1 GENERAL

This is a near-beta alloy in which the high temperature beta-phase is stabilized by nominal alloying additions of 2 weight percent iron and 10 weight percent vanadium. The 3 weight percent aluminum is a natural ingredient in the master alloy and acts as a solid solution strengthener for the low temperature precipitating alpha-phase. The alloy exhibits excellent hot die isothermal forgeability above its beta transus temperature of about 1460 F. Net or near-net forged shapes are produced at lower temperatures and pressures than required for Ti-6Al-4V alloy, a significant cost saving feature which lowers die material cost and extends die life, reduces energy consumption, simplifies handling, and minimizes forging cleanup. Properties of the alloy can vary with section thickness, and from center to surface of a given sized section. However, guaranteed property minimums can be met in sections up to 5 inch, with a wide range of strengths and corresponding toughness achievable through the appropriate selection of forging parameters and heat treatment. The alloy is used principally in nonfatigue airframe structural component applications. The alloy is available as billet, bar, plate, and forgings and is covered by United States Patent No. 3,802,877, dated April 9, 1974.

1.01 Commercial Designation

Ti-10V-2Fe-3Al Alloy.

1.02 Alternate Designation

Ti-10-2-3.

1.03 Specifications

Boeing Material Specification BMS-7-260 (6-18-79).

1.04 Composition

1.041 Producer's specified composition, Table 1.041.

1.042 User's specified composition, Table 1.042.

1.043 Oxygen content. The guaranteed maximum oxygen content is set at 0.13 weight percent in order to ensure high toughness. The effect of oxygen content on room temperature strength and toughness is given in Table 3.02728.

1.044 Iron segregation, see 1.092.

1.05 Heat Treatment

1.051 Solution treat + age (high strength condition): 1400 F, 1 hr, WQ + 950 F, 8 hr, AC.

1.052 Solution treat + overage (intermediate strength condition): 1350 to 1400 F, 1 hr, AC or faster + 1075 F, 8 hr, AC.

1.053 For enhanced fracture toughness it is recommended that finish forging or rolling be done above the beta transus temperature (at approximately 1500 to 1550 F). For enhanced ductility (reduction in area and elongation) in the aged condition, finish forging or rolling below the beta transus temperature is recommended. In general, heat treatment is accomplished by subtransus solution treatment (1350 to 1400 F), followed by aging at 950 F for the high strength condition, or by overaging at 1050 to 1150 F for the intermediate strength condition. The latter overaging cycle is found to be compatible with plate fabrication and results in higher fracture toughness. Solution temperature and quench rate, and aging temperature and heat up rate all affect aging response. Aged strength is increased by increasing solution temperature, by rapid (water) quenching, and by decreasing aging temperature and aging heat up rate. Solution time has only a minor effect compared to thickness (cooling rate) and aging parameters. For thin sections in the high strength condition, approximately half of the yield strength is derived from aging.

Aging of this alloy is rapid, and overaging is recommended for enhanced fracture toughness and reduced property scatter. Aging at 900 F or higher also provides insurance against the formation of omega-phase.

1.054 An intensive study of the effects of heat treated microstructure on tensile properties and fatigue crack-growth rates has been made by Terlinde, Duerig, and Williams (16)(17)(18). Some of their results are presented in Figures 3.02110, 3.02127, 3.02144, and 3.0511 through 3.0516 and Table 3.02150. Their general findings are that for a constant volume fraction of primary alpha-phase it is possible to vary the yield strength over a wide range. It is also possible to reach comparable yield levels for different volume fractions of primary alpha-phase by an appropriate choice of aging temperatures and times as well as heat up rates to the aging temperature. Increasing the volume fraction of primary alpha-phase reduces ductility at comparable yield strengths for the alpha-aged condition. Only the beta solution treated conditions with no primary alpha-phase are an exception. They have lower ductilities than alpha + beta solution treated conditions. Heat treating to produce omega-aged microstructures results in the lowest ductilities at comparable yield strength levels. The differences between the alpha + beta solution treated and alpha-aged, the beta solution treated and alpha-aged, and the omega-aged microstructures are qualitatively related to different fracture modes. Microstructures from forgings with elongated primary alpha-phase structures exhibit lower ductilities than those with globular primary alpha-phase microstructures. Fatigue crack-growth characteristics are unaffected by the alpha-aged microstructure, but are far different from the omega-aged microstructures (see Figures 3.0511 through 3.0516).

No such study has been made of the fracture toughness characteristics for varying microstructures, though generally it would be expected that those producing high ductility would suffer reduced fracture toughness.

1.06 Hardness

1.061 The hardening response of beta solution treated and quenched hot-rolled plate aged in molten salt is presented in Figure 1.062. The observed trends are explained (18) in terms of the precipitation reactions that occur at the aging temperature (refer to 2.01213 on heat treat phase transformations). At 392 F, the only precipitating phase is isothermal omega-phase; no overaging is observed within the time range shown. At 573 F, a transition from isothermal omega-phase to uniform alpha-phase gradually occurs during hardening, but the transition is incomplete within the time span shown and peak hardness is not achieved. At 752 F, isothermal omega-phase is replaced by uniform alpha-phase plus patchy sympathetic alpha-phase at an early time. The transition is nearly complete after 10 minutes, but still no overaging is observed. At 932 F, the hardening phase is entirely sympathetic alpha-phase; hardening is rapid and overaging occurs in about 10 minutes.

The hardening response for plate alpha + beta solution treated at various temperatures and then aged in molten salt at 932 F is shown in Figure 1.063. Peak hardness decreases with decreasing solution treat temperature as the time to achieve peak hardness increases.

The hardening response of the same hot-rolled plate directly aged in molten salt or beta solution treated and then aged in molten salt, are compared in Figure 1.064. The directly aged material achieves notably lower peak hardness and at slightly longer aging times.

The hardness of isothermally forged pancakes is shown in Figure 1.065 for beta solution treatment prior to molten salt aging, and in Figure 1.066 for alpha + beta solution treatment prior to molten salt aging. For the forging schedules used, only small effects are observed for the beta solution treated material (Figure 1.065), but appreciable differences in hardness are observed for the alpha + beta solution treated material (Figure 1.066).

1.062 Effect of aging time on hardness of hot-rolled plate, beta solution treated and aged at several temperatures, Figure 1.062.

1.063 Effect of 500 F aging time on hardness of hot-rolled plate, alpha + beta solution treated and aged at 932 F, Figure 1.063.

1.064 Effect of 932 F aging time on hardness of hot-rolled plate either directly aged or beta solution treated and then aged, Figure 1.064.

1.065 Effect of 932 F aging time on hardness of beta solution treated isothermally forged pancakes, Figure 1.065.

1.066 Effect of 932 F aging time on hardness of alpha + beta solution treated isothermally forged pancakes, Figure 1.066.

1.067 Effect of solution temperature and cooling rate on aged hardness of 1-inch cubes, Table 1.067.

1.07 Forms and Conditions Available

Billet, bar, plate, and forgings (23). Forging billet and bar are supplied as hot worked or in an annealed condition suitable for further forging (1). Plate is normally supplied in the annealed, descaled and pickled condition (1).

1.08 Melting and Casting Practice

Consumable-electrode vacuum-arc melted.

1.09 Special Considerations

1.091 Stability. Retained room temperature tensile properties following creep exposure at 600 F, 100 ksi, for 100 hr are shown in Tables 3.045 and 3.046. Some instability under this exposure condition is indicated by changes in strength and ductility measured after exposure.

1.092 Iron segregation. Inhomogeneity, principally in in the form of iron segregation on both a micro and macroscale, has been observed in billets from large (28 inch) ingots (12). Variations in iron content as large as 0.5 weight percent have been reported (12) with a corresponding variation in beta transus temperature of 75 F. The center of the billet generally exhibits the highest iron content and the mid-radius position the lowest. Depression of the beta transus temperature in the iron-rich areas produces zones void of, or lean in alpha-phase, known as beta flecks. The resultant variation in structure can produce substantial variations in mechanical properties. Refinements in melting procedures have reportedly disposed of this problem (1)(12)(24).

1.093 Deformation assisted martensite. Because this is a "lean" modestly stabilized beta alloy, martensitic decomposition of the beta-phase can be accomplished by externally stressing the solution treated and quenched material (15). The temperature below which deformation assisted martensite is formed is designated M_d, and for this alloy M_d lies above room temperature. As a result, stress assisted martensite (orthorhombic α'') can be produced at room temperature.

The production of α'' causes an inflection in the tensile stress-strain curves of Figure 3.0211. The stress needed to initiate the α'' reaction corresponds to the onset of the inflection (premature departure from linearity) and is dependent on the solution treatment temperature. In the beta solution treated condition (1562 F, WQ), a stress of only 35 ksi is required to produce a deviation from linearity in the stress-strain curve. In the alpha + beta solution treated and quenched conditions, the beta matrix contains retained primary alpha-phase. Although the primary alpha-phase is too coarse to directly affect strength, it does increase the chemical stability of the surrounding beta matrix because of solute partitioning between the alpha and beta phases. Thus, as the solution temperature is reduced, the amount of primary alpha-phase is increased, the M_s temperature is further suppressed and M_d approaches room temperature. A greater stress is needed to initiate the α'' distortion, and the stress level of the inflection in the stress-strain curves rises. Finally, when the beta composition is rich enough in Fe and V to depress M_d below room temperature, the material deforms by slip, no α'' is formed, and the stress-strain curve has no inflection. While the production of α'' is evidenced by its effect on the flow curves of Figure 3.0211, no results are available regarding its effect on other mechanical properties.

Strain induced martensite has been observed at the surfaces of solution treated and quenched products, but it is local and believed to be due to quenching stresses. Surface microstructure of solution treated and quenched products cannot therefore, be considered typical of the general product.

1.094 Aging heat up rate. Heat up rate to the aging temperature will affect the transformed structure and mechanical properties of this alloy as discussed in sections 1.054 and 2.01213 and illustrated by the results in Figure 3.02127 and Table 3.02146.

2 PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS

2.01 <u>Thermal Properties</u>

2.011 Melting range.

2.012 Phase changes. Beta transus, approximately 1460 F (1).

2.0121 Time-temperature-transformation diagrams.

2.01211 Schematic time-temperature-transformation (TTT) diagram for Ti-10V-2Fe-3Al beta solution treated, quenched, and rapidly heated to the aging temperature, Figure 2.01211.

2.01212 Dependence of primary alpha volume fraction on solution treatment temperature, Figure 2.01212.

2.01213 Heat treat phase transformations. Solution treatment establishes beta-phase composition and stability after quenching. Solution treatment above the beta transus temperature dissolves all primary alpha-phase and leads to a strong propensity for decomposition both during and after quenching. Full recrystallization of the beta matrix is rapid, but grain growth is very slow. Solution treatment in the alpha + beta field enriches the beta-phase in Fe and V (thereby stabilizing the beta-phase) and equilibrates the volume fraction of primary alpha-phase to a value characteristic of the solution temperature. Recrystallization of the beta matrix and subsequent grain growth are sluggish, but adjustment of primary alpha-phase is rapid. Propensity for decomposition decreases with decreasing alpha + beta solution temperature.

On quenching from the solution treatment temperature, no athermal martensite (neither hexagonal α' nor orthorhombic α'') is produced, indicating the M_s temperature of this alloy is below room temperature. Strain-induced martensite forms at the quenched surfaces, but is local and only the result of quenching strains. The only general transformation that takes place on quenching is that of athermal omega-phase which appears as coherent, uniformly distributed, nondescript, extremely fine particles. Material solution treated above the beta transus temperature will, after quenching, consist of recrystallized beta-phase with a fine distribution of athermal omega-phase. Alpha + beta solution treated and quenched material will consist of coarse globular primary alpha-phase surrounded by a metastable beta-phase-plus-athermal omega-phase matrix.

Isothermal aging reactions are schematically illustrated in Figure 2.01211 for material, beta solution treated, quenched, and rapidly heated to the aging temperature. At aging temperatures below about 500 F, isothermal omega-phase is uniformly developed. The reaction is anomalously rapid, seemingly too rapid to be a diffusion controlled process, though it apparently is. Above about 500 F, three regimes of alpha-phase precipitation exist. At low aging temperatures (500 F to 700 F), isothermal omega-phase particles are uniformly precipitated in short times, but continued aging of the beta + omega dispersion leads to a uniform alpha-phase precipitation. Although not proven, it would appear that the uniform alpha-phase is nucleated upon the isothermal omega-phase particles. At high aging temperatures (above about 850 F), alpha-phase is precipitated as very long and flat (lenticular) plates nonuniformly distributed at grain boundaries, subgrain boundaries, other alpha + beta interfaces, etc. Growth rates at these high temperatures are high, and therefore the number of nucleation sites is low. The particles tend to be coarse and adopt a preferred or free growth morphology consisting of high aspect ratio plates or laths. These precipitates are referred to as sympathetic, or auto-catalytic alpha-phase, such terms referring to any precipitation process which is locally enhanced by extant, or preexisting precipitation products. In this case, the presence of a first alpha plate locally enhances or encourages the nucleation of others. In the intermediate temperature regime from 700 F to 850 F (dubbed the transition region), both uniform and sympathetic alpha-phase are precipitated. The sympathetic alpha-phase appears as patches, or islands of plates within the beta matrix which is dispersed with uniform alpha-phase. Increasing the aging temperature within this regime increases the frequency of the patches. The patchy microstructure is apparently quite stable and persists to rather long aging times. To reiterate, aging in the transition region begins with isothermal omega-phase precipitation. The isothermal omega-phase then transforms to uniform alpha-phase at a constant but rather slow rate. Competing with this, however, is a nonuniform sympathetic alpha-phase plate reaction which bears no relation to the preceding beta-phase-plus-isothermal omega-phase dispersion. Although the initial nucleation may be slow, once a plate is nucleated, subsequent nucleation occurs quickly and a rapidly grown patch is formed. In zones where this second reaction occurs, the isothermal omega-phase-to-uniform alpha-phase reaction is suppressed. In zones where the sympathetic alpha-phase reaction is slow to get started, the isothermal omega-phase-to-uniform alpha-phase reaction proceeds and quickly stabilizes the zone. Thus is the competition. As the aging temperature is increased, the statistics become biased in favor of the sympathetic alpha-phase reaction. In the high temperature, or sympathetic alpha-phase regime, a grain boundary alpha-phase reaction occurs, which becomes more pronounced as the aging temperature approaches the beta transus temperature. During the early stages of aging, the reaction is discontinuous; but after longer times a continuous grain boundary alpha-phase layer is developed, and this layer thickens as the temperature is increased. The intragranular alpha-phase particles likewise become coarser and fewer in number as the temperature is increased. As the grain boundary alpha-phase layer thickens, a Ti- depleted, alpha-phase free zone surrounding the alpha-phase layer develops. It is not unusual to observe inclusions in the alpha-phase layer, these inclusions having a statistical preference for the grain boundaries.

These transformation reactions have been observed for beta solution treated and quenched material brought rapidly to the aging temperature in molten salt. During slow heating to the aging temperature, as in air aging, more time is spent in the low temperature regime before the aging temperature is reached. The result is that the uniform alpha-phase reaction is favored. Thus at a given aging temperature, uniform alpha-phase will be produced on air aging where molten salt aging would produce sympathetic alpha-phase. Although grain boundary alpha-phase is developed upon aging in air or salt, salt aging produces a much more pronounced and continuous layer.

Solution treating in the alpha + beta field affects the beta-phase composition (as a function of the volume percent primary alpha-phase). Subsequent aging trends are generally the same as those described above for beta solution treated and quenched material, however, the temperature regimes are shifted. The omega-phase and uniform alpha-phase reactions are suppressed in favor of sympathetic alpha-phase by increasing the primary alpha-phase content, thereby forming a more solute rich beta-phase. For example, at temperatures where only uniform alpha-phase would be produced in beta solution treated and quenched material, only sympathetic alpha-phase will be developed in a matrix of beta-phase plus primary alpha-phase for alpha + beta solution treated and quenched material. Similarly, where only isothermal omega-phase is produced in beta solution treated and quenched material, isothermal omega-phase plus uniform alpha-phase will be produced in a matrix of beta-phase plus primary alpha-phase of the alpha + beta solution treated and quenched product. Triplex heat treatments (double solution treating prior to aging, or solution treating plus double aging) have been used in an attempt to adjust the alpha-phase morphology in such a way as to balance the ductility and fracture toughness response. It is believed this can be accomplished with the proper mix of globular (for improved ductility) and platelet (for improved fracture toughness) primary alpha-phase structures. Results for double solution treating plus aging in Table 3.02727 show no improvement over conventional solution treating plus aging (for example, compare the results of Table 3.02727 with the 1400 F, 1/2 hr, AC + 950 F, 8 hr, AC condition in Table 3.02723).

2.013 Thermal conductivity.

2.014 Thermal expansion. Almost all solids expand on heating and contract on cooling. Although the thermal expansion of metals depends largely on the basic modulus of the metal, the thermal expansion may vary in a complex manner with the alloy chemistry, the structural change, and transformation characteristics of the alloy. The tendency for titanium-base alloys to expand on heating may be nullified by its contraction due to phase changes as the temperature approaches the alpha-beta transus. Consequently, the thermal expansion coefficients of titanium-base alloys cannot simply be extrapolated from low temperature results (6).

The average coefficient of thermal expansion for plate from room temperature to 800 F is 5.4 x 10^{-5} in./in./F. For forgings, the average value above the 800 F to 2100 F range is about 4.8 x 10^{-5} in./in./F. This alloy is quite similar to other titanium alloys (1).

2.0141 Thermal expansion of beta processed forging, Figure 2.0141.

2.015 Specific heat.

2.016 Thermal diffusivity.

2.02 Other Physical Properties

2.021 Density, 0.168 lb/in.^{3}. The density of this alloy is approximately 5 percent greater than Ti-6Al-4V but about 4 percent less than the beta alloys Ti-13V-11Cr-3Al and Ti-8Mo-8V-2Fe-3Al.

2.022 Electrical properties.

2.023 Magnetic properties.

2.024 Emittance.

2.025 Damping capacity.

2.03 Chemical Environments

The behavior of this alloy in aggressive chemical environments has essentially not been investigated, presumably because its intended use is in benign environments. The reader, nevertheless, should refer to the discussion of chemical environmental effects on titanium alloys in section 2.03 of alloy chapter 3725. A single finding shows essentially no effect of 3.5 percent NaCl solution on fatigue crack-growth rates above 2 x 10^{-6} in./cycle at R = 0.05 at frequencies ranging from 1 to 30 Hz for an airframe structural forging (Compare Figure 3.0510 with Figure 3.059).

2.04 Nuclear Environments

3 MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 Producer's guaranteed minimum mechanical properties, Table 3.011.

3.012 User's specified minimum mechanical properties, Table 3.012.

3.02 Mechanical Properties at Room Temperature

3.021 Tension – Stress-strain diagrams – Tension properties, see also 3.031, 3.06, and 4.01.

3.0211 Room temperature true stress-true strain curves for hot-rolled plate water quenched from several solution temperatures, Figure 3.0211.

3.0212 Room temperature true stress-true strain behavior of hot-rolled plate solution treated plus aged to three microstructural conditions, Figure 3.0212.

3.0213 Room temperature tensile properties of directly aged hot-rolled plate, Table 3.0213.

3.0214 Room temperature tensile properties of duplex aged hot-rolled plate, Table 3.0214.

3.0215 Comparison of directionality of room temperature tensile properties of hot-rolled plate beta solution treated plus aged and alpha + beta solution treated plus aged to fixed yield strength levels, Table 3.0215.

3.0216 Room temperature tensile properties of as-forged and heat treated hot die, alpha-beta forged pancake forging, Table 3.0216.

3.0217 Statistical variation of room temperature tensile properties of hot die press forged pancakes, Table 3.0217.

3.0218 Room temperature tensile properties of as-forged and heat treated hot die, beta forged airframe structural forgings, Table 3.0218.

3.0219 Effect of solution treatment temperature on room temperature tensile properties of 1-inch thick hot-rolled plate solution treated plus aged at 932 F in air or liquid salt, Figure 3.0219.

3.02110 Effect of solution treatment temperature on room temperature tensile yield strength, true fracture stress and true fracture strain of hot-rolled plate solution treated (primary alpha contents from 30 percent to 0 percent) and aged to maximum strength attainable at 932 F, Figure 3.02110.

3.02111 Effect of supratransus solution anneal temperature on room temperature tensile properties of pressed 1-inch square, beta-forged plus solution treated and aged, Figure 3.02111.

3.02112 Effect of subtransus solution anneal temperature on room temperature tensile properties of pressed 3-inch square, beta forged plus solution treated and aged, Figure 3.02112.

3.02113 Effect of solution treatment time on room temperature tensile properties of 1-inch thick hot-rolled plate solution treated and aged, Figure 3.02113.

3.02114 Effect of solution anneal time and aging temperature on room temperature tensile properties of 1/4-inch and 1-inch plate, Table 3.02114.

3.02115 Effect of solution treatment time and quench rate and of aging temperature on room temperature tensile properties of alpha-beta forged bar solution treated at 1400 F and aged, Figure 3.02115.

3.02116 Effect of solution treatment quench rate and of aging temperature on room temperature tensile properties of alpha-beta forged bar solution treated at 1350 F and aged (low center ductility of water quenched product due to high level of segregated iron at bar center), Figure 3.02116.

3.02117 Effect of aging temperature and test direction on room temperature tensile properties of forged bar, Figure 3.02117.

3.02118 Effect of aging temperature and test direction on room temperature tensile properties of forged bar, Figure 3.02118.

3.02119 Effect of aging temperature on room temperature tensile properties of alpha-beta forged bar solution treated and aged (low center ductility due to high level of segregated iron at bar center), Figure 3.02119.

3.02120 Effect aging temperature on room temperature tensile properties of alpha-beta forged bar solution treated and aged (low center ductility due to high level of segregated iron at bar center), Figure 3.02120.

3.02121 Effect of aging temperature on room temperature tensile properties of alpha-beta forged bar solution treated and aged, Figure 3.02121.

3.02122 Effect of aging temperature on room temperature tensile properties of alpha-beta forged bar double solution treated and aged, Figure 3.02122.

3.02123 Effect of aging temperature on room temperature tensile properties of solution treated and aged 3-inch round forged bar beta processed with final reduction below the beta transus, Figure 3.02123.

3.02124 Effect of aging temperature on room temperature tensile properties of solution treated and aged 3-inch round forged bar beta processed, Figure 3.02124.

3.02125 Effect of aging time on room temperature tensile properties of 1-inch thick hot-rolled plate beta solution treated at 1562 F and aged in salt at 932 F, Figure 3.02125.

3.02126 Effect of aging time on room temperature tensile properties of 1-inch thick hot-rolled plate alpha + beta solution treated at 1328 F and aged in salt at 698 F, Figure 3.02126.

3.02127 Effect of 932 F age time on room temperature yield strength and true fracture strain of hot-rolled plate containing 10 percent constant primary alpha content, heated at two rates to the aging temperature, Figure 3.02127.

3.02128	Effect of aging time on room temperature tensile properties of 1-inch thick hot-rolled plate alpha + beta solution treated at 1436 F and aged in air at 932 F, Figure 3.02128.
3.02129	Effect of aging time on room temperature tensile properties of 1-inch thick hot-rolled plate alpha + beta solution treated at 1436 F and aged in salt at 932 F, Figure 3.02129.
3.02130	Effect of aging time on room temperature ultimate tensile strength of plate of two thicknessses, Figure 3.02130.
3.02131	Effect of aging time on room temperature tensile properties of pressed 5-inch square, beta forged plus directly aged at 950 F, Figure 3.02131.
3.02132	Effect of aging time on room temperature tensile properties of pressed 5-inch square, beta forged plus directly aged at 1000 F, Figure 3.02132.
3.02133	Effect of aging time on room temperature tensile properties of pressed 5-inch square, beta forged plus solution treated and aged at 950 F, Figure 3.02133.
3.02134	Effect of aging time on room temperature tensile properties of pressed 5-inch square, beta forged plus solution treated and aged at 1000 F, Figure 3.02134.
3.02135	Effect of section thickness on room temperature tensile properties of pressed squares, as-beta forged, Figure 3.02135.
3.02136	Effect of section thickness on room temperature transverse tensile properties of pressed squares, beta forged plus directly aged at 1000 F, Figure 3.02136.
3.02137	Effect of section thickness on room temperature longitudinal tensile properties of pressed squares, beta forged plus directly aged at 1000 F, Figure 3.02137.
3.02138	Effect of section thickness on room temperature tensile properties of pressed squares, beta forged plus solution treated, Figure 3.02138.
3.02139	Effect of section thickness on room temperature tensile properties of pressed squares, beta forged plus solution treated and aged at 900 F, Figure 3.02139.
3.02140	Effect of section thickness on room temperature longitudinal tensile properties of pressed squares, beta forged plus solution treated and aged at 950 F, Figure 3.02140.
3.02141	Effect of section thickness on room temperature transverse tensile properties of pressed squares, beta forged plus solution treated and aged at 950 F, Figure 3.02141.
3.02142	Effect of section thickness on room temperature tensile properties of pressed squares, beta forged plus solution treated and aged at 1000 F, Figure 3.02142.
3.02143	Effect of section thickness on room temperature transverse tensile properties of pressed squares, beta forged plus solution treated and aged at 1000 F, Figure 3.02143.
3.02144	Relation between tensile yield strength and true fracture strain or reduction in area for various microstructures, Figure 3.02144.
3.02145	Room temperature tensile properties for selected microstructures, Table 3.02145.
3.02146	Room temperature strength, elongation, and true fracture strain for selected microstructures, Table 3.02146.
3.02147	Effect of microstructure on room temperature tensile properties of hot-rolled plate solution treated and aged to an approximate common yield strength level, Table 3.02147.
3.02148	Loss in room temperature ductility arising from a continuous grain boundary alpha layer in the microstructure of an isothermally forged pancake, Table 3.02148.
3.02149	Room temperature tensile properties of three solution treated and aged isothermally forged pancakes, Table 3.02149.
3.02150	Room temperature tensile properties of isothermally forged pancake solution treated or duplex solution treated prior to aging to nearly equal yield strength level, Table 3.02150.
3.022	Compression–Stress-strain diagrams–Compression properties, see 3.032.
3.023	Impact.
3.0231	Room temperature Charpy V impact energy of heat treated bar, Table 3.0231.
3.024	Bending.
3.025	Torsion and shear, see 3.035.
3.026	Bearing, see 3.036.
3.027	Stress concentration.
3.0271	Notch properties.
3.02711	Room temperature smooth and mild-notch tensile strengths for heat treated bar, Table 3.02711.
3.0272	Fracture toughness, see also Figures 4.0132 and 4.0135 and Table 4.031.
	A wide range of strength/toughness combinations can be achieved in this alloy depending on the composition, processing, and heat treated condition of the product, as illustrated in Figure 3.02721. Some specific effects are represented in Figures and Tables 3.02722 through 3.02728. Superior fracture toughness accrues from beta processing with limited alpha/beta work and oxygen content limited to 0.13 weight percent.
3.02721	Summary representation of room temperature plane strain fracture toughness as a function of tensile yield strength for all products and conditions reported in the reference literature, Figure 3.02721.
3.02722	Room temperature plane strain fracture toughness of heat treated bar, Table 3.02722.
3.02723	Room temperature tensile properties and plane strain fracture toughness of 5/16-inch hot-rolled plate after various heat treatments, Table 3.02723.
3.02724	Effect of section thickness and heat treatment on room temperature tensile yield strength and plane strain fracture toughness of beta forged pressed squares, Figure 3.02724.
3.02725	Effect of die temperature on room temperature strength and toughness of forging, beta forged plus directly aged, Figure 3.02725.
3.02726	Room temperature plane strain fracture toughness of as-forged and heat treated hot die, beta forged airframe structural forgings, Table 3.02726.
3.02727	Room temperature conventional tensile properties and plane strain fracture toughness of heat

3.06 Elastic Properties

3.061 Poisson's ratio.

3.062 Modulus of elasticity.

3.0621 Room temperature ultimate strength and elastic modulus for plate of various thicknesses, beta-rolled and directly aged, Figure 3.0621.

3.0622 Effect of test temperature on tensile elastic modulus of heat treated bar, Figure 3.0622.

3.0623 Room temperature and 600 F tensile elastic modulus for heat treated forging, Table 3.0623.

3.0624 Effect of test temperature on compressive elastic modulus of heat treated bar, Figure 3.0624.

3.0625 Room temperature strength, elastic modulus, and plane strain fracture toughness of electron beam welded plate, Table 4.031.

3.063 Modulus of rigidity.

3.064 Tangent modulus.

3.0641 Typical compressive tangent modulus curves at room temperature, 400 F, and 800 F for heat treated bar, Figure 3.0641.

3.065 Secant modulus.

4 FABRICATION

4.01 Forming

4.011 Hot flow properties. The beta transus of this alloy is only about 1460 F, making it amenable to hot die beta forging at a stock temperature of 1500 to 1550 F with a die temperature at or below 1550 F. Required forge pressure under a forge temperature of 1550 F and a die temperature of 1400 F is comparable to that for Ti-6Al-4V alloy at a forge temperature of 1750 F and a die temperature of 1650 F (see Figures 4.0111 and 4.0112). This advantage derives from the favorable comparison of hot flow stress-strain rate characteristics of this alloy as compared with those for Ti-6Al-4V, as shown in Figure 4.0113.

This alloy is well suited to isothermal forging as indicated by the results in Table 4.0114 and Figures 4.0115 and 4.0116. A strong chill factor is evident from the data in Table 4.0114 Nevertheless, the results in Figures 4.0115 and 4.0116 suggest a much larger plan area for isothermal forging is possible with this alloy compared to Ti-6Al-4V. The slope of the log true stress/log true strain curve for this alloy at 1500 F is not linear as indicated in Figure 4.0117, suggesting this alloy exhibits a mild tendency toward superplasticity. This alloy is very resistant to cracking and good as-forged surfaces generally result from isothermal forging. Use of Acheson and TRW coatings provide excellent surface finishes in most cases.

4.0111 Variation of forge pressure with web thickness for Ti-10V-2Fe-3Al experimental rib-and-web forgings, Figure 4.0111.

4.0112 Variation of forge pressure with web thickness for Ti-6Al-4V and Ti-10V-2Fe-3Al experimental structural shape forgings, Figure 4.0112.

