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NONFERROUS ALLOYS

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	Ti
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

1. GENERAL
This heat-treatable alpha-beta alloy was designed to combine the long-time, elevated-temperature strength characteristics of Ti-6Al-2Sn-4Zr-2Mo with markedly improved short-time strength properties at both room and elevated temperatures. It is intended for use as forgings in intermediate-temperature-range sections of gas turbine engines, particularly in disc and fan blade components of the compressor. The alloy is available in the form of billets and bars for forging stock. It has also been successfully produced and evaluated in the form of sheet and plate. It should be considered for long-time load-carrying applications at temperatures up to 750F and short-time load-carrying applications at temperatures up to 1000F. (1)(2)(3)

1.01 Commercial Designation
Ti-6Al-2Sn-4Zr-6Mo

1.02 Alternate Designations
Ti-6246

1.03 Specifications
1.031 No government, AMS or ASTM specifications have been published for this alloy. Titanium Metals Corp. of America provides information on guaranteed minimum mechanical properties for two heat-treated conditions (1).

1.04 Composition
Table 1.04

1.05 Heat Treatment
1.051 General. Although this alloy requires heat treatment to attain optimum properties, the important variables- temperature, time, and cooling rate - have not been thoroughly and systematically studied; therefore, specific conditions for heat treatment have not been standardized. Generally, optimum properties are attained through a solution treatment at temperatures in the range 1500 to 1700F followed by aging in the range 1000 to 1350F, variations within these ranges having significant effects upon properties as illustrated by Figures 3.021004 through 3.021007. Cooling rate from the solution temperature is also an important heat-treating variable, faster cooling rates generally resulting in higher strength and reduced ductility. For a given section size, cooling rates after solution treatment are controlled by the following techniques, from the slowest to the fastest: air cool (AC), forced air cool (FAC), oil quench (OQ), and water quench (WQ). Because of its influence on cooling rate, section size is also a significant variable in the heat treatment of this alloy, larger sections, of course, tending to cool more slowly than thin sections for a given cooling technique. The effects of these variables - cooling technique after solution treatment and section size - are illustrated in a number of Figures and Tables in this text. The effects of time at temperature are probably less clearly established than those of the other heat-treating variables. Reported solution treatment times range from a few minutes to one hour, the shorter times being used for sheet and the longer times for forgings. Aging times range from a one-quarter hour to eight hours, the shorter times usually being applied at the higher temperatures and for thin (sheet) sections.

1.052 Nomenclature. The following terminology is usually used to describe, in a general way, the heat treatments applied to this alloy:
Solution Treat (ST): Treat at a temperature between 1500 and 1700F and quench in water or oil.
Solution anneal (SA): Treat at a temperature between 1500 and 1700F and cool in still air or forced air.
Solution treat and age (STA): Solution treat and age at a temperature between 1000 and 1350F.
Duplex anneal (DA): Solution anneal and age at a temperature between 1000 and 1350F.
Triplex anneal (TA): Solution anneal and age twice at temperatures between 1000 and 1350F, the first aging treatment being at a higher temperature than the second.

1.053 Because of the sensitivity of the properties of this alloy to variations in heat treatment and other processing variables, efforts are being made to correlate properties with microstructure (9)(10). One such study shows that, at a yield-strength level of 170 to 180 ksi, optimum fracture toughness and ductility are obtained with a microstructure of 10 percent equiaxed (primary) alpha with relatively coarse alpha prime (secondary, martensitic alpha) and aged beta, regardless of the processing and heat-treatments used to obtain the structure (9).

1.06 Hardness
Table 1.06

1.07 Forms and Conditions Available
Available in the form of billets and bars for forging stock and in the form of forgings. Also can be made available as plate and sheet.

1.08 Melting and Casting Practice
Double consumable-electrode vacuum melted (2).

1.09 Special Considerations
1.091 The alloy has excellent strength stability when exposed to elevated temperatures up to 1000F, both when stressed and when free of stress. At the higher combinations of temperature and stress, however, somewhat erratic and inconsistent losses in ductility tend to occur. These effects are illustrated in Tables 3.021010 through 3.021012.

1.092 Considerable study has been devoted to the relative merits of forging the alloy at temperatures below the beta transus (alpha-beta forging) and at temperatures above the beta transus (beta forging). In general, the alpha-beta forging tends to result in slightly better strength and ductility. The effects on fracture toughness in air were inconsistent and inconclusive, but beta processing appears to be beneficial to salt-water crack-propagation resistance. Based upon limited data, alpha-beta forged material appears to be more resistant to the effects of creep-exposure surface contamination than beta-forged material (3).

1.093 Good through hardenability has been demonstrated for this alloy in sections up to 3 inches, but deep hardenability decreases in thicker sections (1)(2).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties
2.011 Melting range. Approximately 3000F.
2.012 Phase changes.
2.0121 Alpha-beta to beta transition temperature, 1720F (2).
2.0122 The strengthening of the solution-treated alloy during aging is in part due to tempering of the alpha prime (martensite). Further strengthening is due to a dispersion of fine alpha produced by decomposition of retained beta (7).
2.013 Thermal conductivity, Figure 2.013.
2.014 Thermal expansion, Figure 2.014.
2.015 Specific heat.
2.016 Thermal diffusivity.

2.02 Other Physical Properties
2.021 Density. 0.169 lb per cu in (1).
2.022 Electrical properties.
2.023 Magnetic properties. Nonmagnetic.
2.024 Emittance.
2.025 Damping capability.

2.03 Chemical Properties
2.031 The resistance to crack propagation of this alloy in salt water has been reported to be better after beta forging than after alpha-beta forging (3). No further studies of its corrosion resistance and other chemical properties have been reported. It is believed that

these characteristics are similar to those of other titanium alloys, particularly Ti-6Al-2Sn-4Zr-2Mo (See Code 3718, Sections 2.03 through 2.0333).

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties
3.011 Producers guaranteed tensile properties, Table 3.011.

