatures, Fig. 3.0351.
3.036 Bearing
3.0361 Effect of test temperature on bearing properties of mill annealed sheet, Fig. 3.0361.
3.037 Stress concentration
3.0371 Notch properties
3.03711 Effect of test temperature and annealing temperature on notch properties of duplex annealed bar, Fig. 3.03711.
3.03712 Effect of test temperature on notch properties of 1350F mill annealed sheet, Fig. 3.03712.
3.03713 Effect of test temperature and sheet thickness on notch properties of 1850F duplex annealed sheet, Fig. 3.03713.

TABLE 3.02712

Source	(5)					
Alloy	Ti-8Al-1Mo-1V					
Form	0.032 in sheet					
Condition	Mill ann 1450F, 8hr, FC		Lab ann 1850F, 5 min, AC + 1375F, 15min, AC		Mill ann 1850F, 5 min, AC + 1375F, 15 minAC	
Direction	L	T	L	T	L	T
F_{tu} - ksi	147	145	141	138	141	138
F_{ty} - ksi	139	137	130	127	130	127
e(2 in) - percent	15	15	10	10	10	10
Notch strength-ksi	79	74	125	123	132	123
K_c - ksi $\sqrt{in}$ (a)	138	137	> 225	> 225	> 225	> 225

(a) Nominal



Slow Crack Extension Not Measured
Cracked after Anneal

Center Fatigue Crack Specimen

3.03714 Effect of low test temperature on notch properties of 1800F duplex annealed sheet, Fig. 3.03714.
3.03715 Effect of low test temperature on notch properties of quenched and aged sheet, Fig. 3.03715.

3.03716 Effect of test temperature on sharp notch strength of duplex annealed sheet from three heats, Fig. 3.03716.

3.03717 Effect of test temperature on nominal fracture toughness of three heats of duplex annealed sheet, Fig. 3.03717.

3.03718 Effect of crack length on sharp notch properties of triplex annealed sheet at several temperatures, Fig. 3.03718.

3.03719 Effect of reannealing temperature on the -110F sharp notch properties of duplex annealed sheet, Fig. 3.03719.

3.037110 Effect of cooling rate from reannealing temperature on -110F sharp notch properties of duplex annealed sheet, Fig. 3.037110.

3.037111 Effect of exposure and test temperature on sharp notch properties of mill annealed sheet, Fig. 3.037111.

3.037112 Effect of exposure and test temperature on sharp notch properties of duplex annealed sheet, Fig. 3.037112.

3.037113 Effect of thickness and elevated temperature exposure on sharp notch strength of duplex annealed sheet, Fig. 3.037113.

3.037114 Effect of room temperature stretching on -110F sharp notch properties of duplex annealed sheet, Fig. 3.037114.

3.0372 Fracture toughness. The fracture toughness of annealed sheet is very high at room temperature and above. At subzero temperature the toughness of duplex annealed sheet is superior to that of mill annealed sheet (compare Figs. 3.037111 with Fig. 3.037112). In general rapid cooling from temperatures above about 1350F is necessary for development of optimum combinations of strength and toughness (eg. see Figs. 3.037110). However, the benefits of this rapid cooling are lost if the alloy is heated for long periods of time at elevated temperature. (See Fig. 3.02714). Room temperature stretching reduces the low temperature toughness of sheet (see Fig. 3.037114). Plane strain fracture toughness data is not yet available, (see also 1.09).

3.038 Combined properties

3.04 Creep and Creep Rupture Properties

3.041 Creep deformation curves for mill and duplex annealed sheet, Fig. 3.041.

3.042 0.1 percent creep deformation curves for duplex annealed sheet at 450 to 650F, Fig. 3.042.

3.043 Isochronous stress-strain curves for mill annealed sheet, Fig. 3.043.

3.044 Creep properties at various temperatures for mill and duplex annealed sheet, Table 3.044.

TABLE 3.044

Source	(4)(21)								
Alloy	Ti-8Al-1Mo-1V								
Form	0.056 to 0.080 in thick								
Condition	Mill Ann. 1450F, 8hr, FC					1850F, 5 min, AC + 1100F, 8hr, AC			
Creep Stress and Temp - F	550F 67 ksi	800F 65 ksi	900F 45 ksi	1000F 25 ksi	1100F 10 ksi	800F 65 ksi	900F 45 ksi	1000F 25 ksi	1100F 10 ksi
Total Deformation Percent in 150 hrs		0.36	0.92	2.48	4.82	0.14	0.28	0.52	2.18
1000 hrs	0.032								
12000 hrs	0.032								

3.045 Creep properties at various temperatures for duplex annealed bar, Table 3.045.

TABLE 3.045

Source	(1)								
Alloy	Ti-8Al-1Mo-1V								
Form	1/2 in dia bar								
Condition	1650F, 1hr, AC + 1100F, 8hr, AC			1800F, 1hr, AC + 1100F, 8hr, AC			1950F, 1hr, AC + 1100F, 8hr, AC		
	Stress - ksi at temp								
	850F	1000F	1100F	850F	1000F	1100F	850F	1000F	1100F
Total Def. in 150hr 0.2 percent	50	15	-	50	(13)	4	(70)	25	(20)
0.5 percent	60	20	-	60	24	8	-	45	-
1.0 percent	-	28	-	-	30	12	-	-	-

() Value extrapolated.

3.046 Creep rupture properties for duplex annealed bar and forgings, Fig. 3.046.

3.047 Creep properties at two temperatures for compression forging, Table 3.047.

TABLE 3.047

Source	(14)							
Alloy	Ti-8Al-1Mo-1V							
Form	21 in dia x 1 1/2 in Compressor forging							
Direction	Radial							
Condition	1650F, 1 hr, AC + 1100F, 8 hr, AC		1850F, 1 hr, AC + 1100F, 8 hr, AC		1850F, 1 hr, WQ + 1100F, 8 hr, AC		1850F, 1 hr, WQ + 1375F, 30 min, AC	
Creep stress and temperature	900F 45 ksi	1000F 25 ksi	900F 45 ksi	1000F 25 ksi	900F 45 ksi	1000F 25 ksi	900F 45 ksi	1000F 25 ksi
Total deformation percent in 150 hr	0.39	0.18	0.29	0.20	0.31	0.16	0.28	0.15

3.05 Fatigue Properties
3.051 Axial load fatigue properties of duplex annealed sheet at low and elevated temperature, Fig. 3.051.
3.052 Axial load notch fatigue properties of duplex annealed sheet at low and elevated temperatures, Fig. 3.052.
3.053 Axial load sharp notch fatigue properties of duplex annealed sheet at room and elevated temperature, Fig. 3.053.
3.054 Rotating beam fatigue properties of mill and duplex annealed bar, Table 3.054.

TABLE 3.054

Source	(1)							
Alloy	Ti-8Al-1Mo-1V							
Form	Bar							
Condition	Method	Stress Ratio		Stress Conc	Fatigue strength - ksi, at cycles		
		A	R		10^5	10^6	10^7
Ann. 1400F, 24 hr, AC	Rot Beam		-1	Smooth $K_t = 1$	97	86	82
1800F, 4 hr, AC, 1000F, 24hr, AC					103	91	-

3.055 Axial load fatigue properties of duplex annealed sheet at elevated temperatures, Table 3.055.

TABLE 3.055

Source	(27)							
Alloy	Ti-8Al-1Mo-1V							
Form	0.050 in sheet							
Condition	1450F, 8 hr, FC + 1450F, 30 min, AC							
Temp - F	Method	Stress Ratio		Stress Conc	Fatigue strength - ksi at cycles			
		A	R		10^4	10^5	10^6	10^7
RT	Direct Stress		0.1	Notch K = 2 (a)	80	50	45	40
400					74	48	43	40
650					67	45	42	40
RT	Direct Stress		-0.5		58	40	34	28
400					50	39	34	28
650					45	38	34	28
RT	Direct Stress		0.1	Smooth K = 1	145	102	99	90
400					125	97	90	85
650					105	95	90	85
RT	Direct Stress		-0.5		120	83	75	72
400					94	70	65	63
650					87	70	60	58

(a) For specimen see Fig. 3.057

3.056 Effect of elevated temperature stress exposure on the 10^5 cycle fatigue strength of duplex annealed sheet at room and elevated temperatures, Fig. 3.056.
3.057 Effect of elevated temperature stress exposure on the 10^5 cycle notch fatigue strength of duplex annealed sheet at room and elevated temperatures, Fig. 3.057.

3.06 Elastic Properties
3.061 Poisson's ratio
3.062 Modulus of elasticity
3.0621 Tensile modulus of elasticity for duplex annealed sheet at low and elevated temperatures, Fig. 3.0621.
3.0622 Tensile modulus of elasticity at various temperatures for annealed bars and sheet, Fig. 3.0622.
3.0623 Compression modulus for mill annealed sheet at various temperatures, Fig. 3.0623.
3.063 Modulus of rigidity
3.064 Compressive tangent modulus at various temperatures for mill annealed sheet, Fig. 3.064.
3.065 Compressive secant modulus at various temperatures for mill annealed sheet, Fig. 3.065.

4. FABRICATION

4.01 Formability
4.011 General. Forming practices for this alloy are similar to those of other alpha rich titaniums. The beta transus of this alloy is higher than Ti-6Al-4V, and this permits higher hot work temperatures. Finish working temperatures above the beta transus (aproximately 1900F) produce coarser grain size than is characteristic of finishing below the beta transus. (See 1.09). Sheet forming is more difficult than in Ti-6Al-4V, and for severe operations forming temperatures between 1325F and 1375F are required, (3).
4.012 Hot sizing 1450F, (5).
4.013 Forging. Starting temperature 1950F maximum. Finishing temperature 1800F minimum and 1900F maximum, (1).
4.0131 Tensile properties for duplex annealed bar upset forged at 1850 to 1950F, Table 4.0131.

