_ NONFERROUS ALLOYS _

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	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

1. GENERAL

This is a super-alpha titanium alloy having an alpha-stabilized Ti-Al matrix solid solution strengthened by the additions of tin and zirconium. The beta-stabilizing addition, molybdenum, increases room and elevated temperature tensile strength and stability. The alloy is used primarily in jet engine compressor parts and airframe skin components.

The alloy possesses good strength properties up to 1000F, exceeding Ti-8Al-1Mo-1V and, for the annealed condition, Ti-6Al-4V. On a strength-to-weight basis, it is also superior to Ti-679. Its creep properties are better than Ti-8Al-1Mo-1V, Ti-6Al-4V and, above 900F, Ti-679. The alloy is more susceptible to solid salt stress corrosion than Ti-679 but less susceptible then Ti-6Al-4V, Ti-8Al-1Mo-1V and Ti-5Al-2.5Sn in the range of commercial mill products and heat treatments. At elevated temperatures, the alloy is more fatigue resistant than Ti-8Al-1Mo-1V and Ti-679. The alloy appears metallurgically stable up to 800F. Forgeability of the alloy is judged similar to Ti-8Al-1Mo-1V and Ti-6Al-4V. Weld properties of the alloy are variable.

1.01 Commercial Designation
6Al-2Sn-4Zr-2Mo Titanium Alloy

1.02 Alternate Designation
Ti-6242

1.03 Specifications
Table 1.03.

1.04 Composition

1.041 AMS specified composition, Table 1.041.

1.042 Silicon in the range 0.08 to 0.1 weight percent is sometimes added to improve the creep resistance of this alloy. Figures 1.0421 and 1.0422 indicate this may be the optimum addition (although the data is enormously scattered). Thermal stability is unaffected by the addition, as shown in Figure 1.0423 where exposure effects for the alloy with added silicon are not different from those for the base alloy (residual 0.03 weight percent silicon). The silicon produces only a slight increase in room temperature and 900F strength, but a significant drop in the reduction of area at these temperatures (Figure 1.0424) and in the -40F Charpy-V impact values (Figure 1.0425).

Producers (78) (79) give assurances that silicon segregation in the modified alloy is no problem with modern melting practice, and that the high solubility of silicon in the alloy (due principally to the alloy's molybdenum content) precludes precipitation of a silicide compound during heat treatment or thermal exposure. It is considered essential (79) that the silicon-modified alloy be beta processed if improvements in creep resistance are to be assured.

Creep resistance and thermal stability of the silicon-modified alloy are enhanced by solution treating high in the alpha-beta field (commonly at beta transus - 25F). These effects are illustrated in Figures 1.0426 and 1.0427 for rolled bar and forged upsets. The rolled bar primary-alpha grains were small, equiaxed, noncontinuous and nonaligned, surrounded by aged metastable beta products. Its thermal stability was unaffected over the range of solution temperatures from 80F to 25F below the beta transus. The forged upsets had large, elongated, aligned, and continuous primary-alpha grains, which are damaging to creep resistance and thermal stability (78). High-temperature solution treatment reduces the amount of primary alpha as shown in Figure 1.0428 (and hence the amount of continuous primary alpha), and broadens elongated grains so that they tend to become equiaxed and alignment is diminished. This improves creep resistance (Figure 1.0426), and metallurgical stability as expressed in Figure 1.0427 most notably by a rise in post-exposure reduction-of-area for the forged upsets.

Early modification of this alloy involved additions up to 0.25 weight percent silicon. Unlike the data of Figures 1.0421 and 1.0422 which show less benefit at 0.2 than at 0.1 weight percent silicon, Tables 1.0429 and 1.04210 show substantial increases in creep resistance for beta forged disks from the 0.25 weight percent silicon alloy. Thermal stability, however, is far inferior to the base alloy (Tables 1.04211 thru 1.04213). Other mechanical properties are given for the 0.25 weight percent silicon alloy in Figures and Tables 1.04214 thru 1.04220, and only the conventional tensile strength and smooth low cycle fatigue properties are improved by the additional silicon. Ductility, high cycle fatigue, fretting fatigue, notch rupture and hot salt stress corrosion resistance are either unchanged or damaged by the silicon addition. As a consequence of the limited benefit, 0.25 weight percent silicon addition is generally not used, although some specifications (40) (74) (75) still allow it.

Molybdenum additions beyond current specified limits slightly increase strength, but with substantial sacrifice in creep resistance (Table 1.04221).

Because boron in concentrations that could produce segregated borides can be introduced during sponge refurbishment and master alloy preparation (51) (53), their levels are limited to 10, 30 or 50 ppm in recently revised specifications (40) (43) (50) (72) (73). Similarly, yttrium is limited to the same levels in recent specifications (41 thru 46) (50) (72 thru 75). Based on a common experience with tramp element introduction in the production of superalloys (53), concentrations of copper and manganese are limited each to 100 ppm in several specifications (46) (50) (73).

1.0421 Effect of silicon content on time to 0.1 percent creep deformation at 950F, 35 ksi, for duplex annealed bar, Figure 1.0421.

1.0422 Effect of silicon content on 100-hour creep deformation at 950F and 35 ksi for duplex annealed bar, Figure 1.0422.

1.0423 Effect of 100-hour exposure at 950F, 35 ksi on room temperature tensile properties of duplex annealed bar of varying silicon content, Figure 1.0423.

1.0424 Effect of silicon content on the room temperature and 900F tensile properties of duplex annealed bar, Figure 1.0424

1.0425 Effect of silicon content on -40F Charpy-V impact energy of duplex annealed bar, Figure 1.0425.

1.0426 Effect of solution annealing temperature on 100-hour, 1000F, 25 ksi creep deformation of duplex annealed Ti-6Al-2Sn-4Zr-2Mo-0.9Si rolled bar and forged upsets, Figure 1.0426.

1.0427 Effect of solution annealing temperature on room temperature tensile properties of duplex annealed Ti-6Al-2Sn-4Zr-2Mo-0.9Si rolled bar and forged upsets subsequent to 100-hour creep exposure at 1000F, 25 ksi, Figure 1.0427.

1.0428 Effect of solution annealing temperature on percent primary alpha in Ti-6Al-2Sn-4Zr-2Mo-0.9Si alloy, Figure 1.0428.

1.0429 Combined effect of 0.25% silicon addition and forge/heat treat combinations on time to 0.1% creep at 1000F, 35 ksi, of duplex annealed forged disks, Table 1.0429.

1.04210 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on time to 0.1% creep at various temperatures and stresses, of duplex annealed forged disks, Table 1.04210.

1.04211 Combined effect of 0.25% silicon addition and forge/heat treat combinations on room temperature tensile properties of duplex annealed forged disks subsequent to 0.1% creep exposure at 1000F, 35 ksi, Table 1.04211.

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1.04212 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on room temperature tensile properties of duplex annealed forged disks subsequent to 0.1% creep exposure at various exposure temperatures and stresses, Table 1.04212.

1.04213 Effect of exposure to elevated temperature with load on room temperature tensile properties of beta forged, duplex annealed Ti-6Al-2Sn-4Zr-2Mo + 0.25Si forged disks, Table 1.04213.

1.04214 Combined effect of 0.25% silicon addition and forge/heat treat combinations on room temperature tensile properties of duplex annealed forged disks, Table 1.04214.

1.04215 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on the elevated temperature tensile properties of duplex annealed forged disks, Figure 1.04215.

1.04216 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 900F axial load smooth and mild notch low cycle fatigue properties of duplex annealed forged disks, Figure 1.04216.

1.04217 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 900F smooth and mild notch fatigue properties of duplex annealed forged disks, Figure 1.04217.

1.04218 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 1100F smooth and mild notch fatigue properties of duplex annealed forged disks, Figure 1.04218.

1.04219 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 900F fretting fatigue resistance of duplex annealed forged disks, Figure 1.04219.

1.04220 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on room temperature mild-notch stress rupture properties of duplex annealed forged disks, Table 1.04220.

1.04221 Effect of molybdenum addition and solution annealing temperature on strength and creep resistance of duplex annealed forged bar, Table 1.04221.

1.04222 Effect of oxygen content on room temperature tensile properties of consumable electrode melted castings, (see Figure 1.0811).

1.04223 Effect of oxygen content on room temperature mild-notch strength of consumable electrode melted castings, (see Table 1.0812).

1.04224 Effect of oxygen content on room temperature Charpy-V impact energy for consumable electrode melted castings, (see Figure 1.0813).

1.04225 Effect of oxygen content on room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings, (see Table 1.0814).

1.04226 Effect of iron content on room temperature tensile properties of consumable electrode melted castings, (see Figure 1.0815).

1.04227 Effect of iron content on room temperature mild-notch strength of consumable electrode melted castings, (see Figure 1.0816).

1.04228 Effect of iron content on room temperature Charpy-V impact energy for consumable electrode melted castings, (see Table 1.0817).

1.04229 Effect of iron content on room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings, (see Table 1.0818).

1.05 Heat Treatment

1.051 General. This alloy is used in either a duplex or triplex annealed condition. The first cycle of either treatment is a solution anneal (1650F, alpha solution anneal, or 1750F, alpha + beta solution anneal). The subsequent 1450F heating cycle for sheet is a stabilization anneal having little or no effect on room temperature tensile properties. The final 1100F heating cycle for triplex annealed sheet and duplex annealed bar and forgings produces a modest improvement in room temperature tensile strength indicating some aging takes place; this treatment is sometimes referred to as a stabilization age.

1.052 Anneal.

1.0521 Sheet: Duplex; 1650F, ½ hour, air cool + 1450F, ½ hour, air cool. Triplex: 1650F, ½ hour, air cool + 1450F, ½ hour, air cool + 1100F, 2 hours, air cool. The second cycle of either treatment is designed to be compatible with forming operations such as hot sizing. The additional 1100F, 2 hours treatment is also compatible with certain hot forming operations or may be added as an aging treatment following the hot sizing operation if higher uniaxial strength at room and elevated temperatures is desired. This triplex treatment has little if any effect on sharp notch tensile strength and produces superior creep resistance and smooth tensile strength stability. Sharp notch strength stability without load is extended to higher exposure temperatures by triplex annealing, but embrittlement is more pronounced at those temperatures where embrittlement occurs. The triplex treatment is damaging to sustained load failure characteristics in salt water environment (see Table 2.0331).

1.0522 Bar and Forgings: Less than 2½ inch section; 1750F, 1 hour, air cool + 1100F, 8 hours, air cool. Greater than 2½ inch section; 1650F, 1 hour, air cool + 1100F, 8 hours, air cool; or, 1750F, 1 hour, air cool + 1100F, 8 hours, air cool.

The 1650F solution anneal with an 1100F, 8 hour stabilization age provides somewhat higher tensile strengths at room and elevated temperatures and fatigue strength as good or better than that for the higher solution anneal temperature (1750F). The higher solution anneal with the same stabilization age provides superior creep resistance, but no demonstrated improvement in smooth tensile strength stability. Room temperature notch stress rupture strength is somewhat improved, as is the Charpy-V impact energy at room temperature and -80F.

Solution annealing at 1790F (beta transus - 25F) can further improve creep resistance, but not consistently. However, its potential benefit warrants its use. As discussed in section 1.042, solution treating at 1790F in combination with 0.08 to 0.1 weight percent silicon addition and beta processing substantially improves creep resistance and stability. The higher solution treatment for the standard composition benefits room and elevated temperature strength, room temperature plane strain fracture toughness, room temperature and -80F Charpy-V impact energy, and room temperature mild-notch stress rupture life.

Solution treating above the beta transus is not beneficial.

Faster quenching from the solution temperature in media other than air improves tensile strength but with a sacrifice in creep resistance.

1.053 Stress relief. An 1100F, 2 hour stress relief cycle provides nearly 100 percent relief of residual stresses (see Figure 1.0531) and is identical to the final cycle of the triplex anneal treatment for sheet. Depending on convenience and need, lesser stress relief at lower temperatures may be satisfactory.

1.0531 Effect of stress relief time and temperature on relaxation of restrained bend specimens of triplex annealed sheet, (see Figure 3.0531)

1.054 Mill anneal. 1300-1550F, 1-8 hours, slow cool to 1050F, air cool. (17) (37)

1.06 Hardness

Stabilization aging at 1100F raises the solution annealed tensile strength of this alloy about 10 ksi indicating only slight hardenability. Sections up to 3 inch, in the recommended duplex condition, exhibit uniform tensile properties throughout; however, water quenching from the solution anneal treatment followed by a stabilization age produces a 15-ksi strength differential from center to outside. Thus the alloy has hardening characteristics

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about like Ti-6Al-4V, (7).

1.061 Effect of exposure to elevated temperature on room temperature hardness of duplex annealed sheet, Figure 1.061.

1.07 Forms and Conditions Available

Ingot, bloom, bar, billet, sheet, plate, wire, (79).

1.08 Melting and Casting Practice

1.081 Wrought products. Multiple melted using consumable electrode vacuum practice: standard quality, double melted; premium quality, triple melted.

1.082 Castings. Two recent programs (Air Force Contracts F33615-70-C-1409 with TRW, Inc. and F33615-70-1410 with REM Metals Corp.) have been carried out to study various aspects of casting this alloy, including foundary variables, alloy chemistry and heat treatment effects, casting defects and cast properties. The programs are distinguished principally by the melting methods used: induction melting by TRW and consumable electrode skull melting by REM. The two programs are discussed separately below according to the melting practice employed.

1.083 Induction melting. Chemical interaction between molten alloy and crucible has been a major deterent to induction melting titanium-base alloys. TRW, however, has recently developed a semi-levitation induction melting process which purportedly allows for good control of power input and limits the amount of crucible contamination by making use of levitation forces generated during induction melting, (54). Graphite crucibles are used, with minimized molten metal/crucible contact time, and direct pour into the mold. Melt temperature is uniform and constant during pouring, and fixed for a given setup. Unlike consumable electrode melting, superheating is possible with induction melting, an important feature considering titanium alloys' limited solidification range. Molten metal temperature is measured using infrared pyrometers which have rapid response and, unlike optical pyrometers operating in the visible portion of the spectrum, are relatively insensitive to emissivity changes with temperature.

Using this melting technique, castings were made to determine the castability (fluidity) of this alloy and the mechanical properties of the cast metal. Pyrolytic graphite faced silicate bonded molds produced by a patented process (55) were used. Castability castings weighed six pounds and consisted of two clusters of four bars each. Bar sizes were 0.75-inch wide x 4-inch long x 0.030-, 0.060-, 0.090- and 0.250-inch thick. One cluster was gated at both top and bottom, the other gated only at the bottom. Two pour temperatures were used: low superheat (liquidus + 100-200F) and high superheat (liquidus + 200-350F). Liquid metal temperature was determined in the pour cup using tungsten-rhenium thermocouples in molybdenum tubes. Mold preheat temperatures of 1000, 1500 and 2000F were investigated. The effects of these casting variables on mold fill are presented in Table 1.085. These results reveal difficulty in filling sections as thin as 0.060 inch. Filling was complete for the heavier gages, but radiographic analyses revealed internal defects: 0.090 inch sections were porous; 0.250 inch sections contained microshrink or slight porosity.

Six-pound tensile bar cluster castings were made to determine the room temperature and 600F tensile properties of the cast metal. Each casting contained six standard 0.250-inch diameter test specimens, three bottom gated and three top and bottom gated. The same combinations of pour and mold preheat temperatures used in the castability determinations were used for these castings. Complete mold fill was achieved in every case; however some minor surface reaction was evident on all test bars. Companion specimens of Ti-6Al-4V alloy had 0.0001-inch surface reaction layers of TiC which caused marked reductions in conventional tensile ductility. On the basis of this experience, test bars of the present alloy were sand-blasted to remove 0.001 inch of the test section surface prior to testing. Test results for selected specimens are presented in Table 1.086. The castings were not completely sound, showing some evidence of centerline microshrink or slight porosity. These defects appear to have no effect on the strength properties of the cast alloy, but may be presumed responsible for the observed scatter in ductility values.

Production of a shaped casting was attempted using a quarter-section of the #2 bearing housing of the General Electric TF-39 engine. Casting weight was 10 pounds; minimum casting wall thickness was 0.125 inch. Castings were poured using the same techniques used for the castability and tensile bar castings. In all instances complete mold fill was achieved; however the quality of the castings produced was generally disappointing. Particular problems were surface defects and porosity. Surface defects were similar to those encountered in more conventional casting processes: hot tears caused by mold cracking during solidification; cold shuts resulting from the use of too cold a mold; fold-type defects produced by titanium carbide formation on the surface of the liquid as it entered the mold and, due to stream turbulence, folding at the casting surface; inclusions caused by spalling of the pyrolytic graphite mold coating; and rattails resulting from entrapment of zirconium silicate mold material disrupted by the molten metal.

The gas porosity encountered in these casting trials is not uncommon in the casting of titanium-base alloys, arising in part from the large difference in gas solubility between liquid and solid. Pouring under vacuum magnifies the effect, as does the lightness of titanium which keeps it from developing a high metallostatic head. In the present case, gas porosity occurred randomly throughout the castings and efforts to eliminate it by gating and venting modifications of the casting were unsuccessful. Void pocket analyses identified the entrapped gas as hydrogen. The use of degassed charge material and vacuum degassing the molds and crucibles prior to pouring had no appreciable effect in reducing porosity. It was concluded that the only effective means for eliminating gas pores would be the use of massive gating systems for static casting, or resort to centrifugal or other nonstatic forms of casting.

Conventional mechanical properties were determined on specimens extracted from the sidewalls of the bearing castings and found to be little different from the properties of cast tensile bars, except for reduced ductility associated with gas porosity and/or massive alpha grain microstructures. Weld repairability was cursorily investigated with the result that, using the maximum bend angle to fracture in three-point loading as criterion, TIG welding reduced the ductility of the cast product.

General problems with the use of graphite crucibles and molds were pervasive in the attempt to produce acceptable castings by the induction melting technique. Surface reaction with the mold, as indicated by the titanium carbide surface layer, subsurface carbide network and alpha case, was prevalent and appeared to increase with increasing melt superheat and mold preheat temperature (see Table 1.087). Carbon pick-up during melting due to crucible dissolution was appreciable and independent of superheat. Determinations on castings poured into steel molds showed increases from an initial value of 0.02 weight percent to between 0.10 and 0.15 weight percent. These values not only exceed present allowables for wrought stock, but have an unfavorable effect on castability (see Fig-

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ure 1.088). Remelting further increased carbon pick-up, but less than during initial melting (see Figure 1.089). On the basis of these results (using 6 to 10 pound charges), it appears that carbon pickup associated with this melting process cannot be reliably controlled to currently accepted levels, and the prospect of reclaiming sprues, gates, scrap castings, etc., is dim. No changes were found in the oxygen or nitrogen levels during melting. As expected for vacuum melting processes, hydrogen levels dropped from the as-received melt stock levels.

Consumable electrode melting. The problem of molten metal reaction with the furnace crucible is purportedly circumvented by consumable electrode vacuum "skull" melting in water cooled copper crucibles, (56). A skin of solid titanium, called a "skull", is formed which provides a nonreactive wall between the molten titanium and the copper crucible. This melting method is used by REM Metals Corporation.

The basic operation of skull melting is identical to conventional consumable arc melting, except the arc power (current) requirements are about twice that of conventional arc melting. This is so that a large molten pool forms rapidly and that a minimum of alloy solidifies before the melt is poured. The size of the molten pool will depend on melt rate, crucible size, and electrode configuration. When a sufficient pool is formed, the power is cut, the electrode stub withdrawn, and the charge poured into the mold by tilting the copper crucible. The complete sequence takes only a matter of minutes, with the casting portion taking only seconds. The time from electrode withdrawal to the completion of pour is very critical due to the narrow solidification range of most titanium alloys. Following pouring, the furnace is backfilled with a partial pressure of argon to promote cooling. When the mold has cooled sufficiently to avert harmful reaction with air, the furnace is opened and the mold removed.

The temperature of the melt is a continuous gradient from the hottest region (near the arc) to the coldest (near the crucible wall). No attempt is made to determine melt temperature before pouring, but pour conditions are replicated by controlling power input and coolant flow rate.

All castings produced by REM in their program were by their patented "REMET" investment casting process using tungsten lined ceramic molds preheated to 700F (except when mold preheat was an experimental variable). Fluidity was determined as the ability to fill either 0.030-inch or 0.060-inch thick "wings" appended to combination tensile bar/Charpy bar cluster castings. Like TRW's experience, the results indicated difficulty in filling sections as thin as 0.060 inch.

Four foundary practice variables were studied: mold preheat temperature, electrode size, crucible size and melt weight. Each of these factors could be expected to influence metal temperature, or heat content, and thereby affect surface finish and internal soundness and, consequently, mechanical properties. Triplicate variable-thickness, step-plate castings were poured for each foundary variable. Throughout, power input, cooling water flow rate, pour speed and mold configuration (except for a slightly larger pouring cup when enlarged melt size was studied) were held constant. Castings were heat treated (1650F, 1 hour, HeC + 1100F, 8 hours, HeC) in full section prior to sectioning for smooth tensile specimens.

Casting quality as influenced by foundary practice is documented in Table 1.0810. Despite the inability to superheat by consumable electrode melting (increasing arc power merely increases electrode consumption rate) and the alloy's limited solidification range, all castings were completely filled. However, some evidence of cold metal was observed as lines (cold laps or cold shuts) or circles (cold shot) on casting surfaces. Most of these surface imperfections were slight, many requiring directional lighting to even be seen. This accounts for the disparity between the reported visual and fluorescent penetrant surface imperfection indications in Table 1.0810. The "reference" and "hot mold" conditions gave the least number of indications and the least internal shrinkage (porosity) in the thinnest cast sections. All other changes in foundary practice reduced casting quality by these measures. Overall dimensional shrinkage was the only quality index unaffected by variations in foundary practice, the uniformity being well within the normal casting tolerance of $\pm$0.005 in/in.

Room temperature smooth tensile properties were generally unaffected by variations in foundary practice variables, except that in a few cases thin-section shrinkage markedly reduced ductility. Grain size for the step castings rose smoothly from the thinnest to the thickest section. Average grain diameter was unaffected by foundary variables, as were macrostructure and microhardness.

An attempt was made, using microhardness measurements, to determine the extent of possible casting surface reaction with the mold or other processing environments. Average hardness was essentially uniform from about 0.002 inch to as much as 0.250 inch below the casting surface. Scatter in the data was considerable; however, no attempt was made to identify its source (i.e., compositional or microstructural differences, or both). It should be recalled that TRW observed metallographic indications of surface reaction by their casting process at depths nearer the surface than explored here and that such a possibility cannot be ruled out here. The conventional smooth tensile properties of stabilization aged bars (1100F, 8 hours, HeC) with and without test section machining indicated, however, no evidence of surface reaction as regards its influence on these properties.

The separate influences of oxygen and iron contents on the stabilization aged mechanical properties of cast bars are presented in Figures 1.0811 thru 1.0818. Increasing oxygen has the anticipated effect of increasing strength and reducing ductility, toughness and mild-notch creep rupture strength. Increasing iron had no practical effect over the range studied.

An important consideration in the usefulness of cast products is weldability. Welding is essential in removing harmful defects, affecting the economics of production particularly as the casting size and complexity increase, and in the ability to join cast parts to mating components. Weld repairability was determined by comparing unwelded cast specimens with those whose test cross section was 50 percent TIG repair weld. Results, for specimens with and without post weld heat treatment, are given in Table 1.0819. The elongation of repair welded samples without post weld heat treatment and those alpha solution annealed plus stabilization aged (1650F, 1 hour, HeC + 1100F, 8 hours, HeC) were below companion unwelded values. Isothermal treatment of 1900F, 1 hour + 1650F, 1 hour + 1100F, 4 hours, HeC restored repair weld ductility, but at a reduced strength level for both welded and unwelded specimens (compared to as-cast values). Beta solution treating plus aging (1900F, 1 hour, HeC + 1100F, 4 hours, HeC) produces strengths and ductilities for repair welded and unwelded specimens equal to each other and to the as-cast values. It is claimed that this treatment produces microstructural uniformity throughout the repair welded stock. However, all mechanical properties do not benefit from this heat treatment as do

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the smooth tensile properties. Charpy impact energy, 100-hour creep strain at 1000F, 35 ksi, and post-creep tensile properties were all equivalent for repair welded and unwelded specimens given the beta solution anneal plus age treatment; but repair weld damage to the room temperature step-loaded mild notch creep rupture and smooth axial fatigue strengths was not remedied by the heat treatment.

Difficulty was experienced in weld joining thin-to-thin and thin-to-thick sections; lack of penetration and/or severe porosity were particularly damaging to ductility, and the situation was only partially improved by modifications in welding technique. Problems with welding this alloy, discussed in section 4.03, cast doubt on the investigators' claim that further improvements in technique will eventually produce acceptable weld joints.

The effects of heat treatment on the mechanical properties of the cast product are presented in Tables 1.0820 thru 1.0823. Test specimens were machined from cast-oversize bars following heat treatment. The smooth tensile properties of bars stabilization aged 1100F, 8 hours, AC (Table 1.0820) are in agreement with those determined in the TRW program for induction melted cast bars similarly aged. Prior alpha-beta solutioning at 1750F has no affect on aged strength, but produces considerable scatter in ductility (not withstanding the possibility of variable cast bar quality). Other mechanical properties reported in Tables 1.0821 thru 1.0823 appear either unaffected or somewhat improved by the alpha-beta solution treatment preceding aging.

In an attempt to produce a more uniform structure (alpha precipitate) than was initially established on cooling the newly frozen alloy, a beta solution treatment at 1900F was applied to two groups of specimens. This treatment requires less careful control of the temperature than is required for alpha-beta solutioning, where small variations can produce large differences in aged properties. Water quenching from the beta solution temperature, and subsequently aging, produces substantial strengthening but has a calamitous effect on ductility and those properties reported in Tables 1.0821 thru 1.0823. Slower cooling from the solution treatment followed by an abbreviated age produces properties little different from those obtained by simple stabilization aging except to scatter the results a bit more. This latter treatment, however, is considered necessary for repair welds as described previously in connection with weld repair studies. Consequently, the mechanical properties reported in the balance of this section on castings (Figures and Tables 1.0824 thru 1.0828) are for this heat treated condition.

To check the suitability of this casting technique to actual hardware, production of several C-5A cargo tie down rings was attempted. Casting quality was judged satisfactory by the producer and smooth tensile properties matched those of cast-to-size bars and bars extracted from step castings.

1.085 Effect of metal pour temperature and mold preheat temperature on mold fill for induction melted castings, Table 1.085.

1.086 Room temperature and 600F tensile properties of induction melted cast bars, Table 1.086.

1.087 Surface reaction of ½-inch-thick single-gated castability sections induction melted in graphite crucibles and cast into pyrolytic faced silicate bonded molds, Table 1.087.

1.088 Effect of carbon content on mold fill for castings induction melted in graphite crucibles and cast into stainless steel molds, Figure 1.088.

1.089 Effect of induction remelting in graphite crucibles on carbon content of castings poured into stainless steel molds, Figure 1.089.

1.0810 Influence of foundary practice (casting conditions) on nondestructive testing (NDT) quality of consumable electrode melted castings, Table 1.0810.

1.0811 Effect of oxygen content on room temperature tensile properties of consumable electrode melted castings, Figure 1.0811.

1.0812 Effect of oxygen content on room temperature mild-notch strength of consumable electrode melted castings, Table 1.0812.

1.0813 Effect of oxygen content on room temperature Charpy-V impact energy for consumable electrode melted castings, Figure 1.0813.

1.0814 Effect of oxygen content on room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings, Table 1.0814.

1.0815 Effect of iron content on room temperature tensile properties of consumable electrode melted castings, Figure 1.0815.

1.0816 Effect of iron content on room temperature mild-notch strength of consumable electrode melted castings, Figure 1.0816.

1.0817 Effect of iron content on room temperature Charpy-V impact energy for consumable electrode melted castings, Table 1.0817.

1.0818 Effect of iron content on room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings, Table 1.0818.

1.0819 Effect of post-weld heat treatment on room temperature smooth tensile properties of TIG repair welded, consumable electrode melted cast specimens, Table 1.0819.

1.0820 Room temperature tensile properties of consumable electrode melted castings variously heat treated, Table 1.0820.

1.0821 Room temperature mild notch strength of consumable electrode melted castings variously heat treated, Table 1.0821.

1.0822 Room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings variously heat treated, Table 1.0822.

1.0823 Room temperature Charpy-V impact energy for consumable electrode melted castings variously heat treated, Table 1.0823.

1.0824 Effect of test temperature on tensile properties of consumable electrode melted castings, Figure 1.0824.

1.0825 Effect of exposure to elevated temperature with load on room temperature tensile properties of consumable electrode melted castings, Table 1.0825.

1.0826 Effect of cast section thickness on the creep deformation of a consumable electrode melted casting, Table 1.0826.

1.0827 Effect of 100-hour exposure under load to hot solid salt on subsequent room temperature tensile properties of consumable electrode melted castings, Table 1.0827.

1.0828 Effect of cast section thickness on the fatigue properties of consumable electrode melted castings, Figure 1.0828.

1.09 Special Considerations

Stability - General. For many high-temperature applications, the usefulness of a particular alloy is limited by its elevated-temperature stability. This property is commonly evaluated from room temperature tensile tests on specimens previously exposed to elevated temperatures with and without load. Because of the importance of this property for critical applications, a large body of such information has been accumulated for Ti-6Al-2Sn-4Zr-2Mo alloy. The effect of exposure on room temperature smooth tensile properties for sheet, bar and forgings in the whole range of commercial sizes are presented in Figures and Tables 3.02114 through 3.02132. Exposure effects on room temperature notch tensile properties of sheet are presented in Figures 3.02718 through 3.027111. Limited data on the effect of exposure on the room temperature shear strength of sheet are presented in Figure 3.0251. The influence of forging and solution annealing temperatures on the elevated temperature

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

stability of forgings is given in Tables 4.0121 and 4.0122. A single set of data on the effect of elevated temperature exposure on the smooth tensile properties of sheet at the exposure temperature is presented in Figure 3.03126.

The extent to which room temperature properties will be affected by previous exposure will depend on the form and condition of the product as well as the time, temperature and stress level of exposure. While the available data are extensive, they are not systematic and no firm generalizations can be made at this time. However, the following conclusions appear to be supported by the present results.

Stability - 150-hour: For sheet in both the duplex and triplex annealed conditions, 150-hour exposure at 1000F, 25-ksi produces no deleterious effect on subsequent room temperature tensile properties. This is also true for exposure at lower temperatures and higher stress levels; for example 900F at 45-ksi and 800F at 65-ksi (Figure 3.02116, Table 3.02117 and Figure 3.02119). Likewise 100-hour exposure to 1000F without load produces no loss in room temperature sharp notch tensile strength of either duplex or triplex annealed sheet (Figures 3.02718 and 3.027110).

Duplex annealed rolled bar may or may not be affected by exposures of 150 hours with load at temperatures up to 1000F depending on the exposure stress. At 25 ksi stress level no practical loss in room temperature smooth tensile properties is observed (Table 3.02121) while at 30 ksi a sensible loss in ductility is observed (Figure 3.02120). Bar rolled in the beta region is unaffected by 150 hour exposure at 1000F, 30 ksi (Table 3.02124).

Forged bar in the recommended duplex annealed condition exposed 150 hour up to 1000F, 25 ksi exhibits no loss in subsequent room temperature smooth tensile properties (Figure 3.02126 and Table 3.02127). Contrasting results were obtained from forged compressor wheels (Tables 3.02128 and 3.02129). The hub location in one wheel exposed at 800F, 70 ksi, 150 hour showed losses in elongation and reduction of area (Table 3.02128). Other locations in the same forging, however, were essentially unaffected. A second wheel forging, water quenched from the solution anneal, showed losses in ductility after exposures at 900F/55 ksi, 1000 F/35 ksi or 1100 F/15 ksi (Table 3.02129).

Stability - Long Time. 1000 hour exposure up to 1000F without load has no deleterious effect on subsequent room temperature tensile properties of duplex annealed sheet (Figure 3.02115). In contrast, 1000 hour exposure with load produces a serious loss in ductility at 900F, 20 ksi for duplex annealed sheet and at 1000F, 10 ksi for triplex annealed sheet (Table 3.02118). At 950F, 15 ksi no damage is done to triplex annealed sheet for 1000 hour exposure (Table 3.02118). It appears from these limited results that the triplex annealed condition is more stable than the duplex condition. As expected, no change in tensile properties at the exposure temperatures is observed after 1000 hour exposure without load up to 1000F and perhaps beyond (Figure 3.03126).

Figures 3.02718 to 3.027111 show the influence of exposure to elevated temperature without load on the subsequent room temperature sharp notch strength of sheet. This property is a sensitive indicator of instability and reveals the onset of serious embrittlement at 900F for 1000 hour exposure for both duplex and triplex annealed conditions.

Bar in the recommended duplex annealed condition exposed 1000 hours with load at temperatures up to 1000F exhibits no significant instability (Table 3.02122). However, for longer exposure times a loss in room temperature tensile ductility is observed for lower exposure temperatures (Table 3.02123). Thus a marked reduction in ductility results from 3000 hours exposure at 825F, 47.5 ksi.

Substantial losses in ductility are observed for forgings in the recommended duplex annealed condition following 500 hours exposure at 800F, 75 ksi (Table 3.02131). A single result for the same forgings showed no ductility loss for 1000 hours exposure at 800F, 80 ksi; however, additional forgings (Figure 3.02130) substantiate the onset of instability at exposure temperatures as low as 800F as indicated by losses in reduction-of-area. These results (Figure 3.02130) were independent of specimen surface machining following exposure, indicating metallurgical changes rather than mere surface damage. The results of Figure 3.02130 also seem to contradict the suggestion (78) (79) (85) that solution annealing temperatures approaching the beta transus temperature improve metallurgical stability. On the other hand, high solution temperatures (below the beta transus) are not damaging, and their beneficial effect on creep resistance and stability when combined with modest silicon additions warrants their use as discussed in section 1.042. Solution annealing above the beta transus temperature is also ineffectual in improving thermal stability (Table 4.0121), as is beta forging followed by the recommended duplex anneal treatment (Table 4.0122). As discussed in section 1.042, however, beta processing in combination with added silicon is effective (indeed considered essential (79)) in improving creep resistance.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range, Table 2.011.

2.012 Phase changes. Beta transus, 1820 to 1830F, (70) (71). Variations in oxygen level will affect the beta transus temperature, as oxygen is a strong alpha stabilizer. Results in Figure 2.0121 show rapid changes in beta transus temperature with silicon variations in the normal specification range.

According to the isothermal TTT diagram (Figure 2.0122), M_s temperature is about 1470F and M_f temperature is about 1415F. Under continuous cooling (nonequilibrium) conditions, these temperatures are lowered substantially (see comparison of TTT and CCT diagrams in Figure 4.0317). The transformation kinetics of this alloy are discussed at length in section 4.03 on welding.

2.0121 Effect of silicon content on beta transus temperature, Figure 2.0121.

2.0122 Isothermal time-temperature-transformation (TTT) diagram for Ti-6Al-2Sn-4Zr-2Mo, Figure 2.0122.

2.0123 Continuous-cooling-transformation (CCT) diagram for Ti-6Al-2Sn-4Zr-2Mo, (see Figure 4.0315).

2.0124 Effect of compositional variations within specification on continuous-cooling-transformation (CCT) diagram for Ti-6Al-2Sn-4Zr-2Mo, (see Figure 4.0316).

2.0125 Comparison of continuous-cooling-transformation (CCT) diagram and isothermal-transformation (TTT) diagram for Ti-6Al-2Sn-4Zr-2Mo alloy, (see Figure 4.0317).

2.013 Thermal conductivity.

2.0131 Thermal conductivity of duplex annealed sheet, Figure 2.0131.

2.0132 Thermal conductivity of duplex annealed bar, Figure 2.0132.

2.014 Thermal expansion.

2.0141 Thermal expansion for duplex annealed sheet, Figure 2.0141.

	Ti
6	Al
2	Sn
4	Zr
2	Mo

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2.0142 Thermal expansion for duplex annealed bar, Figure 2.0142.
2.0143 Thermal expansion for cast compressor casing and duplex annealed pancake forging, Figure 2.0143.
2.015 Specific heat.
2.0151 Specific heat for duplex annealed sheet, Figure 2.0151.
2.0152 Specific heat for duplex annealed bar, Figure 2.0152.

2.02 Other Physical Properties
2.021 Density. 0.164 lb per cu in, 4.54 gr per cu cm.
2.022 Electrical resistivity.
2.0221 Electrical resistivity of duplex annealed sheet, Figure 2.0221.
2.023 Magnetic properties. Alloy is nonmagnetic.
2.024 Emittance.
2.025 Damping capacity.

2.03 Chemical Properties
2.031 Corrosion resistance. General. In common with other titanium alloys, Ti-6Al-2Sn-4Zr-2Mo is susceptible to solid salt stress corrosion at elevated temperatures and exhibits delayed failure of cracked specimens at room temperature in aqueous salt environments.

2.032 Solid salt corrosion. Embrittlement and/or cracking of titanium alloys while stressed in salt environments at elevated temperatures is well known and commonly referred to as hot-salt stress corrosion. Measured salt deposits and operating stresses and temperatures of compressor components in current aircraft turbine engines are sufficient to cause failure by this mode in laboratory specimens, but no such service failures have been reported in the literature. It is presumed that the lack of correspondence between predicted behavior and service experience lies in a lack of correspondence between laboratory simulation and actual engine operation. Added to this, there is a distressing lack of test standardization which makes any prediction of service failure open to question.

A common test for hot-salt stress corrosion involves exposure of salt-coated specimens to elevated temperature under load (usually static tension) and subsequent visual examination for corrosion or cracking, and/or measurement of residual room temperature mechanical properties for indications of embrittlement. On a plot of exposure stress versus exposure temperature, threshold curves separate regions of cracking from no cracking, or embrittlement from nonembrittlement. Substantial variations in test procedure and stress corrosion criteria account for substantial differences in thresholds reported by different investigators.

A particularly interesting series of tests by Gray and Johnston (57) (58) (61) (62) (63) (64) has been directed toward the problems of hot-salt stress corrosion testing and to the disparity between laboratory and service experience. Most of the work was done on Ti-8Al-1Mo-1V alloy because of its known sensitivity to hot-salt stress corrosion and because of its early consideration for application in hot-salt environments. A substantial amount of information was also developed in those studies for Ti-6Al-2Sn-4Zr-2Mo alloy. The data are combined in what follows in a general discussion of hot-salt stress corrosion testing, with particular emphasis on the behavior of Ti-6Al-2Sn-4Zr-2Mo alloy.

In Gray and Johnston's studies, tubular specimens were used in conjunction with a dynamic air apparatus which simulated salt deposition and exposure conditions of actual aircraft turbine engines. The influences of both specimen preparation and specimen exposure conditions on hot-salt stress corrosion behavior were examined. Specimen preparation variables were residual machining stresses, salt deposition temperature and salt concentration. Exposure variables were airflow, air pressure, air dewpoint (humidity), salt-in-air concentration, temperature and stress. Post-exposure tensile tests were performed at a constant test machine crosshead speed to specimen failure of 0.005 in/min. This loading was considered essential to the believed stress corrosion mechanism of hydrogen production, absorption, diffusion and embrittlement, observable only at temperatures at or slightly exceeding room temperature and at loading rates compatible with hydrogen diffusion rates (62). Stress corrosion thresholds were based either on cracking during exposure or on an arbitrarily-assigned reduction in subsequently-measured room temperature tensile ductility; elongation less than 15% and reduction of area (based on change in outside diameter) less than 25%. Cracking during exposure was evidenced by the presence on the fracture surface of regions covered with oxides and corrosion products. It is claimed that cracks as small as 0.001 inch were easily detected under X30 magnification. Specimen cylindrical surfaces were not inspected for damage, and the possibility of microcracks contributing to reduced ductility (embrittlement) was not explored. Specimens customarily were coated by exposing, without applied load, the inner bore for one hour to a salt-in-air concentration of 40 parts per billion at an air velocity of 1000 feet per second at 400F and dewpoint of -120F and 30 psia pressure. This elaborate procedure produced uniform deposits of 0.6 mg/in^2, which was within the range measured on service airfoils (59) (60). Higher deposition temperatures, or continuous deposition during test exposure, were examined only for mill annealed Ti-8Al-1Mo-1V and were seen to raise the apparent embrittlement threshold (61); data for Ti-6Al-2Sn-4Zr-2Mo were not obtained.

Salt concentrations of 0.2 and 2.0 mg/in^2, bracketing the range measured on actual airfoils, produced substantially identical embrittlement thresholds for Ti-8Al-1Mo-1V alloy in Gray and Johnston's experiments (61). However, earlier studies (65) (66) (67) showed that light coatings were more damaging than heavy coatings (purportedly due to the greater availability of moisture and oxygen in the case of the light coatings). Puffer et al (60) show cracking for Ti-6Al-2Sn-4Zr-2Mo increases continually with increasing salt concentration from very light to very heavy concentrations (0.05 to 50 mg/in^2).

Compressive surface stresses can raise the stress corrosion threshold, sometimes substantially. For Ti-8Al-1Mo-1V, the embrittlement threshold, for as-machined specimens (presumably with residual compressive machining stresses) exceeded that for specimens annealed either by heat treatment or by chemically milling (dissolving) the surface, by a factor of two. For Ti-6Al-2Sn-4Zr-2Mo mill annealed bar, much smaller effects were observed, as shown for dynamic exposures in Figure 2.0324. Attempts to confirm the presence of residual machining stresses in these tests with x-ray analyses were unsuccessful, and the equally plausible effect of contamination and/or attack during heat treatment or chemically milling was not disposed of. However, the very substantial benefit from glass bead blasting compressor disc forgings shown in Figure 2.03212 seems to substantiate the presumption of residual compressive stresses in the previous work, and attests to the potentially significant benefit of same. One should be advised, however, that initial benefits from compressive surface stresses could disappear in service due to stress relief during exposure.

Actual engine environmental conditions are unique and considered less conducive to stress corrosion than laboratory exposure conditions. This in fact appears borne out by the lack of recorded service failures. Possible ameliorating engine conditions are high air

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velocities, high pressures, salt-air conditions, oil contamination and/or unique operating cycles. In the same relevant studies of Gray and Johnston, air velocity of 1100 ft/sec and air pressure increase from 30 to 52 psia were each determined to have only a minor effect on the embrittlement threshold of Ti-8Al-1Mo-1V alloy (61). Essentially no effect of air velocity is seen for the Ti-6Al-2Sn-4Zr-2Mo alloy in Figure 2.0324 (compare dynamic and static air exposures for chemically-milled specimens). Gray and Johnston report no systematic influence of exposure air moisture in the range -120 to +40F dewpoint for Ti-8Al-1Mo-1V, but this is at variance with numerous experiments reported in the literature which show increased hot-salt stress corrosion with increasing moisture in the environment. As expected, increased exposure times universally produce increased indications of stress corrosion.

The influence of exposure cycling was studied for Ti-8Al-1Mo-1V (64). Temperature and stress were cycled separately and in combination, the latter simulating a service cycle of current aircraft turbine engine compressor components. Cyclic exposure in which both temperature and stress were applied for 1 hour and removed for 3 hours, for a total of 96 hours at temperature, had associated crack threshold stresses twice those for continuous 96-hour exposure. The same was true for cycles of temperature, 1 hour on and 3 hours off, at constant stress. Other temperature cycles (3 hours on/ 3 hours off, 1 hour on/ 1 hour off, and 3 hours on/ 1 hour off) at constant stress, and a stress cycle of 1 hour on and 3 hours off at constant temperature raised the continuous-exposure (for the same total time at temperature) threshold by 60 to 90% at the lowest exposure temperature, but these improvements disappeared as the exposure temperature increased. It has been suggested that temperature cycling interferes with the production and decomposition of the intermediate corrosion product titanium dichloride ($TiCl_2$), necessary for the production of the embrittling corrosion product, hydrogen. Stress cycling is thought to lessen the buildup of diffused hydrogen by virtue of homogenization during off-cycles. It is quite believable that these cycles, plus repeated errosion (washing) of the engine components plays an important role in engine reliability.