3.02 Mechanical Properties at Room Temperature
3.021 Tension.
3.021001 Tensile properties of square die-press forgings of various section sizes, Table 3.021001.
3.021002 Tensile properties at various locations in disc forging, Table 3.021002.
3.021003 Tensile properties of upset forgings with variations in forge temperature, solution temperature, cooling rate from solution temperature, and aging temperature, Table 3.021003.
3.021004 Effect of solution temperature on tensile properties of 1-1/2" and 3" square bars forged at two different temperatures, Figure 3.021004.
3.021005 Effect of aging temperature on tensile properties of α-β forged upsets after two different solution treatments, Figure 3.021005.
3.021006 Effect of aging temperature on tensile properties of 1.25-in thick discs forged at two different temperatures and subjected to three different solution treatments, Figure 3.021006.
3.021007 Effect of aging temperature and time on the tensile properties of 0.500-in thick plate. Figure 3.021007.
3.021008 Effect of thickness on tensile properties of sheet in three heat-treated conditions, Figure 3.021008.
3.021009 Effect of cooling rate on tensile properties of solution-annealed sheet. Table 3.021009.
3.021010 Effect of creep exposures at temperatures from 750 to 1000F on tensile properties of forgings in the solution-treated and aged condition, Table 3.021010.
3.021011 Effect of creep exposures at 800F on tensile properties of forgings from 1 to 3 in thick in both the duplex-annealed and the solution-treated and aged conditions, Table 3.021011.
3.021012 Effect of creep exposures at 600 and 750F on tensile properties of forgings in two duplex-annealed conditions, Table 3.021012 .
3.021013 Effect of exposures of 500 hours at 600F on tensile properties of sheet in the duplex-annealed and triplex-annealed conditions, Table 3.021013 .
3.0211 Stress-strain diagrams.
3.02111 Duplicate stress-strain curves for forgings subjected to two different duplex annealing treatments, Figure 3.02111.
3.022 Compression.
3.0221 Stress-strain diagrams.
3.0222 Compressive yield strength of sheet in the duplex-annealed and triplex-annealed conditions, Table 3.0222
3.023 Impact.
3.0231 Charpy V-notch impact strength of duplex-annealed press upsets in various sizes, Table 3.0231.
3.0232 Charpy V-notch impact strength of upset forgings with variations in forging temperature and heat treatment, Table 3.0232.
3.024 Bending.
3.025 Torsion and shear.
3.026 Bearing.
3.027 Stress concentration.
3.0271 Notch properties.
3.02711 Notch tensile strength at various locations in disc forging, Table 3.02711.
3.02712 Notch time fracture properties at various locations in disc forging, Table 3.02712.
3.0272 Fracture toughness.
3.02721 Fracture toughness at various locations in solution-treated and aged disc forging, Table 3.02721.
3.02722 Variations in fracture toughness of forgings with different forging conditions, heat treatments, and section thicknesses, Table 3.02722.
3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Effect of temperature on tensile properties of 3-in thick sections forged at two different temperatures, Figure 3.0312.
3.0313 Effect of temperature and various cooling rates after solution treatment on tensile properties of α-β forged 3-in thick sections, Figure 3.0313.
3.0314 Effect of temperature on tensile properties of sheet in the solution-annealed condition, Figure 3.0314.
3.0315 Effect of temperature on tensile properties of sheet in the duplex-annealed condition, Figure 3.0315.
3.0316 Effect of temperature on tensile properties of sheet in the triplex-annealed condition, Figure 3.0316.
3.032 Compression.
3.0321 Stress-strain diagrams.
3.0322 Effect of temperature on compressive yield strength of sheet in the triplex-annealed condition, Figure 3.0322.
3.033 Impact.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.0372 Fracture toughness.
3.038 Combined properties.

3.04 Creep and Creep Rupture Properties
3.041 Variations in creep deformation with different creep exposures, Table 3.041.

3.05 Fatigue Properties
3.051 Low-cycle axial fatigue properties of α-β forged materials in two heat-treated conditions, Figure 3.051
3.052 Smooth and notched axial fatigue strength at 10^7 cycles of forgings in two duplex-annealed conditions, Table 3.052.

3.06 Elastic Properties
3.061 Poisson's ratio.
3.062 Modulus of elasticity
3.0621 Effect of temperature on tensile and compressive modulus of elasticity of sheet in the triplex-annealed condition, Figure 3.0621.
3.063 Modulus of rigidity.

4. FABRICATION

4.01 Formability
4.011 The alloy appears to have good forgeability in the high alpha-beta range (1600 to 1720 F) and in the low beta range (1720 to 1825 F).
4.012 Minimum bend radii of sheet in various heat-treated conditions at room temperature, Table 4.012.

4.02 Machining and Grinding
4.021 See Commercially Pure Titanium, Code 3701, Section 4.03 through 4.033.
4.022 The machinability of Ti-6246 in the as-forged condition is similar to that of annealed Ti-6Al-4V and Ti-6Al-6V-2Sn; in the solution-treated-and-aged condition it is similar to that of Ti-6Al-6V-2Sn and Ti-7Al-4Mo alloys in the same type of heat-treated condition (4).

4.03 Welding
4.031 No data on fusion-welded properties have been reported. One producer says that, in general, fusion welds have poor ductility and that the alloy should not be considered suitable for fusion welding, except that for some purposes electron-beam welding may be possible (4).

	Ti
6	Al
2	Sn
4	Zr
6	Mo

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4.032 Limited experimental work has shown that the alloy can be diffusion bonded at 1660F, but the optimum conditions of time, pressure, deformation, surface finish, and temperature have not been established.(7) (8).

4.04 Surface Treatment

4.041 See Commercially Pure Titanium, Code 3701, Section 4.05 through 4.055.

Alloy	Ti-6246	
Source	(1) (2)	
	Percent	
Element	Minimum	Maximum
Aluminum	5.5	6.5
Tin	1.8	2.2
Zirconium	3.6	4.4
Molybdenum	5.5	6.5
Iron	--	0.15
Oxygen	--	0.15
Carbon	--	0.04
Nitrogen	--	0.02
Hydrogen	--	0.15
Titanium	Balance	

TABLE 1.04 COMPOSITION.

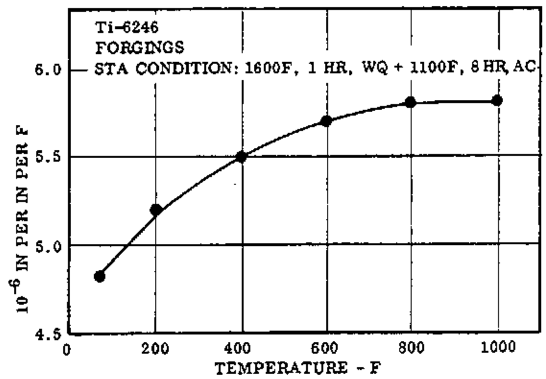

FIG. 2.014 THERMAL EXPANSION. (1)

Alloy	Ti-6246	
Source	(4)	
	Hardness	
Condition	Brinnell	Rockwell C
As Forged	310-370	33-38
STA	350-450	36-42

TABLE 1.06 HARDNESS.

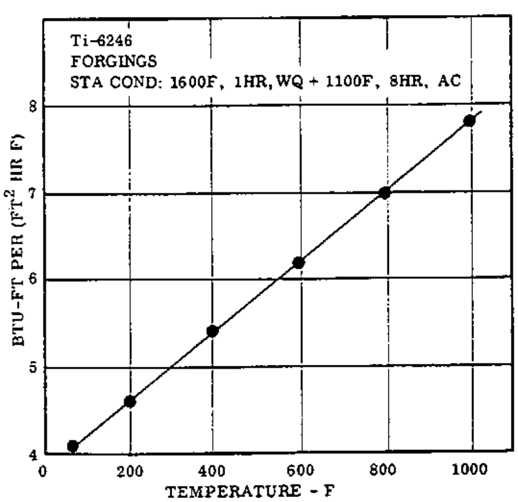

FIG. 2.013 THERMAL CONDUCTIVITY. (1)

Alloy	Ti-6246			
Source	(1)			
Form	Forgings			
Condition	STA (a)		DA (b)	
Thickness	up to 3 in	3-4 in	up to 2 in	2-3 in
F_{tu}-ksi, min	170	160	160	150
F_{ty}-ksi, min	160	150	150	140
e(1 in) percent, min				
Longitudinal	8	8	10	10
Transverse	6	6	10	8
RA, percent, min				
Longitudinal	20	20	20	20
Transverse	12	12	20	20

(a) STA: 1600F, 1hr, WQ+1100F, 8hr, AC
(b) DA: 1600F, 1hr, AC+1000F, 8hr, AC

TABLE 3.011 PRODUCERS GUARANTEED TENSILE PROPERTIES.