TABLE 4.0131

Source	(1)			
Alloy	Ti-8Al-1Mo-1V			
Form	3 in long quarter section of 9 1/2 in round axial upset to 3/4 in			
Upset temp	1850 F		1950 F	
Duplex anneal(a)	1650 F	1800 F	1650 F	1800 F
Radial and tang. Average of properties at center				
F_{tu} - ksi	151	141	138	142
F_{ty} - ksi	139	128	124	124
e(4D) - percent	16	17	12	15
RA - percent	24	34	21	31

(a) Indicated temp 1 hr, AC + 1100 F, 8 hr, AC.

4.014 Rolling. Finish rolling temperature for sheet is normally about 1800F, however, special rolling schedules may use a different temperature in order to improve stress corrosion resistance.

4.02 Machining and Grinding
Machines similar to Ti-6Al-4V but requires stress relief, (see 1.054), (3).

4.03 Welding
4.031 General. Sheet is readily welded by the TIG process using a parent alloy filler and the welds have high joint efficiencies, (4)(7). Resistance welding is readily accomplished providing care is taken to insure the facing surfaces are clean at the time of welding, (46). For thick sections the MIG process has been successfully employed, although experience with welding of thick sections of this alloy is very limited as yet, (47).
4.032 Stress relief. Stress relief heat treatments should not be carried out in the temperature range between 1000 and 1200F in order to avoid loss in fracture toughness as well as increased sensitization of the weld metal and parent metal to stress corrosion, see 1.054. In fusion welding of sheet a preheat of 500F has been found beneficial in reducing residual stress, (48).
4.033 Effect of test temperature and reannealing on tensile properties of welded sheet, Fig. 4.033.

4.04 Heat Treatment
See Ti, commercially pure.

4.05 Surface Treatment
See Ti-6Al-4V.

	Ti
8	Al
1	Mo
1	V

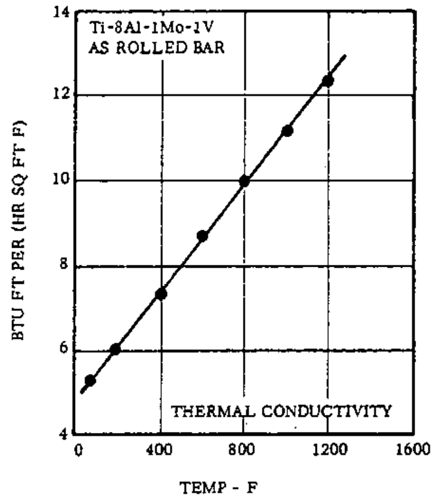


FIG. 2.013 THERMAL CONDUCTIVITY (1)

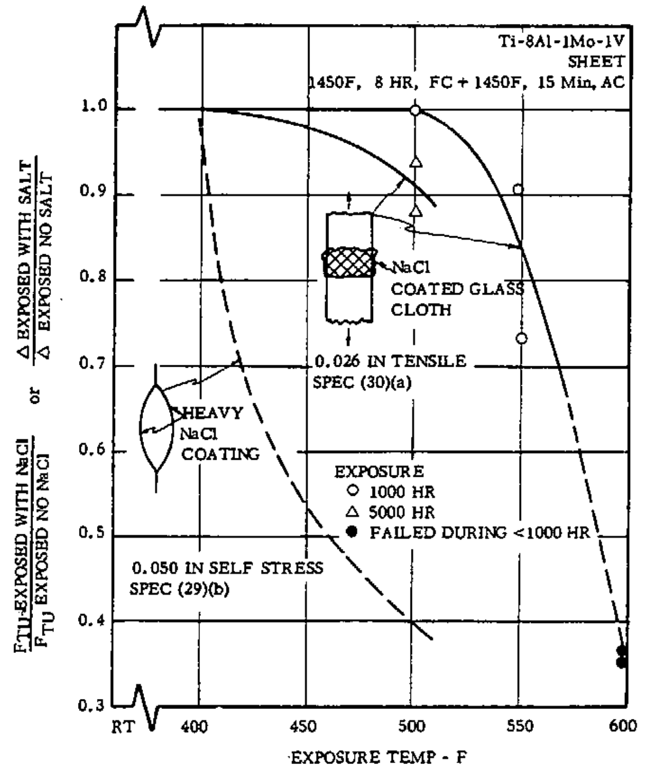


FIG. 2.0321 EFFECT OF EXPOSURE TEMPERATURE AND TIME ON SOLID SALT STRESS CORROSION OF DUPLEX ANNEALED SHEET (29)(30)

(a) Exposed 40 ksi plus room temperature tension to determine F_{tu}.
(b) Exposed 50 ksi 5000 hours plus room temperature compression to determine shortening Δ to failure.

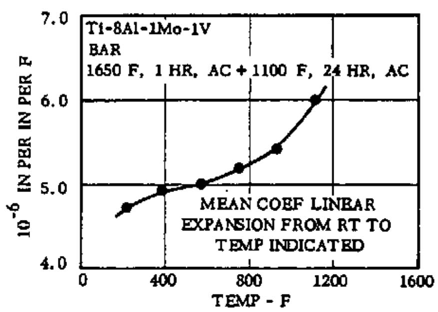


FIG. 2.014 THERMAL EXPANSION (1)

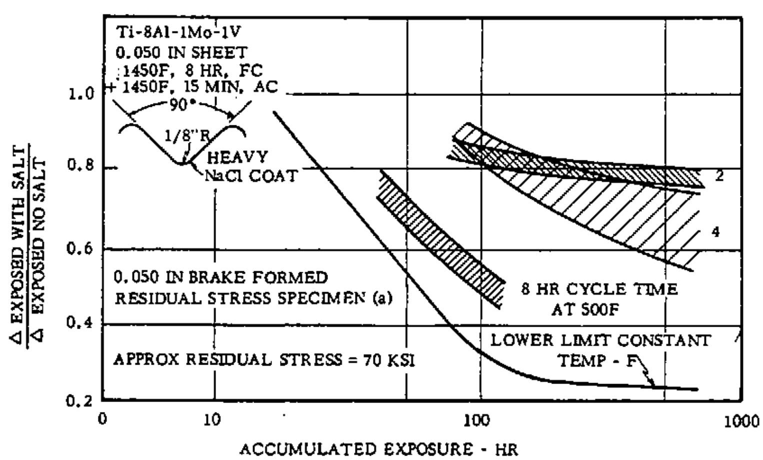


FIG. 2.0322 EFFECT OF CYCLIC HEATING ON SOLID SALT CORROSION SUSCEPTIBILITY OF DUPLEX ANNEALED SHEET (29)

(a) Exposed at 550F plus room temperature compression to determine shortening Δ to failure.

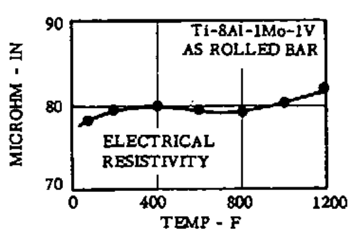


FIG. 2.022 ELECTRICAL RESISTIVITY (1)

	Ti
8	Al
1	Mo
1	V

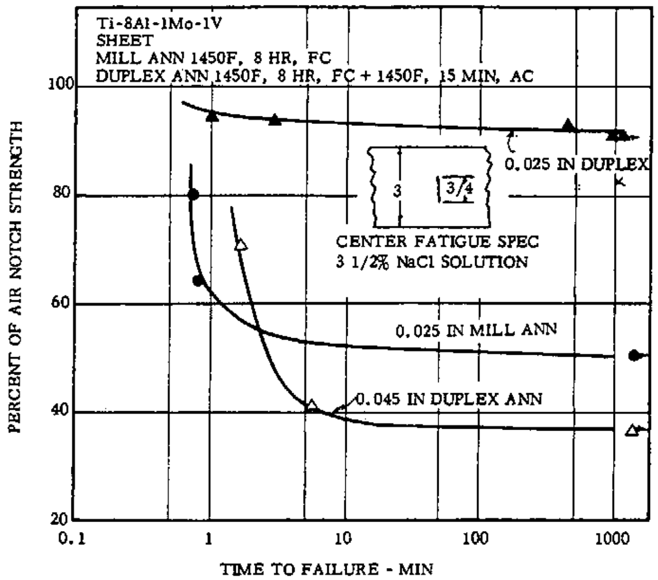


FIG. 2.0331 DELAYED FAILURE CURVES IN 3 1/2 PERCENT SALT SOLUTION FOR MILL AND DUPLEX ANNEALED SHEET (36)(41)

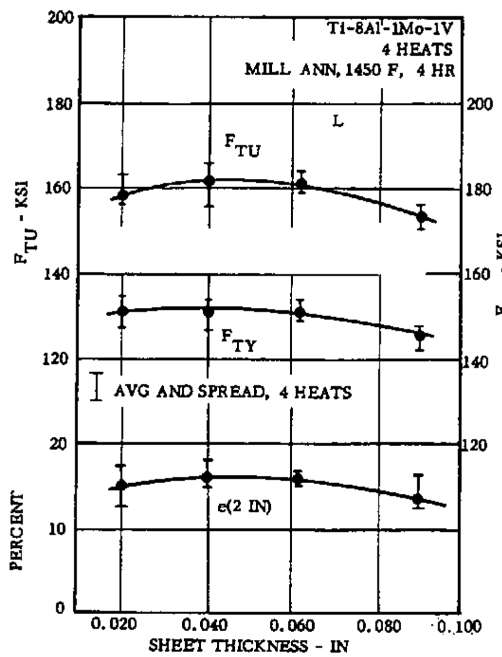


FIG. 3.0212 AVERAGE AND SPREAD OF LONGITUDINAL TENSILE PROPERTIES FOR MILL ANNEALED SHEET OF VARIOUS THICKNESSES (4)

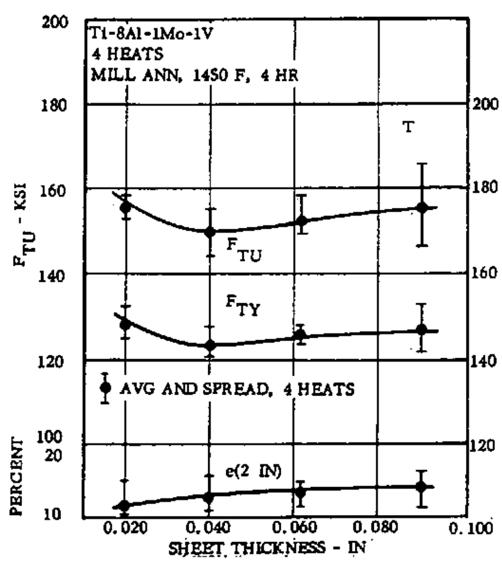


FIG. 3.0213 AVERAGE AND SPREAD OF TRANSVERSE TENSILE PROPERTIES FOR MILL ANNEALED SHEET OF VARIOUS THICKNESSES (4)