Stress corrosion characteristics can depend on alloy processing and heat treatment, and can vary from heat to heat. There appears little difference between mill annealing and duplex annealing bar of Ti-6Al-2Sn-4Zr-2Mo (compare Figures 2.0324 and 2.0325). Heavy forging can reduce the embrittlement and cracking thresholds, as shown in Figure 2.0326. The cracking thresholds reported for sheet at 100-hour exposure in Figures 2.0321 and 2.0322 are generally lower than those reported for bar in Figures 2.0324 through 2.0326 and the compressor wheel forging in Table 2.03211, but no worse than the compressor disc forging in Figure 2.03212.

No stress corrosion experiments have been conducted wherein salt-free specimens were exposed to the same high stresses and temperatures producing embrittlement or cracking in salt-coated specimens. In this regard the representations of Figures 2.0327 through 2.03210 are of unusual interest. Associated with the exposure of salt-coated specimens to elevated temperatures under load, are changes in residual room temperature properties not unlike those one might expect from accelerated aging under stress. It would be interesting, indeed, to perform such salt-free specimen tests. Interesting, too, would be the use of more sensitive indicators of embrittlement such as sustained-load notch tests.

It is clear from the foregoing that no single hot-salt stress corrosion threshold can be claimed for this alloy. Material condition, exposure variables, post-exposure test procedure and corrosion criteria are all influential and account for the variability of results from one investigator to another. Some insights have been gained in resolving the disparity between laboratory and service experiences, but no assurance can be given that increased service requirements might not one day penetrate the region of unsafe combinations of stress, temperature and time in salt environments.

Results for resistance spot-welded sheet in Figure 4.0310 show freedom from salt corrosion cracking within the range of exposure conditions investigated. Significant loss of strength accompanies the elevated temperature exposure above 600F. The influence of a 1100F, 2 hour postweld treatment is to reduce initial cross tension strength but minimize further reduction when exposed to elevated temperature.

2.0321 Hot-salt stress corrosion cracking characteristics of duplex annealed sheet at 550, 800 and 1000F, Figure 2.0321.

2.0322 Short-time hot-salt stress corrosion cracking characteristics of triplex annealed sheet subjected to static or cyclic exposure temperatures, Figure 2.0322.

2.0323 Effect of heat treatment and thermal exposure, with and without a salt environment, on room temperature cross-tension strength of single resistance spot welds, (see Figure 4.0310).

2.0324 100-hour embrittlement and crack threshold curves for NaCl-coated (aerosol deposit on hot surface) as-machined or chemically-milled tubular specimens (from mill annealed bar) exposed to elevated temperature with load in either a laboratory or simulated aircraft turbine engine compressor environment and subsequently tensile tested at room temperature, Figure 2.0324.

2.0325 100-hour embrittlement and crack threshold curves for NaCl-coated (aerosol deposit on hot surface) as-machined or chemically-milled tubular specimens (from duplex annealed bar) exposed to elevated temperature with load in either a laboratory or simulated aircraft turbine engine compressor environment and subsequently tensile tested at room temperature, Figure 2.0325.

2.0326 Effect of alloy processing on 100-hour embrittlement and crack threshold curves for NaCl-coated (aerosol deposit on hot surface) chemically-milled tubular specimens (from duplex annealed bar) exposed to elevated temperature with load in a laboratory environment and subsequently tensile tested at room temperature, Figure 2.0326.

2.0327 Effect of 100-hour exposure to elevated temperature with load in a simulated aircraft turbine engine compressor environment on subsequent room temperature tensile properties of NaCl-coated (aerosol deposit on hot surface) as-machined tubular specimens from mill annealed bar, Figure 2.0327.

2.0328 Effect of 100-hour exposure to elevated temperature with load in either a laboratory or simulated aircraft turbine engine compressor environment on subsequent room temperature tensile properties of NaCl-coated (aerosol deposit on hot surface) chemically-milled tubular specimens from mill annealed bar, Figure 2.0328.

2.0329 Effect of 100-hour exposure to elevated temperature with load in a simulated aircraft turbine engine compressor environment on subsequent room temperature tensile properties of NaCl-coated (aerosol deposit on hot surface) as-machined tubular specimens from duplex annealed bar, Figure 2.0329.

2.03210 Effect of 100-hour exposure to elevated temperature with load in a laboratory environment on subsequent room temperature tensile properties of NaCl-coated (aerosol deposit on hot surface) chemically-milled tubular specimens from duplex annealed bar, Figure 2.03210.

Ti	
6	Al
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Ti-6-2-4-2

2.03211 Effect of 100-hour exposure to elevated temperature with load on stress corrosion cracking and subsequent room temperature tensile properties of NaCl-coated specimens from duplex annealed compressor wheel forging, Table 2.03211.

2.03212 Effect of glass bead blasting on 100-hour hot-salt stress corrosion cracking characteristics of duplex annealed compressor forging, Figure 2.03212.

2.03213 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on hot salt stress corrosion characteristics of duplex annealed forged disks, Table 2.03213.

2.03214 Effect of 100-hour exposure under load to hot solid salt on subsequent room temperature tensile properties of consumable electrode melted castings, (see Table 1.0827).

2.033 Delayed failure. The tendency for delayed failure of cracked specimens under sustained load in aqueous salt environments appears to be less for the duplex than for the mill or triplex annealed sheet conditions. For either duplex or triplex annealed condition, the tendency for delayed failure increases with increases in sheet thickness (Table 2.0331). This thickness dependence has also been observed for Ti-8Al-1Mo-1V alloy (21).

One study (56) indicates a substantial (at least 50%) reduction in the plane strain fracture toughness for monotonic loading in ASTM D1141-52 (reapproved 1965) substitute ocean water as compared to air for consumable electrode melted castings.

2.0331 Delayed failure in salt water of fatigue-cracked specimens from duplex and triplex annealed sheet, Table 2.0331.

2.0332 Delayed failure in salt water of fatigue-cracked specimens from sheet variously heat treated, Table 2.0332.

2.034 Fretting Fatigue.

2.0341 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 900F fretting fatigue resistance of duplex annealed forged disks, (see Figure 1.04219).

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specified mechanical properties, Table 3.011.

3.012 Producer's guaranteed mechanical properties, Table 3.012.

3.013 User's specified mechanical properties for sheet, strip, plate, bars, forgings, rings, extrusions, forged parts, compressor blades and vanes, and premium forged parts, Table 3.013.

3.014 Users' specified mechanical properties for bars, forgings and forging stock, premium quality bars, forgings and forging stock, and investment castings, Table 3.014.

3.015 User's specified mechanical properties for bars, forgings, forging stock, forged parts, and compressor blades and vanes, Table 3.015.

3.016 User's specified mechanical properties for bars, forgings and forging stock from Ti-6Al-2Sn-4Zr-2Mo-0.25Si, Table 3.016.

3.02 Mechanical Properties at Room Temperature

3.021 Tension. Stress-strain diagrams and tension properties. See also 3.031.

3.0211 Stress-strain curves in tension for duplex annealed forged compressor discs at room temperature, Figure 3.0211.

3.0212 Effect of solution anneal temperature on room temperature tensile properties of solution annealed sheet, Figure 3.0212.

3.0213 Effect of solution anneal temperature on room temperature tensile properties of duplex and triplex annealed sheet, Figure 3.0213.

3.0214 Effect of stabilization anneal temperature on room temperature tensile properties of duplex annealed plate, Figure 3.0214.

3.0215 Effect of solution anneal temperature on room temperature tensile properties of solution annealed bar, (see Figure 3.0212).

3.0216 Effect of solution annealing near the beta transus temperature on room temperature tensile properties of duplex annealed bar, Table 3.0216.

3.0217 Effect of solution annealing at temperatures up to and beyond the beta transus temperature on room temperature tensile properties of duplex annealed bar, Figure 3.0217.

3.0218 Effect of section size on room temperature tensile properties of duplex annealed bar, Table 3.0218.

3.0219 Effect of stabilization age time and temperature on room temperature tensile properties of duplex annealed rolled bar, Figure 3.0219.

3.02110 Effect of solution anneal temperature on room temperature tensile properties of solution annealed forging, (see Figure 3.0212).

3.02111 Effect of solution anneal temperature on room temperature tensile properties of duplex annealed forging, Figure 3.02111.

3.02112 Room temperature tensile properties of duplex annealed upset forging, Table 3.02112.

3.02113 Typical room temperature tensile properties of forged jet engine compressor discs, Table 3.02113.

3.02114 Effect of exposure to elevated temperature with load on room temperature tensile properties of solution annealed sheet, Figure 3.02114.

3.02115 Effect of exposure to elevated temperature on room temperature tensile properties of duplex annealed sheet, Figure 3.02115.

3.02116 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed sheet given various solution anneal treatments, Figure 3.02116.

3.02117 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex and triplex annealed sheet, Table 3.02117.

3.02118 Effect of long time exposure to elevated temperature with load on room temperature tensile properties of duplex and triplex annealed sheet, Table 3.02118.

3.02119 Effect of exposure to elevated temperature with load on room temperature tensile properties of triplex annealed sheet of various thicknesses, Figure 3.02119.

3.02120 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed bar given various solution anneal treatments, Figure 3.02120.

3.02121 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed rolled bar of various sizes, Table 3.02121.

3.02122 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed rolled bar variously heat treated, Table 3.02122

3.02123 Effect of long time exposure to elevated temperature with load on room temperature tensile properties of duplex annealed rolled bar, Table 3.02123.

3.02124 Effect of exposure to elevated temperature with load on room temperature tensile properties of beta-rolled duplex annealed bar, Table 3.02124.

3.02125 Effect of exposure to elevated temperature with load on room temperature tensile properties of solution annealed forging, Figure 3.02125.

3.02126 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed forging, Figure 3.02126.

3.02127 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed forged bar, Table 3.02127.

3.02128 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed compressor hub forging, Table 3.02128.

3.02129 Effect of exposure to elevated temperature with load on room temperature tensile properties of duplex annealed compressor wheel forgings, Table 3.02129.

	Ti
6	Al
2	Sn
4	Zr
2	Mo

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3.02130 Effect of solution anneal temperature on room temperature tensile properties of duplex annealed compressor disk forgings subsequent to long-time exposure to elevated temperature with load, Figure 3.02130.

3.02131 Effect of long-time exposure to elevated temperature with load on room temperature tensile properties of duplex annealed pancake forgings, Table 3.02131.

3.02132 Effect of high solution annealing temperature (beta transus - 25F) on exposure stability properties of duplex annealed forged disk, Table 3.02132.

3.02133 Combined effect of 0.25% silicon addition and forge/heat treat combinations on room temperature tensile properties of duplex annealed forged disks, (see Table 1.04214).

3.02134 Effect of molybdenum addition and solution annealing temperature on strength and creep resistance of duplex annealed forged bar, (see Table 1.04221).

3.02135 Effect of oxygen content on room temperature tensile properties of consumable electrode melted castings, (see Figure 1.0811).

3.02136 Effect of iron content on room temperature tensile properties of consumable electrode melted castings, (see Figure 1.0815).

3.02137 Effect of post-weld treatment on room temperature smooth tensile properties of TIG repair welded, consumable electrode melted cast specimens, (see Table 1.0819).

3.02138 Room temperature tensile properties of consumable electrode melted castings variously heat treated, (see Table 1.0820).

3.02139 Effect of heat treatment and filler wire composition on room temperature tensile and bend properties of welded sheet, (see Figure 4.036).

3.02140 Effect of exposure to elevated temperature with load on room temperature tensile properties of welded sheet given various heat treatments, (see Table 4.038).

3.02141 Effect of postweld anneal temperature and time on tensile properties of welded duplex annealed 0.025-inch sheet, (see Figure 4.0318).

3.02142 Effect of postweld anneal temperature and time on tensile properties of welded duplex annealed 0.080-inch sheet, (see Figure 4.0319).

3.02143 Effect of exposure to elevated temperature on room temperature tensile properties of welded duplex annealed sheet postweld annealed for two hours at various temperatures, (see Table 4.0320).

3.02144 Effect of loading rate on room temperature and 900F tensile properties of duplex annealed bar, (see Table 3.03113).

3.022 Compression. Stress-strain diagrams and compression properties. See 3.032.

3.023 Impact. See also 3.033.

3.0231 Standard Charpy-V impact energy of duplex annealed compressor wheel forging, Table 3.0231.

3.0232 Effect of oxygen content on room temperature Charpy-V impact energy for consumable electrode melted castings, (see Figure 1.0813).

3.0233 Effect of iron content on room temperature Charpy-V impact energy for consumable electrode melted castings, (see Table 1.0817).

3.0234 Room temperature Charpy-V impact energy for consumable electrode melted castings variously heat treated, (see Table 1.0823).

3.024 Bending.

3.0241 Effect of solution anneal temperature on room temperature minimum bend radius of solution annealed, duplex annealed and triplex annealed sheet, Figure 3.0241.

3.0242 Effect of sheet thickness on minimum bend radius of duplex and triplex annealed sheet, Table 3.0242.

3.0243 Effect of heat treatment and filler wire composition on room temperature tensile and bend properties of welded sheet, (see Figure 4.036).

3.0244 Minimum bend radii of duplex and triplex annealed sheet of various thicknesses from several heats, welded and cooled at two different rates from the weld cycle, (see Table 4.0312).

3.025 Torsion and shear. See also 3.035.

3.0251 Effect of exposure to elevated temperature on room temperature ultimate shear strength of duplex annealed sheet, Figure 3.0251.

3.026 Bearing. See 3.036

3.027 Stress concentration.

3.0271 Notch properties.

3.02711 Effect of solution anneal temperature on room temperature sharp notch properties of solution annealed sheet, Figure 3.02711.

3.02712 Effect of solution anneal temperature on room temperature sharp notch properties of duplex annealed sheet, Figure 3.02712.

3.02713 Effect of solution anneal temperature on room temperature sharp notch properties of triplex annealed sheet, Figure 3.02713.

3.02714 Effect of annealing time on smooth and sharp notch tensile properties of duplex and triplex annealed sheet, Table 3.02714.

3.02715 Effect of stabilization age time and temperature on room temperature smooth and sharp notch tensile properties of triplex annealed sheet, Figure 3.02715.

3.02716 Effect of thickness on room temperature smooth and sharp notch tensile properties of duplex and triplex annealed sheet, Table 3.02716.

3.02717 Effect of thickness on room temperature smooth and sharp notch tensile properties of triplex annealed sheet, Figure 3.02717.

3.02718 Effect of exposure to elevated temperature on room temperature sharp notch strength of duplex annealed sheet, Figure 3.02718.

3.02719 Effect of exposure to elevated temperature on room temperature smooth and sharp notch tensile properties of duplex annealed sheet, Figure 3.02719.

3.027110 Effect of exposure to elevated temperature on room temperature sharp notch strength of triplex annealed sheet, Figure 3.027110.

3.027111 Effect of exposure to elevated temperature on room temperature smooth and sharp notch tensile properties of triplex annealed sheet, Figure 3.027111.

3.027112 Effect of oxygen content on room temperature mild-notch strength of consumable electrode melted castings, (see Table 1.0812).

3.027113 Effect of iron content on room temperature mild-notch strength of consumable electrode melted castings, (see Figure 1.0816).

3.027114 Room temperature mild notch strength of consumable electrode melted castings variously heat treated, (see Table 1.0821).

3.027115 Effect of heat treatment on room temperature sharp notch tensile properties of welded sheet, (see Table 4.037).

3.0272 Fracture toughness.

3.02721 The plane strain fracture toughness of as-received and (unconventionally) duplex annealed 2-inch plate is reported in Figure 3.02722. The data exhibit the usual strong inverse relation between strength and toughness. An attempt (80) to characterize the toughness of heavy sections in two useful duplex annealed conditions was largely frustrated by the selection of an inadequately-thick specimen. Those results are given in Table 3.02723. Only one value qualifies in every respect as valid according to ASTM Method E-399-74: TS orientation toughness of 52 ksi-in$^{\frac{1}{2}}$ for the 1650F solution annealed (plus stabilization aged) stock. All other values in the Table may be compared to that result, from which it appears that the higher 1790F solution temperature produces a tougher duplex condition with no significant sacrifice in strength, and that directionality is inconsistent and only moderate.

3.02722 Effect of specimen thickness on plane strain fracture toughness of as-received and duplex annealed plate, Figure 3.02722.

3.02723 Plane strain fracture toughness of duplex annealed bar, Table 3.02723.

3.028 Combined properties.

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

3.03 Mechanical Properties at Various Temperatures

3.031 Tension. Stress-strain diagrams and tension properties. See also 3.021.

3.0311 Typical stress-strain curves at elevated temperatures for duplex annealed bar, Figure 3.0311.

3.0312 Stress-strain curves in tension for duplex annealed forged compressor discs at 600F, Figure 3.0312.

3.0313 Stress-strain curves in tension for duplex annealed forged compressor discs at 800F, Figure 3.0313.

3.0314 Stress-strain curves in tension for duplex annealed forged compressor discs at 1000F, Figure 3.0314.

3.0315 Effect of test temperature on tensile properties of duplex annealed sheet, Figure 3.0315.

3.0316 Spread of tensile properties at elevated temperatures for duplex annealed sheets from two heats, Figure 3.0316.

3.0317 Effect of test temperature on tensile properties of triplex annealed sheet, Figure 3.0317.

3.0318 Smooth tensile properties at room and elevated temperatures for duplex and triplex annealed sheet, Figure 3.0318.

3.0319 Tensile properties at very high temperatures for triplex annealed sheet, Figure 3.0319.

3.03110 Effect of test temperature on tensile properties of solution annealed bar, Figure 3.03110.

3.03111 Effect of test temperature on tensile properties of duplex annealed bar, Figure 3.03111.

3.03112 Effect of section size on elevated temperature tensile properties of duplex annealed bar, Figure 3.03112.

3.03113 Effect of loading rate on room temperature and 900F tensile properties of duplex annealed bar, Table 3.03113.

3.03114 Spread of tensile properties at room and elevated temperature for thirteen duplex annealed pancake forgings from three heats, Figure 3.03114.

3.03115 Effect of test temperature on tensile properties of duplex annealed compressor wheel forging, Figure 3.03115.

3.03116 Total variation in tensile properties for duplex annealed compressor hub, Table 3.03116.

3.03117 Typical 900F tensile properties of forged jet engine compressor discs, Table 3.03117.

3.03118 Room and elevated temperature tensile properties of beta-forged upset, Table 3.03118.

3.03119 Effect of solution anneal temperature on 800F tensile properties of solution annealed and duplex annealed bar, Figure 3.03119.

3.03120 Effect of quench rate from solution anneal on 800F tensile properties of duplex annealed bar, Figure 3.03120.

3.03121 Effect of heat treatment on elevated temperature tensile properties of duplex annealed rolled bar, Figure 3.03121.

3.03122 Effect of solution annealing temperature on elevated temperature tensile properties of forged compressor disks, Figure 3.03122.

3.03123 Effect of solution anneal treatment on room temperature and 1000F tensile properties of beta-forged, duplex annealed compressor wheel, Table 3.03123.

3.03124 Effect of quench rate from solution anneal on elevated temperature tensile properties of duplex annealed forging, Table 3.03124.

3.03125 Effect of forging and annealing temperatures on the elevated temperature tensile properties of forged bar, Figure 3.03125.

3.03126 Effect of exposure to elevated temperature on tensile properties of duplex annealed sheet at the exposure temperature, Figure 3.03126.

3.03127 Effect of silicon content on the room temperature and 900F tensile properties of duplex annealed bar, (see Figure 1.0424).

3.03128 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on the elevated temperature tensile properties of duplex annealed forged disks, (see Figure 1.04215).

3.03129 Room temperature and 600F tensile properties of induction melted cast bars, (see Table 1.096).

3.03130 Effect of test temperature on tensile properties of consumable electrode melted castings, (see Figure 1.0824).

3.03131 Elevated temperature tensile properties of welded sheet, (see Table 4.039).

3.032 Compression. Stress-strain diagrams and compression properties.

3.0321 Effect of test temperature on compressive yield strength of duplex annealed sheet, Figure 3.0321.

3.033 Impact. See also 3.023.

3.0331 Effect of solution anneal temperature on standard Charpy-V impact energy for solution annealed and duplex annealed bar at room temperature and -80F, Figure 3.0331.

3.0332 Effect of silicon content on -40F Charpy-V impact energy of duplex annealed bar, (see Figure 1.0425).

3.034 Bending. See 3.024.

3.035 Torsion and shear. See also 3.025.

3.0351 Effect of test temperature on ultimate shear strength of duplex annealed sheet, Figure 3.0351.

3.0352 Effect of exposure to elevated temperature on ultimate shear strength of duplex annealed sheet at the exposure temperature, Figure 3.0352.

3.036 Bearing.

3.0361 Effect of test temperature on bearing properties of duplex annealed sheet, Figure 3.0361.

3.037 Stress concentration.

3.0371 Notch properties. See also 3.0271.

3.03711 Mild-notch strength of duplex annealed sheet at room and elevated temperatures, Table 3.03711.

3.03712 Effect of test temperature on center-crack tensile and yield strengths of duplex annealed sheet, Figure 3.03712.

3.03713 Smooth and mild-notch tensile properties of duplex annealed compressor disc forgings at room and elevated temperatures, Figure 3.03713.

3.0372 Fracture toughness. See 3.0272.

3.038 Combined properties.

3.04 Creep and Creep Rupture Properties

3.041 Creep rates.

3.0411 Minimum creep rate curves at 800, 900 and 1000F, for duplex annealed sheet, Figure 3.0411.

3.042 Creep deformation.

3.0421 Creep deformation curves at 800F for duplex annealed sheet, Figure 3.0421.

3.0422 Creep deformation curves at 900F for duplex annealed sheet, Figure 3.0422.

3.0423 Creep deformation curves at 1000F for duplex annealed sheet, Figure 3.0423.

3.0424 Effect of sheet thickness on 150-hour creep deformation of duplex and triplex annealed sheet, Table 3.0424.

3.0425 Effect of stabilization aging temperature on creep deformation of triplex annealed sheet of various thicknesses, Table 3.0425.

3.0426 Effect of solution anneal temperature on 150-hour creep of duplex annealed rolled bar, Table 3.0426.

3.0427 Effect of stabilization anneal temperature on 150-hour creep of duplex annealed rolled bar, Table 3.0427.

3.0428 Creep properties of duplex annealed bar, Table 3.0428.

3.0429 Effect of silicon content on time to 0.1 percent creep deformation at 950F, 35 ksi, for duplex annealed bar, (see Figure 1.0421).

3.04210 Effect of silicon content on 100-hour creep deformation at 950F and 35 ksi for duplex annealed bar, (see Figure 1.0422).

3.04211 Effect of molybdenum addition and solution annealing temperature on strength and creep resistance of duplex annealed forged bar, (see Table 1.04221).

3.04212 Creep deformation curves at 800F to 1000F for duplex annealed pancake forgings, Figure 3.04212.

3.04213 Effect of solution anneal temperature and quench rate on creep properties at 900F to 1100F for duplex annealed compressor wheel forging, Table 3.04213.

3.04214 Effect of solution annealing temperature on time to 0.1 percent creep deformation at 800F, 900F and 1000F for duplex annealed forgings, Figure 3.04214.

3.04215 Effect of solution anneal temperature on time to 2.0

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

percent creep at 1000F, 30 ksi, for duplex annealed forgings, Table 3.04215.

3.04216 Effect of solution annealing at high temperature (beta - 25F) on creep deformation for duplex annealed forging, Table 3.04216.

3.04217 Effect of solution annealing temperature on 100-hour, 1000F, 25 ksi creep deformation of duplex annealed Ti-6Al-2Sn-4Zr-2Mo-0.9Si rolled bar and forged upsets, (see Figure 1.0426).

3.04218 Combined effect of 0.25% silicon addition and forge/heat treat combinations on time to 0.1% creep at 1000F, 35 ksi, of duplex annealed forged disks, (see Table 1.0429).

3.04219 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on time to 0.1% creep at various temperatures and stresses, of duplex annealed forged disks, (see Table 1.04210).

3.04220 Effect of cast section thickness on the creep deformation of a consumable electrode melted casting, (see Table 1.0826).

3.043 Creep rupture.

3.0431 Short-time creep rupture strength of triplex annealed sheet specimens preloaded and rapidly heated to test temperature, Figure 3.0431.

3.0432 1000F stress rupture properties of duplex annealed bar, Table 3.0432.

3.0433 Monotonic creep-rupture and strain-limited cyclic creep-rupture curves at 900F and 1100F for duplex annealed bar, Figure 3.0433.

3.0434 Effect of solution anneal treatment on 1000F stress rupture properties of duplex annealed forgings, Figure 3.0434.

3.0435 Effect of solution anneal temperature on room temperature mild-notch stress rupture properties of duplex annealed compressor wheel forging, Table 3.0435.

3.0436 Effect of solution anneal temperature on room temperature mild-notch stress rupture properties of duplex annealed, beta forged compressor wheel forging, Table 3.0436.

3.0437 Effect of solution annealing at high temperature (beta - 25F) on room temperature tensile and mild-notch stress rupture properties of duplex annealed compressor hub forging, Table 3.0437.

3.0438 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on room temperature mild-notch stress rupture properties of duplex annealed forged disks, (see Table 1.04220).

3.0439 Stress rupture properties at 700F to 1000F for duplex annealed pancake forgings and as-cast compressor casing, Figure 3.0439.

3.04310 Effect of oxygen content on room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings, (see Table 1.0814).

3.04311 Effect of iron content on room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings, (see Table 1.0818).

3.04312 Room temperature step-loaded mild-notch creep rupture properties of consumable electrode melted castings variously heat treated, (see Table 1.0822).

3.05 Fatigue Properties

3.051 Axial load smooth and notch fatigue properties at 70F for duplex annealed sheet, Figure 3.051.

3.052 Axial load smooth and notch fatigue properties at 400F for duplex annealed sheet, Figure 3.052.

3.053 Axial load smooth and notch fatigue properties at 800F for duplex annealed sheet, Figure 3.053.

3.054 Room temperature stress range diagram at 10^7 cycles for smooth specimens of duplex annealed sheet, Figure 3.054.

3.055 Room temperature and 900F smooth fatigue properties for duplex annealed bar, Figure 3.055.

3.056 900F smooth and notch fatigue properties for duplex annealed bar, Figure 3.056.

3.057 High-frequency axial-load fatigue properties at room temperature and 900F for duplex annealed bar, Figure 3.057.

3.058 Notch fatigue strength at 600F and 900F for duplex annealed compressor disk forging, Figure 3.058.

3.059 400F smooth and notch fatigue properties for duplex annealed compressor disk forgings, Figure 3.059.

3.0510 850F smooth and notch fatigue properties for duplex annealed compressor disk forgings, Figure 3.0510.

3.0511 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 900F axial load smooth and mild notch low cycle fatigue properties of duplex annealed forged disks, (see Figure 1.04216).

3.0512 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 900F smooth and mild notch fatigue properties of duplex annealed forged disks, (see Figure 1.04217).

3.0513 Combined effect of 0.25% silicon addition, beta forging and solution annealing variation on 1100F smooth and mild notch fatigue properties of duplex annealed forged disks, (see Figure 1.04218).

3.0514 Effect of cast section thickness on the fatigue properties of consumable electrode melted castings, (see Figure 1.0828).

3.06 Elastic Properties

3.061 Poisson's ratio. (see also Figure 3.0433)

3.0611 Poisson's ratio for duplex annealed pancake forging, Figure 3.0611.

3.062 Modulus of elasticity.

3.0621 Static tensile modulus of elasticity at room and elevated temperatures for duplex annealed sheet, Figure 3.0621.

3.0622 Static compressive modulus of elasticity at room and elevated temperatures for duplex annealed sheet, Figure 3.0622.

3.0623 Dynamic tensile modulus of elasticity of duplex annealed sheet at room and elevated temperature, Figure 3.0623.

3.0624 Static tensile modulus of elasticity at room and elevated temperatures for duplex annealed bar, Figure 3.0624.

3.0625 Effect of loading rate on room temperature and 900F tensile properties (including tensile modulus of elasticity) of duplex annealed bar, (see Table 3.03113).

3.0626 Dynamic tensile modulus of elasticity at room and elevated temperatures for duplex annealed pancake forging, Figure 3.0626.

3.063 Modulus of rigidity.

3.064 Tangent modulus.

3.065 Secant modulus.

4. FABRICATION

4.01 Forming

4.011 Bending. Bend properties are equivalent to those for competitive alpha or alpha-beta alloys. See bend properties, section 3.024.

4.012 Forging. The producer of this alloy classifies its forgeability as similar to Ti-6Al-4V, (2). Others classify the forgeability of this alloy as better than that of Ti-8Al-1Mo-1V, not as good as Ti-6Al-4V, (11), and comparable to Ti-6Al-6V-2Sn, (4). Current specifications limit the forging temperature of this alloy to 1750F or beta transus temperature - 50F. One investigator reports that this produces a structure having superior fatigue properties. At these low temperatures, however, cracking can occur. (12). Forging high in the alpha-beta region reduces cracking tendency and imparts higher creep resistance. Creep resistance is further increased by forging well into the beta region, with no essential difference in the conventional tensile properties or in post-creep tensile properties (12) (Tables 4.0121 and 4.0122). As discussed in section 1.042, beta processing is considered essential if improved creep resistance of the silicon-modified variant of this alloy is to be assured, (79).

Beta recrystallization results in Tables 4.0123 and 4.0124 indicate that high temperature, large reduction forging processes are effective in refining the beta grain size. Low temperature forging and beta annealing is also useful in refining the beta grain size (86), but it appears considerable work is required to obtain complete recrystallization.

4.0121 Effect of beta forging and beta annealing on elevated temperature stability of duplex annealed forged bar, Table 4.0121.

4.0122 Effect of processed structure on elevated temperature stability of duplex annealed forging, Table 4.0122.

4.0123 High temperature forging and recrystallization results, Table 4.0123.

4.0124 Lower temperature forging and recrystallization results, Table 4.0124.

4.02 Machining and Grinding

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

4.03 WELDING

4.031 General. Two phase, alpha-beta titanium alloys characteristically produce welds with properties different from those of the unwelded metal. Generally, as the amount of stable beta phase increases, weld strength increases and ductility and toughness decrease. The normal annealed microstructure of Ti-6Al-2Sn-4Zr-2Mo alloy is alpha phase with a small amount of beta phase. It would be expected that, with such slight beta stabilization, the alloy would have excellent weldability. This, however, is not the case. The alloy produces a weld, the properties of which are difficult to predict and markedly different from the unwelded metal. (30).

Weld properties for this alloy have been reported in references (10) (13) (27) and (30). The results are summarized here. Sizeable differences have been observed in room temperature strength and notch toughness for fusion welded sheet of two thicknesses from separate heats (Figure 4.036 and Table 4.037). Postweld heat treatment in the stress relief range (i.e., 1100F, 2 hours) aged the welds, increasing their strength and reducing their notch toughness. In contrast to the results of Figure 4.036 and Table 4.037, Figures 4.0318 and 4.0319 show essentially no differences in ordinary tensile properties for welds of two different sheet gages from a single heat, and that possible benefits may derive from postweld annealing (this is discussed at greater length in Section 4.035). By comparison with creep data for parent sheet in Tables 3.0424 and 3.0425, poor creep resistance is seen for welded sheet in Table 4.038. Some evidence of thermal instability is also seen for welded sheet in Table 4.038. Postweld heat treatment at 1100F for 2 hours (stress relief cycle) improves creep resistance but not elevated temperature stability (also shown in Table 4.038). The elevated temperature weld strengths reported in Table 4.039 represent 100 percent weld efficiencies. Room temperature strengths of unexposed, as-welded spot welds presented in Figure 4.0310 and Table 4.0311 are considered "satisfactory" by the alloy producer (30). Postweld heat treatment (1100F, 2 hours) and elevated temperature exposure in air or salt environments, however, have deleterious effects on spot weld strength (again see Figure 4.0310).

It has been suggested (27) (30) that the variable weld properties of this alloy are attributable to nonequilibrium transformations which accompany weld cooling. Series of tests designed to study the influences of weld cooling rate (varied by altering sheet thickness, welding speed, and copper chill fixturing), base metal composition and heat treated condition on structure and properties have been conducted (27) (30). Results of bend tests in Table 4.0312, though sometimes not very pronounced, are consistent in suggesting that for this alloy the weld properties may vary with ingot source (composition), gage of material welded, weld cooling rate, and possibly, prior heat treatment. Variability of weld properties may be explained in part by reference to the transformation kinetics of this alloy as follows.

4.032 Nonequilibrium Beta Phase Decomposition. In titanium alloys, which are allotropic, there occur nonequilibrium transformations during relatively rapid cooling (or heating). The familiar time-temperature-transformation (TTT) diagram is frequently used for the study of such nonequilibrium transformations. However, the TTT diagram is usually determined by isothermal quench techniques, and can only be used as a guide to the phase changes which take place during continuous cooling: the continuous-cooling-transformation (CCT) diagram is necessary for this purpose. As the name implies, the CCT diagram describes the phase changes which take place while the metal is cooling, as a function of its cooling rate.

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

A schematic CCT diagram for alpha-lean beta titanium alloys is shown in Figure 4.0313. Curve A represents very slow cooling with transformation occurring in the neighborhood of the beta transus. The reaction is a near-equilibrium transformation of beta to alpha platelets. Cooling indicated by curve B is more rapid than that represented by curve A (but still slow) and results in an alpha structure more serrated in nature. Cooling indicated by curve C produces fine (acicular) alpha, but insufficient time in the upper range of temperature prevents the completion of this transformation. Some beta thus transforms to martensite (α') at the lower temperature. This split transformation, a nonequilibrium beta phase decomposition, occurs between rates C_1 and C_2. Variable cooling rates within this range result in variable transformations believed to cause many structural and mechanical uncertainties in Ti-6Al-2Sn-4Zr-2Mo welds. At sufficiently fast cooling rates, as indicated by curve D, transformation does not occur until a low temperature is reached. Here a uniform fully-martensitic structure is obtained.

4.033 Mechanical Properties. On the basis of the CCT diagram, maximum hardness for this alloy would be expected for intermediate cooling rates. Faster rates would not permit transformation to alpha, but rather martensite, which in titanium is usually considered a soft, ductile structure. Slower rates would result in alpha precipitates increasingly massive, soft and ductile, the slower the cooling rate.

Hardness measurements have been made on specimens cooled at various rates from above the beta transus. At slow cooling rates, transformation takes place at high temperatures and approaches equilibrium. The alpha growth rate exceeds the nucleation rate and the resultant structure is relatively soft. As the cooling rate is increased from the slowest rate, hardness increases as alpha platelet size diminishes. The nucleation rate for alpha transformation exceeds the growth rate. Hardness continues to increase with cooling rate as the "knee" of the curve is approached and the region of precipitation from an unstable beta is entered. (In actual welding situations the heat affected zone may be further complicated by an incomplete transformation upon heating due to the short times involved - see the CCT diagram for this alloy in Figure 4.0315.) To the left of the "knee", martensite is formed, characterized by a criss-cross needle appearance. Titanium martensite is usually soft, and therefore the hardness would be expected to fall for cooling rates to the left of the "knee". However, for this alloy it does not. One authority (35) feels that this is to be expected for stock cooled from above the beta transus. The "soft" martensite is produced by quenching from below the beta transus. These two martensites differ in hardness, lattice parameters and transformation mechanism. These hardness observations are consistent with hardness surveys made on weldments, a typical result shown in Figure 4.0314. The cooling rate increases with distance from the weld centerline, and so does the hardness before it falls to the base plate value. There is no drop in the heat affected zone to a value less than the base plate value as would be expected were the

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

martensite in this region "soft". The full range of mechanical properties as a function of cooling rate for this alloy has not yet been developed.

4.034 Composition. The nominal CCT diagram for this alloy is shown in Figure 4.0315. Figure 4.0316 shows that variations in chemical composition within normal specification tolerances can cause significant changes in the positions of the CCT diagram curves (i.e., M_s, M_f and times to start and finish transformations). While the differences shown may appear small, they are of considerable practical significance. A cooling rate considered slow enough to miss the region of nonequilibrium beta phase decomposition for one heat may, in fact, not be slow enough to miss it due to the curves' shift with slight chemistry changes. The heat affected zone which cools at quite a variable rate can be expected to consist of an equally broad range of microstructures and consequent mechanical properties.

The CCT diagram for this alloy is positioned to the right and below the TTT diagram (see Figure 4.0317). This is to be expected since the CCT diagram is essentially nonequilibrium and the TTT diagram is pseudoequilibrium. The time required to start the beta-to-alpha transformation is greater at higher temperatures. At a given transformation temperature, the continuously cooled specimen has been above the temperature throughout its entire cooling cycle, whereas the isothermally treated sample has been at the given reaction temperature for a finite time. Thus, the continuously cooled sample is not ready to form alpha at this given temperature in the time interval the isothermally treated sample is; that is, more time is required for transformation to begin. This explains why the CCT diagram lies below and to the right of the TTT diagram. It is a more difficult and abstract case to rationalize the discrepancy in M_s temperatures.

The transformation kinetics of martensite formation are different from those of the beta-to-alpha reaction. The former is by a shear mechanism (which defines martensite) and results in a supersaturated microstructure; the latter by a nucleation and growth process. It has been shown (31) (32) that the M_s temperature for titanium alloys is virtually independent of cooling rate at rates faster than critical (i.e., C_1 in Figure 4.0313). Thus the M_s temperature determined from either isothermal quenching or continuous cooling procedures should be the same. However, the CCT diagram shows an M_s temperature of about 1300F; the TTT diagram, 1475F. Two explanations for this disagreement have been offered.

Armitage (33) suggests that martensite may form isothermally above the apparent M_s temperature. The possible formation of small dispersed particles of omega phase (even after cold water quenching) would produce zones of transitory enriched beta. This segregation of beta stabilizing solute elements (here molybdenum) could then promote isothermal martensite transformation by increasing M_s temperature of small solute depleted regions.

Another source (30) suggests that heat to heat differences might also contribute to M_s differences. A variation of 1 weight percent molybdenum can depress the M_s of the Ti-Mo binary by about 50F in the range of 2 to 3 weight percent molybdenum, (31) (32) (34). Conceivably, the combined effects of compositional variations in Ti-6Al-2Sn-4Zr-2Mo might account for the observed difference in M_s temperature for the two transformation diagrams.

4.035 Postweld Annealing. The martensite formed by rapid cooling is unstable and reverts to alpha and beta upon reheating. If the reheat temperature is relatively low, the weld "age hardens". At higher reheat temperatures, the weld equilibrates and softens - commonly called annealing.

The variable structure (of variable hardness) produced at slower cooling rates is unstable due to the retention of unstable beta and ages when reheated to moderate temperatures. Reheating to sufficiently high temperatures, on the other hand, causes some of the alpha products producing hardening during cooling to be partially taken into solution. Others coalesce, equilibrium is approached, and general softening occurs - this again is called annealing.

The large alpha plates formed at cooling rates slower than those in the unstable transformation range is a "soft structure" - reheating to moderate temperatures has little effect. At higher reheat temperatures, in the annealing range, some hardening may occur due to redistribution of elements between the alpha and beta phases.

The effects of postweld annealing temperature and time on the room temperature tensile properties of duplex annealed 0.025-inch and 0.080-inch sheet are shown in Figures 4.0318 and 4.0319. The welds in the 0.025-inch sheet were thought (30) to have quenched to a martensitic (alpha prime) structure; welds in the 0.080-inch sheet cooled at a slower rate producing an "indefinite" structure. Both gages exhibited essentially identical properties in the as-welded condition. Structural differences, however, account for quite different property trends with time at the annealing temperature for the two gages. It appears, nevertheless, that both sheet aged at all annealing temperatures. Overaging (or annealing) occurred, however, in a very short time at the higher temperatures.

The effect of 150-hour exposure at 1000F without load on the subsequent room temperature tensile properties of both sheet gages annealed for 2 hours over the same range of annealing temperatures is shown in Table 4.0320. It is not surprising that the instability shown was not fully eliminated by annealing even at 1400F for 2 hours, since, as shown in Figures 4.0318 and 4.0319, four hours are required for the overaged properties to return to the unaged values. That some thermal instability might not be observed for fully annealed stock similarly exposed has not been demonstrated. It should be cautioned, however, that the specimen type used for this study (longitudinal weld orientation) tends to integrate the properties of the weld fusion and heat affected zones as well as the unwelded sheet and that the possibility that the base metal was controlling the tensile properties of the exposed specimens can not be ruled out.

While the data are incomplete, it appears that postweld annealing may be a useful method of approaching uniform weld properties in an alloy that has demonstrated wide variability. A cycle of 1300-1400F for at least one hour seems indicated. This tends to equilibrate the weld; however, its effect on base metal properties is unknown. Undoubtedly, the advantages gained by the 1100F part of the triplex anneal would be lost.

4.036 Effect of heat treatment and filler wire composition on room temperature tensile and bend properties of welded sheet, Figure 4.036.

4.037 Effect of heat treatment on room temperature sharp notch tensile properties of welded sheet, Table 4.037.

4.038 Effect of exposure to elevated temperature with load on room temperature tensile properties of welded sheet given various heat treatments, Table 4.038.

4.039 Elevated temperature tensile properties of welded sheet, Table 4.039.

4.0310 Effect of heat treatment and thermal exposure, with and without a salt environment, on room temperature cross-tension strength of single resistance spot welds, Figure 4.0310.

4.0311	Room temperature shear-tension and cross-tension strengths of single resistance spot welds given various heat treatments, Table 4.0311.
4.0312	Minimum bend radii of duplex and triplex annealed sheet of various thicknesses from several heats, welded and cooled at two different rates from the weld cycle, Table 4.0312.
4.0313	Hypothetical cooling curves A, B, C_2, C, C_1 and D, superimposed on schematic continuous-cooling-transformation (CCT) diagram for an alpha-lean beta titanium alloy, Figure 4.0313.
4.0314	Microhardness of weld cross section in 0.025-inch thick Ti-6Al-2Sn-4Zr-2Mo sheet, Figure 4.0314.
4.0315	Continuous-cooling-transformation (CCT) diagram for Ti-6Al-2Sn-4Zr-2Mo, Figure 4.0315.
4.0316	Effect of compositional variations within specification on continuous-cooling-transformation (CCT) diagram for Ti-6Al-2Sn-4Z4-2Mo, Figure 4.0316.
4.0317	Comparison of continuous-cooling-transformation (CCT) diagram and isothermal-transformation (TTT) diagram for Ti-6Al-2Sn-4Zr-2Mo alloy, Figure 4.0317.
4.0318	Effect of postweld anneal temperature and time on tensile properties of welded duplex annealed 0.025 inch sheet, Figure 4.0318.
4.0319	Effect of postweld anneal temperature and time on tensile properties of welded duplex annealed 0.080 inch sheet, Figure 4.0319.
4.0320	Effect of exposure to elevated temperature on room temperature tensile properties of welded duplex annealed sheet postweld annealed for two hours at various temperatures, Table 4.0320.

