

REVISED: DECEMBER 1975
 AUTHOR: W. F. BROWN, JR.

NONFERROUS ALLOYS

1. GENERAL
 This is a heat treatable alpha + beta alloy that in many respects is similar to Ti-6Al-4V but containing increased content of beta stabilizing elements which provide higher strength potential at a sacrifice in toughness and weldability. In forged sections and plate up to one inch thick solution treated and aged material has a guaranteed minimum $F_{T1} = 170$ ksi. For forged sections between 3 and 4 inches the corresponding $F_{T1} = 150$ ksi. The response to heat treatment may vary from heat to heat and the correct aging temperature is best determined by tests on the heat in question. As is characteristic of other titanium alloys exposure to stress at elevated temperature produces changes in the retained mechanical properties. The stress and temperature limits below which these changes will not occur have not yet been established for this alloy. Structural applications should be based on a knowledge of the low toughness characterizing the higher strength conditions of this alloy and the limited toughness of welds. Particular attention should be given to the influence of aggressive environments in the presence of cracks. Such environments include aqueous solutions of chlorides and possibly certain organic solvents such as methanol.
- 1.01 Commercial Designation
 6Al-6V-2Sn-Ti alloy.
- 1.02 Alternate Designations
 None
- 1.03 Specifications
 1.031 AMS Specifications, Table 1.031.
- 1.04 Composition
 1.041 Producers and AMS specified composition, Table 1.041.
- 1.05 Heat Treatment
 1.051 General. Heat treatment has an important effect on the mechanical properties of this alloy through its control of the microstructure. Details concerning the influence of heat treatment on microstructure may be found in (42). The tensile strength increases with solution temperature in the alpha + beta range but the tensile ductility and the sharp notch strength decrease (Figures 3.0215, 3.0216, 3.02122 and 3.02713). At solution temperatures above the beta transus, the tensile strength decreases somewhat and the ductility drops rapidly (Figure 3.02125). An aging temperature of about 800F produces a full aged condition of the solution treated material with a tensile strength of about 240 ksi (Figure 3.02128). This fully aged condition is relatively brittle (Figure 3.02715) and overaging in the temperature range between 1000 and 1150F is generally employed. In this range the tensile strength decreases relatively slowly with increasing aging temperature and the tensile ductility and the plane strain fracture toughness increase (Figures 3.02114, 3.02117, 3.02123, 3.02126 and 3.02723). Several so called duplex annealing treatments have been investigated (Tables 3.02724 and 3.02725). In some cases these appeared to increase the plane strain fracture toughness as compared with the mill annealed material but resulted in some loss in tensile yield strength. However, a toughness improvement was not noted for all product forms.
 1.052 AMS specified heat treatments, Table 1.052.
 1.053 Producers recommended heat treatments, Table 1.053.
- 1.06 Hardness
 1.061 Jominy hardenability curve and hardness distribution after aging, Figure 1.061.
 1.062 Effect of solution temperature on the hardness, Figure 1.062.
 1.063 Hardness as a function of aging time and temperature for two solution temperatures, Figure 1.063.
 1.064 Hardness as a function of aging temperature and time, Figure 1.064.
- 1.07 Forms and Conditions Available
 Sheet and plate in annealed, solution treated and solution treated and aged condition. Bar stock and forging billet in as-rolled or annealed conditions. Extruded shapes up to a size that can be circumscribed by a 5-1/4 inch diameter circle in annealed or heat treated condition.
- 1.08 Melting and Casting Practice
 1.081 For melting practice see Ti-6Al-4V (Code 3707). The alloy is not normally used in the cast form, however, a limited amount of information on precision casting can be found in (31).
- 1.09 Special Considerations
 1.091 Notch tensile strength of annealed sheet at room temperature as influenced by hydrogen content, Figure 1.091.
 1.0911 Hardenability. An attempt has been made to improve the hardenability of this alloy as compared with Ti-6Al-4V by increasing the amount of beta stabilizing alloy additions. These modifications have increased the maximum strength potential. However, the available evidence indicates that percentage wise the strength loss produced by increasing the solution treated section size is about the same for this alloy and for Ti-6Al-4V. This is illustrated in Figure 1.0911 which shows the reduction in F_{T1} as the solution treated section size is increased for forgings, bar and plate. All but one set of data indicates the hardenability for this alloy is essentially the same as for Ti-6Al-4V. If the amount of hot working is the same for each heat treated section size, then ductility as measured by reduction in area may be essentially unchanged or increase as the heat treated section size increases (see Figures 3.02112 and 3.02113). If the heat treated size variation represents a variation in the degree of working, the ductility may decrease with increasing section size (see Figures 3.02112 and 3.02121).
 1.0912 Hardenability of various forms of alloy, Figure 1.0912.
 1.092 Stability. Long time exposure to elevated temperature with or without stress produces the so called creep instability characteristic of the higher aluminum titanium alloys. This instability is probably due to a combination of structural change and interstitial embrittlement. It is evidenced by an increase in the tensile and yield strength and a decrease in the elongation and reduction in area (Tables 3.02119 and 3.02120 and Figures 3.02130 and 3.02131). Tests on cracked specimens (55) indicate that the fracture toughness is also reduced by elevated temperature exposure. However, these tests did not yield valid (ASTM E-399) K_{Ic} values. The magnitude of the instability depends on both time and temperature of exposure (Figure 3.02130) with shorter times shifting the effects to higher temperatures. The data is not sufficient to define the role of stress on the exposure effect. However, apparently substantial instability can occur in the annealed alloy due to temperature alone (Figure 3.02130). Instability may be noticed at temperatures as low as 250F for extended exposure times, however, large effects are not noticed below about 600F (Figures 3.02130 and 3.02131). The solution treated and aged condition appears to be somewhat less susceptible to instability perhaps because exposure effects are reduced by concurrent overaging. A special heat treatment has been suggested to reduce the instability. This treatment appears to increase the unexposed tensile and yield strength and to decrease the exposure effect on these properties but the ductility is still adversely affected (Figure 3.02130). On the basis of the data available it is evident that exposure instability effects should be given careful consideration in elevated temperature applications of this alloy.
 Segregation. The relatively high beta stabilizing element content of this alloy makes it particularly prone to effects associated with microsegregation of the beta stabilizing elements iron and copper. These segregated regions will have a reduced transus temperature and may transform to beta on heating during fabrication processes. After solution quenching these regions

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

- will be softer than the matrix and will consist of stable beta and martensite with the prior beta grain boundaries being outlined in alpha. Aging will transform the martensite to acicular alpha and the regions will then be harder than the matrix. These areas of transformed beta have been called "beta flecks" although they sometimes appear as bands. The possibility of segregation will increase as the ingot size increases and beta flecks are most likely to be encountered at the center of heavy sections. Their significance is not understood as yet. It has been reported (63) that they reduce the tensile ductility and it is possible that other properties such as fracture toughness and fatigue strength may be affected. Interstitials. Reduction in the oxygen level improves the Charpy impact strength of the annealed and of the solution treated and aged conditions (Table 3.02115). It should be noted that substantial improvement in these properties can be obtained with relatively small loss in smooth tensile or yield strength. The notch fatigue strength is also improved by a reduction in the oxygen content (Table 3.0519).
- 1.094 Environmental Effects. See 2.03 and 3.052.
- 1.095 Fracture toughness. See 3.02721.
- 1.096 Hydrogen embrittlement. This alloy is subject to hydrogen embrittlement. One investigation (62) indicated that hot forming of annealed sheet between 1225 and 1425F followed by air cooling resulted in a significant strength reduction and an increase in the susceptibility to hydrogen pickup during chem milling. A stabilization treatment, 1100F, 1 hr, AC + 900F, 1 hr, AC, following hot forming significantly reduced the hydrogen pick up during chem milling and gave acceptable tensile properties.
- 1.097
2. PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS.
- 2.01 Thermal Properties
- 2.011 Melting range.
- 2.012 Phase changes. Beta transus approximately 1700F varying with the composition.
- 2.013 Thermal conductivity, Figure 2.013.
- 2.014 Thermal expansion, Figure 2.014.
- 2.015 Specific heat, Figure 2.015.
- 2.016 Thermal diffusivity.
- 2.02 Other Physical Properties
- 2.021 Density. 0.164 lb per cu in. 4.58 gr per cu cm (1).
- 2.022 Electrical properties.
- 2.0221 Electrical resistivity, Figure 2.0221.
- 2.024 Emissivity
- 2.025 Damping capacity.
- 2.03 Chemical Environments
- See also 3.052.
- 2.031 General. This alloy is susceptible to stress corrosion in the presence of solid NaCl at elevated temperatures and exhibits delayed failure of cracked specimens in aqueous solutions of chlorides. Smooth specimens exposed to stress in solutions simulating human body fluids show increasingly positive electropotential with time indicating film repair (see Figure 2.036) but cracked specimens do exhibit accelerated crack growth under cyclic loads when subjected to these solutions (see Figure 3.0522).
- 2.032 Delayed failure. A short cut procedure was used (21) to determine a stress intensity level below which delayed failure in 3-1/2 percent salt solution did not occur in some specified time period. Pre-cracked notch bend specimens were immersed in salt water and subject to stresses below those causing failure when rapidly applied in air. Specimens were held under load until failure occurred or until "one to three hours" elapsed with no indication of crack propagation after which the load was increased. The maximum stress intensity sustained without failure was called "ksi held". The lowest sustained stress intensity that produced failure was also reported. It is doubtful whether such types of tests can establish a stress intensity threshold below which failure would never occur in the corrosion media, however, they do establish stress ksi levels above which rapid failure can be expected. A large number of heat treatments were investigated for both extrusions and forgings. The data is too limited and unsystematic to define preferred heat treatments for maximum resistance to stress corrosion, however, there does appear to be a trend of decreasing susceptibility with decreasing strength level (see Figure 2.034). The susceptibility of high strength conditions of this alloy is also indicated by tests on plate run at NRL (20). For the annealed and the solution treated and aged conditions, crack growth has been observed under sustained load when specimens were subjected to stress intensities as low as 30 ksi-in^{1/2} for 100 hours in air having a relative humidity of 10 percent. The same type of tests in air with a 100 percent relative humidity did not give different results. The data available are not of sufficient duration to establish a threshold below which no crack growth would occur nor was the test time long enough to rule out transient phenomena (see Figure 2.036).
- 2.033 Solid salt corrosion. Smooth tensile specimens 1/8 inch thick in either the annealed (1350F, 1/4 hr FC) or solution treated and aged condition (1550F, 5 minutes WQ + 1100F, FC) were coated with 0.002 inch of NaCl and loaded at 550 or 650F, to various fractions of their yield strength for different lengths of time (16). An attempt was made to establish the nucleation time for stress corrosion by examination of the surface for cracks (after cleaning) at 500X. In addition, cyclic exposure was investigated using a heating time of 10 to 15 minutes, a hold time of 3 hours and a cooling time of 45 to 50 minutes. Preliminary tests showed the transverse direction to be more sensitive than the longitudinal direction and all tests were run in the transverse direction. The data are too limited to define stress limits below which stress corrosion would not occur or to accurately establish stress vs. time to cracking curves. The essential feature of the results are summarized in Table 2.035. As might be expected stress corrosion occurs at lower fractions of the yield strength at 650F, than at 550F. At 550F, cracking was observed at less than 0.6 F_{ty} for the aged condition and at less than 0.5 F_{ty} for the annealed condition. At 650F, cracking was observed at less than 0.3 F_{ty} for both conditions with the aged condition being more sensitive than the annealed condition. There is an indication that cyclic stressing may be less severe than continuous loading although more data is needed to definitely establish such an effect.
- Tests on smooth specimens exposed to solid NaCl for 1000 hours at elevated temperatures show a rapid loss in retained room temperature tensile strength at exposure temperatures above 500F (see Figure 2.037).
- 2.034 Effect of yield strength level on delayed failure characteristics in salt water, Figure 2.034.
- 2.035 Results of elevated temperature solid salt stress corrosion test of sheet, Table 2.035.
- 2.036 Sustained load crack extension in air, Figure 2.036.
- 2.037 Residual tensile strength at room temperature following elevated temperature stress exposure to solid salt, Figure 2.037.
- 2.038 Potential time curves for stressed wire in simulated human body environment, Figure 2.038.
- 2.04 Nuclear Properties
3. MECHANICAL PROPERTIES
- 3.01 Specified Mechanical Properties
- 3.011 AMS specified minimum mechanical properties for bars forgings and rings in the solution treated and aged condition, Table 3.011.
- 3.012 AMS specified mechanical properties for annealed extrusions and for bars, forgings and rings, Table 3.012.

REVISED: DECEMBER 1975

NONFERROUS ALLOYS

- 3.013 AMS specified mechanical properties for sheet strip and plate, Table 3.013.
- 3.014 Producers guaranteed tensile properties of solution treated and aged bar and forging stock, Table 3.014.
- 3.015 Producers guaranteed tensile properties of annealed bar, Table 3.015.
- 3.016 Producers guaranteed tensile properties of annealed and of solution treated and aged extrusion, Table 3.016.
- 3.017 Producers guaranteed tensile properties of annealed solution treated and solution treated and aged plate, Table 3.017.
- 3.018 Producers guaranteed tensile properties of annealed solution treated and solution treated and aged sheet, Table 3.018.
- 3.02 Mechanical Properties at Room Temperature
- 3.021 Tension. Stress strain diagrams and tension properties.
- 3.0211 Stress strain curve in tension for forging (specimens heat treated), Figure 3.0211.
- 3.0212 Stress strain curves for plate in several conditions of heat treatment, Figure 3.0212.
- 3.0213 Tensile properties of investment cast specimens given several heat treatments, Table 3.0213.
- 3.0214 Effect of solution temperature on the as quenched tensile properties of extrusion, Figure 3.0214.
- 3.0215 Effect of solution temperature on tensile properties of 1000F aged extrusion, Figure 3.0215.
- 3.0216 Effect of solution temperature on tensile properties of 1100F aged extrusion, Figure 3.0216.
- 3.0217 Tensile properties for extruded cylinders from three heats aged at two temperatures and tested at various crosssectional locations, Table 3.0217.
- 3.0218 Tensile properties of solution treated and aged extruded bar at various crosssectional locations, Table 3.0218.
- 3.0219 Tensile properties in various locations in a forged section, Table 3.0219.
- 3.02110 Variation of tensile properties of center section of test forging with heavy ribs and thin webs, Table 3.02110.
- 3.02111 Effect of solution treated section size and age time on tensile properties of forging (forged to solution treated size), Figure 3.02111.
- 3.02112 Effect of heat treated section size on tensile properties of specimens removed from center of solution treated and aged bar sections, Figure 3.02112.
- 3.02113 Effect of heat treated section size on tensile properties of square sections removed from center of 4 inch square press forging, Figure 3.02113.
- 3.02114 Effect of aging temperature on tensile properties of specimens cut from forging and solution treated at two temperatures, Figure 3.02114.
- 3.02115 Tensile properties of forged bar at two interstitial levels, Table 3.02115.
- 3.02116 Effect of forging and quench temperature on tensile properties of hammer forged disks, Table 3.02116.
- 3.02117 Effect of age temperature on tensile properties of a beta forging solution treated at various temperatures, Figure 3.02117.
- 3.02118 Tensile properties of annealed and of solution treated and aged specimens from forged bar, Table 3.02118.
- 3.02119 Effect of elevated temperature exposure on tensile properties of annealed and solution treated and aged bar, Table 3.02119.
- 3.02120 Effect of 150 hour exposure to stress and elevated temperature on tensile properties of forged bar, Table 3.02120.
- 3.02121 Effect of thickness on tensile properties of solution treated and aged plate, Figure 3.02121.
- 3.02122 Effect of solution treating and aging temperature on the tensile properties of plate, Figure 3.02122.
- 3.02123 Effect of aging and solution treating temperature on the tensile properties of plate, Figure 3.02123.
- 3.02124 Effect of exposure to stress and temperature on retained tensile properties of plate, Table 3.02124.
- 3.02125 Effect of solution temperature on tensile properties of aged sheet, Figure 3.02125.
- 3.02126 Effect of aging temperature on the tensile properties of sheet, Figure 3.02126.
- 3.02127 Effect of aging time on tensile properties of sheet, Figure 3.02127.
- 3.02128 Effect of aging temperature on tensile properties of sheet, Figure 3.02128.
- 3.02129 Tensile properties of plate, bar and forging annealed or solution treated and aged, Table 3.02129.
- 3.02130 Effect of stressed and unstressed elevated temperature exposure on the tensile properties of annealed plate, Figure 3.02130.
- 3.02131 Effect of stressed exposure at elevated temperature on tensile properties of solution treated and aged plate, Figure 3.02131.
- 3.02132 Effect of as quenched section size on tensile properties of beta forged bars, Table 3.02132.
- 3.022 Compression - stress strain diagrams - compression properties, (see 3.032)
- 3.023 Impact, (see also 3.033).
- 3.0231 Impact strength of investment cast specimens, Table 3.0231.
- 3.0232 Effect of heat treated section size on impact strength of specimens removed from center of solution treated and aged bar sections, Figure 3.0232.
- 3.024 Bending.
- 3.025 Torsion and shear (see 3.0325)
- 3.026 Bearing (see 3.0326)
- 3.027 Stress concentration (see also 3.037)
- 3.0271 Notch properties.
- 3.02711 Effect of notch diameter on sharp notch properties of annealed billet, Figure 3.02711.
- 3.02712 Notch strength of forging at various locations, Table 3.02712.
- 3.02713 Effect of solution treating and aging temperatures on the sharp notch tensile properties of plate, Figure 3.02713.
- 3.02714 Notch strength as a function of root radius for annealed sheet, Figure 3.02714.
- 3.02715 Effect of aging temperature on strength of double edge crack sheet specimens, Figure 3.02715.
- 3.02716 Effect of surface cracks on the strength of solution treated and aged sheet, Figure 3.02716.
- 3.0272 Fracture toughness.
- 3.02721 General. The plane strain fracture toughness is strongly dependent on the yield strength and can be expected to decrease with factors that increase the yield strength such as heat treatment, low temperatures and elevated temperature exposure. The general effects of yield strength on toughness are shown in Figure 3.03724 for plate and forging. The substantial differences in toughness between these two product forms is probably due to processing differences which can influence the microstructure and should not be taken as typical. On the basis of the limited data available it appears that the optimum combination of toughness and yield strength is associated with solution treated and substantially overaged conditions (Table 3.02722) and with duplex annealed treatments (Table 3.02724 and Table 3.02725 Condition B). It should be noted that the smooth fatigue properties of this latter condition are reported to be poorer than annealed material of about the same yield strength. Beta annealing does not appear to benefit the toughness as compared with the above treatments (Table 3.02724). Low interstitial material appears to have superior toughness to normal interstitial material at the same yield strength level (Figure 3.03724).
- 3.02722 Plane strain fracture toughness of extrusions given several heat treatments, Table 3.02722.
- 3.02723 Effect of aging temperature on the plane strain fracture toughness of plate, Figure 3.02723.
- 3.02724 Plane strain fracture toughness of two heats of plate given several heat treatments, Table 3.02724.
- 3.02725 Plane strain fracture toughness of plate, bar and forging given several heat treatments, Table 3.02725.
- 3.028 Combined properties.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension-stress strain diagrams-tension properties.
- 3.0311 Elevated temperature tension stress-strain curves for aged bar, Figure 3.0311.
- 3.0312 Elevated temperature tension stress strain curves for

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

- 3.0313 annealed sheet, Figure 3.0312.
- 3.0314 Stress strain curves for mill annealed plate at various temperatures, Figure 3.0313.
- 3.0314 Average and spread of room temperature and 800F tensile properties of solution treated and aged extrusion, Table 3.0314.
- 3.0315 Effect of test temperature on tensile properties of annealed extrusions of various shapes (14), Table 17 (39) Table 6, Figure 3.0315.
- 3.0316 Effect of test temperature on tensile properties of a hammer forged disk, Figure 3.0316.
- 3.0317 Effect of test temperature and specimen location on tensile properties of forgings at two interstitial levels, (specimens heat treated), Figure 3.0317.
- 3.0318 Effect of test temperature on the tensile properties of Forging, Figure 3.0318.
- 3.0319 Effect of test temperature on the tensile properties of low interstitial forging (forging, heat treated), Figure 3.0319.
- 3.03110 Effect of low test temperatures on tensile properties of annealed and aged bar, Figure 3.03110.
- 3.03111 Effect of test temperature on tensile properties of solution treated and aged plate, Figure 3.03111.
- 3.03112 Effect of test temperature on tensile properties of annealed plate from two heats, Figure 3.03112.
- 3.03113 Effect of low test temperatures on tensile properties of low interstitial plate, Figure 3.03113.
- 3.03114 Effect of thickness on the tensile properties of solution treated and aged plate at 600F, Figure 3.03114.
- 3.03115 Effect of test temperature on tensile properties of sheet, Figure 3.03115.
- 3.032 Compression.
- 3.0321 Effect of temperature on compressive yield strength of annealed extrusion, Figure 3.0321.
- 3.0322 Effect of test temperature and specimen location on compressive yield strength of solution treated and aged forging (specimens heat treated), Figure 3.0322.
- 3.0323 Effect of temperature on compressive yield strength of annealed forgings, Figure 3.0323.
- 3.033 Impact.
- 3.0331 Effect of temperature on impact strength of aged bar, Figure 3.0331.
- 3.0332 Effect of test temperature on impact strength of annealed extrusion, Figure 3.0332.
- 3.0333 Effect of low test temperature on impact strength of annealed and solution treated and aged low interstitial plate, Figure 3.0333.
- 3.034 Bending.
- 3.035 Torsion and shear.
- 3.0351 Shear ultimate strength at room and elevated temperature for several forms and conditions of alloy, Table 3.0351.
- 3.0352 Effect of test temperature on double shear strength of annealed extrusion, Figure 3.0352.
- 3.036 Bearing.
- 3.0361 Bearing strength at room and elevated temperature for several forms and conditions of alloy, Table 3.0361.
- 3.0362 Effect of test temperature on bearing strength of annealed extrusion, Figure 3.0362.
- 3.037 Stress concentration.
- 3.0371 Notch properties (see also 3.0271).
- 3.03711 Effect of test temperature on strength of center cracked specimens of two thicknesses cut from forging (specimens heat treated), Figure 3.03711.
- 3.03712 Effect of test temperature on strength of fatigue cracked notch rounds from annealed forgings (specimens re-annealed), Figure 3.03712.
- 3.03713 Effect of test temperature on strength of fatigue cracked notch rounds cut from forging, (specimens solution treated and aged), Figure 3.03713.
- 3.03714 Strength of fatigue cracked notch rounds cut from two locations in a solution treated and aged forging, Table 3.03714.
- 3.03715 Effect of low test temperatures on sharp notch strength of annealed and solution treated and of aged bar, Figure 3.03715.
- 3.03716 Effect of low test temperatures on sharp notch strength of low interstitial plate, Figure 3.03716.
- 3.0372 Fracture toughness.
- 3.03721 Effect of test temperature on strength of double edge crack specimens and plane strain fracture toughness of low interstitial forging (K_{Ic} by technique of ASTM E 399-70T), Figure 3.03721.
- 3.03722 Effect of specimen orientation on the -110F plane strain fracture toughness of low interstitial forging, Figure 3.03722.
- 3.03723 Effect of specimen orientation on the -110F plane strain fracture toughness of plate, Table 3.03723.
- 3.03724 Effect of strength level on the plane strain fracture toughness of various forms and conditions of alloy, Figure 3.03724.
- 3.03725 Plane strain fracture toughness of forged bar in annealed and in solution treated and aged condition, Figure 3.03725.
- 3.038 Combined properties.
- 3.04 Creep and Creep Rupture Properties
- 3.041 Creep strength for annealed extrusion, Table 3.041.
- 3.042 Stress for 0.2 percent creep strain at several temperatures for aged bar, Figure 3.042.
- 3.043 Total creep strain for aged sheet at several temperatures and stresses, Table 3.043.
- 3.05 Fatigue Properties
- 3.051 Conventional properties.
- 3.0511 Smooth and notched fatigue strength of annealed extrusions at room temperature, Table 3.0511.
- 3.0512 Smooth and notch fatigue strength of solution treated and aged extrusion, Table 3.0512.
- 3.0513 Stress range diagram at 400F and 600F for smooth and notched specimens from annealed extrusion, Figure 3.0513.
- 3.0514 Stress range diagrams at room temperature for smooth and notched specimens from annealed extrusion, Figure 3.0514.
- 3.0515 Smooth and notched fatigue strength at room temperature for alpha + beta and for beta processed forgings, Figure 3.0515.
- 3.0516 Smooth and notch fatigue strength of solution treated and aged forging at room and elevated temperature, Table 3.0516.
- 3.0517 Smooth and notch fatigue strength of annealed bar, Table 3.0517.
- 3.0518 Strain cycling results for annealed bar at room and elevated temperature, Figure 3.0518.
- 3.0519 Notched fatigue strength at room temperature for plate at two interstitial levels in annealed and solution treated and aged conditions, Table 3.0519.
- 3.05110 Stress range diagram for notched specimens of mill annealed plate tested at room temperature, Figure 3.05110.
- 3.05111 Stress range diagram for specimens of solution treated and aged plate tested at room temperature, Figure 3.05111.
- 3.05112 Stress range diagram for notched specimens of solution treated and aged plate tested at room temperature, Figure 3.05112.
- 3.05113 Stress range diagram for smooth specimens of solution treated and aged plate tested at room temperature, Figure 3.05113.
- 3.05114 Smooth and notch fatigue strength of annealed and of solution treated and aged plate, Table 3.05114.
- 3.05115 Smooth and notched fatigue strength of annealed plate and solution treated and aged plate and sheet at room temperature, Table 3.05115.
- 3.05116 Smooth and notch fatigue strength of annealed and of solution treated and aged sheet tested at room temperature and 450F, Table 3.05116.
- 3.05117 Smooth and notch fatigue strength of annealed sheet tested at room temperature, Table 3.05117.
- 3.05118 Rotating beam fatigue life curve for three heat treated conditions of bar tested in simulated human body environments, Figure 3.05118.
- 3.052 Fatigue crack growth rates.
- 3.0521 General. The lack of standardization in this field of testing often makes meaningful comparison among the results from different investigators essentially impossible. However, the published fatigue crack growth data

for this alloy are derived from reasonably consistent experimental techniques so that certain general observations are possible.

Results from one investigation on forged bar (30) show that the fatigue growth rates in air for mill annealed and for solution treated and aged material are essentially the same at low and intermediate ΔK levels. However, as might be expected from its lower K_{Ic} the rate is more rapid for the solution treated and aged condition at high ΔK levels (compare Figures 3.0523 and 3.0524). In contrast, data from another investigation (36) do not clearly reveal substantial differences between a variety of heat treatments applied to plate, including mill annealing and solution treating and aging (Figure 3.05213).

The available information does not indicate any significant effect of relative humidity (Figures 3.0523 and 3.0524) or distilled water (Figures 3.0528 and 3.0529) on the crack growth rates for either the mill annealed or the solution treated and aged conditions. Sodium chloride solutions including those intended to simulate human body environments increase the crack propagation rates for both mill annealed and solution treated and aged conditions (Figures 3.0528, 3.0529 and 3.0522). It should be noted that similar environments have no effect on the smooth fatigue strength (see Figure 3.05119). Beta annealed material appears to behave the same in 3.5 NaCl as in air (Figure 3.05210).

The crack propagation rate for annealed material appears to be essentially the same at -65F, R.T. and 300F (compare Figures 3.0524, 3.0525 and 3.0527). On the other hand, the crack propagation rate of the solution treated and aged condition decreases with increasing temperature in the same range (compare Figures 3.0523, 3.0525 and 3.0526).