4.0113 Hot flow stress Ti-10V-2Fe-3Al compared to that of Ti-6Al-4V, Figure 4.0113.

4.0114 Results of hot compression tests, Table 4.0114.

4.0115 Temperature dependence of tensile yield strength for Ti-10V-2Fe-3Al and Ti-6Al-4V alloys, Figure 4.0115.

4.0116 Hot compression test results, Figure 4.0116.

4.0117 Strain rate sensitivity of Ti-10V-2Fe-3Al at 1500 F, Figure 4.0117.

4.012 Heat transfer. Table 4.0121 gives the cooling rate in air for various section thicknessses of this alloy in a flat monolithic forging, indicating achievable properties are limited by the quench. Immediate quenching out of the furnace becomes important as section size decreases. Depending on forging section variations, quench delays can be used to provide property uniformity throughout the forging.

4.0121 Heat transfer in flat monolithic forging during air cool, Table 4.0121.

4.013 Forging procedures and effects on properties. The properties of this alloy are strongly dependent on the forging practice employed. In this regard, beta forging is essential for the low strength, high toughness condition.

To balance ductility and toughness in the high strength condition, beta blocking with some alpha/beta finishing is required. The amount of alpha/beta finishing required will depend on the die and forging designs, whether a press or hammer is used, and the metal flow pattern. Experience (1) with billet has indicated that whereas 30 percent alpha/beta reduction provides ductility without seriously affecting K_{Ic}, 60 percent reduction degrades K_{Ic} significantly. That experience holds also in a general way for high strength hand or die forgings. Alpha/beta reduction, therefore, should be limited in the interest of both ductility and toughness. In press forged parts, alpha/beta finishing should be limited to 10 to 25 percent. During alpha/beta hammer forging, adiabatic heating should be avoided or controlled so that local regions do not exceed the desired working temperature.

4.0131 Effect of forging temperature and percent reduction on room temperature tensile properties of forged pancakes, Figure 4.0131.

4.0132 Effect of forging temperature on room temperature tensile yield strength and plane strain fracture toughness of heat treated 1-inch thick upset forgings, Figure 4.0132.

4.0133 Effect of upset forging temperature on room temperature tensile properties of heat treated 1-inch thick upset forgings, Figure 4.0133.

4.0134 Effect of upset forging temperature on room temperature tensile properties of forged plus directly aged 1-inch thick upset forgings, Figure 4.0134.

4.0135 Effect of forging temperature on room temperature tensile yield strength and plane strain fracture toughness of forged plus directly aged 1-inch thick upset forgings, Figure 4.0135.

4.0136 Effect of upset temperature on room temperature tensile properties of 1-inch thick forged upsets, Table 4.0136.

4.0137 Effect of isothermal forging conditions on room temperature tensile properties of solution treated and aged forged pancakes, Table 4.0137.

4.0138 Conversion schedule for 3-inch diameter bar isothermally forged to 0.5-inch thick flat plate for use in processing and heat treatment study reported upon in Tables 4.0139 through 4.01311, Figure 4.0138.

4.0139 Room temperature tensile properties of supratransus processed 3-inch round bar conventionally and isothermally subtransus forged to 0.5-inch thick flat plate and variously heat treated, Table 4.0139.

4.01310 Room temperature tensile properties of supratransus processed 3-inch round bar conventionally and isothermally supratransus forged to 0.5-inch flat plate and variously heat treated, Table 4.01310.

4.01311 Room temperature tensile properties of subtransus processed 3-inch round bar conventionally and isothermally subtransus forged to 0.5-inch thick flat plate and variously heat treated, Table 4.01311.

4.01312 Room temperature tensile and cold deformability properties of hot-rolled bar variously heat treated, Table 4.01312.

4.02 Machining and Grinding

This alloy is somewhat more difficult to machine than Ti-6Al-4V but less difficult than all beta titanium alloys (1). When water quenching is used during heat treatment there can be distortion during machining resulting from locked-in quenching stresses, but because of the alloy's low creep strength at the aging temperature, distortion is not excessive.

4.03 Joining

The weldability of this alloy is judged (7) to be comparable to that for Ti-6Al-4V. It can be electron beam welded using parameters similar to those for Ti-6Al-4V. Data are presented in Table 4.031 for two heat treated conditions. As expected, variations in heat treatment produce significant differences in mechanical properties, but weld properties are generally comparable to those of the base metal.

4.031 Room temperature strength, elastic modulus, and plane strain fracture toughness of electron beam welded plate, Table 4.031.

4.04 Surface Treating

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Alloy	Ti-10V-2Fe-3Al	
Form	Billet, Bar, Plate, and Forgings	
	Weight Percent	
Composition	Min	Max
Al	2.6	3.4
V	9.0	11.0
Fe	1.7	2.2
O		0.13
C		0.05
N		0.05
H		0.015
Other, Each		0.10
Other, Total		0.30
Ti	Balance	

TABLE 1.041. PRODUCER'S SPECIFIED COMPOSITION (1)

Alloy	Ti-10V-2Fe-3Al	
Form	Forgings	
	Weight Percent(a)	
Composition	Min	Max
Al	2.6	3.4
V	9.0	11.0
Fe	1.7	2.2
O		0.13
C		0.05
N		0.05
H		0.015(b)
Y		0.005
Other, Each		0.10
Other, Total		0.30
Ti	Balance	

(a) Check analysis shall be in accordance with AMS 2249.

(b) Hydrogen shall be determined on each lot of the product as shipped.

TABLE 1.042. USER'S SPECIFIED COMPOSITION (22)

Alloy	Ti-10V-2Fe-3Al					
Form	1-inch Cubes					
Solution Temperature	1300 F		1350 F		1375 F	
Cooling Rate from Solution Temp(a)	VC	WQ	VC	WQ	VC	WQ
Aging Treatment	Hardness, R_C(b)					
None	30.3	29.6	35.8	32.4	35.5	30.3
900 F, 8 hr, AC	36.1	38.1	35.0	40.3	35.4	41.2
925 F, 8 hr, AC	33.1	32.8	35.5	38.8	33.2	36.5
950 F, 8 hr, AC	32.7	34.5	35.4	37.0	34.8	37.7

(a) VC = Cool from solution temperature under vermiculate; WQ = Water quench.

(b) Average of eight measurements.

TABLE 1.067. EFFECT OF SOLUTION TEMPERATURE AND COOLING RATE ON AGED HARDNESS OF 1-INCH CUBES (1)

Alloy	Ti-10V-2Fe-3Al								
Form	Forgings and Plate								
				e, percent			RA, percent		
Heat Treatment	Section Size, inch	F_{ty}, ksi	F_{tu}, ksi	L	T	ST	L	T	ST
Solution Treat + Age	≤1	170	180	10	10	–	20	20	–
1400-1425 F, 1 hr, WQ	>1-2	160	170	10	10	–	20	20	–
+ 900-950 F, 8 hr, AC	>2-4	150	160	8	8	8	15	15	12
	>4-5	145	155	8	8	8	15	15	12
Solution Treat + Overage(a)									
1350-1400 F, 1 hr, AC or Faster	≤3	130	140	10	10	–	20	20	–
+1075 F, 8 hr, AC	>3-5	125	135	10	10	8	20	20	15

(a) Higher solution treat + overage strengths can be obtained by using lower overaging temperatures.

TABLE 3.011. PRODUCER'S GUARANTEED MINIMUM MECHANICAL PROPERTIES (1) (22)

Alloy	Ti-10V-2Fe-3Al
Form	Forgings
Condition	Optional Duplex Solution Treat Plus Age $< T_{\beta(Min)}^{(a)}$, 1/2 hr Min, FC or AC + Standard Solution Treat Standard Solution Treat Plus Age 1350 F Min but $< T_{\beta(Min)}^{(a)}$, 1/2 hr Min, WQ + 900 F Min, 8 hr Min, AC
F_{tu}, ksi	180
F_{ty}, ksi	160
e (4D), percent	4
RA, percent	Report for Information Only.
K_{Ic}, ksi$\sqrt{in.}$	40

(a) Minimum beta transus temperature for the lot of forgings.

TABLE 3.012. USER'S SPECIFIED MINIMUM MECHANICAL PROPERTIES (22)

Alloy	Ti-10V-2Fe-3Al			
Form	1-inch Thick Hot-Rolled Plate, Beta Processed With Final 50% Reduction in Alpha-Beta Field Starting From 1292 F			
Direct Aging Treatment	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
None	132	136	7.8	51
932 F, 1.7 hr in Liquid Nitrate Salt	145	154	15.7	53
752 F, 16.7 hr in Liquid Nitrate Salt	158	174	13.5	44
392 F, 166.7 hr in Liquid Nitrate Salt	148	149	16.0	47

TABEL 3.0213. ROOM TEMPERATURE TENSILE PROPERTIES (LONGITUDINAL) OF DIRECTLY AGED HOT-ROLLED PLATE (18)

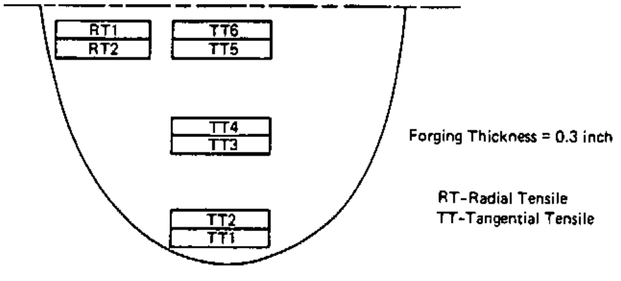
Alloy	Ti-10V-2Fe-3Al			
Form	1-inch Thick Hot-Rolled Plate, Beta Processed With Final 50% Reduction in Alpha-Beta Field Starting From 1292 F			
Condition	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1346 F, 11.7 hr, WQ + 572 F, 5 hr in Liquid Nitrate Salt + 932 F, 76 hr in Liquid Nitrate Salt	148	150	4.4	15.4
1562 F, 2 hr, WQ + 572 F, 2.5 hr in Liquid Nitrate Salt + 932 F, 0.33 hr in Liquid Nitrate Salt	Brittle Fracture	–	–	–
1562 F, 2 hr, WQ + 572 F, 3 hr in Liquid Nitrate Salt + 932 F, 80 hr in Liquid Nitrate Salt	210	211	0.67	3.1

TABLE 3.0214. ROOM TEMPERATURE TENSILE PROPERTIES (LONGITUDINAL) OF DUPLEX AGED HOT-ROLLED PLATE (18)

Alloy	Ti-10V-2Fe-3Al				
Form	1-inch Thick Hot-Rolled Plate, Beta Processed With Final 50% Reduction in Alpha-Beta Field Starting From 1292 F				
Condition	Test Direction	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
Beta Solution Treated, WQ + 932 F, 0.1 hr in Liquid Nitrate Salt	L	192	200	5.5	28.0
Beta Solution Treated, WQ + 932 F, 4 hr in Liquid Nitrate Salt	T	192	203	7.5	4.1
1328 F, 0.83 hr, WQ + 698 F, 16.7 hr in Liquid Nitrate Salt	L	187	206	5.0	11.0
1328 F, 1.7 hr, WQ + 698 F, 13.3 hr in Liquid Nitrate Salt	T	187	213	5.0	10.0

TABLE 3.0215. COMPARISON OF DIRECTIONALITY OF ROOM TEMPERATURE TENSILE PROPERTIES OF HOT-ROLLED PLATE BETA SOLUTION TREATED PLUS AGED AND ALPHA + BETA SOLUTION TREATED PLUS AGED TO FIXED YIELD STRENGTH LEVELS (18)

Alloy	Ti-10V-2Fe-3Al				
Form	Hot Die, Alpha-Beta Forged Pancake Forging				
		RT Tensile Properties			
Condition	Specimen Location	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
As Forged 1425 F, AC (Die Temp 1425 F)	RT1	139.0	153.0	9.5	20.2
	RT2	140.0	152.2	9.5	21.2
	TT6	142.0	156.0	8.8	12.0
	TT5	140.0	154.4	9.5	21.2
	TT4	141.6	155.6	8.1	16.1
	TT3	144.0	157.6	9.5	21.2
	TT2	142.4	155.6	7.4	19.0
	TT1	140.4	153.0	10.2	22.4
1400 F, 1 hr, WQ	RT1	96.8	122.0	34.8	41.4
	RT2	98.0	122.0	30.5	38.5
	TT5	94.0	122.0	34.8	42.3
	TT4	92.8	121.6	33.3	39.7
	TT3	94.0	121.6	32.0	38.8
	TT2	94.0	119.2	30.5	38.8
	TT1	94.0	119.2	30.5	38.8
1400 F, 1 hr, WQ + 950 F, 8 hr, AC	RT2	180.8	190.8	8.1	18.2
	TT6	188.4	197.8	8.1	17.2
	TT5	189.0	197.8	8.1	13.0
	TT4	185.0	194.0	8.1	17.2
	TT3	187.2	196.0	6.7	14.8
	TT2	185.6	193.6	8.1	18.2
	TT1	186.4	196.0	8.1	15.1



Forging Half-Section

TABLE 3.0216. ROOM TEMPERATURE TENSILE PROPERTIES OF AS-FORGED AND HEAT TREATED HOT DIE, ALPHA-BETA FORGED PANCAKE FORGING (2)

Alloy	Ti-10V-2Fe-3Al			
Form	Hot Die Press Forged Pancakes Upset From 1.72 inch to 0.29 inch			
Condition	RT Tensile Properties	Mean, $\overline{X}$	Std Dev, S	Number of Samples, N
As Forged 1425 F, AC	F_{tu}, ksi	155	1.9	8
	F_{ty}, ksi	141	1.6	8
	e, percent	9.1	0.9	8
	RA, percent	19.2	3.5	8
As Forged + 1400 F, 1 hr, WQ	F_{tu}, ksi	121	1.3	7
	F_{ty}, ksi	95	1.9	7
	e, percent	32.3	2.0	7
	RA, percent	39.8	1.5	7
As Forged + 1400 F, 1 hr, WQ + 950 F, 8 hr, AC	F_{tu}, ksi	195	2.5	7
	F_{ty}, ksi	186	2.8	7
	e, percent	7.9	0.5	7
	RA, percent	16.2	2.0	7

TABLE 3.0217. STATISTICAL VARIATION OF ROOM TEMPERATURE TENSILE PROPERTIES OF HOT DIE PRESS FORGED PANCAKES (9)

Alloy	Ti-10V-2Fe-3Al						
Form	Hot Die, Beta Forged Airframe Structural Forgings						
			Section	RT Tensile Properties			
Condition	Specimen Location	Test Direction	Thickness, inch	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
As Forged 1550 F, AC (Die Temp 1550 F)	TR1 (Rib)	L	0.3	174.8	188.4	8.1	20.2
	TR2 (Rib)	L	0.3	176.0	189.6	9.5	26.1
	TR3 (Rib)	ST	1.2	159.6	174.4	9.5	38.8
	TW1 (Web)	L	0.6	162.8	178.4	9.5	20.2
	TW2 (Web)	L	0.6	166.0	183.0	6.7	10.9
	TW3 (Web)	T	0.6	160.8	177.2	8.8	17.2
	TW4 (Web)	T	0.6	167.0	180.8	8.7	22.3
1400 F, 1 hr, WQ + 950 F, 8 hr, AC	TR1 (Rib)	L	0.3	174.0	185.0	9.5	19.0
	TR2 (Rib)	L	0.3	174.0	185.2	10.9	31.7
	TR3 (Rib)	ST	1.2	174.0	186.4	8.1	21.2
	TR4 (Rib)	T	1.2	172.6	184.5	6.7	33.0
	TW1 (Web)	L	0.6	166.0	176.0	11.6	24.6
	TW2 (Web)	L	0.6	174.0	183.8	8.1	16.1
	TW3 (Web)	T	0.6	174.4	183.0	8.8	19.0
	TW4 (Web)	T	0.6	179.0	185.2	9.3	26.0
1350 F, 1 hr, AC + 1075 F, 8 hr, AC	TR1 (Rib)	L	0.3	136.8	144.0	22.8	55.5
	TR2 (Rib)	L	0.3	135.6	142.0	20.7	57.0
	TR3 (Rib)	ST	1.2	128.8	138.0	19.3	54.8
	TR4 (Rib)	T	1.2	131.6	140.8	20.7	56.2
	TW2 (Web)	L	0.6	134.0	141.6	22.1	56.2
	TW3 (Web)	T	0.6	130.0	138.4	22.1	57.0
	TW4 (Web)	T	0.6	129.6	138.4	20.7	55.5
	TW5 (Web)	T	0.6	131.2	140.8	20.0	54.0
	TW6 (Web)	T	0.6	134.8	144.2	20.0	53.6

All forgings produced from a single starting bar.

See Figure 3.0314 for elevated temperature tensile properties, Table 3.02726 for fracture toughness results, Figure 3.041 for creep curves, and Table 3.046 for effect of exposure to elevated temperature with load on RT tensile properties, all from these same forgings.

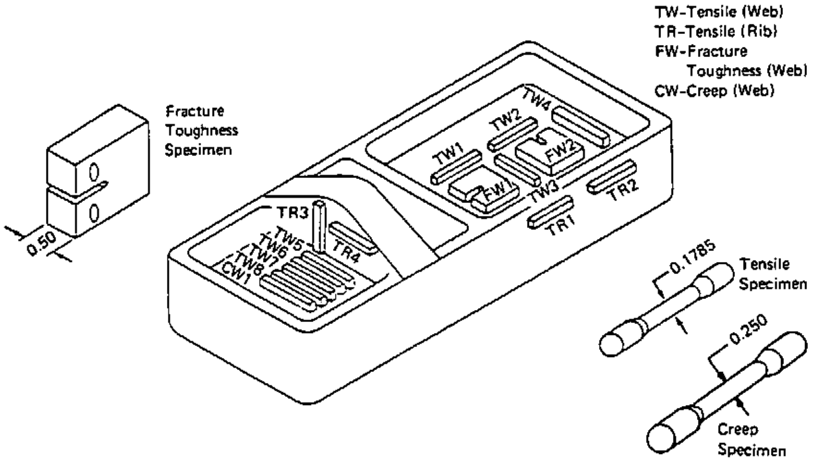


TABLE 3.0218. ROOM TEMPERATURE TENSILE PROPERTIES OF AS-FORGED AND HEAT TREATED HOT DIE, BETA FORGED AIRFRAME STRUCTURAL FORGINGS (2) (1)

Alloy	Ti-10V-2Fe-3Al			
Form	Plate			
	RT Tensile Properties			
Condition	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1/4-inch Plate				
1400 F, 1/2 hr, AC	144	158	6	11
1400 F, 1/2 hr, AC + 950 F, 8 hr, AC	183	192	8	19
1400 F, 1 hr, AC + 950 F, 8 hr, AC	185	194	8	21
1400 F, 2 hr, AC + 950 F, 8 hr, AC	182	193	9	19
1400 F, 1/2 hr, AC + 1050 F, 8 hr, AC	154	163	14	40
1400 F, 2 hr, AC + 1050 F, 8 hr, AC	161	169	9	27
1-inch Plate				
1400 F, 1/2 hr, AC	150	166	6	13
1400 F, 1/2 hr, AC + 950 F, 8 hr, AC	155	170	12	31
1400 F, 1 hr, AC + 950 F, 8 hr, AC	160	177	10	20
1400 F, 2 hr, AC + 1050 F, 8 hr, AC	162	177	7	16
1400 F, 1/2 hr, AC + 1050 F, 8 hr, AC	141	150	16	50
1400 F, 2 hr, AC + 1050 F, 8 hr, AC	146	157	14	38

Beta transus temperature = approx. 1467 F.

TABLE 3.02114. EFFECT OF SOLUTION ANNEAL TIME AND AGING TEMPERATURE TENSILE PROPERTIES OF 1/4-INCH AND 1-INCH PLATE (9)

Alloy	Ti-10V-2Fe-3Al					
Form	1.75-inch x 7-inch Cross Section Forged Plate Hot-Rolled From 1346 to 1-inch x 4.5-inch Cross Section Plate					
Heat Treatment	Microstructure	F_{ty}, ksi	F_{tu}, ksi	Uniform Elongation, percent	e, percent	RA, percent
1346 F, 48 hr, WQ	20% Primary $\alpha + \beta$ + Athermal ω	107.5	125.1	9.7	18.6	35.0
1562 F, 2 hr, WQ	β + Athermal ω	38.0	127.4	15.7	21.8	32.0
1292 F, 5 hr, WQ + 482 F, 100 hr	$\alpha + \beta$ + Isothermal ω	176.8	182.7	0.26	0.58	2.25
1562 F, 2 hr, WQ + 482 F, 166.7 hr	β + Isothermal ω	Brittle-No Yield	–	0	0	0
1328 F, 1.7 hr, WQ + 698 F, 16.7 hr	20% Primary $\alpha + \beta$ + Uniform α	180.0	207.4	2.7	8.9	16.0
1562 F, 1.7 hr, WQ + 698 F, 16.7 hr	β + Uniform α	Brittle-No Yield	–	0	0	0
1346 F, 12 hr, WQ + 932 F, 1 hr	20% Primary $\alpha + \beta$ + Sympathetic α	154.3	160.5	4.6	17.5	58.0
1562 F, 1.7 hr, WQ + 932 F, 4 hr	β + Sympathetic α	177.8	180.4	2.3	8.7	14.0

TABLE 3.02145. ROOM TEMPERATURE TENSILE PROPERTIES FOR SELECTED MICROSTRUCTURES (17)

Alloy	Ti-10V-2Fe-3Al					
Form	Hot-Rolled Plate and Forged Pancakes					
Condition	Heat Treatment	Microstructure	F_{ty}, ksi	F_{tu}, ksi	e, percent	True Fracture Strain
Hot-Rolled Plate, Beta Processed With Final Working Step in Alpha + Beta Field Starting From 1346 F (Globular Primary α)						
I	1337 F, 20 hr, WQ + 932 F, 1 hr (Salt)	30% Primary α + "Large" Secondary α	154.3	160.5	17.7	0.99
II	1337 F, 1.7 hr, WQ + 698 F, 16.7 hr (Air)	30% Primary α + "Small" Secondary α	180.8	206.0	7.6	0.19
III	1436 F, 3 hr, WQ + 932 F, 1 hr (Salt)	10% Primary α + "Large" Secondary α	174.4	181.0	10.3	0.63
IV	1436 F, 3 hr, WQ + 932 F, 1 hr (Air)	10% Primary α + "Small" Secondary α	209.7	224.1	2.4	0.09
V	1562 F, 2 hr, WQ + 932 F, 4 hr (Salt)	0% Primary α + Grain Boundary α + "Large" Secondary α	181.4	189.8	3.9	0.16
Forged Pancakes, Beta Processed With Finish Upset in Alpha + Beta Field (1425 F) (Elongated Primary α)						
VI	1292 F, 8 hr, WQ + 392, 113.6 hr (Air)	35% Primary α + ω	176.8	183.7	0.5	0.02
VII	1562 F, 2 hr, WQ + 932 F, 4 hr (Salt)	0% Primary α + "Large" Secondary α + Grain Boundary α	171.6	183.6	3.8	0.17
VIII	1400 F, 1.25 hr, WQ + 932 F, 1 hr (Salt)	~ 10% Primary α + "Large" Secondary α	188.4	200.4	4.6	0.23
IX	1292 F, 1.25 hr, WQ + 662 F, 16.7 hr (Air)	~ 30% Primary α + "Small" Secondary α	179.8	202.5	3.9	0.11

TABLE 3.02146. ROOM TEMPERATURE STRENGTH, ELONGATION, AND TRUE FRACTURE STRAIN FOR SELECTED MICROSTRUCTURES (16)

Alloy	Ti-10V-2Fe-3Al						
Form	1-inch Thick Hot-Rolled Plate, Beta Processed With Final 50% Reduction in Alpha + Beta Field[(a)] Starting From 1292 F						
				Room Temperature Tensile Properties			
Condition	Heat Treatment	Microstructure	Test Direction	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1	1562 F, 2.5 hr, WQ + 932 F, 0.1 hr (Salt)[(b)]	100% Recrystallized, 0% Primary α, and Coarse Underaged Sympathetic α	L	179	197	4.0	11.0
			T	190	204	3.0	6.0
2	1472 F, 0.5 hr, WQ + 932 F, 4 hr (Salt)[(b)]	80% Recrystallized, 5% Primary α, and Coarse Sympathetic α Plates	L	178	191	8.7	13.8
			T	192	203	4.1	7.5
3	1436 F, 5.5 hr, WQ + 932 F, 1 hr (Salt)[(b)]	40% Recrystallized, 10% Primary α, and Coarse Peak Aged Sympathetic α	L	178	183	9.8	43.9
			T	183	191	5.5	24.6
4	1400 F, 1.7 hr, WQ + 932 F, 24 hr (Air)	0% Recrystallized, 15% Primary α, and Fine Overaged Uniform α	L	177	181	10.0	39.0
			T	188	193	5.8	28.5
5	1328 F, 1.7 hr, WQ + 698 F, 13.3 hr (Salt)[(b)]	0% Recrystallized, 25% Primary α, and Fine Peak Aged Sympathetic α + Uniform α	L	181	208	9.0	11.0
			T	187	213	5.0	10.0
6	1292 F, 3 hr, WQ + 500 F, 113.3 hr (Salt)[(b)]	0% Recrystallized, 30% Primary α, and Very Fine Isothermal ω	L	177	178	0.6	2.3
			T	205	208	1.0	1.0
	1292 F, 3 hr, WQ + 500 F, 33.3 hr (Salt)[(b)]		T	182	191	2.8	13.2

(a) Beta transus temperature = 1481 F.
(b) Liquid nitrate salt.

TABLE 3.02147. EFFECT OF MICROSTRUCTURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF HOT-ROLLED PLATE SOLUTION TREATED AND AGED TO AN APPROXIMATE COMMON YIELD STRENGTH LEVEL (18)

Alloy	Ti-10V-2Fe-3Al			
Form	Isothermally Forged Pancake, Prefinished Upset 50% at 1550 F + Finish Upset 15% at 1425 F			
	Room Temperature Tensile Properties			
Heat Treatment and Microstructure	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1364 F, 5 hr, WQ + 932 F, 2 hr in Air (Discontinuous Grain Boundary α)	178	199	4.3	12.5
1562 F, 2 hr, WQ + 1364 F, 48 hr, WQ + 932 F, 2 hr in Air (Continuous α Layer on Recrystallized β Grains)	175	181	1.3	2.0

TABLE 3.02148. LOSS IN ROOM TEMPERATURE DUCTILITY ARISING FROM A CONTINUOUS GRAIN BOUNDARY ALPHA LAYER IN THE MICROSTRUCTURE OF AN ISOTHERMALLY FORGED PANCAKE (18)

<table>
<tr><td>Alloy</td><td colspan="6">Ti-10V-2Fe-3Al</td></tr>
<tr><td>Form</td><td colspan="6">Isothermally Forged Pancakes</td></tr>
<tr><td colspan="7">Forging Conditions</td></tr>
<tr><td></td><td colspan="2">Prefinish Upset</td><td colspan="4">Finish Upset</td></tr>
<tr><td>Forging</td><td>Temp, F</td><td>Reduction, percent</td><td colspan="2">Temp, F</td><td colspan="2">Reduction, percent</td></tr>
<tr><td>1</td><td>1550</td><td>50</td><td colspan="2">1425</td><td colspan="2">15</td></tr>
<tr><td>2</td><td>1250</td><td>50</td><td colspan="2">1300</td><td colspan="2">15</td></tr>
<tr><td>3</td><td>1400</td><td>50</td><td colspan="2">1425</td><td colspan="2">15</td></tr>
<tr><td colspan="7">Heat Treatment, Microstructure and Room Temperature Tensile Properties</td></tr>
<tr><td></td><td></td><td></td><td colspan="4">Room Temperature Tensile Properties</td></tr>
<tr><td>Forging</td><td>Heat Treatment</td><td>Microstructure</td><td>F_{ty}, ksi</td><td>F_{tu}, ksi</td><td>e, percent</td><td>RA, percent</td></tr>
<tr><td>1</td><td>1364 F, 5 hr, WQ + 932 F, 24 hr (Air)</td><td>Unrecrystallized, Elongated Primary α</td><td>174</td><td>183</td><td>2.0</td><td>16.0</td></tr>
<tr><td>3</td><td>1364 F, 5 hr, WQ + 932 F, 2 hr (Air)</td><td>Recrystallized, Equiaxed Primary α</td><td>187</td><td>199</td><td>4.3</td><td>12.5</td></tr>
<tr><td>1</td><td>1364 F, 5 hr, WQ + 932 F, 2 hr (Air)</td><td>Unrecrystallized, Equiaxed Primary α</td><td>186</td><td>201</td><td>4.4</td><td>5.9</td></tr>
</table>

TABLE 3.02149. ROOM TEMPERATURE TENSILE PROPERTIES OF THREE SOLUTION TREATED AND AGED ISOTHERMALLY FORGED PANCAKES (18)

Alloy	Ti-10V-2Fe-3Al				
Form	Isothermally Forged Pancake, Prefinish Upset 50% at 1550 F + Finish Upset 15% at 1425 F				
		Room Temperature Tensile Properties			
Heat Treatment	Microstructure	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1364 F, 5 hr, WQ + 932 F, 24 hr (Air)	Unrecrystallized, Elongated Primary α	174	183	2.0	16.0
1425 F, 2 hr, AC + 1400 F, 2 hr, WQ + 950 F, 8 hr (Air)	Unrecrystallized, Elongated Primary α	181	191	3.1	9.2

TABLE 3.02150. ROOM TEMPERATURE TENSILE PROPERTIES OF ISOTHERMALLY FORGED PANCAKE SOLUTION TREATED OR DUPLEX SOLUTION TREATED PRIOR TO AGING TO NEARLY EQUAL YIELD STRENGTH LEVEL (18)

Alloy	Ti-10V-2Fe-3Al	
Form	3-inch diam Bar	
Condition	1400 F, 1 hr, FC + 1050 F, 8 hr, AC	
Specimen No.	Test Direction	IE Charpy V, ft-lb
1	L	26.5
2	L	30.0
3	L	30.0
4	T	20.5
5	T	19.5
6	T	17.0

(See Figure 3.0312 for conventional tensile properties)

TABLE 3.0231. ROOM TEMPERATURE CHARPY V IMPACT ENERGY OF HEAT TREATED BAR (4)

Alloy	Ti-10V-2Fe-3Al				
Form	0.5-inch diam Round Bar				
Heat Treatment	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent	NTS(a), ksi
1400 F, 1/2 hr, AC + 950 F, 4 hr, AC	179	188	13	39	203
	173	180	16	39	234

(a) $K_t = 8.0$.