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

FORM	CONDITION	SPECIFICATION
Bars, Wire and Rings	Duplex Annealed	Aerospace Material Specification AMS-4975B (11-15-71)
Forgings and Forging Stock	Duplex Annealed	Aerospace Material Specification AMS-4976 (5-1-68)
Sheet, Strip and Plate	Mill Annealed, Solution Annealed and Duplex Annealed	Military Specification MIL-T-9046H (3-14-74)
Bars and Forging Stock	Mill Annealed, Solution Annealed and Duplex Annealed	Military Specification MIL-T-009047F(USAF) (9-19-72)
Premium Quality Forgings	Mill Annealed and Duplex Annealed	Military Specification MIL-F-83142A(USAF) (12-1-69)
Investment Castings	Mill Annealed	Military Specification MIL-T-81915 (3-16-73)
Bars and Forgings	Duplex Annealed	AVCO Corporation Lycoming Division M3406 (7-20-66)
Premium Quality Bars and Forgings	Duplex Annealed	AVCO Corporation Lycoming Division M3406A (1-6-72)
Investment Castings	As-Cast	AVCO Corporation Lycoming Division M34AB (9-14-66)
Sheet, Strip and Plate	Duplex Annealed and Triplex Annealed	General Electric Company B50TF21-S3 Amend 1 (6-24-76)
Bars, Rings and Forgings	Solution Annealed and Duplex Annealed	General Electric Company B50TF22-S4 Amend 1 (6-24-76)
Forged Parts	Duplex Annealed	General Electric Company C50TF7-S7 Amend 1 (6-24-76)
Premium Quality Forged Parts	Duplex Annealed	General Electric Company C50TF39-S4 Amend 1 (6-24-76)
Compressor Blades and Vanes	Duplex Annealed	General Electric Company C50TF8-S7 Amend 1 (6-24-76)
Extrusions	Mill Annealed, Solution Annealed and Duplex Annealed	General Electric Company B50TF91-S2 Amend 1 (6-24-76)
Bars	Duplex Annealed	United Technologies Corporation Pratt & Whitney Aircraft Division PWA-1210E (8-4-75)
Bars, Forgings, Forging Stock, Forged Parts and Compressor Blades and Vanes	Duplex Annealed	United Technologies Corporation Pratt & Whitney Aircraft Division PWA-1209L (8-4-75)
Forgings and Forging Stock	Duplex Annealed	United Technologies Corporation Pratt & Whitney Aircraft Division PWA-1214F (8-4-75)
Bars, Forgings and Forging Stock from Alpha-Beta Processed Ti-6Al-2Sn-4Zr-2Mo-0.25Si	Duplex Annealed	United Technologies Corporation Pratt & Whitney Aircraft Division PWA-1211A (8-8-75)
Forgings and Forging Stock from Beta Processed Ti-6Al-2Sn-4Zr-2Mo-0.25Si	Duplex Annealed	United Technologies Corporation Pratt & Whitney Aircraft Division PWA-1218A (8-8-75)

TABLE 1.03 SPECIFICATIONS

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Source	AMS (19)		AMS (20)	
Form	Bars and Rings		Forgings	
	Weight Percent			
	Min	Max	Min	Max
Aluminum	5.50	6.50	5.50	6.50
Tin	1.80	2.20	1.80	2.20
Zirconium	3.60	4.40	3.60	4.40
Molybdenum	1.80	2.20	1.80	2.20
Iron		0.25		0.25
Carbon		0.05		0.05
Oxygen		0.15		0.15
Nitrogen		0.05		0.05
Hydrogen		0.0125		0.0150[a]
Others Each[b]		0.10		0.10
Others Total[b]		0.30		0.30
Titanium	balance		balance	

(a) 0.0125 max for forging stock.
(b) Determination not required for routine acceptance.

TABLE 1.041 AMS SPECIFIED COMPOSITION

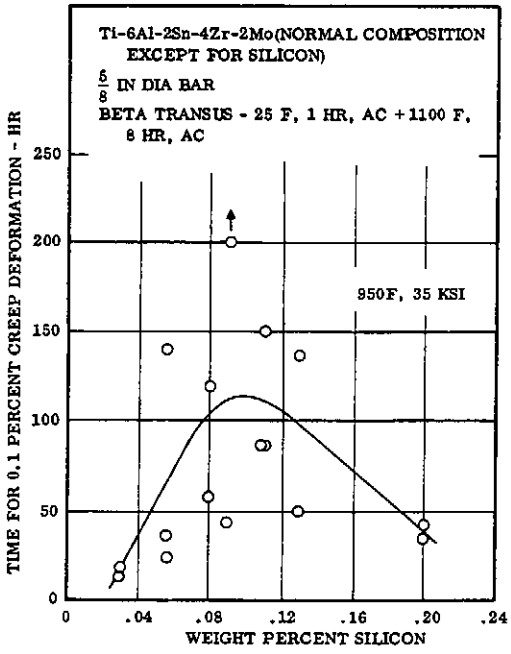


FIG. 1.0421. EFFECT OF SILICON CONTENT ON TIME TO 0.1 PERCENT CREEP DEFORMATION AT 950 F, 35 KSI, FOR DUPLEX ANNEALED BAR. (78)

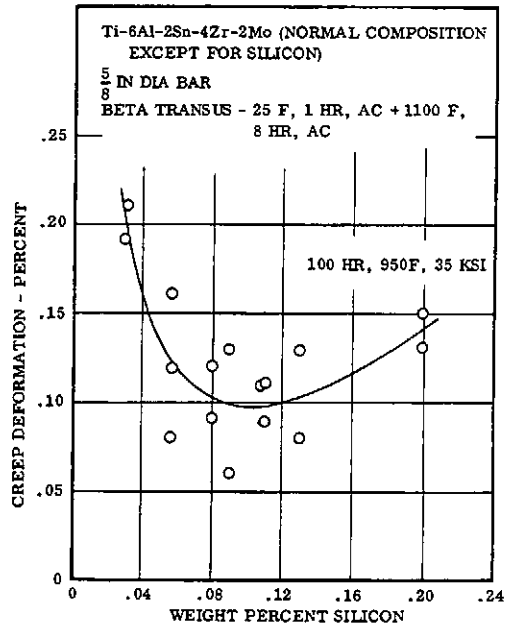


FIG. 1.0422. EFFECT OF SILICON CONTENT ON 100-HR CREEP DEFORMATION AT 950 F AND 35 KSI, FOR DUPLEX ANNEALED BAR. (78)

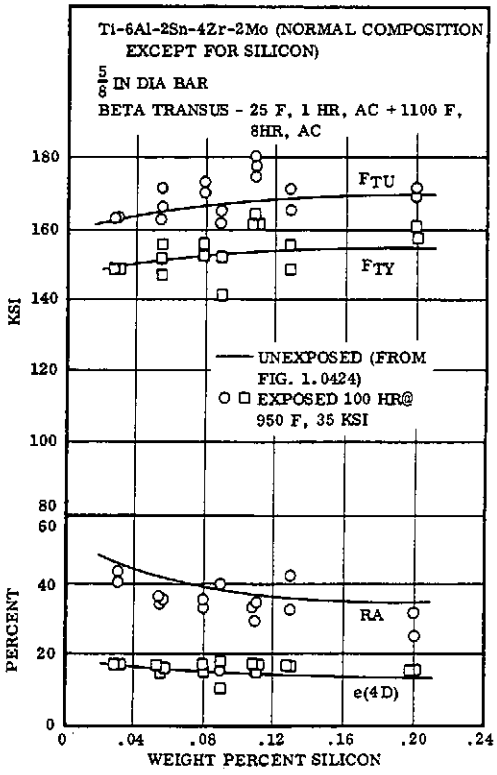


FIG. 1.0423. EFFECT OF 100 HR EXPOSURE AT 950 F, 35 KSI, ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED BAR OF VARYING SILICON CONTENT. (78)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

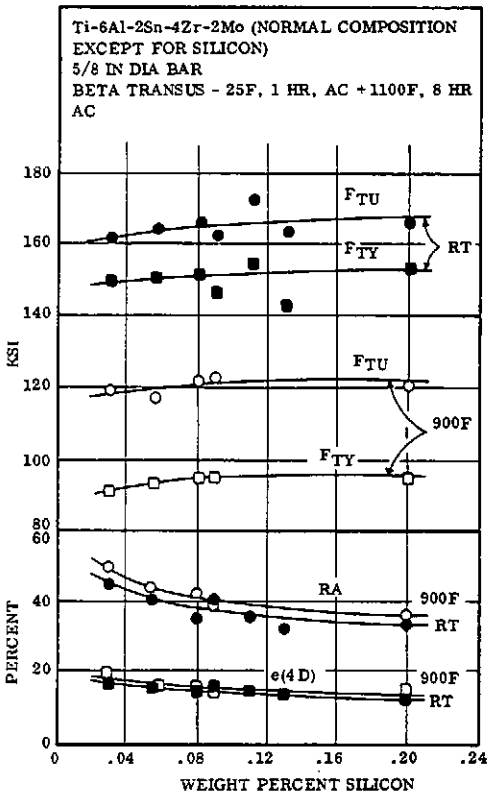


FIG. 1.0424 EFFECT OF SILICON CONTENT ON THE ROOM TEMPERATURE AND 900F TENSILE PROPERTIES OF DUPLEX ANNEALED BAR (78)

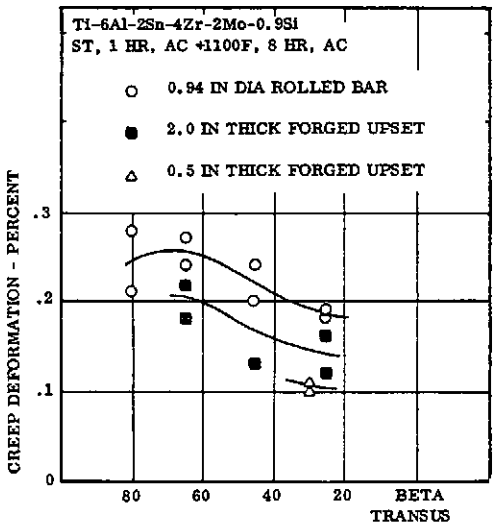


FIG. 1.0426 EFFECT OF SOLUTION ANNEALING TEMP ON 100 HR, 1000F, 25 KSI CREEP DEFORMATION OF DUPLEX ANNEALED Ti-6Al-2Sn-4Zr-2Mo-0.9Si ROLLED BAR AND FORGED UPSETS (78)

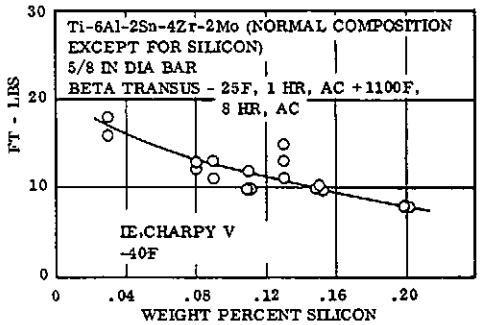


FIG. 1.0425 EFFECT OF SILICON CONTENT ON -40F CHARPY-V IMPACT ENERGY OF DUPLEX ANNEALED BAR (78)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

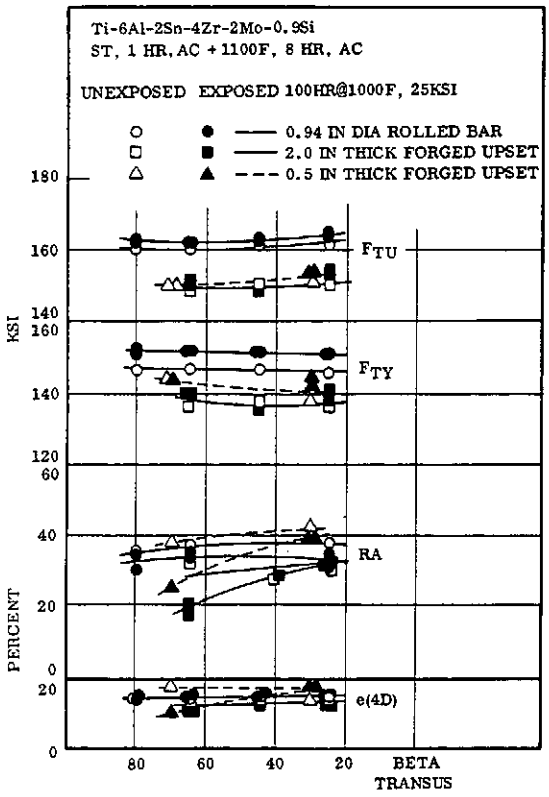


FIG. 1.0427. EFFECT OF SOLUTION ANNEALING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED Ti-6Al-2Sn-4Zr-2Mo-0.9Si ROLLED BAR AND FORGED UPSETS SUBSEQUENT TO 100-HR CREEP EXPOSURE AT 1000 F, 25 KSI. (78)

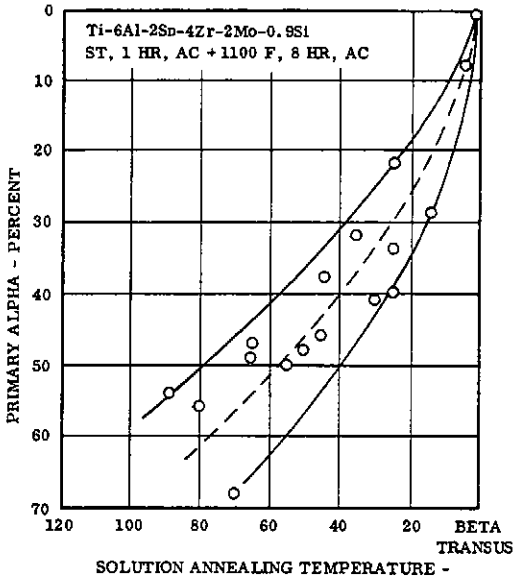


FIG. 1.0428. EFFECT OF SOLUTION ANNEALING TEMPERATURE ON PERCENT PRIMARY ALPHA IN Ti-6Al-2Sn-4Zr-2Mo-0.9Si ALLOY. (78)

Form		1½-in x 15-in dia pancake type forged disks	
Beta Transus F	Forge Temp F	Duplex Anneal Treatment	Time to 0.1% Creep at 1000F, 35 ksi hrs
		Ti-6Al-2Sn-4Zr-2Mo	
1830	1750	1805F, 1 hr, AC + 1100F, 8 hrs, AC	14.4 23.4
		Ti-6Al-2Sn-4Zr-2Mo + 0.25Si	
1820	1770	1770F, 1 hr, AC + 1100F, 8 hrs, AC	10.9 10.7
1820	1770	1770F, 1 hr, OQ + 1100F, 8 hrs, AC	15.3 20.3
1820	1870	1770F, 1 hr, AC + 1100F, 8 hrs, AC	127.8 117.2
1820	1870	1770F, 1 hr, OQ + 1100F, 8 hrs, AC	131.1 187.6

TABLE 1.0429 COMBINED EFFECT OF 0.25% SILICON ADDITION AND FORGE/HEAT TREAT COMBINATIONS ON TIME TO 0.1% CREEP AT 1000F, 35 KSI, OF DUPLEX ANNEALED FORGED DISKS, (70).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Form	1½-in x 15-in dia pancake type forged disks	
Condition	Duplex Annealed	
Temp F	Stress ksi	Hrs to 0.1% Creep
	Ti-6Al-2Sn-4Zr-2Mo[a]	
800	60	313.5
800	65	110.0
1000	25	128.0
1000	30	55.0
1000	35	14.4
1000	35	23.4
1200	10	8.0
1200	15	3.4
	Ti-6Al-2Sn-4Zr-2Mo + 0.25Si[b]	
800	60	1000.0(c)
800	65	1000.0(d)
1000	25	396.0
1000	30	96.0
1000	35	131.1
1000	35	187.6
1200	10	5.4
1200	15	on Loading

(a) Forged: 1750F. Duplex Annealed: 1805F, 1 hr, AC + 1100F, 8 hrs, AC. Beta transus = 1830F.
(b) Forged: 1870F. Duplex Annealed: 1770F, 1 hr, OQ + 1100F, 8 hrs, AC. Beta transus = 1820F.
(c) 0.081% creep deformation.
(d) 0.092% creep deformation.

TABLE 1.04210 COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON TIME TO 0.1% CREEP AT VARIOUS TEMPERATURES AND STRESSES, OF DUPLEX ANNEALED FORGED DISKS, (70).

Form		1½-in x 15-in dia pancake type forged disks					
Beta Transus F	Forge Temp F	Duplex Anneal Treatment	Exposure Condition	Subsequent RT Tensile Properties[a] F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent
		Ti-6Al-2Sn-4Zr-2Mo					
1830	1750	1805F, 1 hr, AC + 1100F, 8 hrs, AC	Unexposed	147.0	133.5	16.0	35.6
				150.0	137.9	16.5	33.7
			Exposed[b]	145.5	135.1	19.0	44.6
				149.5	138.2	18.5	42.4
		Ti-6Al-2Sn-4Zr-2Mo + 0.25Si					
1820	1770	1770F, 1 hr, AC + 1100F, 8 hrs, AC	Unexposed	153.7	146.2	12.0	34.3
				155.0	147.0	13.0	33.0
			Exposed[b]	156.7	147.7	16.0	30.6
				158.0	148.1	14.0	28.1
1820	1770	1770F, 1 hr, OQ + 1100F, 8 hrs, AC	Unexposed	172.0	157.5	10.0	12.3
				173.0	158.0	15.0	27.7
			Exposed[b]	177.3	166.3	9.0	13.8
				174.7	164.9	16.0	31.6
1820	1870	1770F, 1 hr, AC + 1100F, 8 hrs, AC	Unexposed	149.7	138.1	9.0	27.2
				151.7	138.9	13.0	23.0
			Exposed[b]	153.5	142.0	13.0	18.2
				153.6	140.5	11.5	12.0
1820	1870	1770F, 1 hr, OQ + 1100F, 8 hrs, AC	Unexposed	166.8	151.8	7.0	15.0
				165.0	149.5	7.0	15.8
			Exposed[b]	176.4	153.5	6.0	9.3
				171.7	156.5	8.0	11.6

(a) Tested after exposure without surface conditioning.
(b) 0.1% creep deformation at 1000F, 35 ksi.

TABLE 1.04211 COMBINED EFFECT OF 0.25% SILICON ADDITION AND FORGE/HEAT TREAT COMBINATIONS ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS SUBSEQUENT TO 0.1% CREEP EXPOSURE AT 1000F, 35 KSI, (70).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2

Form			1½-in x 15-in dia pancake type forged disks			
Condition			Duplex Annealed			
0.1% Creep Exposure at			Subsequent RT Tensile Properties[a]			
Temp F	Stress ksi	Time hr	F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent
		Ti-6Al-2Sn-4Zr-2Mo[b]				
	Unexposed		147.0	133.5	16.0	35.6
	Unexposed		150.0	137.9	16.5	33.7
800	60	313.5	146.7	132.9	19.0	34.0
800	65	110.0	145.9	129.9	13.5	32.5
1000	25	128.0	146.7	135.5	16.0	24.9
1000	30	55.0	146.1	136.2	19.0	39.6
1000	35	14.4	145.5(c)	135.1(c)	19.0(c)	44.6(c)
1000	35	23.4	149.5(c)	138.2)c)	18.5(c)	42.4(c)
1200	10	8.0	145.4	132.6	16.5	32.9
1200	15	3.4	144.9	135.6	17.5	37.6
		Ti-6Al-2Sn-4Zr-2Mo + 0.25Si[d]				
	Unexposed - Disk #1		166.8	151.8	7.0	15.0
	Unexposed - Disk #1		165.0	149.5	7.0	15.8
	Unexposed - Disk #2		165.1	149.1	10.0	14.6
	Unexposed - Disk #2		169.0	153.4	8.5	13.0
800	60	1000.0[e]	175.1	160.7	6.0	8.5
800	65	1000.0[f]	165.8	149.4	8.0	11.0
1000	25	396.0	168.2	154.3	5.5	6.8
1000	30	96.0	165.8	150.0	11.5	11.4
1000	35	131.1	167.4[c]	153.5[c]	6.0[c]	9.3[c]
1000	35	187.6	171.7[c]	156.5[c]	8.0[c]	11.6[c]
1200	10	5.4	163.6	150.0	7.5	9.7
1200	15	on Loading	158.7	148.0	7.5	8.0

(a) 0.020 in removed from surface after exposure and before RT test, except where noted.
(b) Forged: 1750F. Duplex annealed: 1805F, 1hr, AC + 1100F, 8 hrs, AC.
Beta transus = 1830F.
(c) Tested after exposure without surface removal.
(d) Forged: 1870F. Duplex annealed: 1770F, 1 hr, OQ + 1100F, 8 hrs, AC.
Beta transus = 1820F.
(e) 0.081% creep deformation.
(f) 0.092% creep deformation.

TABLE 1.04212. COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS SUBSEQUENT TO 0.1% CREEP EXPOSURE AT VARIOUS EXPOSURE TEMPERATURES AND STRESSES, (70).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo + 0.25Si						
Form	1½-in x 15-in dia pancake type forged disks						
Condition	Beta Forged + Duplex Annealed[a]						
Creep Exposure				Subsequent RT Tensile Properties [b]			
Temp F	Stress ksi	Time hr	Deformation percent	F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent
	Unexposed			165.1	149.1	10.0	14.6
	Unexposed			169.0	153.4	8.5	13.8
800	60	1000	0.081	175.1	160.7	6.0	8.5
800	65	1000	0.092	165.8	149.4	8.0	11.0
800	90	896	0.173	170.5	163.0	9.0	9.3
900	30	130	0.026	167.6	151.1	10.0	12.7
900	30	130	0.059	161.8	144.6	10.0	13.4
900	30	300	0.062	173.7	158.3	7.0	8.3
900	30	300	0.068	165.5	152.3	8.5	10.6
900	30	600	0.032	164.5	149.1	11.5	13.2
900	30	600	0.034	167.5	150.0	10.0	13.0
1000	20	50	0.017	165.7	150.0	9.0	11.3
1000	20	50	0.018	164.0	146.8	10.0	12.1
1000	20	150	0.042	165.0	149.0	9.0	11.0
1000	25	396	0.100	168.2	154.3	5.5	6.8
1000	25	500	----	164.8	148.6	10.5	12.7
1000	30	96	0.100	165.8	150.0	11.5	11.4
1000	45	295	0.202	173.6	165.0	4.0	6.0
1100	5	25	0.034	161.0	146.0	8.5	9.6
1100	5	25	0.049	166.5	151.2	6.0	6.0
1200	10	5.4	0.100	163.6	150.0	7.5	9.7
1200	15	on Loading	0.100	158.7	148.0	7.5	8.0

(a) Forged: 1870F. Duplex annealed: 1770F, 1 hr, OQ + 1100F, 8 hrs, AC. Beta transus = 1820F.
(b) 0.020 in removed from surface after exposure and before RT tensile test.

TABLE 1.04213. EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF BETA FORGED, DUPLEX ANNEALED Ti-6Al-2Sn-4Zr-2Mo + 0.25Si FORGED DISKS, (70).

Form	1½-in x 15-in dia pancake type forged disks					
Beta Transus F	Forge Temp F	Duplex Anneal Treatment	RT Tensile Properties			
			F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent
		Ti-6Al-2Sn-4Zr-2Mo				
1830	1750	1805F, 1 hr, AC + 1100F, 8 hrs, AC	147.0	133.5	16.0	35.6
			150.0	137.9	16.5	33.7
		Ti-6Al-2Sn-4Zr-2Mo + 0.25Si				
1820	1770	1770F, 1 hr, AC + 1100F, 8 hrs, AC	153.7	146.2	12.0	34.3
			155.0	147.0	13.0	33.0
1820	1770	1770F, 1 hr, OQ + 1100F, 8 hrs, AC	172.0	157.5	10.0	12.3
			173.0	158.0	15.0	27.7
1820	1870	1770F, 1 hr, AC + 1100F, 8 hrs, AC	149.7	138.1	9.0	27.2
			151.7	138.9	13.0	23.0
1820	1870	1770F, 1 hr, OQ + 1100F, 8 hrs, AC	166.8	151.8	7.0	15.0
			165.0	149.5	7.0	15.8

TABLE 1.04214. COMBINED EFFECT OF 0.25% SILICON ADDITION AND FORGE/HEAT TREAT COMBINATIONS ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS, (70).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

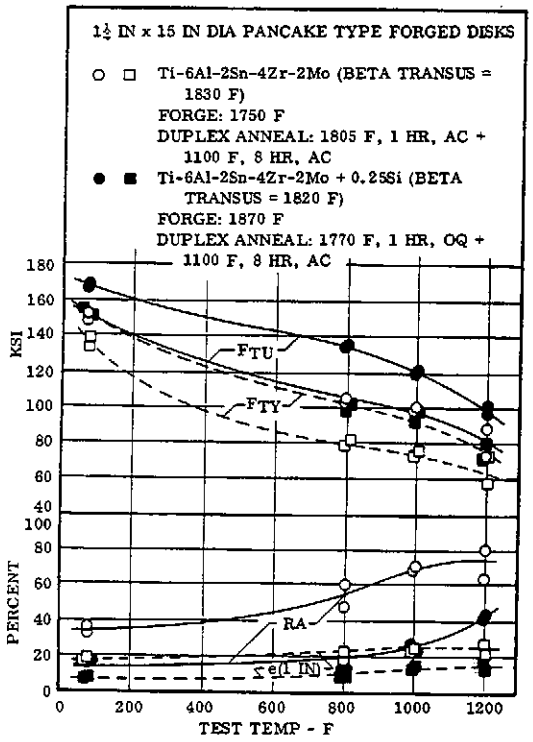


FIG. 1.04215. COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON THE ELEVATED TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS (70)

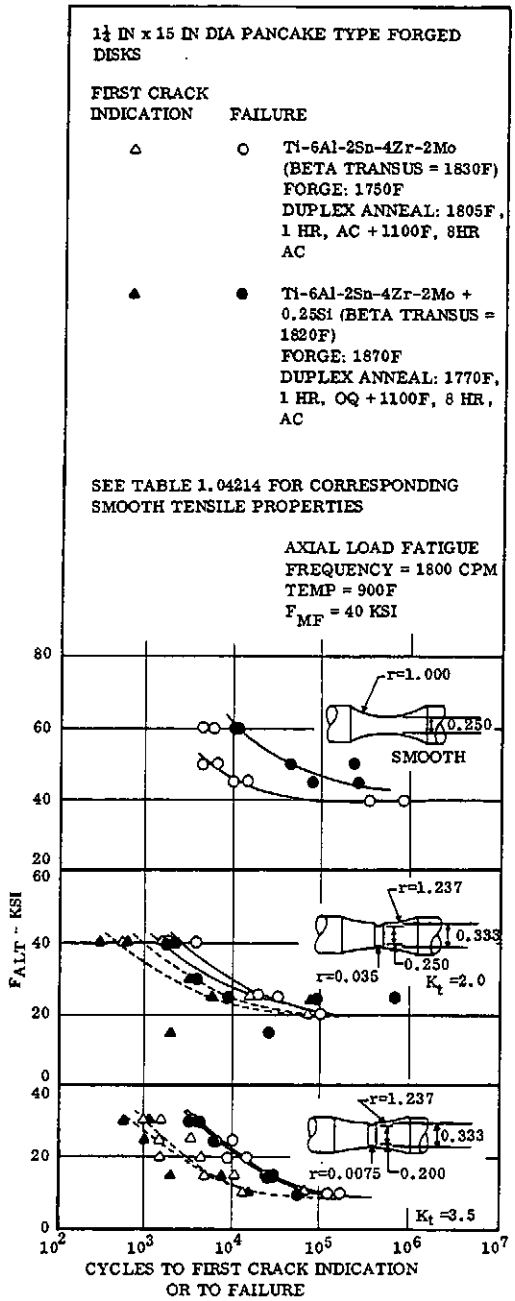


FIG. 1.04216 COMBINED EFFECT OF 0.25 PERCENT SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON 900 F AXIAL LOAD SMOOTH AND MILD NOTCH LOW CYCLE FATIGUE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS (70)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

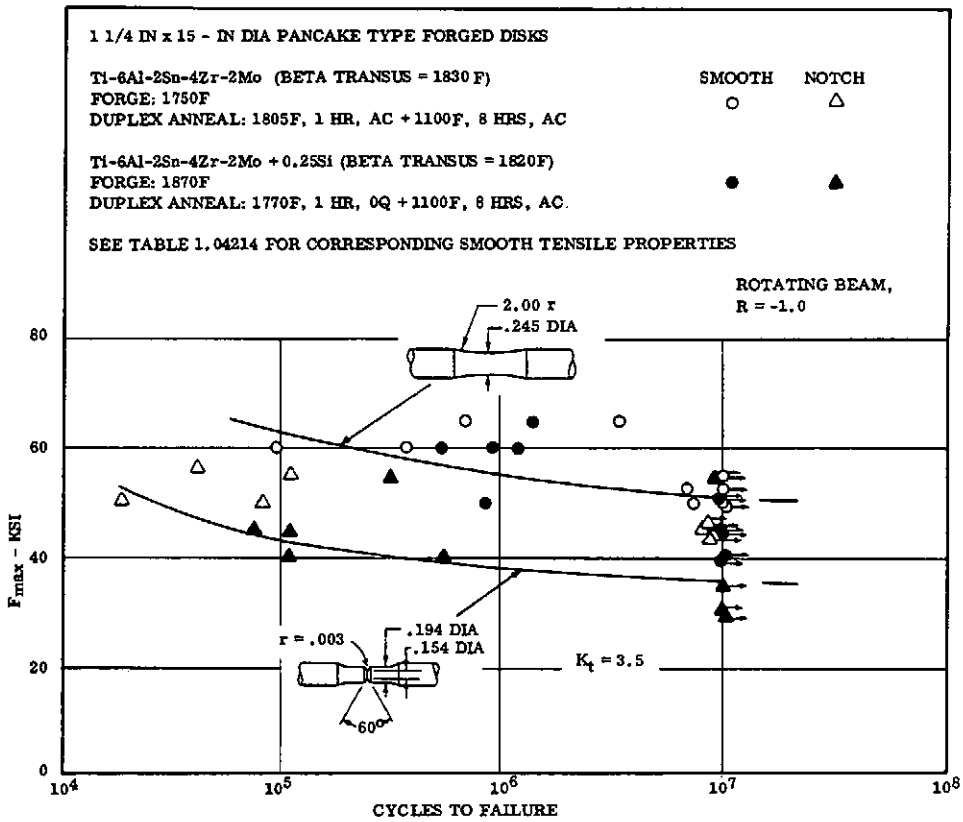


FIG. 1.04217 COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON 900F SMOOTH AND NOTCH FATIGUE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS (70)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

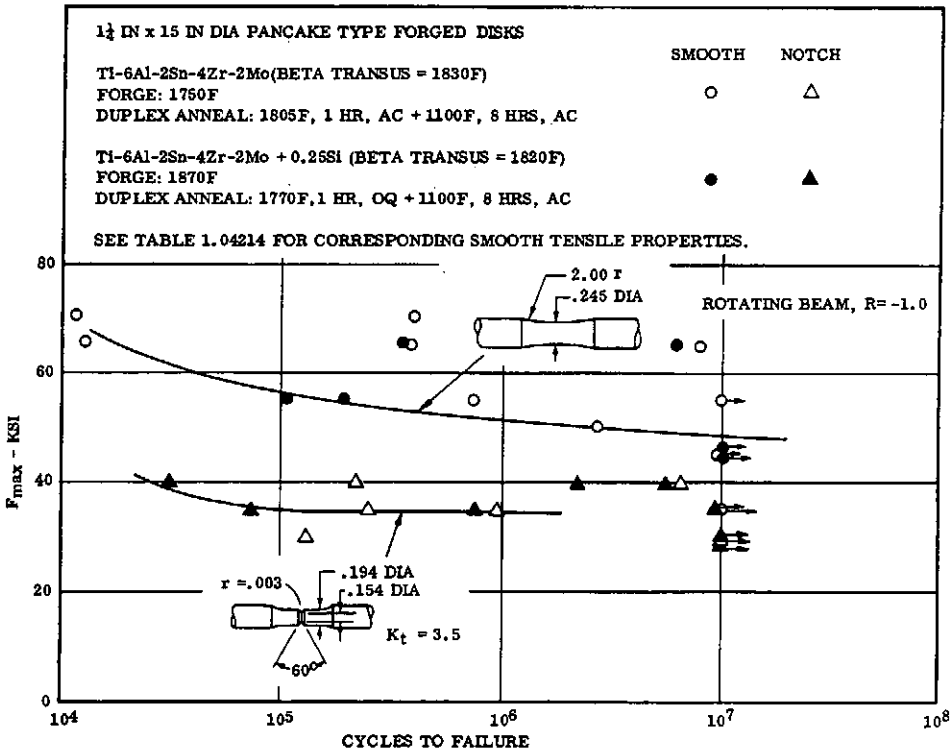


FIG. 1.04218 COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON 1100F SMOOTH AND MILD NOTCH FATIGUE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS. (70)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

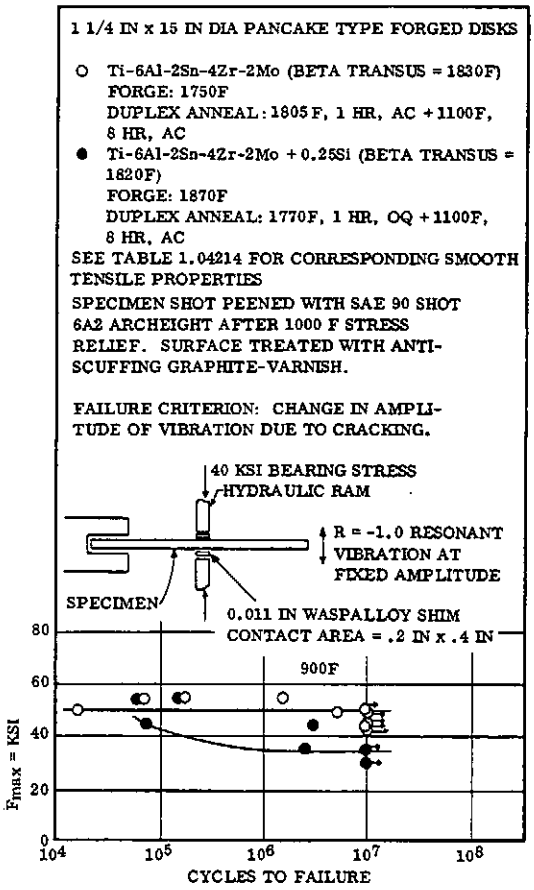
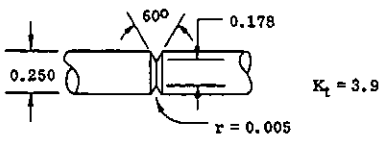


FIG. 1.04219 COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON 900F FRETTING FATIGUE RESISTANCE OF DUPLEX ANNEALED FORGED DISKS. (70)

Form	1¼-in x 15-in dia pancake type forged disks	
Alloy/Condition	RT Notch Stress Rupture	
	Stress at Failure[a] ksi	Time at Failure Stress hr
Ti-6Al-2Sn-4Zr-2Mo (Beta transus = 1830F)		
Forge: 1750F	200	2.3
Duplex Anneal: 1805F, 1 hr, AC + 1100F, 8 hrs, AC	200	2.5
Ti-6Al-2Sn-4Zr-2Mo + 0.25Si (Beta transus = 1820F)		
Forge: 1870F	190	0.1
Duplex Anneal: 1770F, 1 hr, OQ + 1100F, 8 hrs, AC	190	0.6

(a) Stress increased from 160 ksi in 5-ksi increments every 5 hours.



See Table 1.04214 for corresponding smooth tensile properties.

TABLE 1.04220 COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON ROOM TEMPERATURE MILD NOTCH STRESS RUPTURE PROPERTIES OF DUPLEX ANNEALED FORGED DISKS, (70).

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Form			3-in Forged Bar					
Condition[a]			1650F, 1 hr, AC + 1100F, 8 hrs, AC			1750F, 1 hr, AC + 1100F, 8 hrs, AC		
Alloy	150-hr Creep Exposure Temp F	150-hr Creep Exposure Stress ksi	Creep Deformation percent	F_{tu} ksi	F_{ty} ksi	Creep Deformation percent	F_{tu} ksi	F_{ty} ksi
Ti-6Al-2Sn-4Zr-2Mo	900	45	0.10-0.12	141-142	131-132	0.11-0.12	137-138	127-129
Ti-6Al-2Sn-4Zr-3Mo	900	45	0.40-0.52	144-145	132-135	0.27-0.40	142-143	131-133
Ti-6Al-2Sn-4Zr-4Mo	900	45	0.28-0.60	148-150	134-139	0.21-0.23	150-151	134-135
Ti-6Al-2Sn-4Zr-2Mo	1000	25	0.14-0.21	142-145	134-136	0.05-0.12	138-139	130-131
Ti-6Al-2Sn-4Zr-3Mo	1000	25	1.00-1.29	145	135	0.61-1.07	142	131
Ti-6Al-2Sn-4Zr-4Mo	1000	25	0.51-1.12	148-151	137-141	0.25-0.35	150-151	134-135

[a] Duplex annealed as 7-in long specimens.

TABLE 1.04221. EFFECT OF MOLYBDENUM ADDITION AND SOLUTION ANNEALING TEMPERATURE ON STRENGTH AND CREEP RESISTANCE OF DUPLEX ANNEALED FORGED BAR, (85).

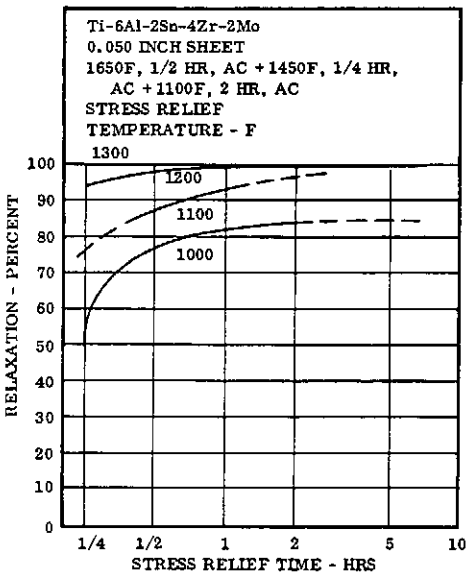


FIG. 1.0531 EFFECT OF STRESS RELIEF TIME AND TEMPERATURE ON RELAXATION OF RESTRAINED BEND SPECIMENS OF TRIPLEX ANNEALED SHEET. (30, p. 23)

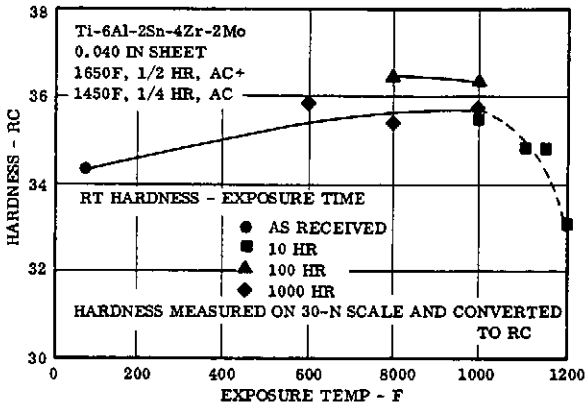


FIG. 1.061 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE HARDNESS OF DUPLEX ANNEALED SHEET. (1, P.268)

Alloy		Ti-6Al-2Sn-4Zr-2Mo							
Form		Castability Casting[1]							
Metal Pour Temp	Mold Preheat Temp-F	Percent Mold Fill[2]							
		Bottom Gated Section Thickness - inch[3]				Top & Bottom Gated, Section Thickness - inch[3]			
		0.250	0.090	0.060	0.030	0.250	0.090	0.060	0.030
High(4)	1000	100	100	20.7	22.4	100	100	100	9.0
Low (5)	1000	100	100	50.7	18.6	100	100	96.0	43.2
High	1500	100	100	58.4	41.5	100	100	76.2	22.8
Low	1500	100	100	70.3	32.4	100	100	100	22.8
High	2000	100	100	100	14.5	100	100	100	20.4
Low	2000	100	100	67.1	23.4	100	100	100	18.2

(1) Induction melted in graphite crucibles and cast into pyrolytic graphite faced silicate bonded molds.
(2) Determined as percent of total section surface.
(3) 0.75-inch wide x 4-inch long bars (see Section 1.083 for description).
(4) Liquidus + 200-350F.
(5) Liquidus + 100-200F.

TABLE 1.085 EFFECT OF METAL POUR TEMPERATURE AND MOLD PREHEAT TEMPERATURE ON MOLD FILL FOR INDUCTION MELTED CASTINGS, (54).

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo		
Form		0.250-inch Dia Cast Tensile Bars[1]		
Condition		Cast + Sandblasted + 1100F, 8 hrs, Rapid FC		
Test Temp F	F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent
RT	141.5	123.7	15.0	19.6
RT	138.9	125.3	11.0	6.2
RT	139.7	122.3	18.0	13.3
RT	139.0	123.1	9.5	13.8
600	96.0	74.3	18.5	27.0
600	90.8	71.7	10.0	17.0
600	94.2	75.1	10.5	16.6
600	92.1	71.3	13.0	23.9

(1) Induction melted in graphite crucibles and cast into pryolytic graphite faced silicate bonded molds. Castings not completely sound - some centerline microshrink or porosity evident.

TABLE 1.086 ROOM TEMPERATURE AND 600F TENSILE PROPERTIES OF INDUCTION MELTED CAST BARS, (54).

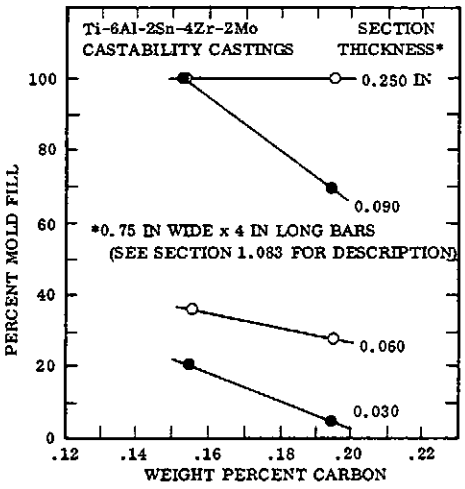


FIG. 1.088. EFFECT OF CARBON CONTENT ON MOLD FILL FOR CASTINGS INDUCTION MELTED IN GRAPHITE CRUCIBLES AND CAST INTO STAINLESS STEEL MOLDS. (54)

Alloy		Ti-6Al-2Sn-4Z4-2Mo		
Form		1/4-inch-Thick Single-Gated Castability Section[1]		
Metal Pour Temp	Mold Preheat Temp F	Surface Carbide Layer inch	Carbide Network inch	Alpha Case inch
High[2]	1000	Trace	None	None
High	1500	0.00012	0.007	0-0.002 intermittent
High	2000	0.00025	0.020	0.005
Low[3]	2000	0.00025	0.0075	0.001-0.0015 intermittent

(1) 0.75-inch wide x 4-inch long bar (see Section 1.083 for description).
(2) Liquidus + 200-350F.
(3) Liquidus + 100-200F.

TABLE 1.087 SURFACE REACTION OF 1/4-INCH-THICK SINGLE-GATED CASTABILITY SECTIONS INDUCTION MELTED IN GRAPHITE CRUCIBLES AND CAST INTO PYROLTYIC GRAPHITE FACED SILICATE BONDED MOLDS, (54).

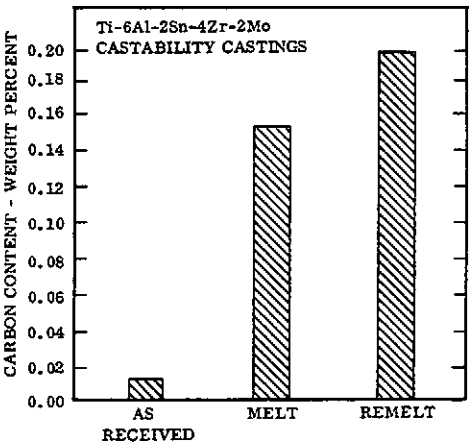


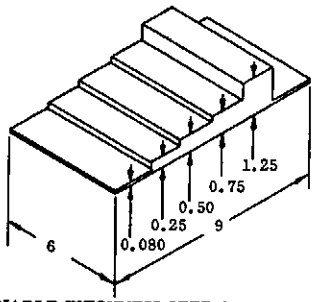
FIG. 1.089 EFFECT OF INDUCTION REMELTING IN GRAPHITE CRUCIBLES ON CARBON CONTENT OF CASTINGS POURED INTO STAINLESS STEEL MOLDS. (54)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo							
Form	Cast(1)							
Casting Conditions					Casting Quality(2)			
Foundary Practice Variable	Mold Temperature	Electrode Diameter	Crucible Size (Capacity)	Melt Size (Weight)	Linear Indications of Surface Imperfections(3)		X-Ray Shrink Indications(4) (Porosity)	Overall Dimensional Shrinkage
	F	in	lb	lb	Visual	Fluorescent Penetrant		in/in
Reference Foundary Conditions	700	5	50	11	31	7	8	0.016
Cold Mold	RT	5	50	12	72	10	101	0.015
Hot Mold	1400	5	50	12	26	6	8	0.014
Smaller Electrode	700	3	50	15	41	5	12	0.016
Smaller Crucible	700	3	25	10	47	9	44	0.017
Larger Melt	700	3	25	>17(5)	82	9	30	0.016

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten lined ceramic molds.
(2) All values average for three castings for each foundary practice variable.
(3) Surface blemishes linearized and expressed as number of one-quarter-inch lengths.
(4) Internal shrinkage in 0.080-inch thick sections. Shrunk areas typically 0.020 to 0.030-inch in length.
(5) Excessive metal splash during pour: melt weight, determined as weight of casting plus pour cup, is conservative.