- 3.0522 Effect of simulated human body environments on fatigue crack propagation rates for annealed sheet, Figure 3.0522.
- 3.0523 Fatigue crack growth rates in humid air for solution treated and aged specimens from a forging, Figure 3.0523.
- 3.0524 Fatigue crack growth rates in humid air for annealed forging, Figure 3.0524.
- 3.0525 Fatigue crack growth rates at 300F for annealed forging and solution treated and aged specimens from forging, Figure 3.0525.
- 3.0526 Fatigue crack growth rates at -65F for solution treated and aged specimens from forging, Figure 3.0526.
- 3.0527 Fatigue crack growth rates at -65F for annealed forging, Figure 3.0527.
- 3.0528 Fatigue crack growth rates for annealed plate in air and in salt water, Figure 3.0528.
- 3.0529 Fatigue crack growth rates for beta processed solution treated and aged plate tested in air, distilled water and salt water, Figure 3.0529.
- 3.05210 Fatigue crack growth rates for beta annealed plate in air and salt water, Figure 3.05210.
- 3.05211 Fatigue crack growth rates at various temperatures for annealed plate, Figure 3.05211.
- 3.05212 Fatigue crack growth rates for specimens cut from plate and given two annealing treatments, Figure 3.05212.
- 3.05213 Average fatigue crack growth rates for plate given several heat treatments and tested in laboratory air, Figure 3.05213.
- 3.05214 Fatigue crack growth rates for annealed plate at several R ratios tested in laboratory air, Figure 3.05214.
- 3.06 Elastic Properties
- 3.061 Poisson's ratio.
- 3.062 Modulus of elasticity at room and elevated temperatures, Figure 3.062.

4. FABRICATION

4.01 Forming

- 4.011 General. Cold working operations are difficult because

of the high loads required and the large amounts of springback encountered. However, cold forming is capable of producing satisfactory parts. Hot forming may be carried out at temperatures up to 1500F, however, above 1100F surface oxidation and interstitial contamination are problems and parts will require surface removal by machining or etching. Hot sizing may be used to creep form parts in metal dies at temperatures between 1000 and 1300F for times between 5 and 20 minutes. When using this process attention should be given to the possibility of interstitial contamination. Hot sizing of solution treated parts may be combined with aging which will start at temperatures above about 500F. More detailed information on forming may be obtained from (42) (57).

4.012 Forging.

4.0121

General. Generally, the alloy is forged in the alpha + beta field at temperatures between 1550 and 1700F. The lower limit is set by workability and the upper limit by the beta transus which varies somewhat with the composition. Increasing amounts of work in the alpha + beta field tend to increase the strength of solution treated and aged material and consequently reduce fracture toughness.

Working primarily within the beta field reduces the energy requirements but results in a transformed beta structure that is frequently associated with reduced tensile elongation and reduction in area. However, it has been reported (58) that beta worked material has improved resistance to hot salt corrosion and improved fracture toughness. Claims for increased fracture toughness are based on a small amount of data from a mixture of fracture toughness tests. None of the available toughness data conforms to the ASTM E 399 K_{Ic} specification. Results from precracked Charpy tests, (Table 4.0122) do not indicate any substantial toughness improvement except for material solution treated at 1525F and aged at 1100F. If insufficient work in the beta field is provided, the tensile properties may be relatively low. It is sometimes difficult to provide sufficient deformation in certain sections of some forgings (e.g. the wall in Table 4.0124) and the design should provide for removal of such "dead" areas during finish machining. Excessive dwell in the beta field in the absence of work will cause rapid grain growth and avoidance of this effect can complicate the forging operation. A detailed discussion of beta forging and precautions is given in (58).

If press speeds are sufficiently reduced and heated dies are employed, advantage may be taken of creep during the forging process (Figure 4.0125) which greatly reduces the press forces and permits better shape definition and dimensional control. This process is called isothermal creep forging. It has the disadvantage that die temperatures in the order of 1700F are required and the dies themselves are subject to creep. To minimize this creep very expensive high temperature alloy dies are used (35)(59). Insufficient forging experience has been gained to assess the life of these dies and the economic feasibility of the process (60).

- 4.0122 Tensile properties and precracked Charpy values for alpha + beta and for beta forged disks, Table 4.0122.
- 4.0123 Effect of upset deformation for beta forging on room temperature tensile properties, Table 4.0123.
- 4.0124 Effect of forging temperatures on room temperature tensile properties of landing gear wheel forging, Table 4.0124.
- 4.0125 Effect of upset temperature and press speed on flow stress, Figure 4.0125.
- 4.0126 Tensile properties at room temperature of isothermally forged and heat treated nose wheel, Table 4.0126.

4.02 Machining and Grinding

Refer to Machinability Data Center, Metcut Research Associates, 390 Rosslyn Drive, Cincinnati, Ohio 45209.

- 4.03 Joining

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

	Ti	4.031
6	Al	4.0311
6	V	
2	Sn	

Ti-6-6-2

Welding.

General. Welding of this alloy required careful attention to ensure adequate fracture toughness in the weldment. Generally, an experimental program tailored to the specific application is desirable as an aid to establishing the proper welding procedures.

The beta stabilization of this alloy is sufficient that transformation hardening will occur during the cooling of weldments and consequently the ductility and fracture toughness of the weld metal and heat affected zone may be below that of the parent metal. Solution treating and aging of welds leads to brittle behavior and should be avoided. GTA, GMA, plasma arc, and EB welding processes have been investigated and all are capable of producing weld metal having tensile strength somewhat higher than annealed parent metal (e.g. Table 4.0312). Inert gas protection is essential to avoid interstitial contamination. Alpha filler metal will produce weld metal of higher toughness than matching filler (Table 4.0313). A postweld heat treatment of from 1200 to 1400F reduces the yield strength and appears to improve the fracture toughness of the weld metal (Table 4.0313). The plane strain fracture toughness data available related only to the fusion zone. Older data on center cracked panels indicate that the crack strength of the heat affected zone is low even when alpha filler is used in conjunction with a postweld heat treatment (Table 4.0314). Results from an investigation of electron beam welds indicate lower toughness in the heat affected zone than in the parent metal (Table 4.0315). A postweld heat treatment did not raise the heat affected zone toughness.

Conventional fatigue tests on weld metal produced with different fillers and by different processes indicate that those welding conditions yielding the highest yield strength (matching filler and no postweld heat treatment) produce the highest fatigue strength. None of the postweld heat treatments produce fatigue strengths as high as mill annealed plate (compare Figures 4.0316 and 4.0317 with Figure 3.0511 and Table 3.05115).

- 4.0312 Tensile properties at room temperature for welds made by several processes with matching filler, Table 4.0312
- 4.0313 Tensile properties and plane strain fracture toughness for GTA weld metal from several fillers, Table 4.0313.
- 4.0314 Crack strength of TIG welded sheet using several filler wires, Table 4.0314.
- 4.0315 Plane strain fracture toughness of the heat affected zone of electron beam welds, Table 4.0315.
- 4.0316 Charpy impact energy for sheet weldments made with two fillers and given different heat treatments, Table 4.0316.
- 4.0317 Fatigue strength of auto GTA welds with matching filler given postweld heat treatments, Figure 4.0316.
- 4.0318 Fatigue strength for auto GTA welds made with different fillers, Figure 4.0317.
- 4.0319 Fatigue strength for several different welds made in annealed plate with matching filler, Figure 4.0318.

4.04 Surface Treatment

4.041 General. Resistance to wear and abrasion can be improved by coatings of Ni or Cr. Electroplating is difficult probably because of the tightly adherent oxide film. Electroless Ni has been successfully applied to the alloy using diffusion hardening treatments which substantially increase the plate depth (Figure 4.042) and increase the wear resistance as measured with a modified McMillan wear tester (Figure 4.043). However, the room temperature tensile strength of solution treated and aged material decreases rapidly with diffusion bond temperature above about 1200F. A recommended best compromise between wear characteristics and loss of tensile strength in the solution treated and aged condition is bonding at 1350F (27). The electroless Ni plate does appear to reduce the smooth specimen fatigue life of annealed material (Figure 4.045).

- 4.042 Effect of diffusion bonding temperature on electroless Ni plate depth, Figure 4.042.
- 4.043 Effect of diffusion bond temperature applied to electro-

- less Ni plate on the failure time in a modified McMillan wear tester, Figure 4.043.
- 4.044 Effect of diffusion bonding temperature on room temperature tensile and impact properties of electroless nickel plated stock heat treated to two strength levels, Figure 4.044.
- 4.045 Effect of various fretting resistant coatings on fatigue life of annealed bar, Figure 4.045.

AMS	Heat Treatment	Ref.	Form
4971A	Annealed or solution treat and age	49	Bars, forgings, wire flash welded rings and stock for forgings or for flash welded rings.
4978A	Annealed	50	As above
4979	Solution treat and age	51	As above
4936	Annealed	52	Extruded bars, tubes, shapes and stock for flash welded rings.
4918C	Annealed	53	Sheet strip and plate.

TABLE 1.031 AMS SPECIFICATIONS

Source	(1) (49 thru 53)	
Alloy	6Al-6V-2Sn	
	Percent	
	Min.	Max.
Aluminum	5.0	6.0
Vanadium	5.0	6.0
Tin	1.5	2.5
Iron	0.35	1.0
Copper	0.35	1.0
Oxygen	-	0.20
Carbon	-	0.05
Nitrogen	-	0.04
Hydrogen	-	0.015
Titanium	Balance	

TABLE 1.041 PRODUCERS AND AMS SPECIFIED COMPOSITION

NONFERROUS ALLOYS

Source	AMS Specifications (49 thru 53)			
Condition	Anneal		Solution Treat and Age	
Heat Treat	1275-1325F 2 hr., cool as required	1300-1500(2) 2 hr., cool as required	1625-1675F, 1 hr., WQ + 1035-1065F, 4 hr., AC	1575-1650F (2) 1 hr., WQ + >1000F, 4 hr., AC
Specification	AMS 4971A	AMS 4978A AMS 4936 AMS 4918C (1)	AMS 4971A	AMS 4979

(1) Hold at temperature 20 min. per inch of thickness but not less than 10 min.
 (2) Hold at a temperature within this range to + 25F.

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

TABLE 1.052 AMS SPECIFIED HEAT TREATMENTS

Source	(1, Table III)		
Alloy	Ti-6Al-6V-2Sn		
Form	Flat Rolled <0.125 in	Flat Rolled >0.125 in	Bar, Forgings & Extrusions
Stress Relief	1000 to 1200F, 1 to 4 hr., A.C.	1000 to 1200F, 1 to 4 hr., A.C.	1000 to 1200F, 1 to 4 hr., A.C.
Anneal	1400F, 4 hr, F.C. to 1100F, A.C.	1400F, 4 hr, F.C. to 1100F, A.C.	1400F, 4 hr, A.C.
Solution Treat	1500 to 1600F, 5 to 15 min. W.Q.	1550 to 1625F, 1/2 hr., W.Q.	1550 to 1650F, 1 hr. W.Q.
Age	1050 to 1150F 4 hr., A.C.	1050 to 1150F 4 hr., A.C.	950 to 1100F 4 to 12 hr., A.C.

TABLE 1.053 PRODUCERS RECOMMENDED HEAT TREATMENTS.

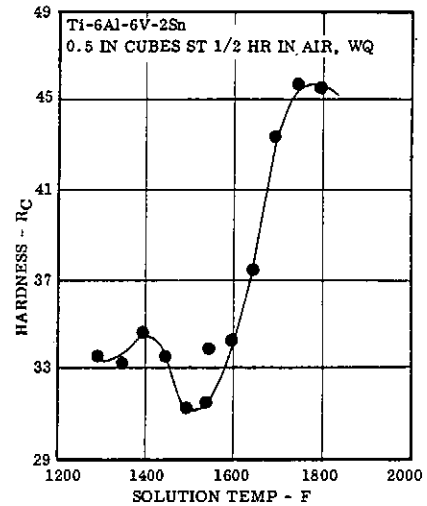


FIG. 1.062 EFFECT OF SOLUTION TEMPERATURE ON HARDNESS. (29, Fig. 1)

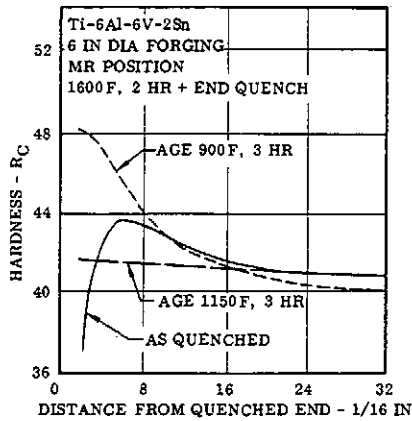


FIG. 1.061 JOMINY HARDENABILITY CURVE AND HARDNESS DISTRIBUTION AFTER AGING. (54, Fig.1)

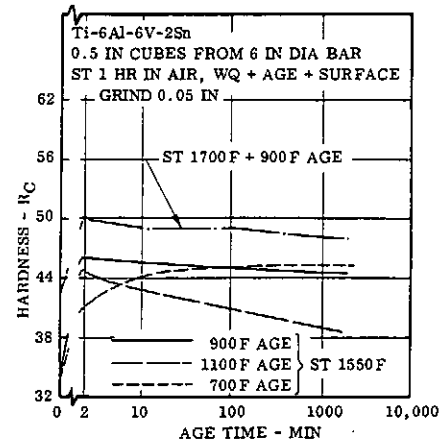


FIG. 1.063 HARDNESS AS FUNCTION OF AGING TIME AND TEMPERATURE FOR TWO SOLUTION TEMPERATURES. (28, Fig. 2)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

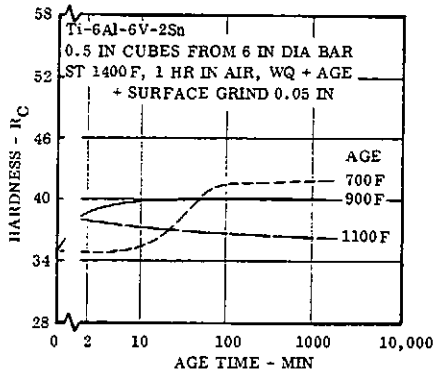


FIG. 1.064 HARDNESS AS FUNCTION OF AGING TEMPERATURE AND TIME. (28, Fig. 2)

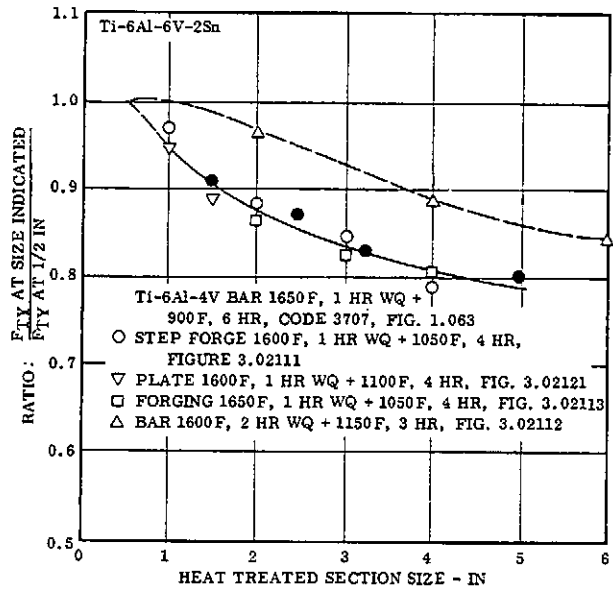


FIG. 1.0912 HARDENABILITY OF VARIOUS FORMS OF ALLOY.

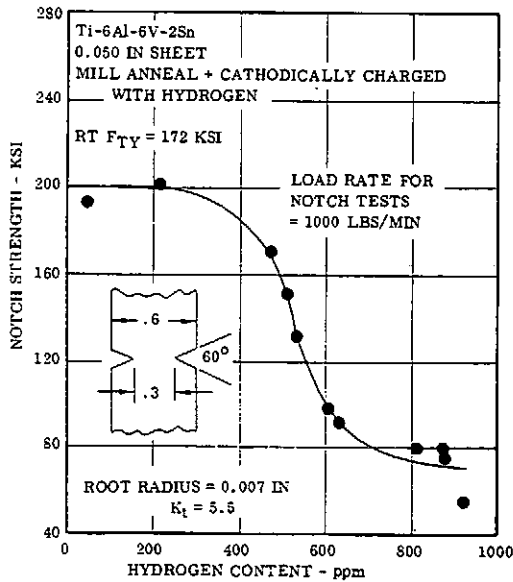


FIG. 1.091 NOTCH TENSILE STRENGTH OF ANNEALED SHEET AT ROOM TEMPERATURE AS INFLUENCED BY HYDROGEN CONTENT. (41, Fig. 3)

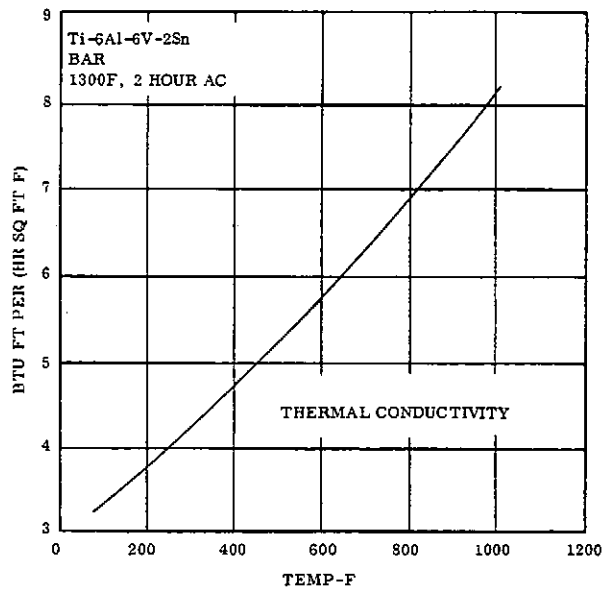


FIG. 2.013 THERMAL CONDUCTIVITY (1)

NONFERROUS ALLOYS

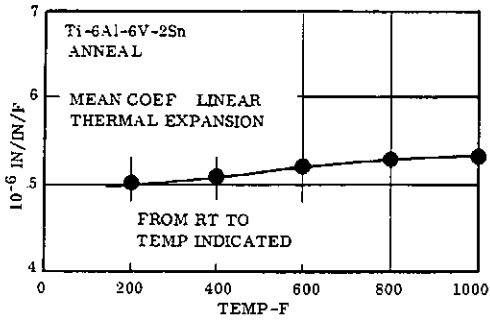


FIG. 2.014 THERMAL EXPANSION (1)

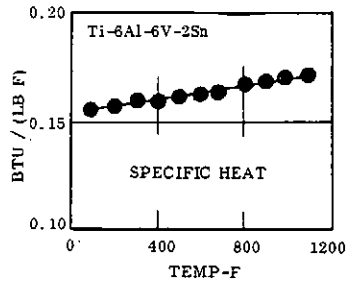


FIG. 2.015 SPECIFIC HEAT (1)

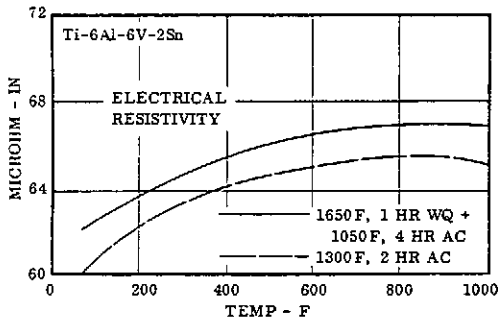


FIG. 2.0221 ELECTRICAL RESISTIVITY. (1)

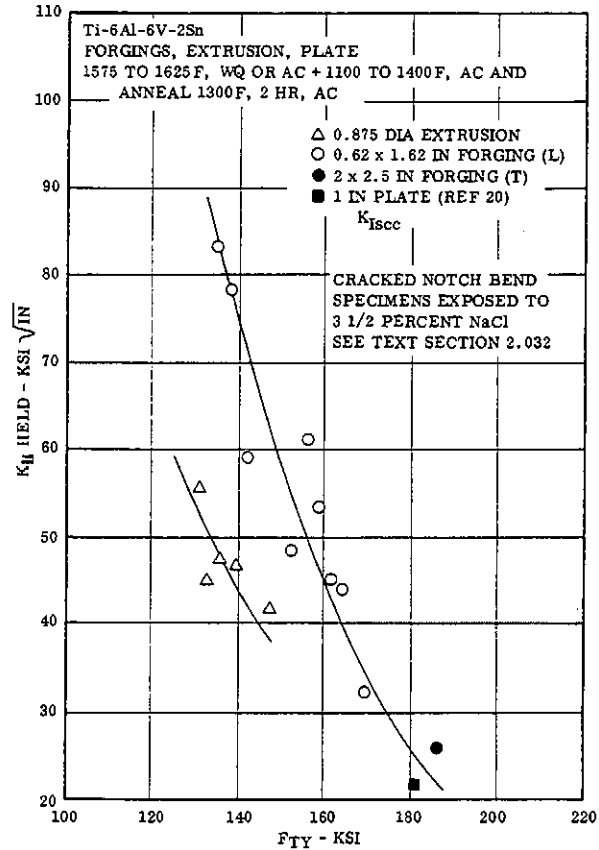


FIG. 2.034 EFFECT OF YIELD STRENGTH LEVEL ON DELAYED FAILURE CHARACTERISTICS IN SALT WATER. (20)(21)

Ti
6 Al
6 V
2 Sn

Ti-6-6-2

Source	(18)				
Alloy	Ti-6Al-6V-2Sn				
Form	0.120 inch sheet				
Condition	Expose Temp-F	Cracks Observed		No Cracks Observed	
		(1) σ_c / F_{ty}	Time at Load-hr.	σ_c / F_{ty}	Time at Load-hr.
1350F, 1/4 hr FC - $F_{ty} = 122$ Ksi	650	0.30	50	0.30	18
1550F, 5 min WQ + 1100F, 4 Hr AC $F_{ty} = 134$ Ksi	650	0.22	10	0.16	10
1350F, 1/4 hr FC - $F_{ty} = 125$ Ksi	550	0.47	18	0.33	65
1550F, 5 min WQ + 1100F, 4 Hr AC $F_{ty} = 137$ Ksi	550	0.58	180	(0.48)(2)	(350)
				< 0.58	180

(1) 0.120 Smooth specimen exposed at stress σ_c
 (2) Cyclic exposure: heat in 10 to 15 min; hold 3 hrs; cool in 45 to 60 min.

TABLE 2.035 RESULTS OF ELEVATED TEMPERATURE SOLID SALT STRESS CORROSION TEST OF SHEET

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

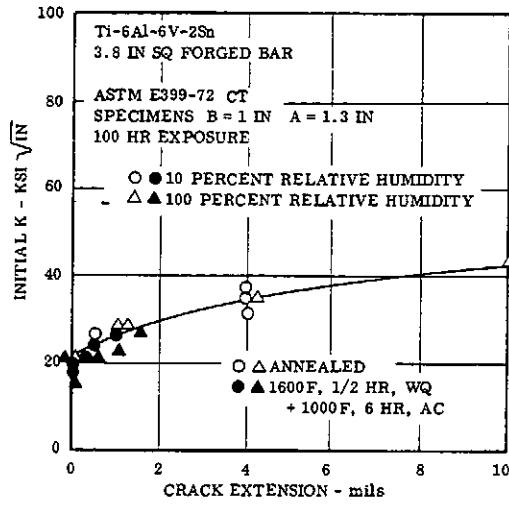


FIG. 2.036 SUSTAINED LOAD CRACK EXTENSION IN AIR. (30, Tables 7, 8)

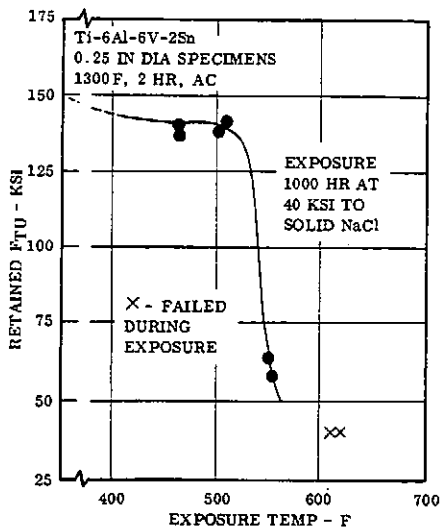


FIG. 2.037 RESIDUAL TENSILE STRENGTH AT ROOM TEMPERATURE FOLLOWING ELEVATED TEMPERATURE STRESS EXPOSURE TO SOLID SALT. (45, Fig. 5)

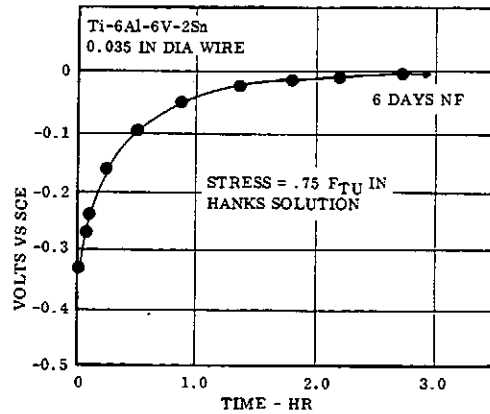


FIG. 2.038 POTENTIAL TIME CURVES FOR STRESSED WIRE IN SIMULATED HUMAN BODY ENVIRONMENT. (26, Fig. 3)

REVISED: DECEMBER 1975

NONFERROUS ALLOYS

Alloy		Ti-6Al-6V-2Sn					
Form		Bars, forgings and rings					
Condition		Solution treated and aged					
AMS		4979 and 4971A					
As Received Size - in. (1)	Heat Treated Size - in. (2)	F _{tu} - ksi	F _{ty} - ksi	e-percent(4)		RA-percent	
				L	T (3)	L	T(3)
≤ 2	≤ 1	175	160	8	6	20	15
	>1 thru 2	<u>170</u>	<u>155</u>	8	6	20	15
> 2 thru 3	≤ 1	170	160	8	6	20	15
	>1 thru 2	165	155	8	6	20	15
	>2 thru 3	<u>155</u>	<u>145</u>	8	6	20	15
> 3 thru 4	≤ 1	165	155	8	6	20	15
	> 1 thru 2	160	150	8	6	20	15
	> 2 thru 3	155	145	8	6	20	15
	> 3 thru 4	<u>150</u>	<u>140</u>	8	6	20	15

(1) Nominal diameter or distance between parallel sides.
(2) AMS 4979 gives As Received Size same as Heat Treated Size. Values underlined apply to both AMS 4979 and 4971A. Other values apply only to AMS 4971A.
(3) Transverse requirements do not apply if a specimen ≥ 2-1/2 in long cannot be abstracted.
(4) In 4D or 2 inches.