TABLE 3.02711. ROOM TEMPERATURE SMOOTH AND MILD-NOTCH TENSILE STRENGTHS FOR HEAT TREATED BAR (1)

Alloy	Ti-10V-2Fe-3Al
Form	3-inch diam Bar
Condition	1400 F, 1 hr, FC + 1050 F, 8 hr, AC
Specimen No.	K_{Ic}, ksi $\sqrt{in.}$
1	73.9
2	74.9
3	80.3
4	80.7

L-T Crack Plane Orientation; Standard Compact Specimens, B = 1.25 inch. (See ASTM Standard E-399) (See Figure 3.0312 for conventional tensile properties)

TABLE 3.02722. ROOM TEMPERATURE PLANE STRAIN FRACTURE TOUGHNESS OF HEAT TREATED BAR (4)

Alloy	Ti-10V-2Fe-3Al			
Form	5/16-inch Hot-Rolled Plate			
Condition	F_{ty}, ksi	F_{tu}, ksi	e (1 inch), percent	K_{Ic}, ksi $\sqrt{in.}$
900 F, 2 hr, AC	181	191	9	31
900 F, 4 hr, AC	179	189	7	32
900 F, 8 hr, AC	179	189	9	29
950 F, 4 hr, AC	170	183	10	50
1400 F, 1/2 hr, AC + 950 F, 4 hr, AC	187	193	6	44
1400 F, 1/2 hr, AC + 950 F, 8 hr, AC	172	179	7	52
1400 F, 1/2 hr, AC + 1000 F, 1 hr, AC	171	185	6	49
1400 F, 1/2 hr, AC + 1000 F, 2 hr, AC	170	177	9	55

TABLE 3.02723. ROOM TEMPERATURE TENSILE PROPERTIES AND PLANE STRAIN FACTURE TOUGHNESS OF 5/16-INCH HOT-ROLLED PLATE AFTER VARIOUS HEAT TREATMENTS (13)

Alloy	Ti-10V-2Fe-3Al			
Form	Hot Die, Beta Forged Airframe Structural Forgings Forge Temp 1550 F, Die Temp 1550 F			
Condition	Specimen(a)	Crack Plane Orientation	F_{ty}, ksi	K_{Ic},(b) ksi $\sqrt{in.}$
As Forged, 1550 F, AC	FW1	T-L	163.9(c)	54.26
	FW2	L-T	164.4(d)	54.97
1400 F, 1 hr, WQ +	FW1	T-L	176.7(c)	49.24
950 F, 8 hr, AC	FW2	L-T	170.0(d)	48.35
1350 F, 1 hr, AC +	FW1	T-L	131.4(e)	> 92.65(f)
1075 F, 8 hr, AC	FW2	L-T	134.0(g)	> 92.42(f)

(a) See Table 3.0218 for specimen locations and orientations.
(b) Tests performed according to ASTM Standard Method E-399-72, using 0.5-inch thick standard compact specimens.
(c) Average of values from specimens TW3 and TW4 of Table 3.0218.
(d) Average of values from specimens TW1 and TW2 of Table 3.0218.
(e) Average of values from specimens TW3 through TW6 of Table 3.0218.
(f) Specimen thickness insufficient; therefore values is underestimate of K_{Ic}.
(g) Value from specimen TW2 of Table 3.0218.

TABLE 3.02726. ROOM TEMPERATURE PLANE STRAIN FRACTURE TOUGHNESS OF AS-FORGED AND HEAT TREATED HOT DIE, BETA FORGED AIRFRAME STRUCTURAL FORGINGS (2)

Alloy	Ti-10V-2Fe-3Al						
Form	Boeing 747 Lower Link Fitting. Beta Forged with Alpha-Beta (≤ 20%) Finish						
Condition	1435 F. 2 hr. AC + 1425 F. 2 hr. WQ + 950 F. 8 hr. AC						
Section Thickness, inch	Conventional RT Tensile Properties					RT Plane Strain Fracture Toughness	
	Test Direction	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent	Crack Plane Orientation	K_{Ic}, ksi $\sqrt{in.}$
1-1.5	L	184.6	195.4	5.0	11.6	L-T	46.3
	T	180.0	189.6	4.5	10.0	T-L	46.0
	ST	174.9	185.0	4.0	9.3	–	–
1.5-2.0	L	177.4	186.9	5.5	16.0	L-T	48.8
	T	176.4	185.2	5.5	10.8	T-L	47.9
	ST	173.8	186.1	6.0	12.2	–	–
2.0-3.25	L	177.1	186.8	6.0	13.7	L-T	54.8
	T	170.0	180.0	5.0	10.8	T-L	48.0
	ST	175.2	185.4	5.5	9.3	T-S	50.7

TABLE 3.02727. ROOM TEMPERATURE CONVENTIONAL TENSILE PROPERTIES AND PLANE STRAIN FRACTURE TOUGHNESS OF HEAT TREATED AIRFRAME STRUCTURAL FORGING (8) (11)

Alloy	Ti-10V-2Fe-3Al		
Form	Rolled Plate		
F_{tu}, ksi	180	190	200
Oxygen Content, percent	K_{Ic}, ksi $\sqrt{in.}$(a)		
0.09	55	50	45
0.11	52	47	42
0.13	49	44	39

(a) Values taken from least squares best fit line for data spanning 0.11-0.17 percent oxygen at 175-200 ksi. Standard error of estimate is 2.8 ksi.$\sqrt{in.}$

TABLE 3.02728. EFFECT OF OXYGEN CONTENT ON ROOM TEMPERATURE ULTIMATE TENSILE STRENGTH AND PLANE STRAIN FRACTURE TOUGHNESS OF ROLLED PLATE (1)

Alloy	Ti-10V-2Fe-3Al								
Form	Pressed Squares, Beta Forged 1500 F Longitudinal, Mid-Radius Tensile Properties								
Pressed Section Size, in.^{2}		RT				600 F			
	Condition	F_{ty}, ksi	F_{tu}, ksi	e(4D), percent	RA, percent	F_{ty}, ksi	F_{tu}, ksi	e(4D), percent	RA, percent
5	As Forged, AC + 1000 F, 8 hr, AC	135.1	142.4	18.0	46.7	91.1	106.4	22.0	69.9
	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	154.6	164.6	13.0	32.2	99.0	126.0	18.0	67.0
	1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	149.1	159.6	14.0	41.6	94.2	125.4	16.0	58.6
4	As Fogred, AC + 1000 F, 8 hr, AC	142.2	148.2	17.5	49.3	96.7	110.3	21.0	67.9
	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	157.9	167.0	14.5	33.4	100.5	130.9	15.0	51.9
	1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	152.9	162.3	12.5	31.6	105.5	131.3	16.0	57.2
3	As Forged, AC + 1000 F, 8 hr, AC	145.5	151.3	16.3	45.7	102.6	115.4	19.0	70.2
	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	161.5	168.3	16.7	44.2	109.8	134.5	18.0	68.0
	1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	160.0	168.6	13.0	35.3	107.5	131.9	19.0	69.7

TABLE 3.0313. ROOM TEMPERATURE AND 600 F TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED AFTER VARIOUS HEAT TREATMENTS (5)

Alloy	Ti-10V-2Fe-3Al							
Form	Pressed Squares, Beta Forged 1500 F							
					RT Mild-Notch Creep Rupture Properties			
					No Failure		Failure	
Pressed Section Size, in.^{2}	Test Direction	Location	Condition	F_{tu}, ksi	Stress, ksi	Time, hr	Stress, ksi	Time, hr
5	T	Mid-Radius	As Forged, AC	145.8	190	5	200	1.0
			As Forged, AC + 950 F, 2 hr, AC	155.5	190	5	200	2.5
			As Forged, AC + 950 F, 4 hr, AC	149.6	210	5	220	BOL(a)
			As Forged, AC + 950 F, 8 hr, AC	145.4	210	5	220	BOL
			As Forged, AC + 950 F, 24 hr, AC	145.0	200	5	210	0.25
			As Forged, AC + 1000 F, 2 hr, AC	144.8	200	5	210	0.25
			As Forged, AC + 1000 F, 4 hr, AC	151.3	200	5	210	BOL
			As Forged, AC + 1000 F, 8 hr, AC	151.2	200	5	210	BOL
			As Forged, AC + 1000 F, 24 hr, AC	140.2	210	5	220	BOL
			1400 F, 1 hr, WQ	149.1	180	5	190	1.0
			1400 F, 1 hr, WQ + 950 F, 2 hr, AC	184.4	210	5	220	BOL
			1400 F, 1 hr, WQ + 950 F, 4 hr, AC	178.2	200	5	210	0.1
			1400 F, 1 hr, WQ + 950 F, 8 hr, AC	176.2	210	5	220	BOL
			1400 F, 1 hr, WQ + 950 F, 24 hr, AC	168.2	200	5	210	3.8
			1400 F, 1 hr, WQ + 1000 F, 2 hr, AC	171.0	210	5	220	BOL
			1400 F, 1 hr, WQ + 1000 F, 4 hr, AC	167.2	200	5	210	0.25
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	161.0	190	5	200	1.1
			1400 F, 1 hr, WQ + 1000 F, 24 hr, AC	156.8	210	5	220	BOL
	L	Mid-Radius	As Forged, AC + 1000 F, 8 hr, AC	142.5	190	5	200	0.3
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	160.6	200	5	210	BOL
4	T	Mid-Radius	As Forged, AC	–	210	5	220	0.25
			As Forged, AC + 1000 F, 8 hr, AC	152.9	210	5	220	0.25
			1400 F, 1 hr, WQ	150.2	180	5	190	BOL
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	167.0	210	5	220	0.25
	L	Mid-Radius	As Forged, AC + 1000 F, 8 hr, AC	149.7	210	5	220	0.25
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	164.6	210	5	220	0.25
3	T	Mid-Radius	As Forged	151.9	210	5	220	BOL
			As Forged, AC + 1000 F, 8 hr, AC	155.2	210	5	220	0.33
			1400 F, 1 hr, WQ	138.9	180	5	190	0.1
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	166.3	210	5	220	0.33
	L	Mid-Radius	As Forged, AC + 1000 F, 8 hr, AC	150.5	210	5	220	0.51
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	162.8	210	5	220	0.33
2	T	Mid-Radius	As Forged, AC	159.1	210	5	220	BOL
			As Forged, AC + 1000 F, 8 hr, AC	156.8	230	5	240	BOL
			1400 F, 1 hr, WQ	136.0	190	5	200	BOL
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	170.5	210	5	220	1.1
	L	Mid-Radius	As Forged, AC + 1000 F, 8 hr, AC	157.5	210	5	220	0.33
			1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	166.5	210	5	220	0.33
5	T	Mid-Radius	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	166.8	220	5	230	BOL
	L	Mid-Radius	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	166.0	210	5	220	0.5
4	T	Mid-Radius	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	170.1	220	5	230	BOL
	L	Mid-Radius	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	163.5	220	5	230	BOL
3	T	Mid-Radius	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	171.0	220	5	230	BOL
	L	Mid-Radius	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	165.1	220	5	230	BOL

(a) Broke on loading.

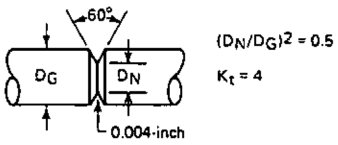


TABLE 3.044. ROOM TEMPERATURE STEP-LOADED MILD-NOTCH CREEP-RUPTURE PROPERTIES OF PRESSED SQUARES, BETA FORGED AFTER VARIOUS HEAT TREATMENTS (5)

Alloy	Ti-10V-2Fe-3Al					
Form	Pressed Squares, Beta Forged 1500 F					
Section Size, in.^{2}	Condition	600 F, 100 ksi, 100 hr Creep Deformation, percent	Subsequent RT Tensile Properties[a]			
			F_{ty}, ksi	F_{tu}, ksi	(4D), percent	RA, percent
5	As Forged, AC + 1000 F, 8 hr, AC	Unexposed	135.1	142.4	18.0	46.6
		0.96	149.3	151.0	16.0	51.9
	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	Unexposed	154.6	164.6	13.0	32.2
		0.83	164.5	167.0	10.0	24.9
	1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	Unexposed	149.0	159.6	14.0	41.6
		0.66	166.2	170.9	10.0	23.1
4	As Forged, AC + 1000 F, 8 hr, AC	Unexposed	142.2	148.2	17.5	49.3
		0.48	152.4	155.1	14.0	45.9
	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	Unexposed	157.8	167.0	13.5	33.4
		0.49	168.9	174.6	8.0	18.8
	1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	Unexposed	142.2	148.2	17.5	49.3
		0.56	170.9	175.3	10.0	28.7
3	As Forged, AC + 1000 F, 8 hr, AC	Unexposed	145.5	151.3	16.3	45.7
		0.38	155.1	158.3	14.0	39.9
	1400 F, 1 hr, WQ + 950 F, 8 hr, AC	Unexposed	161.5	168.3	16.7	44.2
		0.21	170.6	174.0	11.0	42.0
	1400 F, 1 hr, WQ + 1000 F, 8 hr, AC	Unexposed	160.0	168.6	13.0	35.3
		0.43	173.5	178.2	12.0	37.0

(a) Longitudinal, mid-radius (except for 3 in.^{2} sections for which values shown are average of edge and center locations).

TABLE 3.045. EFFECT OF 600 F, 100 KSI, 100 HR, CREEP EXPOSURE ON SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED AFTER VARIOUS HEAT TREATMENTS (5)

Alloy	Ti-10V-2Fe-3Al						
Form	Hot Die, Beta Forged Airframe Structural Forgings, Forge Temp 1550 F, Die Temp 1550 F						
Condition	Specimen[a]	600 F, 100 ksi Exposure		Subsequent RT Tensile Properties			
		Time, hr	Deformation, percent	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1400 F, 1 hr, WQ + 950 F, 8 hr, AC	TW3	Unexposed		174.4	183.0	8.8	19.0
	TW4	Unexposed		179.0	185.2	9.3	26.0
	CW1	117.4	0.44	182.2	190.2	7.0	26.4
1350 F, 1 hr, AC + 1075 F, 8 hr, AC	TW3	Unexposed		130.0	138.4	22.1	57.0
	TW4	Unexposed		129.6	138.4	20.7	55.5
	TW5	Unexposed		131.2	140.8	20.0	54.0
	TW6	Unexposed		134.8	144.2	20.0	53.6
	CW1	100.0	1.10	158.5	165.4	12.0	35.6

(a) See Table 3.0218 for specimen configuration, locations, and test directions.

TABLE 3.046. EFFECT OF 600 F, 100 KSI CREEP EXPOSURE ON SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF HOT DIE, BETA FORGED AIRFRAME STRUCTURAL FORGINGS AFTER VARIOUS HEAT TREATMENTS (2)

Alloy	Ti-10V-2Fe-3Al
Form	Forging
Condition	1400 F, 1 hr, WQ + 950 F, 8 hr, AC
Test Temp, F	E, 10^3 ksi
RT	16.2
600	13.8

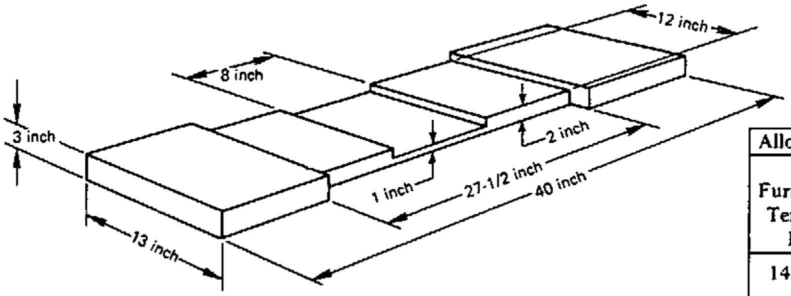
See Figure 3.0314 for forging description and tensile properties.

TABLE 3.0623. ROOM TEMPERATURE AND 600 F TENSILE ELASTIC MODULUS FOR HEAT TREATED FORGING (1)

Alloy	Ti-10V-2Fe-3Al	
Form	2-inch diam x 2-inch High Test Specimens	
Die Temp,[a] F	Final Thickness,[b] inch	Reduction,[c] percent
600	0.840	58
600	0.825	59
900	0.695	65
900	0.625	69
1200	0.475	76
1500	0.330	84
1500	0.335	83

(a) Stock temperature 1500 F.
(b) Stall load 100 tons (91 metric tons) in all cases.
(c) Metal deformation completed within 20-30 seconds after loading.

TABLE 4.0114. RESULTS OF HOT COMPRESSION TESTS (1)



Alloy	Ti-10V-2Fe-3Al			
Furnace Temp, F	Delay Time, sec	Center Temp, F, at Various Section Thickness, inch		
		1	2	3
1425	10	1421	1425	1425
	20	1406	1424	1425
	30	1387	1422	1424
1415	10	1411	1415	1415
	20	1396	1414	1415
	30	1378	1412	1414
1400	10	1396	1400	1400
	20	1382	1399	1400
	30	1364	1397	1399

TABLE 4.0121. HEAT TRANSFER IN FLAT MONOLITHIC FORGING DURING AIR COOL (1)

Alloy	Ti-10V-2Fe-3Al				
Form	1-inch Thick Forged Upset (Upset From 3-inch Thickness[a])				
Condition	1400 F, 1 hr, Fan Cool + 1050 F, 8 hr, AC				
		Room Temperature Tensile Properties			
Upset Temp, F	Test Direction	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1500	Radial	149	156	14	49
	Tangential	148	154	19	61
1400	Radial	149	153	16	60
	Tangential	149	154	18	58

(a) Starting material sliced from 3-inch round forged bar which was beta processed with final 44 percent reduction from same starting temperature as subsequent upset temperature.

TABLE 4.0136. EFFECT OF UPSET TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF 1-INCH THICK FORGED UPSETS (19)

Alloy	Ti-10V-2Fe-3Al			
Form	Isothermally Forged Pancakes			
	Forging Conditions			
	Prefinish Upset[a]		Finish Upset[b]	
Forging	Temp, F	Reduction, percent	Temp, F	Reduction, percent
1	1550	50	1425	15
2	1250	50	1300	15
3	1400	50	1425	15

Room Temperature Tensile Properties					
Forging	Heat Treatment	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
1	1562 F, 2 hr, WQ + 932 F, 4 hr in Liquid Nitrate Salt	172	184	3.8	15.0
2		170	184	4.5	17.0
3		174	186	4.0	15.0
1	1400 F, 1.25 hr, WQ + 932 F, 1 hr in Liquid Nitrate Salt	188	201	4.8	15.0
2		177	187	7.0	39.0
3		178	184	7.6	33.0
1	1364 F, 5 hr, WQ + 932 F, 2 hr in Air	186	201	4.4	5.9
2		183	204	5.5	30.3
3		187	199	4.3	12.5
1	1292 F, 1.25 hr, WQ + 662 F, 16.7 hr in Liquid Nitrate Salt	180	202	3.9	11.0
2		171	186	9.0	38.0
3		179	200	3.3	17.0

(a) 1.5 in./min constant ram velocity.
(b) 0.75 in./min constant ram velocity.

TABLE 4.0137. EFFECT OF ISOTHERMAL FORGING CONDITIONS ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED FORGED PANCAKES (18)

Alloy	Ti-10V-2Fe-3Al					
Form	0.5-inch Thick Flat Plate Conventionally or Isothermally Subtransus Forged From 3-inch diam Supratransus Processed Round Bar					
			Room Temperature Tensile Properties			
Forging Condition(a)	Heat Treatment	Test Direction	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
AC	1350 F, 1 hr, AC + 1100 F, 8 hr, AC	L	137.3	138.2	23.5	55.6
		L	136.3	137.5	24.5	58.7
		T	132.0	135.2	24.0	53.0
		T	132.0	135.2	23.5	57.3
AC	1350 F, 1 hr, AC + 1150 F, 2 hr, AC	L	137.2	143.3	21.0	58.3
		L	133.7	137.9	21.0	55.9
		T	133.0	140.4	21.5	55.7
		T	132.0	137.4	22.0	57.8
AC	1000 F, 8 hr, AC + 1100 F, 2 hr, AC	L	148.4	151.8	19.0	53.9
		L	147.4	150.8	20.5	60.3
		T	148.2	151.6	20.0	58.7
		T	147.5	151.0	18.5	58.0
AC	1375 F, 1 hr, AC + 1050 F, 8 hr, AC	L	143.5	145.1	20.5	55.0
		L	143.5	145.1	22.0	59.0
		T	140.9	145.3	22.0	55.7
		T	141.7	144.3	22.0	59.2
AC	1400 F, 1 hr, AC + 1050 F, 8 hr, AC	L	146.3	150.8	21.0	57.3
		L	144.3	152.8	20.0	55.9
		T	143.5	149.4	20.0	58.0
		T	141.9	148.6	20.5	58.2
AI	1350 F, 1 hr, AC + 1100 F, 8 hr, AC	L	134.9	137.2	21.5	54.5
		L	134.8	138.9	24.0	58.0
		T	132.2	135.7	23.0	54.9
		T	131.7	136.5	23.0	56.6
AI	1350 F, 1 hr, AC + 1150 F, 2 hr, AC	L	135.2	140.8	22.0	59.8
		L	133.4	137.3	21.0	58.5
		T	130.9	135.3	23.0	56.6
		T	133.6	135.8	21.0	57.3
AI	1350 F, 1 hr, AC + 1250 F, 1 hr, AC + 1100 F, 8 hr, AC	L	129.8	132.0	23.5	57.5
		L	129.1	132.1	22.5	55.0
		T	127.8	131.8	22.0	56.3
		T	128.0	131.4	24.0	58.3
AI	1425 F, 1 hr, AC + 1050 F, 8 hr, AC	L	150.2	156.0	20.0	57.0
		L	148.0	154.4	20.0	58.7
		T	147.2	154.6	21.0	57.7
		T	148.6	155.4	20.5	55.2
AI	1400 F, 1 hr, AC + 1000 F, 8 hr, AC	L	152.6	156.7	19.0	55.4
		L	152.0	156.6	18.0	55.9
		T	149.8	155.0	18.0	47.8
		T	148.6	152.8	17.5	60.8

(a) See Figure 4.0138 for conversion schedule.

TABLE 4.0139. ROOM TEMPERATURE TENSILE PROPERTIES OF SUPRATRANSUS PROCESSED 3-INCH ROUND BAR CONVENTIONALLY AND ISOTHERMALLY SUBTRANSUS FORGED TO 0.5-INCH THICK FLAT PLATE AND VARIOUSLY HEAT TREATED (20)

Alloy	Ti-10V-2Fe-3Al					
Form	0.5-inch Thick Flat Plate Conventionally or Isothermally Supratransus Forged From 3-inch diam Supratransus Processed Round Bar					
			Room Temperature Tensile Properties			
Forging Condition(a)	Heat Treatment	Test Direction	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
BC	1350 F, 1 hr, AC + 1100 F, 8 hr, AC	L	129.8	136.6	22.0	56.8
		L	128.8	136.5	22.0	55.4
		T	126.7	134.3	22.0	53.8
		T	127.9	134.7	22.0	53.9
BC	1400 F, 1 hr, AC + 1050 F, 8 hr, AC	L	131.6	137.7	21.5	53.1
		L	132.0	138.1	22.5	55.9
		T	132.1	139.1	23.5	51.0
		T	131.5	138.5	22.5	52.3
BC	1400 F, 1 hr, AC + 1000 F, 8 hr, AC	L	130.9	137.3	22.0	52.9
		L	130.0	136.8	22.0	49.8
		T	131.7	139.0	21.5	55.0
		T	131.6	138.4	20.5	54.1
BC	1530 F, 1 hr, AC + 1150 F, 8 hr, AC	L	139.2	149.4	12.5	18.9
		L	138.6	148.9	14.0	21.1
		T	134.1	143.5	13.5	25.2
		T	134.5	144.5	13.5	25.6
BC	1530 F, 1 hr, AC + 1350 F, 1 hr, AC + 1100 F, 8 hr, AC	L	126.4	134.5	19.0	38.6
		L	126.2	134.5	18.5	39.3
		T	124.2	132.8	17.5	42.8
		T	123.7	132.7	22.0	41.8
BC	1400 F, 1 hr, AC + 950 F, 8 hr, AC	L	149.4	161.1	14.5	39.4
		L	148.0	159.2	15.0	44.3
		T	147.7	160.3	17.5	42.2
		T	149.4	160.8	13.0	38.6
BC	1425 F, 1 hr, AC + 950 F, 8 hr, AC	L	143.3	155.2	15.5	40.7
		L	145.4	155.8	15.0	45.7
		T	146.3	158.2	15.5	39.0
		T	148.4	161.8	15.5	39.5
BC	1425 F, 1/2 hr, Fan Cool + 1375 F, 1 hr, Fan Cool + 950 F, 8 hr Fan Cool	L	148.7	157.1	16.0	41.9
		L	148.3	158.0	17.0	42.9
		T	149.8	155.8	17.0	43.7
		T	146.7	155.4	16.5	41.1
BC	1425 F, 1/2 hr, Fan Cool + 1400 F, 1 hr, Fan Cool, + 950 F, 8 hr Fan Cool	L	155.0	170.9	11.5	29.7
		L	155.8	168.3	13.0	35.5
		T	158.4	168.9	14.0	36.1
		T	156.5	167.8	13.0	35.6
BI	1350 F, 1 hr, AC + 1000 F, 8 hr, AC	L	143.3	147.4	20.0	52.9
		L	141.1	148.6	22.5	56.6
		T	141.7	148.1	20.0	54.3
		T	141.2	147.4	22.0	57.8
BI	1350 F, 1 hr, AC + 1100 F, 8 hr, AC	L	126.3	134.0	20.5	56.3
		L	130.0	137.2	23.0	51.7
		T	128.8	135.7	21.5	53.8
		T	128.0	135.0	23.5	55.2
BI	1400 F, 1 hr, AC + 1075 F, 2 hr, AC	L	131.1	137.9	22.5	55.4
		L	132.0	138.9	21.5	54.3
		T	130.1	138.3	22.0	57.7
		T	131.4	139.6	20.0	57.3
BI	1530 F, 1 hr, AC + 1150 F, 8 hr, AC	L	137.5	147.9	12.5	22.1
		L	137.1	146.7	10.5	19.3
		T	136.2	146.1	12.5	22.9
		T	137.3	145.7	12.0	26.9
BI	1100 F, 8 hr, AC	L	147.6	155.6	17.5	47.1
		L	148.6	157.0	17.0	50.7
		T	148.6	157.0	17.5	45.5
		T	148.4	156.4	15.5	40.4
BI	1425 F, 1/2 hr, Fan Cool + 1350 F, 1 hr, Fan Cool + 950 F, 8 hr, Fan Cool	L	150.4	161.6	16.5	41.1
		L	149.0	160.0	15.5	40.7
		T	150.0	159.4	16.5	41.7
		T	149.4	160.9	16.0	37.1
BI	1425 F, 1/2 hr, Fan Cool + 1375 F, 1 hr, Fan Cool + 900 F, 8 hr, Fan Cool	L	156.5	170.1	13.0	27.7
		L	157.4	170.1	11.5	22.8
		T	155.8	166.7	14.5	35.5
		T	154.8	168.8	11.5	29.1

TABLE 4.01310. (Continued)

Forging Condition(a)	Heat Treatment	Test Direction	Room Temperature Tensile Properties			
			F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
BI	1425 F, 1/2 hr, Fan Cool + 1375 F, 1 hr, Fan Cool + 900 F, 16 hr, Fan Cool	L	157.0	165.7	12.5	30.9
		L	156.4	167.1	12.5	28.0
		T	156.2	166.2	14.5	36.4
		T	155.0	166.0	15.0	38.9
BI	1530 F, 1/3 hr, Fan Cool + 1425 F, 1/2 hr, Fan Cool + 950 F, 8 hr, Fan Cool	L	158.4	169.8	16.5	45.1
		L	157.4	170.8	16.0	40.1
		T	156.7	167.5	12.5	27.8
		T	158.5	170.8	11.0	24.4

(a) See Figure 4.0138 for conversion schedule.

TABLE 4.01310. ROOM TEMPERATURE TENSILE PROPERTIES OF SUPRATRANSUS PROCESSED 3-INCH ROUND BAR CONVENTIONALLY AND ISOTHERMALLY SUPRATRANSUS FORGED TO 0.5-INCH FLAT PLATE AND VARIOUSLY HEAT TREATED (20)

Alloy	Ti-10V-2Fe-3Al					
Form	0.5-inch Thick Flat Plate Conventionally or Isothermally Subtransus Forged From 3-inch diam Subtransus Processed Round Bar					
Forging Condition(a)	Heat Treatment	Test Direction	Room Temperature Tensile Properties			
			F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent
CC	1350 F, 1 hr, AC + 1100 F, 8 hr, AC	L	132.4	137.6	21.0	59.8
		L	134.9	139.1	21.5	63.1
		T	128.6	134.6	22.5	58.3
		T	128.1	133.9	23.5	54.5
CC	1350 F, 1 hr, AC + 1150 F, 8 hr, AC	L	132.9	137.5	21.0	57.5
		L	130.9	134.9	21.0	58.5
		T	123.5	130.3	23.5	53.4
		T	124.3	129.9	23.5	58.2
CC	1100 F, 8 hr, AC	L	136.8	140.8	21.5	59.8
		L	138.1	141.3	21.0	58.2
		T	126.6	133.0	20.5	54.7
		T	128.1	132.3	23.0	57.7
CC	1530 F, 1 hr, AC + 1050 F, 8 hr, AC	L	160.8	169.8	6.0	12.6
		L	161.2	169.8	6.0	15.6
		T	151.2	161.4	11.5	20.6
		T	153.0	162.2	10.0	18.9
CC	1530 F, 1 hr, AC + 1400 F, 1 hr, AC + 1050 F, 8 hr, AC	L	145.8	154.8	10.0	28.8
		L	147.6	157.8	15.0	25.9
		T	134.9	146.8	16.5	24.5
		T	136.0	147.9	16.0	36.9
CI	1350 F, 1 hr, AC + 1100 F, 8 hr, AC	L	136.7	144.5	20.5	54.9
		L	135.3	142.7	21.5	54.3
		T	126.5	133.7	23.0	53.9
		T	129.8	134.4	21.5	59.8
CI	1300 F, 1 hr, AC + 1100 F, 8 hr, AC	L	132.8	136.4	21.5	59.4
		L	133.3	137.3	20.0	56.4
		T	126.7	132.7	23.0	52.9
		T	125.7	131.9	22.0	54.5
CI	1100 F, 8 hr, AC	L	137.8	142.1	20.0	58.3
		L	137.3	142.7	21.0	58.7
		T	132.0	137.8	20.5	56.8
		T	136.2	129.0	21.5	57.8
CI	1425 F, 1 hr, AC + 1050 F, 8 hr, AC	L	150.2	156.6	17.0	59.7
		L	152.6	158.0	13.5	54.7
		T	145.8	154.0	20.0	58.2
		T	147.4	154.6	17.0	58.2
CI	1530 F, 1 hr, AC + 1350 F, 1 hr, AC + 1000 F, 8 hr, AC	L	145.2	151.6	15.0	31.8
		L	143.0	150.4	15.5	35.0
		T	139.5	145.5	16.0	30.3
		T	139.7	147.1	17.5	35.9

(a) See Figure 4.0138 for conversion schedule.