VARIABLE THICKNESS STEP CASTING

TABLE 1.0810 INFLUENCE OF FOUNDARY PRACTICE (CASTING CONDITIONS) ON NONDESTRUCTIVE TESTING (NDT) QUALITY OF CONSUMABLE ELECTRODE MELTED CASTINGS, (56).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

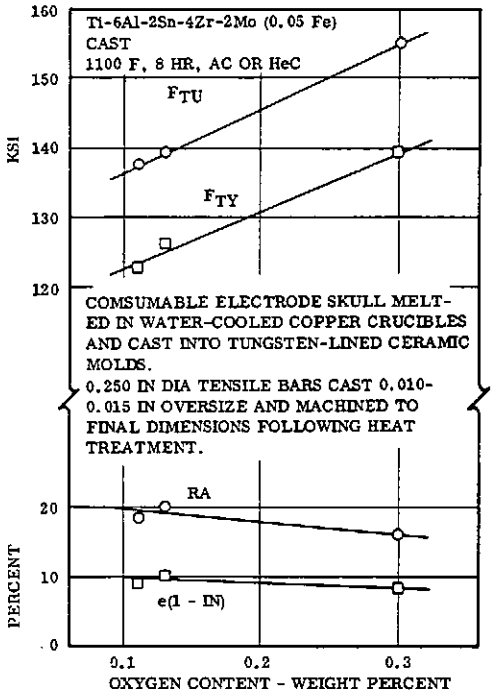


FIG. 1.0811. EFFECT OF OXYGEN CONTENT ON ROOM TEMPERATURE TENSILE PROPERTIES OF CONSUMABLE ELETRODE MELTED CASTINGS. (56)

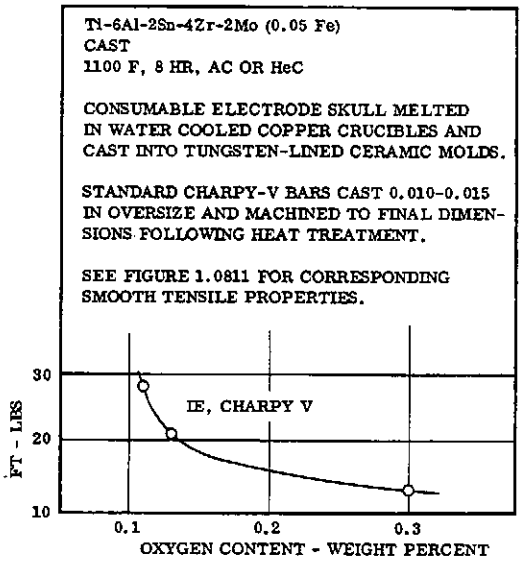


FIG. 1.0813 EFFECT OF OXYGEN CONTENT ON ROOM TEMPERATURE CHARPY-V IMPACT ENERGY FOR COMSUMABLE ELECTRODE MELTED CASTINGS. (56)

Alloy	Ti-6Al-2Sn-4Zr-2Mo (0.05 Fe)	
Form	Cast(1)	
Condition	1100F, 8 hrs, AC or HeC	
Oxygen Content weight percent	F_{ty}(2) ksi	NTS(3) ksi
0.11	123	206.8 215.7 218.1
0.13	126	206.3 211.1 210.4
0.30	139	217.7 223.3 224.1

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) See Figure 1.0811 for balance of smooth tensile properties.
(3) Mild-notch tensile bars cast 0.010-0.015 inch oversize and machined to configuration shown below following heat treatment.

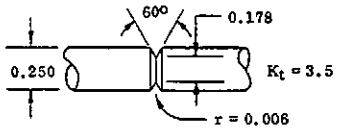


TABLE 1.0812 EFFECT OF OXYGEN CONTENT ON ROOM TEMPERATURE MILD-NOTCH STRENGTH OF CONSUMABLE ELECTRODE MELTED CASTINGS. (56).

Alloy	Ti-6Al-2Sn-4Zr-2Mo (0.05 Fe)	
Form	Cast(1)	
Condition	1100F, 8 hrs, AC or HeC	
Oxygen Content weight percent	RT Mild-Notch Creep Rupture Properties(2)(3)(4)	
	Stress at Failure ksi	Time at Failure Stress hrs
0.11	180	0.9
0.13	170	0.7
0.30	160	0.2

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) Stress increased from 160 ksi in 10 ksi increments every five hours until failure. Least value from three tests reported.
(3) See Figure 1.0811 for corresponding smooth tensile properties.
(4) Mild-notch tensile bars cast 0.010-0.015 inch oversize and machined to configuration shown below following heat treatment.

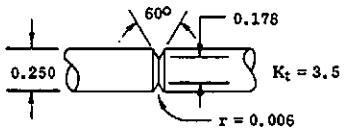


TABLE 1.0814 EFFECT OF OXYGEN CONTENT ON ROOM TEMPERATURE STEP-LOADED MILD-NOTCH CREEP RUPTURE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS, (56).

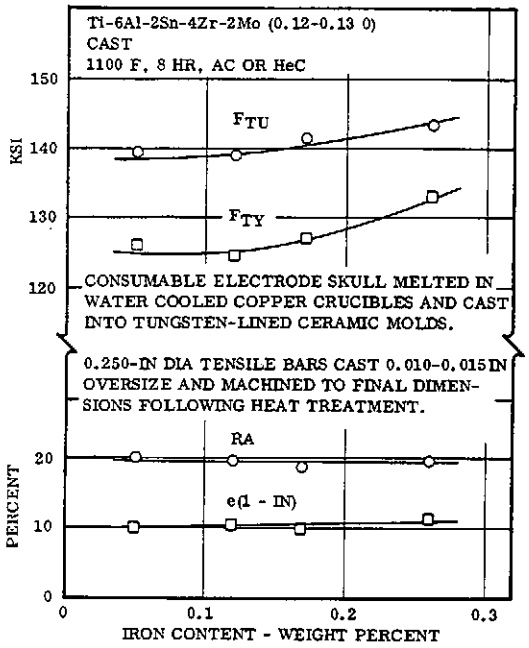


FIG. 1.0815. EFFECT OF IRON CONTENT ON ROOM TEMPERATURE TENSILE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS. (56)

Alloy	Ti-6Al-2Sn-4Zr-2Mo (0.12-0.13 O)	
Form	Cast(1)	
Condition	1100F, 8 hrs, AC or HeC	
Iron Content weight percent	F_{ty}(2) ksi	IE, Charpy-V(3) ft-lbs
0.05	126	21.8 20.8 21.2
0.12	124	27.5 24.0 24.5
0.17	126	24.0 22.5 21.0
0.26	133	19.5 19.5 21.0

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) See Figure 1.0815 for corresponding smooth tensile properties.
(3) Standard Charpy-V bars cast 0.010-0.015 inch oversize and machined to final dimensions following heat treatment.

TABLE 1.0817 EFFECT OF IRON CONTENT ON ROOM TEMPERATURE CHARPY-V IMPACT ENERGY FOR CONSUMABLE ELECTRODE MELTED CASTINGS, (56).

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

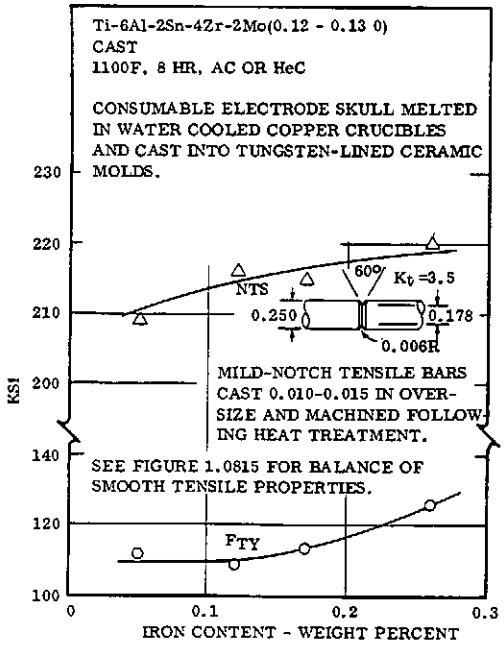


FIG. 1.0816. EFFECT OF IRON CONTENT ON ROOM TEMPERATURE MILD-NOTCH STRENGTH OF CONSUMABLE ELECTRODE MELTED CASTINGS. (56)

Alloy	Ti-6Al-2Sn-4Zr-2Mo (0.12-0.13 O)	
Form	Cast(1)	
Condition	1100F, 8 hrs, AC or HeC	
Iron Content weight percent	RT Mild-Notch Creep Rupture Properties(2)(3)(4)	
	Stress at Failure ksi	Time at Failure Stress hrs
0.05	170	0.7
0.12	180	2.5
0.17	180	1.5
0.26	180	2.5

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) Stress increased from 160 ksi in 10 ksi increments every five hours until failure. Least value from three tests reported.
(3) See Figure 1.0815 for corresponding smooth tensile properties.
(4) Mild-notch tensile bars cast 0.010-0.015 inch oversize and machined to configuration shown below following heat treatment.

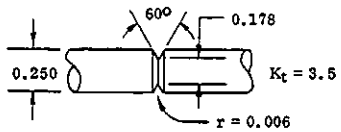


TABLE 1.0818 EFFECT OF IRON CONTENT ON ROOM TEMPERATURE STEP-LOADED MILD-NOTCH CREEP RUPTURE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS, (56).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo			
Form		0.250-inch Dia Tensile Bars			
Condition		Cast(1) + TIG Repair Welded(2) + Heat Treated			
Heat Treatment		RT Tensile Properties(3)			
		F_{tu} ksi	F_{ty} ksi	e(1-in) %	RA %
None	Repair Welded	149.5	127.1	6.8	12.5
	Not Repair Welded	147.2	130.2	9.3	18.8
1650F, 1 hr, HeC + 1100F, 8 hrs, HeC	Repair Welded	150.8	140.5	5.3	16.2
	Not Repair Welded	148.1	133.9	9.7	15.6
1900F, 1 hr + 1650F, 1 hr + 1100F, 4 hrs, HeC	Repair Welded	134.9	122.6	9.2	24.5
	Not Repair Welded	134.0	121.1	10.7	22.2
1900F, 1 hr, HeC + 1100F, 4 hrs, HeC	Repair Welded	145.5	132.5	10.7	18.3
	Not Repair Welded	143.6	131.8	9.0	19.2

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) 50 percent of specimen test cross section machined away and replaced with weld metal.
(3) Each value average of three tests.

TABLE 1.0819 EFFECT OF POST-WELD HEAT TREATMENT ON ROOM TEMPERATURE SMOOTH TENSILE PROPERTIES OF TIG REPAIR WELDED, CONSUMABLE ELECTRODE MELTED CAST SPECIMENS, (56).

Alloy		Ti-6Al-2Sn-4Zr-2Mo				
Form		Cast(1)				
Heat Treatment		F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent	E 10^3 ksi
1100F, 8 hrs, AC	(2)	137.5	123.7	10.5	21.4	
		139.2	130.0	9.0	20.5	
		140.4	123.7	10.0	18.2	
1750F, 1 hr, AC + 1100F, 8 hrs, AC	(2)	146.5	129.7	8.0	21.5	18.4
		142.7	127.6	5.0	13.3	17.2
		144.1	129.4	4.0	8.1	17.1
1900F, 1 hr, WQ + 1100F, 8 hrs, AC	(2)	184.5	178.2	1.0	3.9	
		187.7	(3)	1.0	3.9	
		179.4	179.4	1.0	3.1	
1900F, 1 hr, HeC	(4)(5)	141.2	127.4	7.8	19.3	
+ 1100F, 4 hrs, HeC	(4)(6)	138.8-143.6	125.0-130.5	5.0-12.0	10.9-24.6	

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) 0.250-inch dia tensile bars cast 0.010-0.015 inch oversize and machined to final dimensions following heat treatment.
(3) Failed at less than 0.2 percent indicated strain.
(4) 0.250-inch dia tensile bars machined from three thickest sections of heat treated, variable thickness step castings of the type shown in Table 1.0810.
(5) Average of nine values from three castings.
(6) Range of nine values from three castings.

TABLE 1.0820 ROOM TEMPERATURE TENSILE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS VARIOUSLY HEAT TREATED, (56).

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo	
Form		Cast(1)	
Heat Treatment		F_{ty}(2) ksi	NTS ksi
1100F, 8 hrs, AC	(3)	126	206.3 211.1 210.4
1750F, 1 hr, AC + 1100F, 8 hrs, AC	(3)	129	200.8 205.6 211.5
1900F, 1 hr, WQ + 1100F, 8 hrs, AC	(3)	179	187.2 179.4 174.2
1900F, 1 hr, HeC + 1100F, 4 hrs, HeC	(4)(5)	127	219.8
	(4)(6)		212.0 - 226.9

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) See Table 1.0820 for balance of smooth tensile properties.
(3) Mild notch tensile bars cast 0.010-0.015 inch oversize and machined to configuration shown below following heat treatment.
(4) Mild notch tensile bars of configuration shown below machined from three thickest sections of heat treated, variable thickness step castings of the type shown in Table 1.0810.
(5) Average of nine values from three castings.
(6) Range of nine values from three castings.

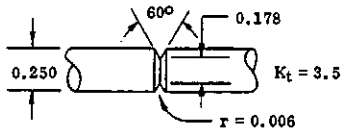


TABLE 1.0821 ROOM TEMPERATURE MILD NOTCH STRENGTH OF CONSUMABLE ELECTRODE MELTED CASTINGS VARIOUSLY HEAT TREATED. (56).

Alloy		Ti-6Al-2Sn-4Zr-2Mo	
Form		Cast(1)	
		RT Mild-Notch Creep Rupture Properties(2)(3)	
Heat Treatment		Stress at Failure ksi	Time at Failure Stress hrs
1100F, 8 hrs, AC	(4)	170	0.7
1750F, 1 hr, AC + 1100F, 8 hrs, AC	(4)	200	1.6
1900F, 1 hr, WQ + 1100F, 8 hrs, AC	(4)	160	Broke on loading
1900F, 1 hr, HeC + 1100F, 4 hrs, HeC	(5)	170	4.7

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) Stress increased from 160 ksi in 10 ksi increments every five hours until failure.
(3) See Table 1.0820 for corresponding smooth tensile properties.
(4) Mild-notch tensile bars cast 0.010-0.015 inch oversize and machined to configuration shown below following heat treatment. Least value from three tests reported.
(5) Mild-notch tensile bars of configuration shown below machined from three thickest sections of heat treated, variable thickness step castings of the type shown in Table 1.0810. Least value from nine tests reported.

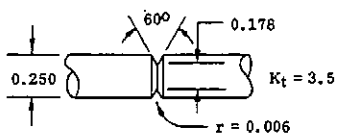


TABLE 1.0822 ROOM TEMPERATURE STEP-LOADED MILD-NOTCH CREEP RUPTURE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS VARIOUSLY HEAT TREATED. (56).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo
Form		Cast(1)
Heat Treatment		IE, Charpy-V at RT(2) ft-lb
1100F, 8 hrs, AC	(3)	22 21 21
1750F, 1 hr, AC + 1100F, 8 hrs, AC	(3)	28 25 26
1900F, 1 hr, WQ + 1100F, 8 hrs, AC	(3)	6 6 6
1900F, 1 hr, HeC + 1100F, 4 hrs, HeC	(4)(5)	21
	(4)(6)	17 - 26

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten-lined ceramic molds.
(2) See Table 1.0820 for corresponding smooth tensile properties.
(3) Standard Charpy-V bars cast 0.010-0.015 inch oversize and machined to final dimensions following heat treatment.
(4) Standard Charpy-V bars machined from three thickest sections of heat treated, variable thickness step castings of the type shown in Table 1.0810.
(5) Average of nine values from three castings.
(6) Range of nine values from three castings.

TABLE 1.0823 ROOM TEMPERATURE CHARPY-V IMPACT ENERGY FOR CONSUMABLE ELECTRODE MELTED CASTINGS VARIOUSLY HEAT TREATED, (56).

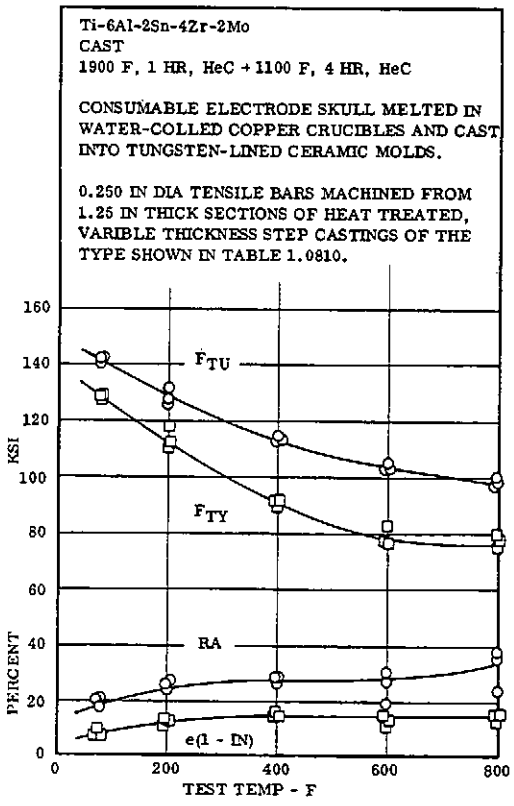


FIG. 1.0824. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS. (56)

Alloy		Ti-6Al-2Sn-4Zr-2Mo			
Form		Cast(1)			
Condition		1900F, 1 hr, HeC + 1100F, 4 hrs, HeC			
Exposure Conditions(2)	Deformation %	Subsequent RT Tensile Properties(3)			
		F_{tu} ksi	F_{ty} ksi	e(1-in) %	RA %
Unexposed(4)	-------	140-142	126-129	7-9	17-21
1000F, 35 ksi, 100hrs(5)	0.24 - 0.47	144-146	128-133	6-10	15-21

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten lined ceramic molds.
(2) 0.250-inch dia tensile bars machined from the three thickest sections of heat treated, variable thickness step castings of the type shown in Table 1.0810
(3) Specimen diameter reduced 0.020 inch following exposure, prior to tensile testing.
(4) Nine tests.
(5) Three tests.

TABLE 1.0825 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS, (56).

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy			Ti-6Al-2Sn-4Zr-2Mo	
Form			Cast(1)	
Condition			1900F, 1 hr, HeC + 1100F, 4 hrs, HeC	
Creep Exposure			Cast Section Thickness	Creep Deformation(2)
Temp F	Stress ksi	Time hrs	in	%
1000	35	100	1.25	0.24
1000	35	100	0.75	0.28
1000	35	100	0.50	0.47

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten lined ceramic molds.
(2) 0.250-inch dia tensile bars machined from each of the three thickest sections of a heat treated, variable thickness step casting of the type shown in Table 1.0810.

TABLE 1.0826 EFFECT OF CAST SECTION THICKNESS ON THE CREEP DEFORMATION OF A CONSUMABLE ELECTRODE MELTED CASTING, (56).

Alloy						Ti-6Al-2Sn-4Zr-2Mo			
Form						Cast(1)			
Condition						1900F, 1 hr, HeC + 1100F, 4 hrs, HeC			
Exposure Conditions(2)						Subsequent RT Tensile Properties			
Temp F	Stress ksi	Time hrs	Medium	Deformation percent		F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent
--- Unexposed ---					(3)	140-142	126-12	7-9	17-21
1000	35	100	Air	0.24-0.47	(4)(5)	144-146	128-133	6-10	15-21
1000	35	100	Salt(6)	0.32	(7)	106	105	129	2.4
800	35	100	Salt(6)	0.00		112	112	3.0	7.8
600	35	100	Salt(6)	0.00		139	123	10.0	14.5

(1) Consumable electrode skull melted in water-cooled copper crucibles and cast into tungsten lined ceramic molds.
(2) 0.250-inch dia tensile bars machined from the three thickest sections of heat treated, variable thickness step castings of the type shown in Table 1.0810.
(3) Nine tests.
(4) Three tests.
(5) Specimen diameter reduced 0.020 inch following exposure, prior to tensile testing.
(6) ASTM D1141-52 (Reapproved 1965) substitute ocean water.
(7) Numerous post-exposure zyglo indications.

TABLE 1.0827 EFFECT OF 100-HOUR EXPOSURE UNDER LOAD TO HOT SOLID SALT ON SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS, (56).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

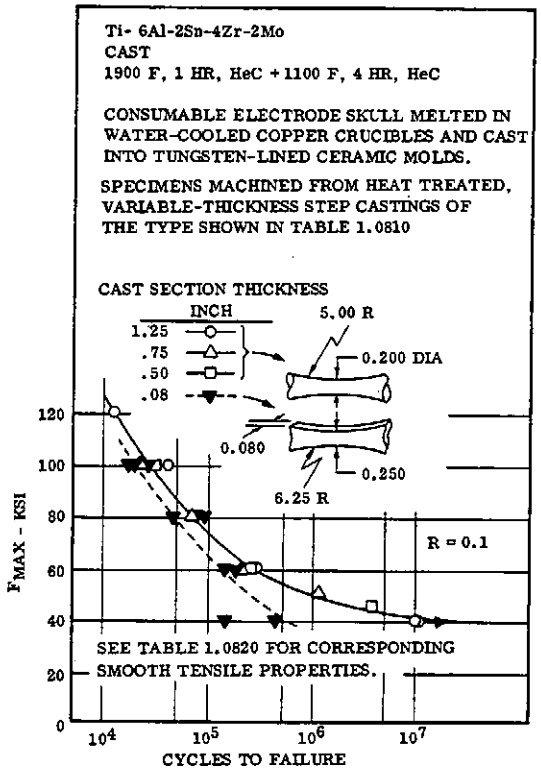


FIG. 1.0828 EFFECT OF CAST SECTION THICKNESS ON THE FATIGUE PROPERTIES OF CONSUMABLE ELECTRODE MELTED CASTINGS. (56)

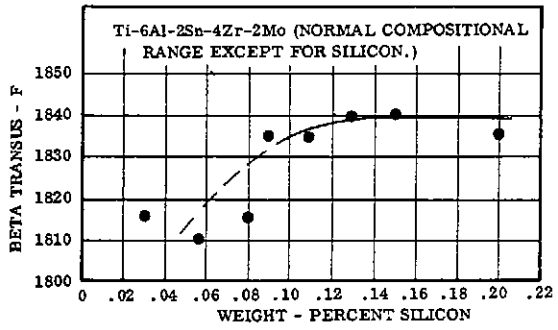


FIG. 2.0121. EFFECT OF SILICON CONTENT ON BETA TRANSUS TEMPERATURE (78)

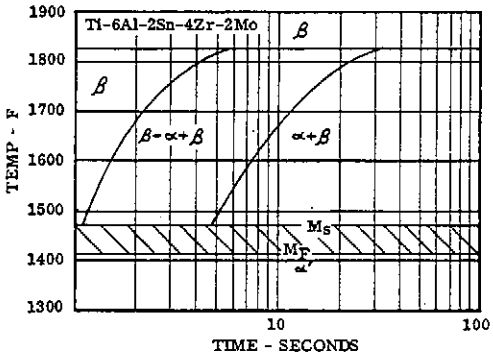


FIG. 2.0122 ISOTHERMAL TIME-TEMPERATURE-TRANSFORMATION (TTT) DIAGRAM FOR Ti-6Al-2Sn-4Zr-2Mo, (7, p. 28)

Alloy	Ti-6Al-2Sn-4Zr-2Mo[a]	
Temperature - F	Solidus (b)(d)	Liquidus (c)(d)
Range	2860 - 2935	3080 - 3160
Average	2890	3120

(a) Composition of melting range sample:

Al	Sn	Zr	Mo	Fe	O	N	H	C	Ti
6.2	2.0	4.2	1.8	0.06	0.124	0.008	0.0052	0.02	Bal.

(b) Four determinations
(c) Two determinations
(d) Temperature measurement accuracy, ± 35F. Some diffusion of support tray material (Nb) into sample may have caused slight elevation of solidus and liquidus temperatures.

TABLE 2.011 MELTING RANGE, (54).

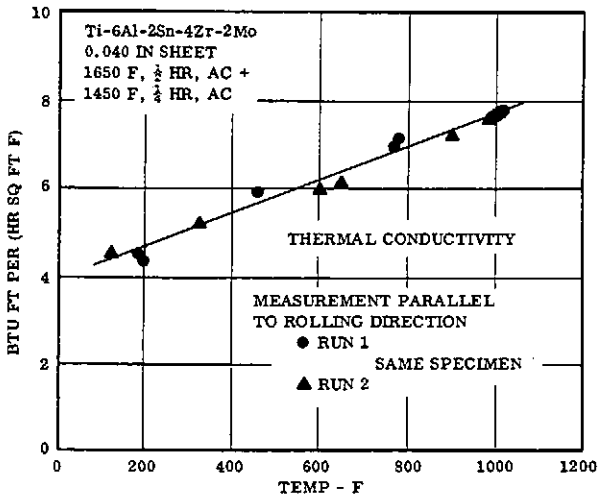


FIG. 2.0131 THERMAL CONDUCTIVITY OF DUPLEX ANNEALED SHEET. (1, P. 319)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

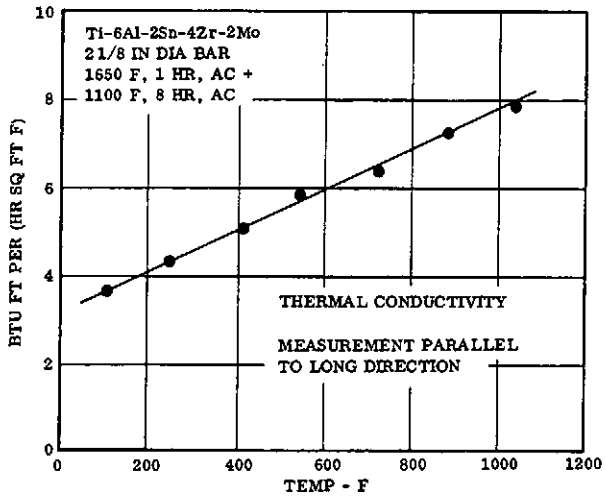


FIG. 2.0132 THERMAL CONDUCTIVITY OF DUPLEX ANNEALED BAR. (6, P.9)

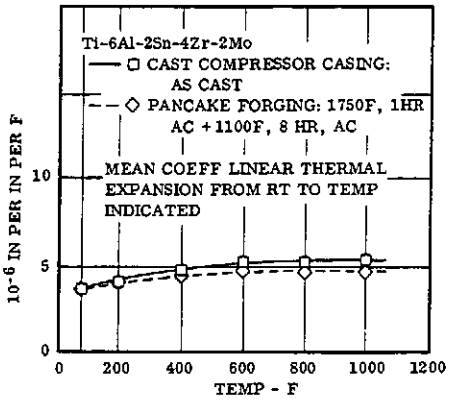


FIG. 2.0143. THERMAL EXPANSION FOR CAST COMPRESSOR CASING AND DUPLEX ANNEALED PANCAKE FORGING. (83)

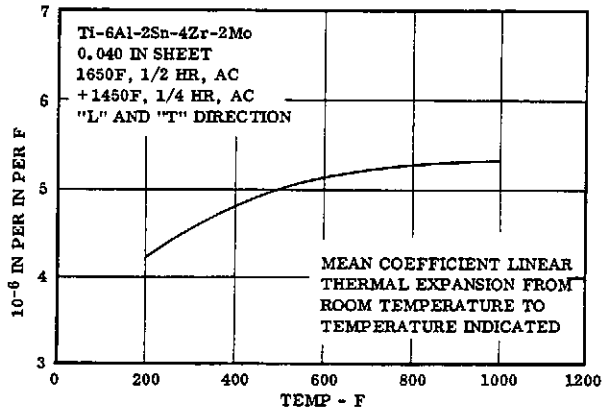


FIG. 2.0141 THERMAL EXPANSION FOR DUPLEX ANNEALED SHEET (1, PP.326-327)

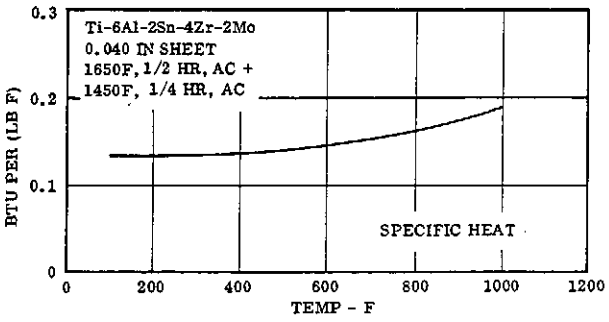


FIG. 2.0151 SPECIFIC HEAT FOR DUPLEX ANNEALED SHEET. (1, P.217)

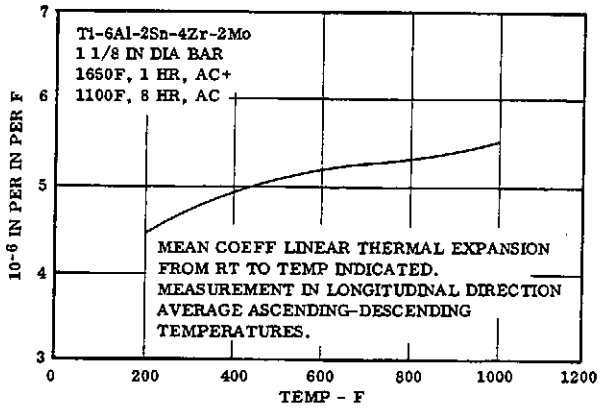


FIG. 2.0142 THERMAL EXPANSION FOR DUPLEX ANNEALED BAR (6, P.10)

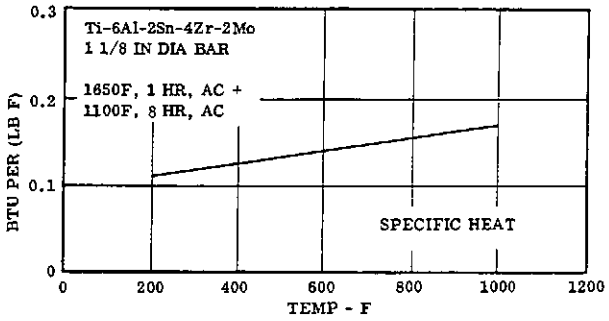


FIG. 2.0152 SPECIFIC HEAT FOR DUPLEX ANNEALED BAR (6, P.8)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

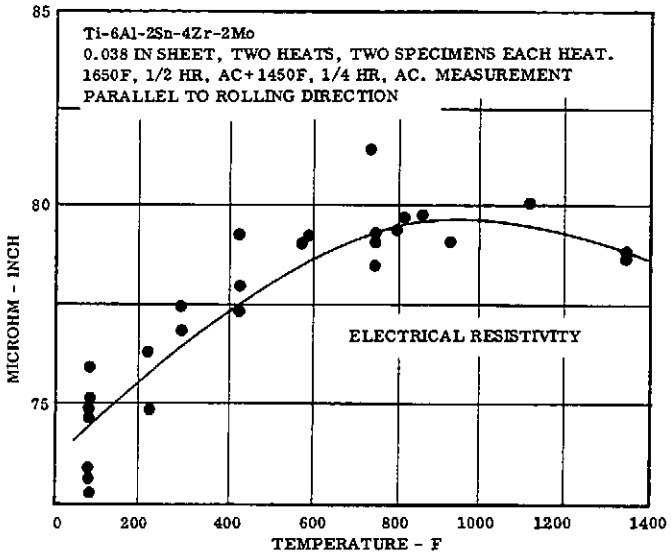


FIG. 2.0221 ELECTRICAL RESISTIVITY OF DUPLEX ANNEALED SHEET. (6, P.12)

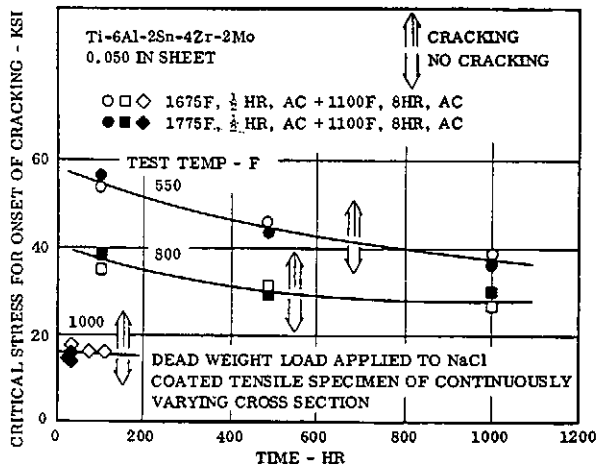


FIG. 2.0321. HOT SALT STRESS CORROSION CRACKING CHARACTERISTICS OF DUPLEX ANNEALED SHEET AT 550, 800, AND 1000 F. (7, p. 68)

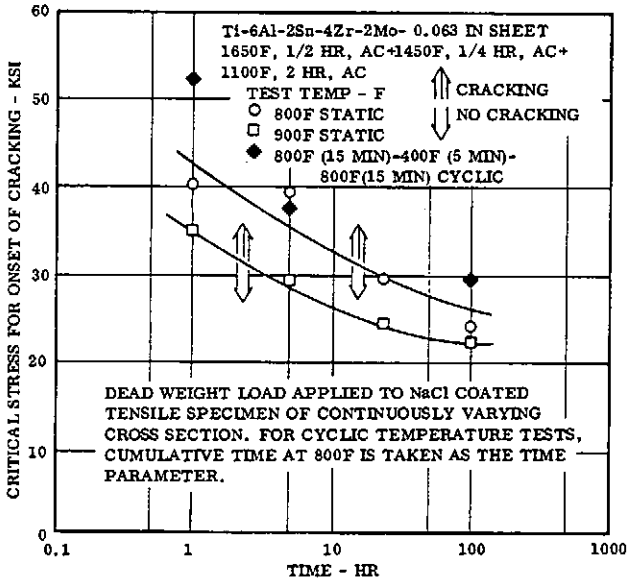
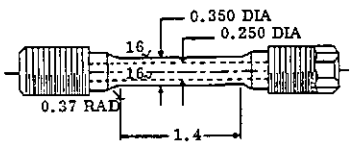


FIG. 2.0322 SHORT-TIME HOT-SALT STRESS CORROSION CRACKING CHARACTERISTICS OF TRIPLEX ANNEALED SHEET SUBJECTED TO STATIC OR CYCLIC EXPOSURE TEMPERATURES. (8, P.15)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Ti-6Al-2Sn-4Zr-2Mo
3/4 IN DIA BAR
1775 F, 1 HR, AC + 1100F, 8 HR, AC



TUBULAR TEST SPECIMAN: UNIFORM 0.6 MG/IN^2 SALT DEPOSIT PRODUCED BY EXPOSING CHEMICALLY-MILLED (APPROX. 0.001 IN METAL REMOVED) SPECIMEN BORE FOR APPROX. 1 HR, WITHOUT APPLIED STRESS TO 400F AIR WITH 40PPB NaCl AT 1000 FT/SEC VELOCITY, 30 PSIA PRESSURE AND -120F DEWPOINT.

EXPOSURE ENVIRONMENT: STATIC AIR AT AMBIENT LABORATORY PRESSURE AND HUMIDITY.

AFTER EXPOSURE, SPECIMENS TENSILE TESTED AT RT AT CONSTANT 0.005 IN/MIN TEST MACHINE CROSSHEAD SPEED.

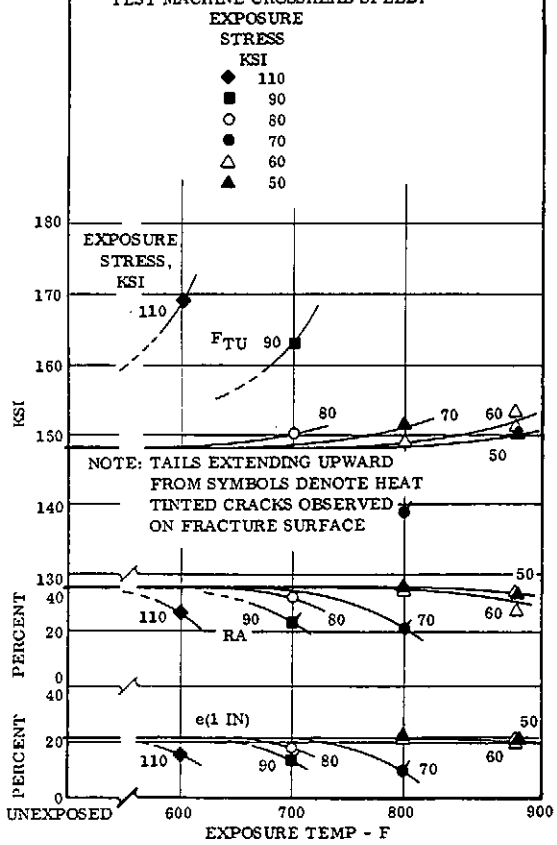
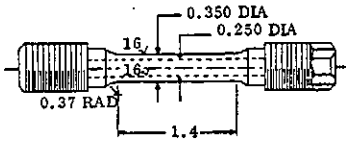


FIG. 2.03210 EFFECT OF 100-HR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD IN A LABORATORY ENVIRONMENT ON SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF NaCl-COATED(AERSOL DEPOSIT ON HOT SURFACE) CHEMICALLY-MILLED TUBULAR SPECIMENS FROM DUPLEX ANNEALED BAR. (57)

Ti-6Al-2Sn-4Zr-2Mo
3/4 IN DIA BAR
MILL ANNEALED 1650F, 1 HR, AC



TUBULAR TEST SPECIMEN: UNIFORM 0.6 MG/IN^2 SALT DEPOSIT PRODUCED BY EXPOSING AS-MACHINED OR CHEMICALLY-MILLED (APPROX. 0.001 IN METAL REMOVED) SPECIMEN BORE FOR APPROX. 1 HR, WITHOUT APPLIED STRESS, TO 400F AIR WITH 40 PPB NaCl AT 1000 FT/SEC VELOCITY, 30 PSIA PRESSURE AND -120F DEWPOINT.

EXPOSURE ENVIRONMENT: STATIC AIR AT AMBIENT LABORATORY PRESSURE AND HUMIDITY, OR DYNAMIC AIR AT 1100 FT/SEC, 30 PSIA AND -120F DEWPOINT.

AFTER EXPOSURE, SPECIMENS TENSILE TESTED AT RT AT CONSTANT 0.005 IN/MIN TEST MACHINE CROSSHEAD SPEED.

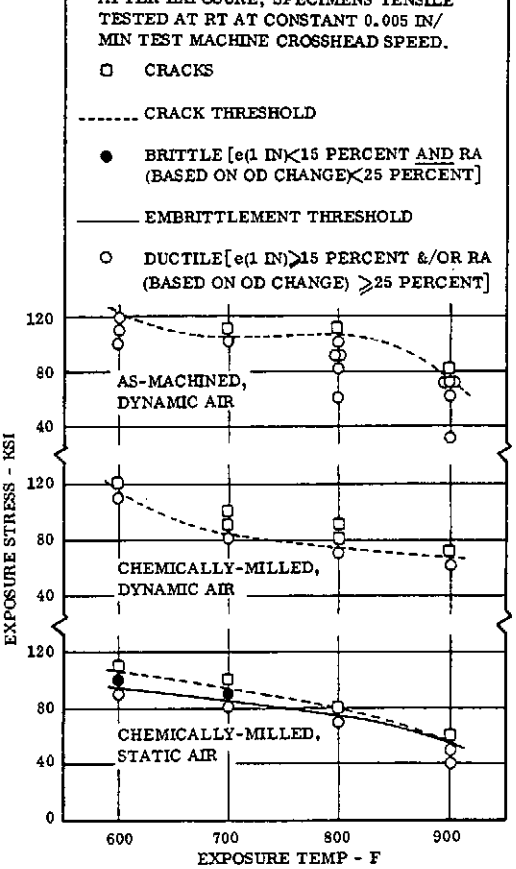
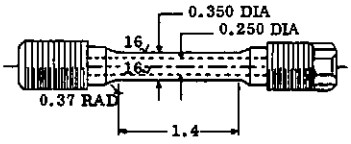


FIG. 2.0324 100-HR EMBRITTLEMENT AND CRACK THRESHOLD CURVES FOR NaCl-COATED (AERSOL DEPOSIT ON HOT SURFACE) AS-MACHINED OR CHEMICALLY-MILLED TUBULAR SPECIMENS (FROM MILL ANNEALED BAR) EXPOSED TO ELEVATED TEMPERATURE WITH LOAD IN EITHER A LABORATORY OR SIMULATED AIRCRAFT TURBINE ENGINE COMPRESSOR ENVIRONMENT AND SUBSEQUENTLY TENSILE TESTED AT ROOM TEMPERATURE. (57)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Ti-6Al-2Sn-4Zr-2Mo
3/4 IN DIA BAR
1775F, 1 HR, AC + 1100F, 8 HR, AC



TUBULAR TEST SPECIMEN: UNIFORM 0.6 MG/IN^2 SALT DEPOSIT PRODUCED BY EXPOSING AS-MACHINED OR CHEMICALLY-MILLED (APPROX. 0.001 IN METAL REMOVED) SPECIMEN BORE FOR APPROX. 1 HR, WITHOUT APPLIED STRESS, TO 400F AIR WITH 40 PPB NaCl AT 1000 FT/SEC VELOCITY, 30 PSIA PRESSURE AND -120F DEWPOINT.

EXPOSURE ENVIRONMENT: STATIC AIR AT AMBIENT LABORATORY PRESSURE AND HUMIDITY, OR DYNAMIC AIR AT 1100 FT/SEC, 30 PSIA AND -120F DEWPOINT.

AFTER EXPOSURE, SPECIMENS TENSILE TESTED AT RT AT CONSTANT 0.005 IN/MIN TEST MACHINE CROSSHEAD SPEED.

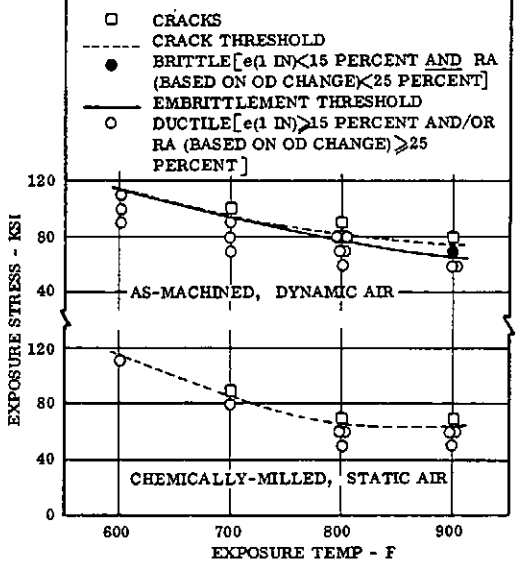
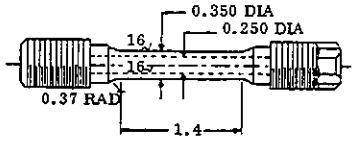


FIG. 2.0325 100-HR EMBRITTLEMENT AND CRACK THRESHOLD CURVES FOR NaCl-COATED (AERSOL DEPOSIT ON HOT SURFACE) AS-MACHINED OR CHEMICALLY-MILLED TUBULAR SPECIMENS (FROM DUPLEX ANNEALED BAR) EXPOSED TO ELEVATED TEMPERATURE WITH LOAD IN EITHER A LABORATORY OR SIMULATED AIRCRAFT TURBINE ENGINE COMPRESSOR ENVIRONMENT AND SUBSEQUENTLY TENSILE TESTED AT ROOM TEMPERATURE (57)

Ti-6Al-2Sn-4Zr-2Mo
3/4 IN DIA BAR
1775 F, 1 HR, AC + 1100F, 8 HR, AC



TUBULAR TEST SPECIMAN: UNIFORM 0.6 MG/IN^2 SALT DEPOSIT PRODUCED BY EXPOSING CHEMICALLY-MILLED (APPROX. 0.001 IN METAL REMOVED) SPECIMEN BORE FOR APPROX. 1 HR, WITHOUT APPLIED STRESS, TO 400F AIR WITH 40PPB NaCl AT 1000 FT/SEC VELOCITY, 30 PSIA PRESSURE AND -120F DEWPOINT.