Ti
8 Al
1 Mo
1 V

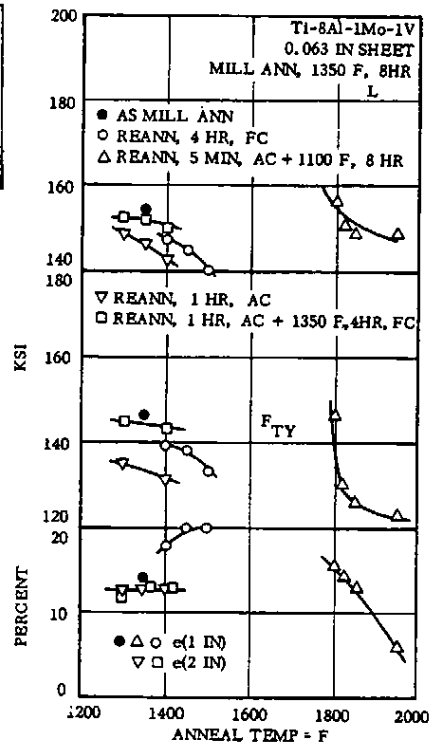


FIG. 3.0214 INFLUENCE OF VARIOUS REANNEALING CYCLES ON TENSILE PROPERTIES OF 1350 F MILL ANNEALED SHEET (8)(4)

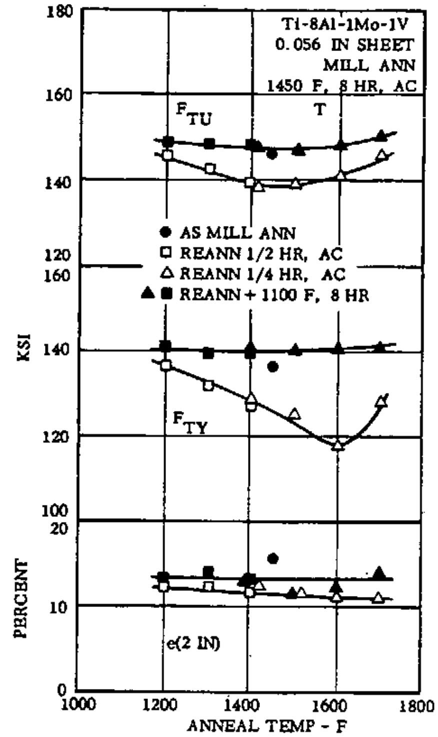


FIG. 3.0215 INFLUENCE OF VARIOUS REANNEALING CYCLES ON THE TENSILE PROPERTIES OF 1450 F MILL ANNEALED SHEET (4)

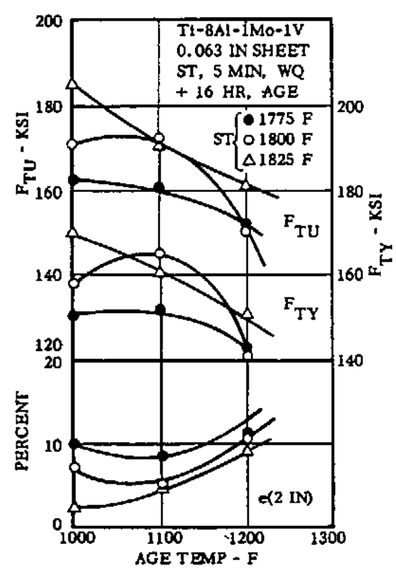


FIG. 3.0216 INFLUENCE OF AGING TEMPERATURE AND SOLUTION TREATING TEMPERATURE ON TENSILE PROPERTIES OF SHEET (4)

	Ti
8	Al
1	Mo
1	V

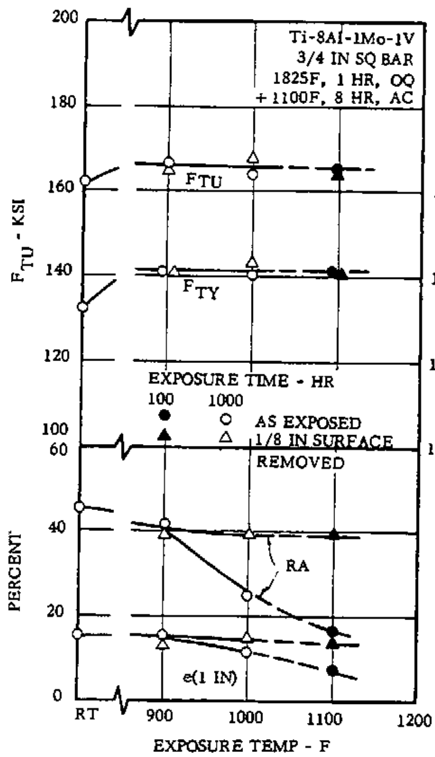


FIG. 3.0217 EFFECT OF ELEVATED TEMPERATURE AIR EXPOSURE ON TENSILE PROPERTIES OF DUPLEX ANNEALED BAR (31)

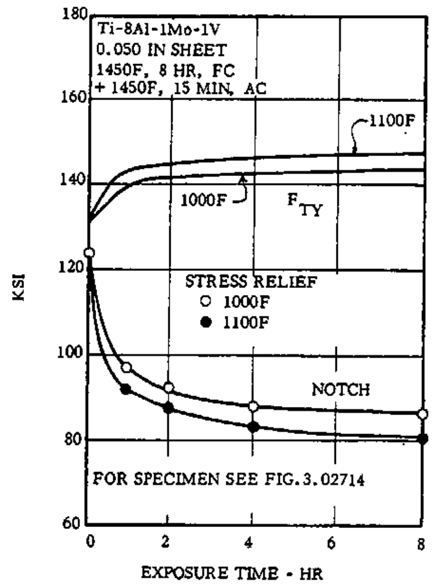


FIG. 3.02713 EFFECT OF STRESS RELIEF TEMPERATURE AND TIME ON SHARP NOTCH PROPERTIES OF DUPLEX ANNEALED SHEET (40)

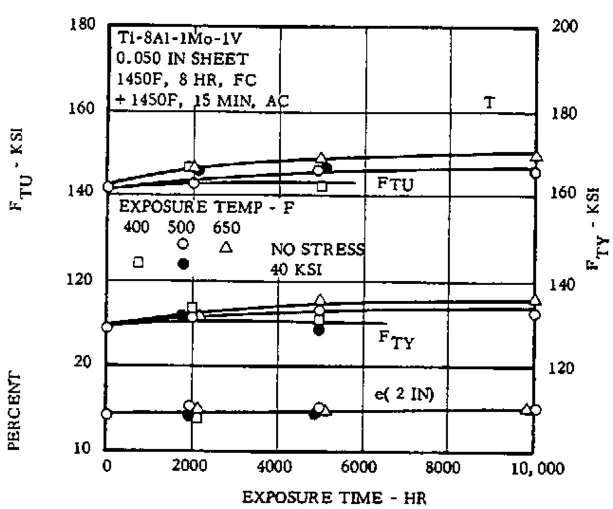


FIG. 3.0218 EFFECT OF ELEVATED TEMPERATURE EXPOSURE WITH AND WITHOUT STRESS ON TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET (40)

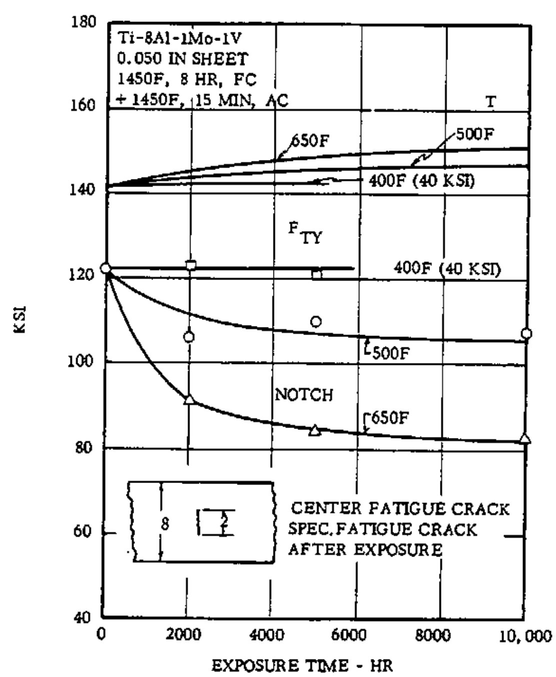


FIG. 3.02714 EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON SHARP NOTCH PROPERTIES OF DUPLEX ANNEALED SHEET (40)

	Ti
8	Al
1	Mo
1	V

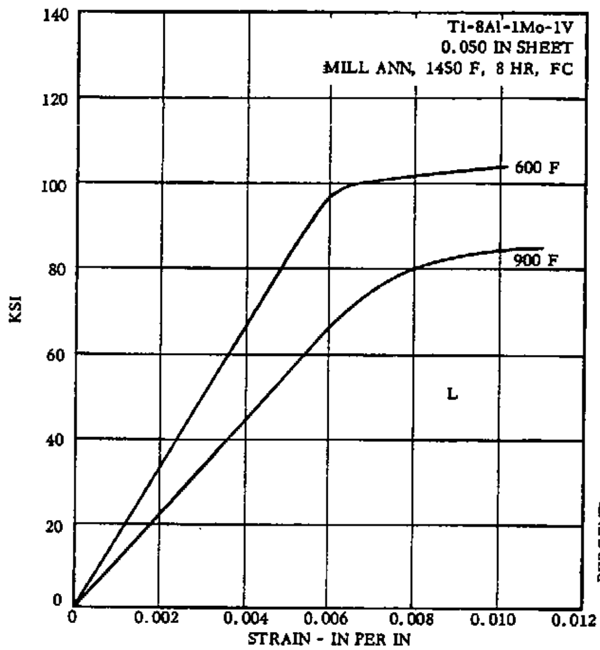


FIG. 3.03111 STRESS STRAIN CURVES FOR MILL ANNEALED SHEET AT ELEVATED TEMPERATURES (13)