TABLE 4.01311. ROOM TEMPERATURE TENSILE PROPERTIES OF SUBTRANSUS PROCESSED 3-INCH ROUND BAR CONVENTIONALLY AND ISOTHERMALLY SUBTRANSUS FORGED TO 0.5-INCH THICK FLAT PLATE AND VARIOUSLY HEAT TREATED (20)

Alloy	Ti-10V-2Fe-3Al				
Form	11/32-inch diam Bar, Hot-Rolled From 1750 F				
	RT Tensile Properties				
Condition	F_{ty}, ksi	F_{tu}, ksi	e (4D), percent	RA, percent	D_f/D_o(a)
As-Hot Rolled	198.5	212.8	8.0	28.5	–
1400 F, 1/4 hr, AC	152.8	171.0	12.0	35.8	1.10
1500 F, 1/4 hr, AC	118.0	130.1	18.0	34.5	–
1400 F, 1/4 hr, WQ	112.5	136.1	20.0	44.6	1.10
1500 F, 1/4 hr, WQ	84.3	126.7	30.0	40.4	1.15
1400 F, 1/4 hr, AC + 900 F, 8 hr, AC	181.8	195.6	16.0	54.5	–
1400 F, 1/4 hr, WQ + 900 F, 8 hr, AC	186.6	198.7	14.0	51.6	–

(a) D_f/D_o represents the cold heading capabilities with D_f = final diameter after upset (puck test) and D_o = initial diameter. Initial height is 2.5 x diameter.

TABLE 4.01312. ROOM TEMPERATURE TENSILE AND COLD DEFORMABILITY PROPERTIES OF HOT-ROLLED BAR VARIOUSLY HEAT TREATED (5)

Alloy	Ti-10V-2Fe-3Al								
Form	3/4-inch Thick Plate Extracted From Rough Upset Forged Billet								
Condition	Solution Treated + Electron Beam Welded + Aged								
				Average Room Temperature Properties					
Heat Treatment	Type of Specimen	Test Direction(a)	Number of Specimens	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent	E, 10^3 ksi	K_{Ic}, ksi $\sqrt{in.}$
(b)	Base Metal	LT	1	138.6	143.9	16.0	51.3	15.15	–
(b)	Weld	TT	3	134.2	138.1	10.0	40.8	15.54	–
(c)	Base Metal	LT	2	175.5	185.8	5.0	7.9	15.41	–
(c)	Weld	TT	3	171.5	182.2	5.5(d)	9.9	15.62	–
(c)	Base Metal	FT	2	–	–	–	–	–	52.5
(c)	Weld	FT	1	–	–	–	–	–	55.7

(a) For base metal specimens, "LT" and "T" designate loading in the grain and perpendicular directions, respectively, while "FT" designates compact tension specimens. For welded specimens, "LT" and "TT" designate longitudinal and transverse welds, respectively, while "FT" designates compact tension specimens.

(b) Solution treat: 1350 F, 1 hr, fan cool; age: 1075 F, 8 hr, air cool.

(c) Solution treat: 1400 F, 1 hr, fan cool; age: 950 F, 8 hr, air cool.

(d) Specimen broke at gage mark.

Welding Parameters: Beam current, 300 MA; beam voltage, 45 KV; travel speed, 40 in./min; gun-to-work distance, 8 inch; focus adjustment, 4.98; focus meter reading, 4.35; focus delta, -5; sharp focus, 4.40.

TABLE 4.031. ROOM TEMPERATURE STRENGTH, ELASTIC MODULUS, AND PLANE STRAIN FRACTURE TOUGHNESS OF ELECTRON BEAM WELDED PLATE (7)

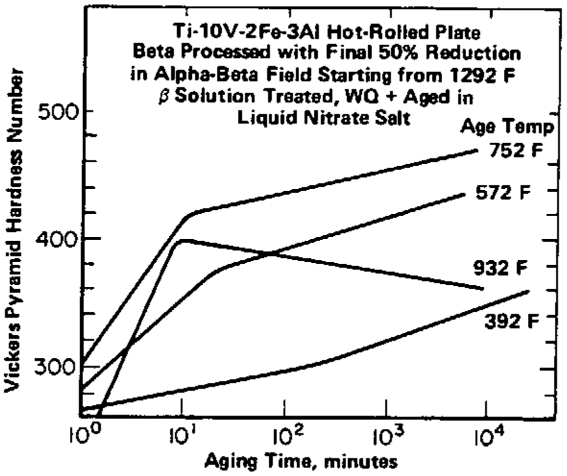


FIGURE 1.062. EFFECT OF AGING TIME ON HARDNESS OF HOT-ROLLED PLATE, BETA SOLUTION TREATED AND AGED AT SEVERAL TEMPERATURES (18)

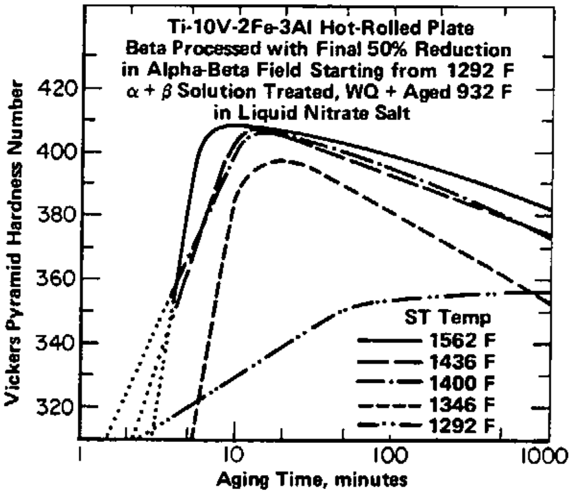


FIGURE 1.063. EFFECT OF 500 F AGING TIME ON HARDNESS OF HOT-ROLLED PLATE, ALPHA + BETA SOLUTION TREATED AND AGED AT 932 F (18)

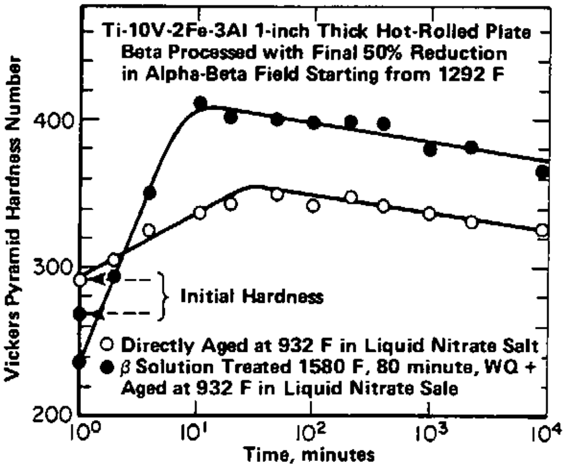


FIGURE 1.064. EFFECT OF 932 F AGING TIME ON HARDNESS OF HOT-ROLLED PLATE EITHER DIRECTLY AGED OR BETA SOLUTION TREATED AND THEN AGED (18)

—— Forging 1
– – – Forging 2
—·— Forging 3

Forging	Prefinish Upset Temp, F	Prefinish Upset Reduction, percent	Finish Upset Temp, F	Finish Upset Reduction, percent
1	1550	50	1425	15
2	1250	50	1300	15
3	1400	50	1425	15

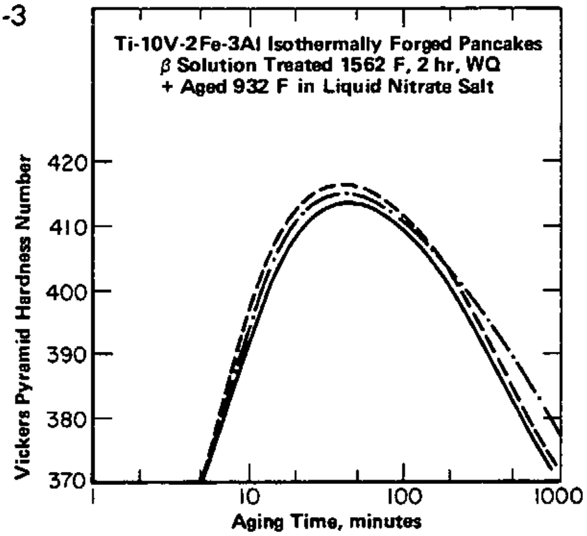


FIGURE 1.065. EFFECT OF 932 F AGING TIME ON HARDNESS OF BETA SOLUTION TREATED ISOTHERMALLY FORGED PANCAKES (18)

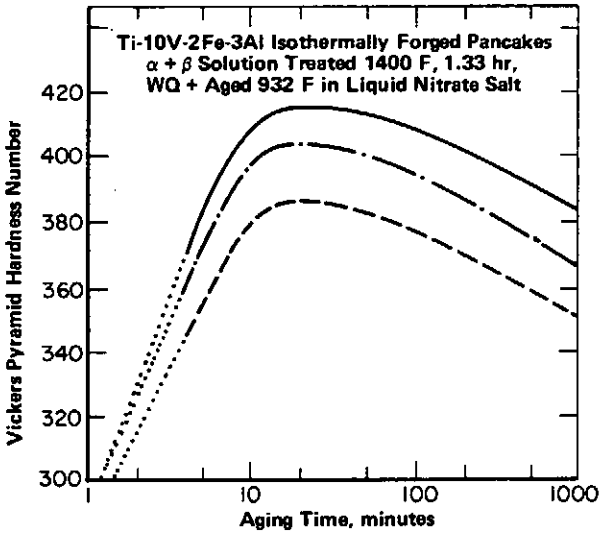


FIGURE 1.066. EFFECT OF 932 F AGING TIME ON HARDNESS OF ALPHA + BETA SOLUTION TREATED ISOTHERMALLY FORGED PANCAKES (18)

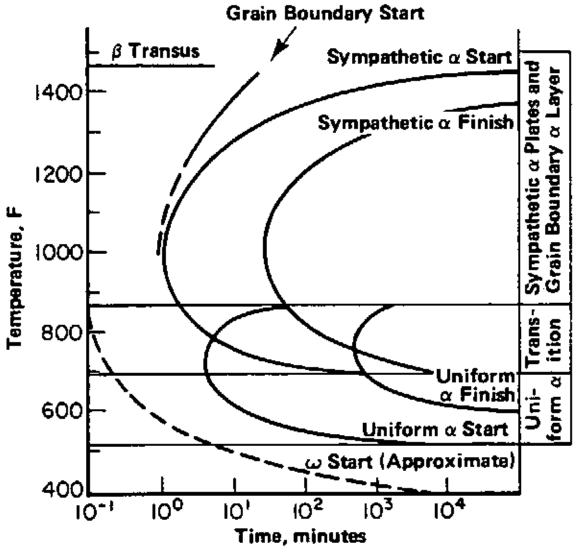


FIGURE 2.01211. SCHEMATIC TIME-TEMPERATURE-TRANSFORMATION (TTT) DIAGRAM FOR Ti-10V-2Fe-3Al BETA SOLUTION TREATED, QUENCHED, AND RAPIDLY HEATED TO THE AGING TEMPERATURE (18)

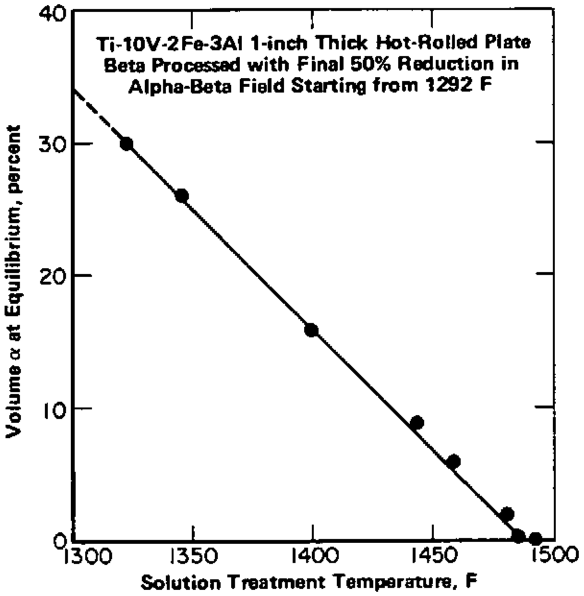


FIGURE 2.01212. DEPENDENCE OF PRIMARY ALPHA VOLUME FRACTION ON SOLUTION TREATMENT TEMPERATURE (18)

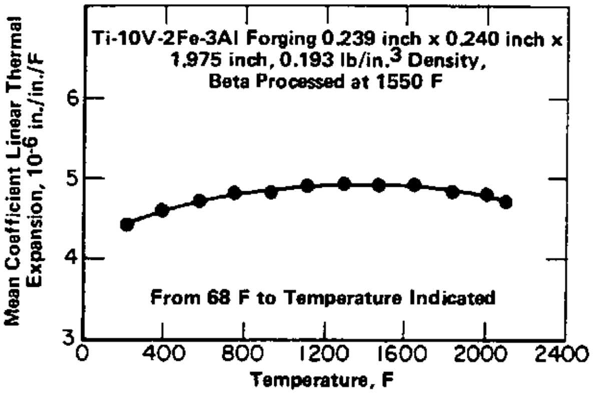
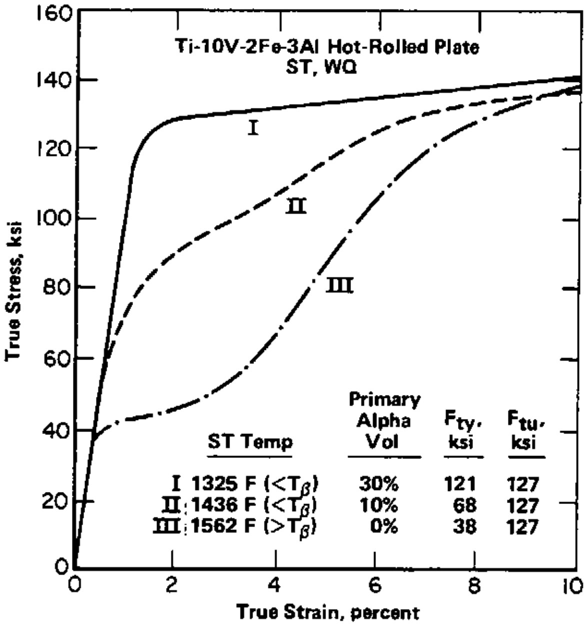
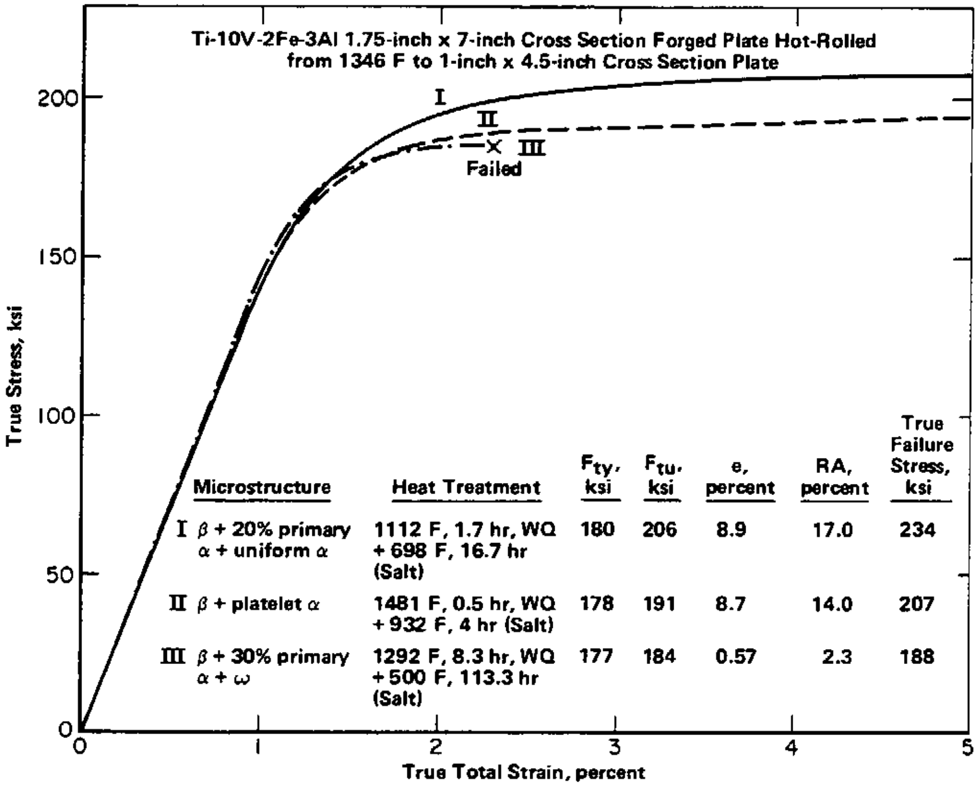


FIGURE 2.0141. THERMAL EXPANSION OF BETA PROCESSED FORGING (6)



	ST Temp	Primary Alpha Vol	F_{ty}, ksi	F_{tu}, ksi
I	1325 F (<T_β)	30%	121	127
II	1436 F (<T_β)	10%	68	127
III	1562 F (>T_β)	0%	38	127

FIGURE 3.0211. ROOM TEMPERATURE TRUE STRESS-TRUE STRAIN CURVES FOR HOT-ROLLED PLATE WATER QUENCHED FROM SEVERAL SOLUTION TEMPERATURES (15)



	Microstructure	Heat Treatment	F_{ty}, ksi	F_{tu}, ksi	e, percent	RA, percent	True Failure Stress, ksi
I	β + 20% primary α + uniform α	1112 F, 1.7 hr, WQ + 698 F, 16.7 hr (Salt)	180	206	8.9	17.0	234
II	β + platelet α	1481 F, 0.5 hr, WQ + 932 F, 4 hr (Salt)	178	191	8.7	14.0	207
III	β + 30% primary α + ω	1292 F, 8.3 hr, WQ + 500 F, 113.3 hr (Salt)	177	184	0.57	2.3	188

FIGURE 3.0212. ROOM TEMPERATURE TRUE STRESS-TRUE STRAIN BEHAVIOR OF HOT-ROLLED PLATE SOLUTION TREATED PLUS AGED TO THREE MICROSTRUCTURAL CONDITIONS (17)

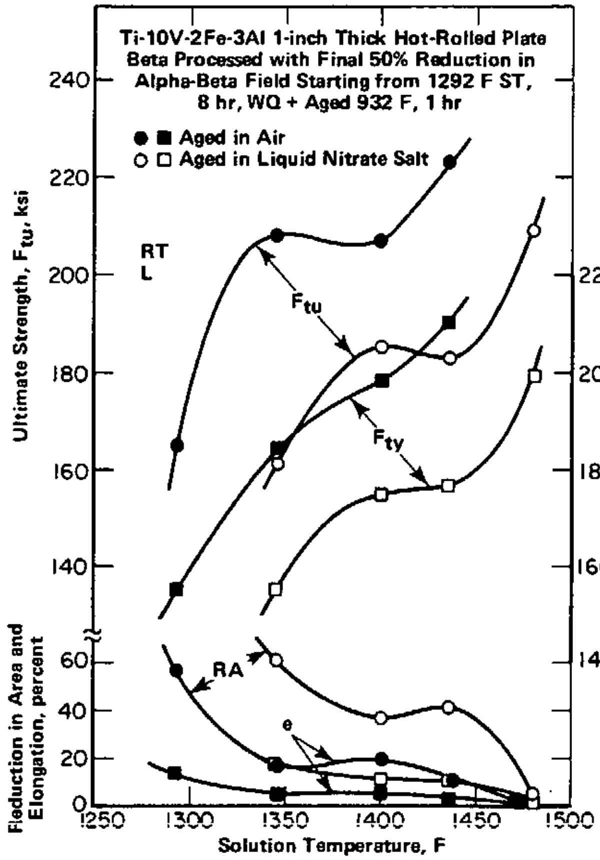


FIGURE 3.0219. EFFECT OF SOLUTION TREATMENT TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF 1-INCH THICK HOT-ROLLED PLATE SOLUTION TREATED AND AGED AT 932 F IN AIR OR LIQUID SALT (18)

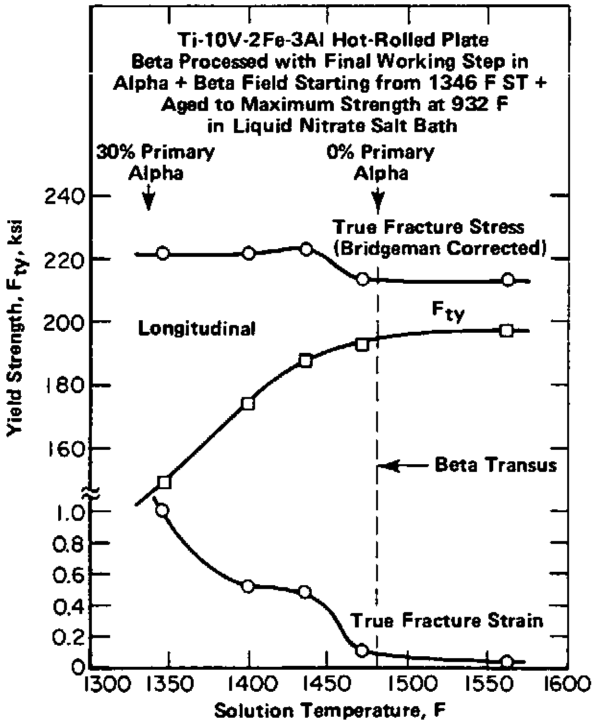


FIGURE 3.02110. EFFECT OF SOLUTION TREATMENT TEMPERATURE ON ROOM TEMPERATURE TENSILE YIELD STRENGTH, TRUE FRACTURE STRESS AND TRUE FRACTURE STRAIN OF HOT-ROLLED PLATE SOLUTION TREATED (PRIMARY ALPHA CONTENTS FROM 30 PERCENT TO 0 PERCENT) AND AGED TO MAXIMUM STRENGTH ATTAINABLE AT 932 F (16)

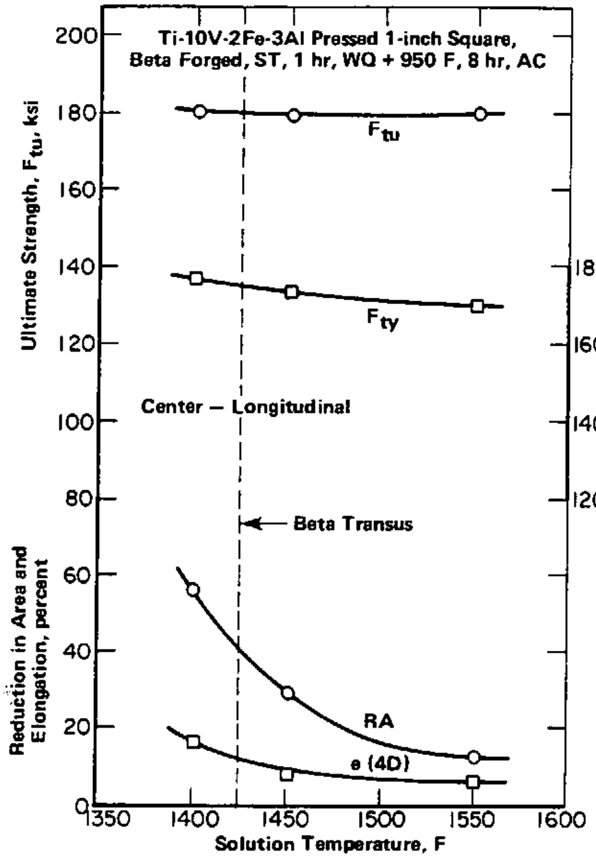


FIGURE 3.02111. EFFECT OF SUPER TRANSUS SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED 1-INCH SQUARE, BETA FORGED PLUS SOLUTION TREATED AND AGED (5)

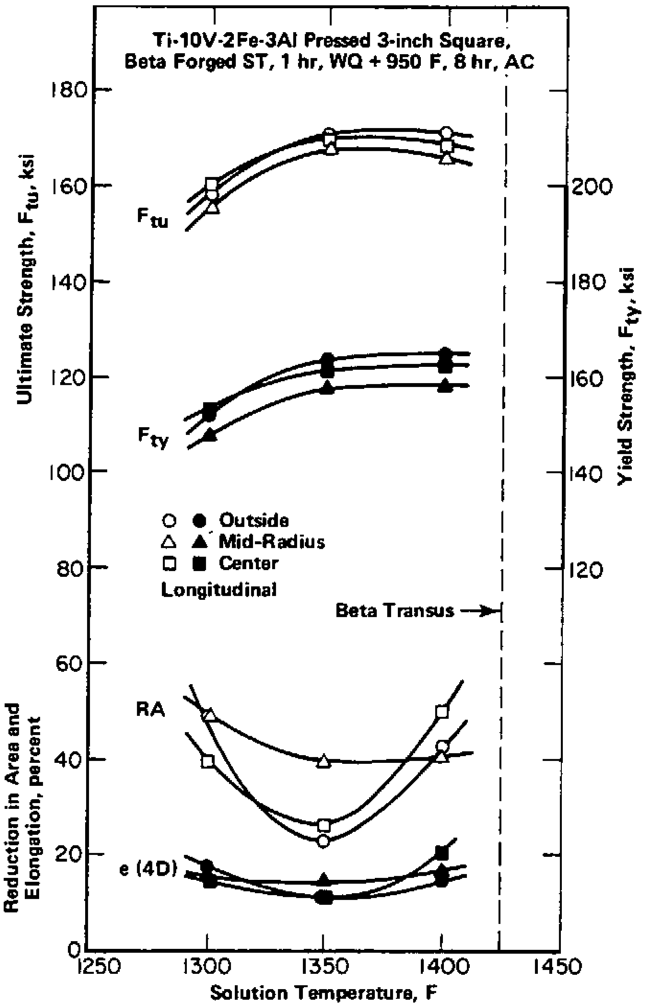


FIGURE 3.02112. EFFECT OF SUBTRANSUS SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED 3-INCH SQUARE, BETA FORGED PLUS SOLUTION TREATED AND AGED (5)

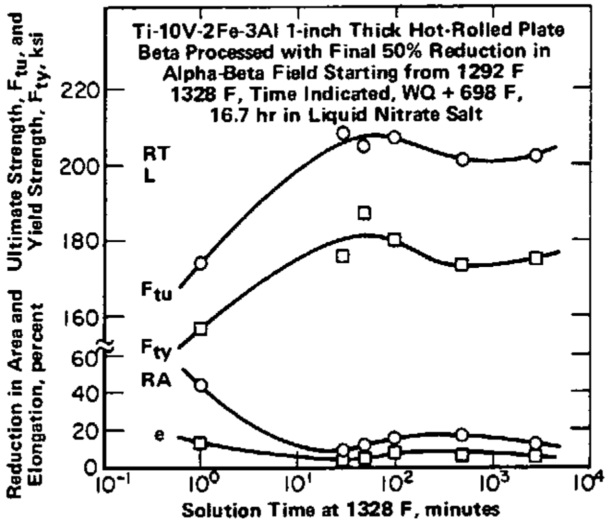


FIGURE 3.02113. EFFECT OF SOLUTION TREATMENT TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF 1-INCH THICK HOT-ROLLED PLATE SOLUTION TREATED AND AGED (18)

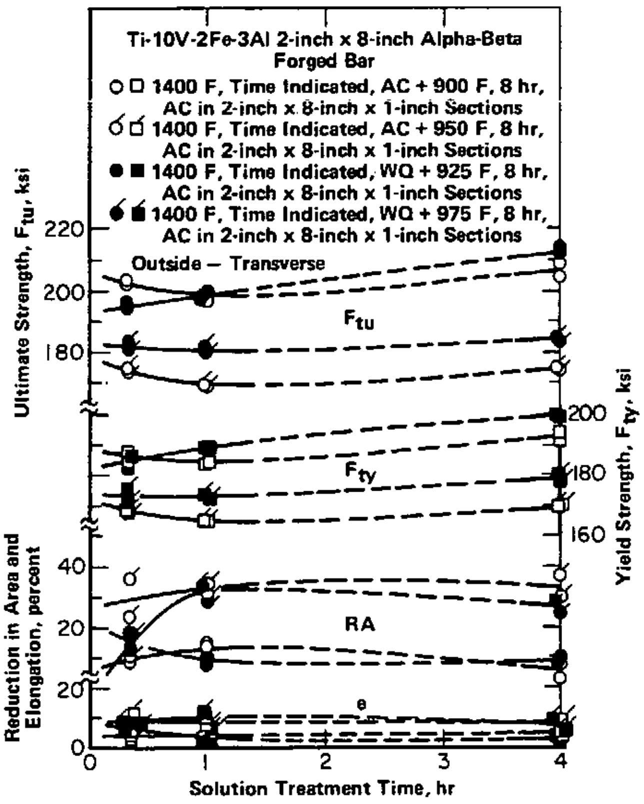


FIGURE 3.02115. EFFECT OF SOLUTION TREATMENT TIME AND QUENCH RATE AND OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF ALPHA-BETA FORGED BAR SOLUTION TREATED AT 1400 F AND AGED (14)