EXPOSURE ENVIRONMENT: STATIC AIR AT AMBIENT LABORATORY PRESSURE AND HUMIDITY.

AFTER EXPOSURE, SPECIMENS TENSILE TESTED AT RT AT CONSTANT 0.005 IN/MIN TEST MACHINE CROSSHEAD SPEED.

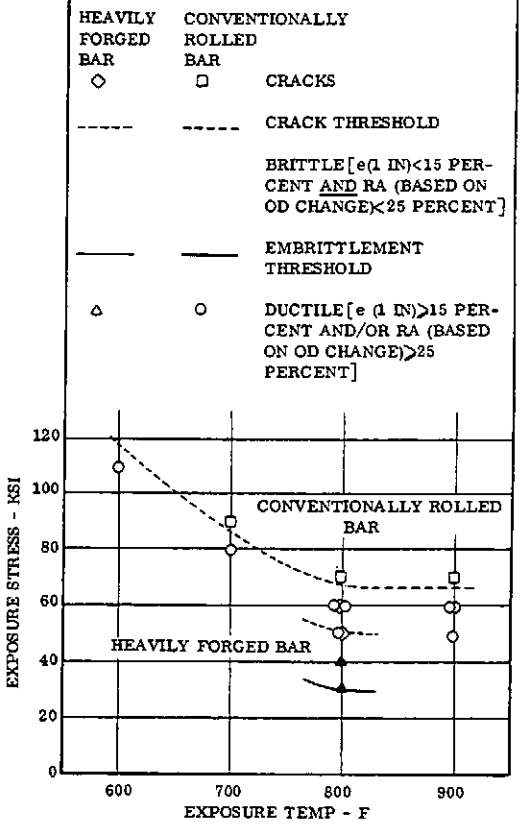


FIG. 2.0326 EFFECT OF ALLOY PROCESSING ON 100-HR EMBRITTLEMENT AND CRACK THRESHOLD CURVES FOR NaCl-COATED (AERSOL DEPOSIT ON HOT SURFACE) CHEMICALLY-MILLED TUBULAR SPECIMENS (FROM DUPLEX ANNEALED BAR) EXPOSED TO ELEVATED TEMPERATURE WITH LOAD IN A LABORATORY ENVIRONMENT AND SUBSEQUENTLY TENSILE TESTED AT ROOM TEMPERATURE (57)(58)

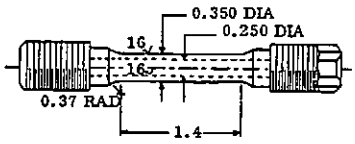
Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Ti-6Al-2Sn-4Zr-2Mo

$\frac{3}{4}$ IN DIA BAR

MILL ANNEALED 1650 F, 1 HR, AC



TUBULAR TEST SPECIMEN: UNIFORM 0.6 MG/IN^2 SALT DEPOSIT PRODUCED BY EXPOSING AS-MACHINED SPECIMEN BORE FOR APPROX. 1 HR, WITHOUT APPLIED STRESS, TO 400 F AIR WITH 40 PPB NaCl AT 1000 FT/SEC VELOCITY, 30 PSIA PRESSURE AND -120 F DEWPOINT.

EXPOSURE ENVIRONMENT: DYNAMIC AIR AT 1100 FT/SEC, 30 PSIA AND -120 F DEW POINT.

AFTER EXPOSURE, SPECIMENS TENSILE TESTED AT RT AT CONSTANT 0.005 IN/MIN TEST MACHINE CROSSHEAD SPEED.

EXPOSURE STRESS - KSI
120
110
100
90
80
70
60

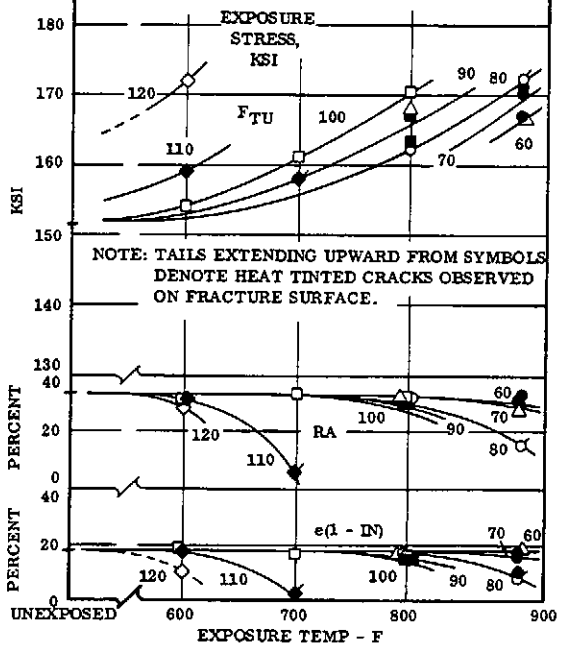
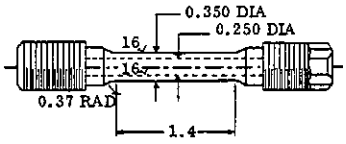


FIG. 2.0327. EFFECT OF 100-HR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD IN A SIMULATED AIRCRAFT TURBINE ENGINE COMPRESSOR ENVIRONMENT ON SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF NaCl-COATED(AERSOL DEPOSIT ON HOT SURFACE) AS-MACHINED TUBULAR SPECIMENS FROM MILL ANNEALED BAR. (57)

Ti-6Al-2Sn-4Zr-2Mo
3/4 IN DIA BAR
MILL ANNEALED 1650 F, 1 HR, AC



TUBULAR TEST SPECIMEN: UNIFORM 0.6 MG/IN^2 SALT DEPOSIT PRODUCED BY EXPOSING CHEMICALLY-MILLED (APPROX. 0.001 IN METAL REMOVED) SPECIMEN BORE FOR APPROX. 1 HR, WITHOUT APPLIED STRESS, TO 400F AIR WITH 40 PPB NaCl AT 1000FT/SEC VELOCITY, 30 PSIA PRESSURE AND -120F DEWPOINT.

EXPOSURE ENVIRONMENT: STATIC AIR AT AMBIENT LABORATORY PRESSURE AND HUMIDITY, OR DYNAMIC AIR AT 1100 FT/SEC, 30 PSIA AND -120F DEWPOINT.

AFTER EXPOSURE, SPECIMENS TENSILE TESTED AT RT AT CONSTANT 0.005 IN/MIN TEST MACHINE CROSSHEAD SPEED.

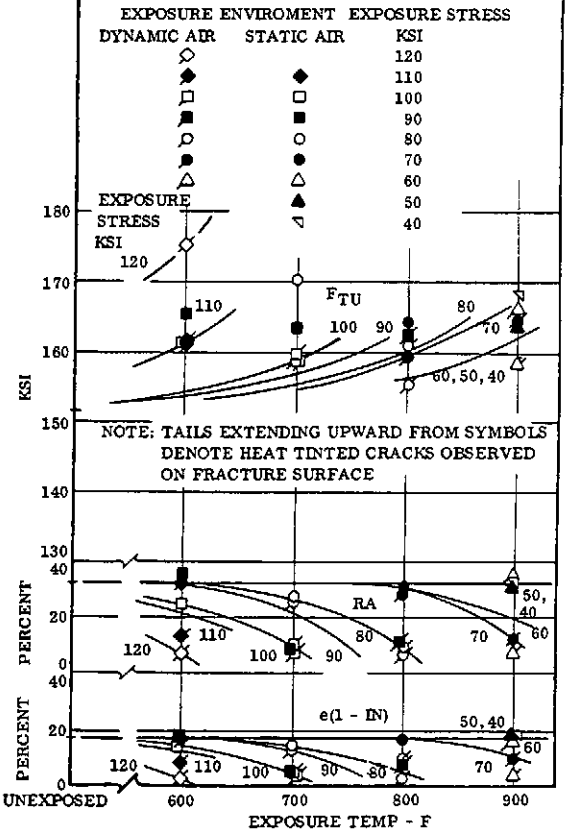


FIG. 2.0328. EFFECT OF 100-HR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD IN EITHER A LABORATORY OR SIMULATED AIRCRAFT TURBINE ENGINE COMPRESSOR ENVIRONMENT ON SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF NaCl-COATED (AERSOL DEPOSIT ON HOT SURFACE) CHEMICALLY-MILLED TUBULAR SPECIMENS FROM MILL ANNEALED BAR. (57)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

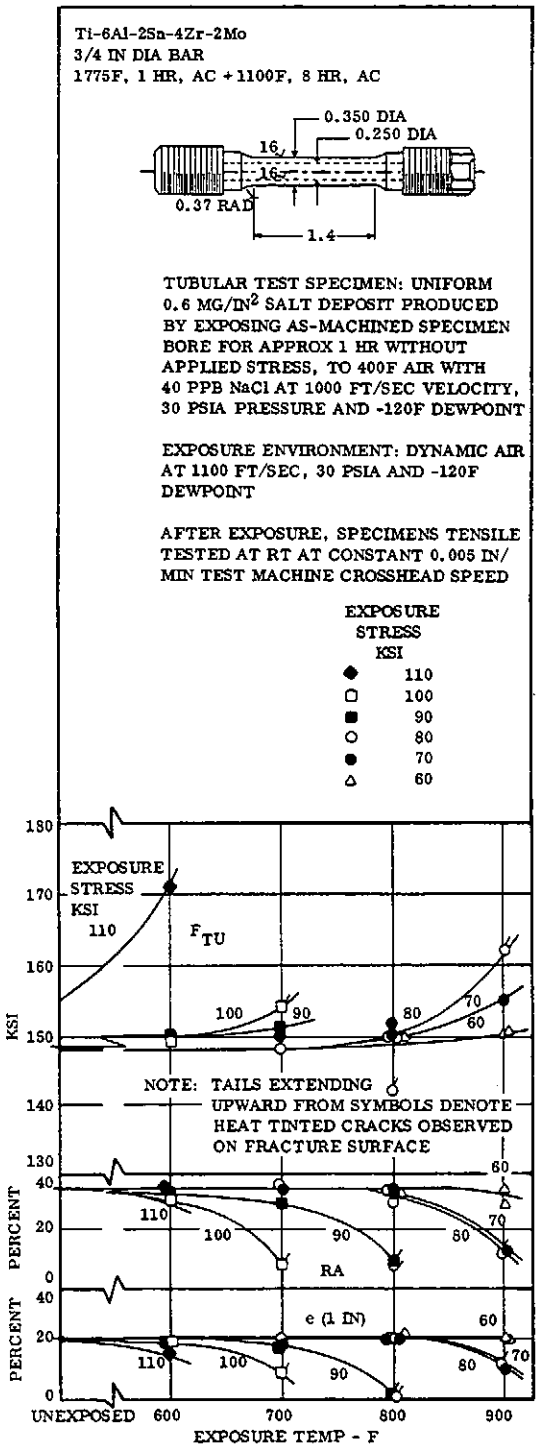


FIG. 2.0329 EFFECT OF 100 HR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD IN A SIMULATED AIRCRAFT TURBINE ENGINE COMPRESSOR ENVIRONMENT ON SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF NaCl COATED (AERSOL DEPOSIT ON HOT SURFACE) AS-MACHINED TUBULAR SPECIMENS FROM DUPLEX ANNEALED BAR (57)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo				
Form	Compressor Wheel Forging[a], 20 in dia				
Condition	Duplex Annealed				
100-Hr NaCl Exposure	Subsequent R.T. Tensile Properties				
Temp F / Stress ksi	F_{tu} ksi	F_{ty} ksi	e, percent	RA percent	Cracking[b]
1750 F, 1-Hr, WQ + 1100 F, 8-Hr, AC					
— None —	165	149	14	40	--
650 / 40	163	149	11	36	No
650 / 50	162	148	11	34	No
800 / 32	161	147	13	39	No
800 / 42	161	147	3	5[c]	Yes
1000 / 21	164	152	5	10	Yes
1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC					
— None —	141	129	17	36	--
650 / 60	Failed during exposure after 81 - Hrs				--
1000 / 11	138	128	16	40	No

[a] 0.250-in dia tensile specimens from axial wheel direction.
[b] Observed after tensile testing with aid of 100x optics.
[c] Broke outside gage length.

TABLE 2.03211 EFFECT OF 100-HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON STRESS CORROSION CRACKING AND SUBSEQUENT ROOM TEMPERATURE TENSILE PROPERTIES OF NaCl-COATED SPECIMENS FROM DUPLEX ANNEALED COMPRESSOR WHEEL FORGING (2, p. 20)(7, p. 67)

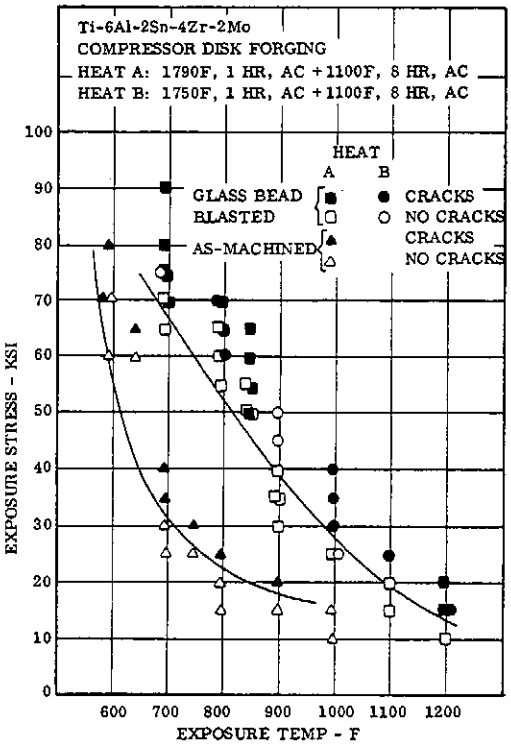


FIG. 2.03212 EFFECT OF GLASS BEAD BLASTING ON 100 HR HOT-SALT STRESS CORROSION CRACKING CHARACTERISTICS OF DUPLEX ANNEALED COMPRESSOR DISC FORGING. (68)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

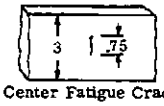
Form	1½-in x 15-in dia pancake type forged disks				
Condition	Duplex Annealed				
900F, 150-Hr NaCl Exposure Stress - ksi	Subsequent RT Tensile Properties(1) F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent	Remarks
	Ti-6Al-2Sn-4Zr-2Mo(2)				
Unexposed	147.0	133.5	16.0	35.6	
Unexposed	150.0	137.9	16.5	33.7	
10	145.3	137.3	6.7	13.4	No stress corrosion observed. Circumferential microcracks along gage length.
10	140.3	133.7	4.7	8.1	
15	140.9	133.9	9.3	17.1	
15	140.1	132.5	9.3	12.0	
20	140.5	133.7	3.3	10.2	Stress corrosion observed.
20	Ruptured 83.2-Hrs				Stress corrosion observed.
	Ti-6Al-2Sn-4Zr-2Mo + 0.25Si(3)				
Unexposed	165.0	149.5	7.0	15.8	
Unexposed	166.8	151.8	7.0	15.0	
10	160.2	157.0	1.3	3.8	No stress corrosion.
10	138.2	-----	---	---	Stress corrosion failure.
15	178.8	172.3	2.7	7.0	No stress corrosion observed.
15	167.3	158.6	4.0	8.2	No stress corrosion observed.
20	78.0	-----	---	---	Stress corrosion observed.
20		-----	---	---	Stress corrosion observed.

(1) 0.178-inch diameter cylindrical specimens.
(2) Forged: 1750F. Duplex annealed: 1805F, 1 hr, AC + 1100F, 8 hrs, AC. Beta transus = 1830F.
(3) Forged: 1870F. Duplex annealed: 1770F, 1 hr, OQ + 1100F, 8 hrs, AC. Beta transus = 1820F.

TABLE 2.03213 COMBINED EFFECT OF 0.25% SILICON ADDITION, BETA FORGING AND SOLUTION ANNEALING VARIATION ON HOT SALT STRESS CORROSION CHARACTERISTICS OF DUPLEX ANNEALED FORGED DISKS. (70).

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	Sheet			
Condition	Duplex and Triplex Annealed			
Sheet Gage in	Direction	NTS in Air, (continuously loaded) ksi	NTS in 3.5 percent NaCl Soln, (sustained load) Failure > 1-Hr (1) ksi	Failure < 1-Hr (2) ksi
1650 F, 1/2 Hr, AC + 1450 F, 1/4 Hr, AC				
0.045	T-L	—	110(3)	(4)
0.080	L-T	127	101	(4)
0.080	T-L	120	101	108
0.125	L-T	129	111	117
0.125	T-L	120	101	108
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 2-Hr, AC				
0.045	T-L	—	100	(4)
0.080	L-T	128	—	63(5)
0.080	T-L	124	87	125
0.125	L-T	120	72	80
0.125	T-L	108	—	53

(1) Maximum stress at which failure does not occur within 60 minutes
(2) Minimum stress to cause failure within 60 minutes
(3) No failure in 68 hrs
(4) Failure stress not established
(5) Failed in 5 minutes



Center Fatigue Crack

TABLE 2.0331 DELAYED FAILURE IN SALT WATER OF FATIGUE-CRACKED SPECIMENS FROM DUPLEX AND TRIPLEX ANNEALED SHEET (13, p. 31)(69, p. 62)

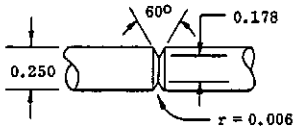
Alloy	Ti-6Al-2Sn-4Zr-2Mo		
Form	0.050 Inch Sheet		
Center fatigue cracked T-L specimens			
Heat Treatment	Applied Net Stress ksi	Time to Rupture in 3.5 percent NaCl Solution	
1350 F, 8-Hr, FC	89.5	Broke on Loading	
	67.7	1 min	
	44.7	7 min	
1350 F, 8-Hr, FC + 1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC	80	> 73 Hr(a)	
	85	> 42 Hr(a)	
	100	> 43 Hr(a)	
	110	> 68 Hr(a)	
1350 F, 8-Hr, FC + 1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 8-Hr, AC	80	> 48 Hr(a)	
	85	> 42 Hr(a)	
	90	> 24 Hr(a)	
	100	> 2 Hr(a)	

(a) No failure

TABLE 2.0332 DELAYED FAILURE IN SALT WATER OF FATIGUE-CRACKED SPECIMENS FROM SHEET VARIOUSLY HEAT TREATED (7, p. 66)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Source	AMS (19)			AMS (20)			
Alloy	Ti-6Al-2Sn-4Zr-2Mo						
Form	Bars, Wire, Flash Welded Rings and Stock for Flash Welded Rings			Forgings and Forging Stock			
Condition	Beta Transus - 25F, 1 hr, AC (or faster) + 1100F, 8 hrs, AC						
Conventional Tensile Properties							
Room Temperature				900F(1)			
F_{tu} - min ksi	F_{ty} - min ksi	e (2-in or 4D) percent	RA - min percent	F_{tu} - min ksi	F_{ty} - min ksi	e (2-in or 4D) percent	RA - min percent
130	120(2)	10	25(2)	90	70(2)	15	(3)(2)
Room Temperature Notched Stress Rupture							
@ 170 ksi, 5 hrs min(4)				Preferred Specimen (See reference for alternate specimens)			

(1) Specimen to be held at test temperature for thirty minutes before testing.
(2) Yield strength and reduction of area requirements do not apply to wire less than 0.125 inch in diameter.
(3) Bars, wire, flash welded rings and stock for flash welded rings, 35 percent. Forgings and forging stock, 30 percent.
(4) Initial stress may be less than 170 ksi and increased to 170 ksi in 10 ksi increments at intervals of not less than 5 hours.

TABLE 3.011 AMS SPECIFIED MECHANICAL PROPERTIES.

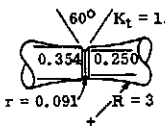
Source			T.M.C.A. (10, p.4)					
Alloy			Ti-6Al-2Sn-4Zr-2Mo					
Mill Form	Size	Heat Treatment	F_{tu}-min ksi	F_{ty}-min ksi	e-min percent L	e-min percent T	RA-min percent L	RA-min percent T
Sheet	Up to 0.187 inch	Duplex	135.0	125.0	8	8	-	-
		Triplex	140.0	130.0	8	8	-	-
Bar	Up to 16 sq inch	1750F, AC + 1100F, 8Hr, AC	130.00	120.0	10	8	20	15
Billet(1)	Up to 16 sq inch	1750F, AC + 1100F, 8Hr, AC	130.0	120.0	10	8	20	15

(1) Testing of billet is based on the results of a simulated forging, generally an upset test.

TABLE 3.012 PRODUCER'S GUARANTEED MECHANICAL PROPERTIES

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Source	General Electric (41)		General Electric (42)		General Electric (43)		General Electric(44)(45)		General Electric (46)	
Alloy	Ti-6Al-2Sn-4Zr-2Mo									
Form	Sheet, Strip and Plate		Bars[d], Forgings and Rings		Extrusions		Forged Parts and Compressor Blades and Vanes		Premium Quality Forged Parts	
Condition	1650F, 30 min, AC or faster + 1450F, 15 min, AC or faster + 1100F, 2 hrs, AC or faster		1750F, 1 hr, AC or faster + 1100F, 8 hrs, AC or faster		1775F, 1 hr, AC + 1100F, 8 hrs, AC		1775F, 1 hr, AC + 1100F, 8 hrs, AC		1775F[f], 1 hr, AC + 1100F, 8 hrs, AC	
Property	Specified Value at		Specified Value at		Specified Value at		Specified Value at		Specified Value at	
	RT	900F	RT	900F	RT	900F	RT	900F	RT	900F
F_{tu} - ksi, min	140	95	130	90	135	95	130	90	130	90
F_{ty} - ksi, min	130	75	120	70	120	70	120	70	120	70
e(2-in or 4D) -percent, min	(c)	(c)	10	15	10	15	10	15	10	15
RA - percent, min	---	---	25	30	20	30	25	30	25	30
RT Notch Stress Rupture Life	Not Specified		Not Specified		Not Specified		Not Specified		Not Specified	
Smooth Stress Rupture Life[a]	Not Specified		Not Specified		@ 975F, 70 ksi[e], 35 hrs min with 20 percent RA min		@ 975F, 70 ksi[e], 35 hrs min			
Creep Stability	Not Specified		Not Specified		Not Specified		Not Specified		Not Specified	
RT Bend Factor, r/t max, for 105° after springback without cracking[b]:										
<0.070-in gage	9									
0.070-in to 0.187-in gage	10									
K_{Ic} @RT - ksi $(in)^{\frac{1}{2}}$, min	Not Specified		Not Specified		Not Specified		Not Specified		50[g]	
RT Notched Low Cycle Fatigue Life 	Not Specified		Not Specified		Not Specified		Not Specified		@F_{max} = 90 ksi, A = 0.95, 10 to 30 cpm, 9000 cycles min	

(a) Specimen diameter 0.252 inch maximum; gage length at least three times the diameter.

(b) Axis of bend shall be parallel to rolling direction. Specimen width shall be at least ten times the nominal thickness.

(c) ≤0.187-in gage, 8; >0.187-in gage, 10.

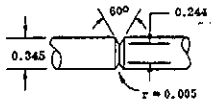
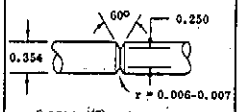
(d) For bar ≤1.5-in dia or distance between flats, specimen axis shall coincide with central axis of material. For bar >1.5-in, specimen axis shall be located midway between the center and the surface and shall be parallel to rolling direction.

(e) Test stress may exceed 70 ksi, but shall not be changed during test and life requirement shall be as specified for 70 ksi applied stress.

(f) Solution treat temperature as high as 50F below the beta transus determined for the heat may be used.

(g) To be tested in accordance with ASTM Method E-399 using 1-inch thick compact tension specimen.

TABLE 3.013 USER'S SPECIFIED MECHANICAL PROPERTIES FOR SHEET, STRIP, PLATE, BARS, FORGINGS, RINGS, EXTRUSIONS, FORGED PARTS, COMPRESSOR BLADES AND VANES, AND PREMIUM FORGED PARTS.

Source	Lycoming (47)	Lycoming (48)	Lycoming (49)
Alloy		Ti-6Al-2Sn-4Zr-2Mo	
Form	Bars, Forgings and Forging Stock	Premium Quality Bars, Forgings and Forging Stock	Investment Castings (b)
Condition	1750F, 1 hr, AC + 1100F, 8 hrs, AC	Beta Transus - 50F, 1 hr, AC + 1100F, 8 hrs, AC	As-Cast
Property	Specified Value at RT	Specified Value at RT	Specified Value at RT
F_{tu} - ksi, min	135	130	125
F_{ty} - ksi, min	125	120	110
e(4D) - percent, min	10	10	5
RA - percent, min	25	25	10
RT Notch Stress Rupture Life	 @ 170 ksi(a), 5 hrs min	 @ 170 ksi(a), 5 hrs min	Not Specified
Smooth Stress Rupture Life	Not Specified	Not Specified	At 800F, 75 ksi, 35 hrs minimum with at least 5 percent elongation. If no rupture in 48 hrs, stress may be increased to 85 ksi until rupture with at least 3 percent elongation.
Creep Resistance	Not Specified	At 950F, 35 ksi, time to 0.1 percent plastic deformation shall be 35 hrs minimum.	Not Specified
IE, Charpy V - ft-lbs, min:			
≤1-in section	16	16	Not Specified
>1-in section	13	13	
Hardness - RC, max	43	43	Not Specified

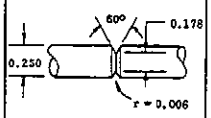
(a) Initial stress may be less than 170 ksi and increased to 170 ksi in 10 ksi increments at intervals of not less than 5 hours.

(b) 0.250-in dia cast-to-size specimens representative of cast product or 0.135-in dia specimens machined from castings.

TABLE 3.014 USERS' SPECIFIED MECHANICAL PROPERTIES FOR BARS, FORGINGS AND FORGING STOCK, PREMIUM QUALITY BARS, FORGINGS AND FORGING STOCK, AND INVESTMENT CASTINGS.

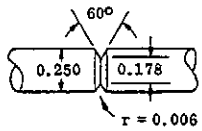
Ti 6 Al 2 Sn 4 Zr 2 Mo

Ti-6-2-4-2

Source	Pratt & Whitney (72)		Pratt & Whitney (50)				Pratt & Whitney(73)	
Alloy	Ti-6Al-2Sn-4Zr-2Mo							
Form	Bars		Bars		Forgings and Forging Stock	Forged Parts and Compressor Blades and Vanes	Forgings and Forging Stock (High Creep Strength)[b]	
Condition	Beta Transus - 25F, 1 hr, AC or faster + 1100F, 8 hrs, AC		Beta Transus - 50F, 1 hr, AC or faster + 1100F, 8 hrs, AC		Beta Transus - 25F, 1 hr, AC or faster + 1100F, 8 hrs, AC	Beta Transus - 50F, 1 hr, AC or faster + 1100F, 8 hrs, AC	Beta Transus - 25F[c], 1 hr, AC or faster + 1100F 8 hrs, AC	
Property	Specified Value at RT	900F	Specified Value at RT	900F			Specified Value at RT	900F
F_{tu} - ksi, min	130	90	130	90			130	90
F_{ty} - ksi, min	120	70	120	70			120	70
e(4D) - percent, min	10	15	10	15			10	10
RA - percent, min	25	30	20	30			20	20
RT Notch Rupture Life  (preferred specimen)	@ 170 ksi[a], 5 hrs min							
Smooth Stress Rupture Life	Not Specified							
Creep Resistance	At 950F, 35 ksi, time to 0.1 percent plastic deformation shall be 35 hrs minimum. (Applicable to Compressor Disks Only)						At 950F, 35 ksi, time to 0.1 percent plastic deformation shall be 125 hrs minimum. (Forgings Only)	
IE, Charpy V - ft-lbs, min	Not Specified							
Hardness - RC, max	43							

(a) Initial stress may be less than 170 ksi and increased to 170 ksi in 10 ksi increments at intervals of not less than 5 hours.
(b) Silicon 0.06 - 0.10 wt%, Iron 0.10 wt% max.
(c) In inert atmosphere for forgings not to be machined all over.

TABLE 3.015 USER'S SPECIFIED MECHANICAL PROPERTIES FOR BARS, FORGINGS, FORGING STOCK, FORGED PARTS, AND COMPRESSOR BLADES AND VANES.

Source	Pratt & Whitney (74)		Pratt & Whitney (75)	
Alloy	Ti-6Al-2Sn-4Zr-2Mo-0.25Si			
Form	Bars, Forgings and Forging Stock		Forgings and Forging Stock	
Condition	Alpha-Beta Processed + Beta Transus - 25F, 1 hr[a], OQ + 1100F, 8 hrs, AC		Beta Processed + Beta Transus - 25F, 1 hr[a], OQ + 1100F, 8 hrs, AC	
Property	Specified Value at RT	800F	Specified Value at RT	800F
F_{tu} - ksi, min	157.5	120	155	117
F_{ty} - ksi, min	140	95	135	92
e(4D) - percent, min	10	12	6	10
RA - percent, min	20	25	12	15
RT Notch Stress Rupture Life  (preferred specimen)	@ 170 ksi[b], 5 hrs min			
Smooth Stress Rupture Life	Not Specified			
Creep Resistance	At 900F, 59 ksi, time to 0.2 percent plastic deformation shall be 35 hrs min. (Applicable to Discs and Blades Only)		At 900F, 66 ksi, time to 0.2 percent plastic deformation shall be 35 hrs min. (Applicable to Discs and Rotor Spacers Only)	
IE, Charpy V - ft-lbs, min	Not Specified			
Hardness - RC, max	43			

(a) In inert atmosphere for forgings not to be machined all over.
(b) Initial stress may be less than 170 ksi and increased to 170 ksi in 10 ksi increments at intervals of not less than 5 hours.

TABLE 3.016 USER'S SPECIFIED MECHANICAL PROPERTIES FOR BARS, FORGINGS, AND FORGING STOCK FROM Ti-6Al-2Sn-4Zr-2Mo-0.25Si

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2

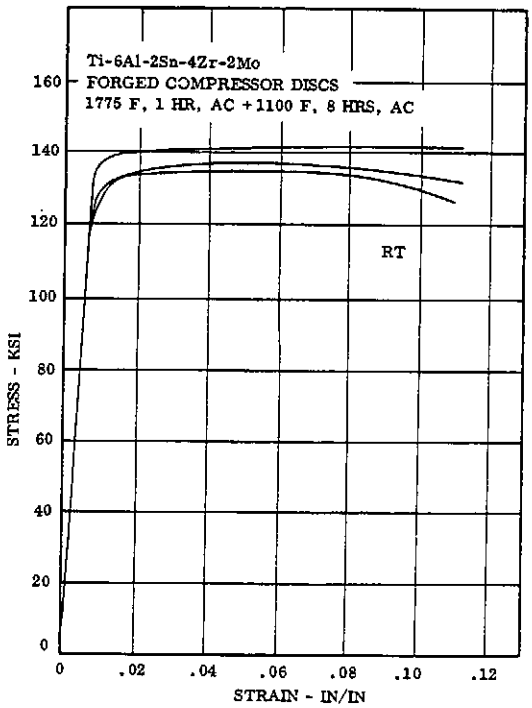


FIG. 3.0211 STRESS-STRAIN CURVES IN TENSION FOR DUPLEX ANNEALED FORGED COMPRESSOR DISCS AT ROOM TEMPERATURE. (82)

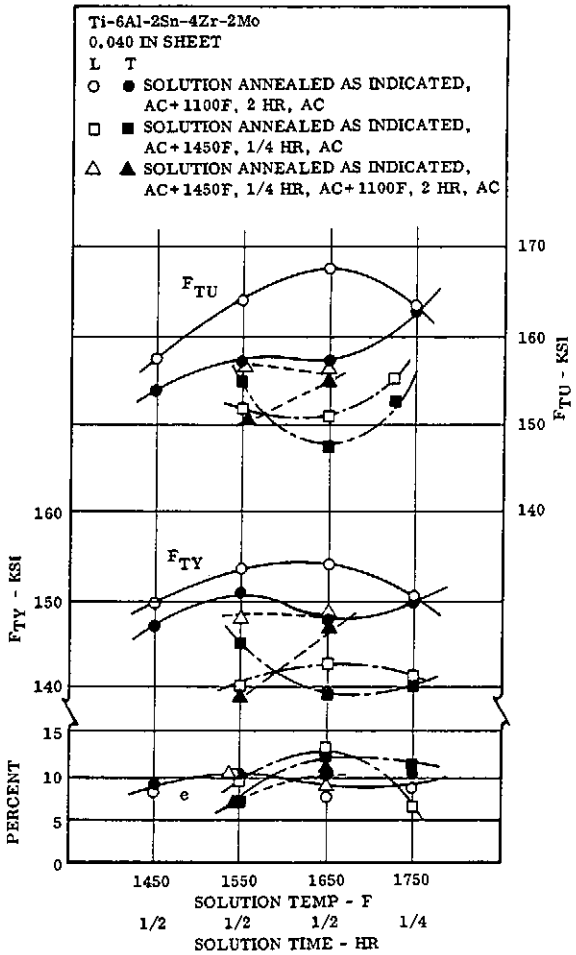


FIG. 3.0213 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX AND TRIPLEX ANNEALED SHEET. (7, P.38) (13, PP.8 AND 9)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

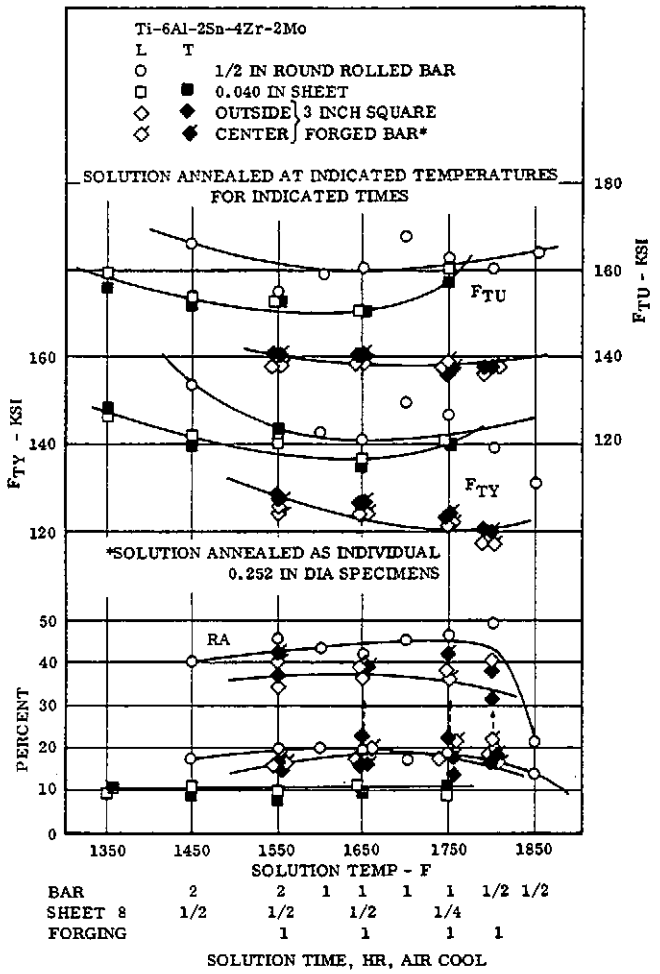


FIG. 3.0212 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION ANNEALED BAR, SHEET AND FORGING. (7, PP. 36,38 AND 41)

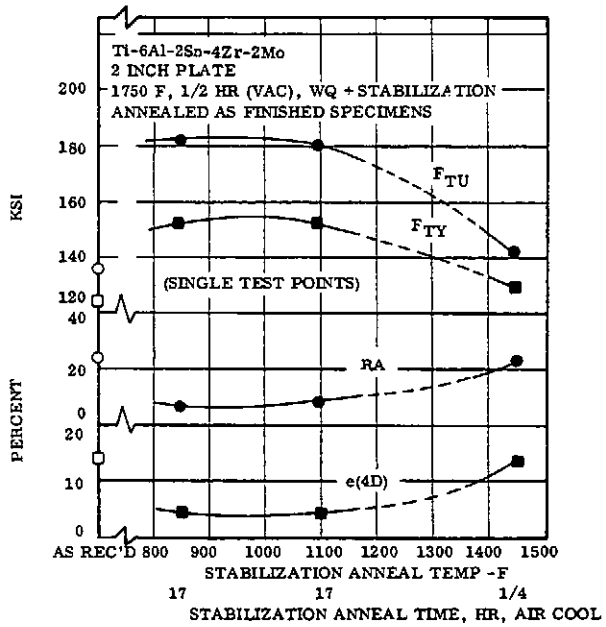


FIG. 3.0214 EFFECT OF STABILIZATION ANNEAL TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED PLATE. (25)(26)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Form	2-in x 4½-in bar					
Alloy Condition	Specimen		RT Tensile Properties(a)			
	Location	Direction	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
1650F, 1 hr, AC + 1100F, 8 hrs, AC	Outside	L	137	127	15	33
	Center	L	134	122	15	32
	Outside	T	137	127	14	27
	Center	T	130	119	10	22
1790F, 1 hr, AC + 1100F, 8 hrs, AC	Outside	L	136	118	18	27
	Center	L	137	119	16	28
	Outside	T	139	125	12	23
	Center	T	140	121	10	24

(a)Each value average two tests.

TABLE 3.0216 EFFECT OF SOLUTION ANNEALING NEAR THE BETA TRANSUS TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED BAR, (80).

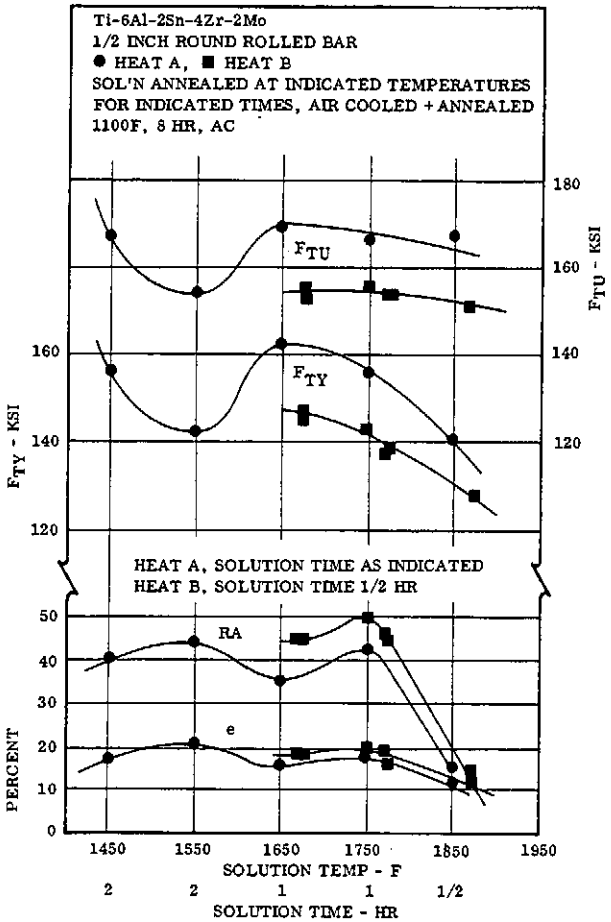


FIG. 3.0217 EFFECT OF SOLUTION ANNEALING AT TEMPERATURES UP TO AND BEYOND THE BETA TRANSUS TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED BAR. (7, P. 36)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo			
Product Size and Form	Location-Direction	F_{tu} ksi	F_{ty} ksi	e(4D) percent	RA percent
1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC (1)					
1 1/8-in Rolled Bar	Long	152.6	140.5	20.0	41.2
2 1/4-in Rolled Bar	Outside — Long	137.0	120.7	15.5	31.2
	Center — Long	143.2	127.1	15.0	24.7
3-in Forged Bar	Outside — Long	141.2	133.1	18.0	40.9
	Center — Long	142.4	132.3	19.0	37.9
	Outside — Trans	142.3	132.8	15.0	33.3
	Center — Trans	144.5	135.5	17.0	43.3
1750 F, 1-Hr, AC + 1100 F, 8-Hr, AC (1)					
2 1/4-in Rolled Bar	Outside — Long	136.3	119.9	15.0	26.0
	Center — Long	141.4	125.8	15.0	24.7
	Center — Trans	138.9	122.7	13.5	23.4
2 1/4-in Forged Bar(2)	Outside — Long	143.3	135.3	20.0	41.5
	Center — Long	144.1	129.5	18.0	32.7
	Outside — Trans	144.7	132.6	17.5	39.3
	Center — Trans	139.3	124.1	14.5	31.3
3-in Forged Bar	Outside — Long	136.5	126.7	19.0	37.9
	Center — Long	138.5	129.3	19.0	39.2
	Outside — Trans	138.5	128.7	18.0	36.6
	Center — Trans	137.8	128.5	16.0	30.7
1750 F, 1-Hr, WQ + 1100 F, 8-Hr, AC (1)					
2 1/4-in Rolled Bar	Outside — Long	147.9	130.5	13.0	25.9
	Center — Long	151.4	134.8	12.0	21.1
3-in Forged Bar	Outside — Long	160.1	146.5	17.0	35.2
	Center — Long	146.2	132.1	20.0	45.9
	Outside — Trans	152.5	138.9	16.0	41.6
	Center — Trans	147.0	134.5	14.0	23.3

(1) All heat treated in full sections.
(2) Stabilization annealed for 24 hours.