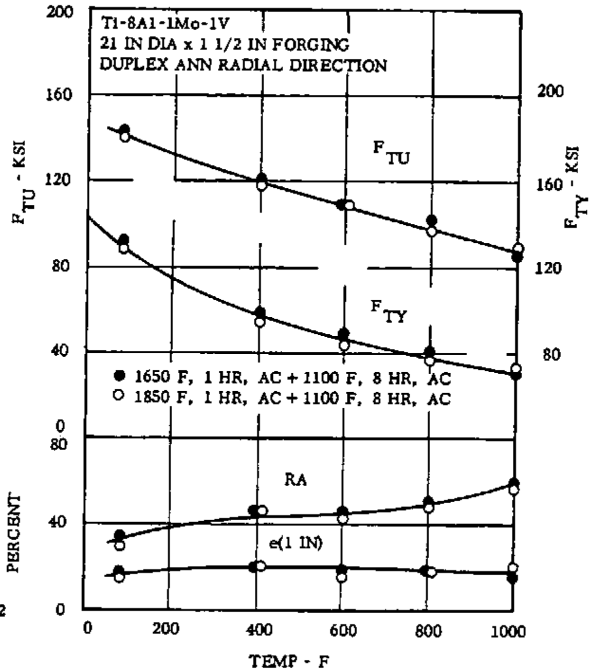


FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF FORGINGS ANNEALED AT TWO TEMPERATURES (14)

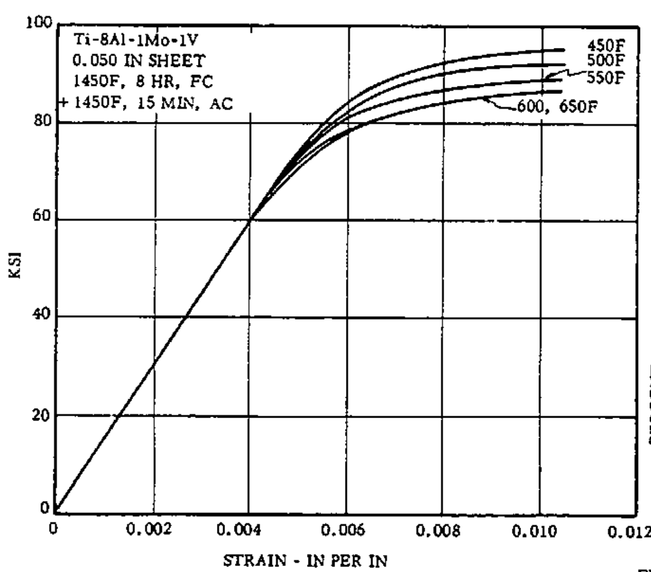


FIG. 3.03112 STRESS-STRAIN CURVES AT ELEVATED TEMPERATURE FOR DUPLEX ANNEALED SHEET (25)

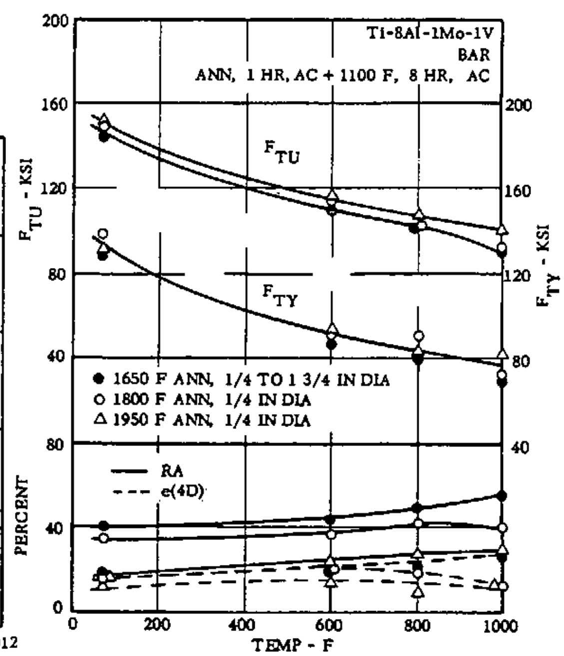


FIG. 3.0313 EFFECT OF TEST TEMPERATURE AND ANNEALING TEMPERATURE ON TENSILE PROPERTIES OF DUPLEX ANNEALED BAR STOCK (1)

	Ti
8	Al
1	Mo
1	V

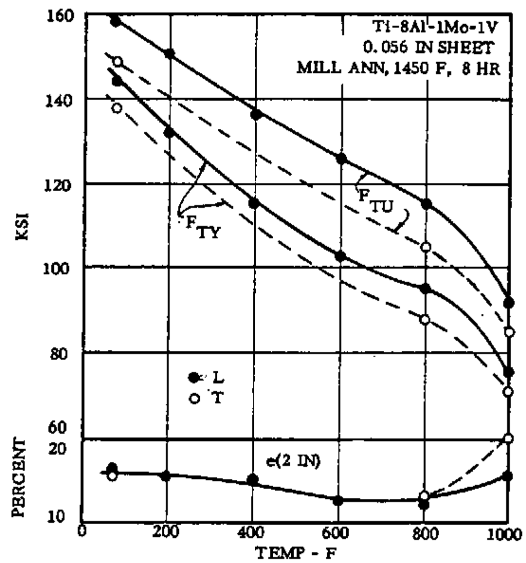


FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF 1450F MILL ANNEALED SHEET (4)

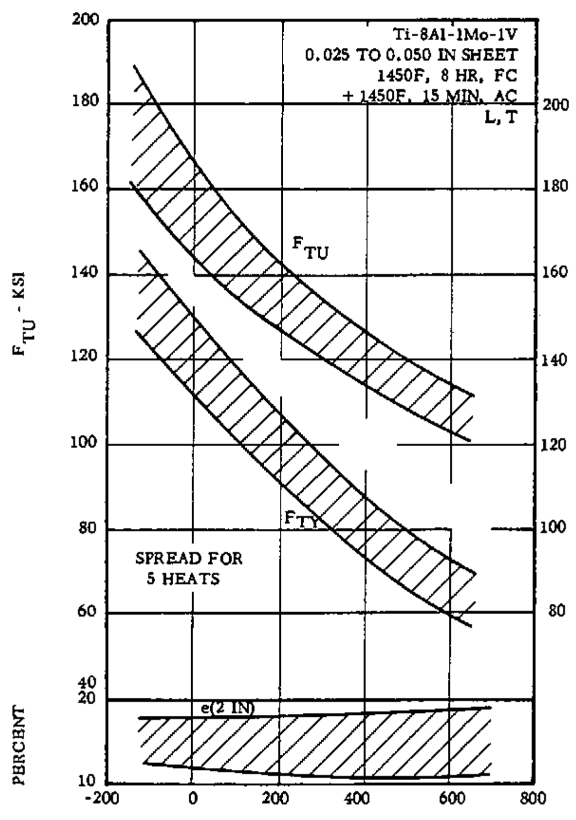


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET FROM FIVE HEATS (25)(26)

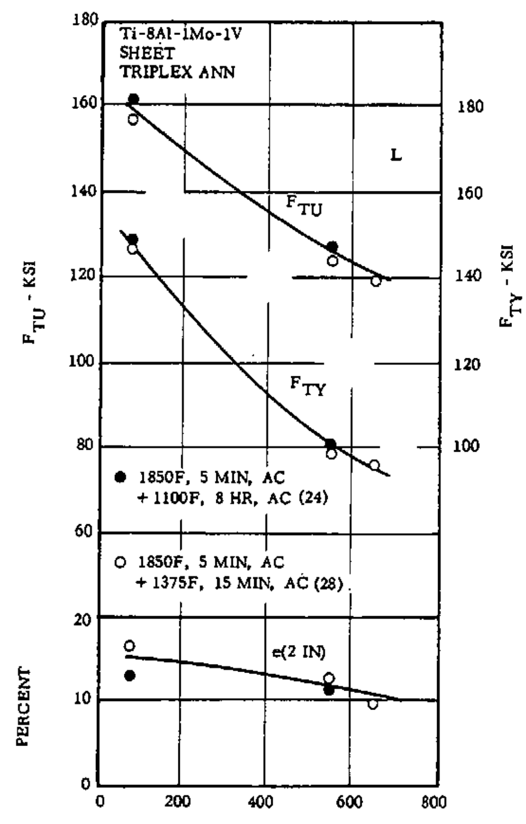


FIG. 3.0316 EFFECT OF TEST TEMPERATURE ON TWO HEATS OF TRIPLEX ANNEALED SHEET (24)(28)

	Ti
8	Al
1	Mo
1	V

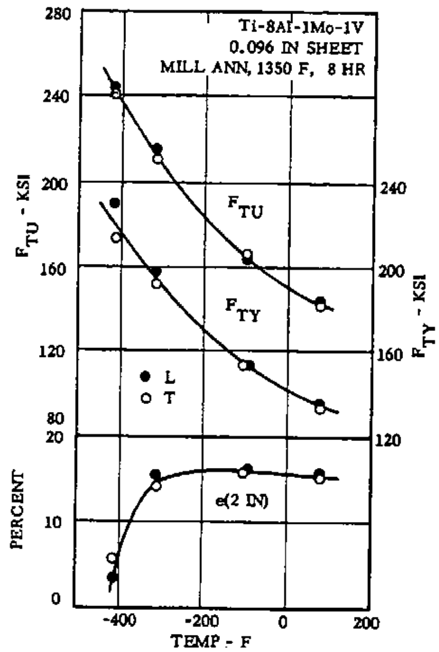


FIG. 3.0317 EFFECT OF LOW TEMPERATURES ON TENSILE PROPERTIES OF 1350 F MILL ANNEALED SHEET (9)