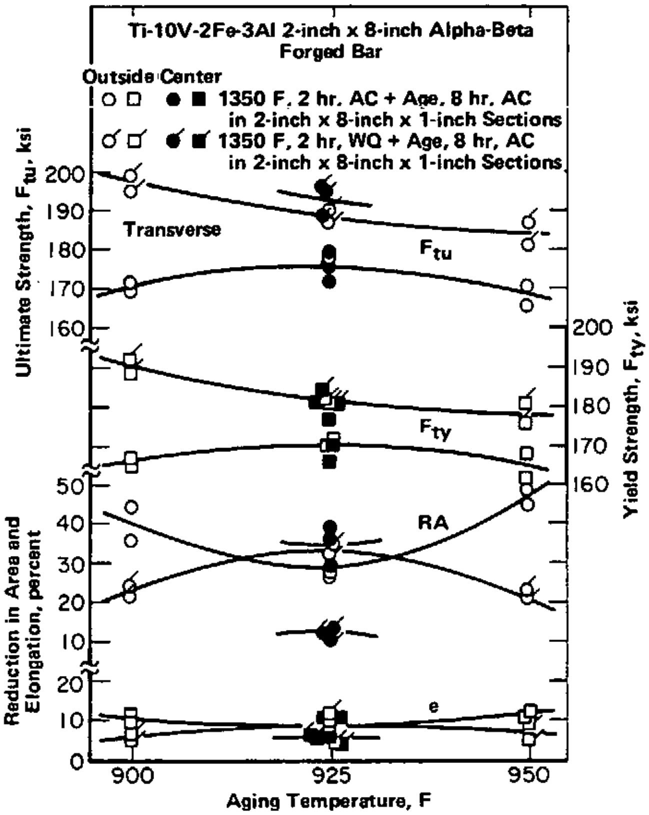


FIGURE 3.02116. EFFECT OF SOLUTION TREATMENT QUENCH RATE AND OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF ALPHA-BETA FORGED BAR SOLUTION TREATED AT 1350 F AND AGED. (LOW CENTER DUCTILITY OF WATER QUENCHED PRODUCT DUE TO HIGH LEVEL OF SEGREGATED IRON AT BAR CENTER) (14)

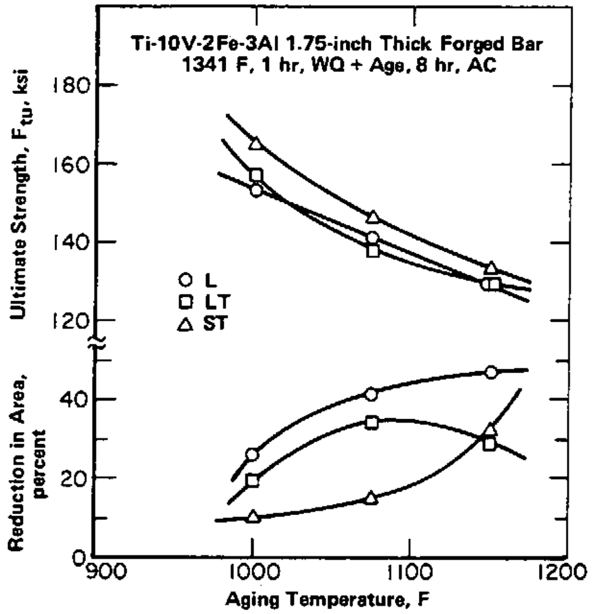


FIGURE 3.02117. EFFECT OF AGING TEMPERATURE AND TEST DIRECTION ON ROOM TEMPERATURE TENSILE PROPERTIES OF FORGED BAR (9)

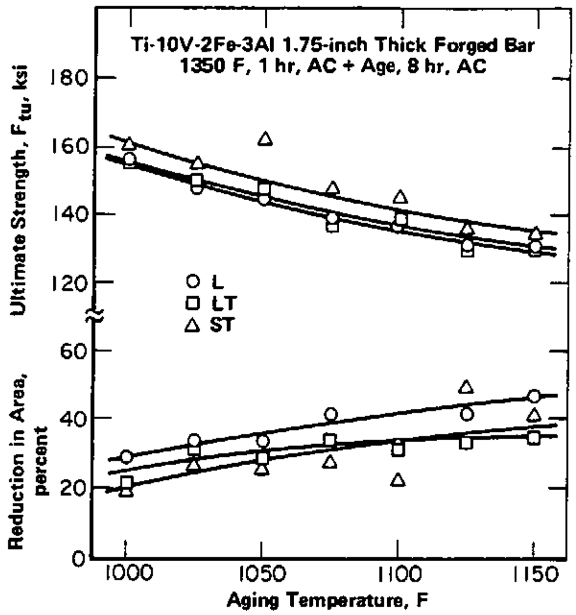


FIGURE 3.02118. EFFECT OF AGING TEMPERATURE AND TEST DIRECTION ON ROOM TEMPERATURE TENSILE PROPERTIES OF FORGED BAR (9)

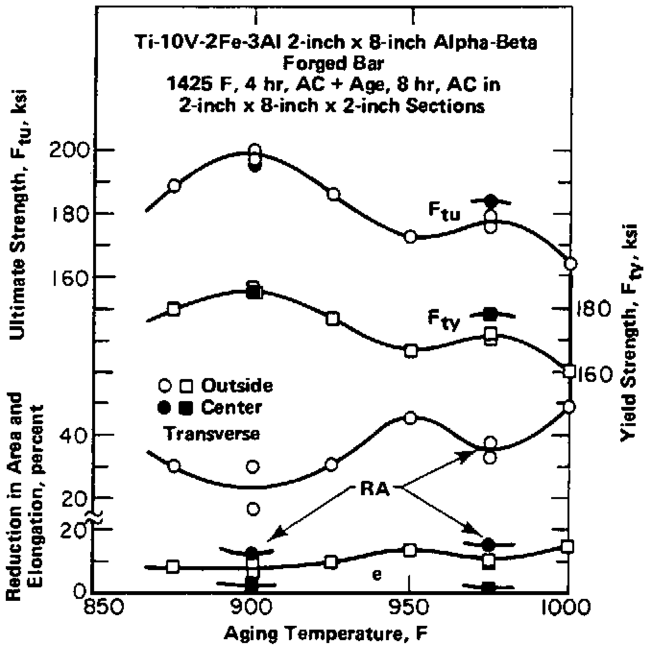


FIGURE 3.02119. EFFECT OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF ALPHA-BETA FORGED BAR SOLUTION TREATED AND AGED. (LOW CENTER DUCTILITY DUE TO HIGH LEVEL OF SEGREGATED IRON AT BAR CENTER) (14)

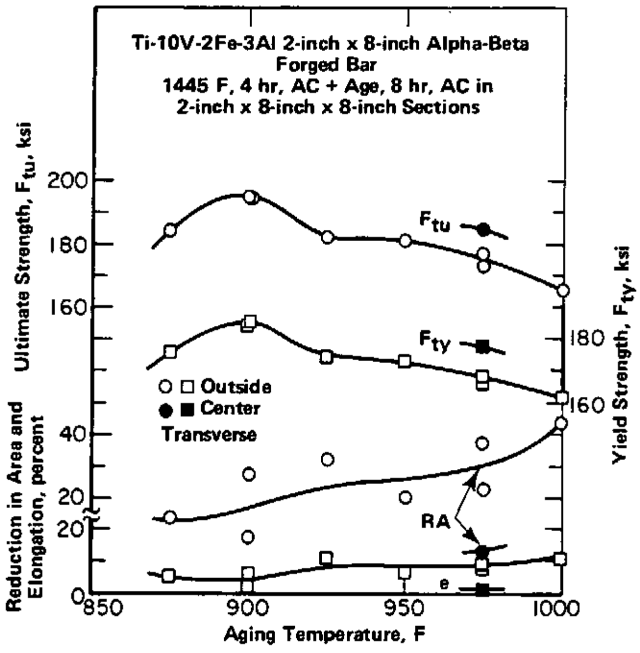


FIGURE 3.02120. EFFECT OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF ALPHA-BETA FORGED BAR SOLUTION TREATED AND AGED. (LOW CENTER DUCTILITY DUE TO HIGH LEVEL OF SEGREGATED IRON AT BAR CENTER) (14)

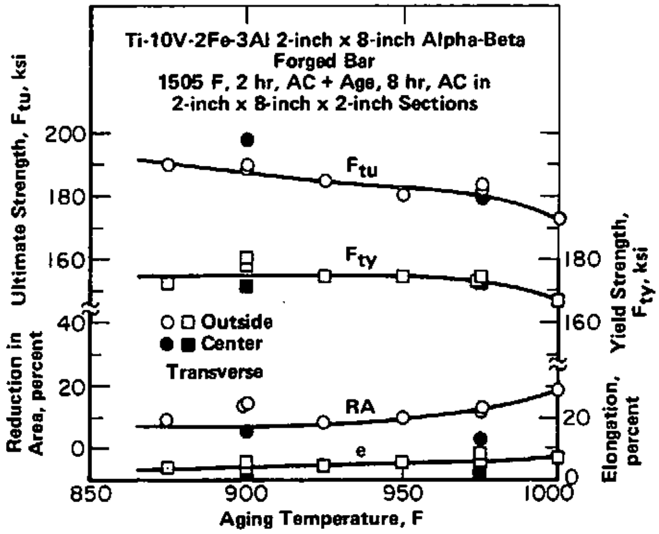


FIGURE 3.02121. EFFECT OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF ALPHA-BETA FORGED BAR SOLUTION TREATED AND AGED (14)

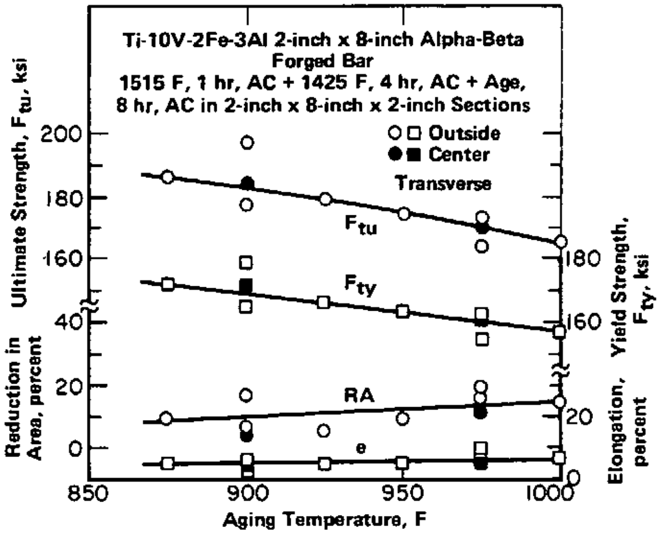


FIGURE 3.02122. EFFECT OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF ALPHA-BETA FORGED BAR DOUBLE SOLUTION TREATED AND AGED (14)

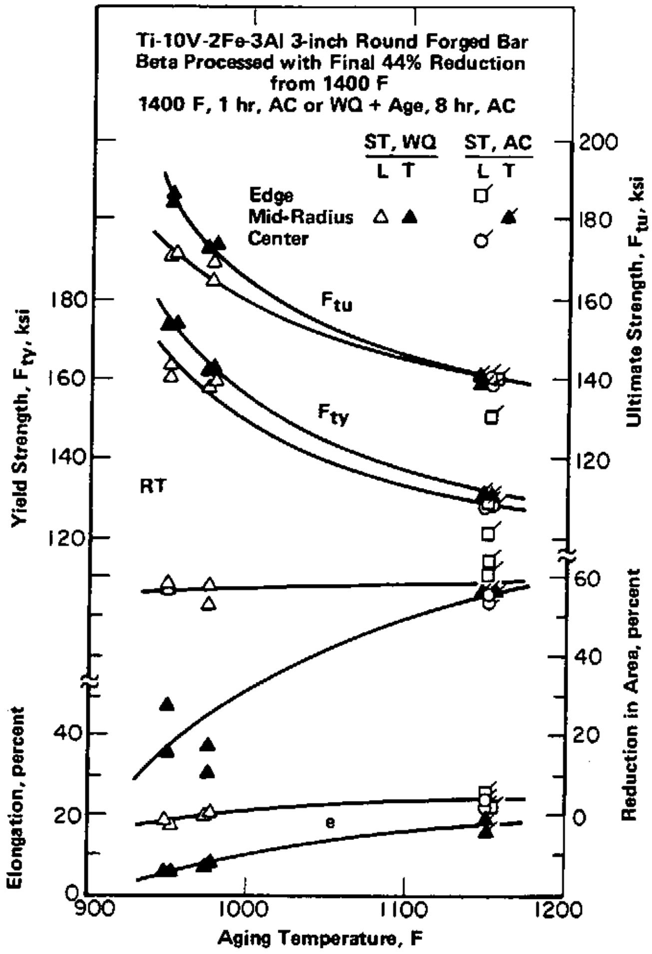


FIGURE 3.02123. EFFECT OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED 3-INCH ROUND FORGED BAR BETA PROCESSED WITH FINAL REDUCTION BELOW THE BETA TRANSUS TEMPERATURE (19)

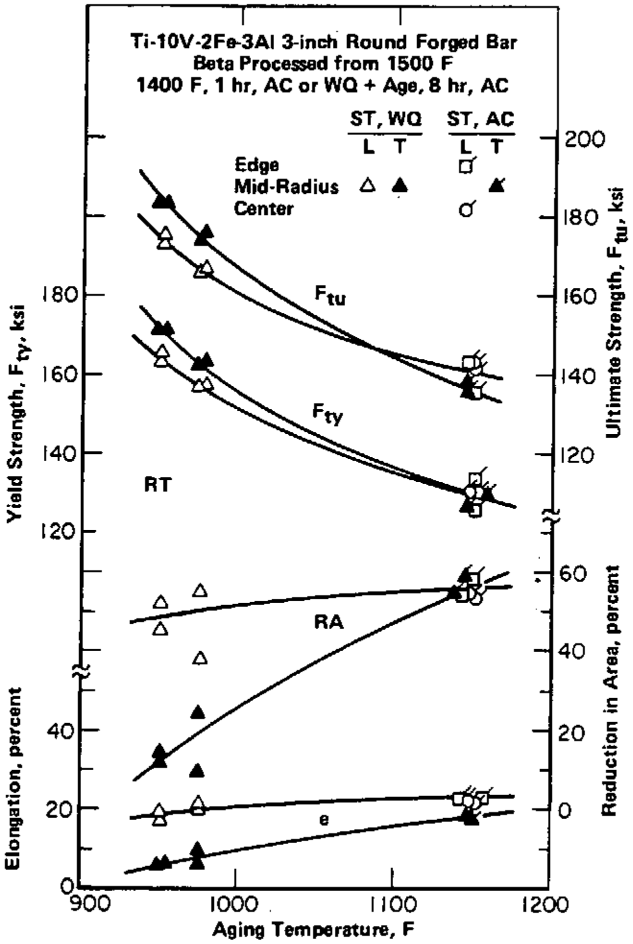


FIGURE 3.02124. EFFECT OF AGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED 3-INCH ROUND FORGED BAR BETA PROCESSED (19)

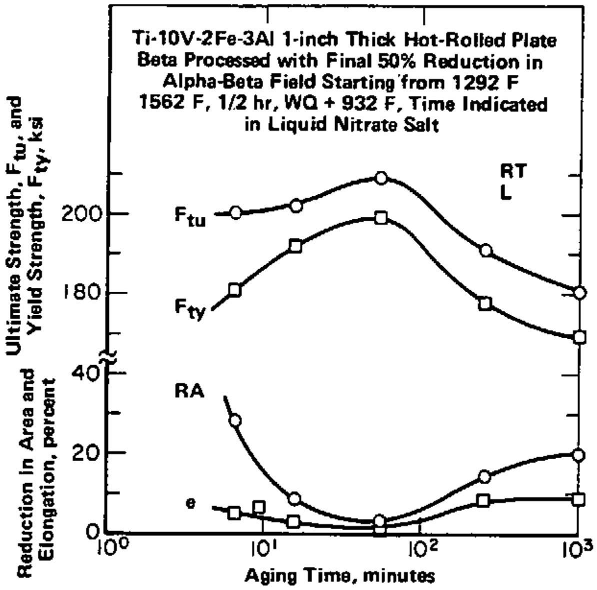


FIGURE 3.02125. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF 1-INCH THICK HOT-ROLLED PLATE BETA SOLUTION TREATED AT 1562 F AND AGED IN SALT AT 932 F (18)

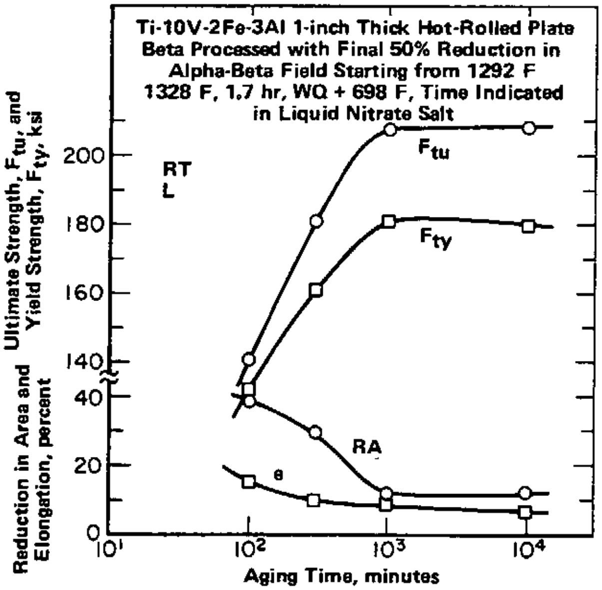


FIGURE 3.02126. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF 1-INCH THICK HOT-ROLLED PLATE ALPHA + BETA SOLUTION TREATED AT 1328 F AND AGED IN SALT AT 698 F (18)

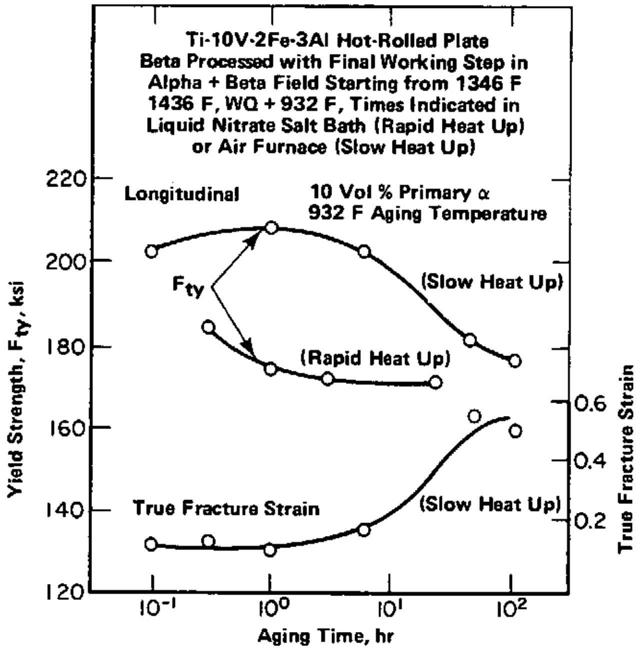


FIGURE 3.02127. EFFECT OF 932 F AGE TIME ON ROOM TEMPERATURE YIELD STRENGTH AND TRUE FRACTURE STRAIN OF HOT-ROLLED PLATE CONTAINING 10 PERCENT CONSTANT PRIMARY ALPHA CONTENT, HEATED AT TWO RATES TO THE AGING TEMPERATURE (16)

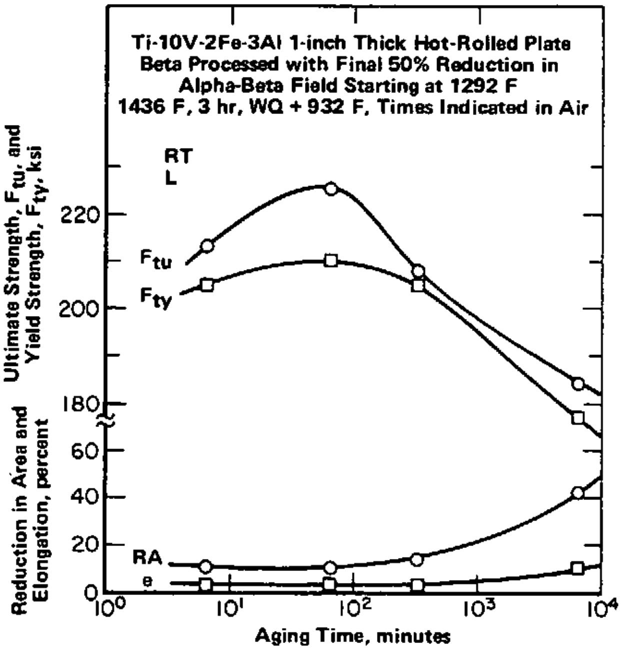


FIGURE 3.02128. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF 1-INCH THICK HOT-ROLLED PLATE ALPHA + BETA SOLUTION TREATED AT 1436 F AND AGED IN AIR AT 932 F (18)

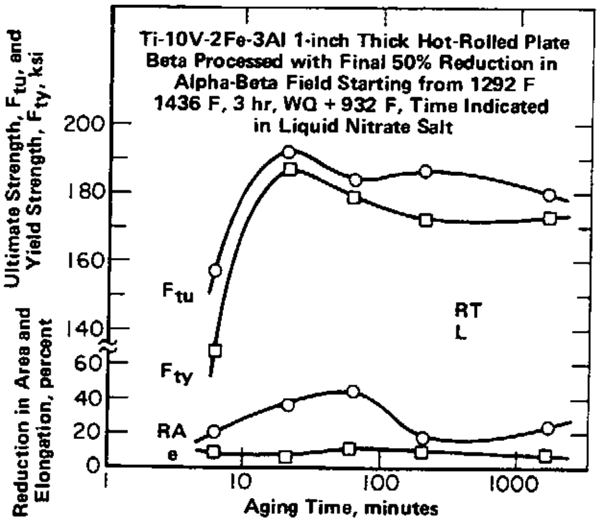


FIGURE 3.02129. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF 1-INCH THICK HOT-ROLLED PLATE ALPHA + BETA SOLUTION TREATED AT 1436 F AND AGED IN SALT AT 932 F (18)

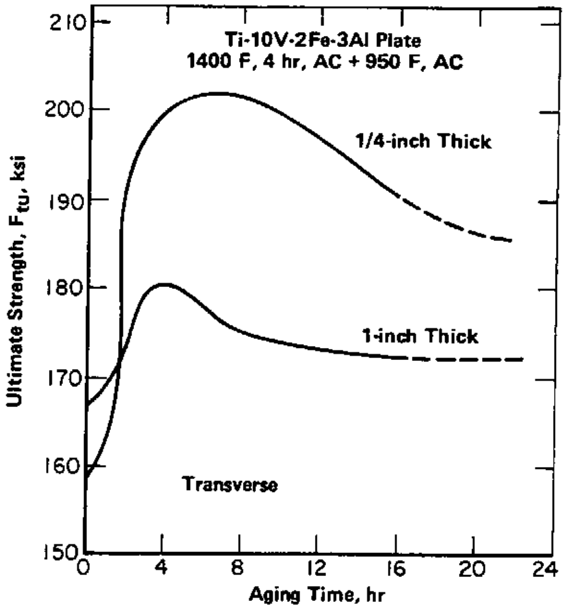


FIGURE 3.02130. EFFECT OF AGING TIME ON ROOM TEMPERATURE ULTIMATE TENSILE STRENGTH OF PLATE OF TWO THICKNESSES (9)

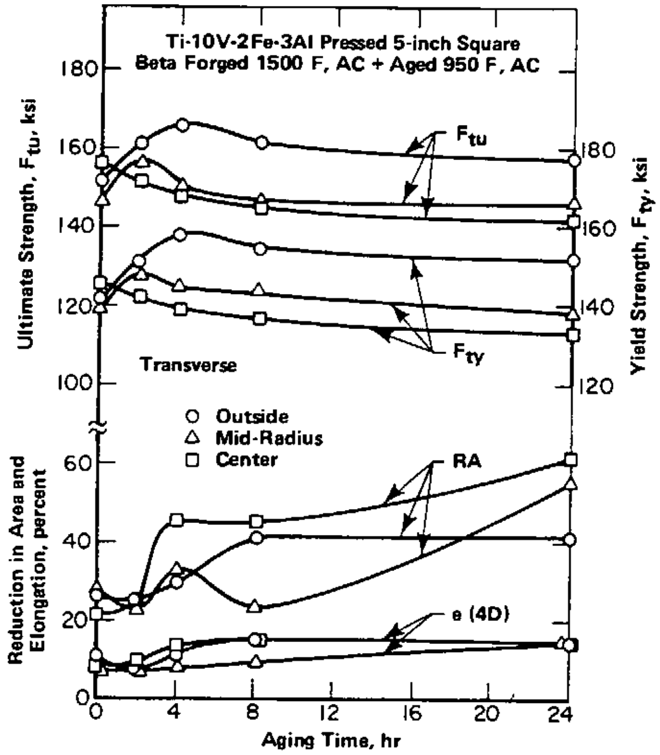


FIGURE 3.02131. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED 5-INCH SQUARE, BETA FORGED PLUS DIRECTLY AGED AT 950 F (5)

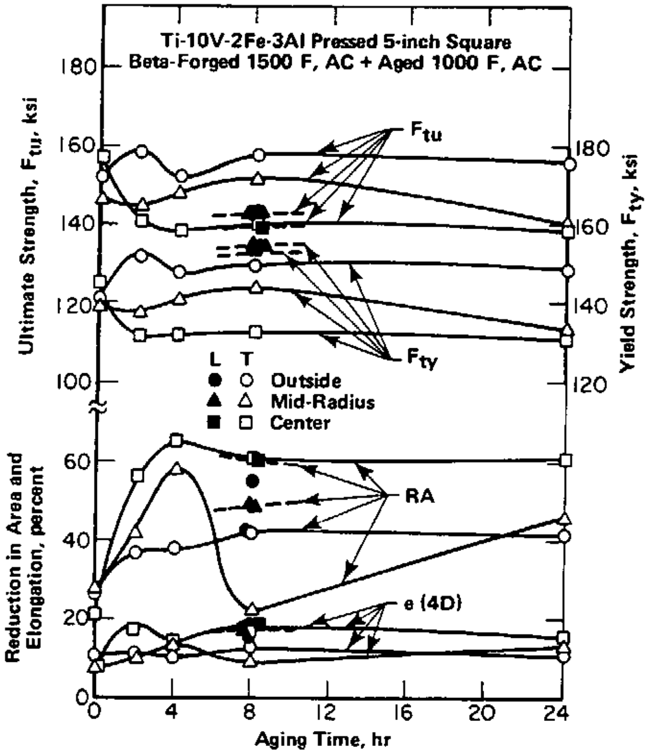


FIGURE 3.02132. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED 5-INCH SQUARE, BETA FORGED PLUS DIRECTLY AGED AT 1000 F (5)

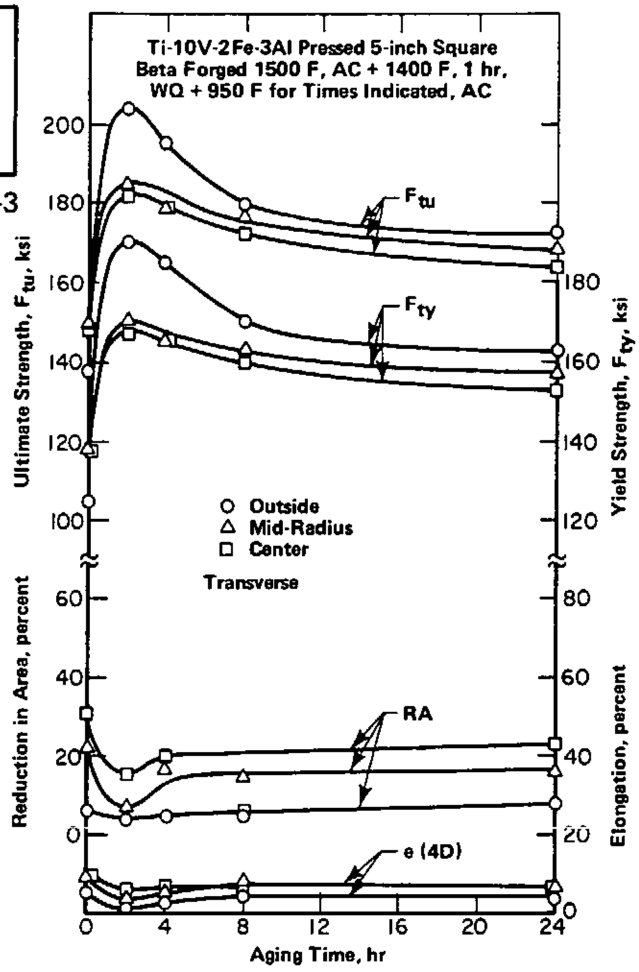


FIGURE 3.02133. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED 5-INCH SQUARE, BETA FORGED PLUS SOLUTION TREATED AND AGED AT 950 F (5)

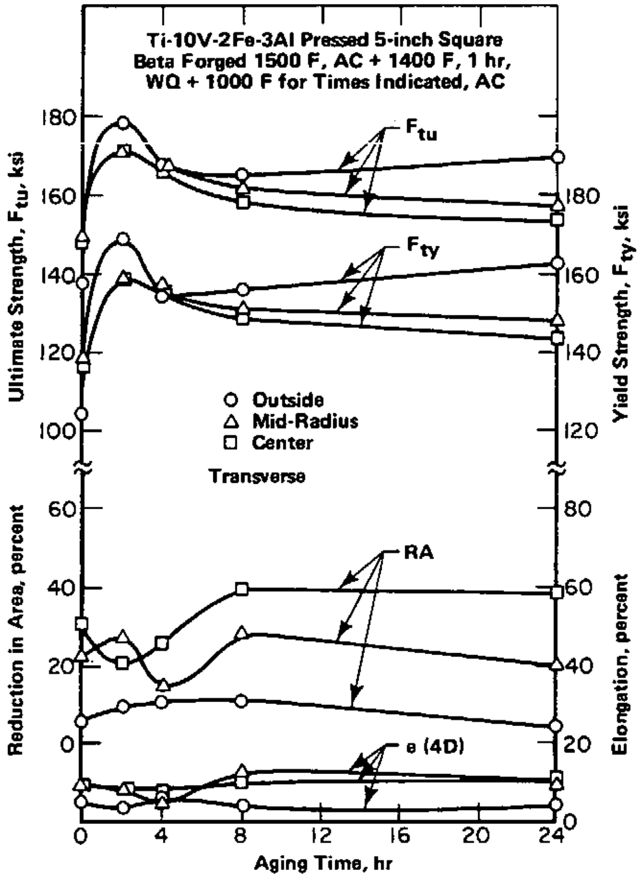


FIGURE 3.02134. EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED 5-INCH SQUARE, BETA FORGED PLUS SOLUTION TREATED AND AGED AT 1000 F (5)