	Ti
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

Alloy	Ti-6246				
Condition	STA: 1600F, 1 hr, WQ +1100F, 8 hr, AC				
Source	(1)				
Form	Square Die-Press Forgings*				
Square Section size, in	Specimen Location	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
1	Ctr long	184.9	165.2	12	27.9
	Ctr long	177.3	165.7	12	41.5
3	Out trans	188.1	174.9	10	32.7
	Out trans	187.4	173.5	9	29.7
	Ctr trans	177.6	164.9	13	42.8
	Out long	195.3	183.9	13	24.9
	Out long	191.4	178.4	12	25.4
	Ctr long	181.1	172.2	15	46.4
6	Out trans	177.8	164.9	8	28.9
	Out trans	184.9	171.3	11	37.1
	Mid rad trans	172.3	161.4	10	32.6
	Mid rad trans	169.6	160.3	9	38.0
	Ctr trans	160.4	144.5	12	33.4
	Out long	189.4	175.3	9	20.9
	Out long	186.4	174.3	11	36.0
	Mid rad long	173.9	162.7	15	28.9
	Mid rad long	165.8	153.8	14	39.7
	Ctr long	167.7	153.7	15	30.9

* α-β forged at 1620F

TABLE 3.021001 TENSILE PROPERTIES OF SQUARE DIE-PRESS FORGINGS OF VARIOUS SECTION SIZES.

Alloy	Ti-6246							
Condition	STA: 1600 F, 1 hr, WQ+1100 F, 8 hr, AC							
Source	(3)							
Form	Disc Forging							
Forge Temperature-F	$\alpha - \beta$ forged at 1620 F				β forged at 1850 F			
Specimen Location	F_{tu}, ksi	F_{ty}, ksi	e(1 in) percent	RA percent	F_{tu}, ksi	F_{ty}, ksi	e(1 in) percent	RA percent
Outside Tangential	197.0	180.4	8.0	23.6	179.5	163.0	2.0	4.0
Outside Tangential	191.8	176.2	13.0	30.5	174.3	157.6	6.5	10.9
Center Tangential	190.4	174.6	11.5	37.8	180.5	162.0	6.0	16.5
Center Tangential	184.6	172.4	8.5	32.8				
Center Axial	192.0	174.2	9.0	24.2	175.0	162.9	8.0	11.2
Center Axial	184.6	172.3	7.0	19.7	178.9	167.5	6.5	9.2
Outside Radial	189.1	173.3	11.0	26.9	181.5	169.2	10.0	17.9
Outside Radial	186.4	175.2	10.5	41.6	185.4	168.0	6.5	8.8
Center Radial	187.9	171.6	10.5	31.8	184.0	168.4	9.0	14.3
Center Radial	184.4	170.0	8.0	20.2	179.7	164.8	9.5	14.3
Center Diametral	196.1	180.0	6.5	11.1	190.4	185.3	10.0	22.7

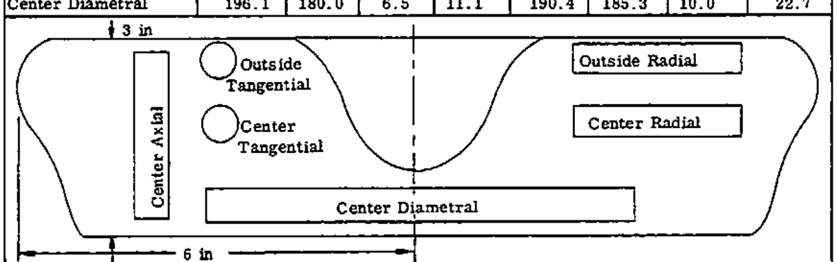

TABLE 3.021002 TENSILE PROPERTIES AT VARIOUS LOCATIONS IN DISC FORGING.

Alloy	Ti-6246						
Source	(6)						
Form	1 3/4 inch Thick Upset Forgings						
Forge Temp, F	Solution Temp, F (a)	Cooling from Solution	Age Temp, F (b)	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
1625	1525	air cool	1000	180	163	13	26.0
			1100	182	167	10	27.5
		oil quench	1000	188	168	9	17.0
			1100	184	170	12	28.0
	1600	air cool	1000	190	169	12	41.0
			1100	181	166	13	28.0
		oil quench	1000	216	184	4	10.0
			1100	192	170	8	12.0
1675	1525	air cool	1000	173	161	12	40.5
			1100	169	160	12	24.0
		oil quench	1000	194	173	8	16.0
			1100	180	170	12	37.5
	1600	air cool	1000	182	167	14	34.0
			1100	185	173	10	24.0
		oil quench	1000	212	185	6	8.0
			1100	197	183	8	20.0
(a) 1 hr at temp							
(b) 8 hr at temp							

TABLE 3.021003 TENSILE PROPERTIES OF UPSET FORGINGS WITH VARIATIONS IN FORGE TEMPERATURE, SOLUTION TEMPERATURE, COOLING RATE FROM SOLUTION TEMPERATURE, AND AGING TEMPERATURE.

	Ti
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

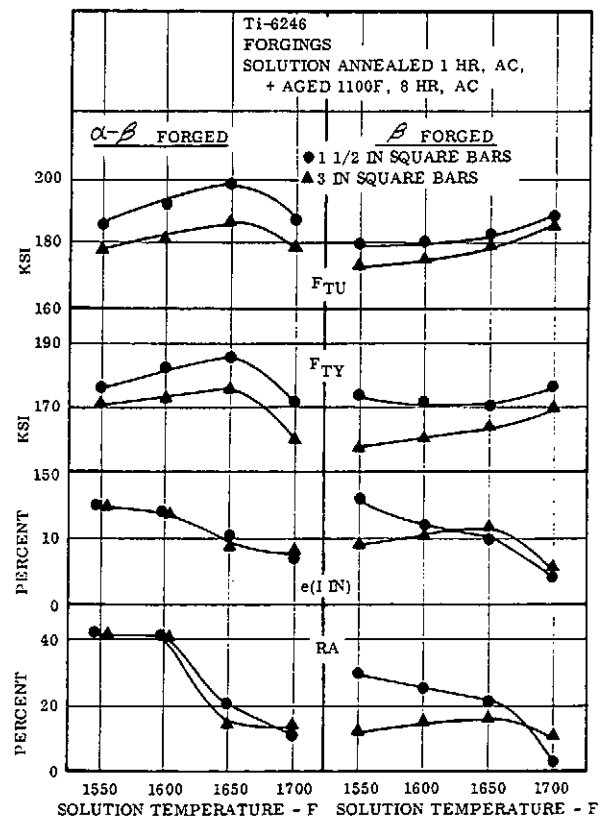

FIG. 3.021004 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF 1 1/2 IN AND 3 IN SQUARE BARS FORGED AT TWO DIFFERENT TEMPERATURES. (5)