Ti
6 Al
6 V
2 Sn

Ti-6-6-2

TABLE 3.011 AMS SPECIFIED MINIMUM MECHANICAL PROPERTIES FOR BARS, FORGINGS AND RINGS IN SOLUTION TREATED AND AGED CONDITION

Alloy		Ti-6Al-6V-2Sn				
Condition		Annealed				
Form		Extrusions AMS 4936			Bars, Forgings and Rings (AMS 4973A)	
Size - in (1)		≤ 1.5	> 1.5 thru 3	> 3 thru 4	≤ 2	> 2 thru 4
F _{tu} (min) - ksi		150	145	140	150	145
F _{ty} - ksi		140 to 165	135 to 160	130 to 155	140 to 165	135 to 160
e - L (min)-percent (2)		10	10	10	10	10
e - T (min)-percent		8	8	8	8	8
RA - L (min)-percent		20	20	20	20	15
RA - T (min)-percent		15	15	15	15	15

(1) Nominal diameter or distance between parallel sides.
(2) In 4D or 2 inches

TABLE 3.012 AMS SPECIFIED MECHANICAL PROPERTIES FOR ANNEALED EXTRUSIONS AND BARS, FORGINGS AND RINGS

Alloy		Ti-6Al-6V-2Sn			
Condition		Annealed			
Form		AMS 4919C Sheet, strip and plate			
Size - in.		< 0.025	≥ 0.025 but < 0.1875	≥ 0.1875 thru 2.000	≥ 2.000 thru 4.000
F _{tu} (min) - ksi		155	150	150	145
F _{ty} - ksi		145-170	145-170	140-165	135-160
e (4D) - percent					
L (min)		8	10	10	8
T (min)		6	8	8	6

TABLE 3.013 AMS SPECIFIED MECHANICAL PROPERTIES FOR ANNEALED SHEET, STRIP AND PLATE

Source		(1)									
Alloy		Ti-6Al-6V-2Sn									
Form		Bar and Forging Stock (STA)									
Condition		1550F, to 1650F, 1 Hr. WQ + 950 to 1100F, AC									
Original Thickness - Inch		≤ 1		> 1 to 2		> 2 to 3		> 3 to 4			
Heat Treated Thickness - In		≤ 1	≤ 1	> 1 to 2	≤ 1	> 1 to 2	> 2 to 3	≤ 1	> 1 to 2	> 2 to 3	> 3 to 4
F _{tu} (min) - ksi		175	175	170	170	165	160	165	160	155	150
F _{ty} (min) - ksi		160	160	155	160	155	150	155	150	145	140
e (4D) - percent											
L		8	8	8	8	8	8	8	8	8	8
T		6	6	6	6	6	6	6	6	6	6
RA - percent											
L		20	20	20	20	20	20	20	20	20	20
T		15	15	15	15	15	15	15	15	15	15

TABLE 3.014 PRODUCERS GUARANTEED TENSILE PROPERTIES OF SOLUTION TREATED AND AGED BAR AND FORGING STOCK

Ti
6 Al
6 V
2 Sn

Ti-6-6-2

Source	(1)		
Alloy	Ti-6Al-6V-2Sn		
Form	Bar		
Condition	Annealed (see Table 1.053)		
Thickness	< 2 inch	> 2 to 4	> 4 to 6
F _{tu} (min) - ksi	150	140	135
F _{ty} (min) - ksi	140	130	125
e (4D) min percent			
L	10	8	8
T	8	6	6
RA - min percent			
L	20	15	15
T	15	12	12

TABLE 3.015 PRODUCERS GUARANTEED TENSILE PROPERTIES OF ANNEALED BAR

Source	(1)		
Alloy	Ti-6Al-6V-2Sn		
Form	0.187 inch Sheet		
Condition (1)	Anneal	Solution Treated	Sol Treat + Age
F _{tu} (min) - ksi	155	-	170
F _{ty} (min) - ksi	145	130 (max)	160
e (2 in) min percent			
< 0.015 inch	6	6	-
0.015 to 0.020 in	8	8	-
> 0.020 inch	10	10	-
> 0.020 inch	-	-	3
0.020 to 0.032 in	-	-	4
> 0.032 to 0.049 in	-	-	5
> 0.049 inch	-	-	6

(1) For recommended heat treatments, see Table 1.052

TABLE 3.018 PRODUCERS GUARANTEED TENSILE PROPERTIES OF ANNEALED SOLUTION TREATED AND SOLUTION TREATED AND AGED SHEET

Source	(1)		
Alloy	Ti-6Al-6V-2Sn		
Form	Extrusions		
Condition (1)	Annealed	Solution Treat + Age	
Size (2)	All	< 1/2	> 1/2 thru 3/4
F _{tu} (min) - ksi	145	170	165
F _{ty} (min) - ksi	135	160	155
e (4D) min percent	8	6	6
RA - min percent	12	12	12

(1) See Table 1.053

(2) Maximum inscribed circle diameter

TABLE 3.016 PRODUCERS GUARANTEED TENSILE PROPERTIES OF SOLUTION TREATED AND AGED EXTRUSION

Source	(1)					
Alloy	Ti-6Al-6V-2Sn					
Form	Plate					
Condition (2)	Annealed		Solution Treated	Solution Treat + Age		
Thickness	> 0.187 to 2 in	> 2 < 4 in	Any	> 0.187 to 1.5 in	> 1.5 to 2.5 in	> 2.5 to 4 in
F _{tu} (min) - ksi	150	135	150	170	160	150
F _{ty} (min) - ksi	140	145	130(1)	160	150	140
e (2 in) - percent						
L	10	8	10	8	6	6
T	8	6	10	8	6	6
RA - percent						
L	20	20	20	15	15	15
T	15	15	15	15	15	15

(1) Guaranteed Maximum

(2) See Table 1.053

TABLE 3.017 PRODUCERS GUARANTEED TENSILE PROPERTIES OF ANNEALED SOLUTION TREATED AND SOLUTION TREATED AND AGED PLATE

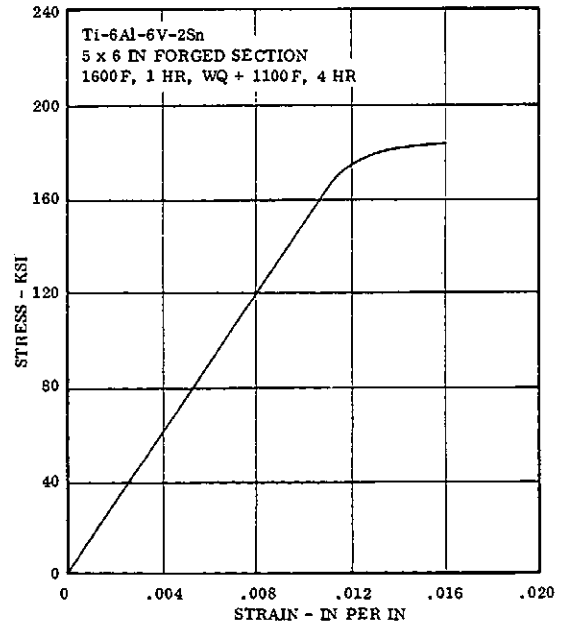


FIG. 3.0211 STRESS-STRAIN CURVE IN TENSION FOR FORGING (SPECIMENS HEAT TREATED). (2)

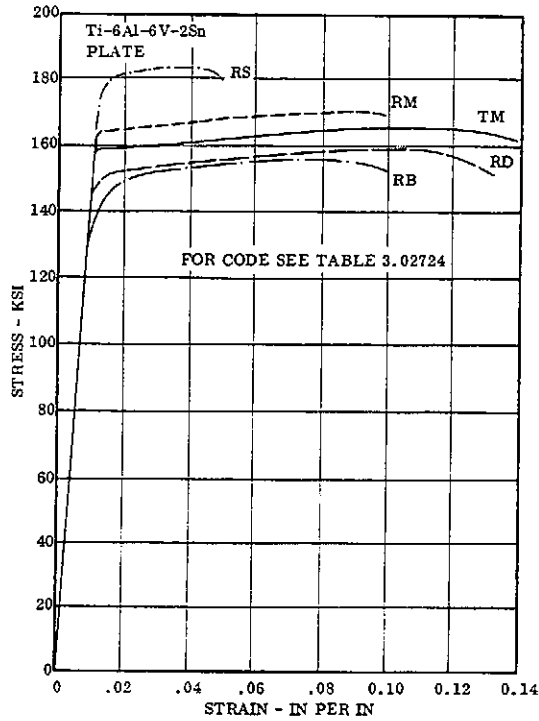


FIG. 3.0212 STRESS STRAIN CURVES FOR PLATE IN SEVERAL CONDITIONS OF HEAT TREATMENT. (36, p. 85)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

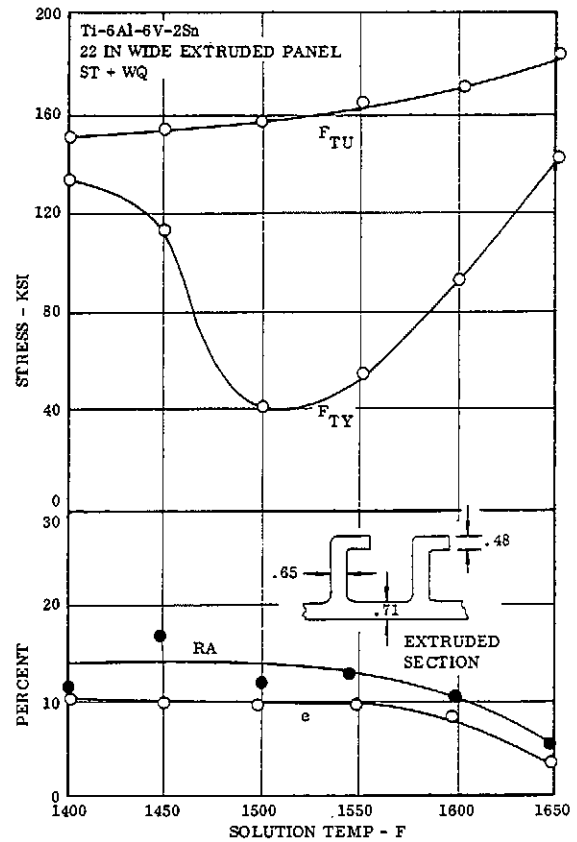


FIG. 3.0214 EFFECT OF SOLUTION TEMPERATURE ON AS QUENCHED TENSILE PROPERTIES OF EXTRUSION. (46, Fig. 22)

Source	(31, Table III)		
Alloy	Ti-6Al-6V-2Sn		
Form	Investment Cast Specimens		
Condition	As Cast	1600F, 1 hr WQ + 1100F, 1 hr AC	1800F, 1 hr WQ + 1200F, 1 hr AC + 1100F, 4 hr AC
F _{tu} - ksi	154	167	189
F _{ty} - ksi	141	158	(1)
e - percent	8	4	1.2
RA - percent	18	10	3

(1) Broke before 0.2 percent yield

TABLE 3.0213 TENSILE PROPERTIES OF INVESTMENT CAST SPECIMENS GIVEN SEVERAL HEAT TREATMENTS

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

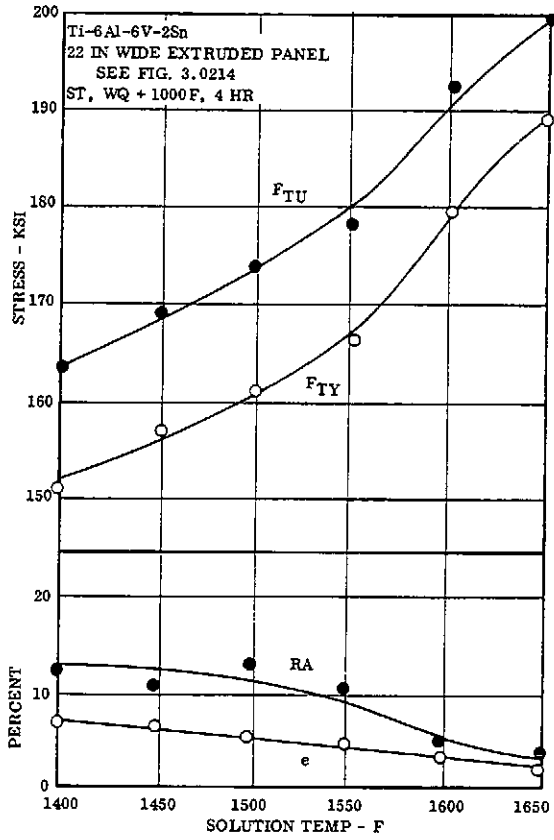


FIG. 3.0215 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF 1000F AGED EXTRUSION. (46, Fig. 23)

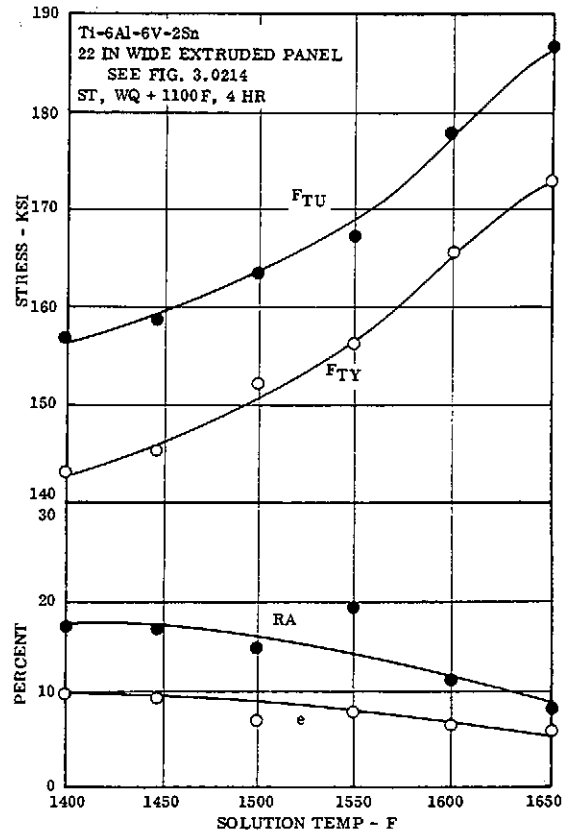
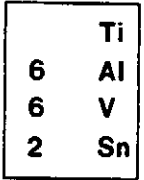


FIG. 3.0216 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF 1100F AGED EXTRUSION. (46, p. 24)

NONFERROUS ALLOYS



Ti-6-6-2

Source	(25, Table III)								
Alloy	Ti-6Al-6V-2Sn								
Form	Extrusion at 1675F to 8-3/4 in OD x 11-3/4 in ID Cylinders								
Condition	St. 1600F, 3 hr WQ								
Age	1300F, 6 hr			1000F, 4 hr					
Heat (1)	A			B			C		
Position (2)	OD	MW	ID	OD	MW	ID	OD	MW	ID
F _{tu} - ksi (L)	154	152	155	209	186	200	176	162	177
F _{tu} - ksi (T)	-	153	154	198	192	202	179	171	177
F _{ty} - ksi (L)	143	143	145	202	181	195	166	149	165
F _{ty} - ksi (T)	143	144	144	193	187	198	161	158	163
e - percent(L)	15	15	17	2	4	4	6	10	8
e - percent(T)	17	17	16	3	2	1	4	8	7
RA - percent(L)	34	37	44	6	9	8	13	21	15
RA - percent(T)	30	36	42	5	4	4	8	15	12

(1) For compositions see Table 3.02722
 (2) OD - outside, MW - midwall, ID - inside

TABLE 3.0217 TENSILE PROPERTIES FOR EXTRUDED CYLINDERS FROM THREE HEATS AGED AT TWO TEMPERATURES AND TESTED AT VARIOUS CROSSSECTIONAL LOCATIONS

Source	(3)		
Alloy	Ti-6Al-6V-2Sn		
Form	2-3/4 x 4 inch center section of test forging with heavy ribs and thin webs		
Condition	1650F, 2 hr, WQ + 1100F, 4 hr, AC		
Direction	L	T	ST
F _{tu} - ksi	166-185	174-194	175-192
F _{ty} - ksi	153-175	161-181	161-181
e (4D) - percent	10-12	6-8	6-10
RA - percent	20-29	17-25	14-20

TABLE 3.02110 VARIATION OF TENSILE PROPERTIES OF CENTER SECTION OF TEST FORGING WITH HEAVY RIBS AND THIN WEBS

Source	(24, Table 4)		
Alloy	Ti-6Al-6V-2Sn		
Form (2)	Extrusion at 1735F 85 percent red. to 3 in diameter bar		
Condition	ST 1600F, 1-1/2 hr WQ + age		
Direction (1)	L, O	L, MR	T
F _{tu} - ksi	166	166	158
F _{ty} - ksi	152	142	143
e - percent	26	20	19
RA - percent	45	39	38

(1) L, O - long outside, L, MR - long mid radius, T - trans.
 (2) For composition see Table 3.02722

TABLE 3.0218 TENSILE PROPERTIES OF SOLUTION TREATED AND AGED EXTRUDED BAR AT VARIOUS CROSSSECTIONAL LOCATIONS

Source	(2)								
Alloy	Ti-6Al-6V-2Sn								
Form	5 x 6 inch forged section								
Condition	1600F, 1 hr WQ + 1100F, 4 hr (specimens heat treated)								
Direction	Edge			Mid Radius			Center		
Direction	L	LT	ST	L	LT	ST	L	LT	ST
F _{tu} - ksi	175	179	178	168	174	174	159	162	164
F _{ty} - ksi	167	170	170	160	165	166	150	150	155
e (1 in) percent	9	10	10	12	10	10	15	13	11
RA - percent	24	28	28	32	27	34	43	42	40

TABLE 3.0219 TENSILE PROPERTIES IN VARIOUS LOCATIONS IN A FORGED SECTION

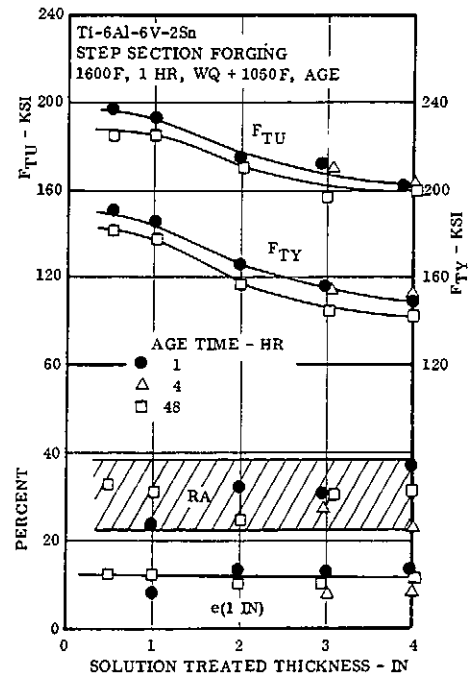


FIG. 3.02111 EFFECT OF SOLUTION TREATED SECTION SIZE AND AGE TIME ON TENSILE PROPERTIES OF FORGING (FORGED TO SOLUTION TREATED SIZE). (4)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

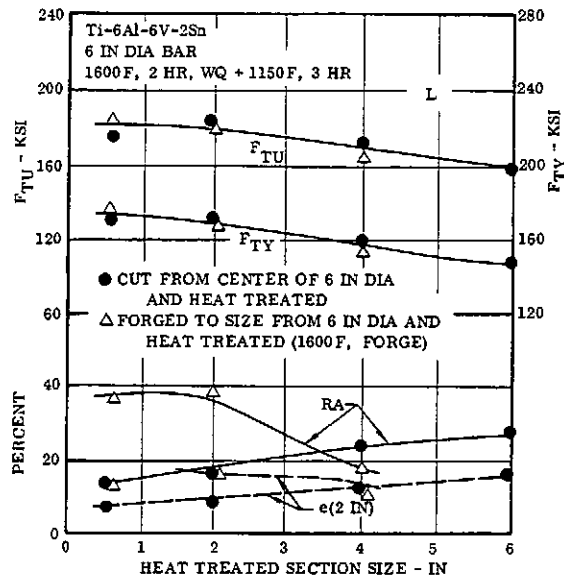


FIG. 3.02112 EFFECT OF HEAT TREATED SECTION SIZE ON TENSILE PROPERTIES OF SPECIMENS REMOVED FROM CENTER OF SOLUTION TREATED AND AGED BAR SECTIONS. (5)

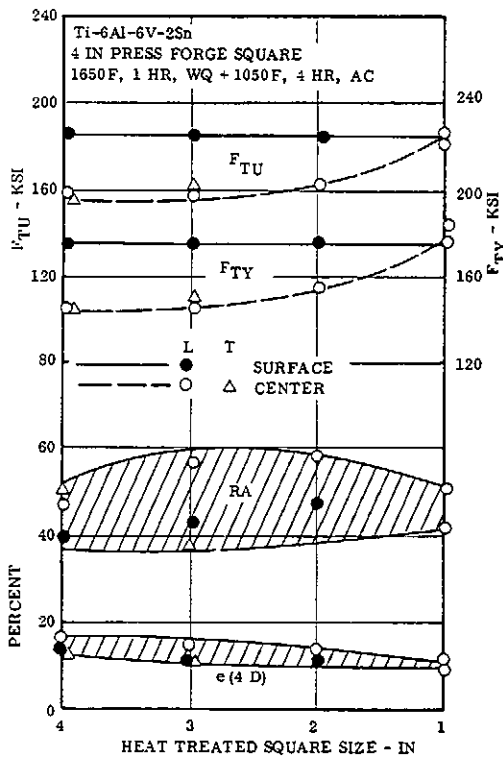


FIG. 3.02113 EFFECT OF HEAT TREATED SECTION SIZE ON TENSILE PROPERTIES OF SQUARE SECTIONS REMOVED FROM CENTER OF 4 INCH SQUARE PRESS FORGING. (1)

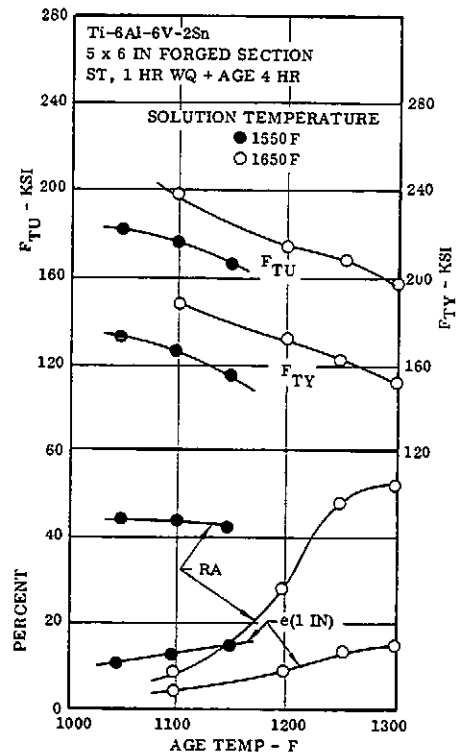
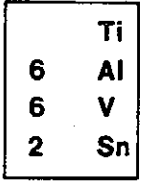


FIG. 3.02114 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF SPECIMENS CUT FROM FORGING AND SOLUTION TREATED AT TWO TEMPERATURES. (2)

NONFERROUS ALLOYS

Source	(4)											
Alloy	Ti-6Al-6V-2Sn											
Form	4 Inch Square Forged Bar (Specimens Heat Treated)											
Composition	0.11 O ₂ , 0.025C, 0.75 Fe						0.16 O ₂ , 0.023C, 0.73Fe					
Heat Treatment	1450F, 2 hr FC		1600F, 1 hr AC +1100F, 8 hr AC		1600F, 1 hr WQ + 1350F, 2 hr AC		1450F, 2 hr FC		1600F, 1 hr AC +1100F, 8 hr AC		1650F, 1 hr WQ +1350F, 2 hr AC	
Direction (1)	L	T	L	T	L	T	L	T	L	T	L	T
F _{TU} - ksi	147	147	143	141	142	151	150	150	150	150	152	153
F _{TY} - ksi	137	136	135	133	130	138	140	142	139	141	141	142
e (1 in)	20	20	20	14	18	14	20	16	19	14	17	17
RA percent	34	33	41	36	29	23	38	32	34	24	33	26
IE Charpy V ft-lbs	18	12	22	15	29	19	12	10	14	9	15	11

(1) Specimens removed from center of forging



Ti-6-6-2

TABLE 3.02115 TENSILE PROPERTIES OF FORGED BAR AT TWO INTERSTITIAL LEVELS

Source	(47, Table 4)							
Alloy	Ti-6Al-6V-2Sn							
Form	13 in dia. x 1.25 in thick hammer forged disk							
Forging temp-F	1665				1725			
Solution temp-F	1 hr. WQ + 1100F, 4 hr							
	1525	1650	Forge→WQ	1525	1650	1725	Forge→WQ	
F _{TU} - ksi (1)	178	193	188	176	195	200	195	
F _{TY} - ksi	170	184	180	166	183	190	190	
e - percent	13	8	10	14	9	5	7	
RA - percent	39	20	27	36	25	8	25	

(1) Specimens taken in tangential direction.

TABLE 3.02116 EFFECT OF FORGING AND QUENCH TEMPERATURE ON TENSILE PROPERTIES OF HAMMER FORGED DISKS

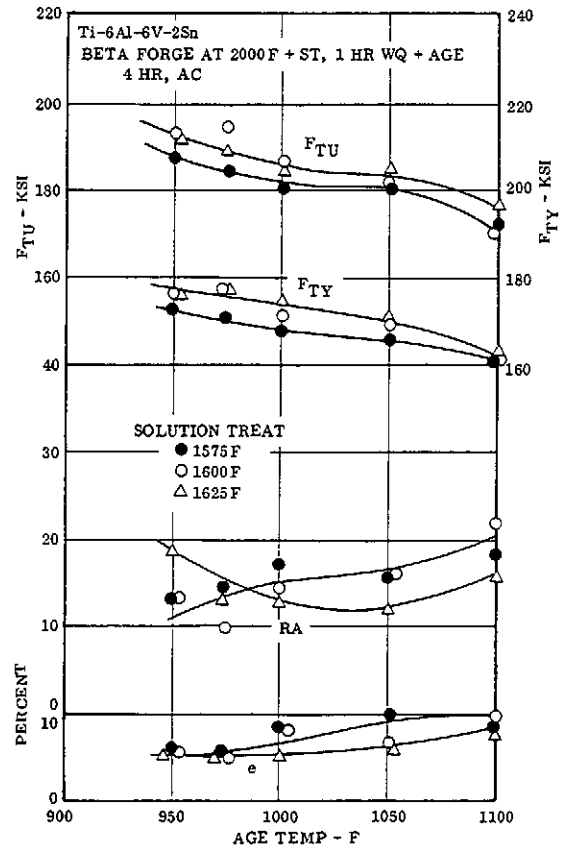


FIG. 3.02117 EFFECT OF AGE TEMPERATURE ON TENSILE PROPERTIES OF BETA FORGING SOLUTION TREATED AT VARIOUS TEMPERATURES. (23, Table 2)

NONFERROUS ALLOYS

REVISED: DECEMBER 1975

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

Source	(30, Table 3)	
Alloy	Ti-6Al-6V-2Sn	
Form	Forged bar 3.8 in sq.	
Condition	Annealed (as received)	1600F, 1/2 hr WQ + 1000F, 6 hr AC (1)
F _{TU} - ksi (2)	155	192
F _{TY} - ksi	149	184
e - percent	16	16
RA - percent	43	18
(1) Specimens heat treated		
(2) Longitudinal tests		

TABLE 3.02118 TENSILE PROPERTIES OF ANNEALED AND OF SOLUTION TREATED AND AGED SPECIMENS FROM FORGED BAR

Source	(1)							
Alloy	Ti-6Al-6V-2Sn							
Form	Bar							
Condition	Annealed				1650F, 1/2 hr WQ + 1050F, 1 hr AC			
140 to 150 hour exposure	None	600F 88 ksi	700F 40 ksi	800F 15 ksi	None	600F 125 ksi	700F 65 ksi	800F 45 ksi
Total creep deformation percent	-	0.45	0.32	0.30	-	0.75	0.48	0.76
F _{TU} - ksi	161	193	193	183	187	194	200	194
F _{TY} - ksi	153	161	168	175	182	192	184	181
e (1 in) percent	17	14	11	12	11	9	8	6
RA - percent	51	32	23	30	31	24	15	10

TABLE 3.02119 EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON TENSILE PROPERTIES OF ANNEALED AND SOLUTION TREATED AND AGED BAR

Source	(1)			
Alloy	Ti-6Al-6V-2Sn			
Form	1 inch forged bar			
Condition	1650F, 1/2 hr, WQ + 1050F, 1 hr			
150 hour creep exposure	None	750F 65 ksi	800F 55 ksi	850F 55 ksi
Plastic creep deformation percent	-	0.72	1.0	3.63
F _{TU} - ksi	194	196	205	202
F _{TY} - ksi	185	185	195	191
e (4D) - percent	9	8.5	7	8
RA - percent	39	37	21	24

TABLE 3.02120 EFFECT OF 150 HOUR EXPOSURE TO STRESS AND ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF FORGED BAR

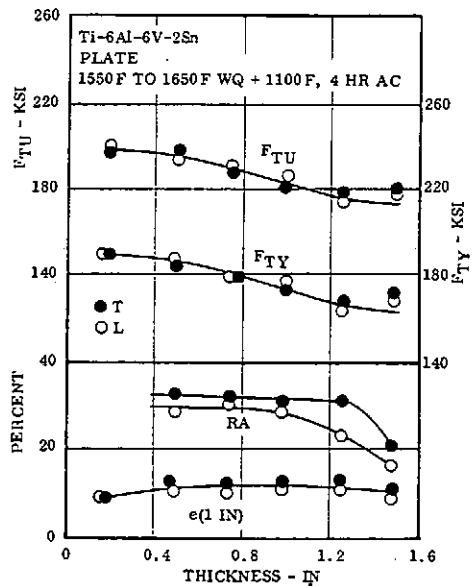


FIG. 3.02121 EFFECT OF THICKNESS ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED PLATE. (1)

NONFERROUS ALLOYS

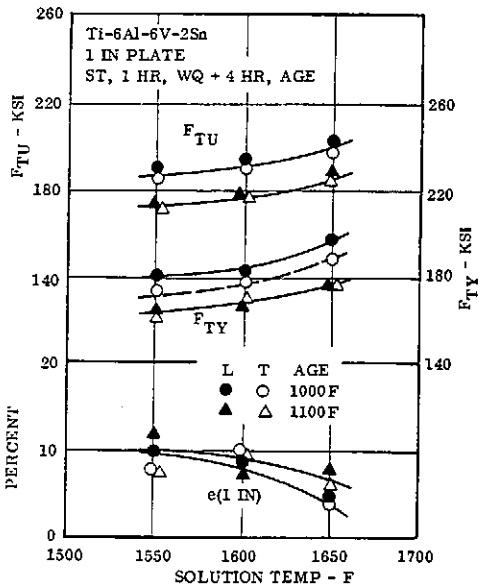
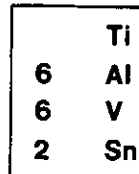


FIG. 3.02122 EFFECT OF SOLUTION TREATING AND AGING TEMPERATURES ON THE TENSILE PROPERTIES OF PLATE. (6)

Source	(42, Table 1-5:7)				
Alloy	6Al-6V-2Sn				
Form	3/4 in plate				
Exposure conditions at 25 ksi	Retained properties (T)				
Heat treat	Anneal 1300F, 2 hr				
Temp - F	Time - hr	F _{TU} - ksi	F _{TY} - ksi	e (in) percent	RA percent
No exposure		158	151	14	32
250	5000	160	154	17	32
350	5000	162	155	16	32
450	2500	166	159	14	35
650	1000	190	163	11	22
Heat treat	1800F, 1/2 hr AC + 1625F, 4 hr WQ + 1200F, AC				
No exposure		166	153	9	18
250	5000	178	166	7	7
350	2500	169	160	9	14
350	5000	170	161	7	9
450	2500	171	162	9	16
650	1000	185	165	7	11



Ti-6-6-2

TABLE 3.02124 EFFECT OF EXPOSURE TO STRESS AND TEMPERATURE ON RETAINED TENSILE PROPERTIES OF PLATE

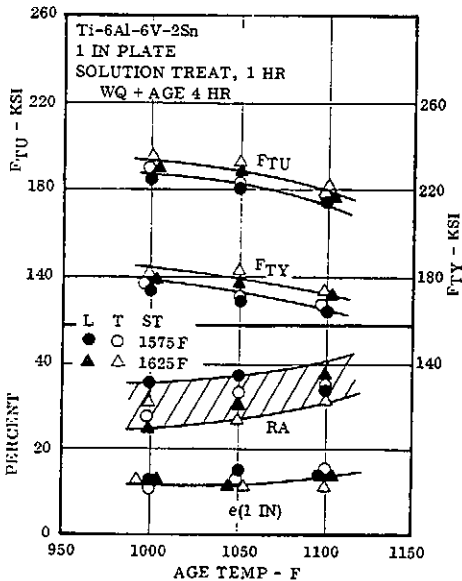


FIG. 3.02123 EFFECT OF AGING AND SOLUTION TREATING TEMPERATURE ON THE TENSILE PROPERTIES OF PLATE. (7)

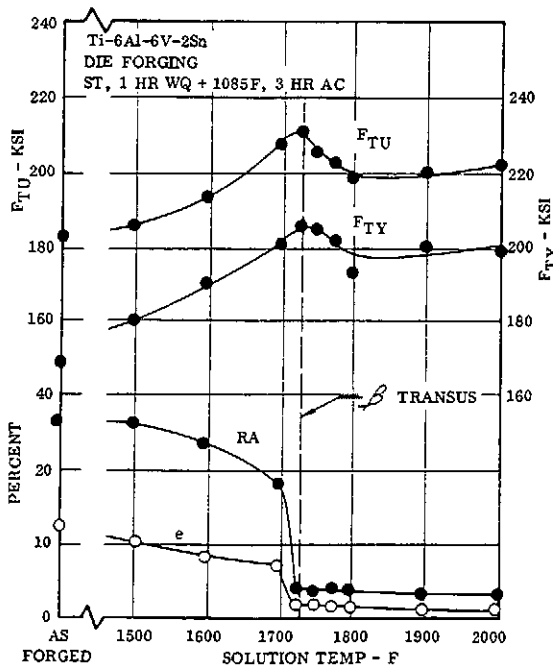


FIG. 3.02125 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF AGED SHEET.