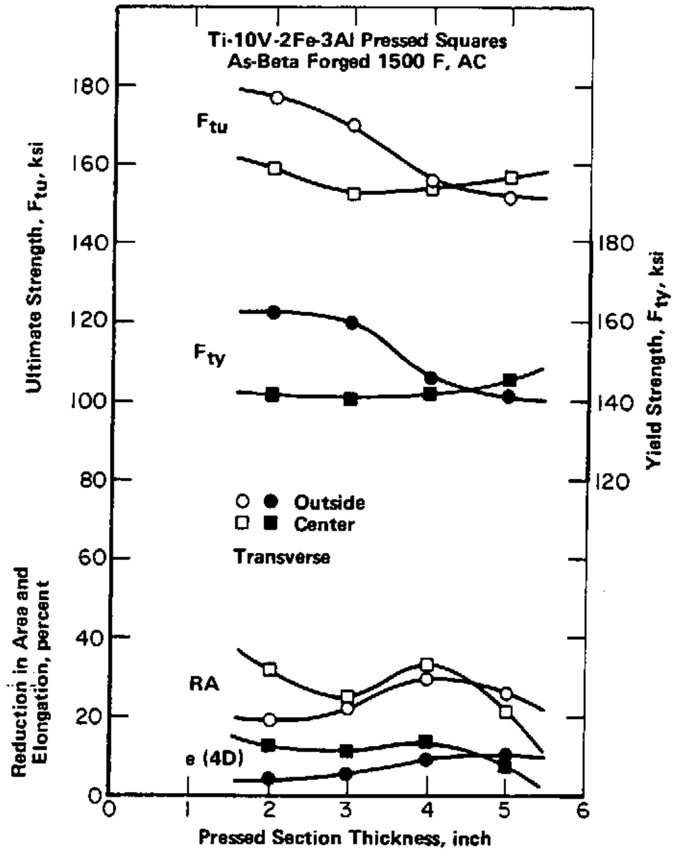


FIGURE 3.02135. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED SQUARES, AS-BETA FORGED (5)

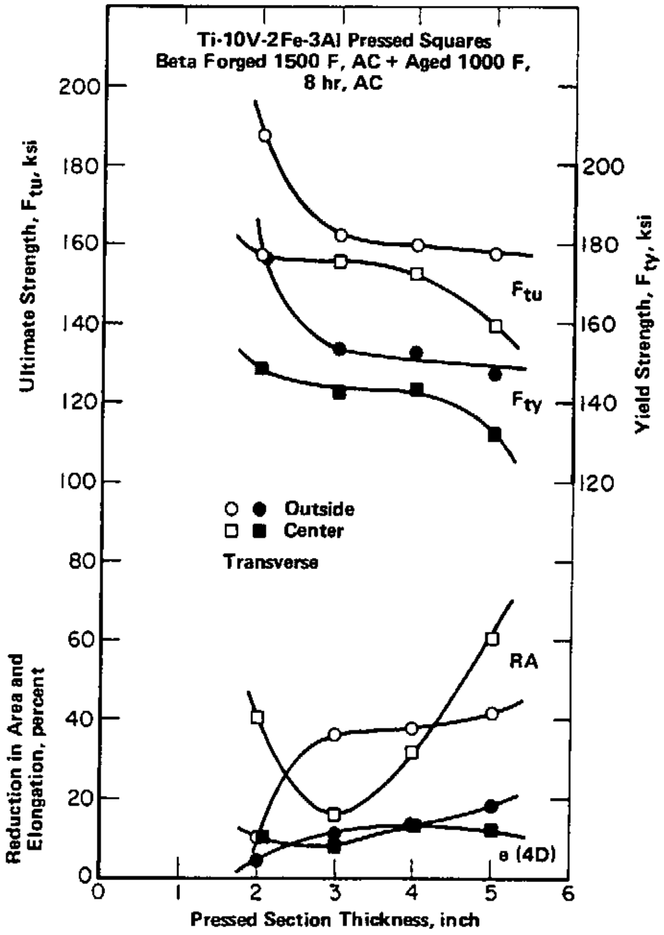


FIGURE 3.02136. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE TRANSVERSE TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS DIRECTLY AGED AT 1000 F (5)

Ti
10 V
2 Fe
3 Al
Ti-10-2-3

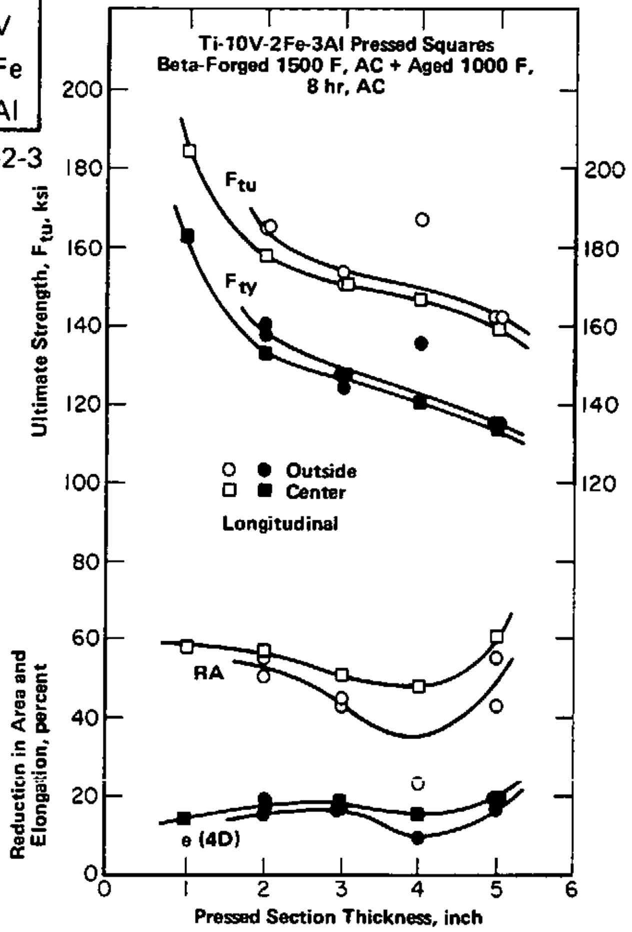


FIGURE 3.02137. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE LONGITUDINAL TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS DIRECTLY AGED AT 1000 F (5)

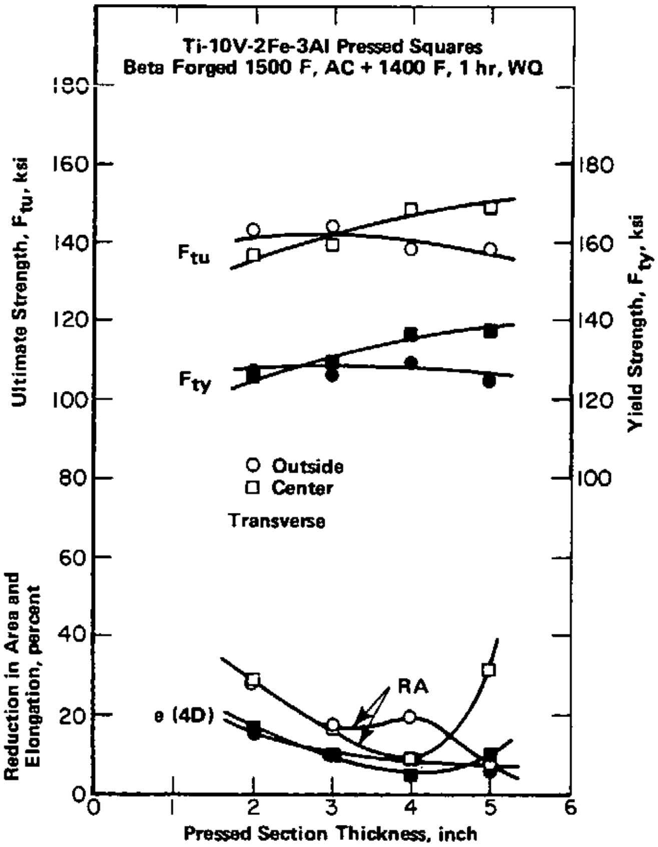


FIGURE 3.02138. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS SOLUTION TREATED (5)

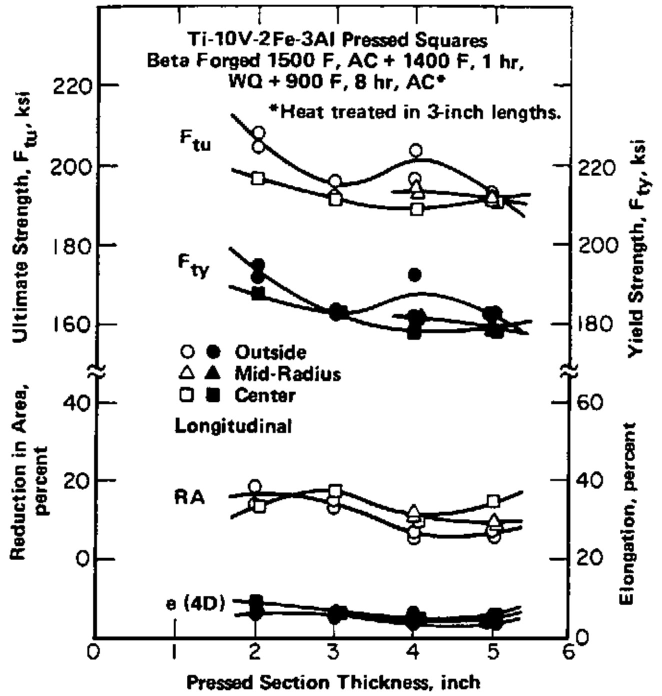


FIGURE 3.02139. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS SOLUTION TREATED AND AGED AT 900 F (5)

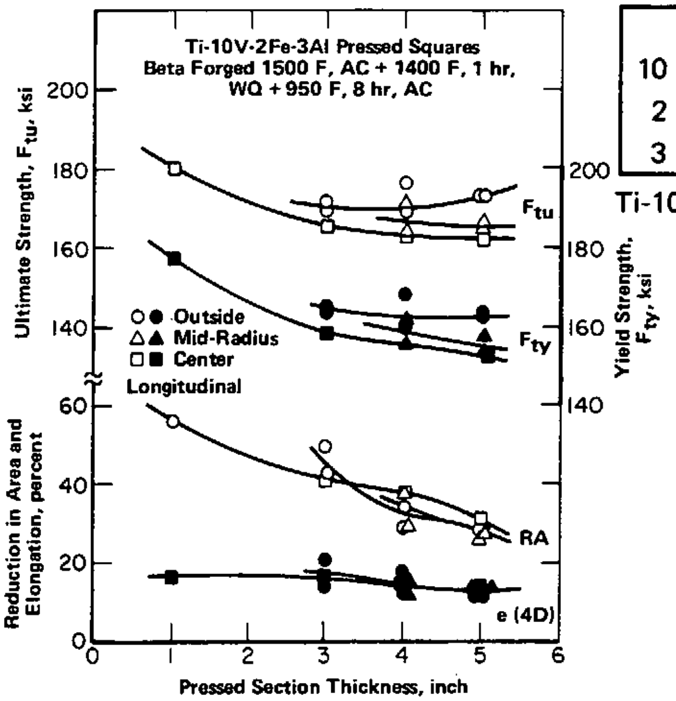


FIGURE 3.02140. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE LONGITUDINAL TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS SOLUTION TREATED AND AGED AT 950 F (5)

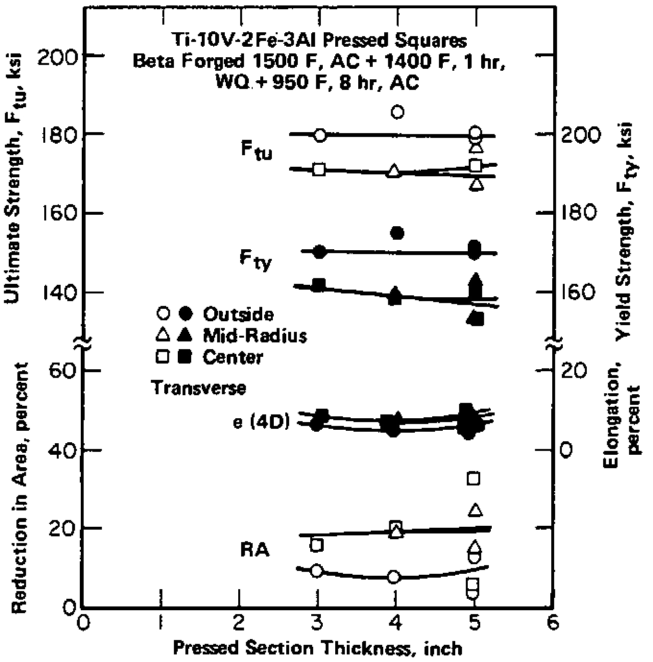


FIGURE 3.02141. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE TRANSVERSE TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS SOLUTION TREATED AND AGED AT 950 F (5)

Ti
10 V
2 Fe
3 Al

Ti-10-2-3

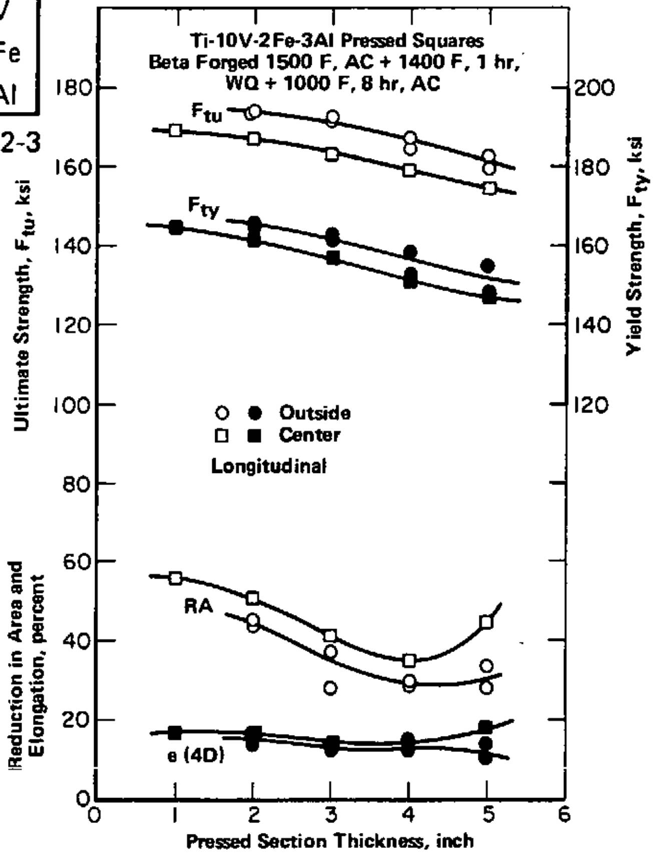


FIGURE 3.02142. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS SOLUTION TREATED AND AGED AT 1000 F (5)

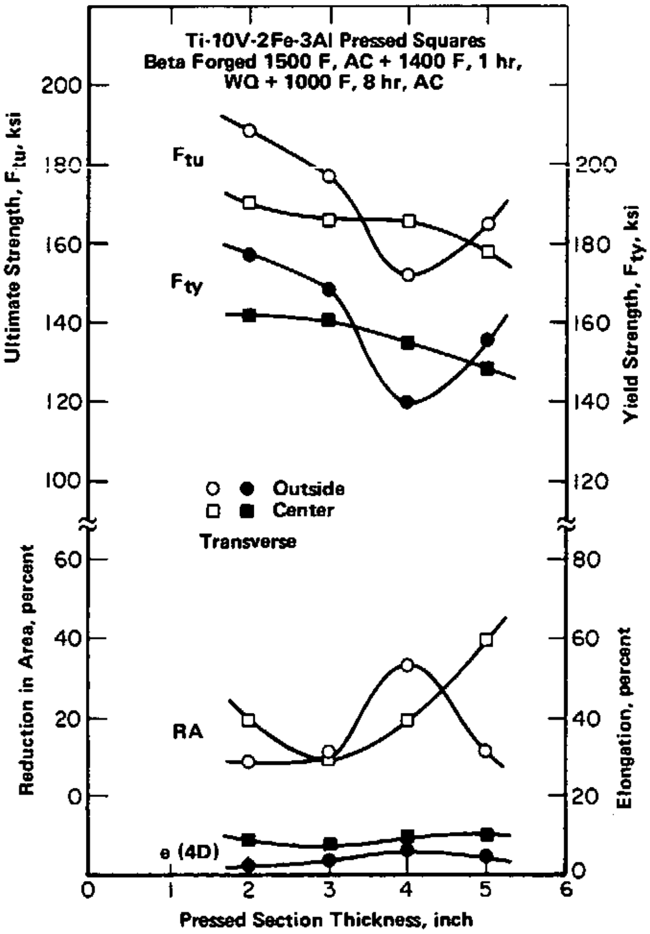


FIGURE 3.02143. EFFECT OF SECTION THICKNESS ON ROOM TEMPERATURE TRANSVERSE TENSILE PROPERTIES OF PRESSED SQUARES, BETA FORGED PLUS SOLUTION TREATED AND AGED AT 1000 F (5)

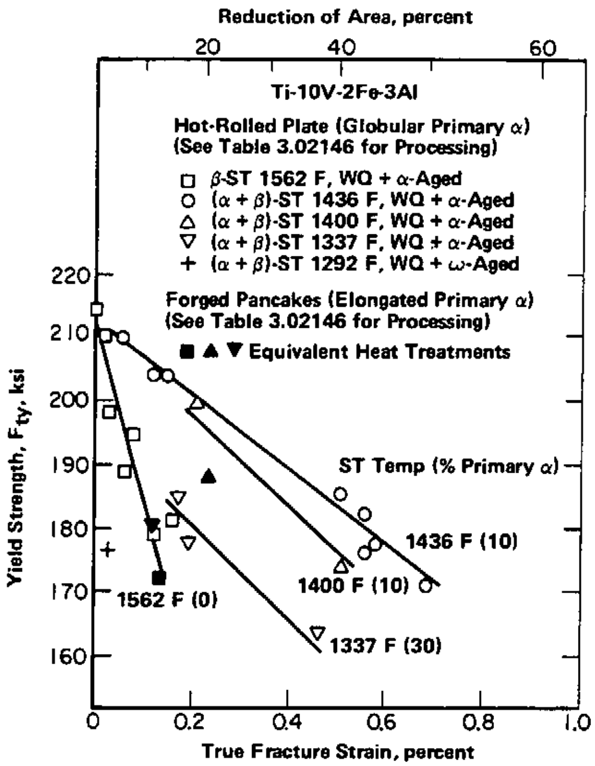


FIGURE 3.02144. RELATION BETWEEN TENSILE YIELD STRENGTH AND TRUE FRACTURE STRAIN OR REDUCTION IN AREA FOR VARIOUS MICROSTRUCTURES (16)

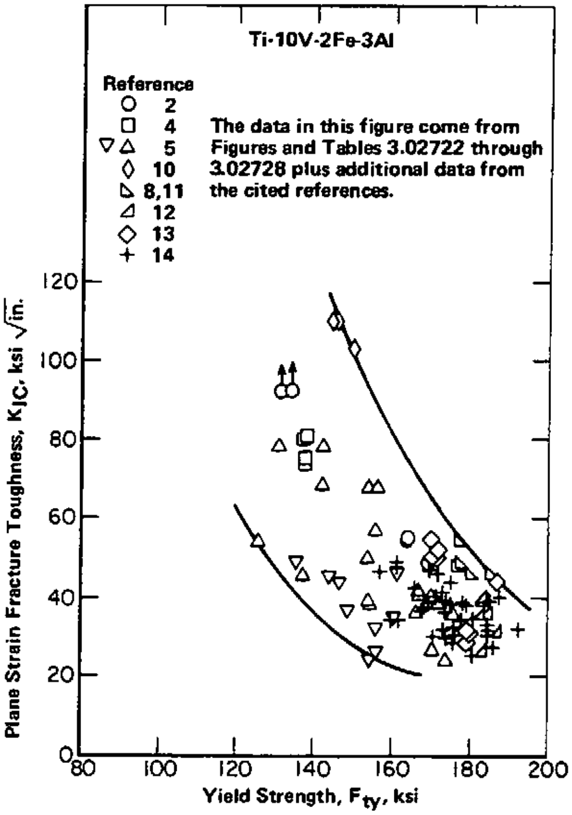


FIGURE 3.02721. SUMMARY REPRESENTATION OF ROOM TEMPERATURE PLANE STRAIN FRACTURE TOUGHNESS AS A FUNCTION OF TENSILE YIELD STRENGTH FOR ALL PRODUCTS AND CONDITIONS REPORTED IN THE REFERENCED LITERATURE

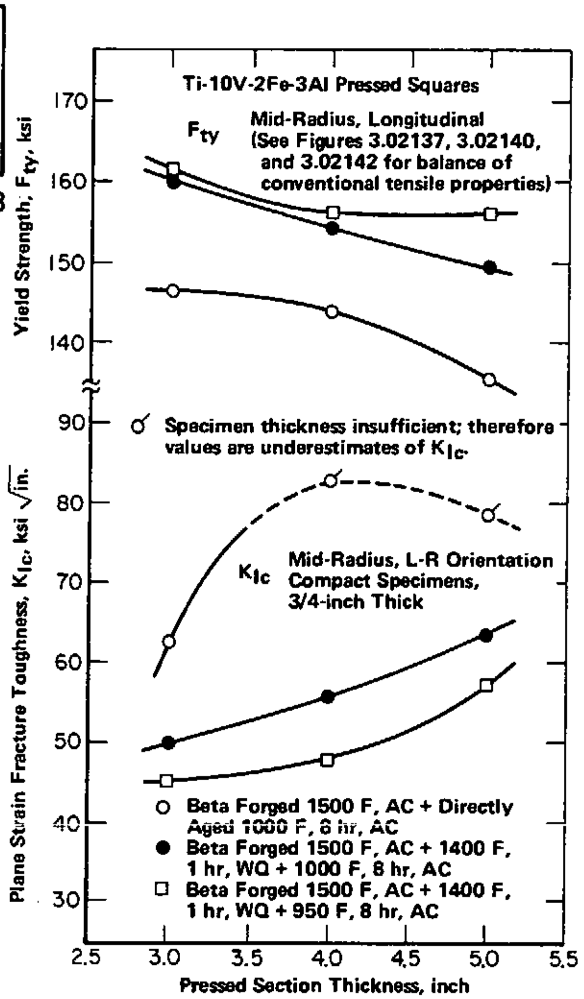


FIGURE 3.02724. EFFECT OF SECTION THICKNESS AND HEAT TREATMENT ON ROOM TEMPERATURE TENSILE YIELD STRENGTH AND PLANE STRAIN FRACTURE TOUGHNESS OF BETA FORGED PRESSED SQUARES (5)

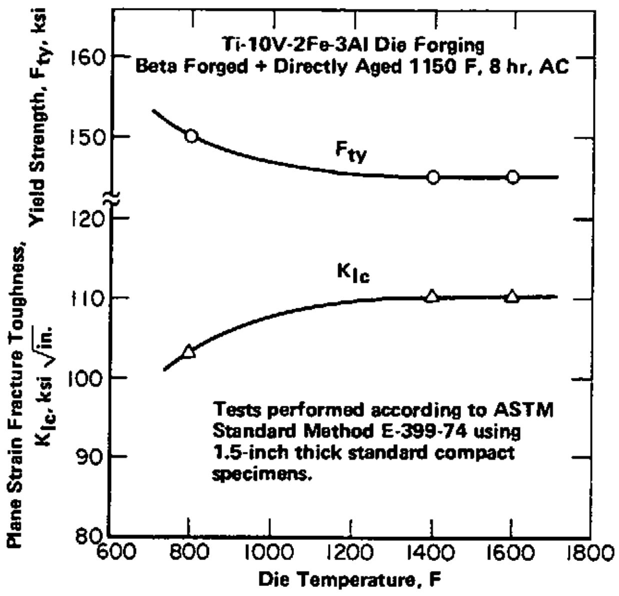


FIGURE 3.02725. EFFECT OF DIE TEMPERATURE ON ROOM TEMPERATURE STRENGTH AND TOUGHNESS OF FORGING, BETA FORGED PLUS DIRECTLY AGED (10)

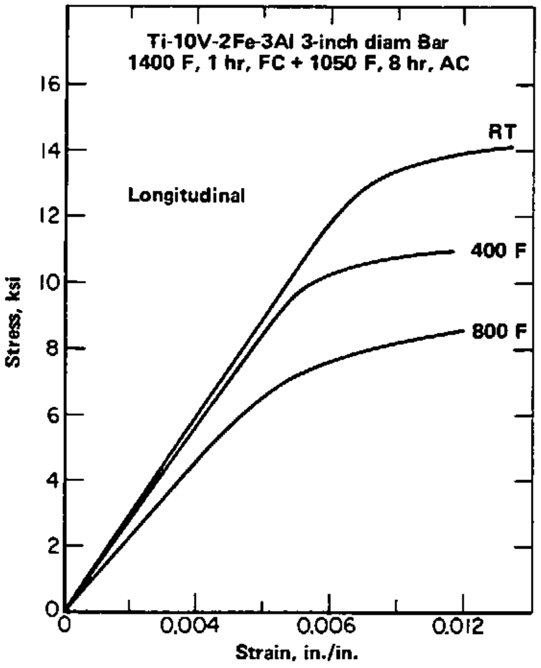


FIGURE 3.0311. TYPICAL TENSILE STRESS-STRAIN CURVES AT ROOM TEMPERATURE, 400 F, AND 800 F FOR HEAT TREATED BAR (4)

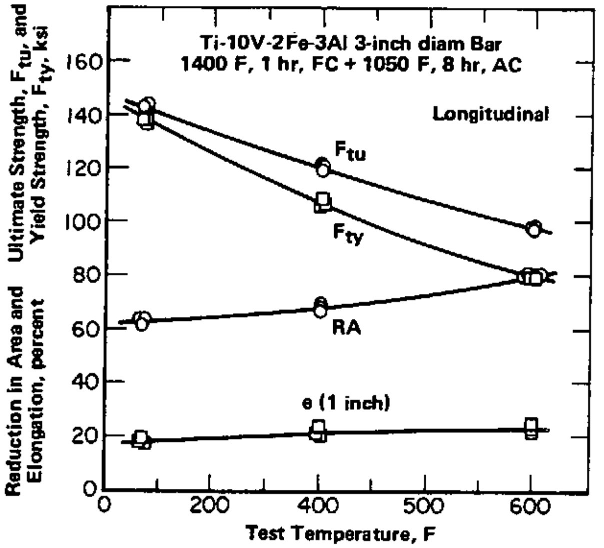


FIGURE 3.0312. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF HEAT TREATED BAR (4)

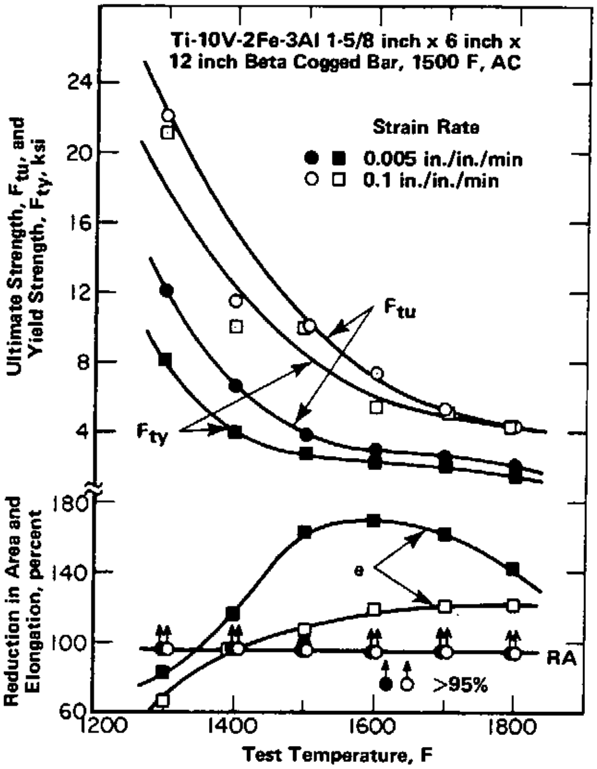


FIGURE 3.0315. EFFECT OF VERY HIGH TEST TEMPERATURES ON TENSILE PROPERTIES AT TWO STRAIN RATES FOR BETA COGGED BAR (3)

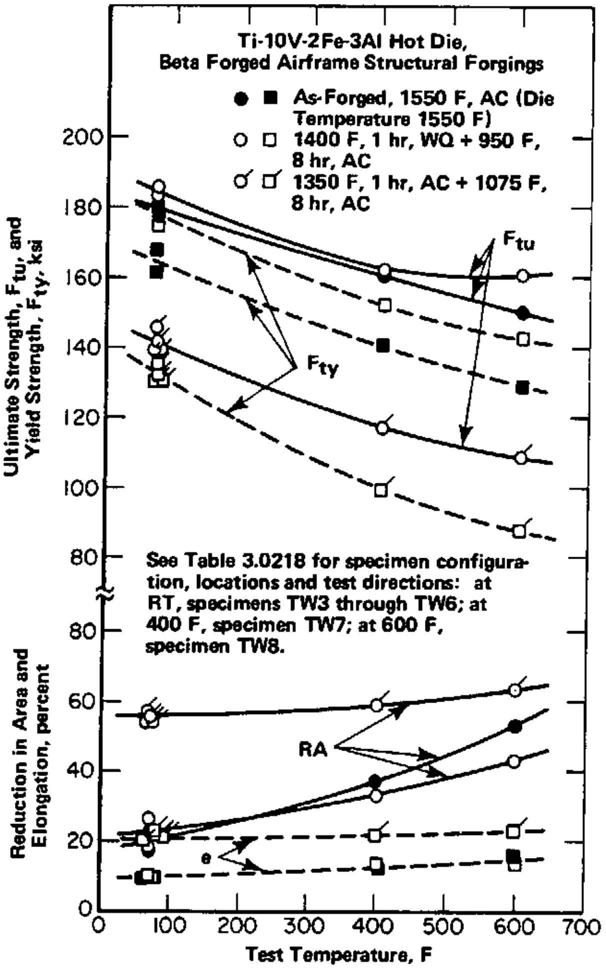


FIGURE 3.0314. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF AS-FORGED AND HEAT TREATED HOT DIE, BETA FORGED AIRFRAME STRUCTURAL FORGINGS (2)