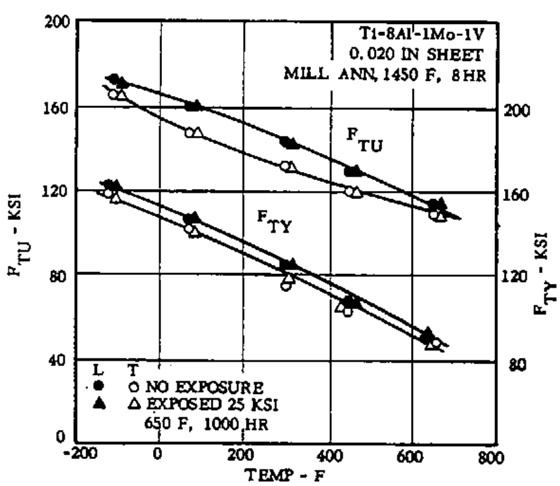


FIG. 3.0318 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF 1450 F MILL ANNEALED SHEET (10)

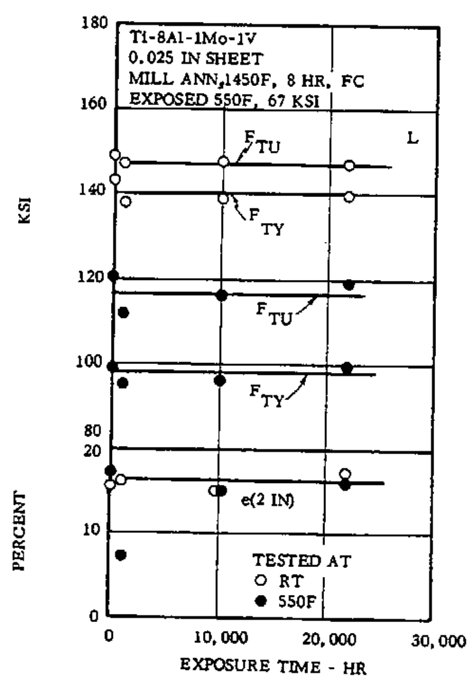


FIG. 3.0319 EFFECT OF ELEVATED TEMPERATURE AND EXPOSURE TIME UNDER STRESS ON TENSILE PROPERTIES OF MILL ANNEALED SHEET AT ROOM TEMPERATURE AND 550F (24)

	Ti
8	Al
1	Mo
1	V

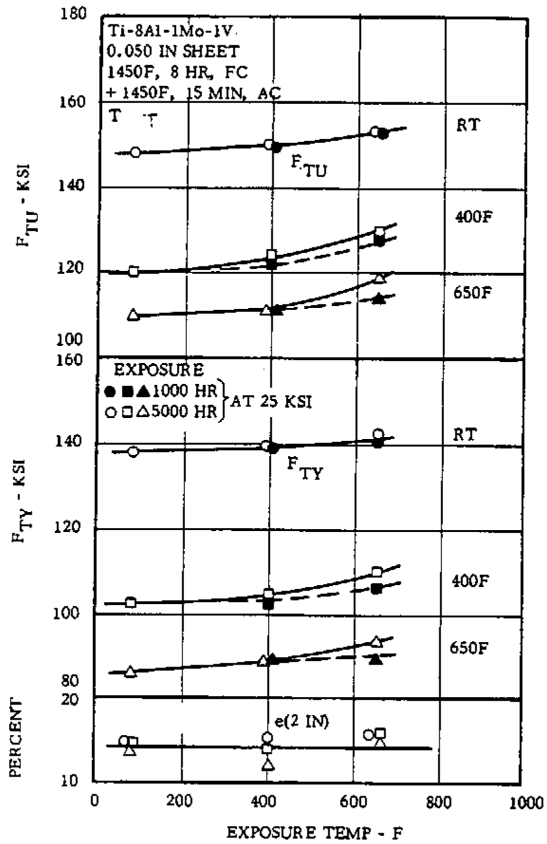


FIG. 3.03191 EFFECT OF ELEVATED TEMPERATURE EXPOSURE UNDER STRESS ON TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET AT SEVERAL TEMPERATURES (27)

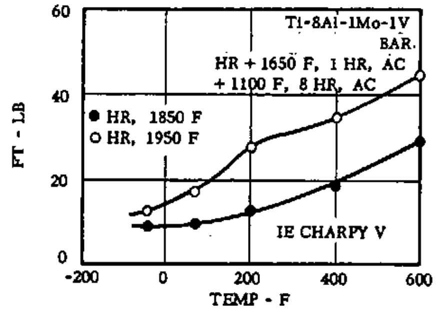


FIG. 3.0331 EFFECT OF TEST TEMPERATURE AND HOT ROLLING TEMPERATURE ON IMPACT STRENGTH OF HOT ROLLED BAR (1)

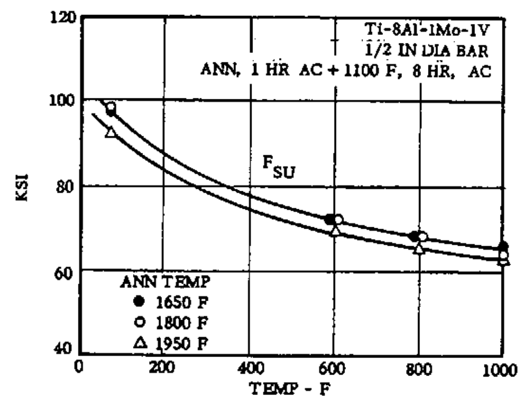


FIG. 3.0351 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF BAR DUPLEX ANNEALED AT VARIOUS TEMPERATURES (1)

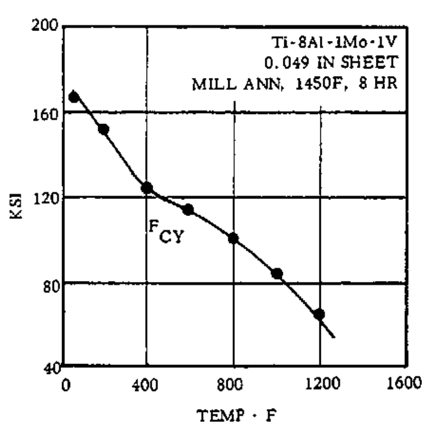


FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF MILL ANNEALED SHEET (4)

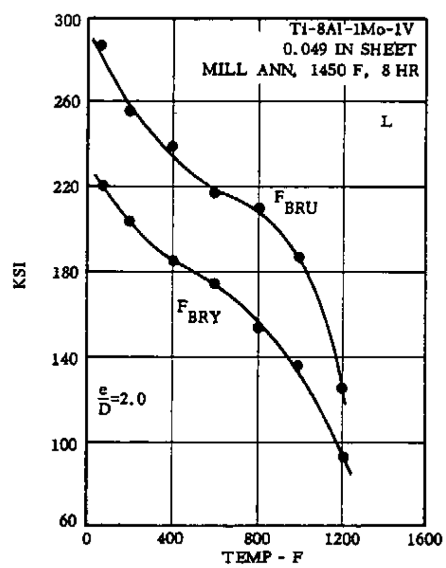


FIG. 3.0361 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF MILL ANNEALED SHEET (4)

	Ti
8	Al
1	Mo
1	V

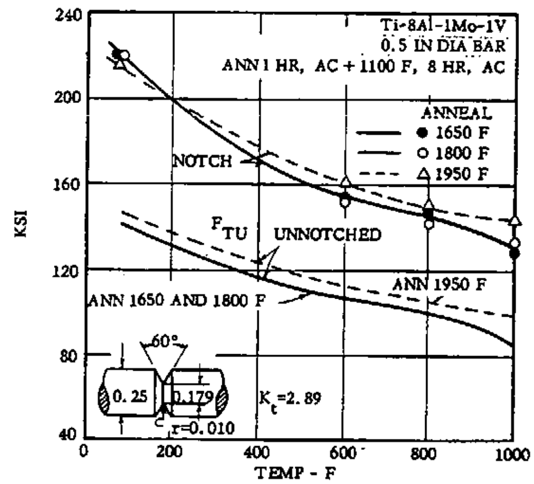


FIG. 3.03711 EFFECT OF TEST TEMPERATURE AND ANNEALING TEMPERATURE ON NOTCH PROPERTIES OF DUPLEX ANNEALED BAR (1)

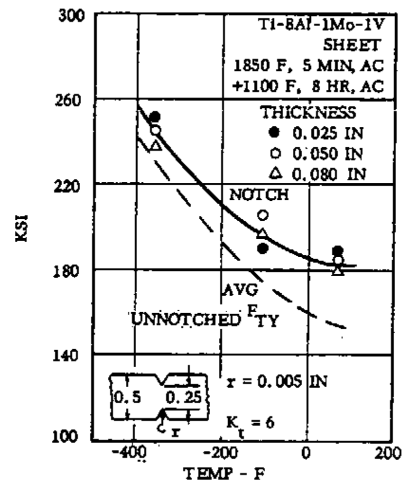


FIG. 3.03713 EFFECT OF TEST TEMPERATURE AND SHEET THICKNESS ON NOTCH PROPERTIES OF 1850 F DUPLEX ANNEALED SHEET (11)

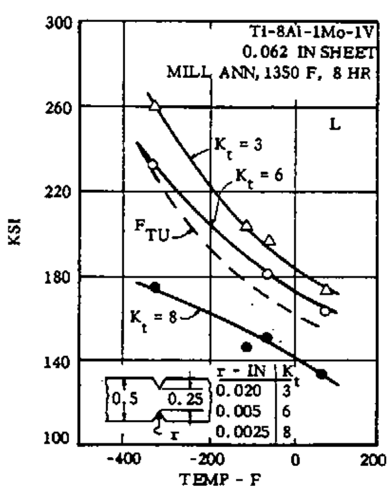


FIG. 3.03712 EFFECT OF TEST TEMPERATURE ON NOTCH PROPERTIES OF 1350 F MILL ANNEALED SHEET (4)