TABLE 3.0218 EFFECT OF SECTION SIZE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED BAR (13, p. 54)

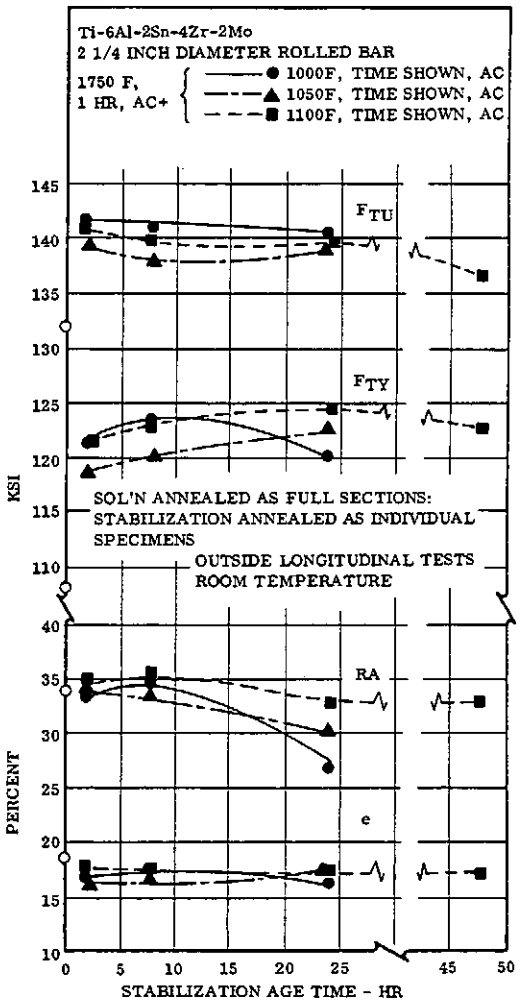


FIG. 3.0219 EFFECT OF STABILIZATION AGE TIME AND TEMPERATURE ON THE ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED ROLLED BAR. (13, P.45)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

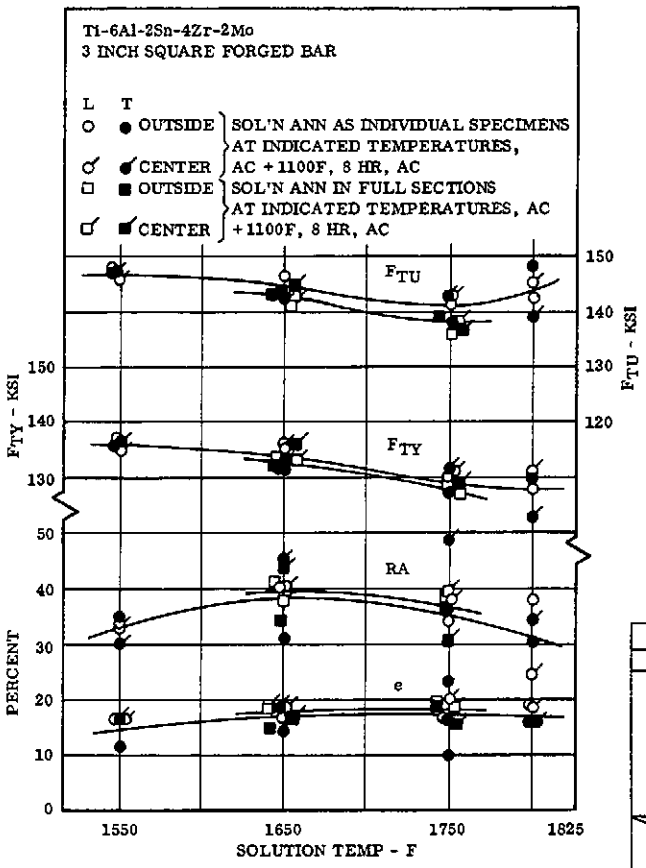


FIG. 3.02111 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGING (7, pp. 41 - 42)

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	Forged Jet Engine Compressor Discs			
Condition	Alpha-Beta Forged + Beta Transus - 25F, 1 hr, AC or faster + 1100F, 8 hrs, AC (a)		Beta Preforged + Alpha-Beta Forged + Beta Transus - 25F, 1 hr, AC or faster + 1100F, 8 hrs, AC (b)	
Value / Property	$\bar{X}$(c)	s(d)	$\bar{X}$(c)	s(d)
F_{tu} - ksi	146.0	1.6	145.9	2.2
F_{ty} - ksi	133.8	1.6	131.3	2.6
e(1-in) - percent	15.3	1.1	11.6	1.2
RA - percent	39.5	2.6	23.3	2.1

(a) 50 tests.
(b) 199 tests.
(c) Arithmetic mean.
(d) One standard deviation.

TABLE 3.02113 TYPICAL ROOM TEMPERATURE TENSILE PROPERTIES OF FORGED JET ENGINE COMPRESSOR DISCS, (77).

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	Pancake Forging, Press Upset			
Condition	Forged 2-in to 3/4-in from 1750 F, + 1650 F, 1 Hr, AC + 1100 F, 8-Hr, AC			
Direction	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
Radial	148.0	138.8	20.0	46.1
Tangential	145.9	137.4	21.0	48.0

TABLE 3.02112 ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED UPSET FORGING (2, p.2)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

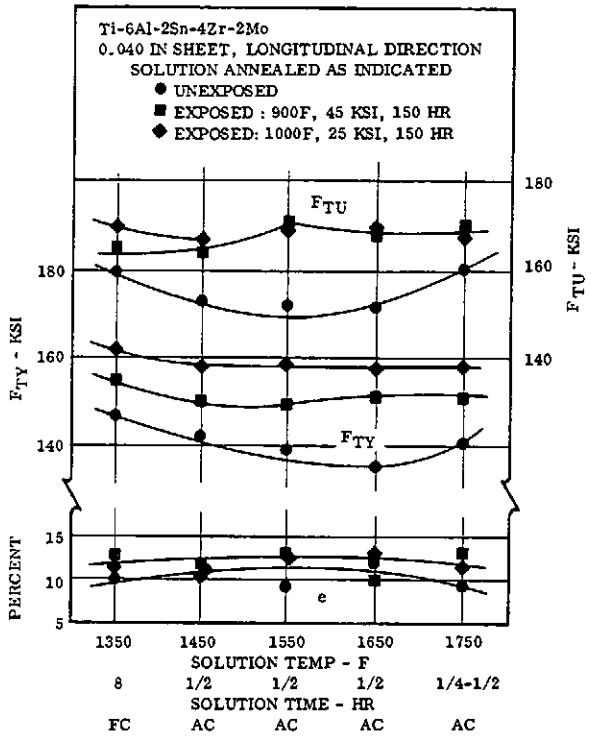


FIG. 3.02114 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION ANNEALED SHEET. (7, PP. 38&50)

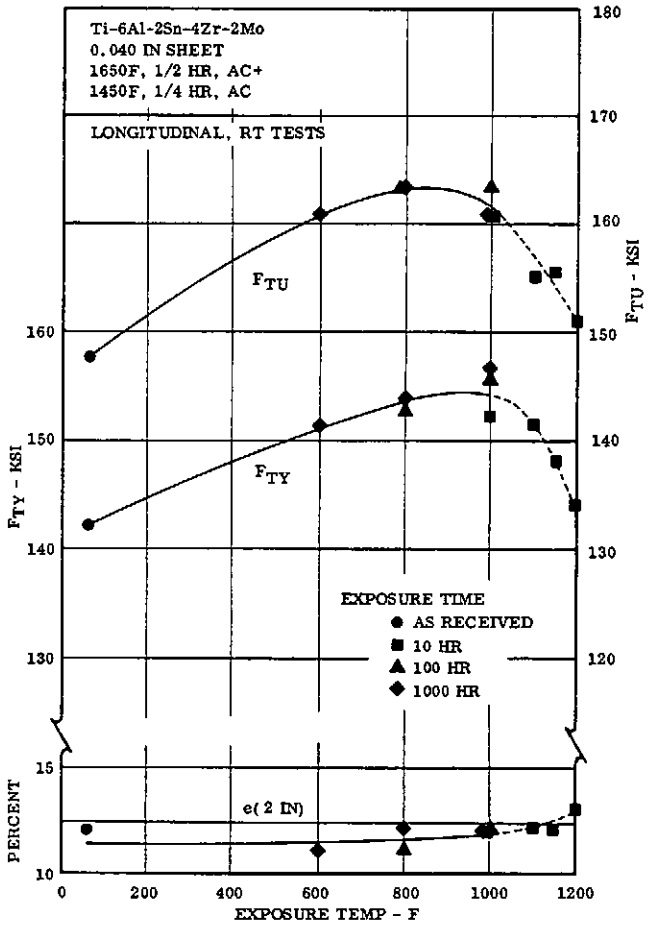


FIG. 3.02115 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET. (1, pp. 265, 266)

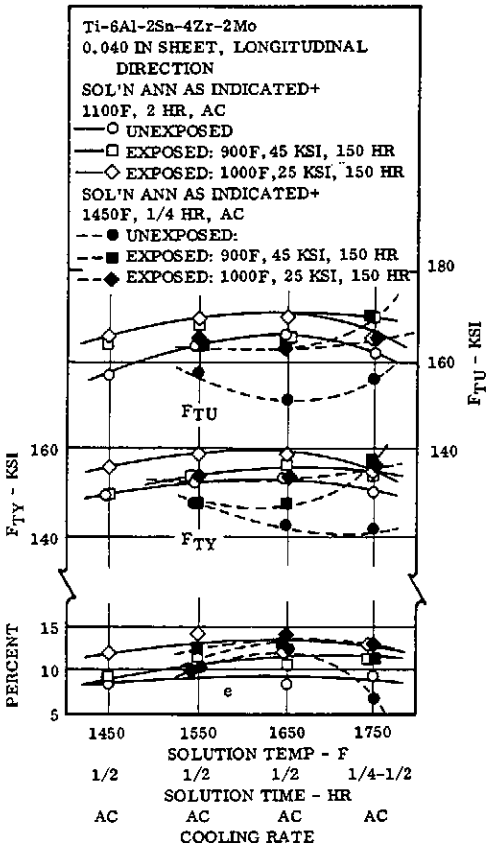


FIG. 3.02116 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET GIVEN VARIOUS SOLUTION ANNEAL TREATMENTS. (7, PP. 38&50)

Alloy			Ti-6Al-2Sn-4Zr-2Mo			
Form			0.040 in sheet			
Condition			Duplex and triplex annealed			
150-Hr exposure at			Subsequent RT tensile properties			
Temp F	Stress ksi	Deformation percent	Direction	F_{tu} ksi	F_{ty} ksi	e(1-in) percent
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC						
None			L	154.4	141.3	14.0
			T	148.9	134.4	14.0
800	65	0.16	L	168.3	144.5	12.0
		0.18	T	167.2	142.1	13.5
900	45	0.29	L	172.0	151.3	14.0
		0.22	T	167.1	147.6	13.0
1000	25	0.36	L	168.9	154.5	13.0
		0.40	T	164.7	152.0	12.0
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 2-Hr, AC						
None			L	162.4	149.2	16.0
			T	156.5	141.9	14.0
800	65	0.05	L	166.5	150.7	12.0
		0.06	T	163.7	148.6	14.0
900	45	0.17	L	167.7	152.0	12.0
		0.16	T	163.0	149.1	14.0
1000	25	0.34	L	169.8	157.1	12.5
		0.32	T	163.6	150.5	14.0

Note: Tests made after creep exposure without surface conditioning

TABLE 3.02117 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX AND TRIPLEX ANNEALED SHEET (13, p. 28)

Alloy			Ti-6Al-2Sn-4Zr-2Mo		
Form			0.040-in sheet, long. direction		
Condition			Duplex and triplex annealed		
1000-Hr exposure at			Subsequent R.T. tensile properties (1)		
Temp F	Stress ksi	Deformation percent	F_{tu} ksi	F_{ty} ksi	e percent
1650F, 1/2 Hr. AC + 1100F, 2 Hr, AC					
None			166.9	154.4	8.0
800	40	0.07	167.5	155.2	14.0
900	20	0.11	166.7	159.1	7.5
950	15	0.19	164.1	161.0	4.0
1000	10	0.50	(2)	160.5	(2)
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC					
None			150.5	142.3	12.5
800	40	0.11	164.4	149.2	13.5
900	20	0.14	162.6	154.7	6.0
950	15	0.16	162.9	157.8	7.0(3)
1000	10	0.25	160.7	159.7	3.0(3)
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 2-Hr, AC					
None			156.2	147.8	9.0
800	40	0.04	159.8	149.6	14.0
900	20	0.08	161.3	152.8	11.0
950	15	0.20	161.7	155.0	12.0
1000	10	0.20	158.5	157.0	4.5

(1) Single longitudinal tests
(2) Broke just beyond yield at end of gage length
(3) Broke at end of gage length

TABLE 3.02118 EFFECT OF LONG TIME EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX AND TRIPLEX ANNEALED SHEET (7, pp. 38 & 52)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

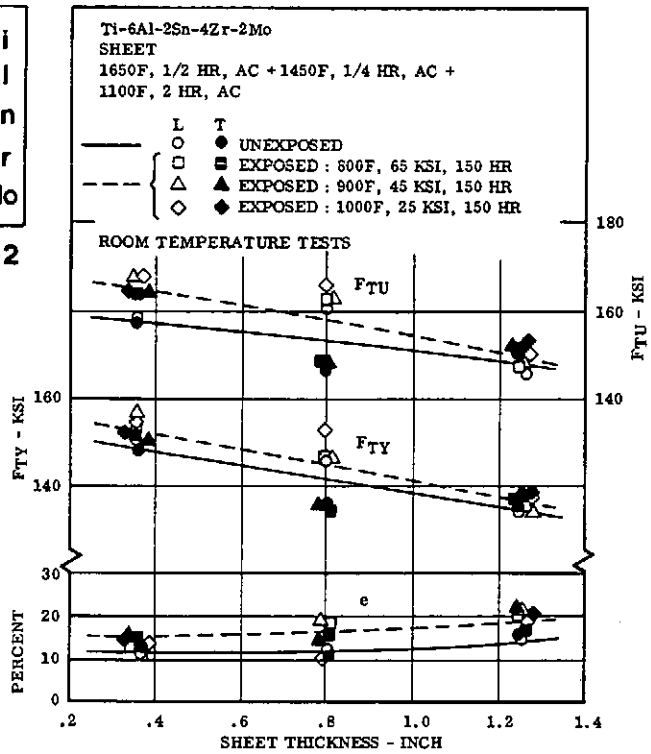


FIG. 3.02119 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF TRIPLEX ANNEALED SHEET OF VARIOUS THICKNESSES (10, p. 10)

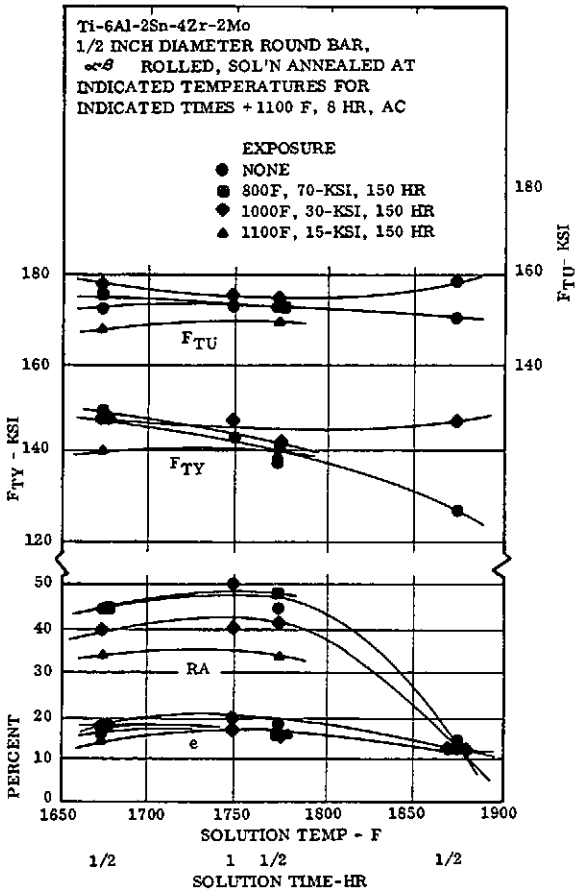


FIG. 3.02120 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED BAR GIVEN VARIOUS SOLUTION ANNEAL TREATMENTS (7, pp. 47-48)

Alloy	Ti-6Al-2Sn-4Zr-2Mo
Form	Rolled Bar
Condition	Duplex Annealed In Full Sections

Bar Size in	150-Hr Exposure At Temp F	Stress ksi	Deformation percent	Supsequent RT Tensile Properties[a] (outside longitudinal) F_{tu} ksi	F_{ty} ksi	e(1-in) percent	RA percent
	1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC						
1 1/8	None			152.6	140.5	20.0	41.2
	900	45	0.14	145.7	133.0	17.0	45.0
	1000	25	0.19	145.9	136.3	15.0	42.0
2 1/4	None			137.0	120.7	15.5	31.2
	800	65	0.17	139.6	129.3	16.0	32.1
	900	45	0.13	141.6	126.8	14.0	31.4
	1000	25	0.14	143.3	134.4	13.0	30.7
	1100	10	0.14	135.3	123.7	14.0	24.0
	1750 F, 1-Hr, AC + 1100 F, 8-Hr, AC						
2 1/4	None			136.3	119.9	15.0	26.0
	800	65	0.12	137.1	123.2	16.0	33.7
	900	45	0.12	135.8	121.7	15.0	28.2
	1000	25	0.11	140.4	127.6	18.0	33.4
	1100	10	0.11	137.8	128.2	16.5	33.5
	1750 F, 1-Hr, AC + 1100 F, 24-Hr, AC						
2 1/4	None			139.5	124.3	17.0	32.8
	850	70	0.32	138.9	129.3	18.5	33.5
	1050	30	0.46	136.1	125.7	20.0	36.1
	1750 F, 1-Hr, WQ + 1100 F, 8-Hr, AC						
2 1/4	None			147.9	130.5	13.0	25.9
	800	65	0.12	156.4	138.6	10.0	17.8
	900	45	0.22	157.7	140.0	12.0	19.1
	1000	25	0.29	153.6	137.6	11.5	19.1
	1100	10	0.20	148.9	135.2	14.0	26.0

[a] Tested after exposure without surface conditioning.

TABLE 3.02121 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED ROLLED BAR OF VARIOUS SIZES (13, pp. 67-68) (7, p. 53)

Alloy	Ti-6Al-2Sn-4Zr-2Mo
Form	2 1/4 - in Diameter Rolled Bar
Condition	Duplex Annealed In Full Sections

1000 - Hr Exposure at Temp F	Stress ksi	Deformation Percent	Subsequent RT Tensile Properties[a] (outside longitudinal) F_{tu} ksi	F_{ty} ksi	e(1-in) Percent	RA Percent
	1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC					
None			137.0	120.7	15.5	31.2
800	55	0.11	147.4	132.3	15.5	34.3
850	50	0.15	143.6	132.3	18.5	34.8
900	40	0.17	142.4	129.1	17.5	28.9
1000	15	0.12	142.1	131.2	15.0	31.6
	1750 F, 1-Hr, AC + 1100 F, 24-Hr, AC					
None			139.5	124.3	17.5	32.8
800	65	0.22	136.7	123.2	18.0	28.2
850	50	0.14	139.2	125.0	20.5	32.2
850	55	0.18	136.5	122.7	18.0	30.2
900	40	0.22	136.6	123.3	19.0	30.2
900	45	0.23	138.1	125.5	19.5	33.5
1000	20	0.17	138.9	128.9	16.5	30.8
	1875 F, 1-Hr, AC + 1100 F, 24-Hr, AC					
None			138.4	121.0	15.0	21.2
800	65	0.19	138.5	126.1	13.5	23.4
850	55	0.14	139.6	125.8	14.5	21.9
900	45	0.16	139.8	126.7	14.5	23.4
1000	20	0.10	141.7	129.7	12.5	18.3

[a] Tested after exposure without surface conditioning

TABLE 3.02122 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED ROLLED BAR VARIOUSLY HEAT TREATED (13, pp. 67-68)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo
Form	1 3/8 in Diameter Rolled Bar
Condition	1775 F, 1-Hr, AC + 1100 F, 8-Hr, AC

Exposure Conditions Temp F	Stress ksi	Time Hrs	Time to 0.1 percent Deformation Hrs	Total Plastic Deformation Percent	Subsequent RT Tensile Properties F_{ty} ksi	F_{tu} ksi	e percent	RA percent
		None			146.6	160.2	21.0	37.3
		None			146.2	159.7	19.0	37.7
825	47.5	3000	185	0.276	144.5	156.2	13.0	22.8
			—	0.192	142.5	155.2	14.0	18.8
925	27.5	2300	98	0.436	148.6	156.6	16.0	31.7
			—	0.240	150.8	160.2	18.0	37.7

Note: Center properties, 1/4-inch diameter specimens

TABLE 3.02123 EFFECT OF LONG TIME EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED ROLLED BAR (5, p. 10)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy			Ti-6Al-2Sn-4Zr-2Mo			
Form			1/2 in dia. bar, Beta rolled			
Condition			Duplex annealed			
150-Hr exposure at			Subsequent RT Tensile Properties			
Temp F	Stress ksi	Deformation percent	F_{tu} ksi	F_{ty} ksi	RA percent	e percent
1650 F, 1-Hr, AC			+ 1100 F, 8- Hr, AC			
None			151	140	36	18
800	70	.11	153	142	34	18
1000	30	.38	150	141	39	19
1100	15	1.83	151	144	25	14
1750 F, 1-Hr, AC			+ 1100 F, 8-Hr, AC			
None			158	140	30	17
800	70	.10	149	138	38	18
1000	30	.26	150	140	37	19
1100	15	.53	150	142	28	16
Duplicates tests						

TABLE 3.02124 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF BETA-ROLLED DUPLEX ANNEALED BAR (7, p.49)

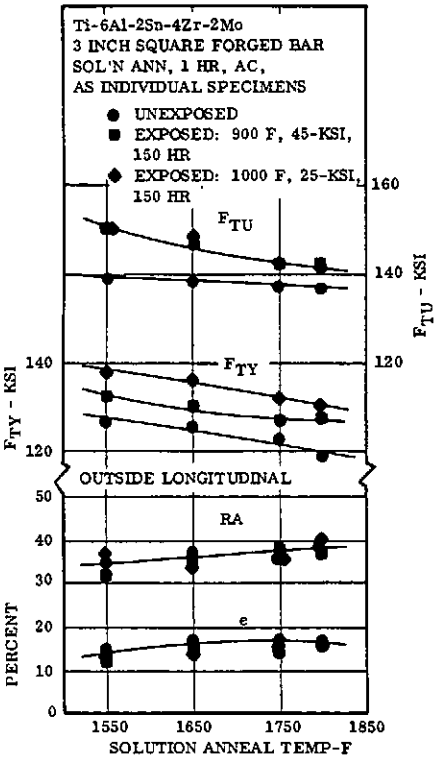


FIG. 3.02125 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION ANNEALED FORGING (7, pp. 41 and 54)

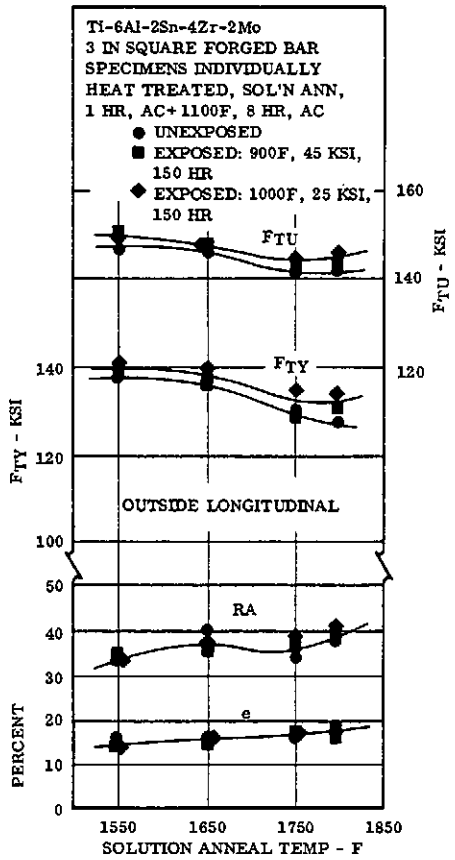


FIG. 3.02126 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGING. (7, PP. 41 AND 54)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2

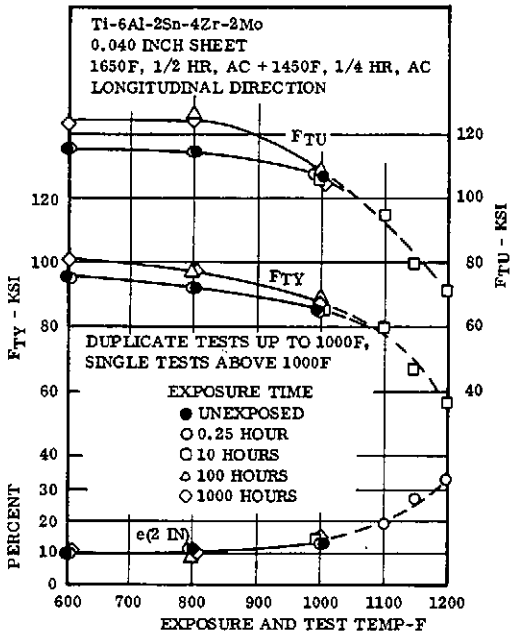


FIG 3.03126 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET AT THE EXPOSURE TEMPERATURE.(1,pp. 51 and 265-266)

Alloy			Ti-6Al-2Sn-4Zr-2Mo			
Form			3 in Square Forged Bar			
Condition			Duplex Annealed in Full Sections			
150-Hr Exposure at			Subsequent RT Tensile Properties* (outside longitudinal)			
Temp F	Stress ksi	Deformation percent	F_{tu} ksi	F_{ty} ksi	e (1-in) percent	RA percent
1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC						
——	None	——	141.2	133.1	18.0	40.9
800	65	0.01	143.0	134.0	19.0	41.6
900	45	0.12	142.2	131.1	16.0	39.2
1000	25	0.18	142.6	133.9	16.0	41.6
1100	10	0.23	141.0	134.1	16.5	35.4
1750 F, 1-Hr, AC + 1100 F, 8-Hr, AC						
——	None	——	136.5	126.7	19.0	37.9
800	65	0.08	139.6	129.5	18.0	37.3
900	45	0.12	136.8	127.0	17.0	42.1
1000	25	0.09	137.9	130.0	17.0	41.6
1100	10	0.32	138.5	131.2	17.0	35.4
1750 F, 1-Hr, WQ + 1100 F, 8-Hr, AC						
——	None	——	160.1	146.5	17.0	35.2
800	65	0.10	156.6	142.8	14.0	38.4
900	45	0.57	154.0	142.2	14.0	28.8
1000	25	0.17	147.7	134.5	14.5	34.1
1100	10	0.30	153.2	141.2	14.0	22.0

* Tested after exposure without surface treatment

TABLE 3.02127 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGED BAR (13,p.69)(7,p.56)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo								
Form		18.5 in Dia Compressor Hub Forging								
Condition		1750F, 1 Hr, AC + 1100F, 8 Hr, AC								
		150-Hr Exposure at		Time to 0.1percent	Time to 0.2percent	Creep in 150-Hr	Subsequent RT Tensile Properties			
Location	Direction	Temp F	Stress ksi	Creep Hr	Creep Hr	percent	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
Rim	Radial	None					140.0	129.6	13.5	28.6
Web							143.2	130.4	13.5	32.7
Hub							140.2	125.8	18.0	42.3
Rim	Radial	800	70	75	225[a]	.149	141.1	132.8	16.0	30.1
Web				42	225[a]	.160	139.7	130.9	16.0	28.1
Hub				50	245[a]	.148	138.5	130.5	15.0	28.8
Rim	Radial	1000	35	7	39	.412	144.2	129.7	12.5	32.8
Web				8	44	.424	145.2	133.6	17.0	29.4
Hub				6	33	.498	138.5	126.4	12.5	34.1

[a] Extrapolated

TABLE 3.02128 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED COMPRESSOR HUB FORGING (12, pp. 13 and 15)

Alloy			Ti-6Al-2Sn-4Zr-2Mo			
Form			20-inch Diameter Compressor Wheel Forging[a]			
Condition			Duplex Annealed			
150-Hr Exposure at			Subsequent RT Tensile Properties			
Stress ksi	Temp F	Total 150Hr Plastic Deformation percent[b]	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC						
None	None		153.0	139.8	16.0	37.3
None	None		147.4	136.0	17.0	44.2
65	850	0.15	141.5	129.0	19.0	42.0
55	900	0.19	141.2	128.8	18.0	43.6
45	950	0.24	142.3	129.6	20.0	42.0
35	1000	0.30	142.7	129.3	19.0	47.6
15	1100	0.54	142.0	132.2	17.0	34.1
1750 F, 1-Hr, WQ + 1100 F, 8-Hr, AC						
None	None		164.0	147.4	14.0	41.9
None	None		166.9	151.2	14.0	37.8
65	850	0.26	164.8	155.2	13.0	40.8
55	900	0.39	165.2	149.4	13.0	34.0
45	950	0.49	164.6	146.3	14.0	38.3
35	1000	0.81	164.4	149.7	11.0	31.5
15	1100	1.04	161.0	148.6	11.0	23.2

[a] All tests in radial direction
[b] Measured at RT after exposure

TABLE 3.02129 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED COMPRESSOR WHEEL FORGINGS (2, p. 10)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2

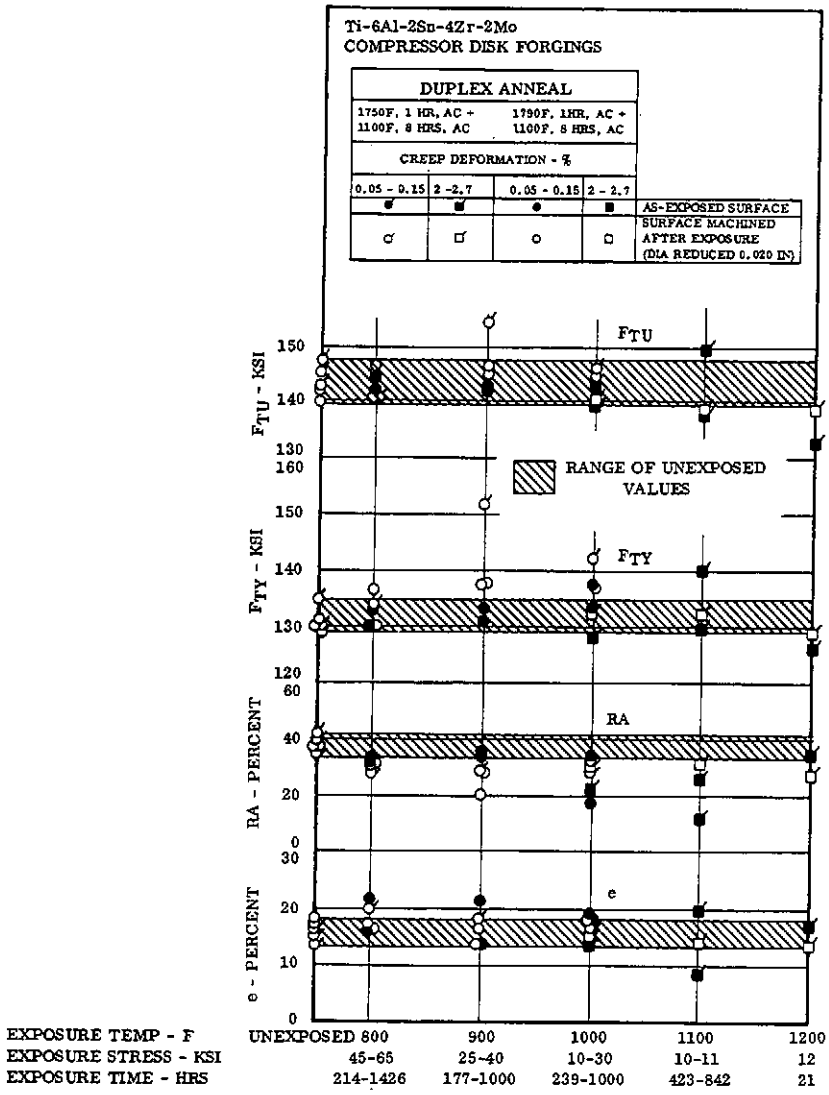


FIG. 3.02130 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED COMPRESSOR DISK FORGINGS SUBSEQUENT TO LONG TIME EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD. (68)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy			Ti-6Al-2Sn-4Zr-2Mo					
Form			Pancake Forgings					
Condition			1750F, 1 hr, AC + 1100F, 8 hrs, AC					
Heat	Exposure Conditions				Subsequent RT Tensile Properties			
	Temp F	Stress ksi	Time hrs	Plastic Deformation percent	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
A	Unexposed				144-150(a)	131-140(a)	14-17(a)	42-51(a)
B	Unexposed				139-145(b)	126-133(b)	11-17(b)	33-52(b)
A	700	100	1500	1.681	155	154	14	44
B	700	80	1500	0.221	147	142	18	39
B	700	60	1500	0.221	144	130	17	39
A	800	90	1500	1.444	154	152	14	28
A	800	85	1000	0.713	154	150	8	10
A	800	80	1000	0.433	150	147	15	44
A	800	75	500	0.256	150	142	8	15
B	800	50	1500	0.158	143	132	16	39
B	900	50	1500	0.592	140	133	17	39
B	900	30	1500	0.173	146	140	9	19
B	1000	30	1500	7.706	135	128	9	19
B	1000	20	1500	2.051	147	134	14	21

(a) Range of values from 6 tests on 2 forgings.
(b) Range of values from 12 tests on 6 forgings.

TABLE 3.02131 EFFECT OF LONG TIME EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED PANCAKE FORGINGS, (83).

Alloy			Ti-6Al-2Sn-4Zr-2Mo			
Form			15 in Diameter Forged Disc			
Condition			Duplex Annealed			
	950F, 35 - ksi 150 Hr Exposure		Post Exposure RT Tensile Properties			
Direction	Time(a) Hour	150-Hr(b) percent	F_{ty} ksi	F_{tu} ksi	e percent	RA percent
	1750F, 1-Hr, AC + 1100F, 8-Hr, AC					
Chordal	44	0.280	144.4	152.2	17.0	39.5
Radial	17	0.240	144.3	150.4	15.0	42.0
	1790F, 1-Hr, AC + 1100F, 8-Hr, AC					
Chordal	43	0.110	144.3	152.8	15.0	22.5
Radial	37	0.131	142.1	150.6	13.0	27.9

(a) To 0.1% Plastic Deformation
(b) Total Plastic Deformation

TABLE 3.02132 EFFECT OF HIGH SOLUTION ANNEALING TEMPERATURE (BETA TRANSUS - 25F) ON EXPOSURE STABILITY PROPERTIES OF DUPLEX ANNEALED FORGED DISC, (14, p. 17).

Alloy	Ti-6Al-2Sn-4Zr-2Mo
Form	20 in Dia Compressor Wheel Forging
Condition	1750F, 1 Hr, AC + 1100F, 8 Hr, AC

Location	Direction	Standard Charpy-V Impact-Energy ft-lb
Web (Center Punch - Out)	Radial	21

TABLE 3.0231. STANDARD CHARPY-V IMPACT ENERGY OF DUPLEX ANNEALED COMPRESSOR WHEEL FORGING, (11, p. 17).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

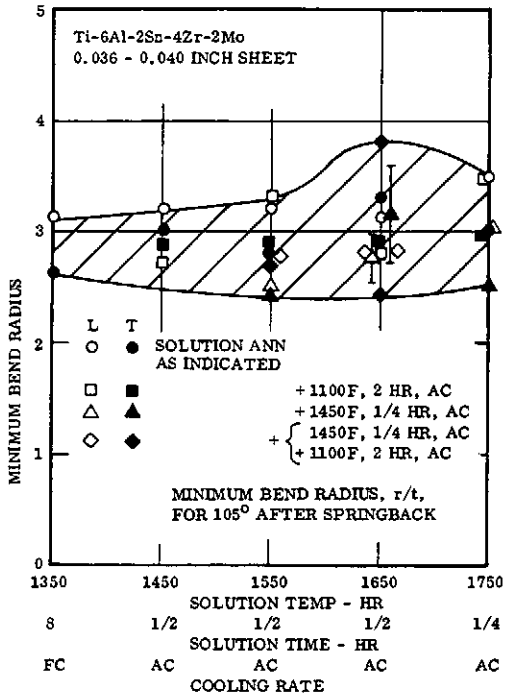


FIG. 3.0241 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE MINIMUM BEND RADIUS OF SOLUTION ANNEALED, DUPLEX ANNEALED AND TRIPLEX ANNEALED SHEET. (7, p. 71)

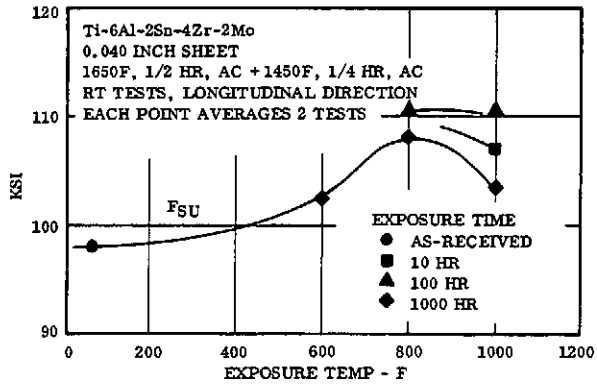


FIG. 3.0251 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE ULTIMATE SHEAR STRENGTH OF DUPLEX ANNEALED SHEET. (1, p. 267)

Alloy		Ti-6Al-2Sn-4Zr-2Mo	
Form		Sheet	
Sheet Thickness Inch	Test Direction	Minimum Bend Radius (1) 1650F, 1/2 Hr, AC + 1450F, 1/4 Hr, AC	1650F, 1/2 Hr, AC + 1450F, 1/4 Hr, AC + 1100F, 2 Hr, AC
0.040	L	3.0	3.0
	T	3.0	3.0
0.080	L	3.0	3.1
	T	2.8	3.2
0.125	L	3.3	3.4
	T	3.5	3.4

(1) Minimum bend radius, r/t, for 105° after Springback

TABLE 3.0242. EFFECT OF SHEET THICKNESS ON MINIMUM BEND RADIUS OF DUPLEX AND TRIPLEX ANNEALED SHEET, (13, p. 22).

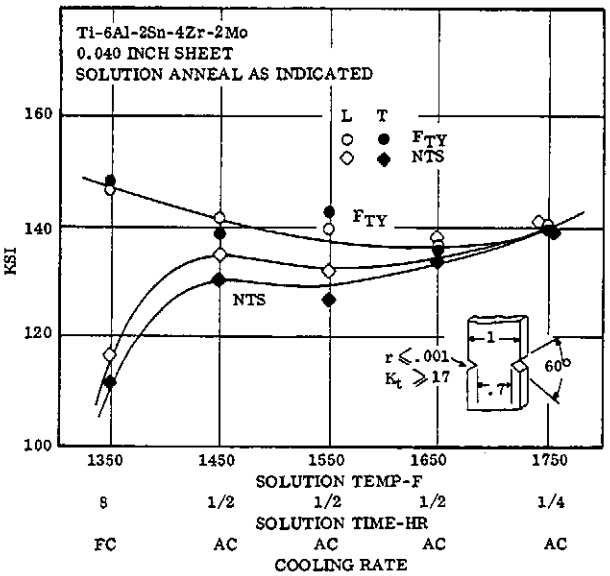


FIG. 3.02711 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE SHARP NOTCH PROPERTIES OF SOLUTION ANNEALED SHEET (7, p 63)(10, pp 8 AND 9)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

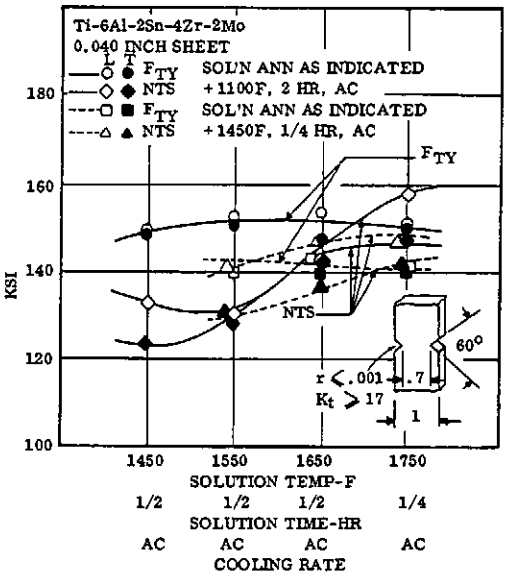


FIG. 3.02712 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE SHARP NOTCH PROPERTIES OF DUPLEX ANNEALED SHEET (7, p. 63)

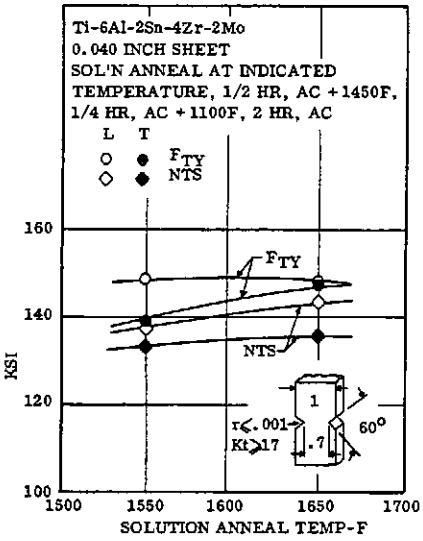


FIG. 3.02713 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE SHARP NOTCH PROPERTIES OF TRIPLEX ANNEALED SHEET (7, pp. 63 - 64)

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	0.040 in Sheet			
Condition	Duplex and Triplex Annealed			
Heat Treatment	F_{tu} ksi	F_{ty} ksi	e(2-in) percent	NTS ksi
1650 F, 1/4-Hr, AC + 1450 F, 1/4-Hr, AC	146.7	138.0	12.3	134.5
1650 F, 1/2-Hr, AC + 1450 F, 1/4 -Hr, AC	147.5	139.2	12.0	137.0
1650 F, 1/4-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 2-Hr, AC	148.3	141.4	13.0	136.5
1650 F, 1/4-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 8-Hr, AC	146.1	137.7	12.8	138.1
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 2-Hr, AC	154.7	146.9	11.0	135.1
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 8-Hr, AC	155.3	146.7	13.0	——
Values averages of duplicate tests				

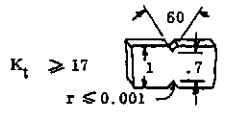


TABLE 3.02714 EFFECT OF ANNEALING TIME ON SMOOTH AND SHARP NOTCH TENSILE PROPERTIES OF DUPLEX AND TRIPLEX ANNEALED SHEET (13, p. 7)

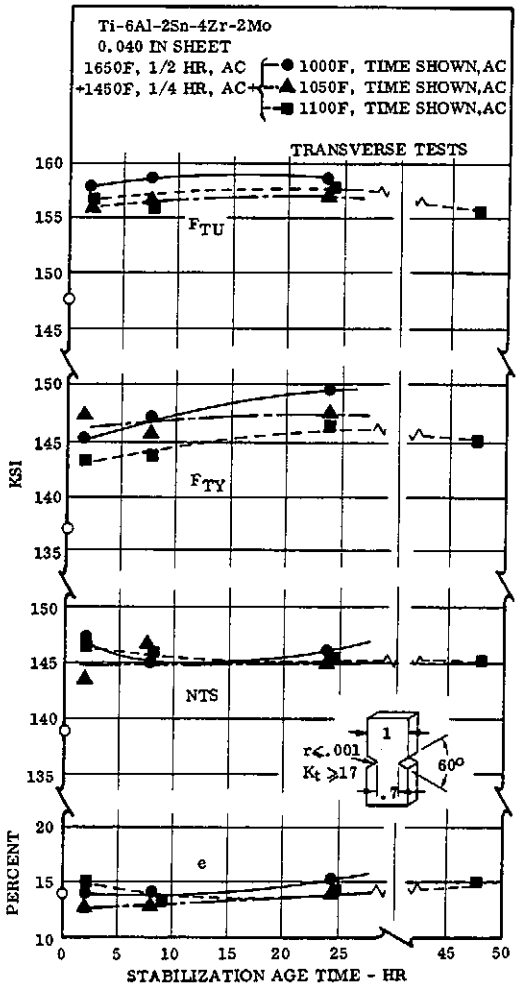


FIG. 3.02715 EFFECT OF STABILIZATION AGE TIME AND TEMPERATURE ON ROOM TEMPERATURE SMOOTH AND SHARP NOTCH TENSILE PROPERTIES OF TRIPLEX ANNEALED SHEET (13, p.20)

Alloy		Ti-6Al-2Sn-4Zr-2Mo			
Form		Sheet			
Condition		Duplex and Triplex Annealed			
Sheet Thickness in	Test Direction	F_{tu}(1) ksi	F_{ty}(1) ksi	e(2-in)(1) percent	NTS(1) ksi
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC					
0.040	L	147.7	133.7	10.8	146.4
"	T	145.1	132.6	11.8	144.6
0.080	L	154.7	142.2	12.0	144.7
"	T	139.9	126.3	11.0	132.7
0.125	L	139.3	125.1	14.0	139.0
"	T	143.0	129.0	15.0	136.3
1650F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 2-Hr, AC					
0.040	L	157.8	145.0	10.7	155.1
"	T	156.4	145.6	9.8	145.1
0.080	L	160.2	145.9	12.3	145.8
"	T	147.6	135.3	11.8	137.1
0.125	L	145.6	133.5	14.8	135.3
"	T	149.4	135.4	15.2	122.7