	Ti
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

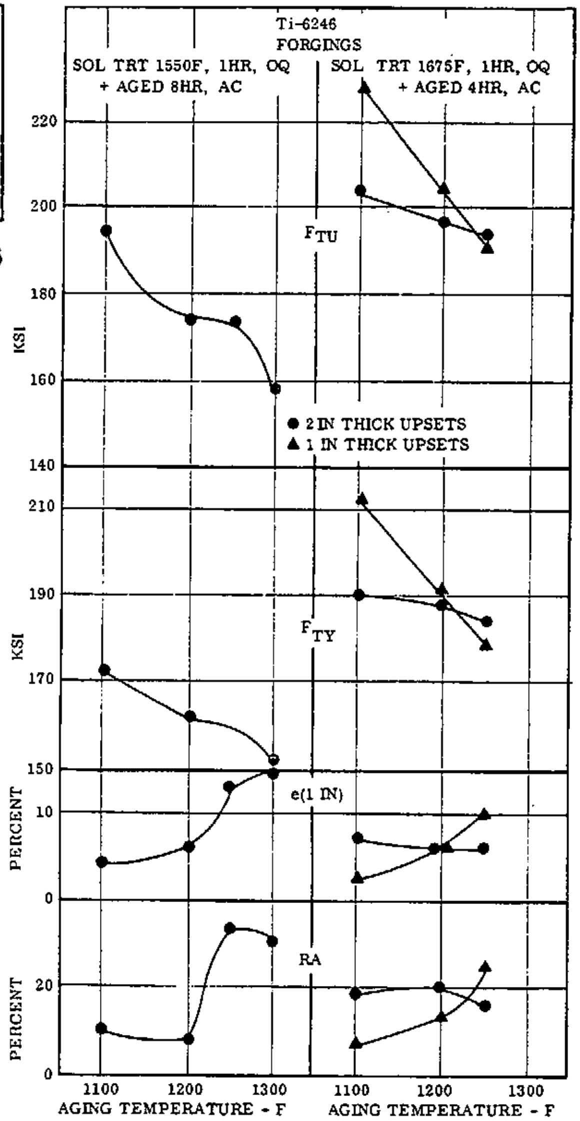

FIG. 3.021005 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF α-β FORGED UPSETS AFTER TWO DIFFERENT SOLUTION TREATMENTS. (5)

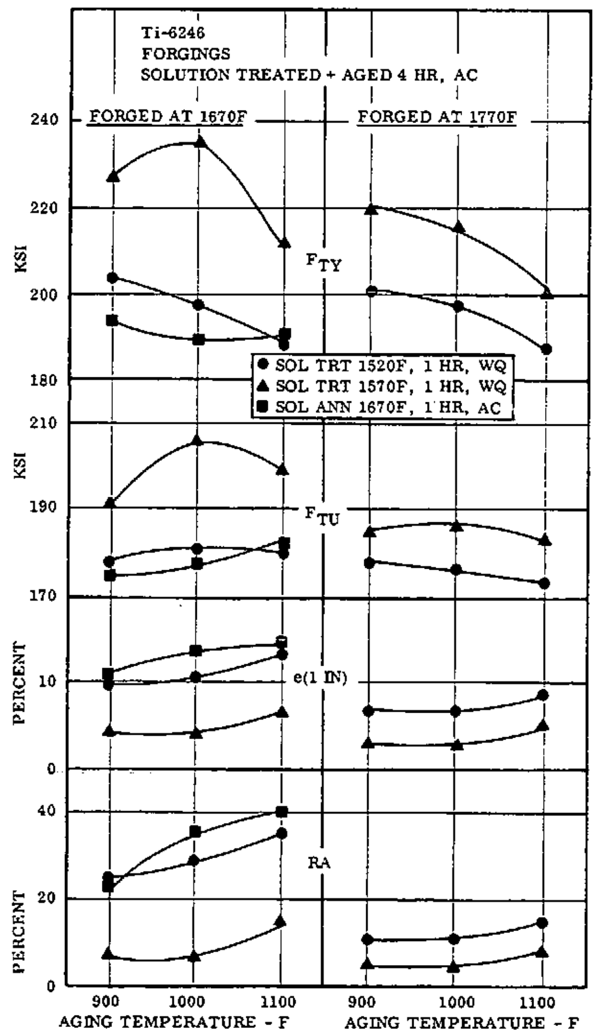

FIG. 3.021006 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF 1.25-IN THICK DISCS FORGED AT TWO DIFFERENT TEMPERATURES AND SUBJECTED TO THREE DIFFERENT SOLUTION TREATMENTS. (2)

Ti	
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

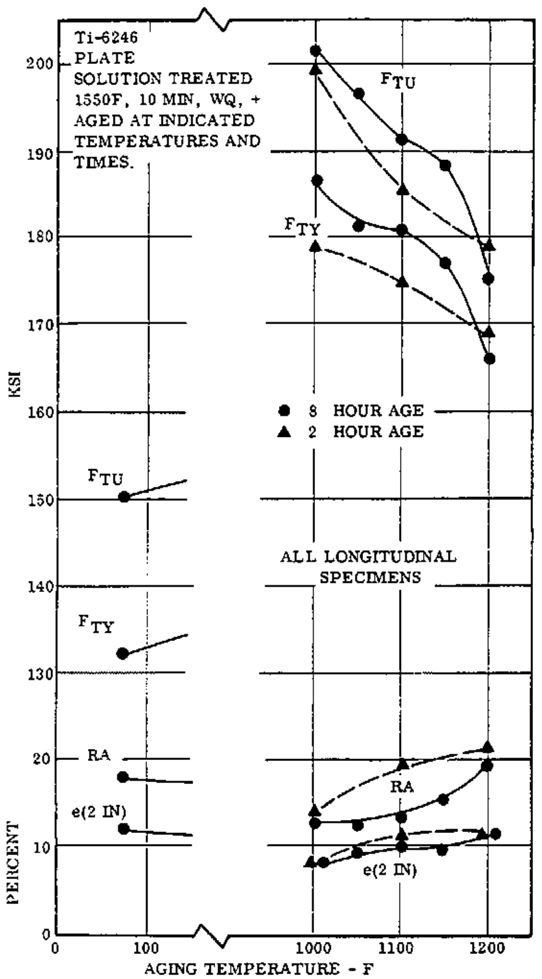

FIG. 3.021007 EFFECT OF AGING TEMPERATURE AND TIME ON THE TENSILE PROPERTIES OF 0.500 - INCH THICK PLATE. (5)

Alloy	Ti-6246			
Source	(5)			
Form	Sheet			
Condition	Orientation	F_{tu}, ksi	F_{ty}, ksi	e(2 in) percent
SA: 1575F, 5 min, FAC	L	163	120	7.5
	T	165	132	7.5
SA: 1600F, 15 min, AC	L	159	58	9.5
	T	160	64	8.0

TABLE 3.021009 EFFECT OF COOLING RATE ON TENSILE PROPERTIES OF SOLUTION-ANNEALED SHEET.