(42, Fig. 1-5:15)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

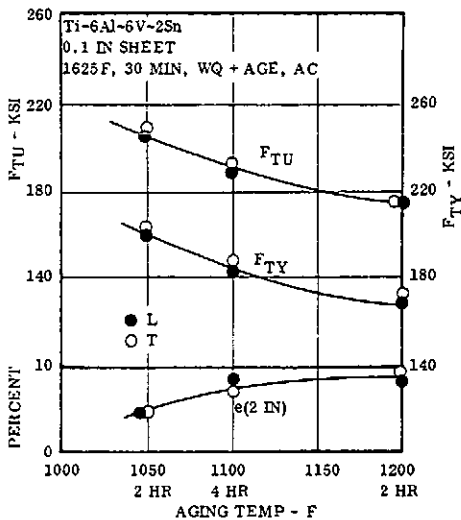


FIG. 3.02126 EFFECT OF AGING TEMPERATURE ON THE TENSILE PROPERTIES OF SHEET. (8)

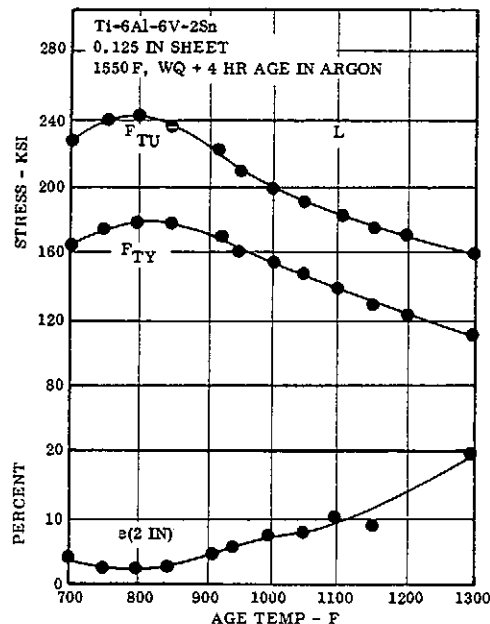


FIG. 3.02128 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF SHEET. (9)

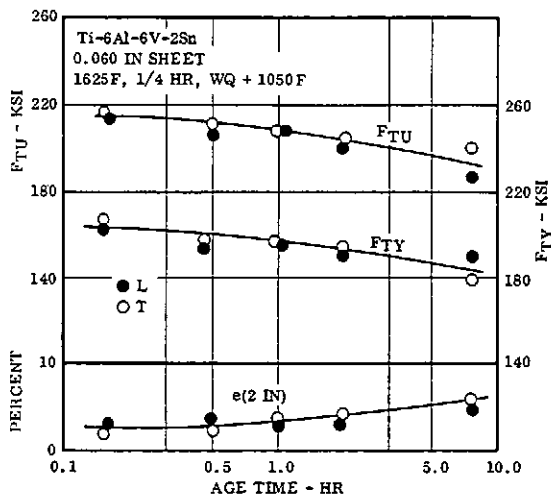


FIG. 3.02127 EFFECT OF AGING TIME ON TENSILE PROPERTIES OF SHEET. (1)

NONFERROUS ALLOYS

Source	(37, p. 3-10 and 3-9)						
Alloy	Ti-6Al-6V-2Sn						
Form	2 in Plate		1-1/2 in dia. bar		Large die forging		
Condition (1)(2)	A	B	C	A	B	A	B
F _{TU} - ksi	161	158	149	157	-	151	145
F _{TY} - ksi	157	150	139	153	-	144	138
e (1 in) percent	10	13	15	14	-	18	19
RA - percent	22	26	28	44	-	44	45
(1) A - mill anneal; B - 1675, 2 hr. AC, + 1600F, 1 hr. FC C - 1700F, 4 hr. AC + 1400F, 1 hr AC							
(2) Specimen blanks heat treated							

TABLE 3.02129 TENSILE PROPERTIES OF PLATE, BAR AND FORGINGS ANNEALED OR SOLUTION TREATED AND AGED

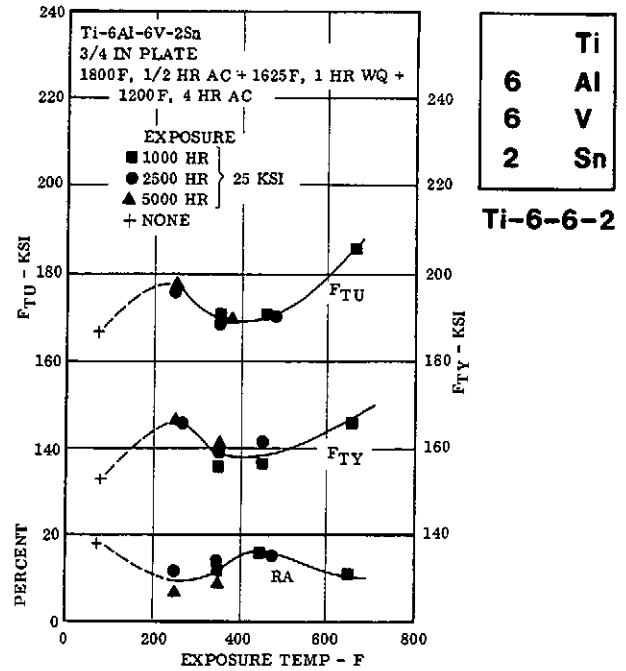


FIG. 3.02131 EFFECT OF STRESSED EXPOSURE AT ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED AND AGED PLATE. (55, Table 4)

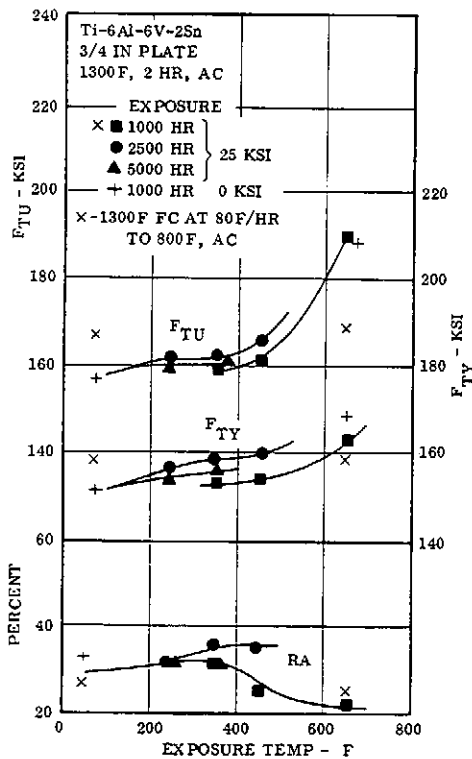


FIG. 3.02130 EFFECT OF STRESSED AND UNSTRESSED ELEVATED TEMPERATURE EXPOSURE ON TENSILE PROPERTIES OF ANNEALED PLATE. (55, Table 4)

Source	(47, Table 15)		
Alloy	Ti-6Al-6V-2Sn		
Form	Beta forged at 1725F		
Condition	1525F 1 hr WQ + 1000F, 4 hr AC		
Quenched section size - in	1.25	2	4
F _{TU} - ksi	187	184	163
F _{TY} - ksi	176	171	149
e (2 in) - percent	11	10	11
RA - percent	25	26	33

TABLE 3.02132 EFFECT OF AS QUENCHED SECTION SIZE ON TENSILE PROPERTIES OF BETA FORGED BARS

6 Ti
6 Al
2 V
2 Sn

Source	(31, Table III)		
Alloy	Ti-6Al-6V-2Sn		
Form	Investment cast specimens		
Condition	As cast	1600F, 1 hr WQ + 1100F, 1 hr AC	1300F, 1 hr WQ + 1100F, 4 hr AC
F _{TY} - ksi	141	158	(1)
IE Charpy V ft-lb	13.3	12.5	6.25
(1) Broke before 0.2 percent yield, F _{tu} = 189 ksi			

Ti-6-6-2

TABLE 3.0231 IMPACT STRENGTH OF INVESTMENT CAST SPECIMENS

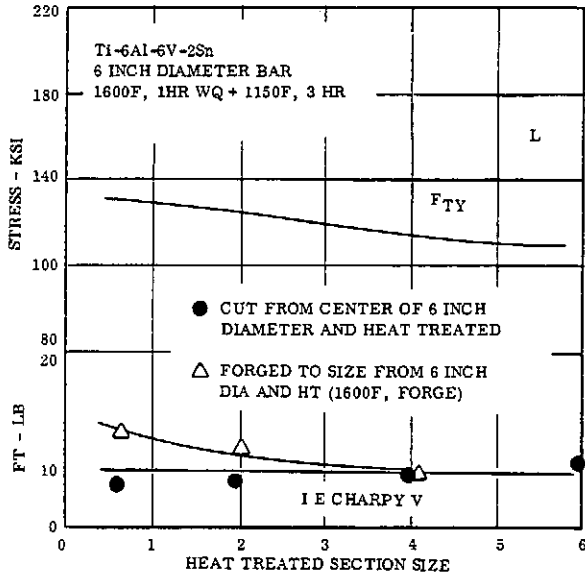


FIG. 3.0232 EFFECT OF HEAT TREATED SECTION SIZE ON IMPACT STRENGTH OF SPECIMENS REMOVED FROM CENTER OF SOLUTION TREATED AND AGED BAR SECTIONS

(5)

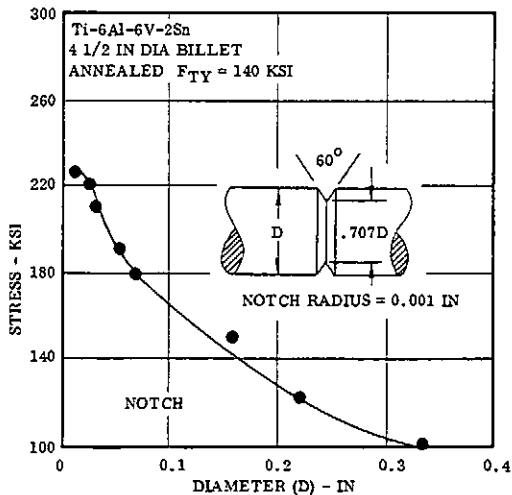


FIG. 3.02711 EFFECT OF NOTCH DIAMETER ON THE SHARP NOTCH PROPERTIES OF ANNEALED BILLET.

(13)

Source	(2)					
Alloy	Ti-6Al-6V-2Sn					
Form	5 x 6 inch forged section					
Condition	1600F, 1 hr WQ + 1100F, 4 hr (Specimens heat treated)					
Location	Edge		Mid radius		Center	
Direction	L	LT	ST	LT	ST	L
F _{tu} - ksi	183	180	190	176	178	185
N.S./F _{tu} (1)	0.96	0.95	0.97	0.99	0.96	1.07

(1) Notch strength

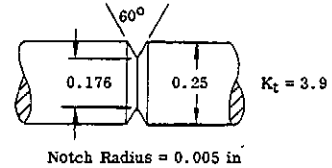


TABLE 3.02712 NOTCH STRENGTH OF FORGING AT VARIOUS LOCATIONS

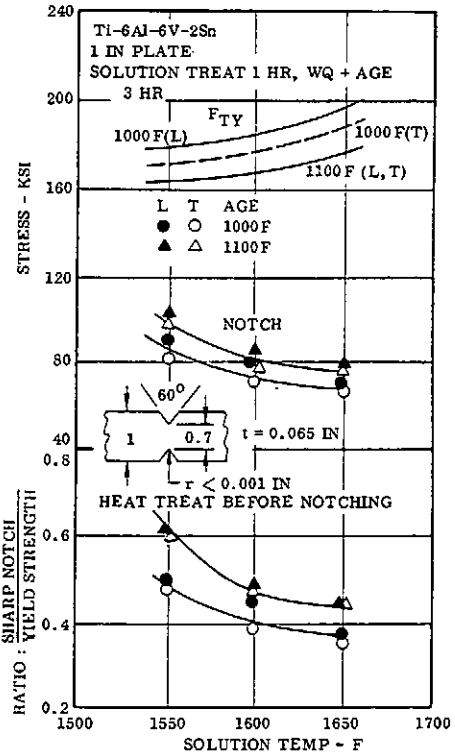


FIG. 3.02713 EFFECT OF SOLUTION TREATING AND AGING TEMPERATURE ON THE SHARP NOTCH TENSILE PROPERTIES OF PLATE.

(6)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

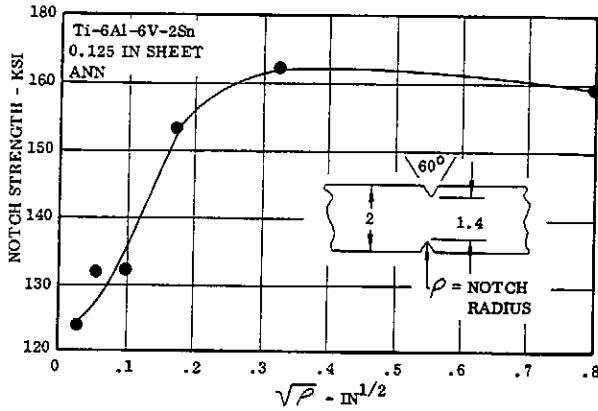


FIG. 3.02714 NOTCH STRENGTH AS FUNCTION OF ROOT RADIUS FOR ANNEALED SHEET.

(32, Table 9)

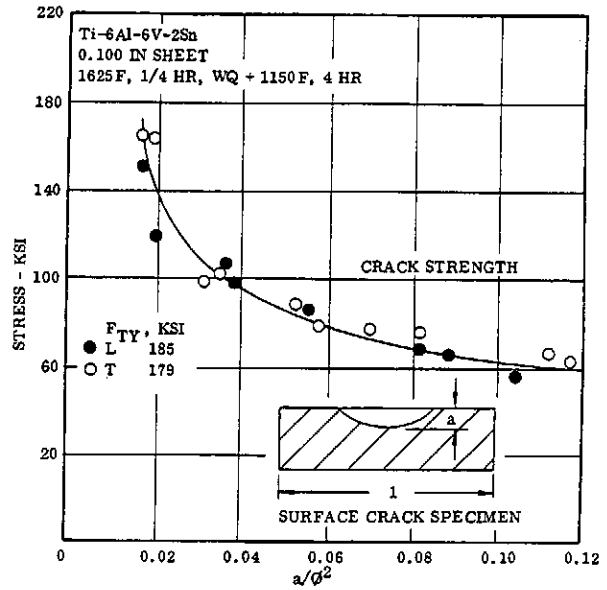


FIG. 3.02716 EFFECT OF SURFACE CRACKS ON STRENGTH OF SOLUTION TREATED AND AGED SHEET.

(17)

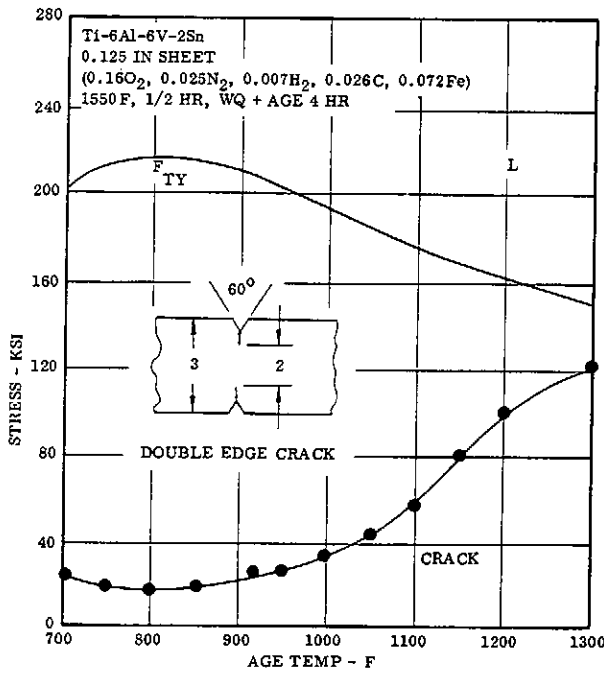


FIG. 3.02715 EFFECT OF AGING TEMPERATURE ON STRENGTH OF DOUBLE EDGE CRACK SHEET SPECIMENS.

(9)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

Source	(25, Table 324) (24)			
Alloy	Ti-6Al-6V-2Sn			
Form	Extrusion at 1675F to 8-3/4 in O.D. x 11-3/4 in I.D.		Extrusion at 1735F, 85 percent reduction to 3 inch diameter bar	
Condition (3)	ST. 1600F, 3 hr WQ + age		St. 1600F, 1-1/2 hr WQ + age	
Age	1300F, 6 hr	1000F, 4 hr	1250F, 6 hr	
Heat (4)	A	B	C	
F_{tu} - ksi (1)	153	192	171	156
F_{ty} - ksi	144	137	156	143
K_{Ic} - ksi $\sqrt{\text{in}}$ (2)	69	32	39	54

(1) Transverse tensile: midwall of tube or center of bar
(2) ASTM E-399-72 orientation CR with crack tip at midwall or at bar center
(3) Extrusions heat treated
(4) A - 0.020C, 0.16 O₂, 0.005 H₂ and 0.015 N₂; B - 0.12C, 0.07 O₂, 0.004 H₂, 0.010 N₂ and 2.0 Zr; C-0.022C, 0.13 O₂, 0.010 H₂ and 0.017 N₂.

TABLE 3.02722 PLANE STRAIN FRACTURE TOUGHNESS OF EXTRUSIONS GIVEN SEVERAL HEAT TREATMENTS

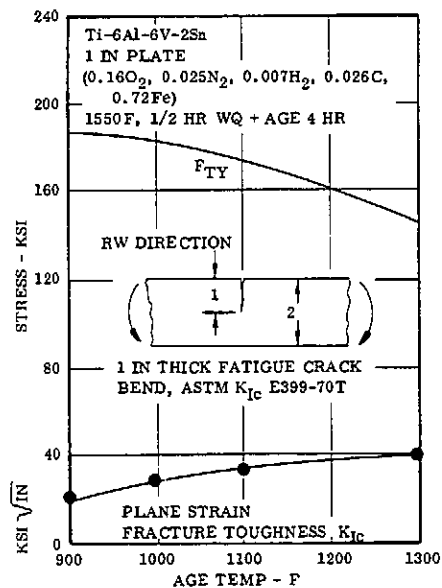


FIG. 3.02723 EFFECT OF AGE TEMPERATURE ON PLANE STRAIN FRACTURE TOUGHNESS OF PLATE. (11)

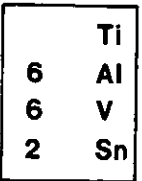
Source	(36, Tables 6 and 7)				
Alloy	Ti-6Al-6V-2Sn				
Form	1/2 in plate			1-1/4 in plate	
Processing	Alpha + beta			Beta	
Heat	T-1	R-2	R-2	R-2	R-1
Code	TM	RM	RB	RD	RS
Condition	Mill ann.	Mill ann.	Beta ann. 1850F, 1 hr in vac. Argon cool	Duplex ann. 1700F, 1 hr in vac. Argon cool + 1400F, 1 hr, Argon cool	STA 1675F, 1/4 hr WQ + 1100F 4 hr
F_{ty} - ksi (T)	159	163	140	151	173
K_{Ic} - ksi $\sqrt{\text{in}}$	-	32	54	65	34
W/B	-	2	2	4	4

ASTM E399-70T C.T. specimens B = 1/2 in

TABLE 3.02724 PLANE STRAIN FRACTURE TOUGHNESS OF TWO HEATS OF PLATE GIVEN SEVERAL HEAT TREATMENTS

NONFERROUS ALLOYS

Source	(37, p. 3-8 and 3-10)						
Alloy	Ti-6Al-6V-2Sn						
Form	2 in plate			1-1/2 in dia bar		Large die forging	
Condition (1)(2)	A	B	C	A	B	A	B
F _{ty} - ksi	157	150	139	153	-	144	138
K _{Ic} - ksi√in	42	54	84	43	60	56	56
(1) A - mill anneal; B - 1675F, 2 hr AC + 1600F, 1 hr, FC C - 1700F, 4 hr AC + 1400F, 1 hr AC							
(2) Specimen blanks heat treated							



Ti-6-6-2

TABLE 3.02725 PLANE STRAIN FRACTURE TOUGHNESS OF PLATE, BAR AND FORGING GIVEN SEVERAL HEAT TREATMENTS

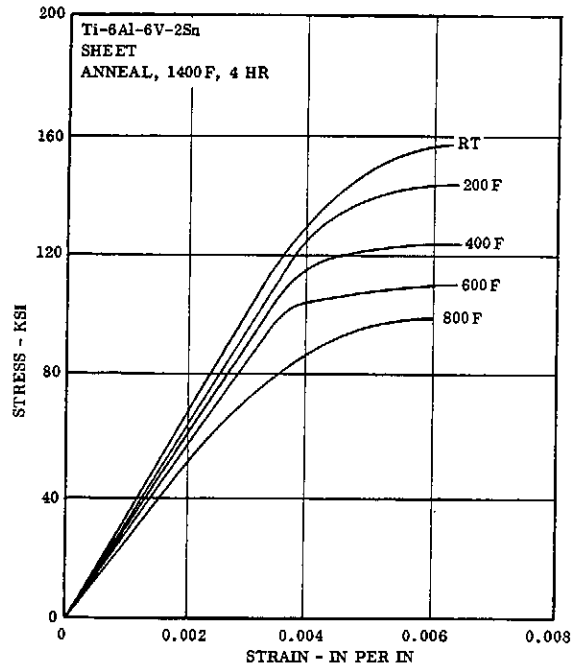


FIG. 3.0312 ELEVATED TEMPERATURE TENSION STRESS-STRAIN CURVES FOR ANNEALED SHEET. (1)

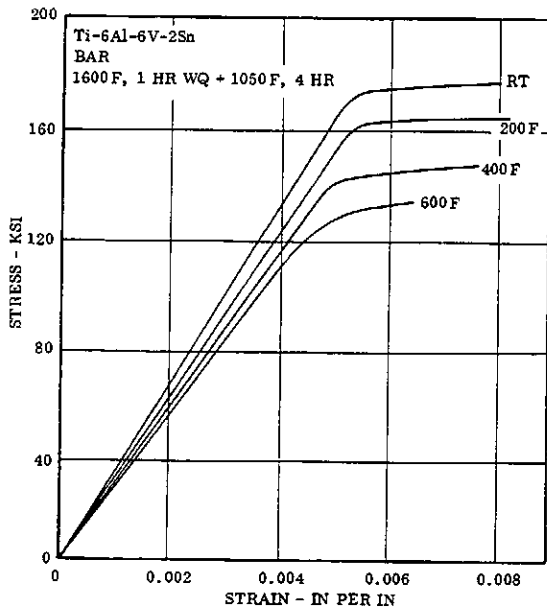


FIG. 3.0311 ELEVATED TEMPERATURE TENSION STRESS-STRAIN CURVES FOR AGED BAR. (1)

NONFERROUS ALLOYS

REVISED: DECEMBER 1975

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

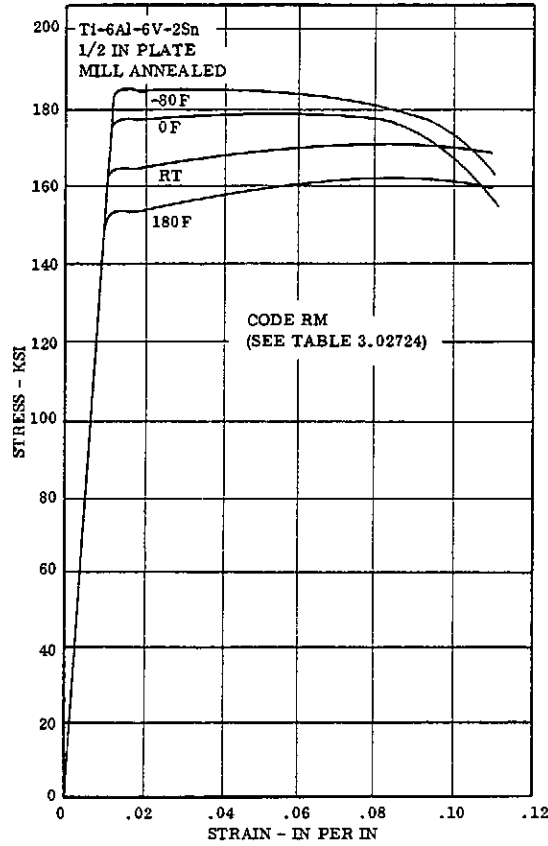


FIG. 3.0313 STRESS STRAIN CURVES FOR MILL ANNEALED PLATE AT VARIOUS TEMPERATURES.