(1) Avg. of duplicate tests

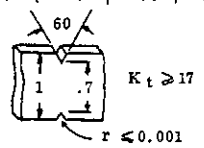


TABLE 3.02716 EFFECT OF THICKNESS ON ROOM TEMPERATURE SMOOTH AND SHARP NOTCH TENSILE PROPERTIES OF DUPLEX AND TRIPLEX ANNEALED SHEET (13, p.22)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2

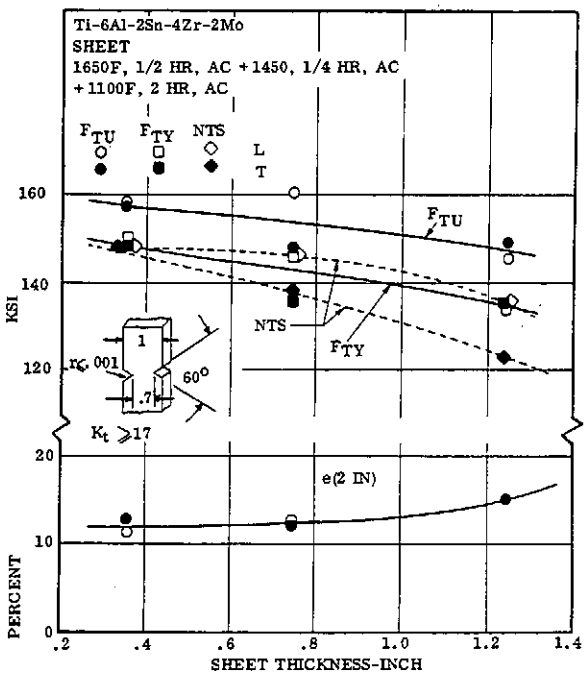


FIG. 3.02717 EFFECT OF THICKNESS ON ROOM TEMPERATURE SMOOTH AND SHARP NOTCH TENSILE PROPERTIES OF TRIPLEX ANNEALED SHEET (10, p.8)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

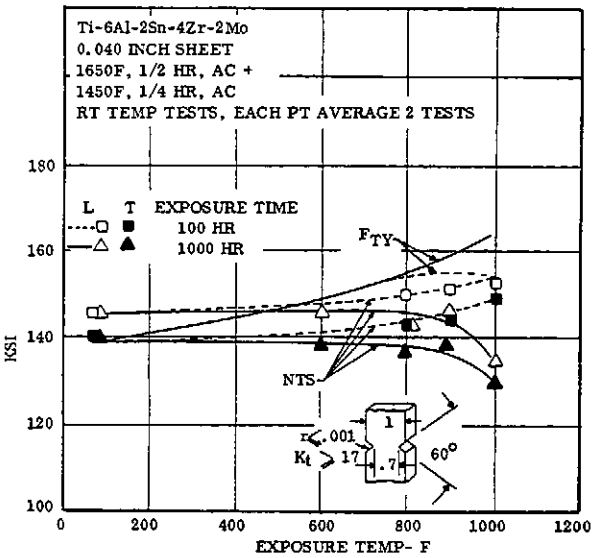


FIG. 3.02718 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE SHARP NOTCH STRENGTH OF DUPLEX ANNEALED SHEET (13,p.29)

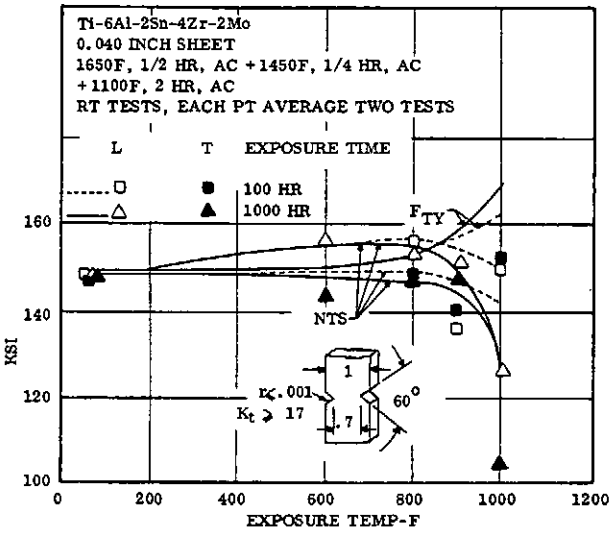


FIG. 3.027110 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE SHARP NOTCH STRENGTH OF TRIPLEX ANNEALED SHEET (13,pp.29-30)

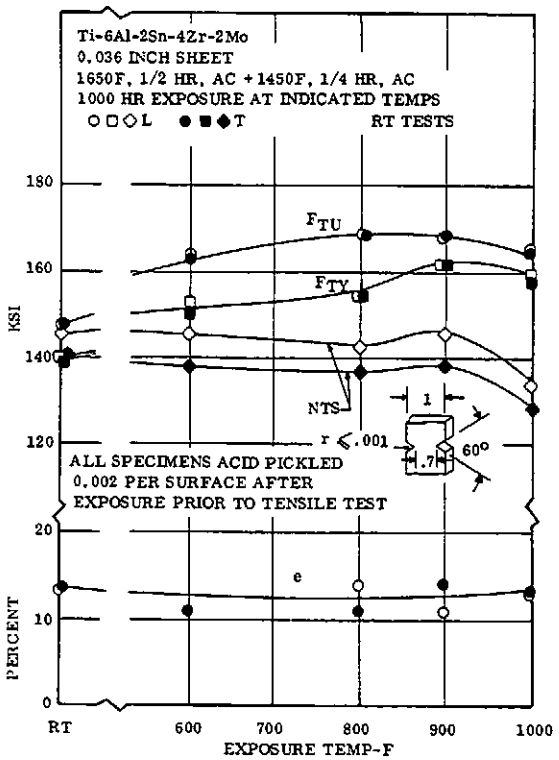


FIG. 3.02719 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE SMOOTH AND SHARP NOTCH TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET (10,p.9)

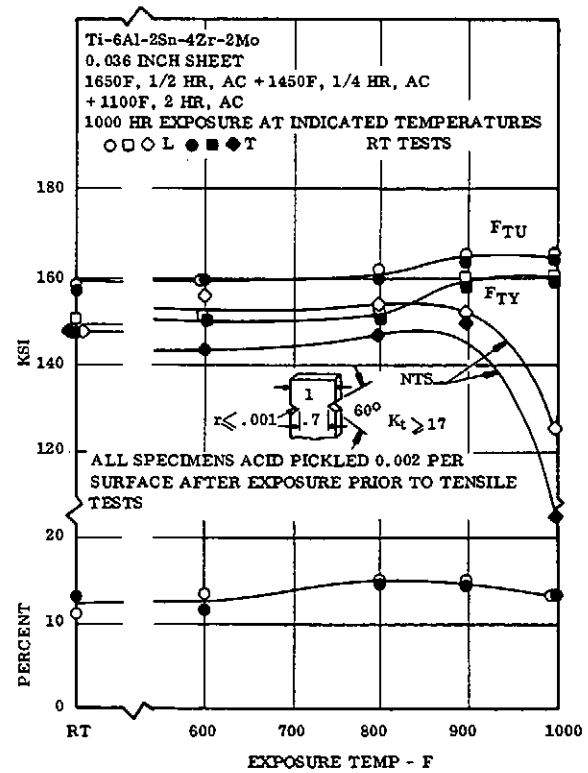


FIG. 3.027111 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE SMOOTH AND SHARP NOTCH TENSILE PROPERTIES OF TRIPLEX ANNEALED SHEET (10,p.9)

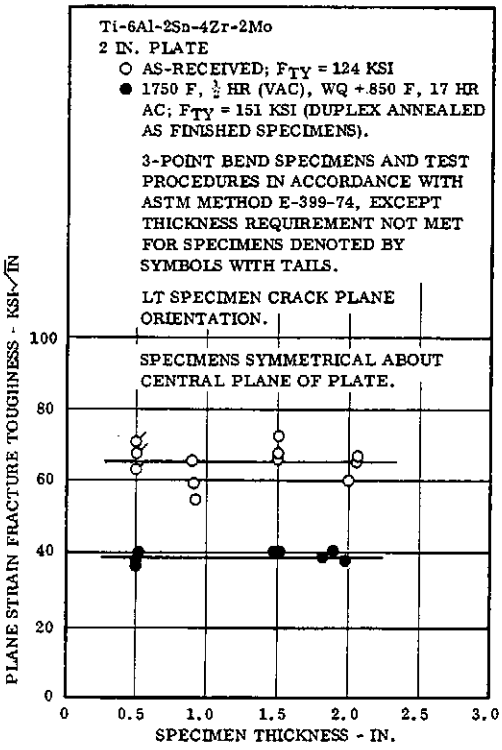


FIG. 3.02722. EFFECT OF SPECIMEN THICKNESS ON PLANE STRAIN FRACTURE TOUGHNESS OF AS-RECEIVED AND DUPLEX ANNEALED PLATE. (25), (26)

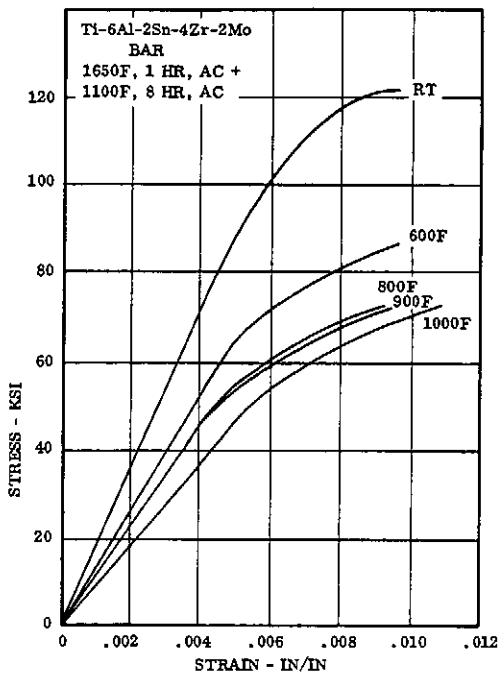


FIG. 3.0311 TYPICAL STRESS - STRAIN CURVES AT ELEVATED TEMPERATURES FOR DUPLEX ANNEALED BAR (10, p. 6)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Form	2-in x 4½-in bar					
		3-Point Bend Specimen				
Alloy Condition	F_{ty} ksi	crack plane orientation	thickness in	width in	crack length in	K_Q ksi√in
1650F, 1 hr, AC + 1100F, 8 hrs, AC	124	LT	0.503	1.003	0.524	62 (a)(b)
			0.504	1.001	0.494	63 (a)(b)
			0.506	1.004	0.527	64 (b)
	123	TL	0.504	1.004	0.507	51 (a)
			0.502	1.001	0.523	68 (b)
			0.505	1.001	0.511	56 (b)
	123	TS	0.501	0.971	0.489	55 (a)
			0.501	1.010	0.511	59 (a)(b)
			0.502	1.010	0.521	52 (c)
1790F, 1 hr, AC + 1100F, 8 hrs, AC	119	LT	0.504	1.001	0.498	71 (a)(b)
			0.504	1.001	0.569	81 (b)
			0.504	1.001	0.587	64 (b)
	123	TL	0.506	1.002	0.533	75 (a)(b)
			0.506	1.001	0.555	70 (b)
			0.505	1.001	0.523	67 (a)(b)
	123	TS	0.502	0.982	0.501	61 (a)(b)
			0.502	0.971	0.538	65 (a)(b)

(a) Excessive crack front curvature according to ASTM E-399-74
(b) Insufficient specimen thickness according to ASTM E-399-74
(c) Valid K_{IC}

TABLE 3.02723 PLANE STRAIN FRACTURE TOUGHNESS OF DUPLEX ANNEALED BAR, (80).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

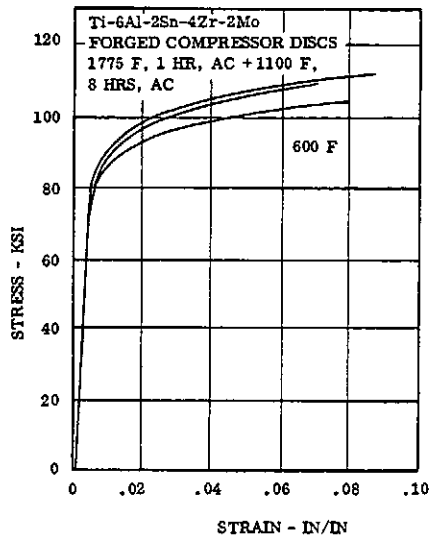


FIG. 3.0312 STRESS-STRAIN CURVES IN TENSION FOR DUPLEX ANNEALED FORGED COMPRESSOR DISCS AT 600 F. (82)

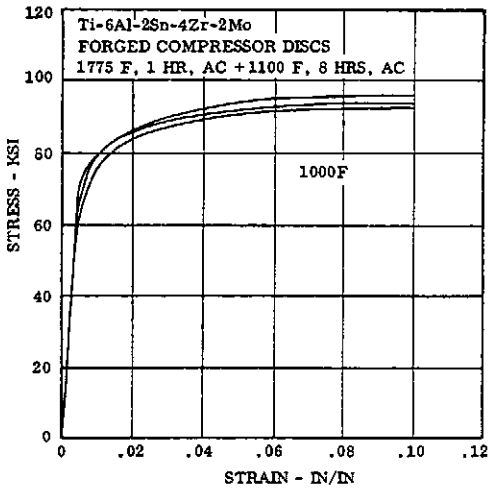


FIG. 3.0314 STRESS-STRAIN CURVES IN TENSION FOR DUPLEX ANNEALED FORGED COMPRESSOR DISCS AT 1000 F. (82)

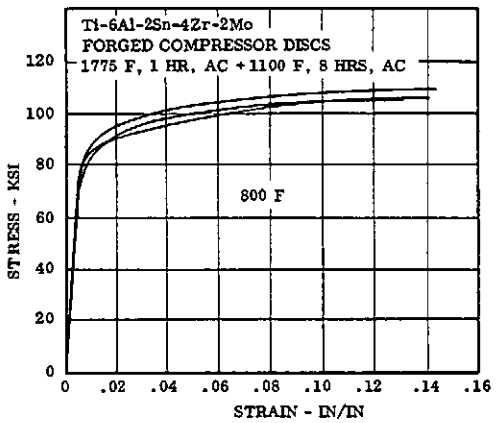


FIG. 3.0313 STRESS - STRAIN CURVES IN TENSION FOR DUPLEX ANNEALED FORGED COMPRESSOR DISCS AT 800 F. (82)

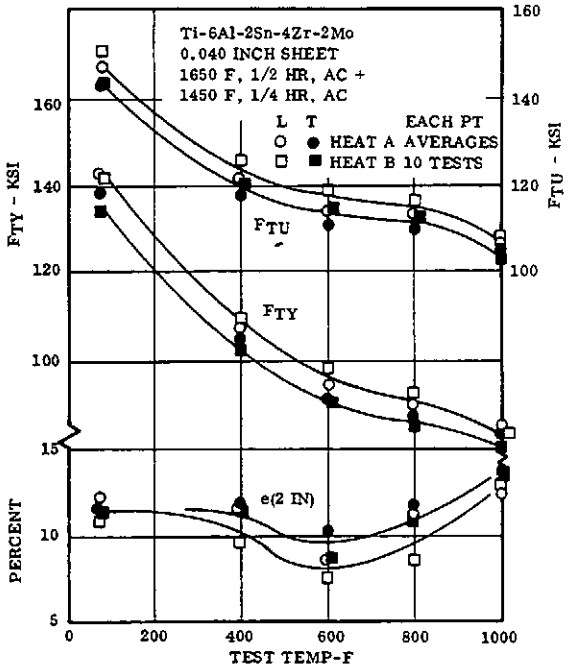


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF DUPLEX ANNEALED SHEET (1, p. 51)(3, p. 5)

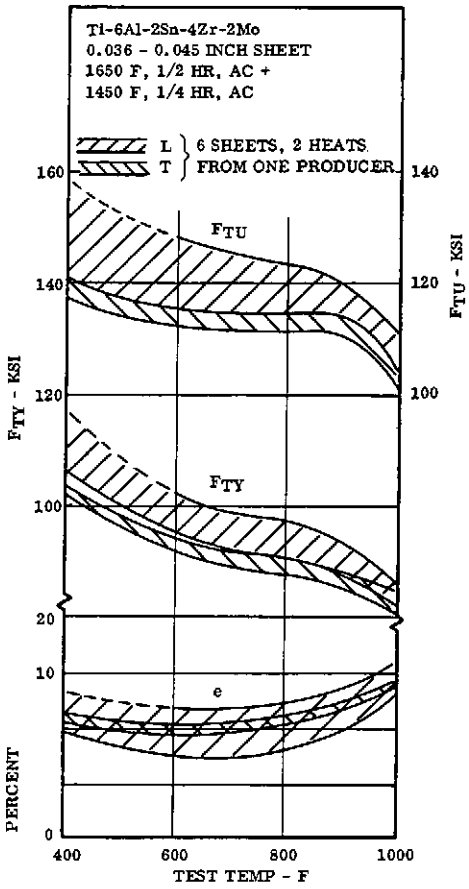


FIG. 3.0316 SPREAD OF TENSILE PROPERTIES AT ELEVATED TEMPERATURES FOR SIX DUPLEX ANNEALED SHEETS FROM FROM TWO HEATS (7, p. 44-45)

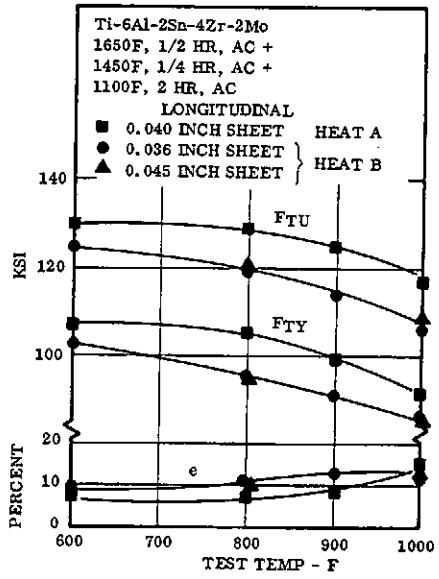


FIG. 3.0317 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF TRIPLEX ANNEALED SHEET (7, p. 44-45)

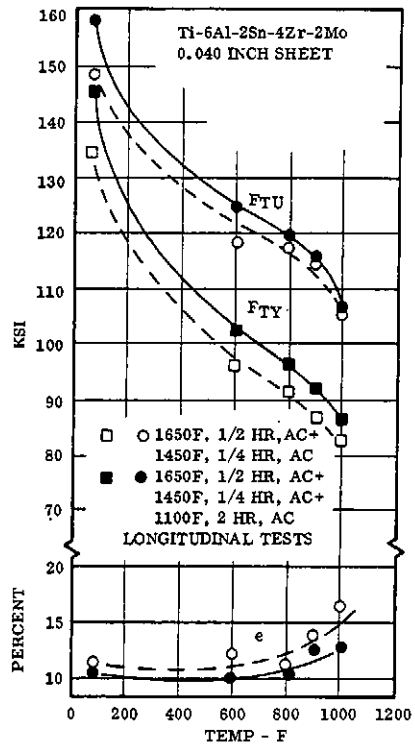


FIG. 3.0318 SMOOTH TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURES FOR DUPLEX AND TRIPLEX ANNEALED SHEET (13, p. 23)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

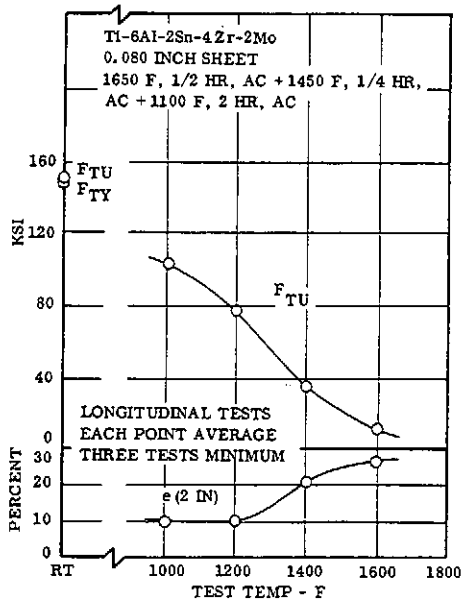


FIG. 3.0319 TENSILE PROPERTIES AT VERY HIGH TEMPERATURES FOR TRIPLEX ANNEALED SHEET. (28)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

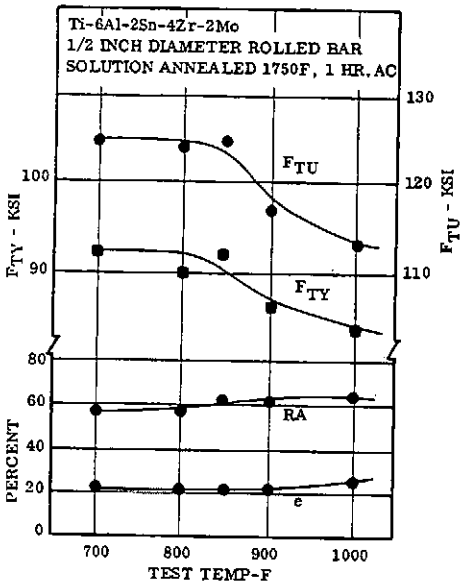


FIG. 3.03110 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION ANNEALED BAR (7, p. 43)

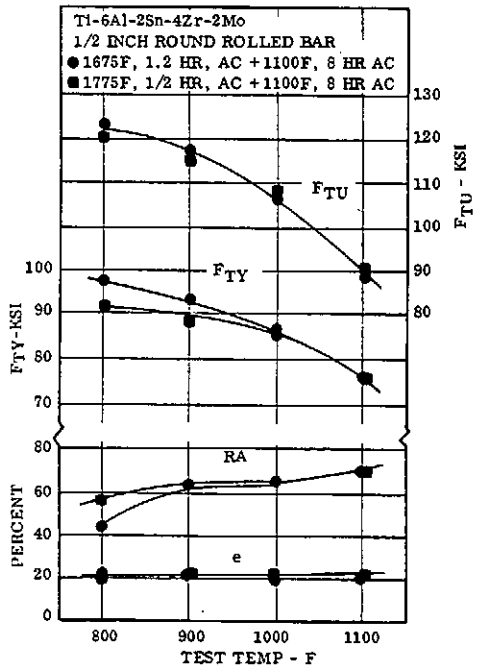


FIG. 3.03111 EFFECT OF TEST TEMP ON TENSILE PROPERTIES OF DUPLEX ANNEALED BAR (7, p. 43)

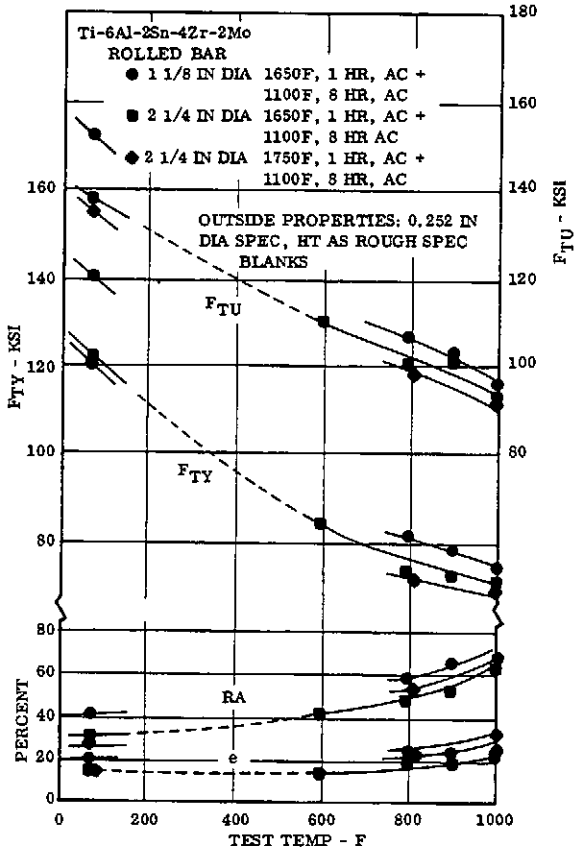


FIG. 3.03112 EFFECT OF SECTION SIZE ON ELEVATED TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED BAR (2, p. 15)

Ti	
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo				
Form	3/4 inch Diameter Bar				
Condition	1750F, 1 hr, AC + 1100F, 8 hrs, AC				
Test Temp F	Loading Rate[a]	F_{tu} ksi	e percent	RA percent	E 10^3 ksi
RT	Slow	152.0	17.0	44.0	16.0
	Dynamic	229.5	15.1	40.3	16.7[b]
900	Slow	106.0	21.0	60.3	11.6
	Dynamic	166.8	20.7	57.2	12.0[b]

(a) Slow loading was at conventional rate for tensile testing (strain rate $< 10^{-1}$ in/in/sec). Dynamic loading was at a strain rate $\sim 10^{3}$ in/in/sec from tests on split Hopkinson pressure-bar equipment.
(b) Dynamic modulus values were obtained from high-frequency fatigue experiments (strain rate $\sim 10^{2}$ in/in/sec).

TABLE 3.03113 EFFECT OF LOADING RATE ON ROOM TEMPERATURE AND 900F TENSILE PROPERTIES OF DUPLEX ANNEALED BAR, (24).

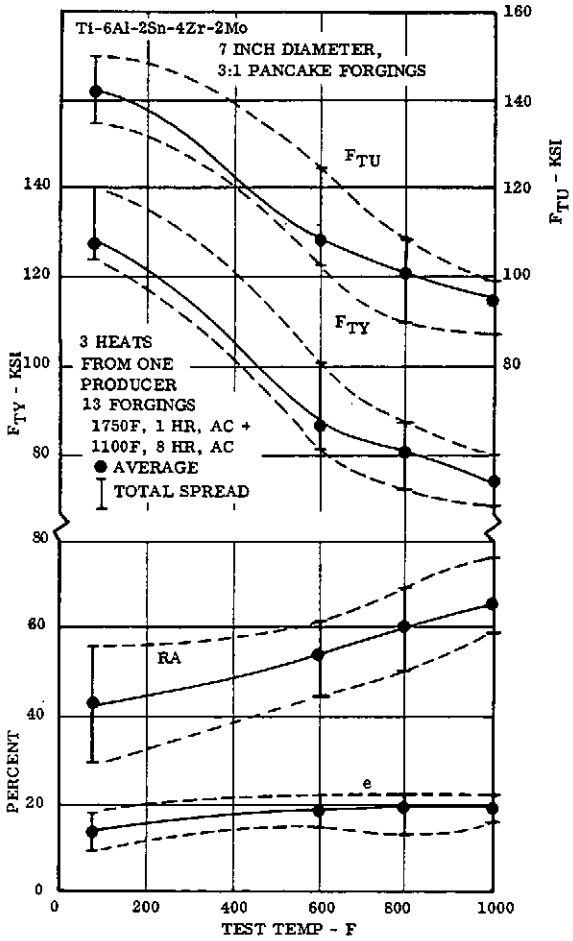


FIG. 3.03114 SPREAD OF TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURE FOR THIRTEEN DUPLEX ANNEALED PANCAKE FORGINGS FROM THREE HEATS (16)

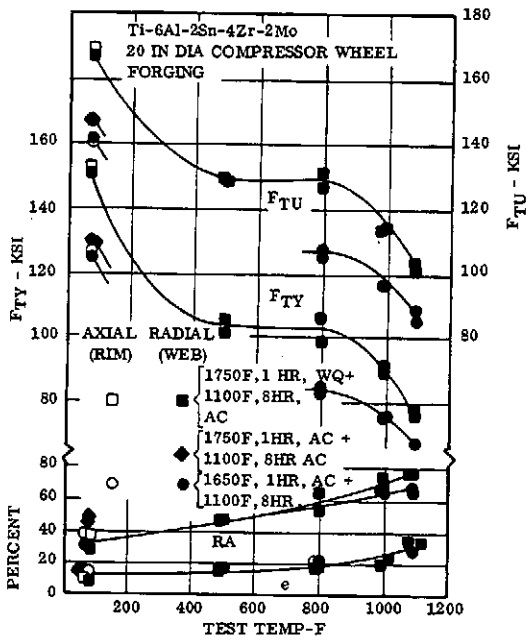


FIG. 3.03115 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF DUPLEX ANNEALED COMPRESSOR WHEEL FORGING (11,p.10)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo
Form	18.5 in Dia Compressor Hub Forging
Condition	1750F, 1 Hr, AC + 1100F, 8 Hr, AC

Test Temp F	Total Variation in Tensile Properties (all locations and directions) F_{tu} ksi	F_{ty} ksi	e percent	RA percent
70	136.4-146.8	124.4-135.6	8.0-18.0	15.2-42.3
400	113.4-119.0	95.8- 98.6	16.0-19.5	36.1-45.9
900	96.6-106.0	76.0- 81.8	15.0-21.0	30.0-57.6

TABLE 3.03116 TOTAL VARIATION IN TENSILE PROPERTIES FOR DUPLEX ANNEALED COMPRESSOR HUB (12, p. 13)

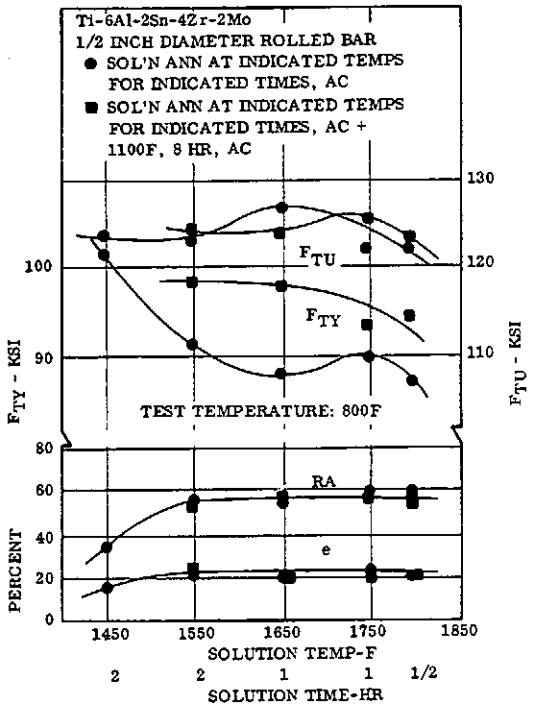


FIG. 3.3119 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON 800F TENSILE PROPERTIES OF SOLUTION ANNEALED AND DUPLEX ANNEALED BAR (7,p 43)

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	Forged Jet Engine Compressor Discs			
Condition	Alpha-Beta Forged + Beta Transus - 25F, 1 hr, AC or faster + 1100F, 8 hrs, AC (a)		Beta Preforged + Alpha-Beta Forged + Beta Transus - 25F, 1 hr, AC or faster + 1100F, 8 hrs, AC (b)	
Property \ Value	$\bar{X}^{(c)}$	$s^{(d)}$	$\bar{X}^{(c)}$	$s^{(d)}$
F_{tu} - ksi	100.6	1.5	100.4	1.9
F_{ty} - ksi	76.6	1.6	76.3	2.0
e(1-in) - percent	19.8	0.8	16.1	1.2
RA - percent	52.5	2.6	34.1	3.4

(a) 50 tests.
(b) 214 tests.
(c) Arithmetic mean.
(d) One standard deviation.
See Table 3.02113 for companion room temperature tensile properties.

TABLE 3.03117 TYPICAL 900F TENSILE PROPERTIES OF FORGED JET ENGINE COMPRESSOR DISCS, (77).

Alloy	Ti-6Al-2Sn-4Zr-2Mo
Form	Upset Forging
Condition	Beta Forged From 1910F (β + 100 F) + 1750F, 1 HR, AC + 1100F, 8 Hr, AC

Test Temp F	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
70	144.9	126.9	11.8	29.2
400	119.2	94.0	16.5	42.5
900	102.6	76.6	16.5	54.5

TABLE 3.03118 ROOM AND ELEVATED TEMPERATURE TENSILE PROPERTIES OF BETA-FORGED UPSET (12,p.17)

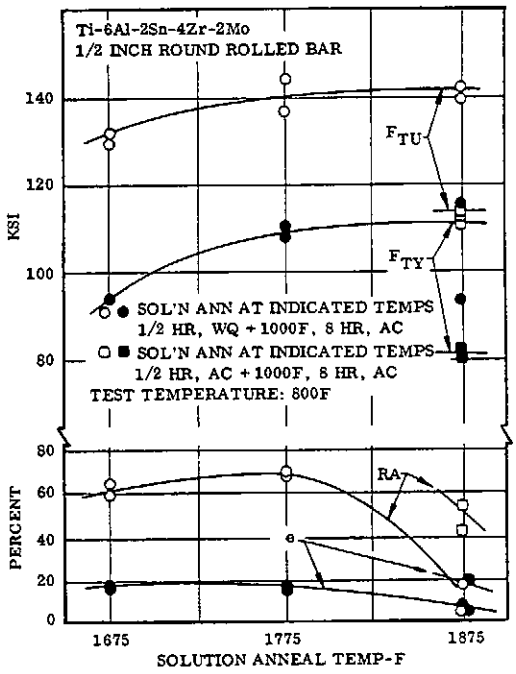


FIG. 3.03120 EFFECT OF QUENCH RATE FROM SOLUTION ANNEAL ON 800 F TENSILE PROPERTIES OF DUPLEX ANNEALED BAR (7,p.43)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

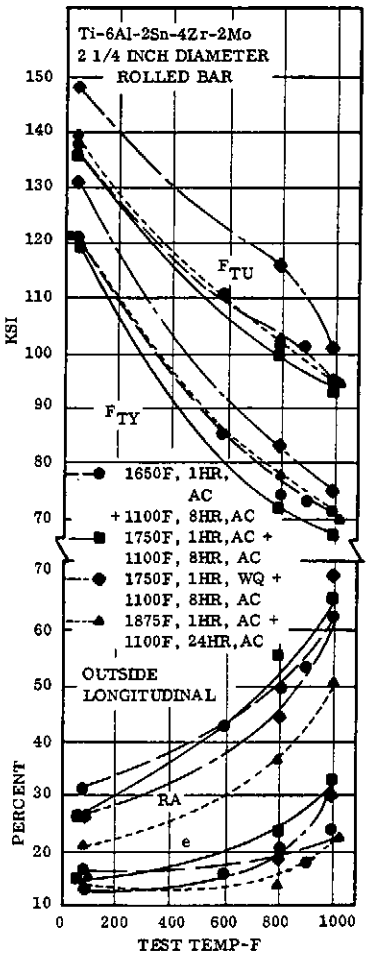


FIG. 3.03121 EFFECT OF HEAT TREATMENT ON ELEVATED TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED ROLLED BAR (13)p.64

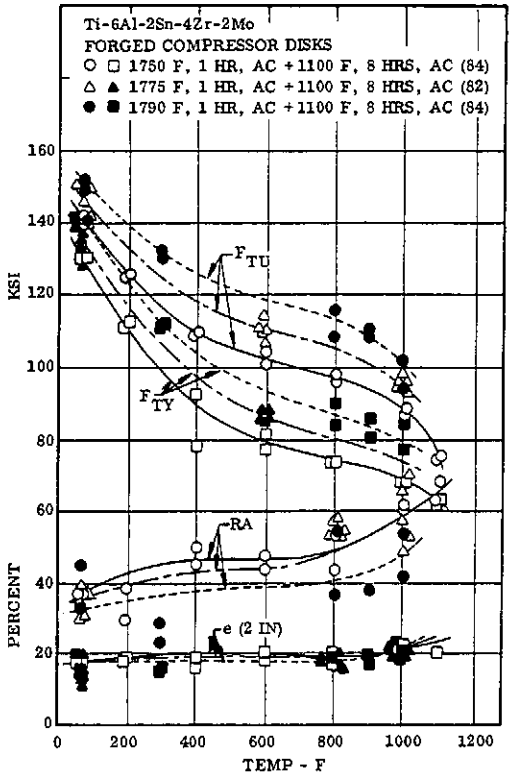


FIG. 3.03122 EFFECT OF SOLUTION ANNEALING TEMPERATURE ON ELEVATED TEMPERATURE TENSILE PROPERTIES OF FORGED COMPRESSOR DISKS. (82)(84)

Alloy				Ti-6Al-2Sn-4Zr-2Mo			
Form				20 in Dia Compressor Wheel			
Condition				Beta Forge + Duplex Annealed			
Location	Direction	Wheel No	Test Temp F	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
1650F, 1 Hr, AC + 1100F, 8 Hr, AC							
Rim	Axial	1	70	138.2	124.8	11.5	31.1
Web	Radial	1	70	139.8	122.4	14.0	25.1
1750F, 1 Hr, WQ + 1100F, 8 Hr, AC							
Rim	Axial	2	70	153.4	135.4	6.5	17.4
Web	Radial	2	70	162.6	142.4	7.0	15.2
1775F, 1 Hr, AC + 1100F, 8 Hr, AC							
Rim	Axial	2	70	144.0	125.6	13.5	40.8
Web	Radial	2	70	144.6	126.5	12.3	34.2
Web	Radial	2	1000	93.4	71.7	22.0	61.4
1775F, 1 Hr, WQ + 1100F, 8 Hr, AC							
Web	Radial	1	70	175.6	154.4	8.8	25.5
Web	Radial	2	70	173.3	154.9	9.2	29.6
Web	Radial	1	1000	124.0	96.9	21.2	68.2
Web	Radial	2	1000	124.0	95.1	20.8	66.9

TABLE 3.03123 EFFECT OF SOLUTION ANNEAL TREATMENT ON ROOM TEMPERATURE AND 1000F TENSILE PROPERTIES OF BETA-FORGED, DUPLEX ANNEALED COMPRESSOR WHEEL (11, p. 11)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	3-in Square,(a)Finish Forged from Beta Field (1875F)			
Condition	Duplex Annealed			
Test Temp F	F_{tu} ksi	F_{ty} ksi	RA percent	e percent
	1750F, 1 Hr, WQ + 1100F, 8 Hr, AC			
800	118	92	50	21
1000	105	82	61	24
	1750F, 1 Hr, AC + 1100F, 8 Hr, AC			
800	102	79	44	22
1000	90	73	55	26

(a) Outside longitudinal properties

TABLE 3.03124, EFFECT OF QUENCH RATE FROM SOLUTION ANNEAL ON ELEVATED TEMPERATURE TENSILE PROPERTIES OF DUPLEX ANNEALED FORGING, (7, p. 46)

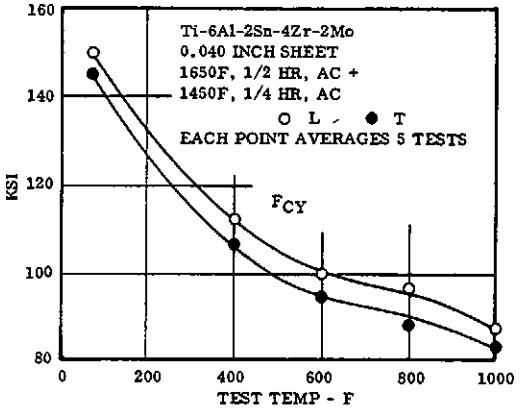


FIG. 3.0321 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF DUPLEX ANNEALED SHEET (1, p. 67)

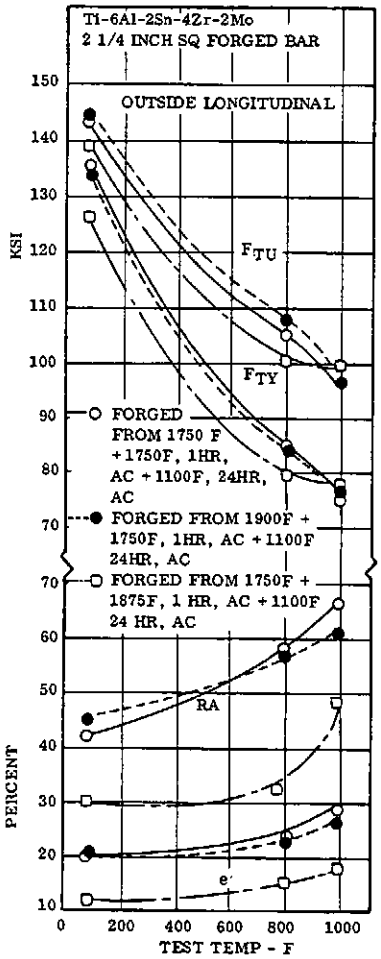


FIG. 3.03125 EFFECT OF FORGING AND ANNEALING TEMPERATURES ON THE ELEVATED TEMPERATURE TENSILE PROPERTIES OF FORGED BAR (13, p. 65)

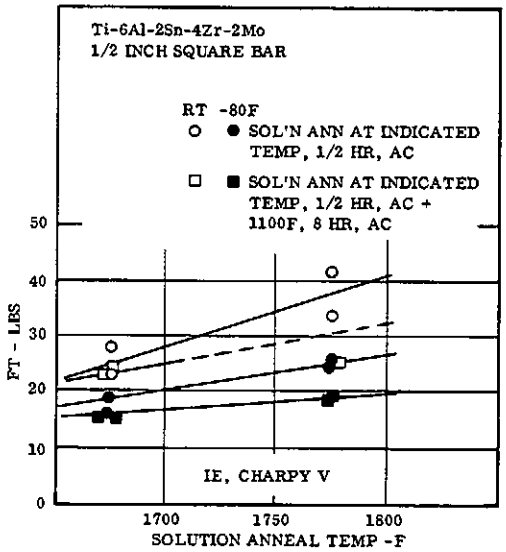


FIG. 3.0331 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON STANDARD CHARPY-V IMPACT ENERGY FOR SOLUTION ANNEALED AND DUPLEX ANNEALED BAR AT ROOM TEMPERATURE AND -80F (7, p. 65)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

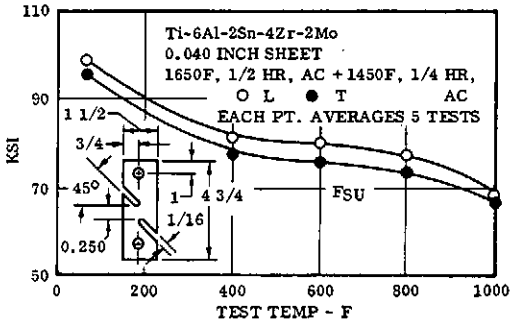


FIG. 3.0351 EFFECT OF TEST TEMPERATURE ON ULTIMATE SHEAR STRENGTH OF DUPLEX ANNEALED SHEET (1, p. 86)(3, p. 10)

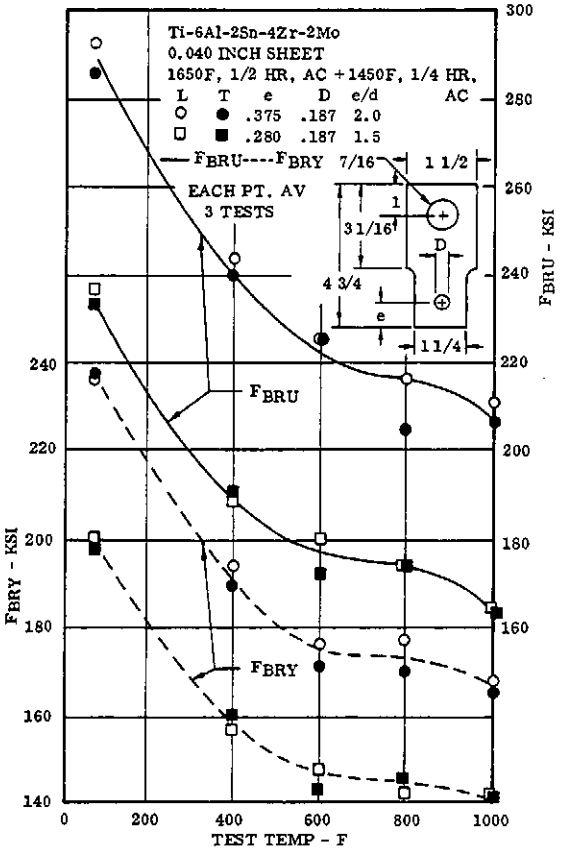


FIG. 3.0361 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF DUPLEX ANNEALED SHEET (1, p. 77)