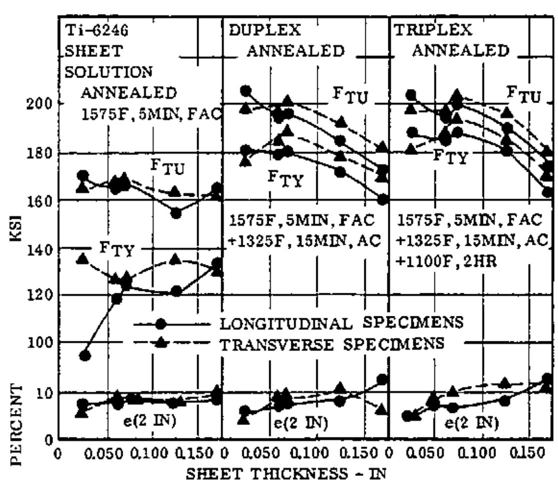

FIG. 3.021008 EFFECT OF THICKNESS ON TENSILE PROPERTIES OF SHEET IN THREE HEAT-TREATED CONDITIONS. (5)

Alloy	Ti-6246					
Condition	STA: 1600F, 1 hr, WQ+1100F 8 hr, AC					
Source	(3)					
Form	Disc Forging, 3 in thick x 11 in dia					
Creep Exposure			F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
Temp, F	Stress, ksi	Time, hr	α - β forged at 1620F			
unexposed			186.9	172.5	10.0	30.1
750	90	1228	198.7	175.8	6.0	22.8
750	89	150	184.7	170.2	6.0	16.2
800	75	504	197.6	174.6	--	--
800	85	241	199.0	175.8	7.0	26.9
800	85	150	188.3	168.6	6.0	16.8
1000	20	51	185.0	167.1	12.0	32.3
1000	30	72	185.0	169.1	--	25.9
1000	30	150	184.1	167.5	5.0	15.7
			β forged at 1850F			
unexposed			182.6	167.6	8.8	13.8
750	90	336	177.9	162.8	5.0	21.0
750	89	150	185.8	167.2	4.0	13.0
800	75	290	180.6	161.5	--	--
800	85	313	183.6	166.1	4.0	12.7
1000	20	120	174.6	161.2	8.0	16.2
1000	30	72	181.7	162.8	5.0	10.4

Note: Specimens had gage sections 0.250 inches in diameter and 1 in long.

TABLE 3.021010 EFFECT OF CREEP EXPOSURES AT TEMPERATURES FROM 750 TO 1000F ON TENSILE PROPERTIES OF FORGINGS IN THE SOLUTION TREATED AND AGED CONDITION.

Alloy	Ti-6246							
Source	(5)							
Form	α-β Forged Discs, 6 in diameter x Various Thicknesses							
Condition	DA: 1675F, 1 hr, AC+1100F, 4 hr, AC							
	Creep Exposure			Creep				
Thickness, inches	Temp F	Stress, ksi	Time, hr	Def. Percent	F_{tu} ksi	F_{ty} ksi	e(1 in) Percent	RA Percent
3	---	---	---	---	172.6	156.6	16.5	43.3
	800	85	50	0.102	167.8	154.2	14.0	40.5
2	---	---	---	---	168.8	154.7	14.0	41.9
	800	85	50	0.136	162.7	148.4	17.0	41.8
1	---	---	---	---	174.1	157.7	14.0	39.4
	800	85	50	0.098	176.2	160.5	14.0	35.0
Condition	STA: 1675F, 1hr, OQ+1100F, 4 hr, AC							
3	---	---	---	---	200.9	189.3	7.0	27.5
	800	85	50	0.071	195.6	186.3	7.0	20.4
2	---	---	---	---	202.1	190.3	7.0	18.3
	800	85	50	0.106	198.9	186.4	5.0	17.5
1	---	---	---	---	228.6	212.9	2.5	8.2
	800	85	50	0.165	227.8	212.0	3.5	10.1

TABLE 3.021011 EFFECT OF CREEP EXPOSURES AT 800F ON TENSILE PROPERTIES OF FORGINGS FROM 1 TO 3 IN THICK IN BOTH THE DUPLEX-ANNEALED AND THE SOLUTION-TREATED AND AGED CONDITIONS.

Alloy	Ti-6246						
Source	(5)						
Form	α-β Forged 1 in Rounds						
Condition	DA: 1600F, 1 hr, AC + 1100F, 8 hr, AC						
Creep Exposure			Creep				
Temp F	Stress ksi	Time hr	Def percent	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
--	--	--	--	195.6	182.9	11.5	24.3
600	100	100	0.020	185.5	175.0	10.0	24.8
750	89	100	0.063	195.2	181.3	9.5	18.0
Condition	DA: 1675F, 1 hr, AC + 1100F, 8 hr, AC						
--	--	--	--	192.9	177.7	13.0	22.1
600	100	100	0.024	191.9	172.6	8.0	14.0
750	89	100	0.057	190.2	172.2	8.5	15.4

TABLE 3.021012 EFFECT OF CREEP EXPOSURES AT 600 AND 750F ON TENSILE PROPERTIES OF FORGINGS IN TWO DUPLEX-ANNEALED CONDITIONS.

Alloy	Ti-6246			
Source	(5)			
Form	Sheet			
Condition	DA: 1600F, 15 min, AC+1300F, 15 min, AC			
Exposure		F_{tu}	F_{ty}	e(1 in)
Temperature, F	Time, hr	ksi	ksi	percent
--	--	184.5	170.2	8.3
600	500	188.6	169.1	8.8
Condition	TA: 1600F, 15 min, AC+1350, 15 min, AC+1100F, 2 hr AC			
--	--	182.1	171.7	9.0
600	500	185.1	170.0	9.5

TABLE 3.021013 EFFECT OF EXPOSURES OF 500 HOURS AT 600F ON TENSILE PROPERTIES OF SHEET IN THE DUPLEX-ANNEALED AND TRIPLEX-ANNEALED CONDITIONS.

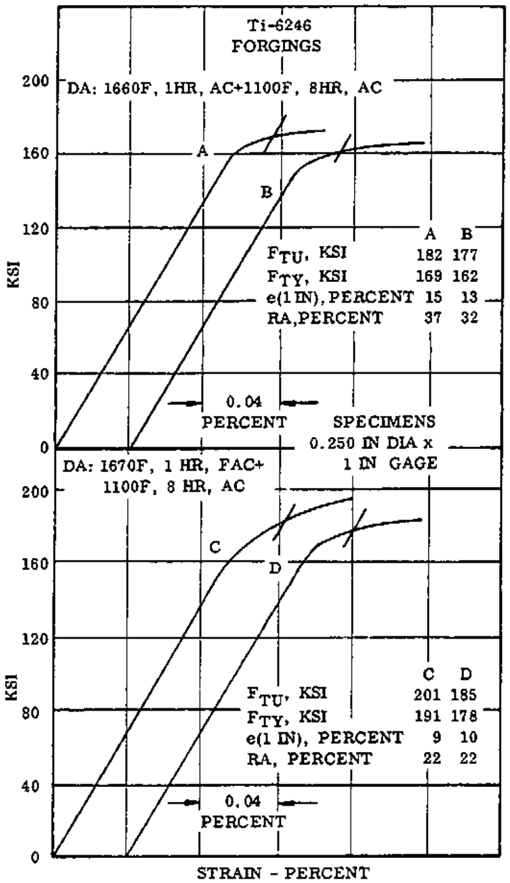

FIG. 3.02111 DUPLICATE STRESS-STRAIN CURVES FOR FORGINGS SUBJECTED TO TWO DIFFERENT DUPLEX-ANNEALING TREATMENTS. (4)

Alloy	Ti-6246	
Condition	DA: 1600F, 1 hr, AC+1100F, 8 hr, AC	
Source	(5)	
Form	Press Upsets	
Forge Temp, F	α-β forged at 1625 F	
Product size, in	Charpy V-notch impact, ft-lb	F_{tu}
6 round x 3/4	7	192.9
8 round x 3/4	10	183.7
9 round x 3/4	11	180.7
4 x 7 x 3/4	7	188.9

TABLE 3.0231 CHARPY V-NOTCH IMPACT STRENGTH OF DUPLEX-ANNEALED PRESS UPSETS IN VARIOUS SIZES.