(36, Fig. 16)

Source	(46, Appendix 8)					
Alloy	Ti-6Al-6V-2Sn					
Form	16 in wide extrusion (see Figure 3.0214)					
Condition	1625F, 1 hr, WQ + 1100F, 4 hr AC					
Test Temp. -F	R. T.				800	
Location (1)	Skin		Riser		Skin	Riser
	1	2	1	2	1	2
F _{tu} (avg) - ksi	167	170	165	168	124	121
Spread	156-179	157-180	151-175	152-180	116-130	112-128
F _{ty} (avg) - ksi	157	157	151	154	98	95
Spread	145-166	140-165	138-161	138-161	94-103	92-99
e (2 in) avg. percent	9	10	10	10	13	13
Spread	5-12	7-13	5-13	7-12	11-17	11-16

(1) Locations 1 and 2 are at opposite end of extrusion designated bottom and top respectively

TABLE 3.0314 AVERAGE AND SPREAD OF R. T. AND 800F TENSILE PROPERTIES IN LARGE SOLUTION TREATED AND AGED EXTRUSION

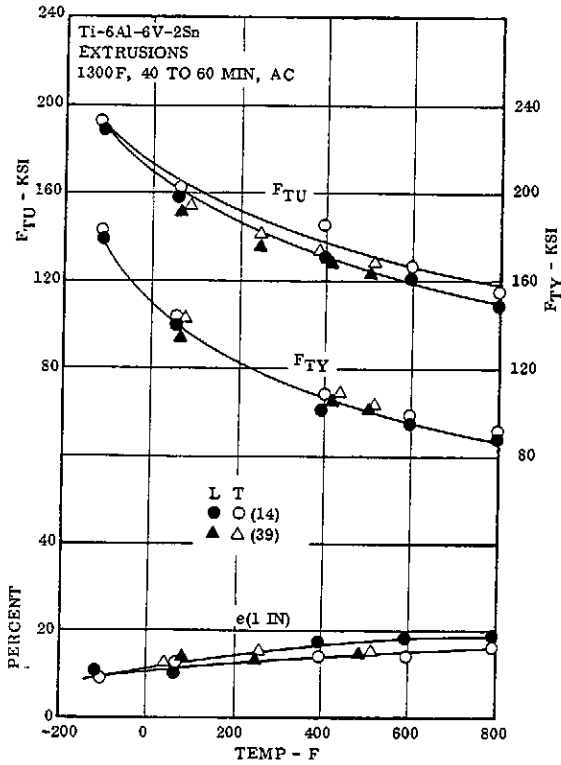
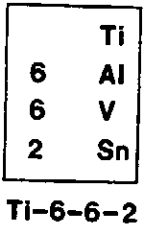


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF ANNEALED EXTRUSIONS OF VARIOUS SHAPES. (14, Table 17)(39, Table 6)

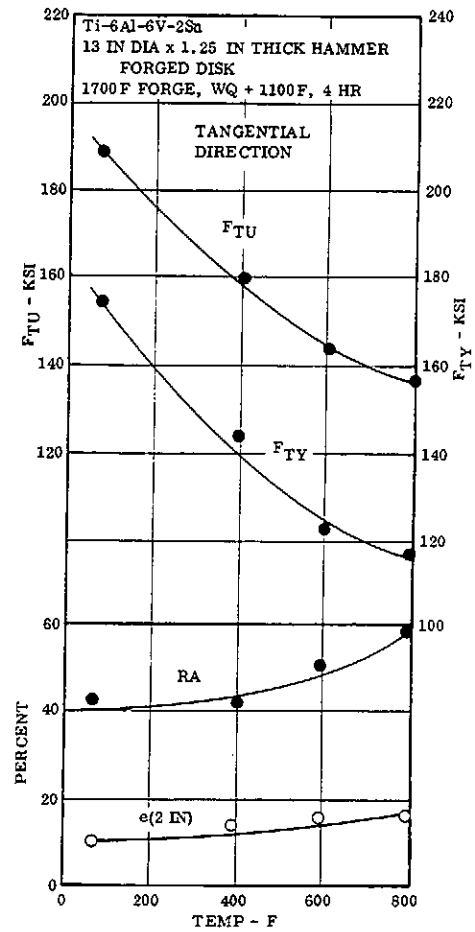


FIG. 3.0316 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF HAMMER FORGED DISK. (47, Table 14)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

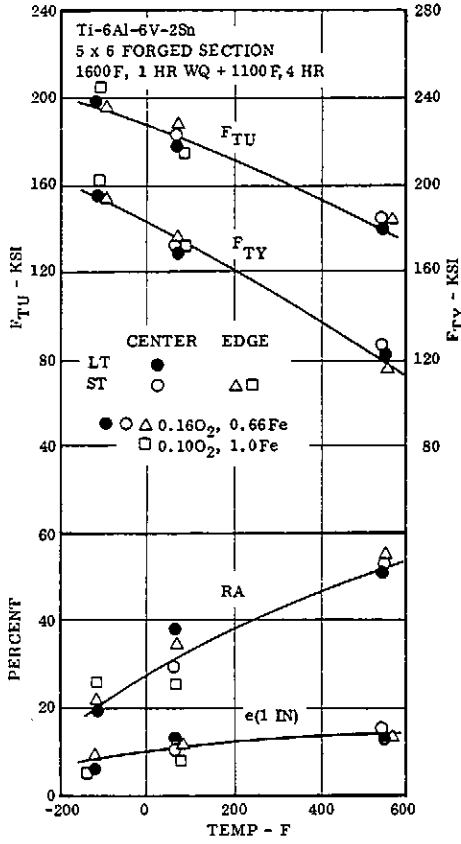


FIG. 3.0317 EFFECT OF TEST TEMPERATURE AND SPECIMEN LOCATION ON TENSILE PROPERTIES OF FORGINGS AT TWO INTERSTITIAL LEVELS (SPECIMENS HEAT TREATED). (2)

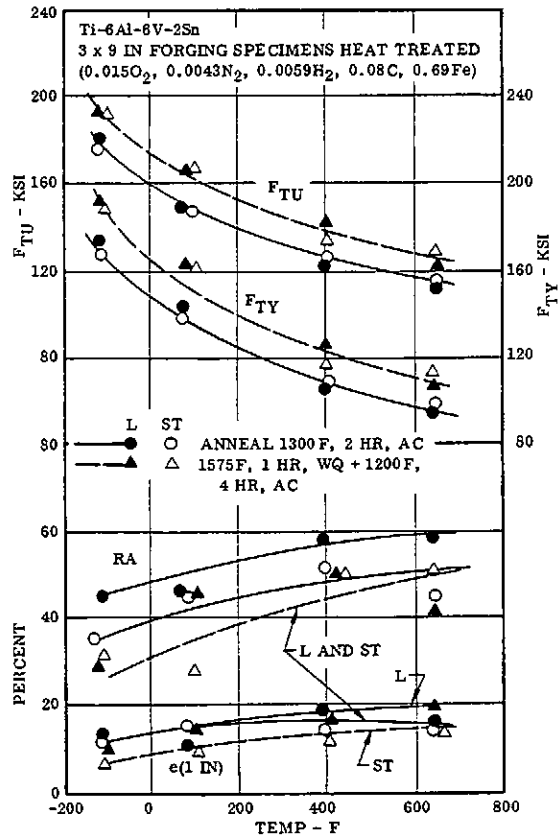


FIG. 3.0318 EFFECT OF TEST TEMPERATURE ON THE TENSILE PROPERTIES OF FORGING. (12)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

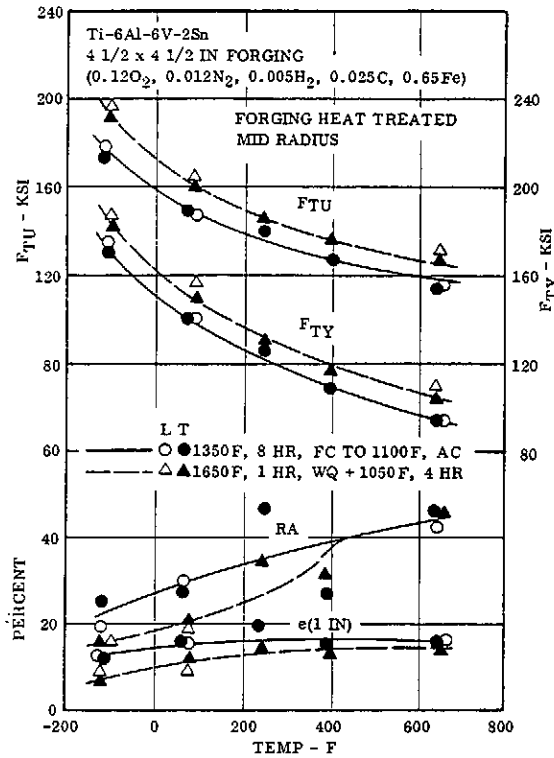


FIG. 3.0319 EFFECT OF TEST TEMPERATURE ON THE TENSILE PROPERTIES OF LOW INTERSTITIAL FORGING, (FORGING HEAT TREATED). (15)

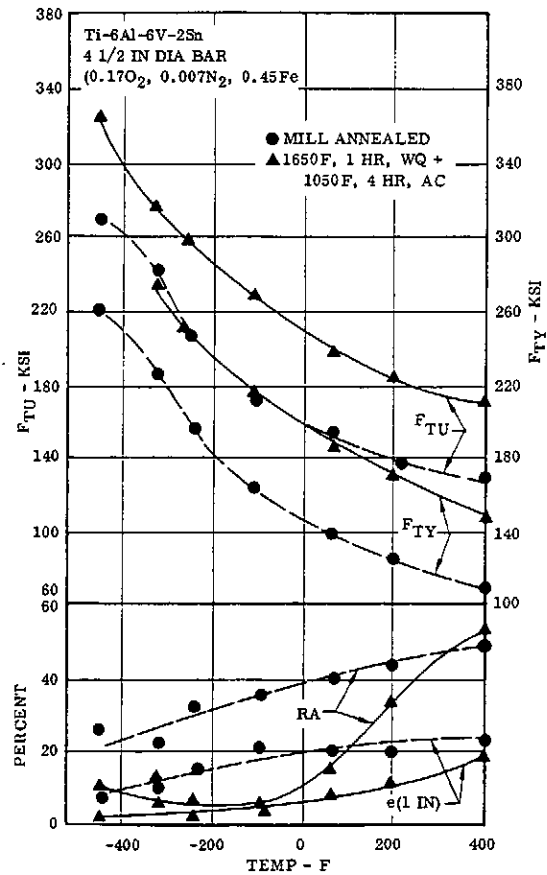


FIG. 3.03110 EFFECT OF LOW TEST TEMPERATURES ON TENSILE PROPERTIES OF ANNEALED AND AGED BAR. (10)

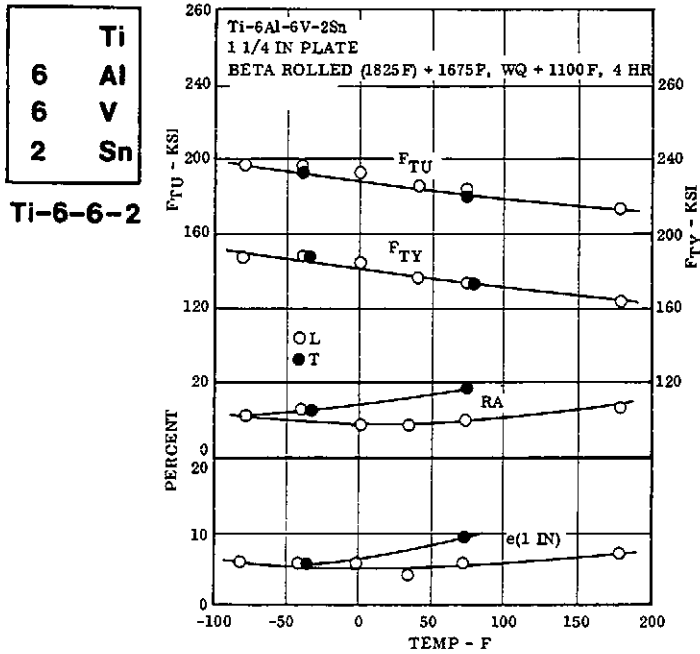


FIG. 3.03111 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED AND AGED PLATE. (36, Table 2)

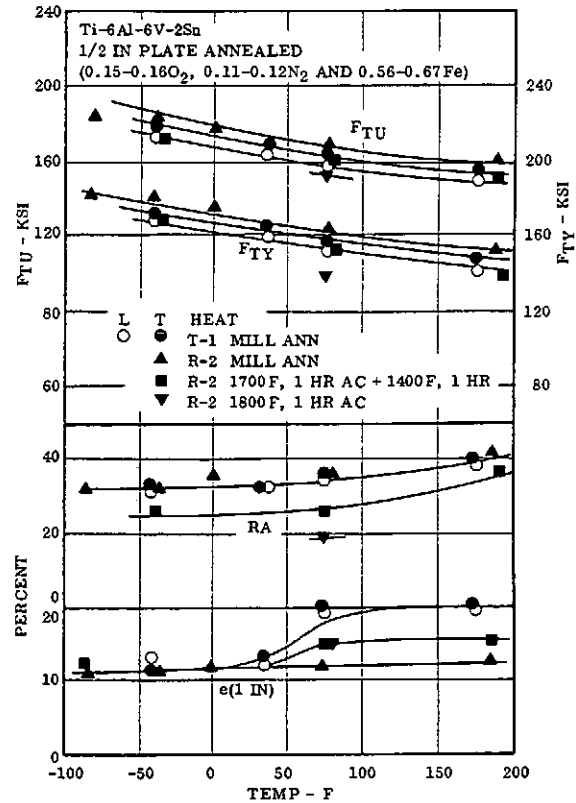


FIG. 3.03112 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF ANNEALED PLATE FROM TWO HEATS. (36, Table 5)

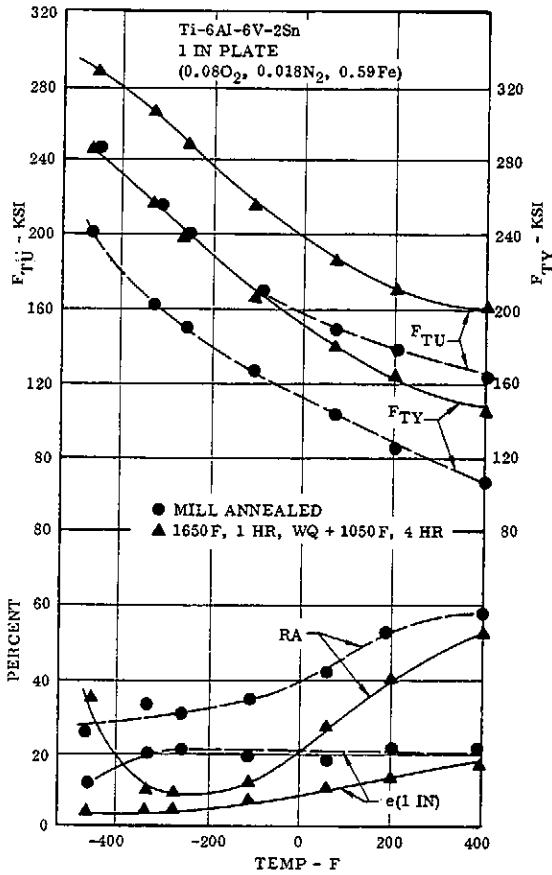


FIG. 3.03113 EFFECT OF LOW TEST TEMPERATURES ON TENSILE PROPERTIES OF LOW INTERSTITIAL PLATE. (10)

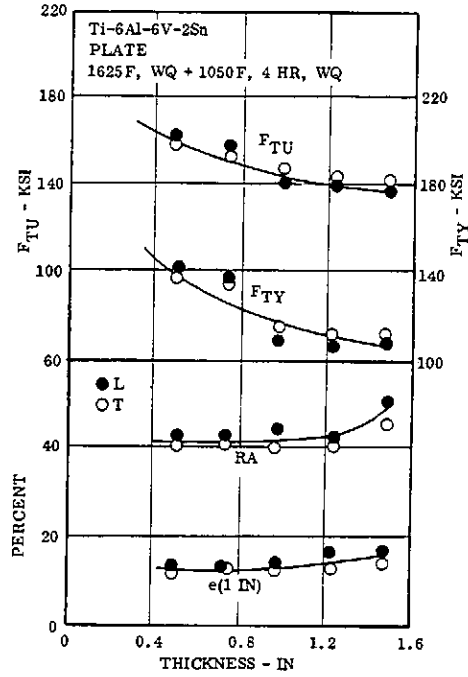


FIG. 3.03114 EFFECT OF THICKNESS ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED PLATE AT 600F. (7)

Ti
6 Al
6 V
2 Sn

Ti-6-6-2

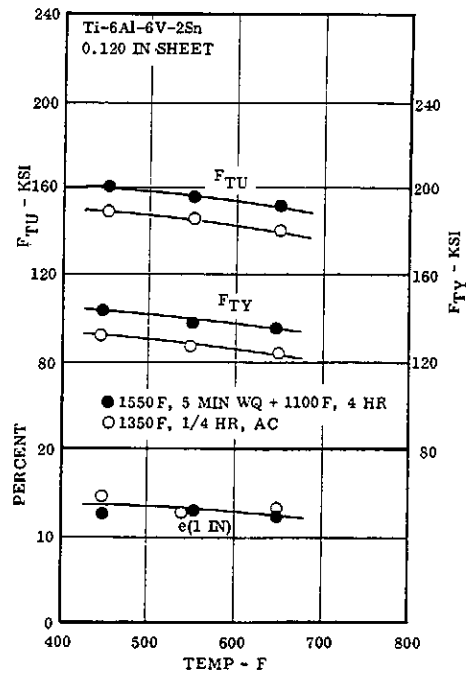


FIG. 3.03115 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET. (16)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

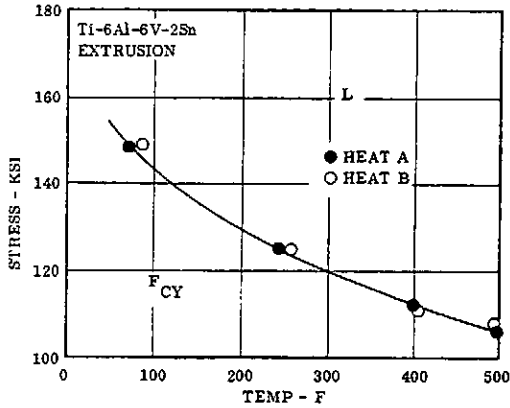


FIG. 3.0321 EFFECT OF TEMPERATURES ON COMPRESSIVE YIELD STRENGTH OF ANNEALED EXTRUSION. (39, Table 9)

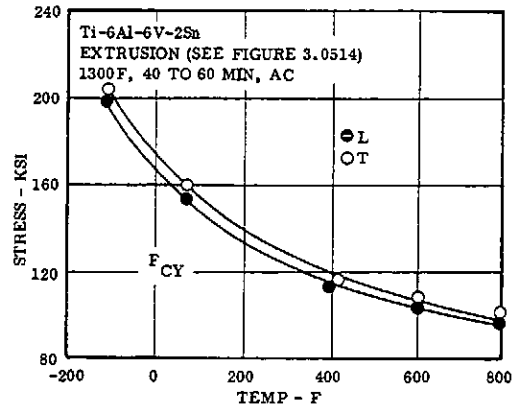


FIG. 3.0323 EFFECT OF TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF ANNEALED FORGINGS. (14)

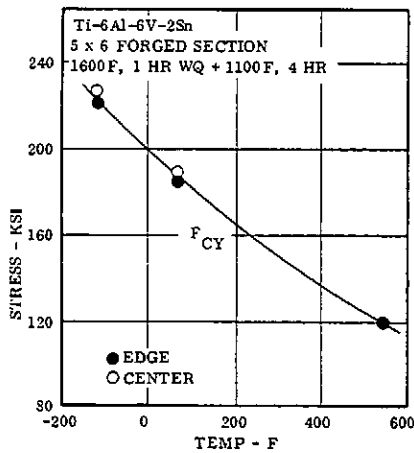


FIG. 3.0322 EFFECT OF TEST TEMPERATURE AND SPECIMEN LOCATION ON COMPRESSIVE YIELD STRENGTH OF SOLUTION TREATED AND AGED FORGING (SPECIMENS HEAT TREATED). (2)

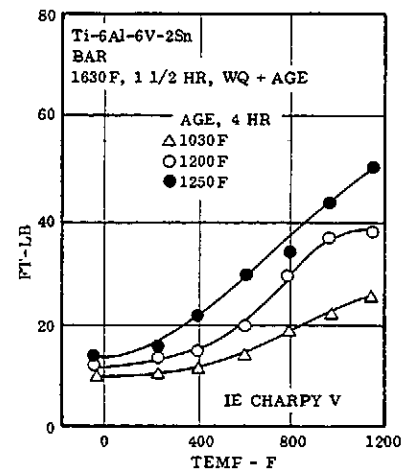
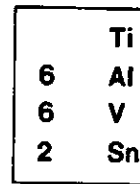
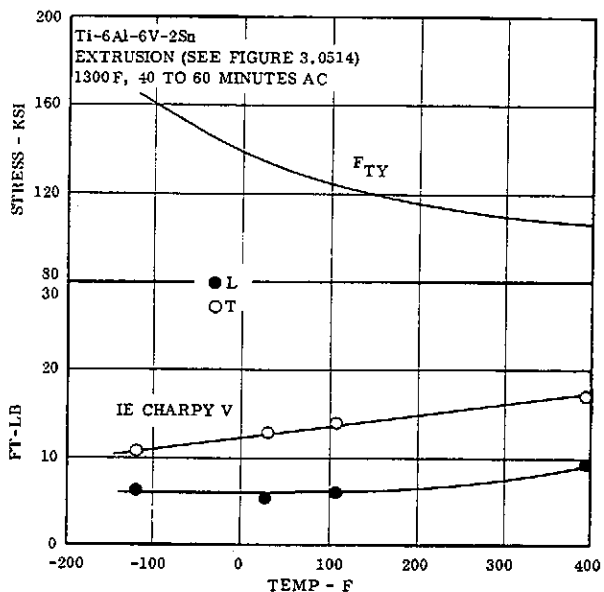


FIG. 3.0331 EFFECT OF TEMPERATURE ON IMPACT STRENGTH OF AGED BAR. (1)

NONFERROUS ALLOYS



Ti-6-6-2



Alloy		Ti-6Al-6V-2Sn				
Source	(2)	(1)				
Form	5 x 6 in forging	Plate		Sheet		
Condition	1600F, 1 hr, WQ + 1100F 4 hr (1)	Anneal 1350F	1600F, 1 hr, WQ + 1100F 4 hr	Anneal	Solution Treat + Age	
Temperature	RT	550F	RT	RT	RT	RT
F _{SU}	105	85	97	111	103	110

(1) Specimens heat treated

TABLE 3.0351 SHEAR ULTIMATE STRENGTH AT ROOM AND ELEVATED TEMPERATURE FOR SEVERAL FORMS AND CONDITIONS OF ALLOY

FIG. 3.0332 EFFECT OF TEST TEMPERATURE ON IMPACT STRENGTH OF ANNEALED EXTRUSION. (14)

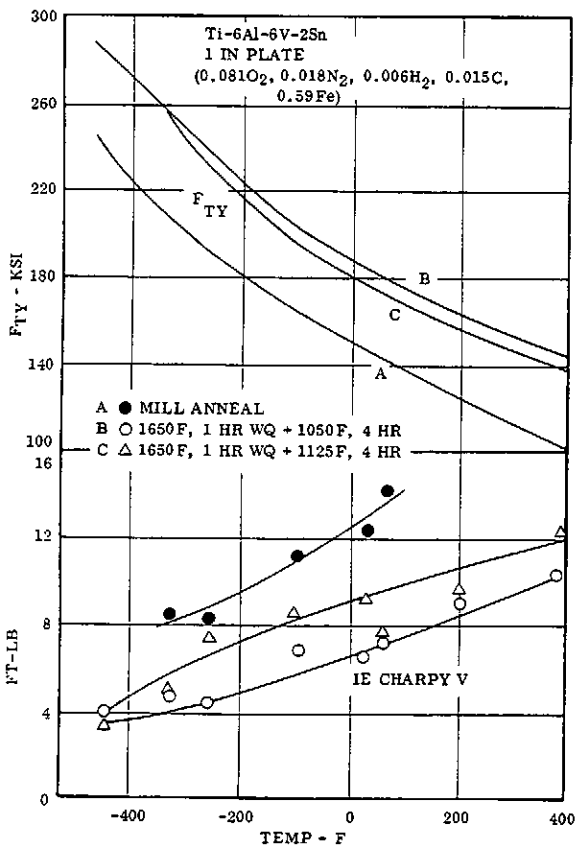


FIG. 3.0333 EFFECT OF LOW TEST TEMPERATURES ON IMPACT STRENGTH OF ANNEALED AND SOLUTION TREATED AND AGED LOW INTERSTITIAL PLATE. (10)

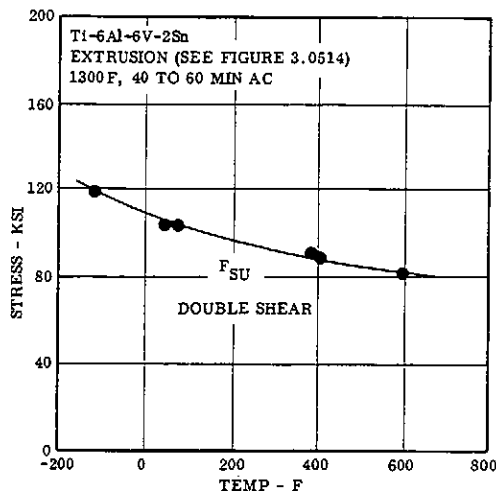


FIG. 3.0352 EFFECT OF TEST TEMPERATURE ON DOUBLE SHEAR STRENGTH OF ANNEALED EXTRUSION. (14)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

Alloy	Ti-6Al-6V-2Sn					
	(2)		(1)			
Source	5 x 6 in Forging		Plate	Sheet		
Condition	1600F, 1 hr WQ + 1100F, 4 hr		Anneal	Solution Treat + Age	Anneal	Solution Treat + Age
Temperature	RT	550F	RT	RT	RT	RT
F _{bru} (1) - ksi	370	300	287	326	299	326
F _{bry} - ksi	338	243	229	262	239	262

(1) e/D = 2

TABLE 3.0361 BEARING STRENGTH AT ROOM AND ELEVATED TEMPERATURE FOR SEVERAL FORMS AND CONDITIONS OF ALLOY

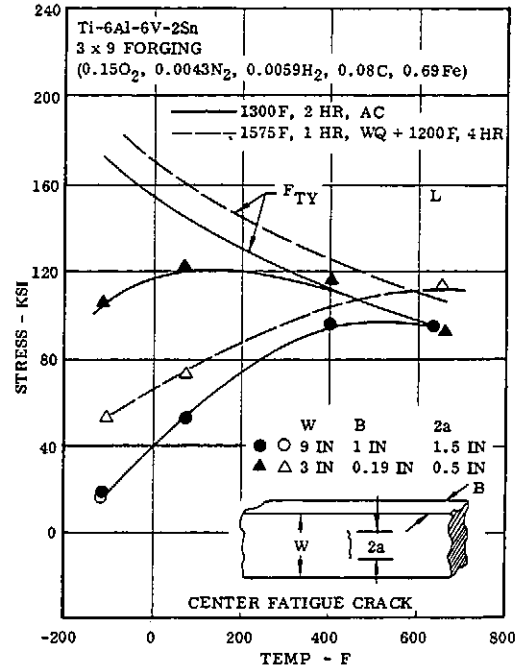


FIG. 3.03711 EFFECT OF TEST TEMPERATURE ON STRENGTH OF CENTER CRACKED SPECIMENS OF TWO THICKNESSES CUT FROM FORGING (SPECIMENS SOLUTION TREATED AND AGED). (12)