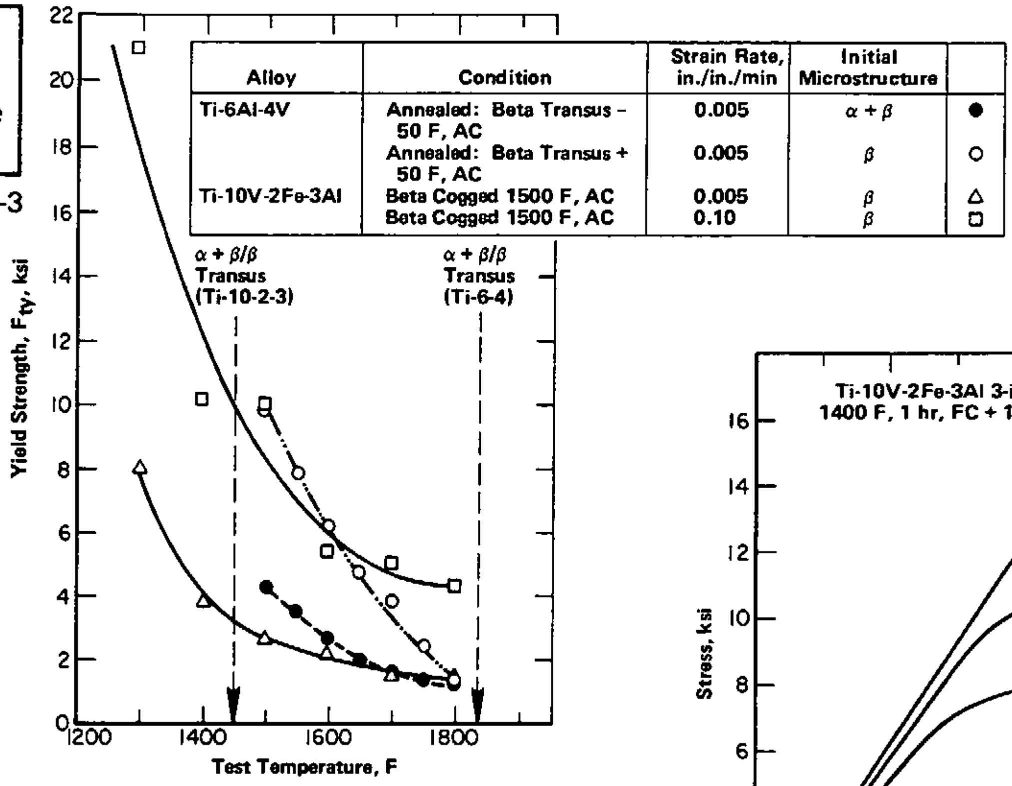


FIGURE 3.0316. COMPARISON OF STRAIN RATE AND TEST TEMPERATURE EFFECTS ON TENSILE YIELD STRENGTH OF Ti-10V-2Fe-3Al AND Ti-6Al-4V ALLOYS (3)

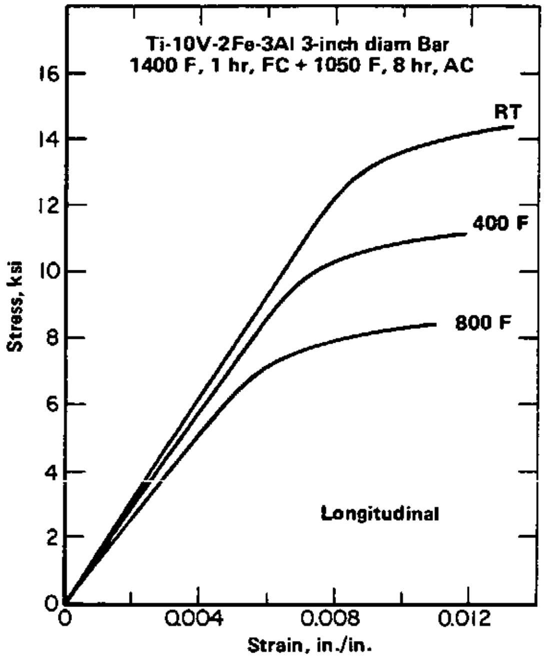


FIGURE 3.0321. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT ROOM TEMPERATURE, 400 F, AND 800 F FOR HEAT TREATED BAR (4)

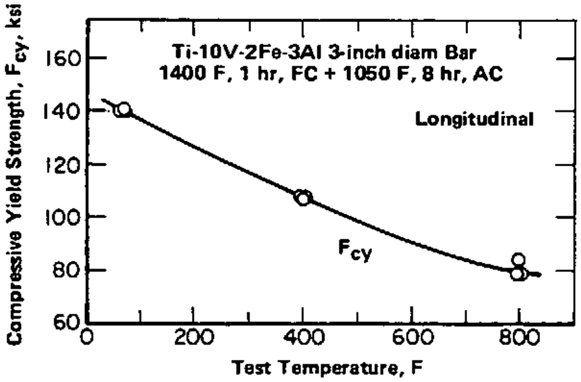


FIGURE 3.0322. EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF HEAT TREATED BAR (4)

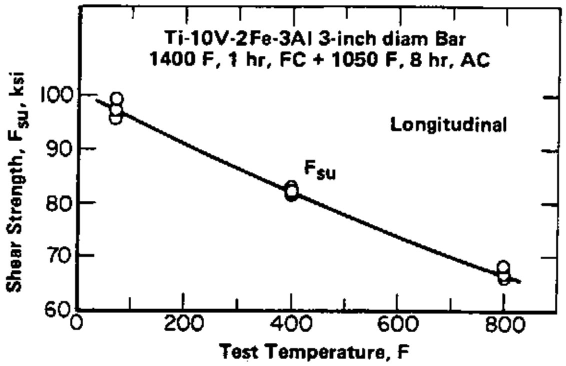


FIGURE 3.0351. EFFECT OF TEST TEMPERATURE ON SHEAR ULTIMATE STRENGTH OF HEAT TREATED BAR (4)

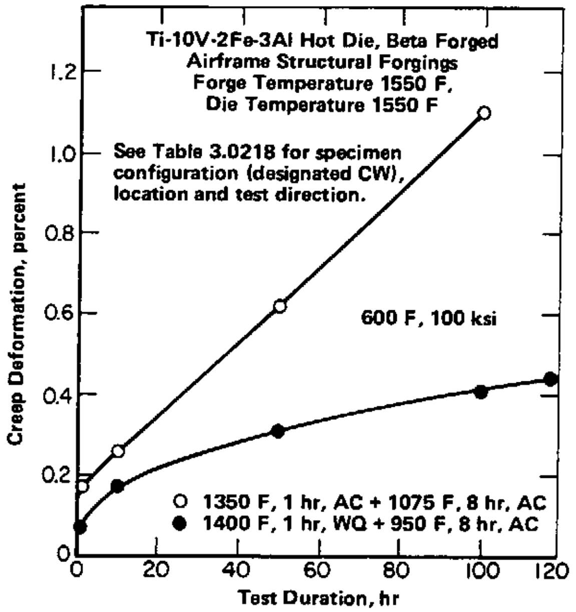


FIGURE 3.041. CREEP CURVES AT 600 F, 100 KSI, FOR HEAT TREATED HOT DIE, BETA FORGED AIRFRAME STRUCTURAL FORGINGS (2)

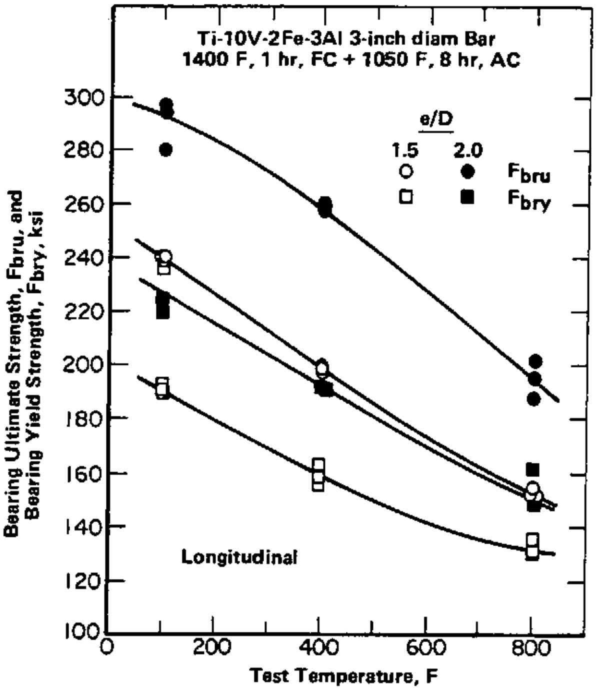


FIGURE 3.0361. EFFECT OF TEST TEMPERATURE ON BEARING STRENGTH OF HEAT TREATED BAR (4)

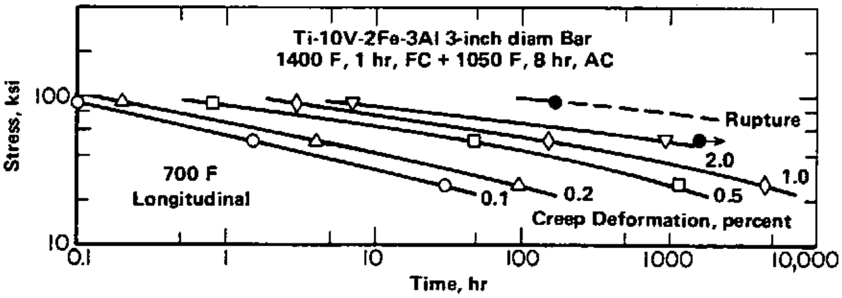


FIGURE 3.042. CREEP DEFORMATION AND RUPTURE CURVES AT 700 F FOR HEAT TREATED BAR (4)

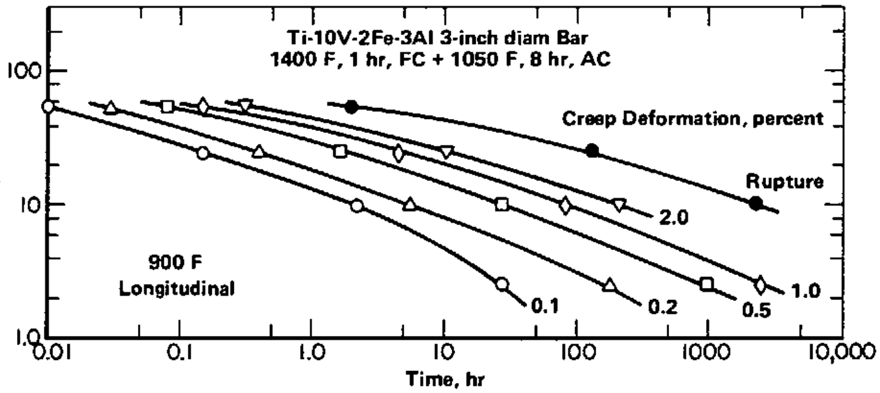


FIGURE 3.043. CREEP DEFORMATION AND RUPTURE CURVES AT 900 F FOR HEAT TREATED BAR (4)

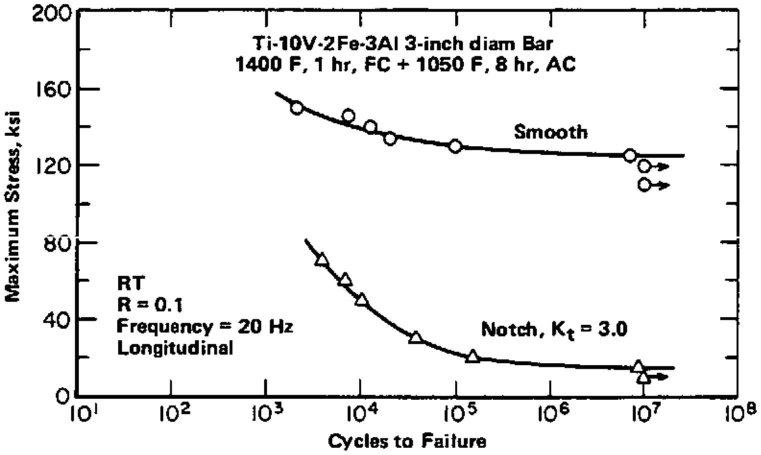


FIGURE 3.051. ROOM TEMPERATURE SMOOTH AND NOTCH AXIAL LOAD FATIGUE PROPERTIES OF HEAT TREATED BAR (4)

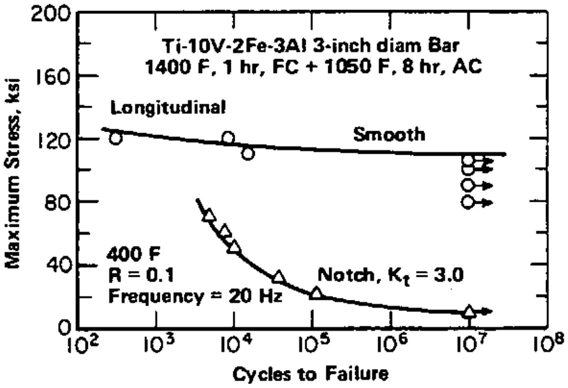


FIGURE 3.052. SMOOTH AND NOTCH AXIAL LOAD FATIGUE PROPERTIES AT 400 F OF HEAT TREATED BAR (4)

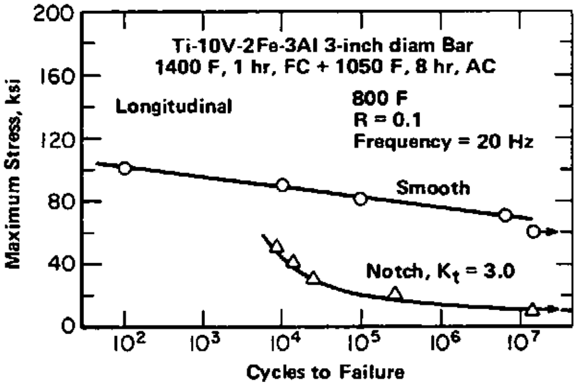


FIGURE 3.053. SMOOTH AND NOTCH AXIAL LOAD FATIGUE PROPERTIES AT 800 F OF HEAT TREATED BAR (4)

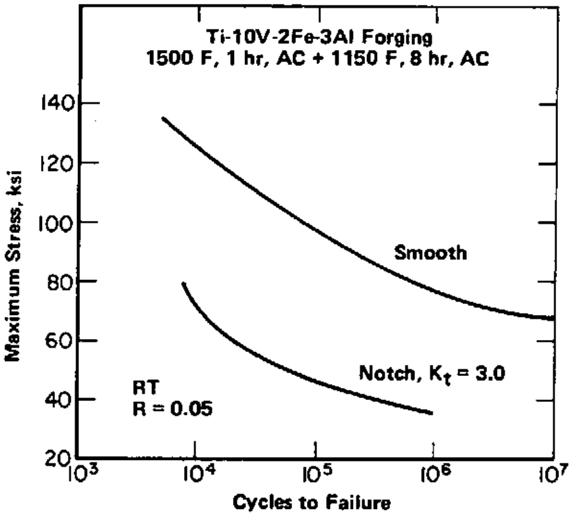


FIGURE 3.054. ROOM TEMPERATURE SMOOTH AND NOTCH AXIAL LOAD FATIGUE PROPERTIES OF HEAT TREATED FORGING (1)

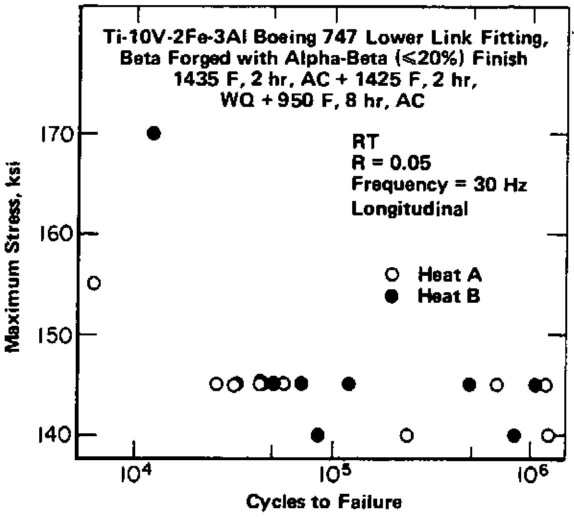


FIGURE 3.055. ROOM TEMPERATURE SMOOTH FATIGUE PROPERTIES OF HEAT TREATED BETA FORGED AIRFRAME STRUCTURAL FORGING (8)

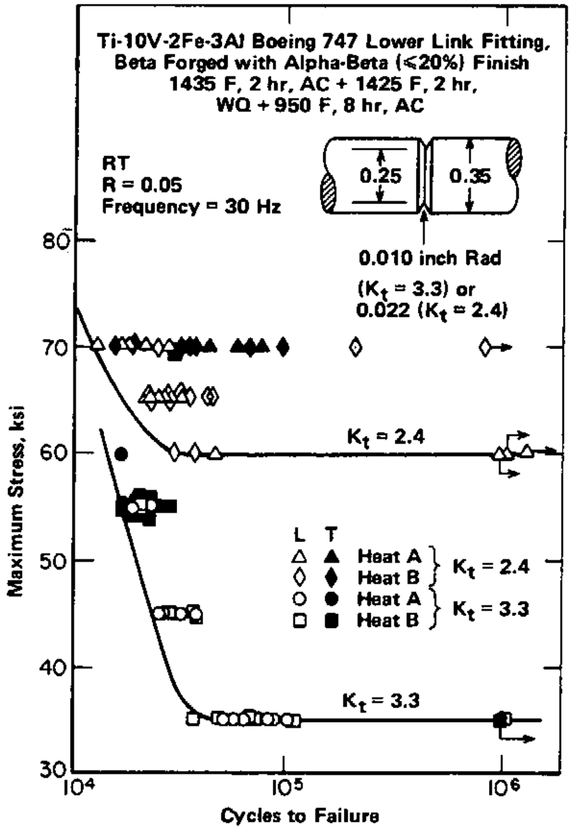


FIGURE 3.056. ROOM TEMPERATURE MILD-NOTCH FATIGUE PROPERTIES OF HEAT TREATED BETA FORGED AIRFRAME STRUCTURAL FORGING (8)

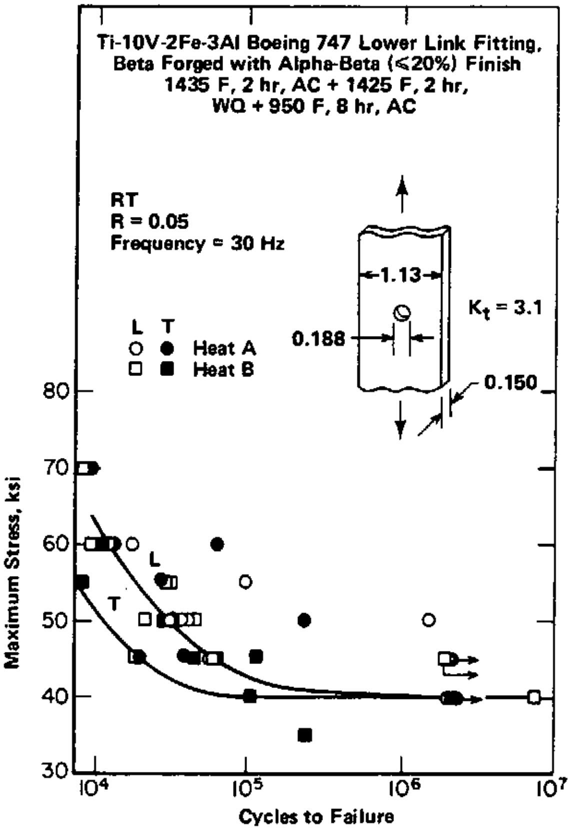


FIGURE 3.057. ROOM TEMPERATURE SINGLE-HOLE SPECIMEN FATIGUE PROPERTIES OF HEAT TREATED BETA FORGED AIRFRAME STRUCTURAL FORGING (8)

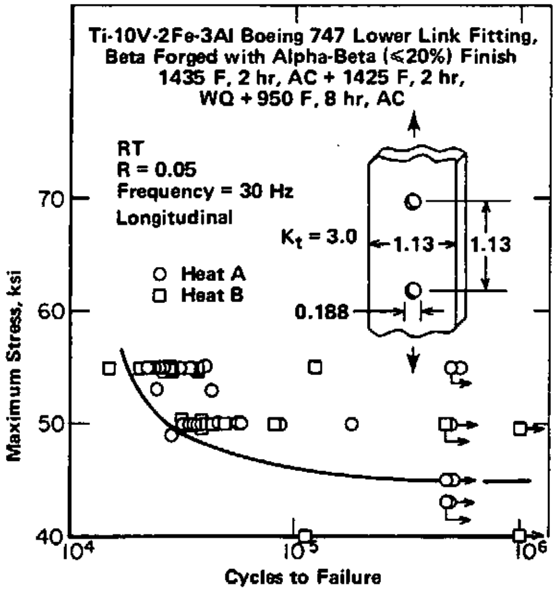
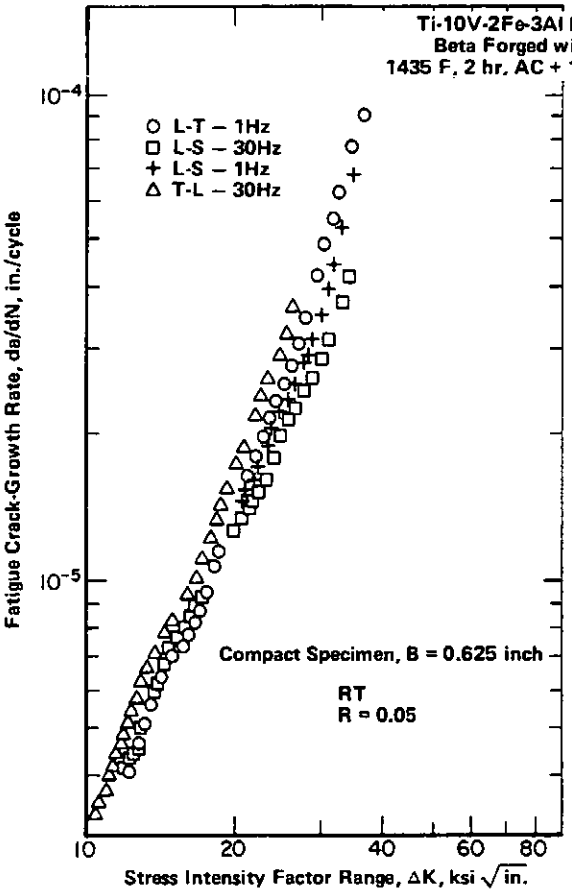


FIGURE 3.058. ROOM TEMPERATURE DOUBLE-HOLE SPECIMEN FATIGUE PROPERTIES OF HEAT TREATED BETA FORGED AIRFRAME STRUCTURAL FORGING (8)



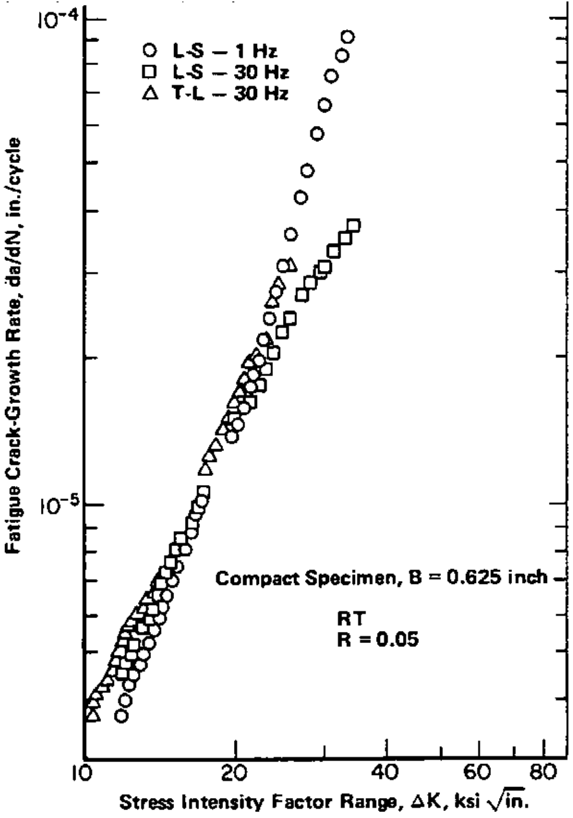


FIGURE 3.059. ROOM TEMPERATURE FATIGUE CRACK-GROWTH IN AIR FOR AIRFRAME STRUCTURAL FORGING (8)

FIGURE 3.0510. ROOM TEMPERATURE FATIGUE CRACK-GROWTH IN 3.5 PERCENT NaCl SOLUTION FOR AIRFRAME STRUCTURAL FORGING (8)

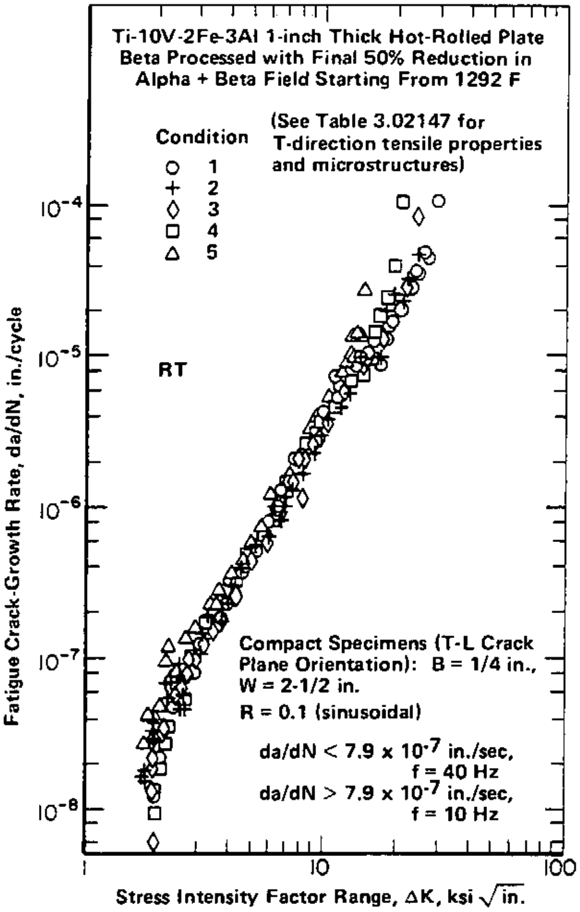


FIGURE 3.0511. ROOM TEMPERATURE FATIGUE CRACK-GROWTH RATES FOR HOT-ROLLED PLATE SOLUTION TREATED AND ALPHA-AGED TO FIVE DIFFERENT MICROSTRUC-CONDITIONS, ALL AT APPROXIMATELY THE SAME YIELD STRENGTH LEVEL (18)

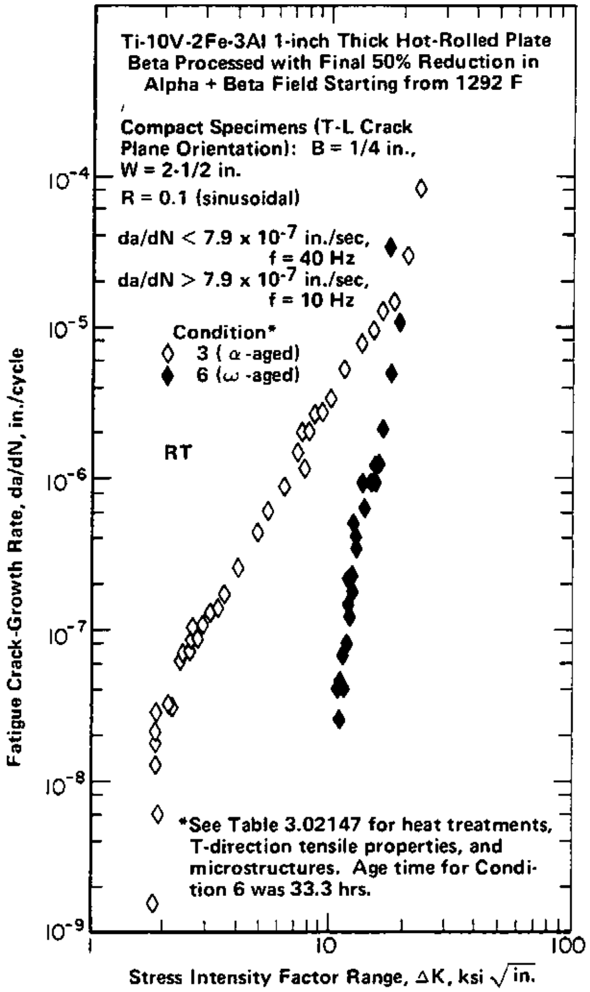


FIGURE 3.0512. ROOM TEMPERATURE FATIGUE CRACK-GROWTH RATES FOR HOT-ROLLED PLATE SOLUTION TREATED AND EITHER ALPHA-AGED OR OMEGA-AGED TO A COMMON YIELD STRENGTH LEVEL (18)

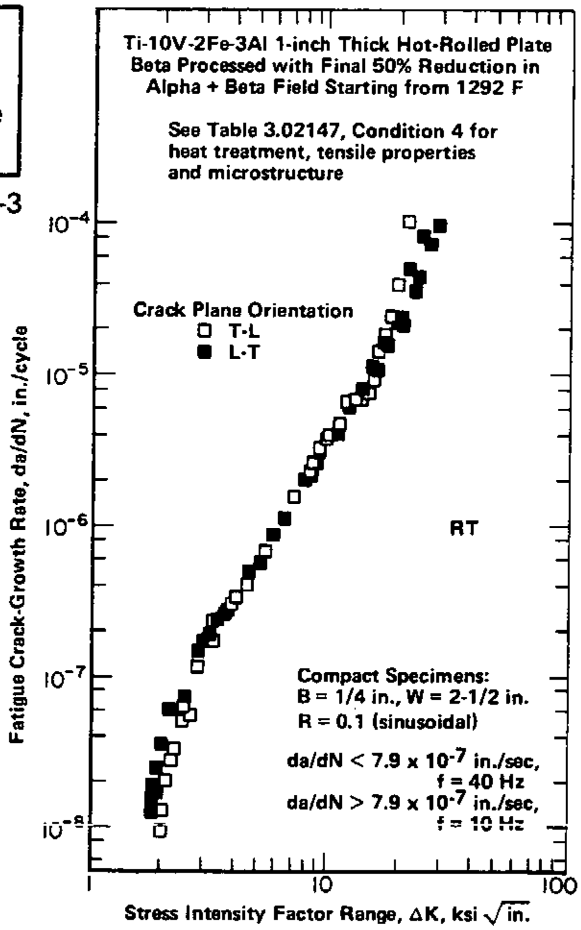


FIGURE 3.0513. EFFECT OF TEST DIRECTION ON ROOM TEMPERATURE FATIGUE CRACK-GROWTH RATE FOR HOT-ROLLED PLATE SOLUTION TREATED AND ALPHA-AGED (18)