Alloy	Ti-6246
Source	(2)
Form	0.060 in sheet
Condition	Fcy, ksi
DA: 1600F, 15 min, AC + 1300F, 15 min, AC	184
TA: 1600F, 15 min, AC + 1300F, 15 min, AC +1100F, 2 hr, AC	182

TABLE 3.0222 COMPRESSIVE YIELD STRENGTH OF SHEET IN THE DUPLEX-ANNEALED AND TRIPLEX-ANNEALED CONDITIONS.

Alloy	Ti-6246				
Source	(6)				
Form	1 3/4 in thick Upset Forgings				
Forge Temp, F	Solution Temp, F(a)	Cooling from Solution	Age Temp, F(b)	Charpy V-notch impact, ft-lb	F_{tu} ksi
1625	1525	air cool	1000	9	180
			1100	10	182
		oil quench	1000	7.5	188
			1100	11	184
	1600	air cool	1000	8.5	190
			1100	7	181
		oil quench	1000	6	216
			1100	6	192
1675	1525	air cool	1000	8	173
			1100	8	169
		oil quench	1000	8	194
			1100	9.5	180
	1600	air cool	1000	9	182
			1100	9.5	185
		oil quench	1000	7	212
			1100	6.5	197

(a) 1 hr at temperature
(b) 8 hr at temperature

TABLE 3.0232 CHARPY V-NOTCH IMPACT STRENGTH OF UPSET FORGINGS WITH VARIATIONS IN FORGING TEMPERATURE AND HEAT TREATMENT.

	Ti
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

Alloy	Ti-6246			
Condition	STA: 1600F, 1hr, WQ+1100F, 8hr. AC			
Source	(3)			
Form	Disc Forging			
Forge Temperature, F	α-β forged at 1620F		β forged at 1850F	
Specimen location (a)	NTS (b), ksi	NTS/F_{ty}	NTS(b), ksi	NTS/F_{ty}
Outside Tangential	217.9	1.21	226.3	1.41
Outside Tangential			213.0	1.33
Center Tangential	218.1	1.25	223.6	1.38
Center Axial	227.9	1.31	167.7	1.01
Center Diametral	235.6	1.31	228.2	1.23
Center Radial	218.8	1.28		

(a) See diagram on Table 3.021002
(b) K_t=3.8 60° Notch tip radius 0.005 in

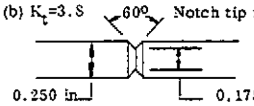

TABLE 3.02711 NOTCH TENSILE STRENGTH AT VARIOUS LOCATIONS IN DISC FORGING.

Alloy	Ti-6246			
Source	(5)			
Form	Forgings			
Forging Conditions	Heat Treat Conditions	Section Thickness, in	F_{tu} ksi	K_{Ic} ksi$\sqrt{in}$
1625F, AC	1600F, 2hr, AC+1100F, 8hr, AC	2	166	33.4
				30.5
1650F, AC	1650F, 1hr, WQ+1200F, 8hr, AC	3	189	19.1
	1650F, 1hr, AC+1200F, 8hr, AC	3	170	24.2
1625F, AC	1675F, 1hr, AC+1100F, 8hr, AC	2	168	45.9
1800F, WQ		2	168	59.9
1625F, AC	1675F, 1hr, AC+975F, 8hr, AC	1	177	29.7
1800F, WQ	1675F, 1hr, AC+975F, 8hr, AC	1	177	41.9
1800F, WQ	1675F, 1hr, AC+1100F, 8hr, AC	1	172	43.3
1650F, AC	1675F, 1hr, AC+1550F, 8hr, OQ + 1100F, 8hr, AC	3	177	35.5
		2 1/8	182	33.1
1800F, AC	1550F, 1hr, OQ+1100F, 8hr, AC	3	172	33.9
		2 1/8	184	32.2
		1 1/2	188	25.2
1625F, AC	1675F, 1hr, AC+1100F, 4hr, AC	3	172	30.7
		2	169	30.3
		1	179	27.3

TABLE 3.02722 VARIATIONS IN FRACTURE TOUGHNESS OF FORGINGS WITH DIFFERENT FORGING CONDITIONS, HEAT TREATMENTS, AND SECTION THICKNESSES.

Alloy	Ti-6246			
Condition	STA: 1600F, 1hr, WQ+1100F, 8hr, AC			
Source	(3)			
Form	Disc Forging			
Forge Temp, F	α-β forged at 1620F		β forged at 1850F	
	Notch(b) time fracture		Notch(b) time fracture	
Specimen Location(a)	Stress, ksi	Time, hr	Stress	Time, hr
Outside Tangential	170	4.92	190	2.75
Outside Tangential			190	0.16
Center Tangential	200	3.75	200	0.33
Center Axial	180	4.92	170	5.00+
Center Radial	220	0.00		
Center Radial	210	5.00+		

(a) See diagram on Table 3.021002
(b) K_t=3.8 60° Notch tip radius 0.005 in

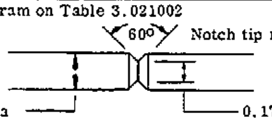

TABLE 3.02712 NOTCH TIME FRACTURE PROPERTIES AT VARIOUS LOCATIONS IN DISC FORGING.

Alloy	Ti-6246	
Condition	STA: 1600F, 1 hr, WQ + 1100F, 8 hr, AC	
Source	(3)	
Form	Disc Forging*	
Forge Temp, F	α-β forged at 1620F	β forged at 1850F
Specimen Location*	K_{Ic}, ksi $\sqrt{in}$	K_{Ic}, ksi $\sqrt{in}$
Center tangential	25.74	
Outside tangential	22.27	19.85
Outside tangential	24.11	
Center diametral		19.52

Note: K_{Ic} values determined with precracked three-point notched bend specimens.
* See diagram on Table 3.021002

TABLE: 3.02721 FRACTURE TOUGHNESS AT VARIOUS LOCATIONS IN SOLUTION-TREATED AND AGED DISC FORGING.