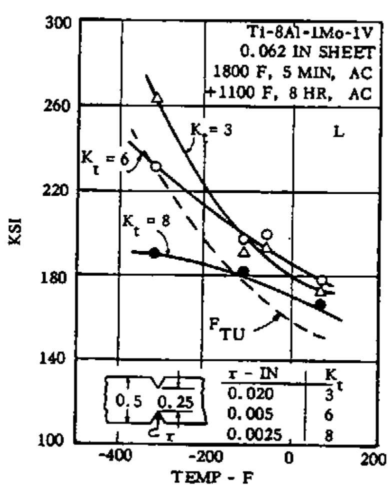


FIG. 3.03714 EFFECT OF LOW TEST TEMPERATURE ON NOTCH PROPERTIES OF 1800 F DUPLEX ANNEALED SHEET (4)(14)

	Ti
8	Al
1	Mo
1	V

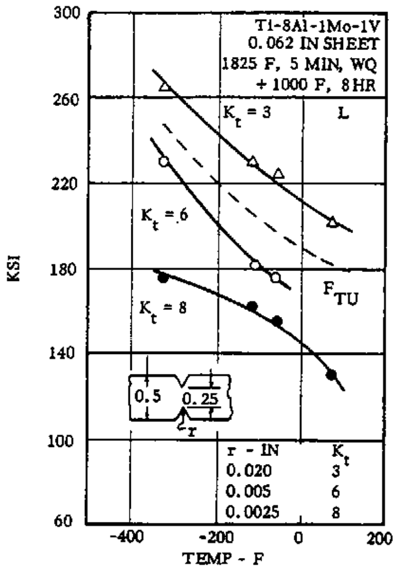


FIG. 3.03715 EFFECT OF LOW TEST TEMPERATURE ON NOTCH PROPERTIES OF QUENCHED AND AGED SHEET (4)(5)

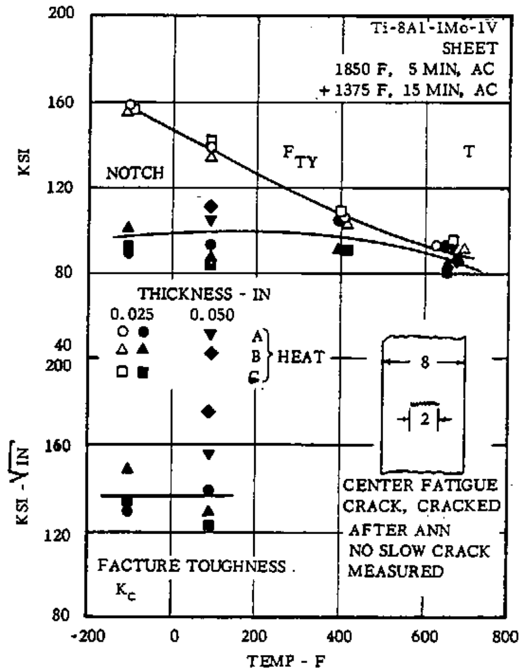


FIG. 3.03717 EFFECT OF TEST TEMPERATURE ON NOMINAL FRACTURE TOUGHNESS OF THREE HEATS OF DUPLEX ANNEALED SHEET (16)

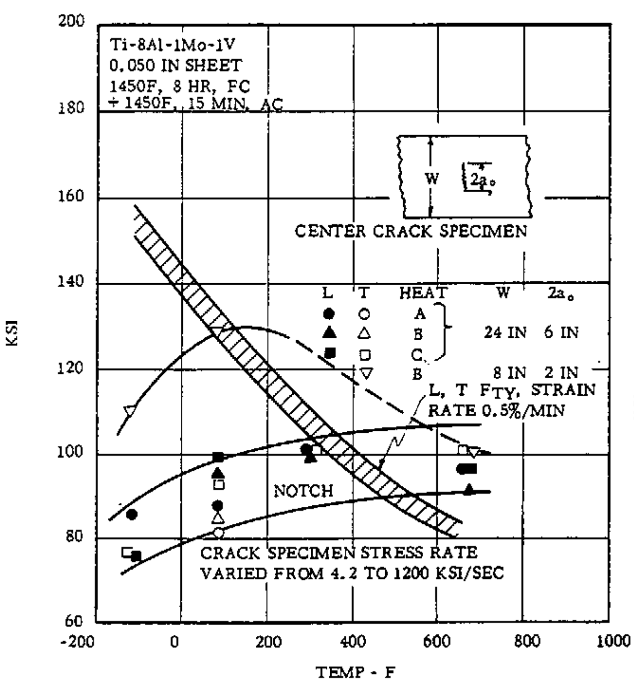


FIG. 3.03716 EFFECT OF TEST TEMPERATURE ON SHARP NOTCH STRENGTH OF DUPLEX ANNEALED SHEET FROM THREE HEATS (26)

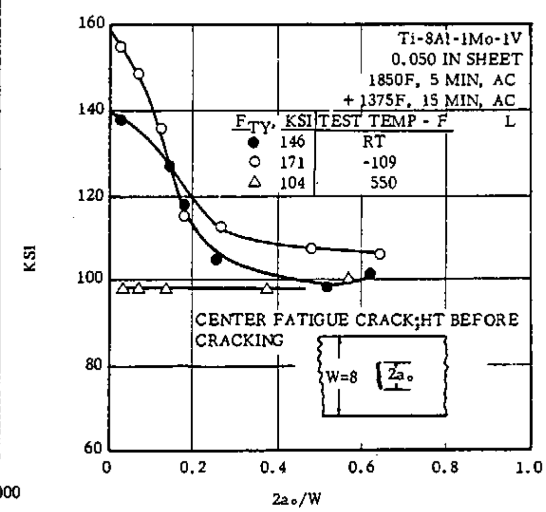


FIG. 3.03718 EFFECT OF CRACK LENGTH ON THE SHARP NOTCH PROPERTIES OF TRIPLEX ANNEALED SHEET AT SEVERAL TEMPERATURES (22)

	Ti
8	Al
1	Mo
1	V

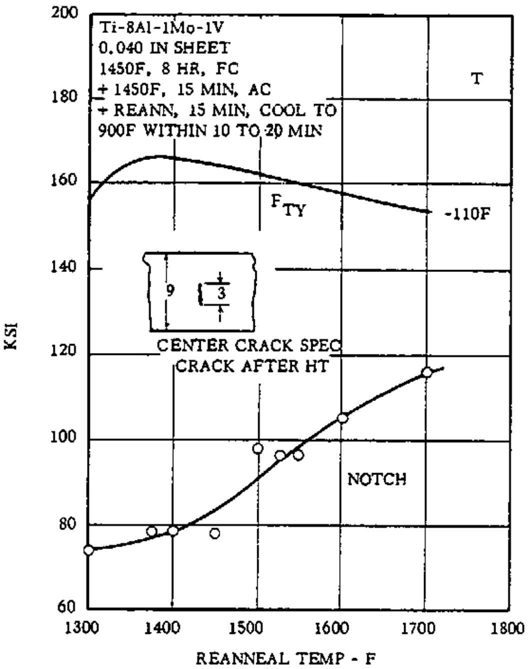


FIG. 3.03719 EFFECT OF REANNEALING TEMPERATURE ON THE -110F SHARP NOTCH PROPERTIES OF DUPLEX ANNEALED SHEET (40)

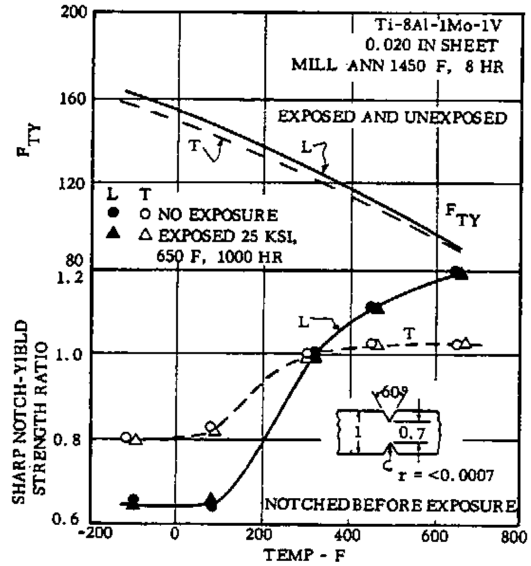


FIG. 3.037111 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON SHARP NOTCH PROPERTIES OF MILL ANNEALED SHEET (10)

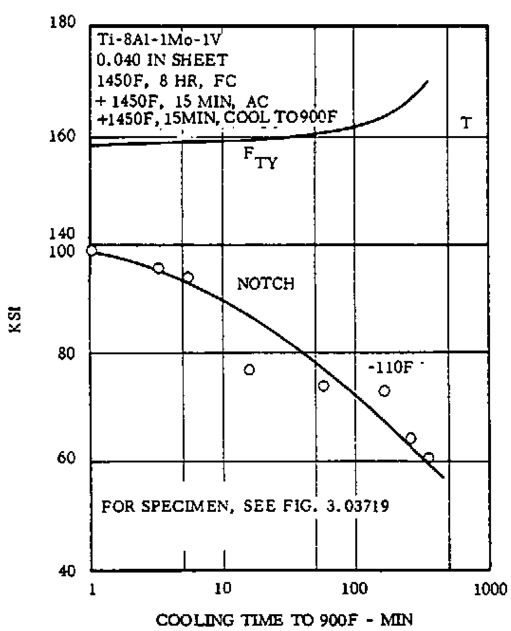


FIG. 3.037110 EFFECT OF COOLING RATE FROM REANNEALING TEMPERATURE ON THE -110F SHARP NOTCH PROPERTIES OF DUPLEX ANNEALED SHEET (40)