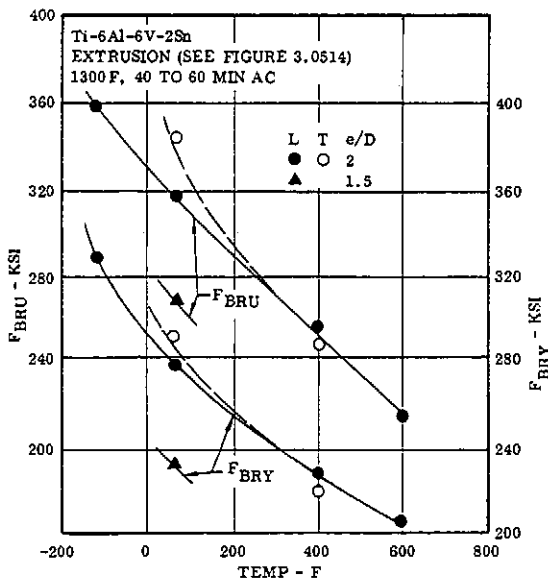


FIG. 3.0362 EFFECT OF TEST TEMPERATURE ON BEARING STRENGTH OF ANNEALED EXTRUSION. (14)

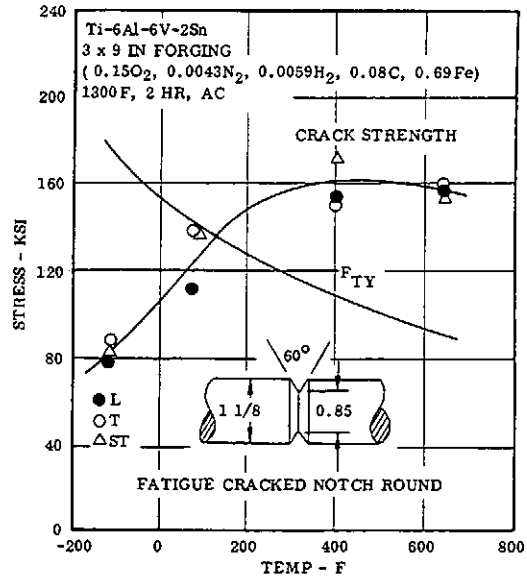


FIG. 3.03712 EFFECT OF TEST TEMPERATURE ON STRENGTH OF FATIGUE CRACKED NOTCH ROUNDS FROM ANNEALED FORGINGS. (SPECIMENS REANNEALED). (12)

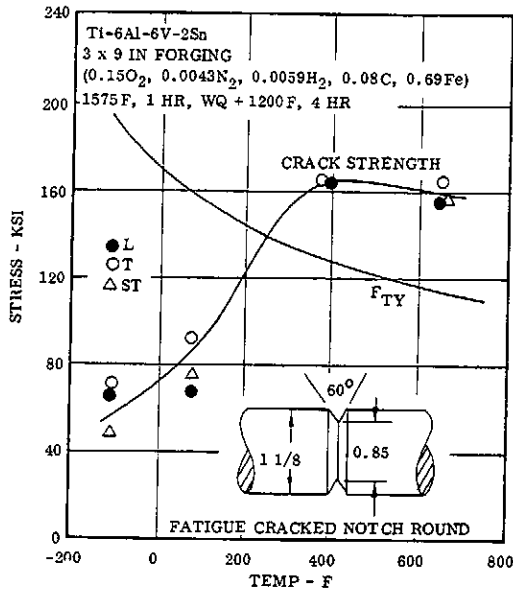


FIG. 3.03713 EFFECT OF TEST TEMPERATURE ON STRENGTH OF FATIGUE CRACKED NOTCH ROUNDS CUT FROM FORGING (SPECIMENS SOLUTION TREATED AND AGED). (12)

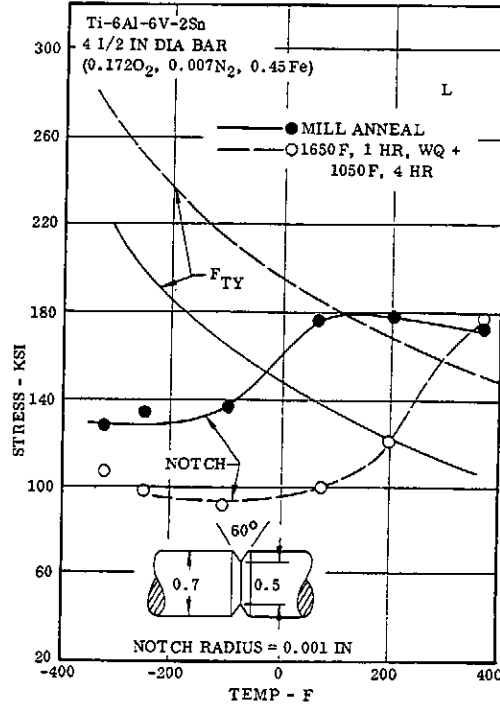


FIG. 3.03715 EFFECT OF LOW TEST TEMPERATURES ON SHARP NOTCH STRENGTH OF ANNEALED AND SOLUTION TREATED AND AGED BAR. (10)

Ti
6 Al
6 V
2 Sn

Ti-6-6-2

Source	(2)					
Alloy	Ti-6Al-6V-2Sn					
Form	5 x 6 inch Forged Section					
Condition	1600F, 1 hr WQ + 1100F, 4 hr (3)					
Forging	Forging A (1)		Forging B (1)		Forging C (2)	
Location	Edge	Center	Edge	Center	Edge	Center
Temp - F	-110	RT	RT	RT	-110	RT
F _{ty} - ksi	194	175	170	155	200	160
N.S./F _{ty}	0.51	0.71	0.47	0.41	0.53	0.46

(1) 0.16 O₂, 0.66 Fe
(2) 0.10 O₂, 1.0 Fe
(3) Specimens heat treated

TABLE 3.03714 STRENGTH OF FATIGUE CRACKED NOTCH ROUNDS CUT FROM TWO LOCATIONS IN A SOLUTION TREATED AND AGED FORGING

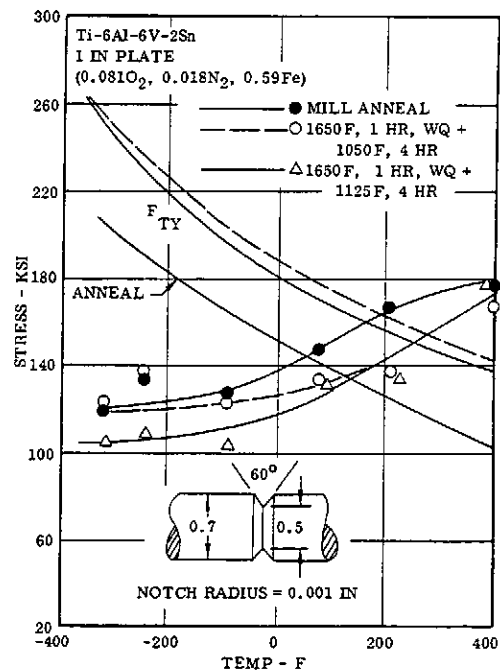
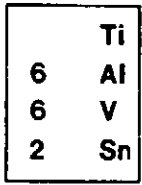


FIG. 3.03716 EFFECT OF LOW TEST TEMPERATURES ON SHARP NOTCH STRENGTH OF LOW INTERSTITIAL PLATE. (10)



Ti-6-6-2

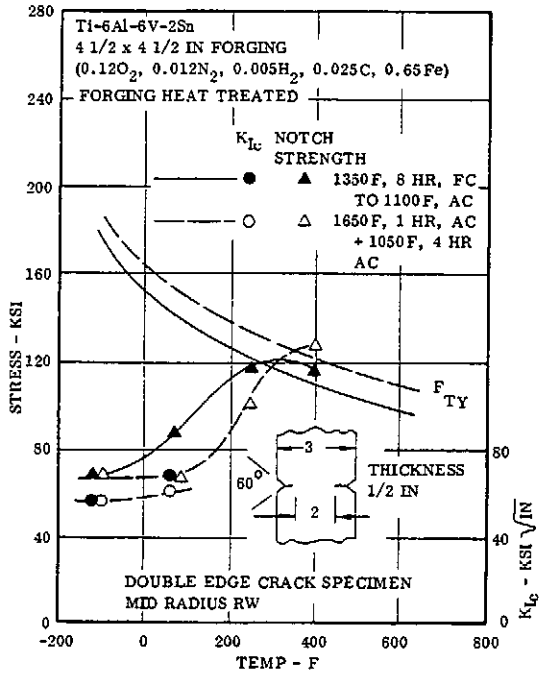


FIG. 3.03721 EFFECT OF TEST TEMPERATURE ON STRENGTH OF DOUBLE EDGE CRACK SPECIMENS AND PLANE STRAIN FRACTURE TOUGHNESS OF LOW INTERSTITIAL FORGING (K_{Ic} BY TECHNIQUE OF ASTM E 399-70T). (15)

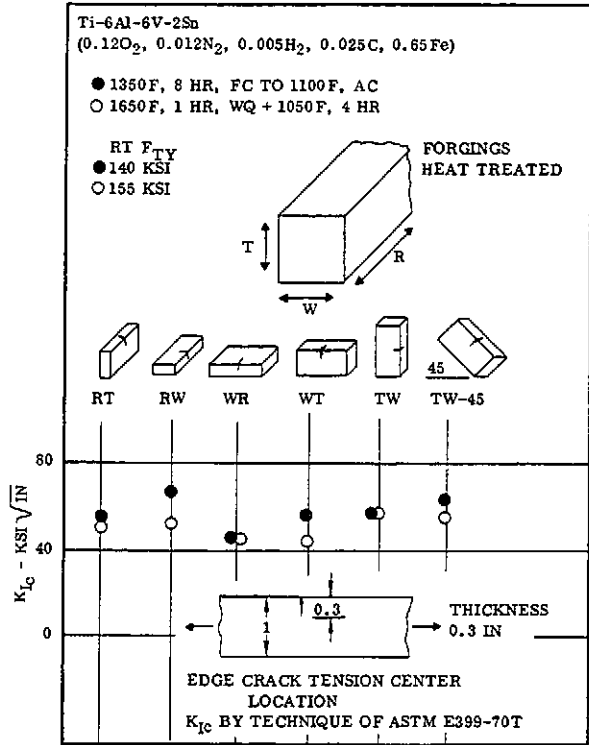


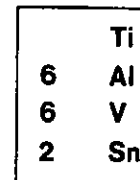
FIG. 3.03722 EFFECT OF SPECIMEN ORIENTATION ON THE -110F PLANE STRAIN FRACTURE TOUGHNESS OF LOW INTERSTITIAL FORGING. (15)

Source	(15)					
Alloy	Ti-6Al-6V-2Sn					
Form	1/2 inch Plate			1-1/2 in Plate		
Condition (3)	1350F, 8 hr, FC to 1100F, AC		1650F, 1 hr, WQ + 1050F, 4 hr		1350F, 8 hr, FC to 1100F, AC	
F_{ty} - ksi	186		208		171	
Direction (2)	RW	WR	RW	WR	RW	WR
K_{Ic} at -110F Ksi sqrt(in) (1)	33	34	34	27	39	38

(1) For specimen see Figure 3.03721
 (2) For directions see Figure 3.03722
 (3) Plate heat treated

TABLE 3.03723 EFFECT OF SPECIMEN ORIENTATION ON THE -110F PLANE STRAIN FRACTURE TOUGHNESS OF PLATE

NONFERROUS ALLOYS



Ti-6-6-2

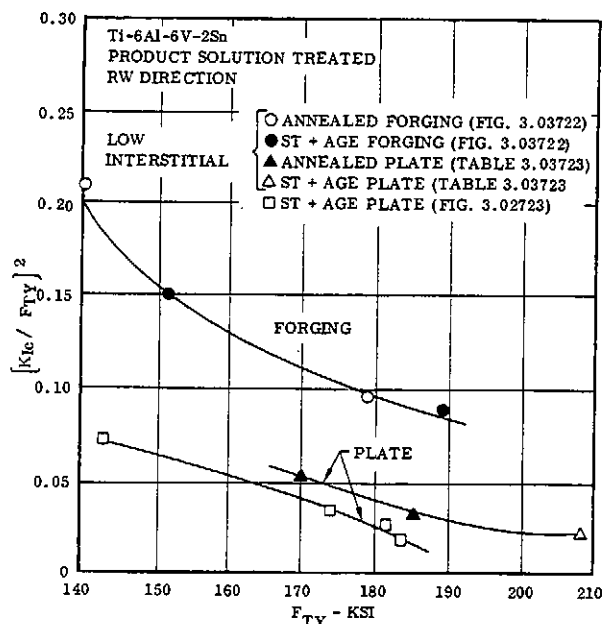


FIG. 3.03724 INFLUENCE OF YIELD STRENGTH ON PLANE STRAIN CRACK PROPAGATION RESISTANCE OF SEVERAL FORMS AND CONDITIONS.

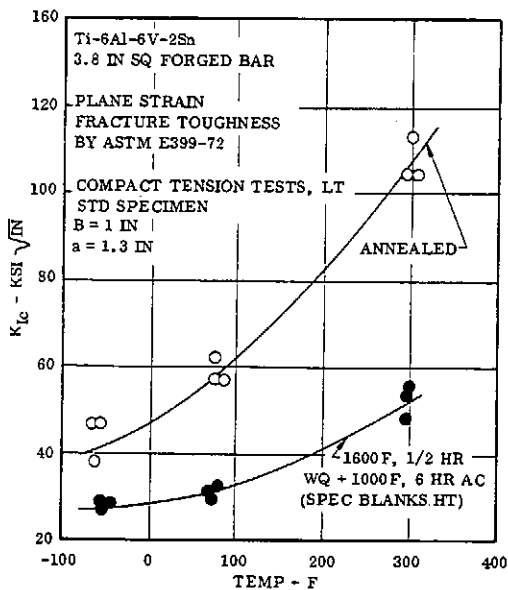


FIG. 3.03725 PLANE STRAIN FRACTURE TOUGHNESS OF FORGED BAR IN ANNEALED AND IN SOLUTION TREATED AND AGED CONDITION. (30, Tables 4,5)

Source	(14)						
Alloy	Ti-6Al-6V-2Sn						
Form	Extrusion (see Figure 3.0514)						
Condition	1300F, 40 to 60 minute AC						
Temp - F	600F ($F_{ty} = 95$ ksi)			800F ($F_{ty} = 90$ ksi)			
Total creep strain percent	0.5	1	2	2	2	2	2
Time-hours	100	500	100	500	100	500	1
Stress - ksi	116	112	119	116	122	119	98

TABLE 3.041 CREEP STRENGTH FOR ANNEALED EXTRUSION

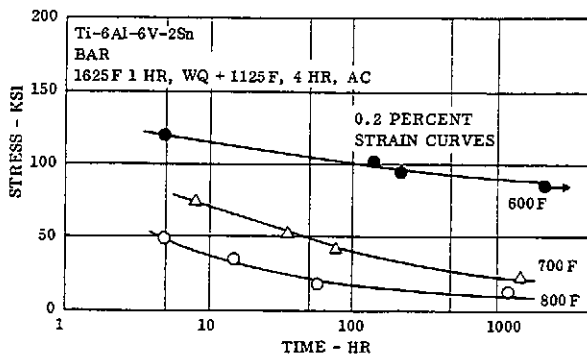


FIG. 3.042 STRESS FOR 0.2 PERCENT CREEP STRAIN AT SEVERAL TEMPERATURES FOR AGED BAR. (42)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

Source	(42, Table 1-5-6)											
Alloy	Ti-6Al-6V-2Sn											
Form	0.060 in sheet											
Condition	1625F 1/4 hr. WQ + 1050F, 4 hr AC			1675F 1/4 hr. WQ + 1100F, 4 hr AC			1550F 1/4 hr. WQ + 1100F, 4 hr AC					
Temp. - F	600	850	550	600	650	550	650	850				
Time - hr	150	47	150	150	150	150	307	22	24			
Stress - ksi	60	70	100	25	120	50	80	35	110	35	30	32
Total creep-percent	.07	.08	.21	.44	.12	.08	.08	.10	.13	.11	.55	.54

TABLE 3.043 TOTAL CREEP STRAIN FOR AGED SHEET AT SEVERAL TEMPERATURES AND STRESSES

Source	(39, Figure 16)				
Alloy	Ti-6Al-6V-2Sn				
Form	Extrusions (lowest of three heats) R. T. $F_{ty} = 153$ ksi				
Condition	Mill annealed $F_{ty} = 137$ to 144 at R. T.				
Method	Stress Conc.	Fatigue strength at cycles - ksi			
		10^4	10^5	10^6	10^7
Axial load	Smooth $K_t = 1$	140	120	106	100
R. T. R = 0.1	Notched $K_t = 4$	70	42	32	32

TABLE 3.0511 SMOOTH AND NOTCHED FATIGUE STRENGTH OF ANNEALED EXTRUSIONS AT ROOM TEMPERATURE

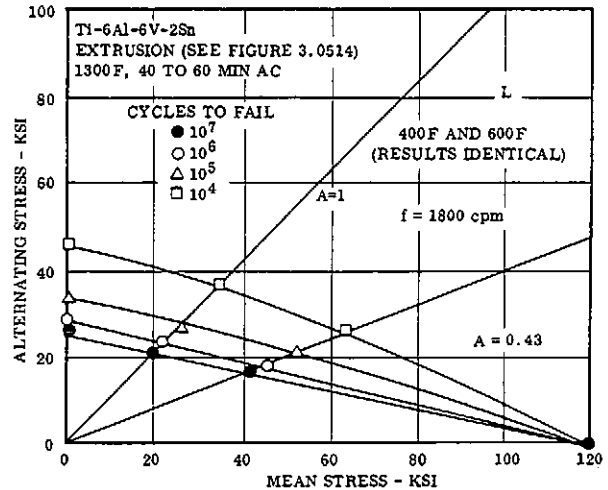


FIG. 3.0513 STRESS RANGE DIAGRAM AT 400 AND 600F FOR NOTCHED SPECIMENS FROM ANNEALED EXTRUSION. (14)

Source	(1)						
Alloy	Ti-6Al-6V-2Sn						
Form	T Extrusion						
Condition	1550F, WQ + 1050F, 4 hr. AC						
Method	Stress Ratio		Direc- tion	Stress Conc.	Fatigue Strength ksi at Cycles		
	A	R			10^5	10^6	10^7
Axial Load	0.82	0.1	L	$K_t = 1$ Smooth $K_t = 3.3$	105	95	90
					45	30	29

TABLE 3.0512 SMOOTH AND NOTCH FATIGUE STRENGTH OF SOLUTION TREATED AND AGED EXTRUSION

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

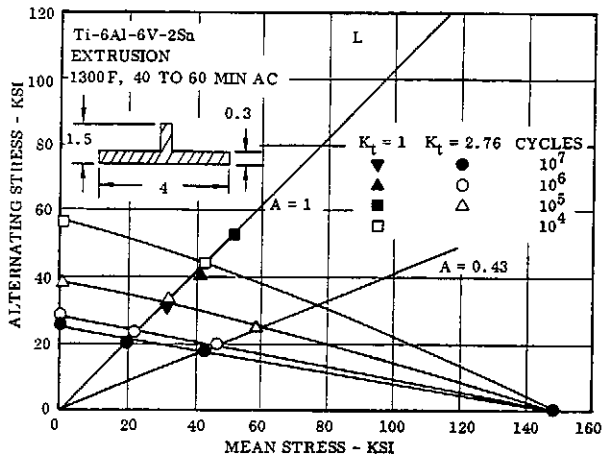


FIG. 3.0514 STRESS RANGE DIAGRAM AT ROOM TEMPERATURE FOR SMOOTH AND NOTCHED SPECIMENS FROM ANNEALED EXTRUSION. (14)

Source (2)											
Alloy Ti-6Al-6V-2Sn											
Form 5 x 6 inch Forged Section											
Condition 1600F, 1 hr, WQ + 1100F, 4 hr. (Specimens heat treated)											
Method	Stress Ratio		Stress Conc.	Forging	Temp F	Fatigue Strength ksi at Cycles					
	A	R				10 ⁴	10 ⁵	10 ⁶	10 ⁷		
Axial Load	0.82	0.1	Smooth K _t = 1	A (1)	RT	155	130	108			
						550	120	105	93	80	
						B (2)	RT	155	130	105	90
								Notched K _t = 3.9	A	RT	78
B	RT	78	45	35	25						

(1) 0.16O₂, 0.66Fe
(2) 0.10O₂, 1.0 Fe

TABLE 3.0516 SMOOTH AND NOTCH FATIGUE STRENGTH OF SOLUTION TREATED AND AGED FORGING AT ROOM AND ELEVATED TEMPERATURE

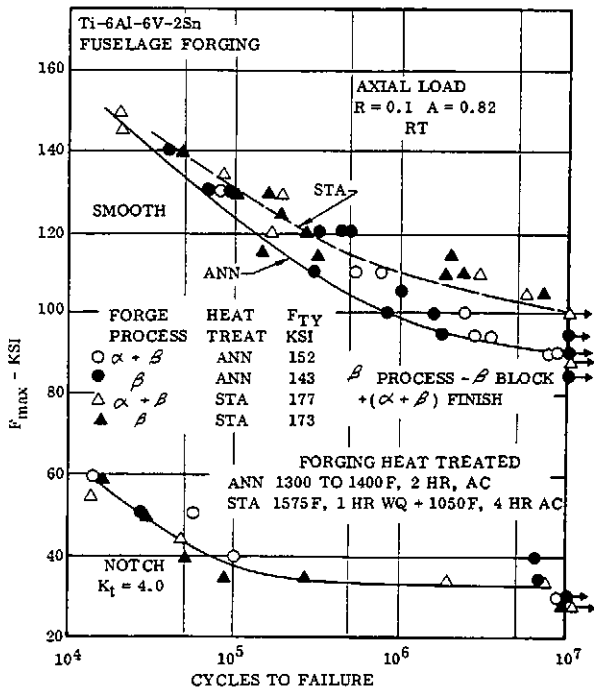


FIG. 3.0515 SMOOTH AND NOTCHED FATIGUE STRENGTH AT ROOM TEMPERATURE FOR ALPHA + BETA AND FOR BETA PROCESSED FORGING. (56)

Source (18)								
Alloy Ti-6Al-6V-2Sn								
Form 1 inch diameter bar								
Condition Specimen vacuum annealed 1300F, 2 hr. FC								
Method	Stress Ratio		Temp - F	Stress Conc. K _t	Fatigue Strength ksi at Cycles			
	A	R			10 ⁵	10 ⁶	10 ⁷	
Axial Load	0	-1	RT	3.4	27	21	20	
					F _{TU} = 160 ksi	19	12	11
					F _{TY} = 153 ksi	20	10	-
					RA = 35 percent	10.0	-	-
600	0	-1	RT	3.4	21	20	19	
					F _{TU} = 127 ksi	16	11	10
					F _{TY} = 104 ksi	10	-	9
					RA = 50 percent	1.0	-	-

Notch radius 0.001, 0.005 and 0.015 inch

TABLE 3.0517 SMOOTH AND NOTCH FATIGUE STRENGTH OF ANNEAL BAR

Ti
6 Al
6 V
2 Sn

Ti-6-6-2

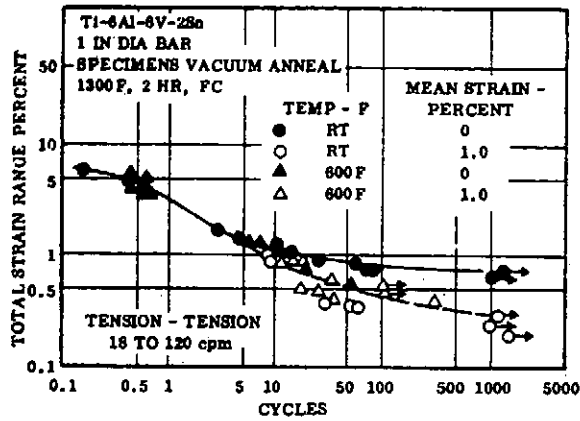


FIG. 3.0518 STRAIN CYCLING RESULTS FOR ANNEALED BAR AT ROOM AND ELEVATED TEMPERATURE. (18)

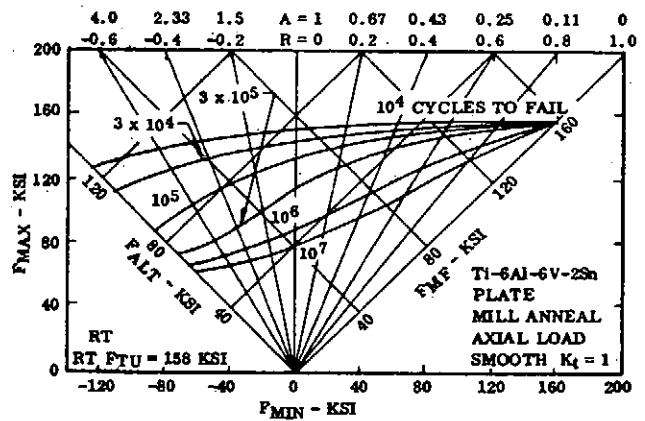


FIG. 3.0511 STRESS RANGE DIAGRAM FOR SMOOTH SPECIMENS OF MILL ANNEALED PLATE TESTED AT ROOM TEMPERATURE. (43, p. 210)

Source	(48, p. 41 and 42)			
Alloy	Ti-6Al-6V-2Sn			
Form	1 to 1-1/4 in plate			
Fatigue	Axial load (A = 0.82, R = 0.1) Notched $K_t = 3.5$			
Heat	A - 0.18 percent O_2		B - 0.11 percent O_2	
Condition	Annealed 1350F 8 hr. AC	1550F, 1 hr WQ + 1150F, 4 hr. AC	Annealed 1350F, 8 hr AC	1550F, 1 hr. WQ + 1150F, 4 hr. AC
Fatigue strength - ksi at cycles				
5×10^4	40	38	40	-
10^5	37	35	37	50
10^6	28	28	28	44
10^7	27	27	27	40

TABLE 3.0519 NOTCHED FATIGUE STRENGTH AT ROOM TEMPERATURE FOR PLATE AT TWO INTERSTITIAL LEVELS IN THE ANNEALED AND SOLUTION TREATED AND AGED CONDITIONS

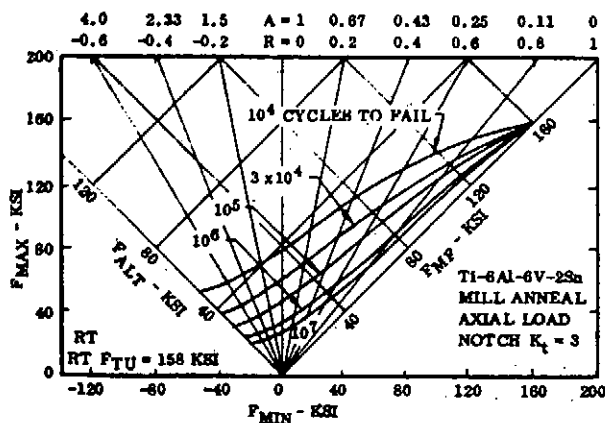


FIG. 3.05110 STRESS RANGE DIAGRAM FOR NOTCHED SPECIMENS OF MILL ANNEALED PLATE TESTED AT ROOM TEMPERATURE. (43, p. 211)

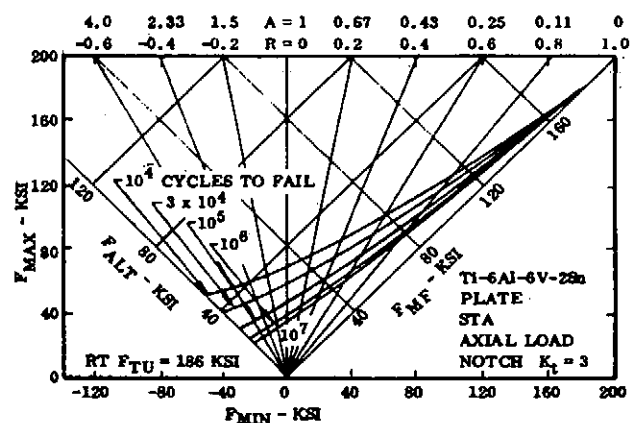
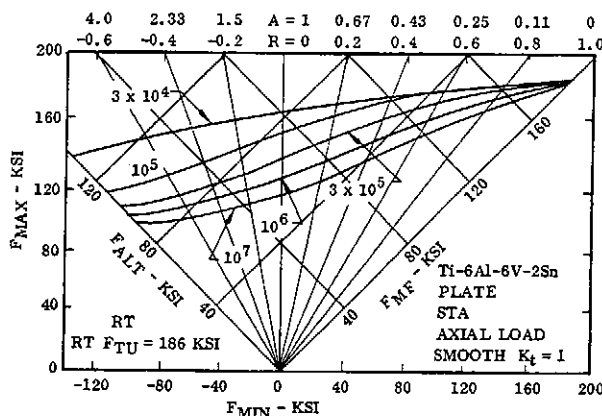