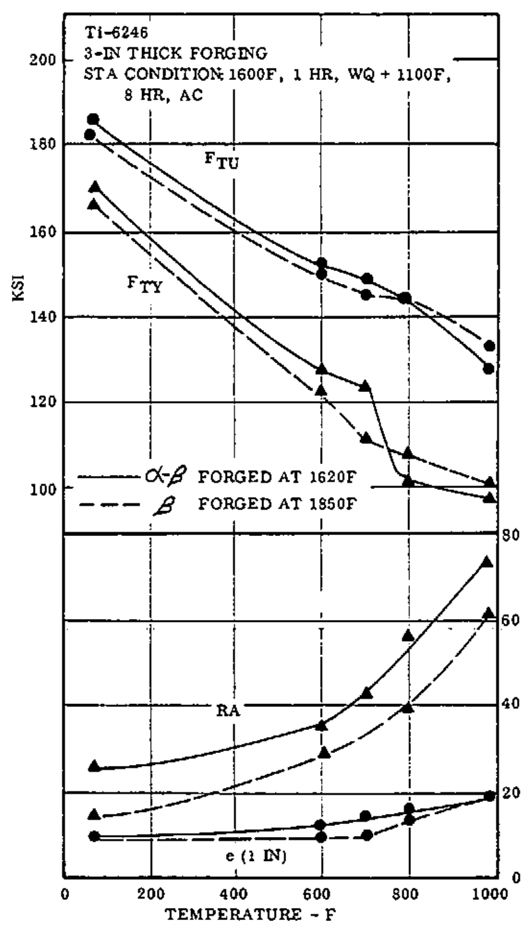

FIG. 3.0312 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF 3-INCH-THICK SECTIONS FORGED AT TWO DIFFERENT TEMPERATURES. (3)

	Ti
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

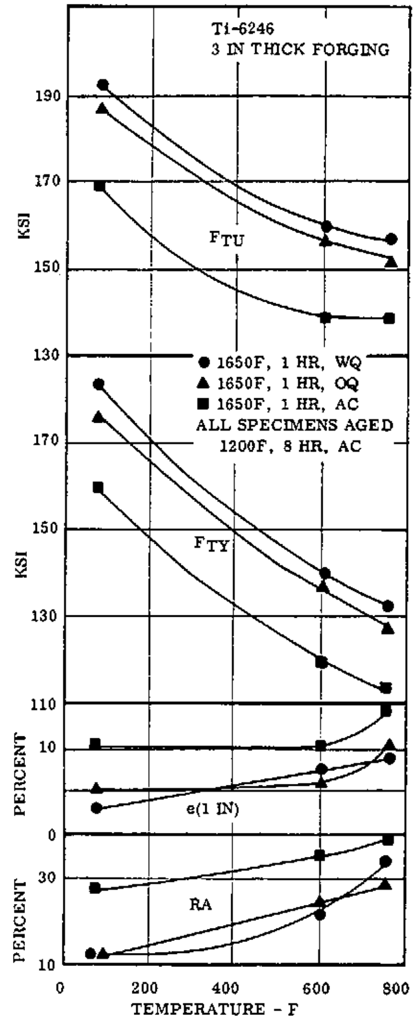

FIG. 3.0313 EFFECT OF TEMPERATURE AND VARIOUS COOLING RATES AFTER SOLUTION TREATMENT ON TENSILE PROPERTIES OF α-β FORGED 3 IN THICK SECTIONS. (5)

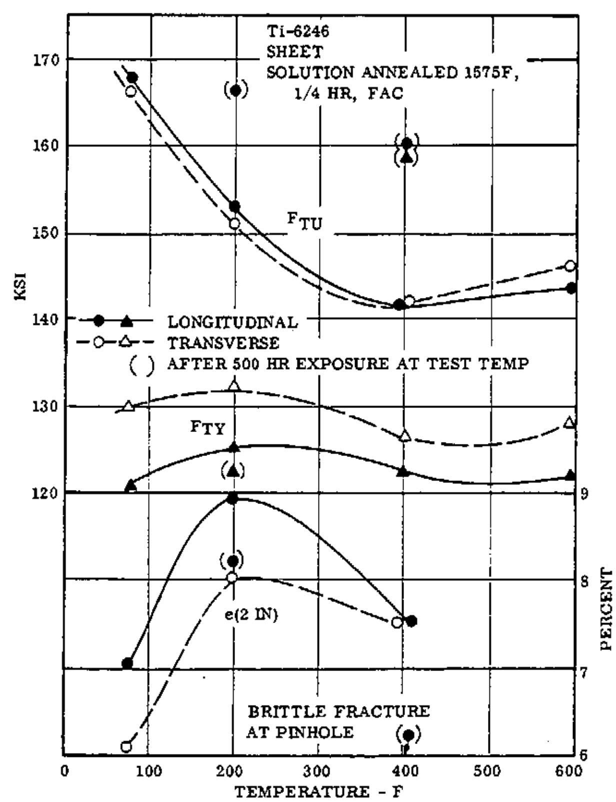

FIG. 3.0314 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF SHEET IN THE SOLUTION-ANNEALED CONDITION. (5)

	Ti
6	Al
2	Sn
4	Zr
6	Mo

Ti-6-2-4-6

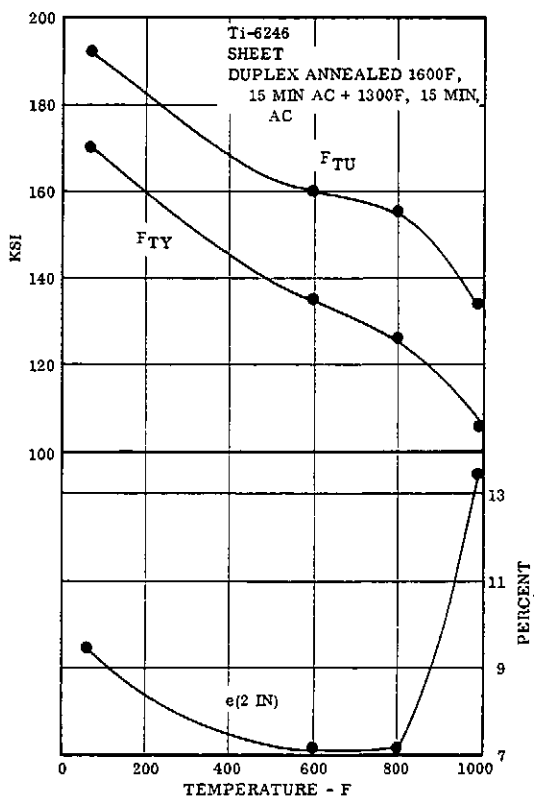

FIG. 3.0315 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF SHEET IN THE DUPLEX-ANNEALED CONDITION. (5)

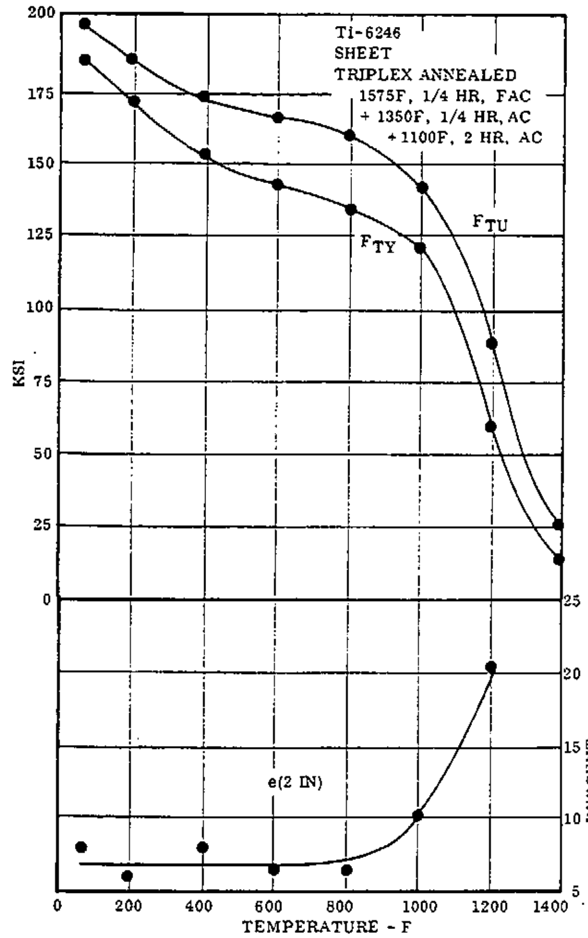

FIG. 3.0316 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF SHEET IN THE TRIPLEX-ANNEALED CONDITION. (5)