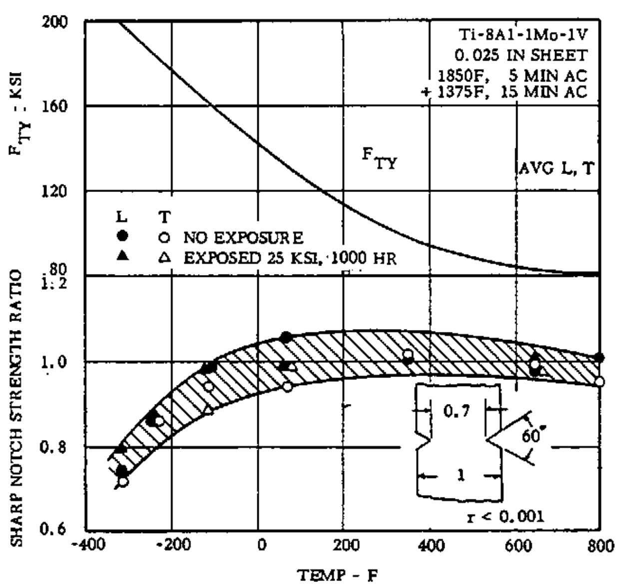


FIG. 3.037112 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON SHARP NOTCH PROPERTIES OF DUPLEX ANNEALED SHEET (17)(18)

	Ti
8	Al
1	Mo
1	V

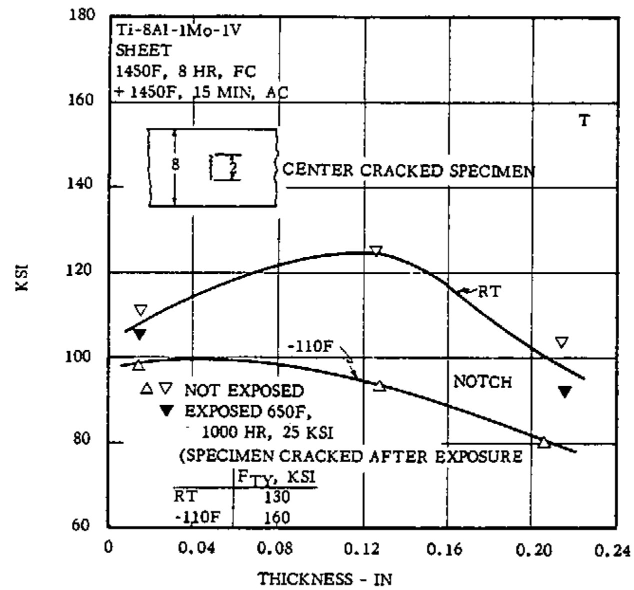


FIG. 3.037113 EFFECT OF THICKNESS AND ELEVATED TEMPERATURE EXPOSURE ON SHARP NOTCH STRENGTH OF DUPLEX ANNEALED SHEET (26)

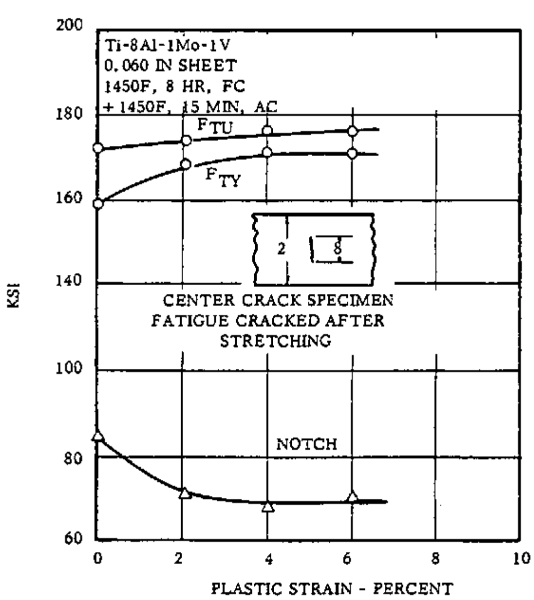


FIG. 3.037114 EFFECT OF ROOM TEMPERATURE STRETCHING ON -110F SHARP NOTCH PROPERTIES OF DUPLEX ANNEALED SHEET (49)

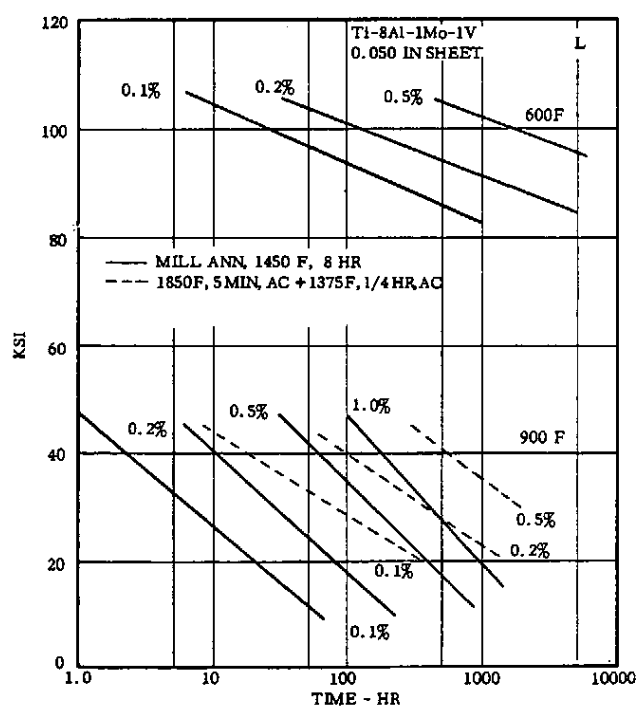


FIG. 3.041 CREEP DEFORMATION CURVES FOR MILL AND DUPLEX ANNEALED SHEET (13)

NONFERROUS ALLOYS

	Ti
8	Al
1	Mo
1	V

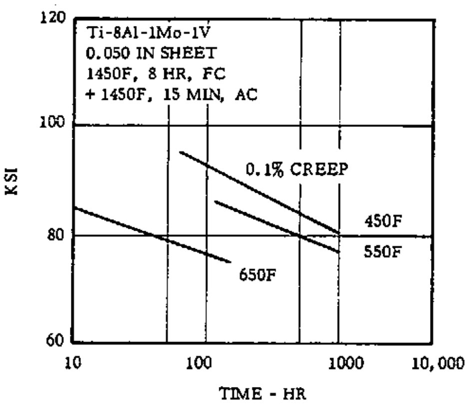


FIG. 3.042 0.1 PERCENT CREEP DEFORMATION CURVES FOR DUPLEX ANNEALED SHEET AT 450 TO 650F (25)

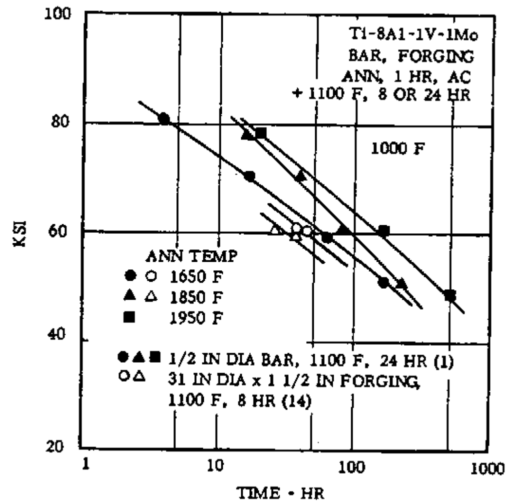


FIG. 3.046 CREEP RUPTURE PROPERTIES FOR DUPLEX ANNEALED BAR AND FORGING (1)(14)

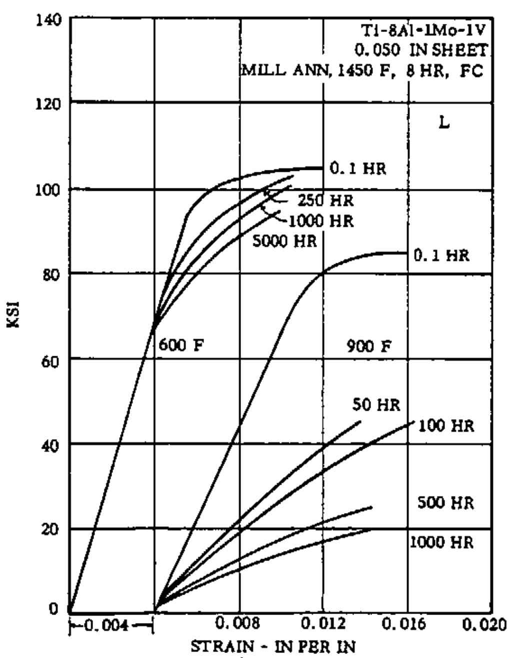


FIG. 3.043 ISOCHRONOUS STRESS STRAIN CURVES FOR MILL ANNEALED SHEET (13)

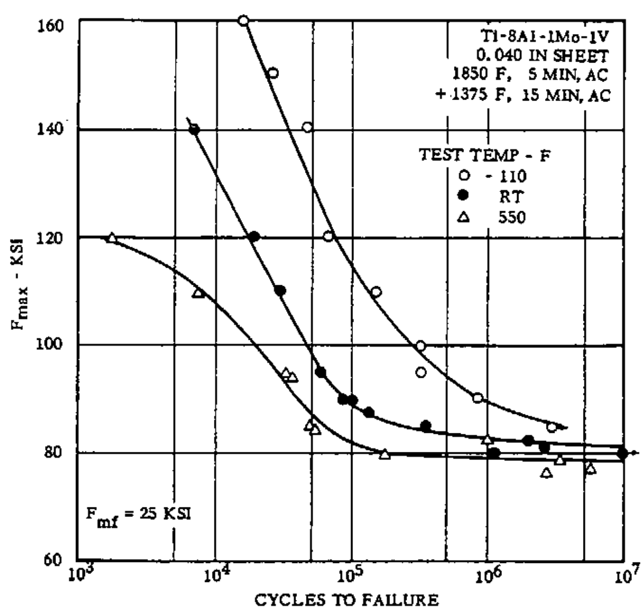


FIG. 3.051 AXIAL LOAD FATIGUE PROPERTIES OF DUPLEX ANNEALED SHEET AT LOW AND ELEVATED TEMPERATURES (15)