FIG. 3.05112 STRESS RANGE DIAGRAM FOR NOTCHED SPECIMENS OF SOLUTION TREATED AND AGED PLATE TESTED AT ROOM TEMPERATURE. (43, p. 233)

NONFERROUS ALLOYS



Ti
6 Al
6 V
2 Sn

Ti-6-6-2

FIG. 3.05113 STRESS RANGE DIAGRAM FOR SMOOTH SPECIMENS OF SOLUTION TREATED AND AGED PLATE TESTED AT ROOM TEMPERATURE. (43, p. 232)

Source		(19)					
Alloy		Ti-6Al-6V-2Sn					
Form		Plate (center)					
Method	Thickness	Condition	Direction	Stress Conc. K_t	Fatigue Strength ksi at Cycles		
					10^5	10^6	10^7
Axial Load	1-1/4 in. 0.18 O ₂	1350F, 8 hr. AC	L & T	1	-	110	86
			L & T	3.5	35	28	26
A = 0.82	1 inch 0.11 O ₂		L & T	1	-	115	90
			L & T	3.5	40	45	30
R = 0.1	1-1/4 in. 0.18 O ₂	1550F, 1 hr. WQ + 1200F, 4 hr.	L	1	-	133	105
			T	1	-	120	95
	L	3.5	40	32	28		
	T	3.5	30	28	25		
1 inch 0.11 O ₂			L & T	1	-	-	115
			L & T	3.5	50	43	40
2 inch 0.18 O ₂	1625F, 1 hr. WQ +1050F, 4 hr.		L & T	1	-	-	95
			L & T	3.5	30	28	25

TABLE 3.05114 SMOOTH AND NOTCH FATIGUE STRENGTH OF ANNEALED AND OF SOLUTION TREATED AND AGED PLATE

Source		(40)								
Alloy		Ti-6Al-6V-2Sn								
Method	Condition	Form	Stress Ratio		Stress Conc.	Fatigue Strength ksi at Cycles				
			A	R		10^4	10^5	10^6	10^7	
Axial Load	1600F, WQ + 1050 to 1100F, 4 hr AC $F_{ty} = 177$ ksi	0.020, 0.100 and 0.125 in sheet	0.82	0.1	Smooth $K_t = 1$	-	120	114	114	
					Notched $K_t = 4.2$	46	32	30	30	
1600F, WQ + 1050 to 1100F, 4 hr AC $F_{ty} = 171$ ksi Mill anneal $F_{ty} = 153$ ksi	1 in plate		0.82	0.1	Smooth $K_t = 1$	(1)	138	120	108	
						(155)	128	90	80	56
					Smooth $K_t = 1$	(150)	123	100	88	
						(110)	76	68	65	

TABLE 3.05115 SMOOTH AND NOTCHED FATIGUE STRENGTH OF ANNEALED PLATE AND SOLUTION TREATED AND AGED SHEET AND PLATE AT ROOM TEMPERATURE

NONFERROUS ALLOYS

REVISED: DECEMBER 1975

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

Source	(34, Figures 11, 12 and 13)		
Alloy	Ti-6Al-6V-2Sn		
Method	Axial Load R = 0.1		
Form and Condition	Stress Conc.	Test Temp. F	Fatigue Strength ksi at Cycles
			10 ⁴ 10 ⁵ 10 ⁶ 10 ⁷
0.1 in sheet annealed F _{tu} = 164 ksi F _{ty} = 155 ksi	Smooth	RT	160 125 110 102
	K _t = 1	450	130 112 100 95
	Notch	RT	50 30 28 28
	K _t = 4.2	450	53 28 24 24
0.125 in sheet solution treated and aged F _{tu} = 181 ksi F _{ty} = 177 ksi	Smooth	RT	- 120 114 114
	K _t = 1	RT	45 31 30 30
	Notch	RT	
	K _t = 4.2		

SMOOTH SPECIMEN

NOTCHED SPECIMEN

TABLE 3.05116 SMOOTH AND NOTCH FATIGUE STRENGTH OF ANNEALED AND SOLUTION TREATED AND AGED SHEET TESTED AT ROOM TEMPERATURE AND 450F

Source	(40)							
Alloy	Ti-6Al-6V-2Sn							
Form	0.020, 0.100 and 0.125 inch sheet							
Condition	Mill annealed (1300 to 1400F), R. T. F _{ty} = 158 ksi							
Method	Stress Ratio	Temp. (F)	Fatigue Strength, ksi					
	A R		At Cycles					
			10 ⁴ 10 ⁵ 10 ⁶ 10 ⁷					
Axial Load	0.82	0.1	RT	Smooth	(155)(a)	125	110	103
				K _t = 1				
	Notched	52	32	28	28			
	0.6	0.25	RT	Smooth	-	125	115	110
K _t = 1								
	0.82	0.1	450	Smooth	128	114	103	97
K _t = 1				54	28	24	24	
				Notched				
				K _t = 4				

(a) Values in () are extrapolated.

TABLE 3.05117 SMOOTH AND NOTCHED FATIGUE STRENGTH OF ANNEALED SHEET TESTED AT R. T.

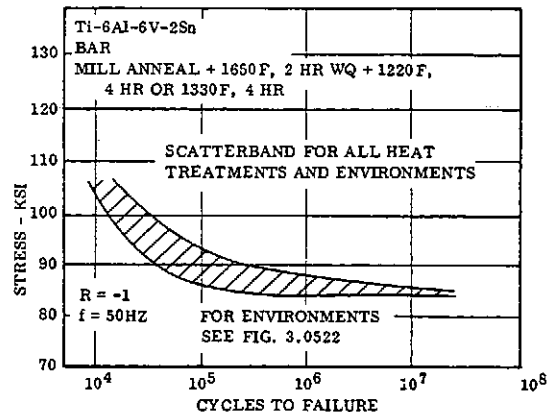


FIG. 3.05118 ROTATING BEAM FATIGUE LIFE CURVE FOR THREE HEAT TREATED CONDITIONS OF BAR TESTED IN SIMULATED HUMAN BODY ENVIRONMENTS. (26, Fig. 46)

NONFERROUS ALLOYS

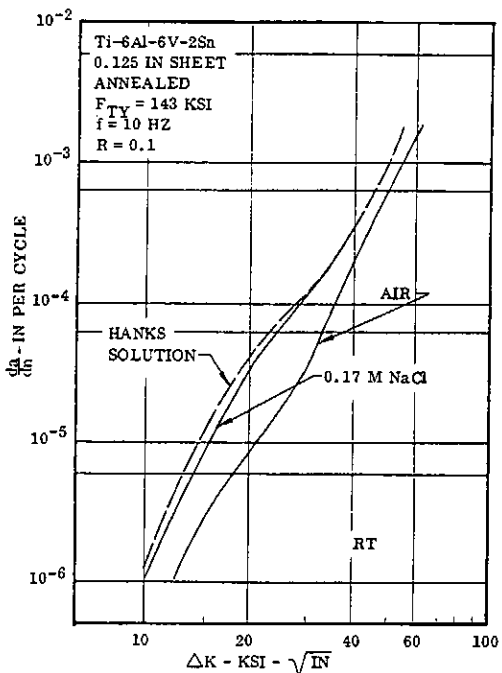
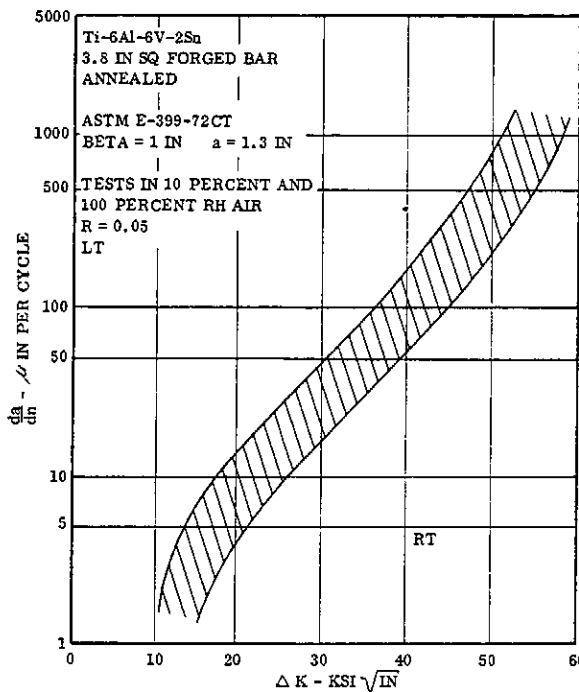


FIG. 3.0522 EFFECT OF SIMULATED HUMAN BODY ENVIRONMENTS ON FATIGUE CRACK PROPAGATION RATES OF ANNEALED SHEET. (26, Fig. 5)



Ti
6 Al
6 V
2 Sn

Ti-6-6-2

FIG. 3.0524 FATIGUE CRACK GROWTH RATES IN HUMID AIR FOR ANNEALED FORGING. (30, Tables B-1, 2, 3, 4 and C-1, 2, 3, 4)

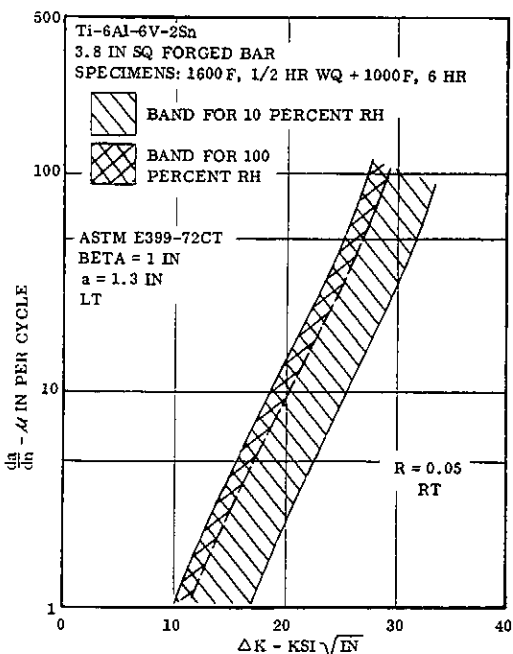


FIG. 3.0523 FATIGUE CRACK GROWTH RATES IN HUMID AIR FOR SOLUTION TREATED AND AGED SPECIMENS FROM FORGING. (30, Tables B-1, 2, 3, 4 and C-1, 2, 3, 4)

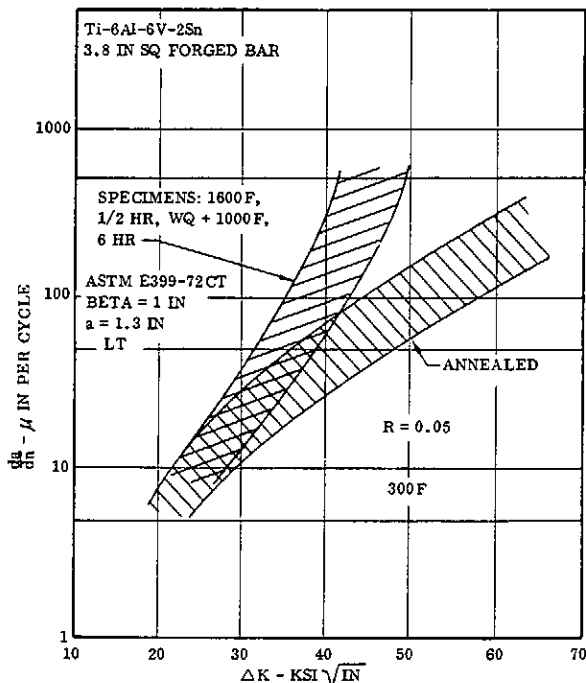


FIG. 3.0525 FATIGUE CRACK GROWTH RATES AT 300 F FOR ANNEALED TREATED AND SOLUTION TREATED AND AGED SPECIMENS FROM FORGING. (30, Tables E-1 thru E-11)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

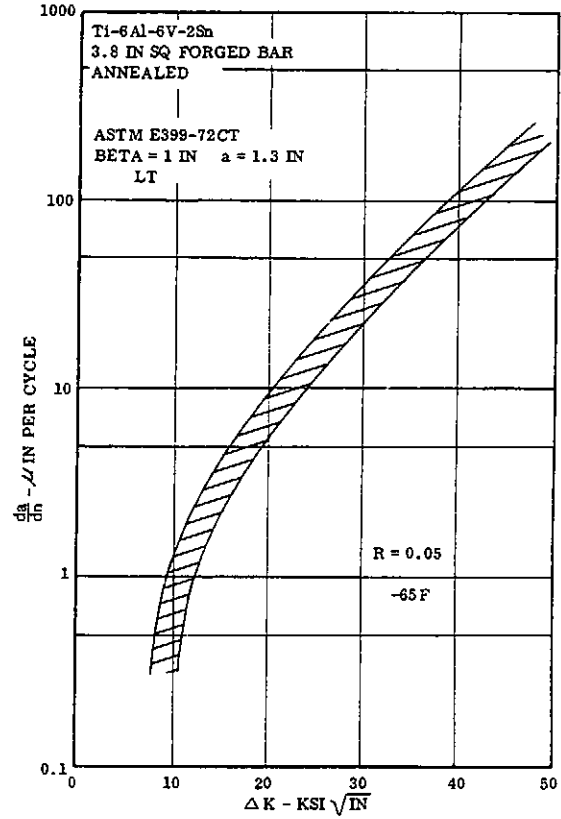


FIG. 3.0527 FATIGUE CRACK GROWTH RATES AT -65F FOR ANNEALED FORGING. (30, Tables D-1, 2, 3, 4, 5)

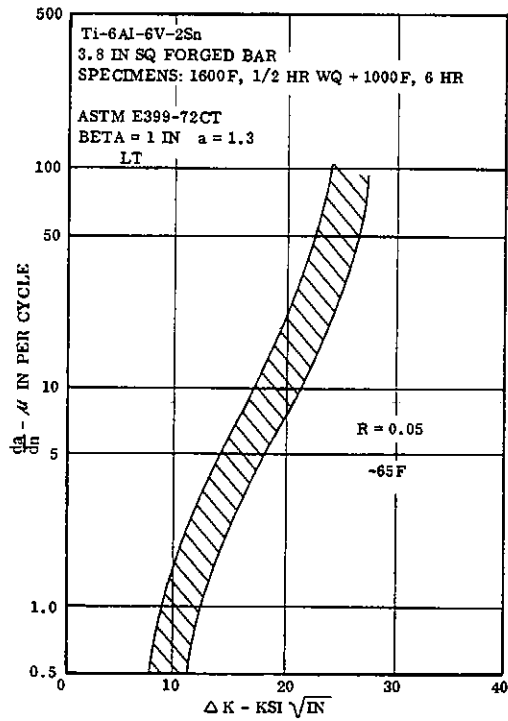


FIG. 3.0526 FATIGUE CRACK GROWTH RATES AT -65F FOR SOLUTION TREATED AND AGED SPECIMENS FROM FORGING. (30, Tables D-6, 7, 8, 9, 10)

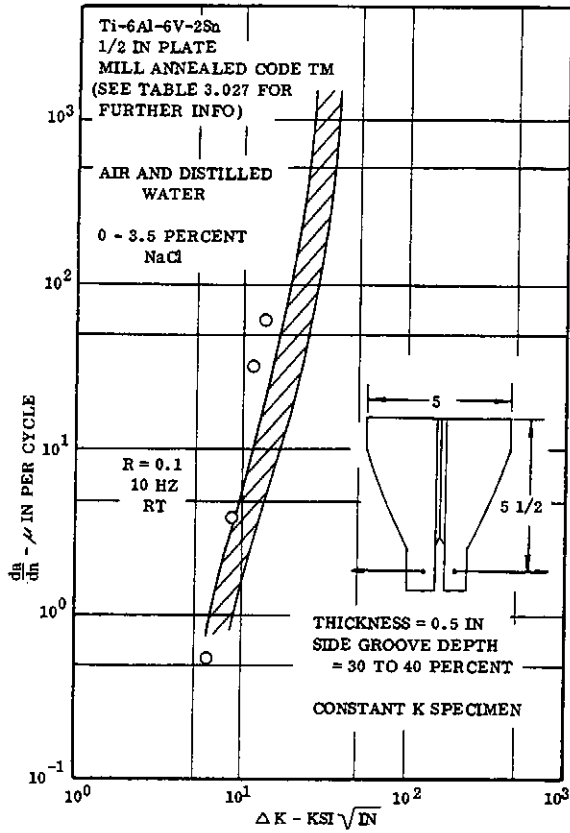


FIG. 3.0528 FATIGUE CRACK GROWTH RATES FOR ANNEALED PLATE IN AIR AND SALT WATER. (36, Fig. 86)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

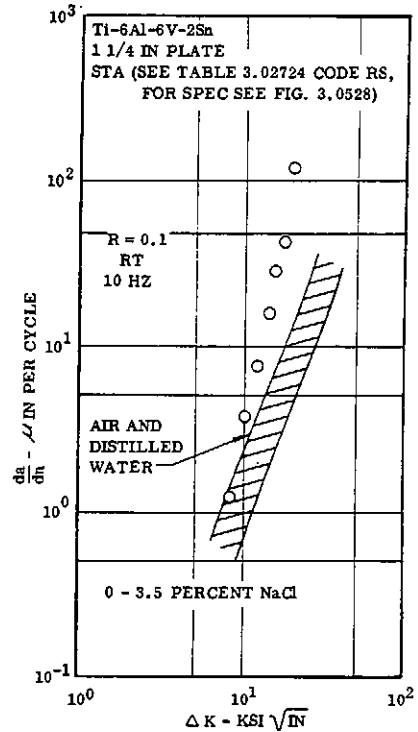


FIG. 3.0529 FATIGUE CRACK GROWTH RATES FOR BETA PROCESSED, SOLUTION TREATED AND AGED PLATE TESTED IN AIR, DISTILLED WATER AND SALT WATER. (36, Fig. 87)

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

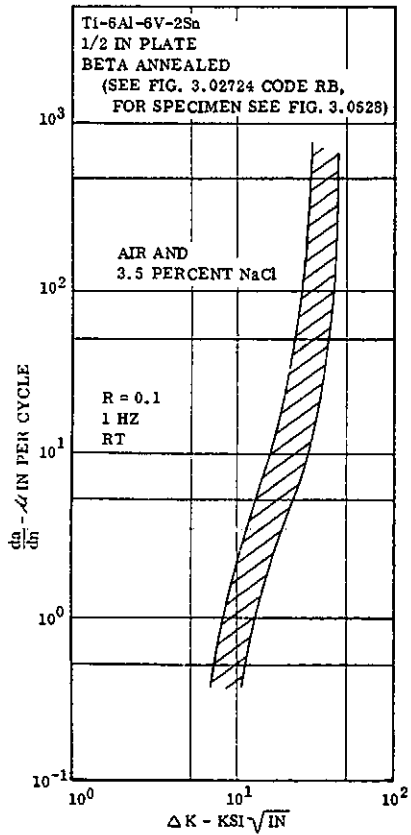


FIG. 3.05210 FATIGUE CRACK GROWTH RATES FOR BETA ANNEALED PLATE IN AIR AND SALT WATER. (36, Fig. 89)

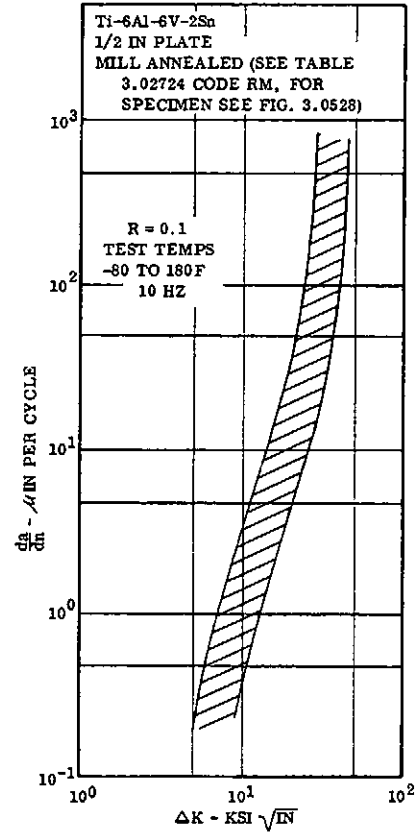


FIG. 3.05211 FATIGUE CRACK GROWTH RATES AT VARIOUS TEMPERATURES FOR ANNEALED PLATE. (36, Fig. 93)

NONFERROUS ALLOYS

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

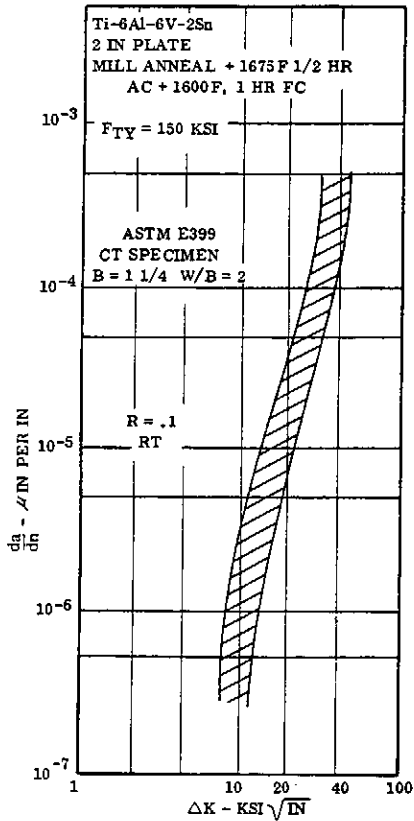


FIG. 3.05212 FATIGUE CRACK GROWTH RATES FOR SPECIMENS CUT FROM PLATE AND GIVEN TWO ANNEALING TREATMENTS. (37, Fig. A-3)

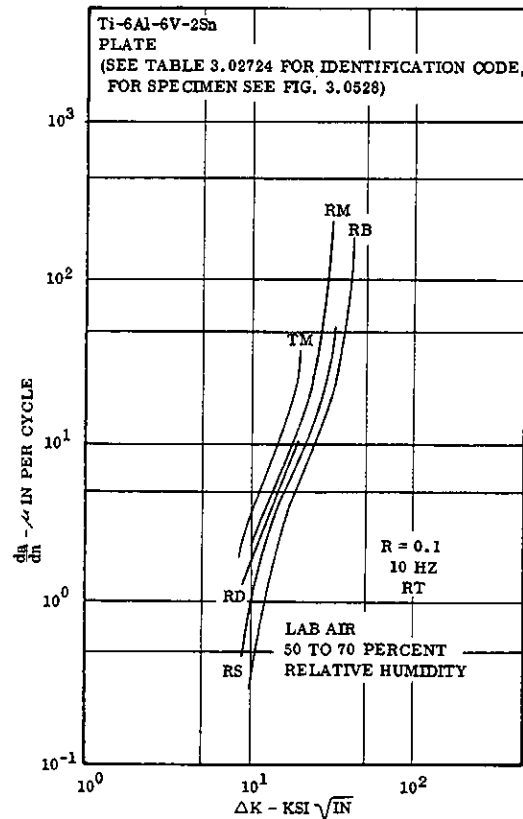


FIG. 3.05213 AVERAGE FATIGUE CRACK GROWTH RATES FOR PLATE GIVEN SEVERAL HEAT TREATMENTS AND TESTED IN LABORATORY AIR. (36, Fig. 92)

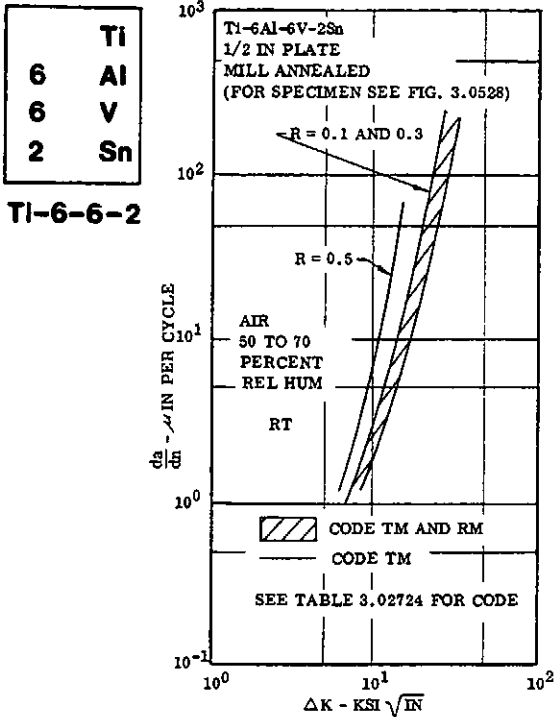


FIG. 3.05214 FATIGUE CRACK GROWTH RATES FOR ANNEALED PLATE AT SEVERAL R RATIOS TESTED IN LABORATORY AIR. (36)

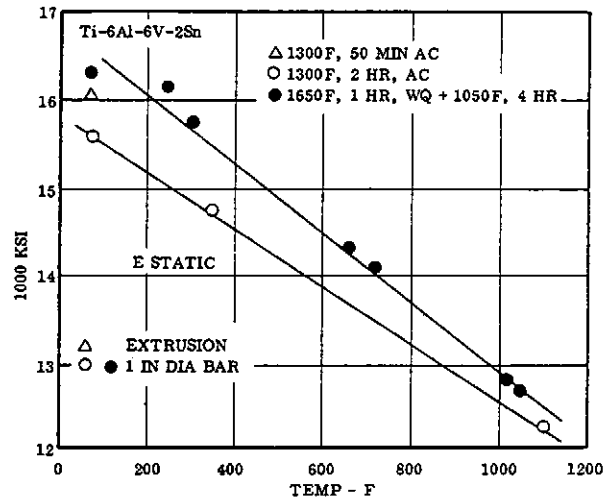


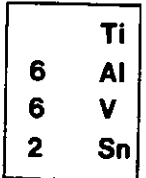
FIG. 3.062 MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES. (1)(14)

Source	(47, Table 4)											
Alloy	Ti-6Al-6V-2Sn											
Form	Start as 6 in dia. billet reduced in three steps to 1-1/4 in thick disk											
Forge Temp.	1725F (Beta forge) (1)						1665F (Alpha + beta forge)					
Solution temp. F	Direct quench		1525		1650		Direct quench		1525		1650	
Age temp - F	1000	1100	1000	1100	1000	1100	1000	1100	1000	1100	1000	1100
F _m - ksi	200	195	190	176	207	195	200	187	192	178	203	193
F _{ty} - ksi	188	188	178	166	193	183	192	180	181	170	194	184
e - percent	7	8	10	14	7	9	5	10	9	13	8	8
RA - percent	20	25	21	36	16	24	11	27	25	39	20	20
W/A in-lb/in ²	74	88	108	285	72	88	68	92	80	106	49	102

(1) 1675F = Beta transus

TABLE 4.0122 TENSILE PROPERTIES AND PRECRACKED CHARPY VALUES FOR ALPHA + BETA AND FOR BETA FORGED DISKS

Source	(23, Table 3)			
Alloy	Ti-6Al-6V-2Sn			
Form	9 in dia. billets press upset at 2000F to reductions shown to 1 in thick pancakes			
Condition	Pancakes: S. T. 1600F WQ + 1000F, 4 hr.			
2 Stage upset red. percent	50 + 0	50 + 10	50 + 25	50 + 40
F _{tu} - ksi	181	185	184	188
F _{ty} - ksi	167	166	166	170
e - percent	3.2	4.5	4.2	5.5
RA - percent	7.4	10.4	9.6	9.6



Ti-6-6-2

TABLE 4.0123 EFFECT OF UPSET DEFORMATION FOR BETA FORGING ON ROOM TEMPERATURE TENSILE PROPERTIES

Source	(23, Table 13)					
Alloy	Ti-6Al-6V-2Sn					
Form	Landing gear wheel forging					
Condition	Finish forging: 1600F, 1 hr WQ + 1000F, 4 hr AC					
Forge	Pot 1675F + extrude 2000F + block and finish as indicated					
Block - F	1700		1700		1950	
Finish - F	1700		1950		1700	
Location	Wall	Rim	Wall	Rim	Wall	Rim
F _{tu} - ksi	196	188	178	178	184	164
F _{ty} - ksi	179	173	156	161	165	164
e - percent	8	9	5	7	4	6
RA - percent	15	21	10	15	8	14

TABLE 4.0124 EFFECT OF FORGING TEMPERATURES ON ROOM TEMPERATURE TENSILE PROPERTIES OF LANDING GEAR WHEEL FORGING

Source	(35, Table 14)				
Alloy	Ti-6Al-6V-2Sn				
Form	Full Scale Nose Wheel Isothermal Creep Forged. In-100 Alloy Die and Work Piece at 1650F.				
Condition	Forge + WQ + 1050F, 4 hr.		Forge + WQ + 1650F, 1/2 hr. WQ + 1050F, 24 hr		
Location	3	1	2	3	4
F _{tu} - ksi	185	200	187	190	190
F _{ty} - ksi	172	192	180	185	180
e - percent	10	4.5	5.5	7.0	5.0
RA - percent	27	8	15	21	20

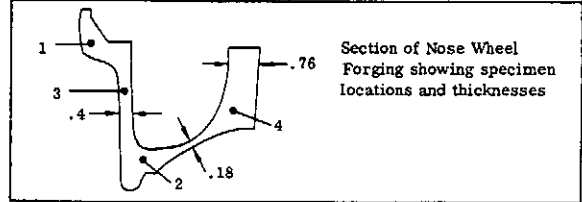


TABLE 4.0126 TENSILE PROPERTIES AT ROOM TEMPERATURE OF ISOTHERMALLY FORGED AND HEAT TREATED NOSE WHEEL.