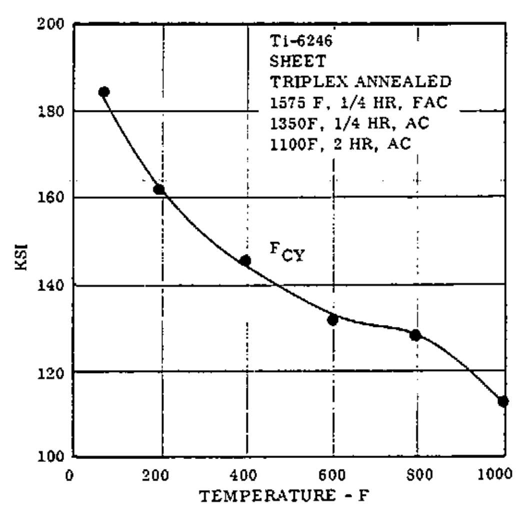

FIG. 3.0322 EFFECT OF TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF SHEET IN THE TRIPLEX-ANNEALED CONDITION. (5)

Ti
6 Al
2 Sn
4 Zr
6 Mo

Ti-6-2-4-6

Alloy	Ti-6246				
Condition	STA: 1600F, 1 hr, WQ + 1100F, 8 hr, AC				
Source	(3)				
Form	Disc Forging, 3 in thick x 11 in dia				
Creep Exposures			Time to 0.1 percent creep, hr	Time to 0.2 percent creep, hr	Total Plastic Def, percent
Temp, F	Stress, ksi	Time, hr	α-β forged at 1620F		
750	90	1228	270	840	0.251
750	89	150	--	--	0.101
800	75	504	105	420	0.217
800	85	241	40	210	0.234
800	85	150	--	--	0.180
1000	20	51	6	27	0.246
1000	30	72	2	8	0.760
1000	30	150	--	--	0.820
			β forged at 1850F		
750	90	336	75	264	0.203
750	89	150	--	--	0.091
800	75	290	35	250	0.223
800	85	313	25	165	0.252
1000	20	120	4	22	0.427
1000	30	72	1	6	0.613

TABLE 3.041 VARIATIONS IN CREEP DEFORMATION WITH DIFFERENT CREEP EXPOSURES.

Alloy	Ti-6246			
Source	(5)			
Form	1-in-round forgings			
Heat Treatment	R	A	Axial Fatigue Str ksi at 10^7 cycles K_t=1	K_t=3.8*
1600F, 1hr, AC+1100F, 8hr, AC	0.1	0.82	115	55
1675F, 1hr, AC+1100F, 8hr, AC	0.1	0.82	120	50

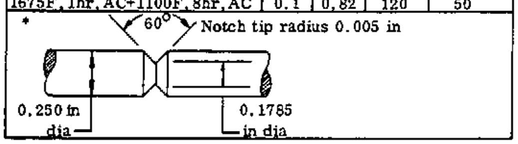

TABLE 3.052 SMOOTH AND NOTCHED AXIAL FATIGUE STRENGTH AT 10^7 CYCLES OF FORGINGS IN TWO DUPLEX-ANNEALED CONDITIONS.

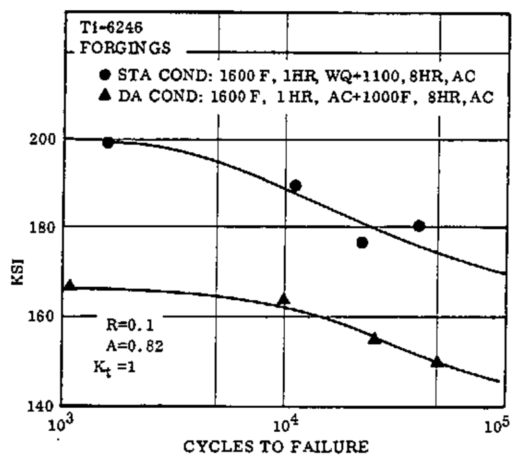

FIG. 3.051 LOW-CYCLE AXIAL FATIGUE PROPERTIES OF α-β FORGED MATERIAL IN TWO HEAT-TREATED CONDITIONS. (1)

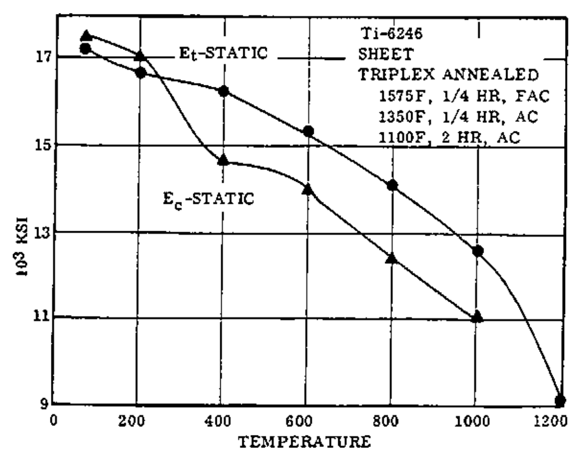

FIG. 3.0621 EFFECT OF TEMPERATURE ON TENSILE AND COMPRESSIVE MODULUS OF ELASTICITY OF SHEET IN THE TRIPLEX-ANNEALED CONDITION. (5)

Ti
6 Al
2 Sn
4 Zr
6 Mo

Ti-6-2-4-6

Alloy	Ti-6246	
Source	(5)	
Form	Sheet	
Condition	SA: 1575F, 5min, FAC	
Sheet Thickness, in	Specimen Orientation	Minimum Bend Radius to Thickness Ratio
0.025	L	4.25
	T	4.0
0.063	L	4.6
	T	5.0
0.070	L	4.25
	T	4.25
0.125	L	4.0
	T	4.0
0.170	L	4.5
	T	4.5
Condition	SA: 1600F, 15 min, AC	
--	L	3.7
--	T	3.8
Condition	DA: 1600F, 15 min, AC + 1300F, 15 min, AC	
--	L	5.0
--	T	5.3

TABLE 4.012 MINIMUM BEND RADII OF SHEET IN VARIOUS HEAT-TREATED CONDITIONS AT ROOM TEMPERATURE.

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8. Doak, R. A., "Diffusion Bonded Titanium Alloy Hollow Fan Disk", Second Interim Technical Report IR-890-9 (II) (1 April 1970 - 30 June 1970), AFML Contract F33615-70-C-1212.
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10. Ruckle, D. L., "Development of Computerized Microstructure Control Procedure for Ti-6Al-2Sn-4Zr-6Mo Alloy Production Compressor Discs", First Interim Technical Report (December 1971), AFML Contract F33615-71-C-1569.