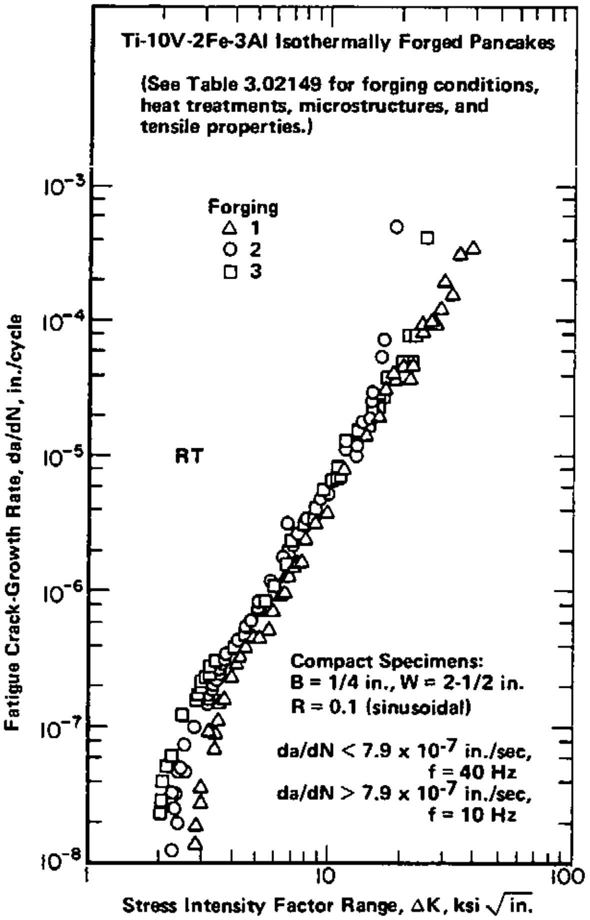


FIGURE 3.0514. ROOM TEMPERATURE FATIGUE CRACK-GROWTH RATES FOR SOLUTION TREATED AND AGED ISOTHERMALLY FORGED PANCAKES (18)

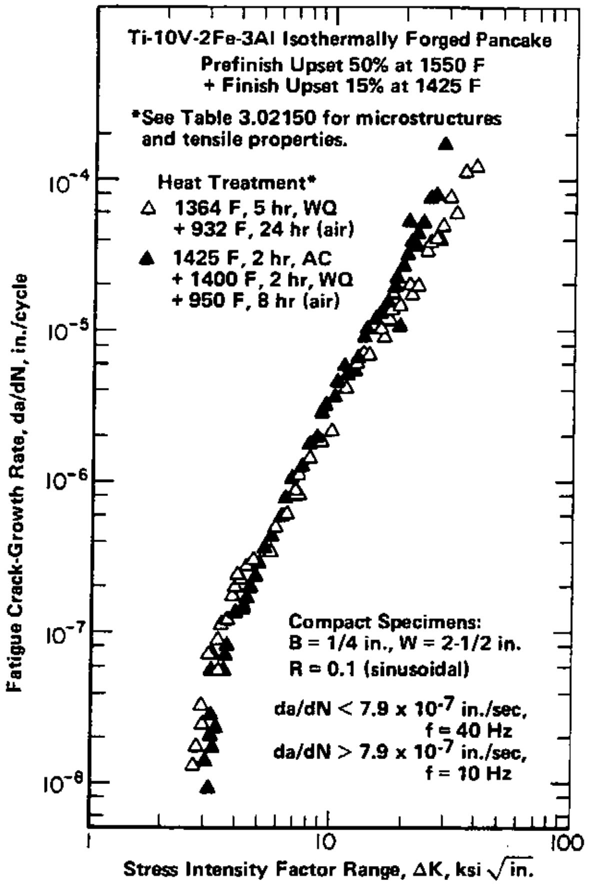


FIGURE 3.0515. ROOM TEMPERATURE FATIGUE CRACK-GROWTH RATES FOR ISOTHERMALLY FORGED PANCAKE SOLUTION TREATED OR DUPLEX SOLUTION TREATED PRIOR TO AGING TO NEARLY EQUAL YIELD STRENTH LEVELS (18)

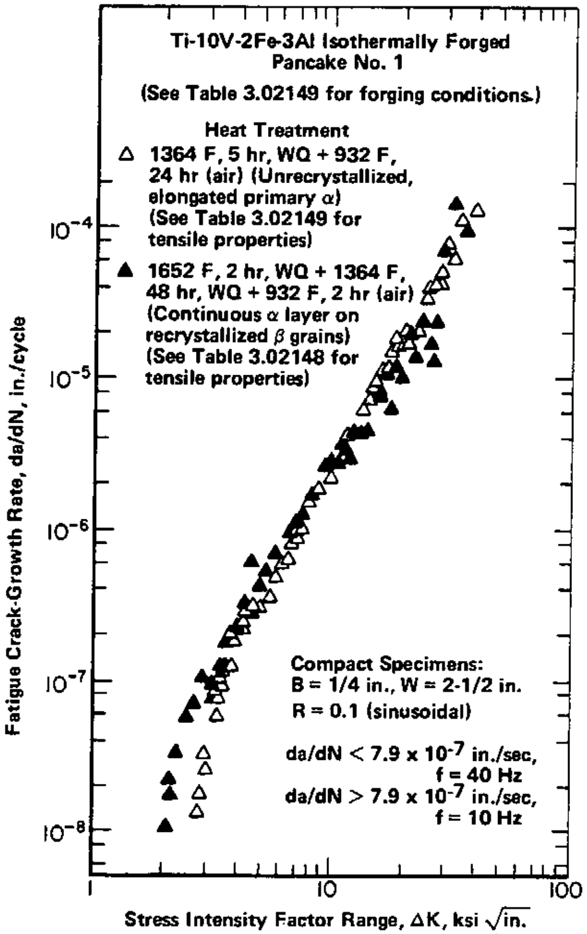


FIGURE 3.0516. ROOM TEMPERATURE FATIGUE CRACK-GROWTH RATES FOR ISOTHERMALLY FORGED PANCAKE SOLUTION TREATED AND AGED (ELONGATED PRIMARY ALPHA) OR DUPLEX SOLUTION TREATED AND AGED (CONTINUOUS GRAIN BOUNDARY ALPHA-LAYER) (18)

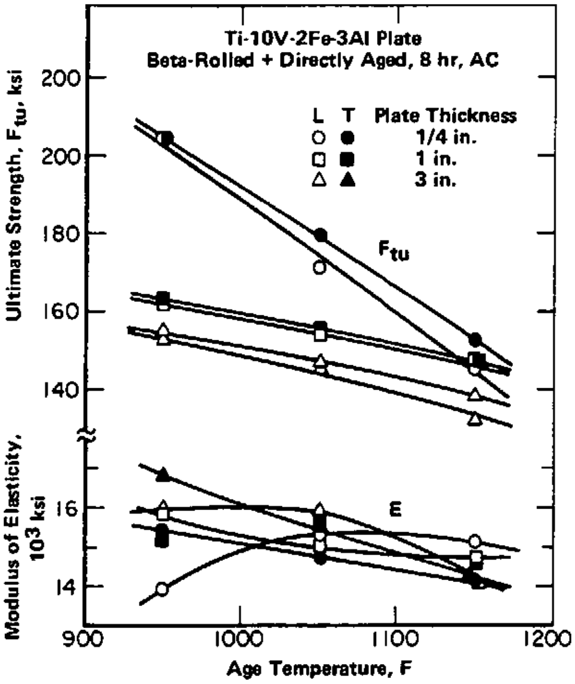


FIGURE 3.0621. ROOM TEMPERATURE ULTIMATE STRENGTH AND ELASTIC MODULUS FOR PLATE OF VARIOUS THICKNESSES, BETA-ROLLED AND DIRECTLY AGED (9)

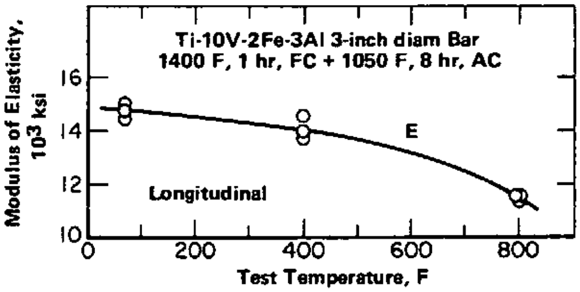


FIGURE 3.0622. EFFECT OF TEST TEMPERATURE ON TENSILE ELASTIC MODULUS OF HEAT TREATED BAR (4)

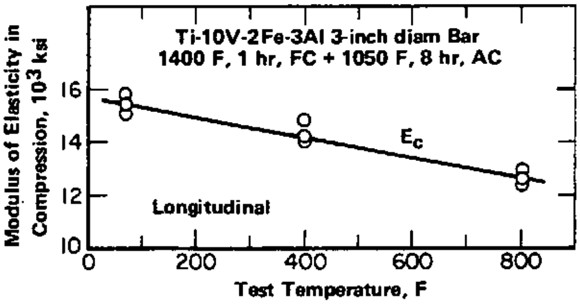


FIGURE 3.0624. EFFECT OF TEST TEMPERATURE ON COMPRESSIVE ELASTIC MODULUS OF HEAT TREATED BAR (4)

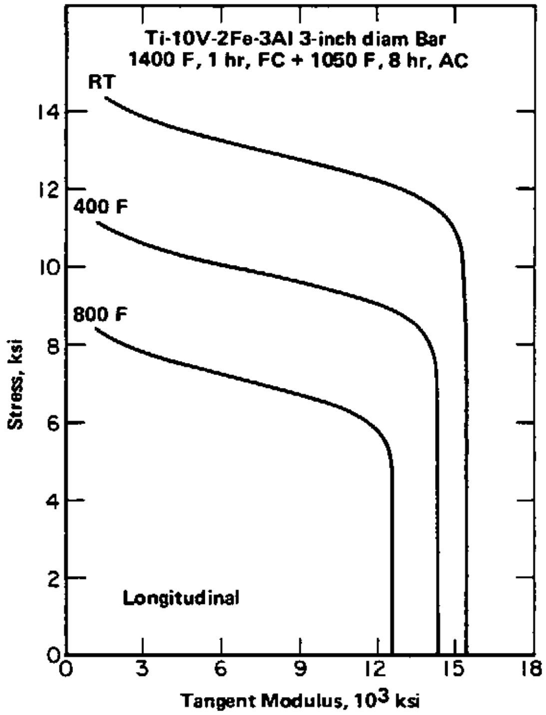


FIGURE 3.0641. TYPICAL COMPRESSIVE TANGENT MODULUS CURVES AT ROOM TEMPERATURE, 400 F, AND 800 F FOR HEAT TREATED BAR (4)

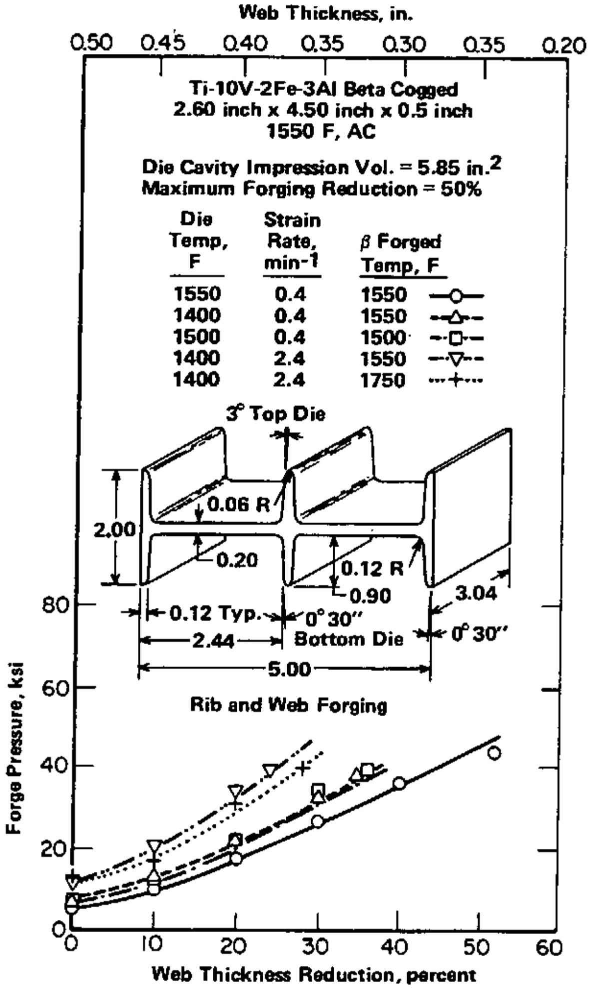


FIGURE 4.0111. VARIATION OF FORGE PRESSURE WITH WEB THICKNESS FOR Ti-10V-2Fe-3Al EXPERIMENTAL RIB-AND-WEB FORGINGS (3)

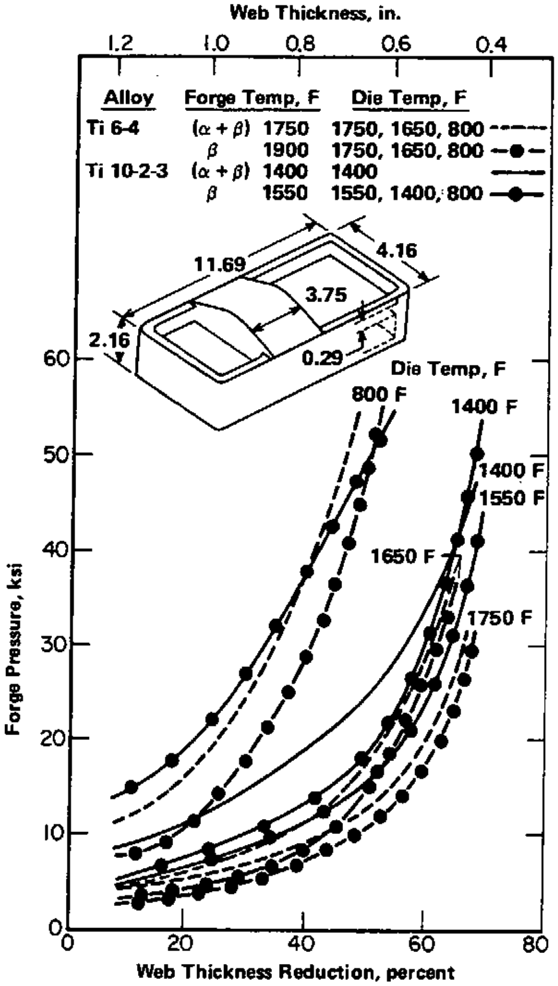


FIGURE 4.0112. VARIATION OF FORGE PRESSURE WITH WEB THICKNESS FOR Ti-6Al-4V AND Ti-10V-2Fe-3Al EXPERIMENTAL STRUCTURAL SHAPE FORGINGS (10)

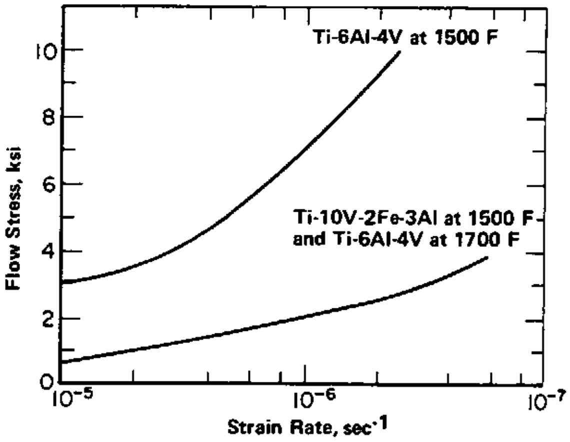


FIGURE 4.0113. HOT FLOW STRESS OF Ti-10V-2Fe-3Al COMPARED TO THAT OF Ti-6Al-4V (9)

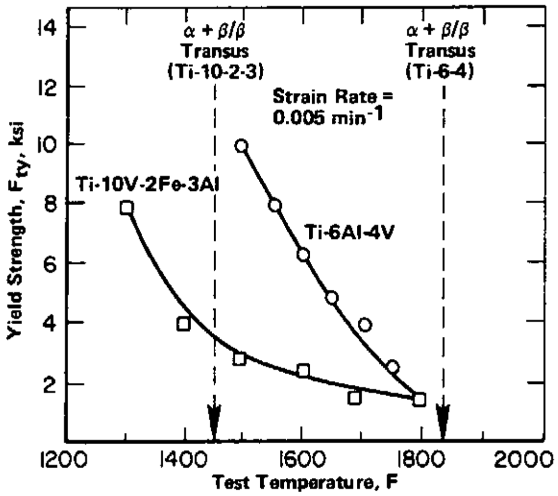


FIGURE 4.0115. TEMPERATURE DEPENDENCE OF TENSILE YIELD STRENGTH FOR Ti-10V-2Fe-3Al AND Ti-6Al-4V ALLOYS (1)

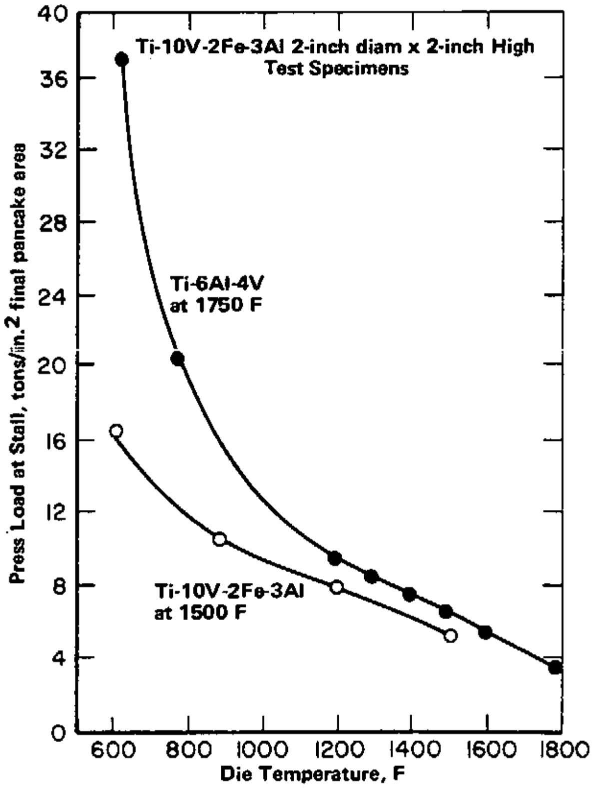


FIGURE 4.0116. HOT COMPRESSION TEST RESULTS (1)

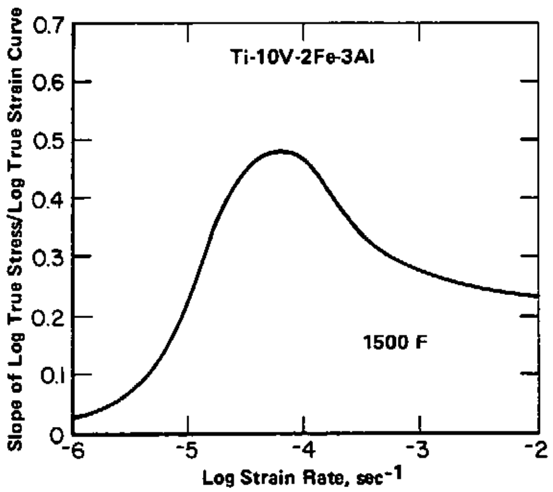


FIGURE 4.0117. STRAIN RATE SENSITIVITY OF Ti-10V-2Fe-3Al AT 1500 F (1)

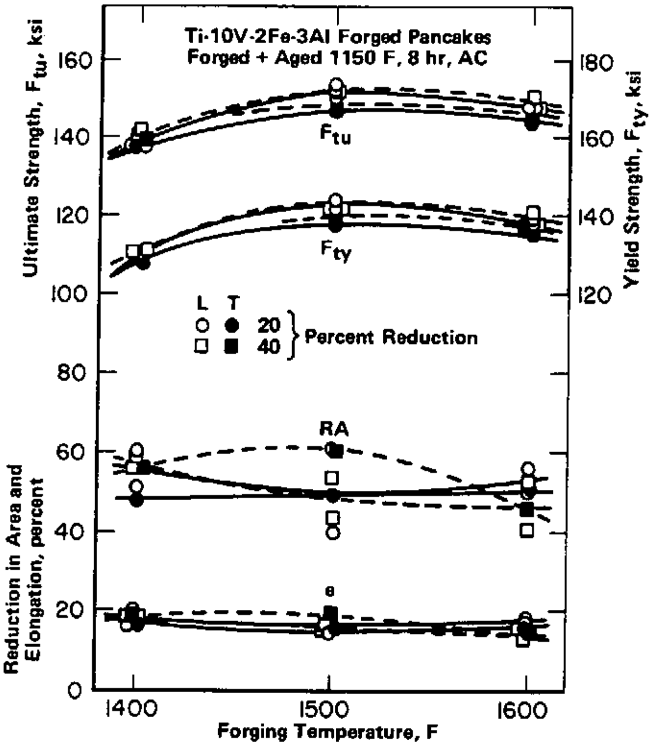


FIGURE 4.0131. EFFECT OF FORGING TEMPERATURE AND PERCENT REDUCTION ON ROOM TEMPERATURE TENSILE PROPERTIES OF FORGED PANCAKES (9)

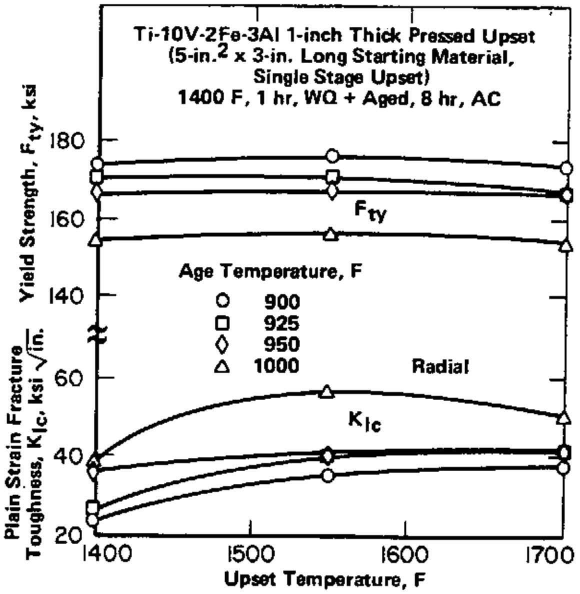


FIGURE 4.0132. EFFECT OF FORGING TEMPERATURE ON ROOM TEMPERATURE TENSILE YIELD STRENGTH AND PLANE STRAIN FRACTURE TOUGHNESS OF HEAT TREATED 1-INCH THICK UPSET FORGINGS (5)

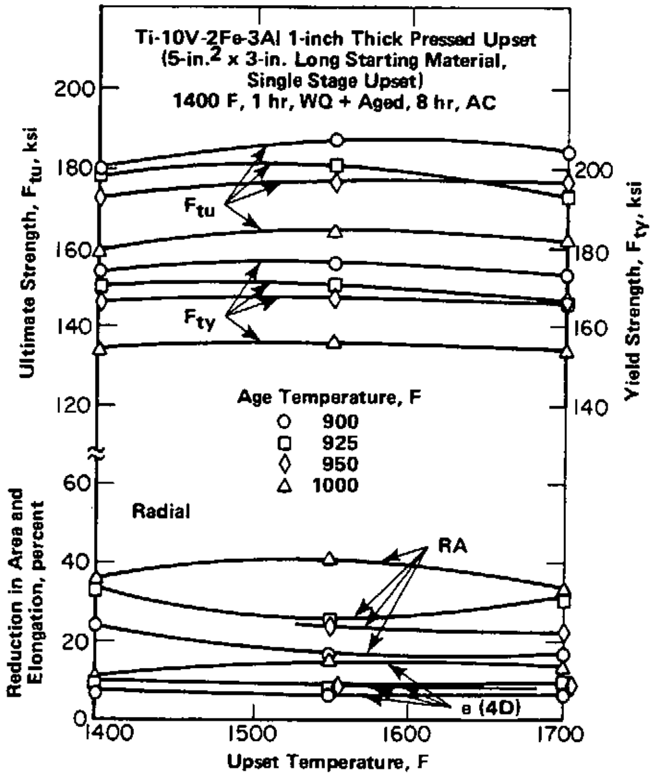


FIGURE 4.0133. EFFECT OF UPSET FORGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF HEAT TREATED 1-INCH THICK UPSET FORGINGS (5)

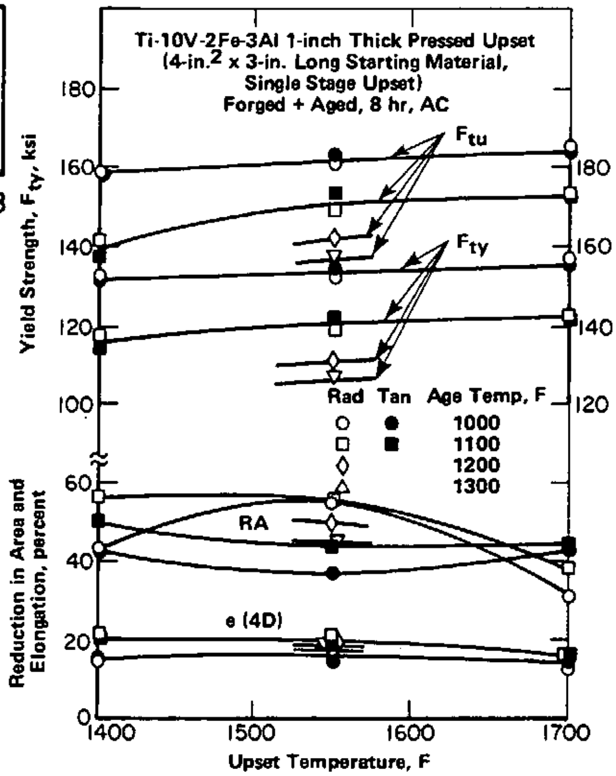


FIGURE 4.0134. EFFECT OF UPSET FORGING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF FORGED PLUS DIRECTLY AGED 1-INCH THICK UPSET FORGINGS (5)

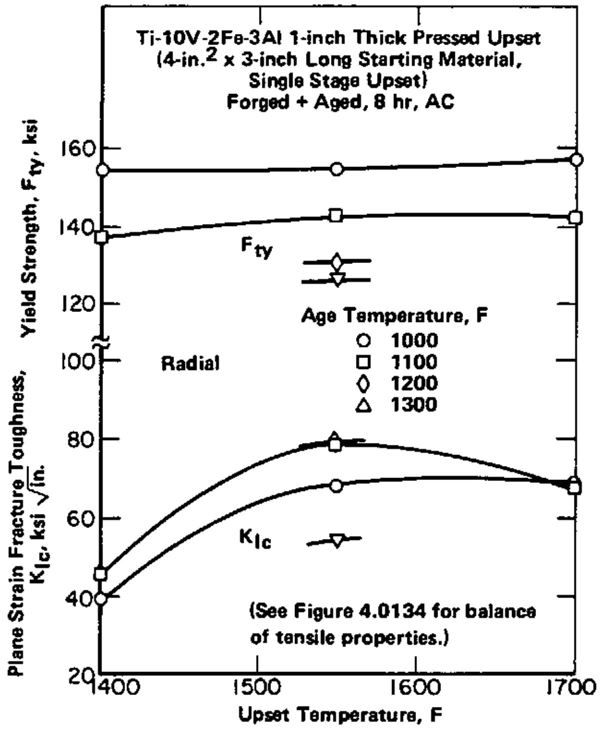


FIGURE 4.0135. EFFECT OF FORGING TEMPERATURE ON ROOM TEMPERATURE TENSILE YIELD STRENGTH AND PLANE STRAIN FRACTURE TOUGHNESS OF FORGED PLUS DIRECTLY AGED 1-INCH THICK UPSET FORGINGS (5)

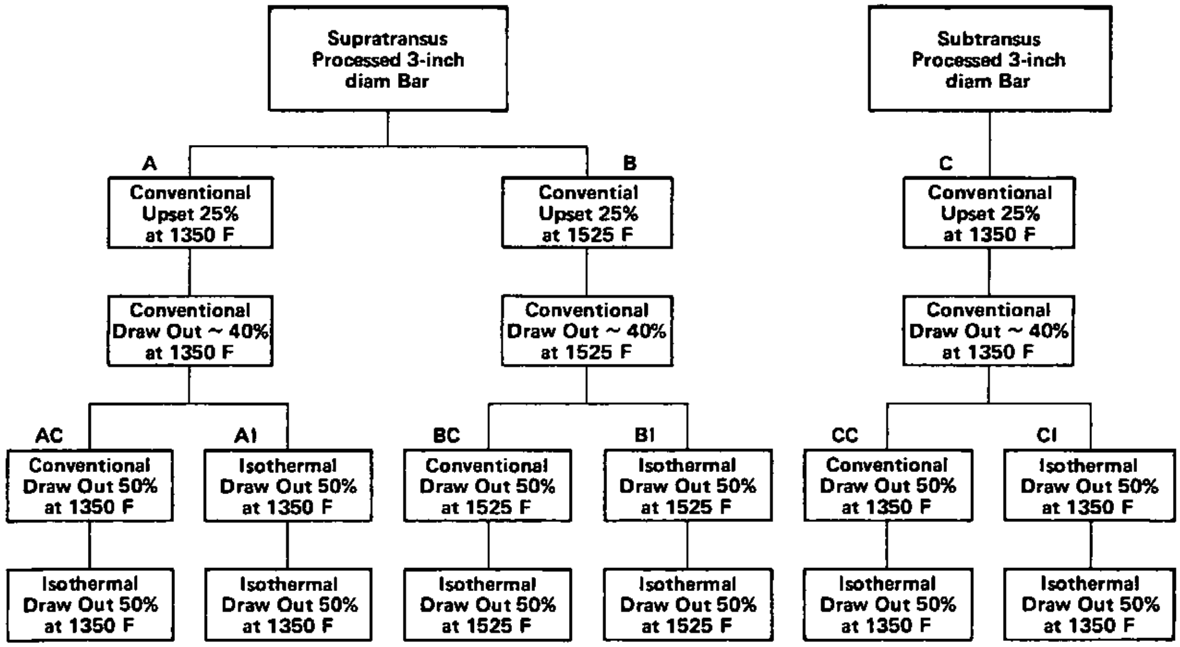


FIGURE 4.0138. CONVERSION SCHEDULE FOR 3-INCH DIAMETER BAR ISOTHERMALLY FORGED TO 0.5-INCH THICK FLAT PLATE FOR USE IN PROCESSING AND HEAT TREATMENT STUDY REPORTED UPON IN TABLES 4.0139 THROUGH 4.01311 (20)