Ti
8 Al
1 Mo
1 V

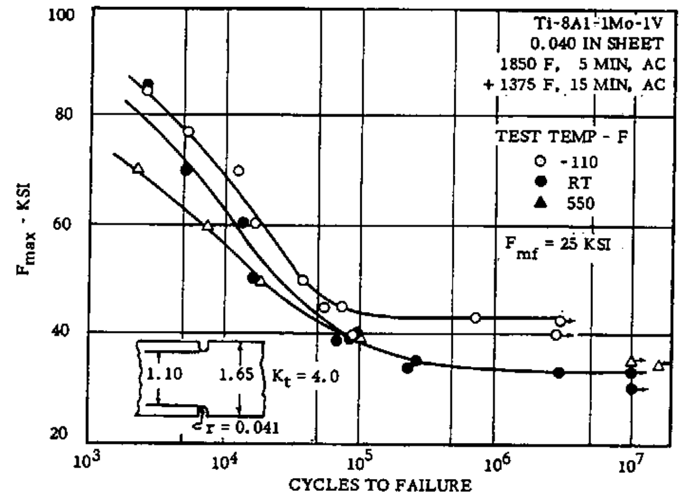


FIG. 3.052 AXIAL LOAD NOTCH FATIGUE PROPERTIES OF DUPLEX ANNEALED SHEET AT LOW AND ELEVATED TEMPERATURE (15)

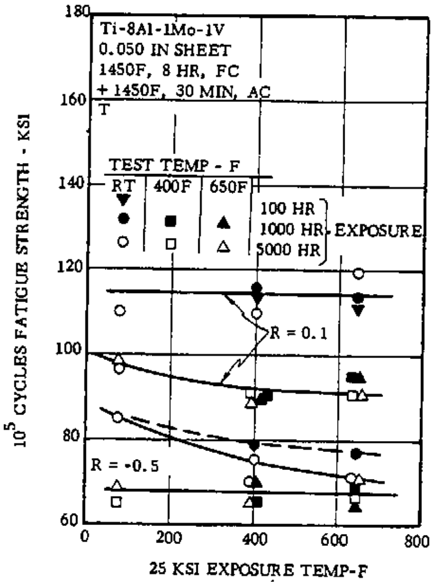


FIG. 3.056 EFFECT OF ELEVATED TEMPERATURE STRESS EXPOSURE ON THE 10^5 CYCLE FATIGUE STRENGTH OF DUPLEX ANNEALED SHEET AT ROOM AND ELEVATED TEMPERATURES (27)

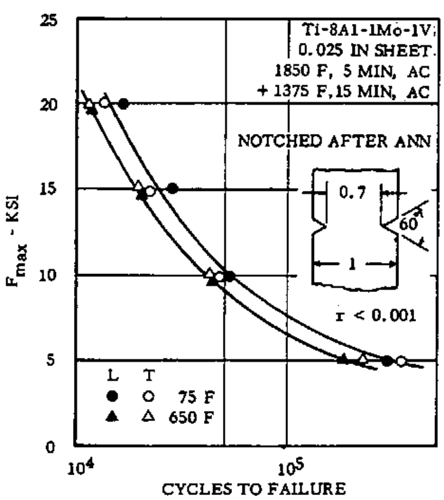


FIG. 3.053 AXIAL LOAD SHARP NOTCH FATIGUE PROPERTIES OF DUPLEX ANNEALED SHEET AT ROOM AND ELEVATED TEMPERATURE (17)

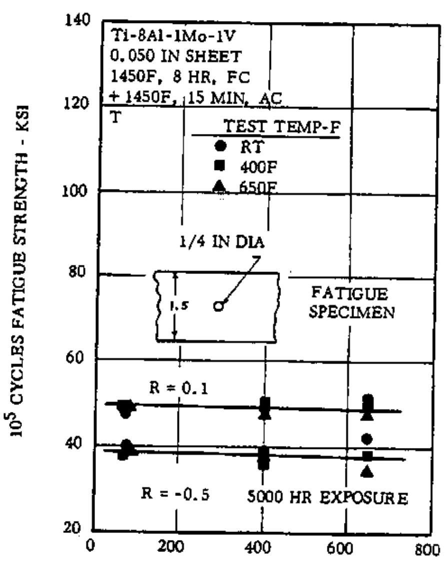


FIG. 3.057 EFFECT OF ELEVATED TEMPERATURE STRESS EXPOSURE ON THE 10^5 CYCLE NOTCHED FATIGUE STRENGTH OF DUPLEX ANNEALED SHEET AT ROOM AND ELEVATED TEMPERATURES (27)

	Ti
8	Al
1	Mo
1	V

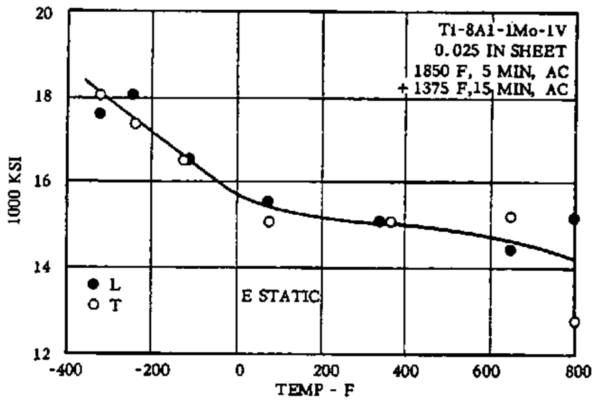


FIG. 3.0621 TENSILE MODULUS OF ELASTICITY FOR DUPLEX ANNEALED SHEET AT LOW AND ELEVATED TEMPERATURES (18)

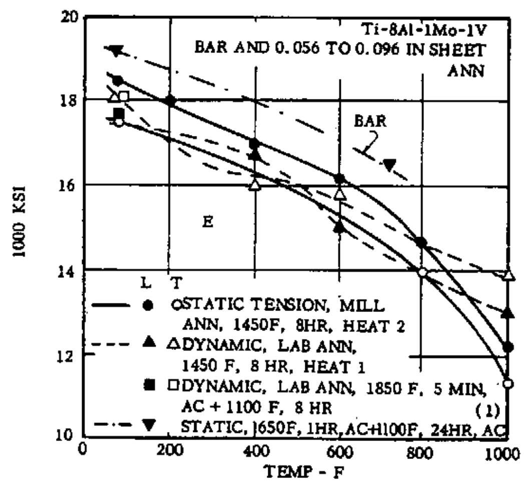


FIG. 3.0622 TENSILE MODULUS OF ELASTICITY AT VARIOUS TEMPERATURES FOR ANNEALED BAR AND SHEET (1)(4)

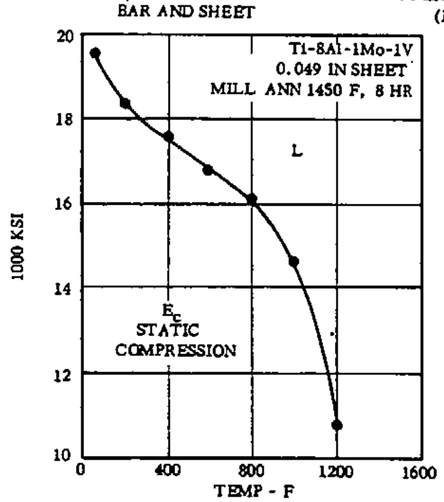


FIG. 3.0623 COMPRESSION MODULUS FOR MILL ANNEALED SHEET AT VARIOUS TEMPERATURES (4)

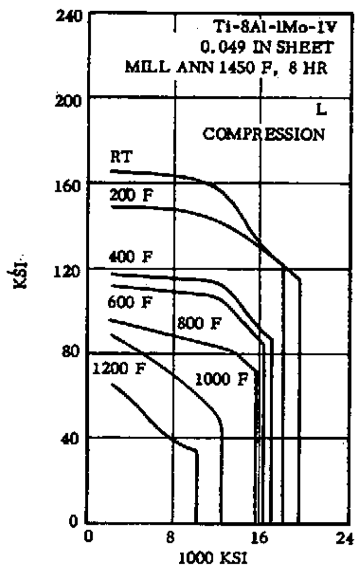


FIG. 3.064 COMPRESSIVE TANGENT MODULUS AT VARIOUS TEMPERATURES FOR MILL ANNEALED SHEET (4)

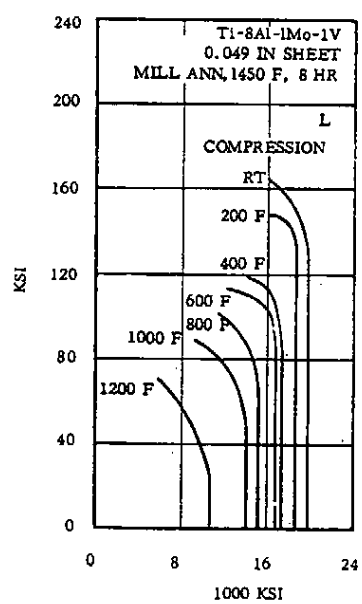


FIG. 3.065 COMPRESSIVE SECANT MODULUS AT VARIOUS TEMPERATURES FOR MILL ANNEALED SHEET (4)

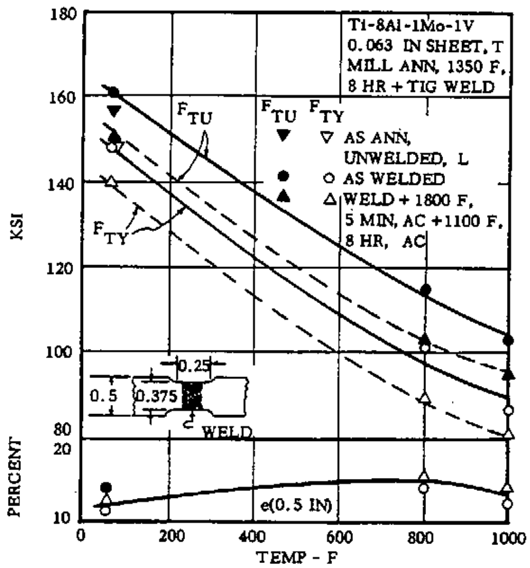


FIG. 4.033: EFFECT OF TEST TEMPERATURE AND REANNEALING ON TENSILE PROPERTIES OF WELDED SHEET (4)

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8	Al
1	Mo
1	V

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