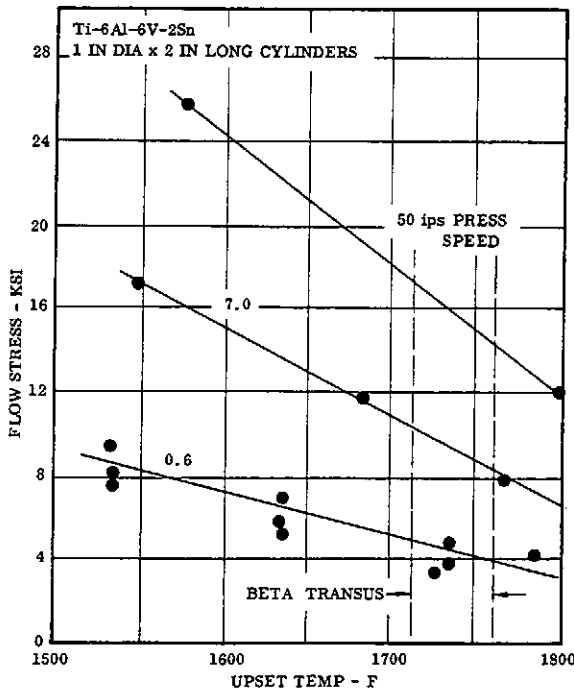


FIG. 4.0125 EFFECT OF UPSET TEMPERATURE AND PRESS SPEED ON FLOW STRESS. (35, Fig. 80)

Source	(44, Table 9)			
Alloy	Ti-6Al-6V-2Sn			
Form	0.35 inch Plate Mill Annealed			
Condition	As Welded			
Weld Type	Manual GTA	Plasma	Auto. GTA	Electron
	Matching Filler	Arc	Matching Filler	Beam
F _{tu} - ksi	172	173	175	173
F _{ty} - ksi	153	156	158	156
e (2 in) percent	4	4	4	5

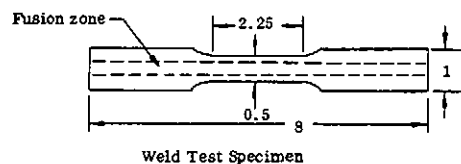


TABLE 4.0312 TENSILE PROPERTIES AT ROOM TEMPERATURE FOR WELDS MADE BY SEVERAL PROCESSES WITH MATCHING FILLER

NONFERROUS ALLOYS

REVISED: DECEMBER 1975

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

Source	(44)				
Alloy	Ti-6Al-6V-2Sn				
Form	0.35 in Plate, Annealed				
Condition	Auto. GTA Weld				
Filler	Ti 75A	Ti 75A + Ti-6-6-2	Ti-6-6-2	Ti-6-6-2	Ti-6-6-2
Post Weld Treatment	None	None	None	1400F, 4 hrs.	1400F, 4 hr +500F, 1000 hr
F _{tu} - ksi (1)	168	172	175	159	162
F _{ty} - ksi	146	156	158	147	147
e (2 in) percent	4	4	4	12	9
K _{Ic} - ksi√in(2)	(68)	(62)	44	(57)	54
(1) For specimen see Table 4.0312.					
(2) ASTM E-399, values in () not valid because of insufficient specimen thickness. Crack at weld center.					

TABLE 4.0313 TENSILE PROPERTIES AND PLANE STRAIN FRACTURE TOUGHNESS FOR GTA WELD METAL FROM SEVERAL FILLERS

Source	(6)										
Alloy	Ti-6Al-6V-2Sn										
Form	0.1 inch Sheet (0.14 O ₂ , 0.014 N ₂ , 0.004 H ₂ , 0.02C, 0.91 Fe)										
Condition	1625F, 1/2 hr + 1200F, 2 hr AC	1625F, 1/2 hr. WQ + 1200F, 2 hr. AC + Weld				1625F, 1/2 hr, WQ + Weld + 1200F, 2 hr, AC					
Filler Wire (3)	Not Welded	6Al-6V-2Sn		6Al-4V		6Al-6V-2Sn		6Al-4V		Ti-55A	
Weld Location (1)		C	E	C	E	C	E	C	E	C	E
F _{ty} - ksi (2)	172	192	191	174	185	192	191	189	182	159	188
Notch (4)											
Strength - ksi	63	30	28	38	35	27	28	24	35	80	43
(1) Location C - weld center, E - weld edge											
(2) Weld yield strength estimated from Hardness tests											
(3) Filler 6Al-6V-2Sn cut from parent sheet Filler Ti-55A (0.11 O ₂ , 0.009 N ₂ , 0.007 H ₂ , 0.03C, 0.11 Fe)											
(4) Center crack specimen W - 3 inch, 2a ₀ = 1 in											

TABLE 4.0314 CRACK STRENGTH OF TIG WELDED SHEET USING SEVERAL FILLER WIRES

Source	(38)							
Alloy	Ti-6Al-6V-2Sn							
Form	1.5 in Plate							
Location	Parent Metal				EB Weld HAZ			
Direction	TL		LT		TL		LT	
Condition (1)	A	B	A	B	A	B	A	B
K _{Ic} - ksi√in	40	33	49	36	36	35	40	34
(1) A - as received, mill annealed B - Stress relieved 1350F, 4 hr								

TABLE 4.0315 PLANE STRAIN FRACTURE TOUGHNESS OF THE HEAT AFFECTED ZONE OF ELECTRON BEAM WELDS

Source	(65, p.17-S)											
Alloy	6Al-6V-2Sn-Ti											
Form	0.125 in Sheet											
Condition	GTA Weld Single Pass											
Filler Metal	6Al-6V-2Sn						6Al-4V					
Location	Base Metal			HAZ (c)			FZ (b)			FZ		
Postweld(d)												
Heat Treat	A	B	C	A	B	C	A	B	C	A	B	C
F _{ty} - (ksi)	161	144	154	-	-	-	127	105	150	-	-	-
Charpy V(a) (ft-lbs)	229	1215	340	116	889	214	96	1020	242	181	810	186
(a) Sub thickness (0.125 in.) Charpy.												
(b) Fusion Zone												
(c) Heat Affected Zone												
(d) A - As welded B - 1350F, 6 hr, F.C. + 1700F, 3 hr. F.C. + 1350F, 3 hr. F.C. C - 1500F, 1 hr + cool 250F/hr to 1200F, 2 hr. A.C. + 1000F, 2 hr., A.C.												

TABLE 4.0316 CHARPY IMPACT ENERGY FOR SHEET WELDMENTS MADE WITH TWO FILLERS AND GIVEN DIFFERENT HEAT TREATMENTS.

NONFERROUS ALLOYS

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

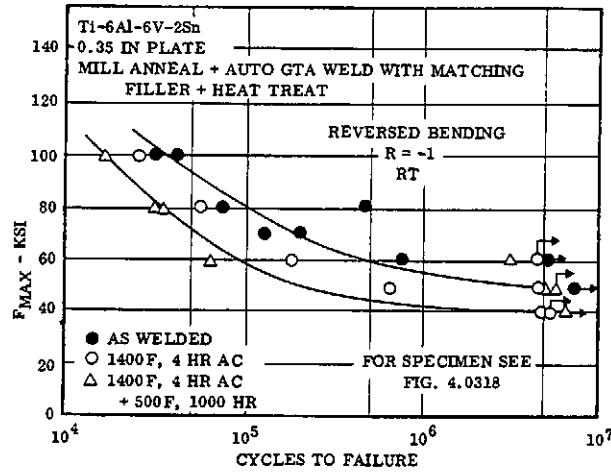


FIG. 4.0317 FATIGUE STRENGTH OF AUTO GTA WELDS WITH MATCHING FILLER GIVEN POST WELD HEAT TREATMENTS. (44, Fig. 80)

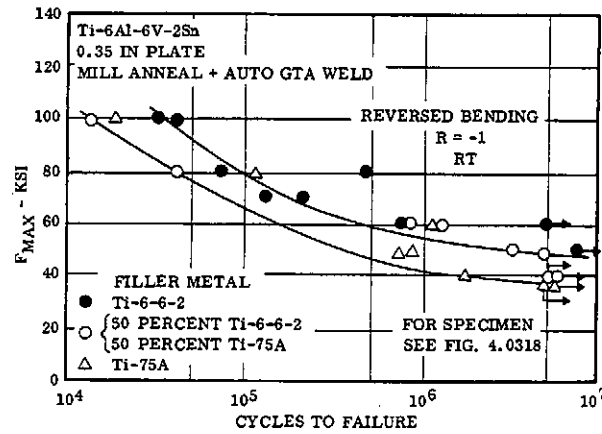


FIG. 4.0318 FATIGUE STRENGTH FOR AUTO GTA WELDS MADE WITH DIFFERENT FILLERS. (44, Fig. 76)

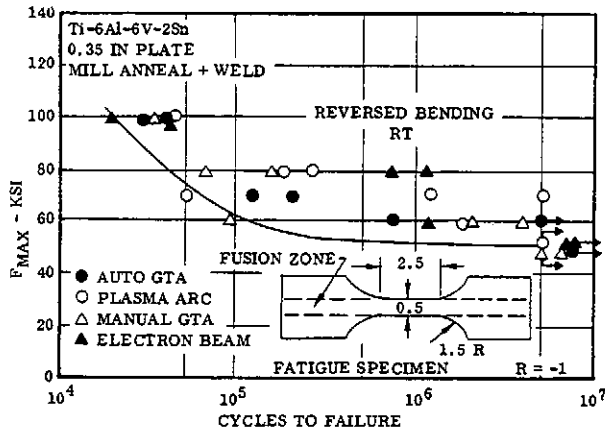


FIG. 4.0319 FATIGUE STRENGTH FOR SEVERAL DIFFERENT WELDS MADE IN ANNEALED PLATE WITH MATCHING FILLER. (44, Fig. 62)

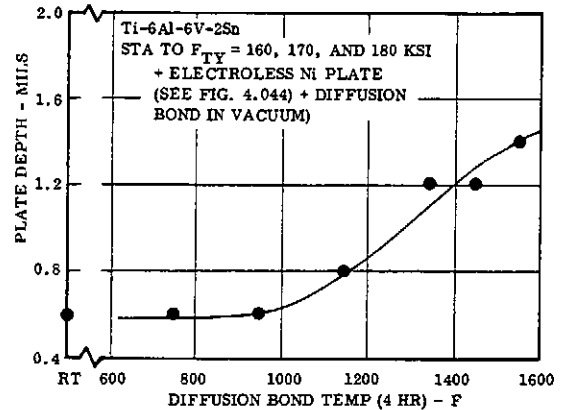


FIG. 4.042 EFFECT OF DIFFUSION BONDING TEMPERATURE ON ELECTROLESS Ni PLATE DEPTH. (27, Table 3)

	Ti
6	Al
6	V
2	Sn

TI-6-6-2

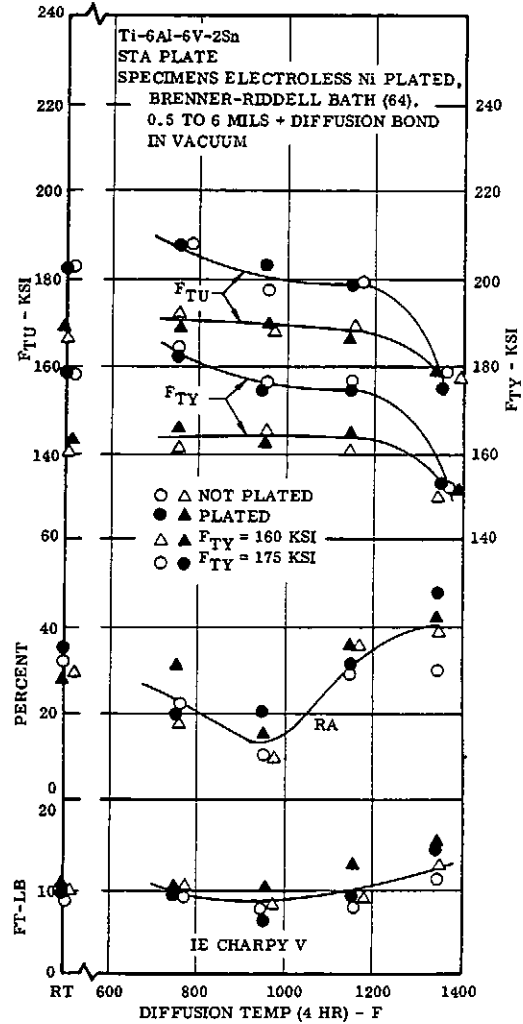


FIG. 4.044 EFFECT OF DIFFUSION BONDING TEMPERATURE ON ROOM TEMPERATURE TENSILE AND IMPACT PROPERTIES OF ELECTROLESS Ni PLATED STOCK HEAT TREATED TO TWO STRENGTH LEVELS. (27, p. 12)

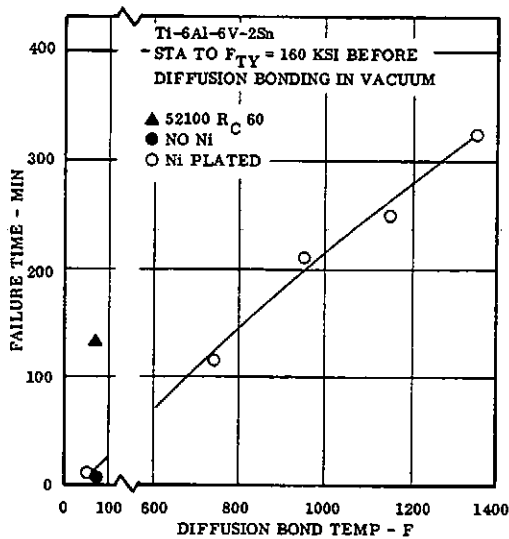
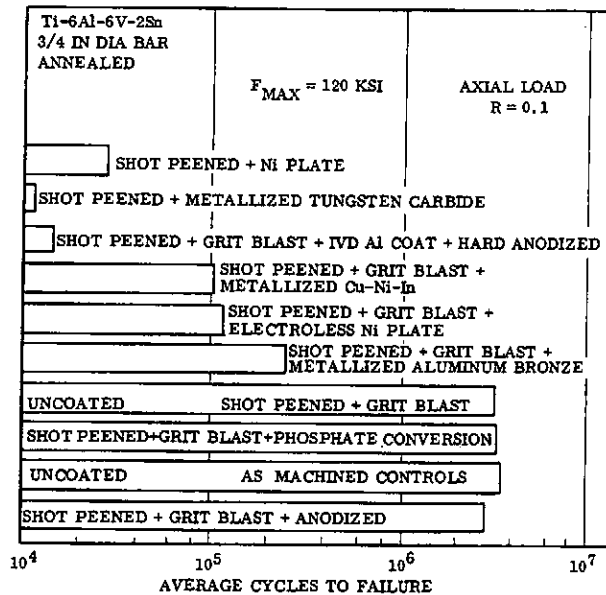


FIG. 4.043 EFFECT OF DIFFUSION BOND TEMPERATURE APPLIED TO ELECTROLESS NICKEL PLATE ON THE FAILURE TIME IN A MODIFIED McMILLAN WEAR TESTER. (22, Table 4)

REVISED: DECEMBER 1975

NONFERROUS ALLOYS



	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

FIG. 4.045 EFFECT OF VARIOUS FRETTING RESISTANT COATINGS ON FATIGUE LIFE OF ANNEALED BAR. (33, Fig. 18)

REFERENCES

1. Timet Titanium Engineering Bulletin No. 10, "Properties Ti-6Al-6V-2Sn", TMCA, N.Y., N.Y. (September 1967).
2. Simenz, R.F. and Maloritto, W.L., "Evaluation of Large Titanium Forgings", Lockheed California Co., AFML TR-65-206 (July 1965).
3. Erbin, E.F., "Evaluation of High Strength Titanium Forgings", Technical Service Dept., TMCA, N.Y., N.Y. (March 7, 1963).
4. Budington, R.A., "Heat Treatability of Ti-6Al-6V-2Sn in Forged Sections up to Four Inches Thick", TMCA, New Jersey (1966).
5. Hickey, C.F., Jr., "Effect of Microstructures and Cooling Rate on Mechanical Properties of Ti-6Al-6V-2Sn", ASTM Journal of Materials, Vol. 1, No. 1 (March 1966, page 89).
6. Greenlee, M.L., "Effect of Heat Treated Tensile Strength on Sharp Notch Strength of One Inch Ti-6Al-6V-2Sn Plate", Technical Service Dept., TMCA, N.Y., N.Y. (August 1963).
7. "Development of High Strength Ti-6Al-6V-2Sn Alloy Plate", Technical Service Dept., TMCA, N.Y., N.Y. (January 1962).
8. Romine, H.E., "Fracture Toughness Study of Ti-6Al-6V-2Sn Titanium Alloy Sheet 0.1 inch Thick for Possible Application in the Construction of Welded Solid Propellant Motor Cases", NWL Report No. 1839, U.S. Naval Weapons Lab., Dahlgren, VA. (February 4, 1963).
9. Jones, M.H., Unpublished data, NASA-Lewis Research Center, Cleveland, Ohio (1967).
10. Desisto, T.S. and Hickey, C.F., "Low Temperature Mechanical Properties and Fracture Toughness of Ti-6Al-6V-2Sn", ASTM, Vol. 65 (1966), page 641.
11. Jones, M.H., NASA-Lewis Research Center, data to be published.
12. "Thick Section Fracture Toughness", Boeing-North American, ML-TDR-64-236, Contract No. AF33(657) 11461, Sponsored by FAA (October 1964).
13. Desisto, T.S., Carr, F.L. and Larson, F.R., "The Influence of Section Size on the Mechanical Properties and Fracture Toughness of 7075-T6 Aluminum, 6Al-6V-2Sn Titanium and AISI 4340 Steel", Proc. ASTM, Vol. 63 (1963), page 768.
14. Brockett, R.M. and Gottbrath, J.A., "Development of Engineering Data on Titanium Extrusion for Use in Aerospace Design", Lockheed, California Co., AFML-TR-67-189, AF Contract No. AF33(615)-5080 (July 1967).
15. Bubsey, R.T., NASA, Lewis Research Center, Cleveland, Ohio, data to be published.
16. Stone, L.H. and Freedman, A.H., "Cyclic Hot Stress Corrosion of Titanium Alloys", Northrup Corporation, Norair Division, Technical Summary Report, NOR 67-151, Contract AF33(615)-3642 (June 1967).
17. Melville, A.G., "Fracture Toughness Investigation of Two Heat Treatable Titanium Alloys", Report WGT-065 Thiokol Chemical Corporation, Bingham City, Utah (January 16, 1963).
18. Mowbray, D.F., "Fatigue Design Data for the Titanium Alloy, Ti-6Al-6V-2Sn", General Electric, KAPAL-3158 (May 20, 1966).

	Ti
6	Al
6	V
2	Sn

Ti-6-6-2

19. "Fatigue Properties of Ti-6Al-6V-2Sn Plate", TMCA Technical Department, West Caldwell N.S. (1967).
20. Judy, R.W., Jr., and Goode, R.S., "Stress Corrosion Cracking Characteristics of Alloys of Titanium in Salt Water", NRL Report 6564 (July 21, 1967).
21. Progress Report on Delayed Fracture Characteristics of Titanium Alloys, Lockheed California Corporation, LR 19741 (May 16, 1966).
22. Aircraft Designers Handbook for Titanium and Titanium Alloys, Office of Supersonic Transport Development F.A.A. and Air Force Materials Laboratory, AFML-TR 67-142 (March 1967).
23. Travis, W.C., Jr., "Manufacturing Techniques for Precision Forging of Titanium Alloy Landing Wheels for the F-111 Aircraft", Fairchild Industries, AFML-TR-71-163 (September 1971).
24. DeSisto, T.S., "Fracture Toughness Measurements of Three Titanium Alloy Extrusions", AMMRC TR-73-31 (July 1973).
25. Chait, R. and DeSisto, T.S., "The Fracture Toughness of Three Heavy Section Titanium Alloys", AMMRC PTR-72-5 (October 1972).
26. Levy, M., Dawson, D.B., Sklover, G.N. and Seitz, D.W., Jr., "The Corrosion Behavior of Titanium Alloys in Chloride Solutions: Materials for Surgical Implants", AMMRC TR-72-33 (November 1972).
27. Levy, M. and Morrossi, J.L., "Wear and Erosion Resistant Coatings for Titanium Alloys in Army Aircraft", AMMRC TR-70-36 (December 1970).
28. Hickey, C.F., Jr. and Fopiano, P.J., "Heat Treatment Effects on the Mechanical Properties in Ti-6Al-6V-2Sn", ASTM Journal of Testing and Evaluation, Vol. 1, No. 2 (1973), p. 166.
29. Fopiano, P.J. and Hickey, C.F., Jr., "Comparison of the Heat Treatment Responses of Three Commercial Titanium Alloys", ASTM Journal of Testing and Evaluation, Vol. 1, No. 6 (1973) p. 514.
30. Fital, C.F. and Beck, E.J. "Development of Fracture Mechanics Data for 6Al-6V-2Sn Titanium Alloy", Martin Marietta, NASA CR 134209 (January 1974).
31. Humphrey, J.R., "Manufacturing Methods for Casting Large Close Tolerance Titanium Shapes for Aircraft Structural Applications", REM Metals Corp., Report IR-162-0 (IX) (November 1973).
32. Weiss, V., Sengupta, M., and Lal, D., "The Significance of Material Ductility and Load Carrying Capacity of Peak Performance Structures", Syracuse University, Naval Air Systems Command Contract No. N00019-71-C-0102 (January 1972).
33. Padberg, D.J., "Fretting Resistant Coatings for Titanium Alloys", McDonnell Aircraft Co., AF Contract F33615-70-C-1538, AFML TR-71-184 (September 1971).
34. Marrocco, A.G., "Room and Elevated Temperature Fatigue Characteristics of Ti-6Al-4V and Ti-6Al-6V-2Sn Sheet Alloys", Grumman Aircraft Engineering Corp. Note No. FSN-AD2-06-68.1 (October 1968).
35. Watmough, T., Kulkarni, K.M. and Parikh, N.M., "Isothermal Forging of Titanium Alloys Using Large Precision Cast Dies", IIT Research Institute, AFML TR-70-161 (July 1970).
36. Amateau, M.F., Hanna, W.D. and Kendall, E.G., "F-15 Program Final Report: Ti-6Al-6V-2Sn and Ti-6Al-4V Fatigue Crack Propagation", The Aerospace Corp., Report No. ATR-72(9990)-3 (September 29, 1971).
37. DeMay, S., "Improved Fracture Toughness of Titanium", Grumman Aerospace Corp., Navy Contract No. N62269-73-C-0127, Final Report (June 1973).
38. Heitzman, R.J., Grumman Aerospace Corp., private communication with Brown, W.F., Jr. (1974).
39. Marrocco, A., "Evaluation of Annealed Ti-6Al-4V and Ti-6Al-6V-2Sn Extrusions", Grumman Aircraft Engineering Corp., Report No. M&P-1-TR-70-1 (September 22, 1970).
40. Marrocco, A.G., "Fatigue Characteristics of Ti-6Al-4V and Ti-6Al-6V-2Sn Sheet and Plate", Grumman Aircraft Engineering Corp., Report No. EMG-81 (November 18, 1969).
41. Grimm, T.C. and Nowak, W.J., Jr., "Tolerance of Annealed 6Al-6V-2Sn Alloy to Hydrogen Embrittlement", Hydrogen in Metals, American Society for Metals (1973)
42. Titanium Alloys Handbook MCIC-HB-02 (December 1972 p. 1-5; 72-1).
43. Sommer, A.W. and Martin, G.R., "Design Allowables for Titanium Alloys", North American Rockwell Corp., A. F. Contract AF33(615)-3979, AFML-TR-69-161 (June 1969).
44. Wu, K.C., "Correlation of Properties and Microstructure in Welded Titanium Alloys", Northrup Corp., Aircraft Div., AFML TR-73-202 (September 1973).
45. Piper, D.E. and Fager, D.N., "The Relative Stress Corrosion Susceptibility of Titanium Alloys in the Presence of Hot Salt", ASTM STP 397 (1966), p. 31.
46. Stacher, G.W., "Titanium Panel Extrusion Program", Lockheed-Georgia Co., AFML TR-69-74 (May 1969).
47. Allen, M.M., "Advanced Titanium Alloy Disk Production", Pratt and Whitney Aircraft, AFML TR-71-78 (February 1972).
48. Hyler, W.S. and Deel, O., "Review of Fatigue Data on Titanium Alloys", DMIC Tech. Note (January 26, 1968).
49. AMS 4971 A (May 1, 1970).
50. AMS 4978 A (May 15, 1971).
51. AMS 4979 (May 1, 1970).
52. AMS 4936 (November 15, 1971).
53. AMS 4981 C (May 15, 1971).
54. Hickey, C.F., Jr., "Some Observations on the Hardenability of Ti-6Al-6V-2Sn, Met. Trans. Vol. 1 (June 1970), p. 1775.
55. Finden, P., "Metallurgical Stability of the Titanium Alloys 8Al-1Mo-1V, 6Al-6V-2Sn and 6Al-4V", Boeing Airplane Co., Commercial Division, Document No. D6-24515 (December 15, 1979).
56. Marrocco, A.G., "Evaluation of Ti-6Al-4V and Ti-6Al-6V-2Sn Forgings", Grumman Aircraft Engineering Corp., EMG-82 (November 27, 1968).
57. Strohecker, D.E., "Forming of Titanium and Titanium Alloys", DMIC Report 238 (September 1, 1967).
58. Hemming, H.J., "Beat Forging of Titanium Alloys", DMIC Report S-24 (August 1, 1968).
59. Kulkarni, K.M., Watmough, T., Parikh, N.M., Stawarz, D. and Malatesta, M., "Isothermal Forging of Titanium Alloy Main Landing Gear Wheels and Nose Wheels", IIT Research Inst., AF Contract F33615-70-C-1533, AFML Report TR 72-270 (December 1972).
60. Vazquez, A.J. and Hayes, A.F., "Isothermal Forging of Reliable Structural Forgings", Ladish Co., AF Contract F33615-71-C-1264, AFML Report TR 74-123 (June 1974).
61. Hall, J.A. and Pierce, C.M., "Improved Properties of Ti-6Al-6V-2Sn through Microstructure Modification", AFML Report TR-70-312 (February 1971).
62. Turner, H.C., McDonnell Aircraft Co., St. Louis, Mo. private communication with Brown, W.F., Jr. (1974).
63. Daykin, R.P., Ladish Co., Cudahy, Wis., private communication with Brown, W.F., Jr. (1974).
64. U.S.A. Patent No. 2,253,283 (December 5, 1950).
65. Simpson, R.P. and Wu, K.C., "Microstructure-Property Control with Postweld Heat Treatment of Ti-6Al-4V-2Sn", Welding Research Supp. p. 13-S (January 1974).