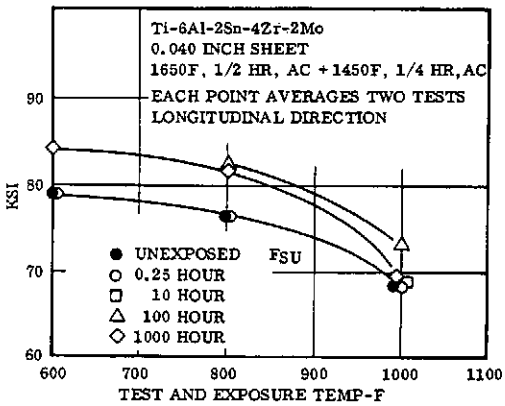


FIG. 3.0352 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ULTIMATE SHEAR STRENGTH OF DUPLEX ANNEALED SHEET AT THE EXPOSURE TEMPERATURE (1, p. 267)

Alloy	Ti-6Al-2Sn-4Zr-2Mo		
Form	0.040 - in Sheet		
Condition	1650 F, 1/2 - Hr, AC + 1450 F, 1/4 - Hr, AC		
	45° 0.375 0.5 R=0.025 K_t = 3 Long. Dir.		
Test Temp-F	70	400	800
Notch Strength - ksi	170	138	133
F_{ty} - ksi	142	107	92

TABLE 3.03711 MILD-NOTCH STRENGTH OF DUPLEX ANNEALED SHEET AT ROOM AND ELEVATED TEMPERATURES (1, pp. 51, 62)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

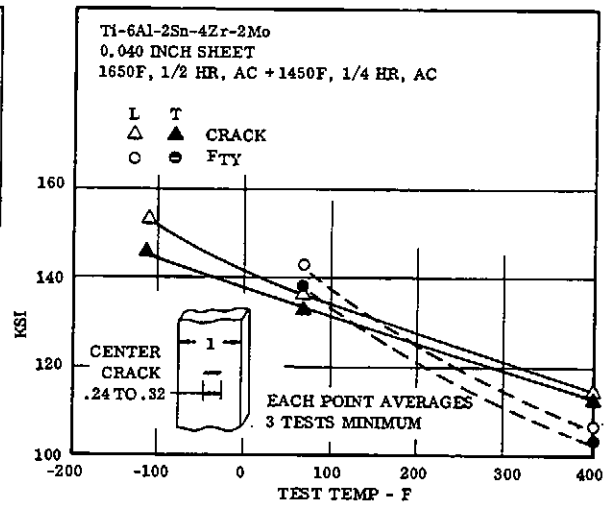


FIG. 3.03712 EFFECT OF TEST TEMPERATURE ON CENTER CRACK TENSILE AND YIELD STRENGTHS OF DUPLEX ANNEALED SHEET (1, pp. 51 AND 285)

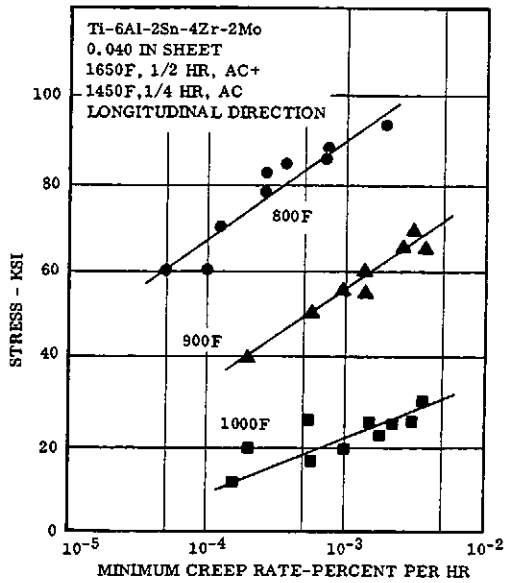


FIG. 3.0411 MINIMUM CREEP RATE CURVES AT 800, 900, AND 1000F, FOR DUPLEX ANNEALED SHEET (1, P. 271)

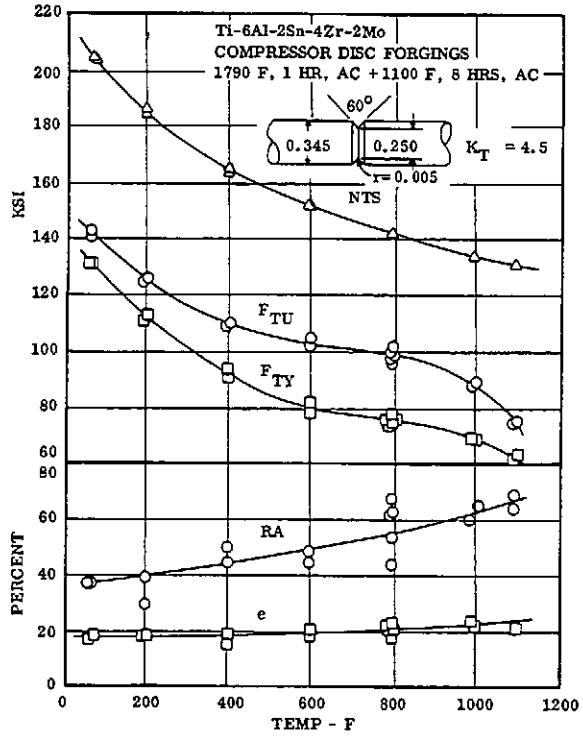


FIG. 3.03713 SMOOTH AND MILD-NOTCH TENSILE PROPERTIES OF DUPLEX ANNEALED COMPRESSOR DISC FORGINGS AT ROOM AND ELEVATED TEMPERATURES. (68)

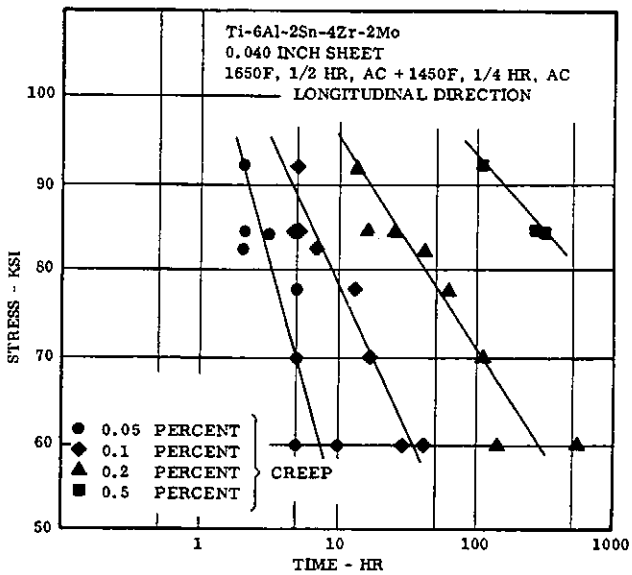


FIG. 3.0421 CREEP DEFORMATION CURVES AT 800F FOR DUPLEX ANNEALED SHEET (1, p. 271)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

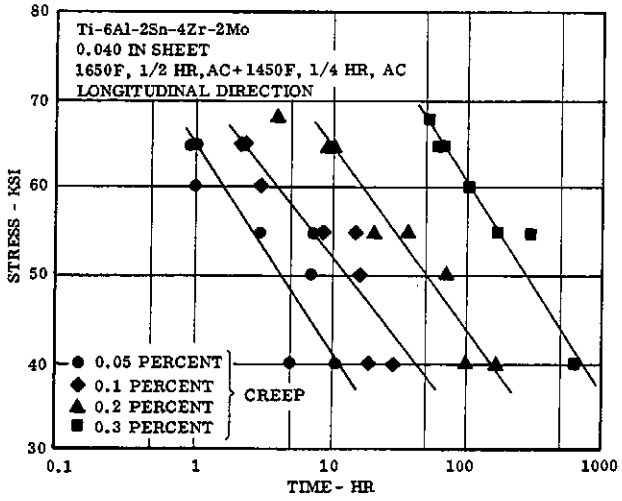


FIG. 3.0422 CREEP DEFORMATION CURVES AT 900F FOR DUPLEX ANNEALED SHEET (1, P.271)

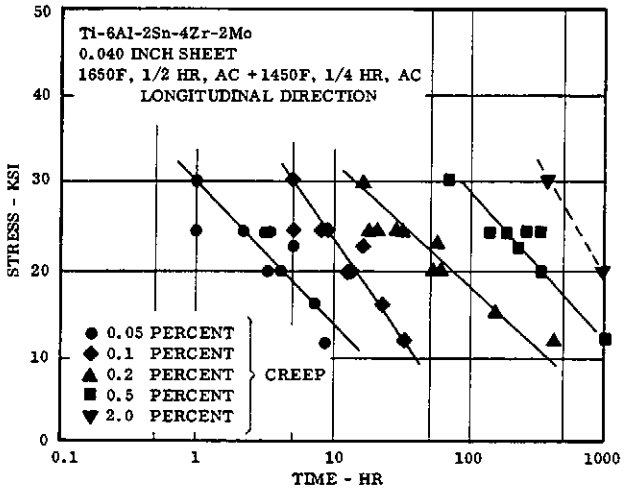


FIG. 3.0423 CREEP DEFORMATION CURVES AT 1000 F FOR DUPLEX ANNEALED SHEET (1, p. 271)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy			Ti-6Al-2Sn-4Zr-2Mo		
Form			Sheet		
Condition			Duplex and Triplex Annealed		
150-Hr Exposure at			Creep Deformation, percent		
Temp F	Stress ksi	Direction	0.040-in Gage	0.080-in Gage	0.125-in Gage
1650 F, 1/2 Hr, AC + 1450 F, 1/4-Hr, AC					
800	65	L	0.18	0.16	0.42(1)
		T	0.22	0.10	0.22
900	45	L	0.23		0.16
		T	0.22	0.22	0.19
1000	25	L	0.33	0.27	0.30
		T	0.39	0.27	0.28
1650 F, 1/2-Hr, AC + 1450 F, 1/4-Hr, AC + 1100 F, 2-Hr, AC					
800	65	L	0.07	0.05	0.06(2)
		T	0.07	0.10	0.06
900	45	L	0.15	0.12	0.19
		T	0.18	0.14	0.14
1000	25	L	0.26	0.24	0.22
		T	0.29		0.19

(1) Creep exposure time was 162.7 Hrs
(2) Creep exposure time was 126 Hrs

TABLE 3.0424 EFFECT OF SHEET THICKNESS ON 150-HOUR CREEP DEFORMATION OF DUPLEX AND TRIPLEX ANNEALED SHEET (13, p. 25)

Alloy				Ti-6Al-2Sn-4Zr-2Mo	
Form				Sheet	
Condition				Triplex Annealed	
				Creep Deformation percent	
Sheet Thickness in	Creep Exposure Temp F	Stress ksi	Time Hr	1650F, 1/2Hr, AC + 1450F, 1/4Hr, AC + 1000F, 8-Hr, AC	1650F, 1/2Hr, AC + 1450F, 1/4Hr, AC + 1100F, 2-Hr, AC
0.040	800	65	150	0.07	0.07
	900	45	150	0.19	0.15
	1000	25	150	0.40	0.26
	900	20	1000	0.11	0.09
	950	15	1000	0.14	0.15
	1000	10	1000	0.33	0.19
0.080	800	65	150	0.10	0.05
	900	45	150	0.14	0.12
	1000	25	150	0.24	0.24
0.125	800	65	150	0.07	0.06
	900	45	150	0.12	0.19
	1000	25	150	0.25	0.22

Results of single longitudinal tests

TABLE 3.0425 EFFECT OF STABILIZATION AGING TEMPERATURE ON CREEP DEFORMATION OF TRIPLEX ANNEALED SHEET OF VARIOUS THICKNESSES (13, p. 18)

Alloy	Ti-6Al-2Sn-4Zr-2Mo		
Form	2 1/4 in Diameter Rolled Bar		
Heat Treatment (1)	150 Hr Exposure at Temp F	Stress ksi	(2) percent
1700F, 1 Hr, WQ + 1100F, 8 Hr, AC	800	65	0.09
	900	45	0.21
	1000	25	0.27
	1100	10	0.31
1750F, 1 Hr, WQ + 1100F, 8 Hr, AC	800	65	0.12
	900	45	0.22
	1000	25	0.29
	1100	10	0.20

(1) Duplex annealed as full sections
(2) Creep Deformation, outside longitudinal tests

TABLE 3.0426 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON 150-HOUR CREEP OF DUPLEX ANNEALED ROLLED BAR (13, p. 46)

Alloy	Ti-6Al-2Sn-4Zr-2Mo		
Form	2 1/4-in Diameter Rolled Bar		
Condition	Duplex Annealed (1)		
Heat Treatment	150-Hr Exposure at Temp F	Stress ksi	(2) percent
1750F, 1 Hr, AC + 1000F, 8 Hr, AC	800	65	0.23
	900	45	0.19
	1000	25	0.18
	1100	10	0.13
1750F, 1 Hr, AC + 1100F, 8 Hr, AC	800	65	0.12
	900	45	0.12
	1000	25	0.11
	1100	10	0.11

(1) Duplex annealed as full sections
(2) Creep Deformation, outside longitudinal tests

TABLE 3.0427 EFFECT OF STABILIZATION ANNEAL TEMPERATURE ON 150-HOUR CREEP OF DUPLEX ANNEALED ROLLED BAR (13, p. 46)

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	1 1/8 in Diameter Bar			
Condition	1650F, 1 Hr, AC + 1100F, 8 Hr, AC			
Creep Exposure Temp F	Creep Exposure Stress ksi	Time to 0.1 percent Creep Hr	Time to 0.5 percent Creep Hr	
600	50	0.044 percent after 3065 Hr		
600	80	0.023 percent after 3045 Hr		
800	59	83.0		
800	69	78.5		
900	55	14.6		
900	55	23.0		
800	75		3220	
800	75		3295	

TABLE 3.0429 CREEP PROPERTIES OF DUPLEX ANNEALED BAR (15)

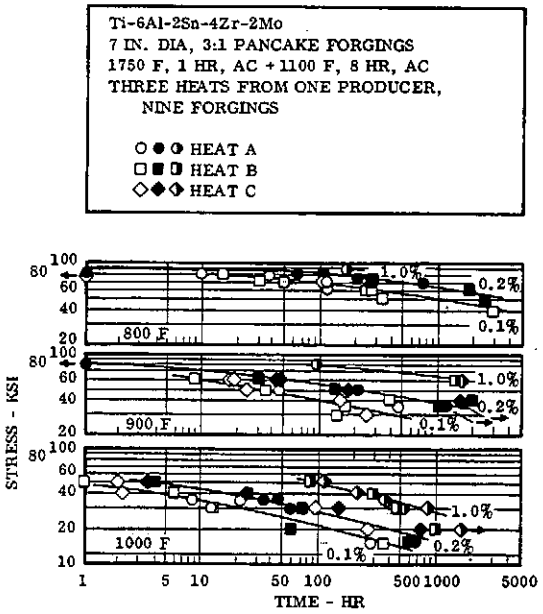


FIG. 3.04212. CREEP DEFORMATION CURVES AT 800 F TO 1000 F FOR DUPLEX ANNEALED PANCAKE FORGINGS. (83)

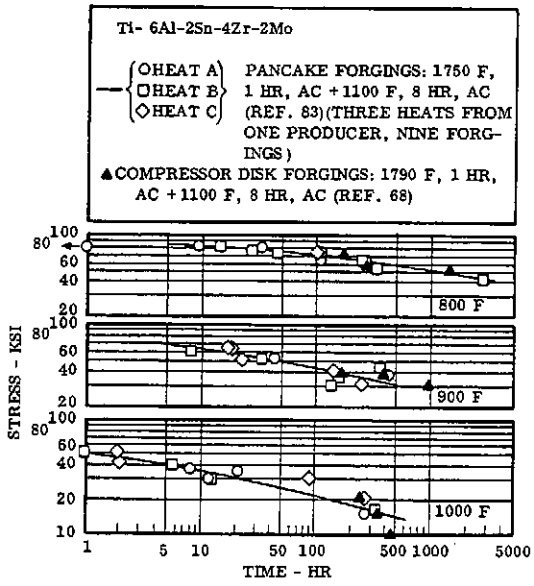


FIG. 3.04214. EFFECT OF SOLUTION ANNEALING TEMPERATURE ON TIME TO 0.1 PERCENT CREEP DEFORMATION AT 800 F, 900 F, AND 1000 F FOR DUPLEX ANNEALED FORGINGS. (83)(68)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo		
Form	20-Inch Diameter Compressor Wheel Forging[a]		
Condition	Duplex Annealed		
Stress ksi	Temp F	Hrs to Creep 0.1%	Hrs to Creep 0.2%	150-Hr Creep Deformation %
	1650F, 1 hr, AC + 1100F, 8 hrs, AC			
50	900	27	102	0.261
55	900	38	>150	0.2
45	950	59	>150	0.2
35	1000	15	56	0.368
15	1100	28	56	
	1750F, 1 hr, AC + 1100F, 8 hrs, AC			
50	900	73	Not Reached	0.168
55	900	25	>150	0.2
45	950	60	>150	0.2
35	1000	15	80	0.301
35	1000	47	117	
15	1100	6	37	
	1750F, 1 hr, WQ + 1100F, 8 hrs, AC			
50	900	17	61	0.301
35	1000	2.5	8	1.03

[a]All tests in axial direction.

TABLE 3.04213 EFFECT OF SOLUTION ANNEAL TEMPERATURE AND QUENCH RATE ON CREEP PROPERTIES AT 900F TO 1100F FOR DUPLEX ANNEALED COMPRESSOR WHEEL FORGING (2, p. 11)

Source	(83)	(68)
Alloy	Ti-6Al-2Sn-4Zr-2Mo	
Form	Pancake Forging	Compressor Disk Forging
Condition	1750F, 1 hr, AC + 1100F, 8 hrs, AC	1790F, 1 hr, AC + 1100F, 8 hrs, AC
Time to 2.0% Creep at 1000F, 30 ksi	695 1244	780 679

TABLE 3.04215 EFFECTS OF SOLUTION ANNEAL TEMPERATURE ON TIME TO 2.0 PERCENT CREEP AT 1000F, 30 KSI FOR DUPLEX ANNEALED FORGINGS (83)(68)

Alloy	Ti-6Al-2Sn-4Zr-2Mo	
Form	15 in Diameter Forged Disc	
Condition	Duplex Annealed	
Direction	950F - 35 ksi Exposure: Time to 0.1 percent Plastic Deformation Hr	950F - 35 ksi Exposure: 150-Hr Total Plastic Deformation percent
	1750F, 1-Hr, AC + 1100F, 8 Hr, AC	
Chordal	44	0.280
Radial	17	0.240
	1790F (B-25F), 1-Hr, AC + 1100F, 8-Hr, AC	
Chordal	43	0.110
Radial	37	0.131

TALBE 3.04216 EFFECT OF SOLUTION ANNEALING AT HIGH TEMPERATURE (BETA - 25F) ON CREEP DEFORMATION FOR DUPLEX ANNEALED FORGING (14, p. 17)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

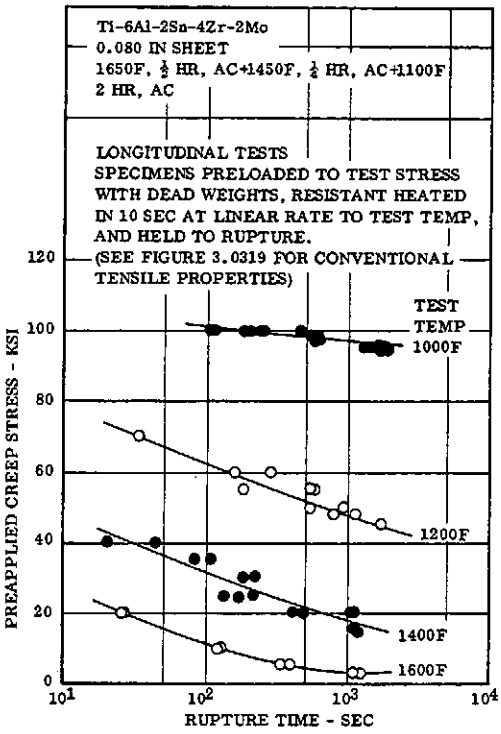


FIG. 3.0431 SHORT-TIME CREEP RUPTURE STRENGTH OF TRIPLEX ANNEALED SHEET SPECIMENS PRELOADED AND RAPIDLY HEATED TO TEST TEMP. (28)

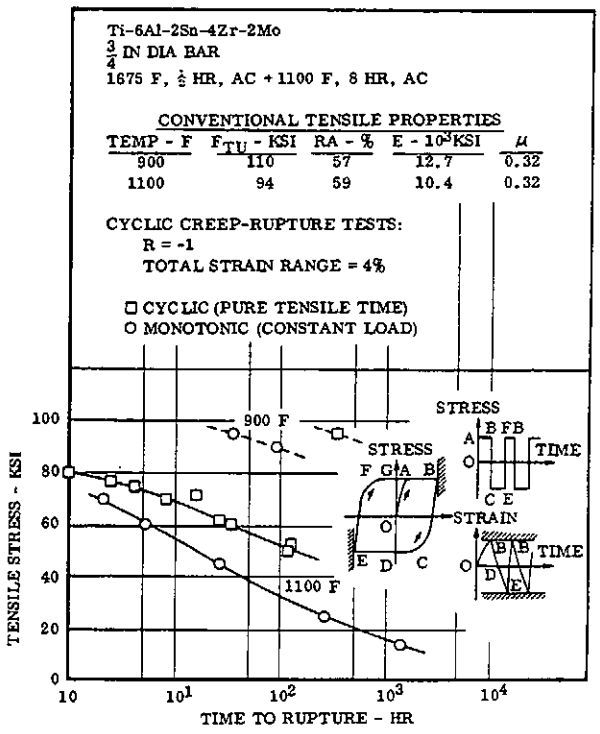


FIG. 3.0433. MONOTONIC CREEP-RUPTURE AND STRAIN-LIMITED CYCLIC CREEP-RUPTURE CURVES AT 900F AND 1100 F FOR DUPLEX ANNEALED BAR, (29) (29)

Alloy		Ti-6Al-2Sn-4Zr-2Mo		
Form		1 1/8 in Diameter Bar		
Condition		1650F, 1 HR, AC + 1100F, 8 Hr, AC		
Creep Exposure Temp F	Stress ksi	Stress Rupture Life-Hr	e percent	RA percent
1000	57.5	347.6	60.0	67.2
		307.5	50.7	63.0
		343.0	45.6	64.3
1000	70.0	94.2	48.1	63.9
		105.0	46.3	67.0
		105.5	48.7	62.5
		113.5	43.3	65.1

TABLE 3.0432 1000 F STRESS RUPTURE PROPERTIES OF DUPLEX ANNEALED BAR (15)

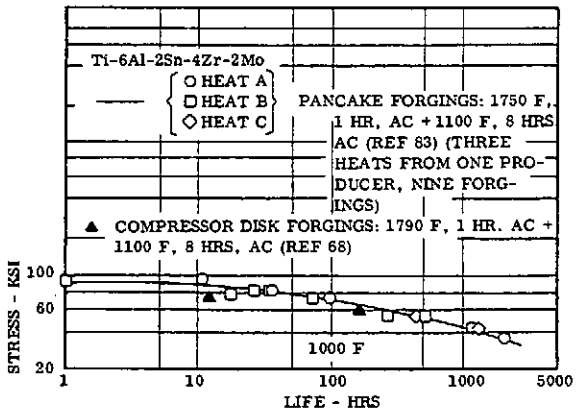


FIG. 3.0434 EFFECT OF SOLUTION ANNEAL TREATMENT ON 1000 F STRESS RUPTURE PROPERTIES OF DUPLEX ANNEALED FORGINGS. (83)(68)

Alloy		Ti-6Al-2Sn-4Zr-2Mo
Form		20-in Diameter Compressor Wheel Forging
Condition		Duplex Annealed
		RT Notch Stress Rupture, K_t=3.8
Location	Direction	Stress at Failure ksi / Time to Failure Hr
1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC		
Rim	Axial	190 / 3.3
Web	Radial	190 / 2.0
1750 F, 1-Hr, AC + 1100 F, 8-Hr, AC		
Web (Center punch-out)	Radial	200 / 2.5
		200 / 1.0
1750 F, 1-Hr, WQ + 1100 F, 8-Hr, AC		
Rim	Axial	200 / >5.0
Web	Radial	200 / >5.0
1775 F, 1-Hr, AC + 1100 F, 8-Hr, AC		
Web (Center punch out)	Radial	200 / 1.5
		200 / 1.4

Note: Stress increased from 150-ksi in 10-Ksi increments every 5-Hrs

TABLE 3.0435 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE MILD-NOTCH STRESS RUPTURE PROPERTIES OF DUPLEX ANNEALED COMPRESSOR WHEEL FORGING, (11, p. 12).

Alloy			Ti-6Al-2Sn-4Zr-2Mo
Form			20-in Diameter Compressor Wheel Forging
Condition			Beta Forged + Duplex Annealed
			RT Notch Stress Rupture, K_t=3.8
Location	Direction	Wheel No.	Stress at Failure ksi / Time to Failure Hr
1650 F, 1-Hr, AC + 1100 F, 8-Hr, AC			
Rim	Axial	1	200 / 3.25
Web	Radial	1	190 / 1.5
1750 F, 1-Hr, WQ + 1100 F, 8-Hr, AC			
Web	Radial	2	200 / >5.0
1775 F, 1-Hr, WQ + 1100 F, 8-Hr, AC			
Web	Radial	1	200 / 1.0
Web	Radial	1	200 / >5.0
Web	Radial	2	200 / >5.0
Web	Radial	2	200 / >5.0

Note: Stress increased from 150-ksi in 10-ksi increments every 5-Hrs

TABLE 3.0436 EFFECT OF SOLUTION ANNEAL TEMPERATURE ON ROOM TEMPERATURE MILD-NOTCH STRESS RUPTURE PROPERTIES OF DUPLEX ANNEALED, BETA FORGED COMPRESSOR WHEEL FORGING, (11, p. 12).

Alloy			Ti-6Al-2Sn-4Zr-2Mo					
Form			18.5 in Diameter Compressor Hub Forging					
Condition			1750F, 1 Hr, AC + 1100F, 8 Hr, AC + Re-Heat Treated as Noted					
			RT Tensile Properties				(1) - *	
Re-Treatment	Location	Direction	F_{tu} ksi	F_{ty} ksi	e percent	RA percent	(a)	(b)
(c)	Rim	Tang.	144.6	134.8	14.0	40.1		
	Web	Rad.	148.6	135.8	16.0	38.2		
	Rim	Axial					170	2.2
	Web	Axial					180	2.0
(d)	Rim	Tang.	153.0	137.0	16.5	34.4		
	Web	Rad.	147.4	134.0	15.0	33.8		
	Rim	Axial					190	.25
	Web	Axial					180	.75

(1) R T notch stress rupture, K_t =3.8
* Stress increased from 150-ksi in 10-ksi increments every 5 hours.
(a) Stress at failure - ksi
(b) Time to failure-hr
(c) 1750F, 1-Hr, AC +1100F, 8-Hr, AC
(d) 1790F (Beta-25F), 1 Hr, AC + 1100F, 8 Hr, AC

TABLE 3.0437 EFFECT OF SOLUTION ANNEALING AT HIGH TEMPERATURE (BETA - 25 F) ON ROOM TEMPERATURE TENSILE AND MILD-NOTCH STRESS RUPTURE PROPERTIES OF DUPLEX ANNEALED COMPRESSOR HUB FORGING (12, p. 16)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

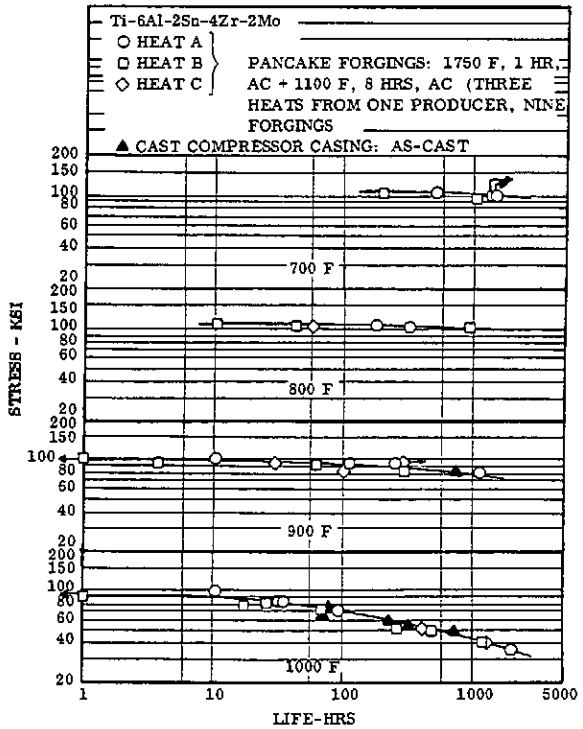


FIG. 3.0439 STRESS RUPTURE PROPERTIES AT 700 F TO 1000 F FOR DUPLEX ANNEALED PANCAKE FORGINGS AND AS - CAST COMPRESSOR CASING. (83)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

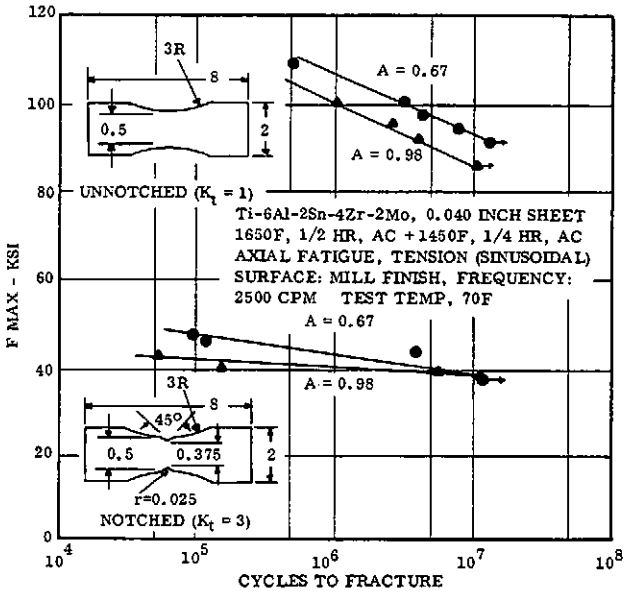


FIG. 3.051 AXIAL LOAD SMOOTH AND NOTCH FATIGUE PROPERTIES AT 70F FOR DUPLEX ANNEALED SHEET (1, pp. 277-278)

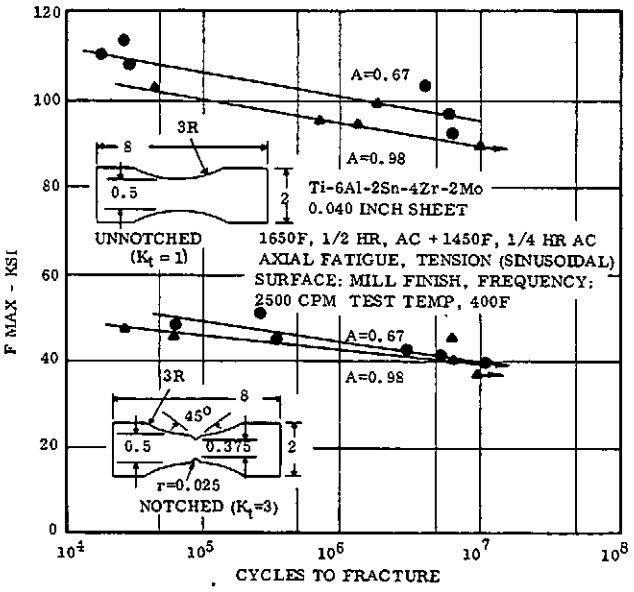


FIG. 3.052 AXIAL LOAD SMOOTH AND NOTCH FATIGUE PROPERTIES AT 400F FOR DUPLEX ANNEALED SHEET (1, pp. 277-278)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

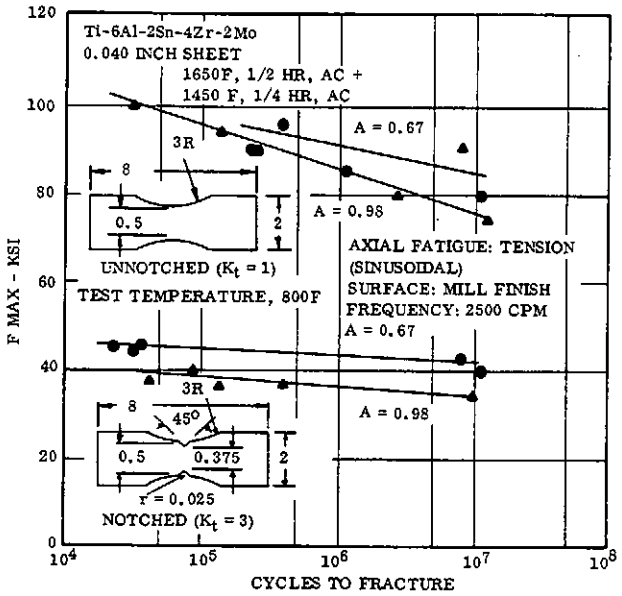


FIG. 3.053 AXIAL LOAD SMOOTH AND NOTCH FATIGUE PROPERTIES AT 800 F FOR DUPLEX ANNEALED SHEET (1,pp. 276-279)

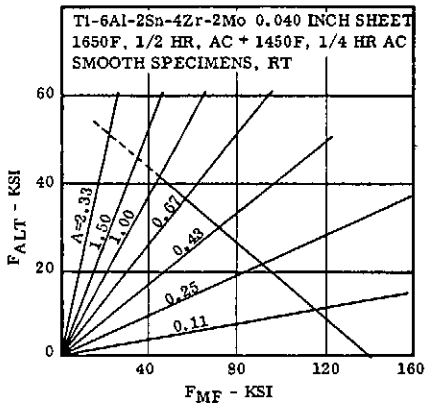


FIG. 3.054 ROOM TEMPERATURE STRESS RANGE DIAGRAM AT 10^7 CYCLES FOR SMOOTH SPECIMENS OF DUPLEX ANNEALED SHEET (10,p.13)

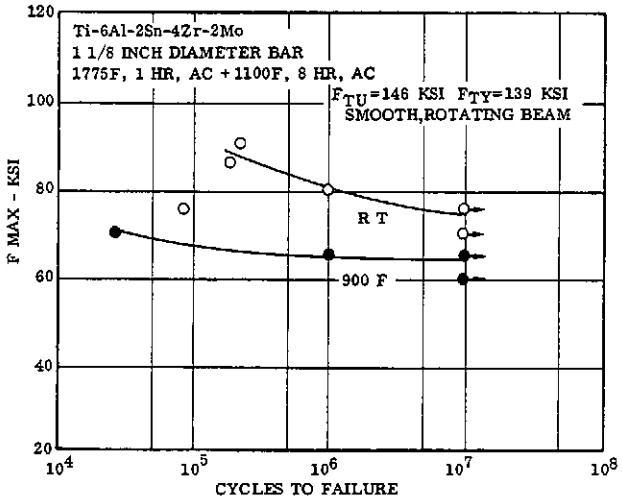


FIG. 3.055 ROOM TEMPERATURE AND 900 F SMOOTH FATIGUE PROPERTIES FOR DUPLEX ANNEALED BAR (15)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

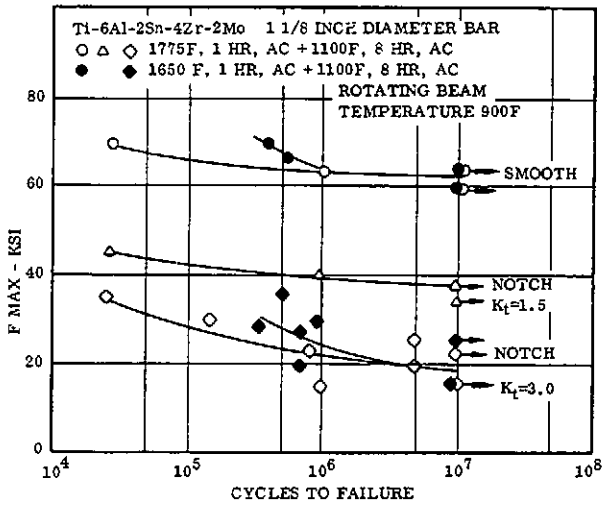


FIG. 3.056 900 F SMOOTH AND NOTCH FATIGUE PROPERTIES FOR DUPLEX ANNEALED BAR (15)

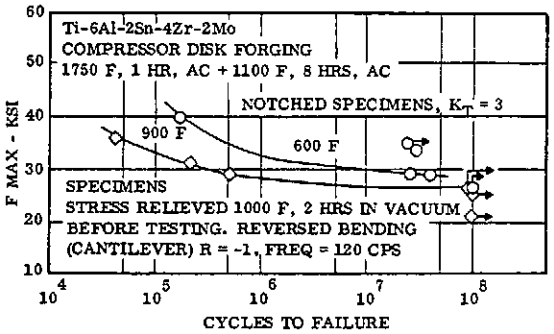


FIG. 3.058 NOTCH FATIUGE STRENGTH AT 600 F AND 900 F FOR DUPLEX ANNEALED COMPRESSOR DISK FORGING. (68)

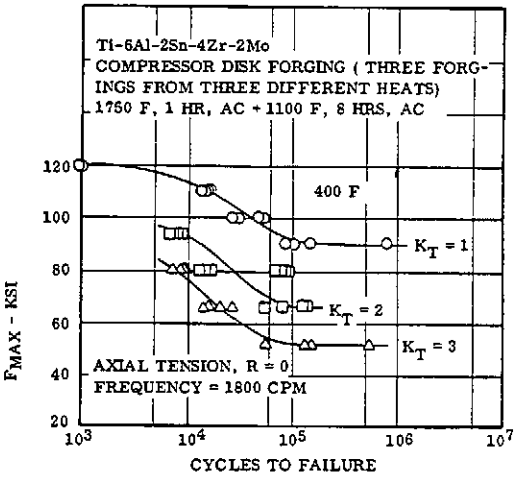


FIG. 3.059 400 F SMOOTH AND NOTCH FATIGUE PROPERTIES FOR DUPLEX ANNEALED COMPRESSOR DISK FORGINGS. (68)

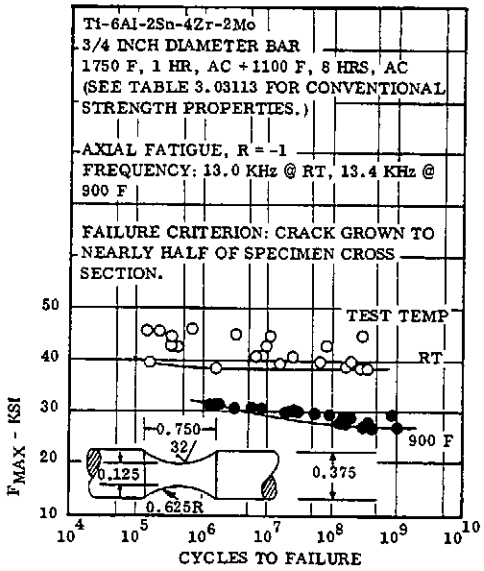


FIG. 3.057 HIGH-FREQUENCY AXIAL-LOAD FATIGUE PROPERTIES AT ROOM TEMPERATURE AND 900 F FOR DUPLEX ANNEALED BAR. (24)

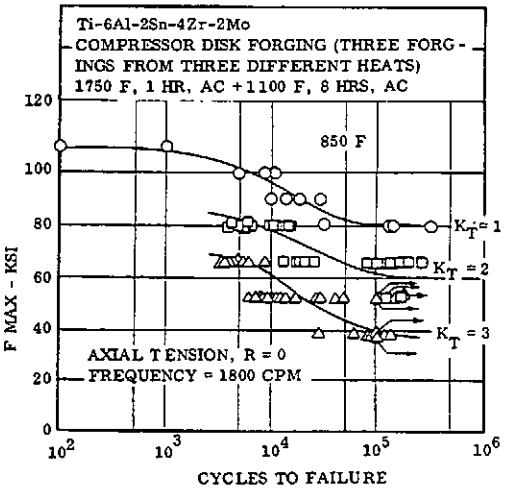


FIG. 3.0510 850 F SMOOTH AND NOTCH FATIGUE PROPERTIES FOR DUPLEX ANNEALED COMPRESSOR DISK FORGINGS. (68)

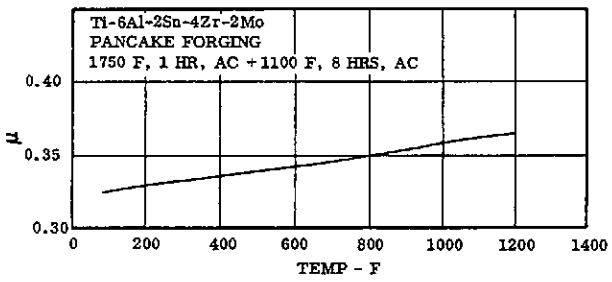
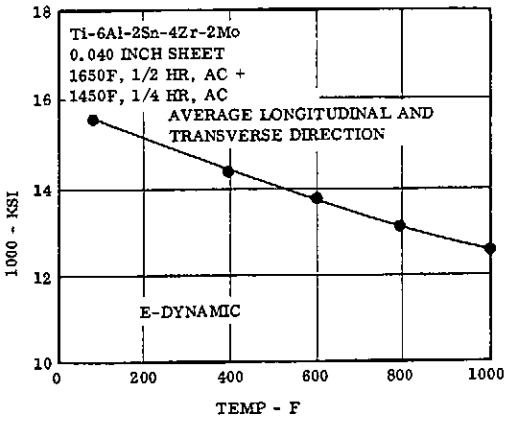


FIG. 3.0611 POISSON'S RATIO FOR DUPLEX ANNEALED PANCAKE FORGING. (83)



	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

FIG. 3.0623 DYNAMIC TENSILE MODULUS OF ELASTICITY OF DUPLEX ANNEALED SHEET AT ROOM AND ELEVATED TEMPERATURE (1, p. 143)

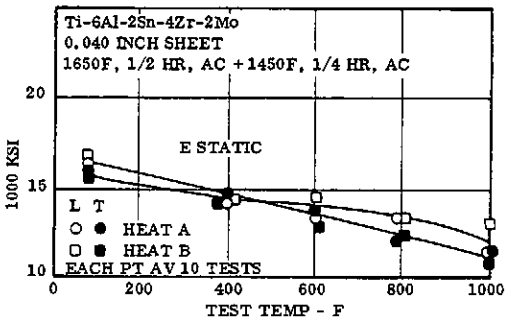


FIG. 3.0621 STATIC TENSILE MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES FOR DUPLEX ANNEALED SHEET (1, p. 51)

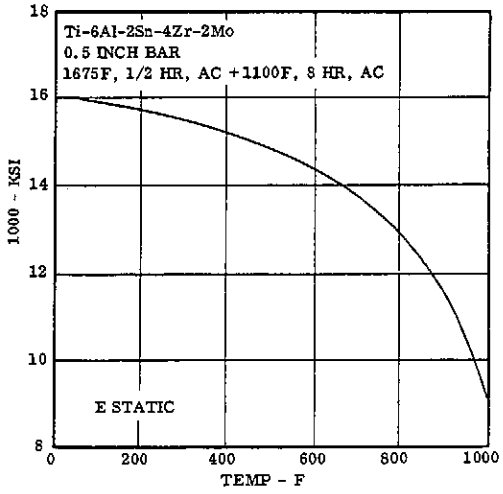


FIG. 3.0624 STATIC TENSILE MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES FOR DUPLEX ANNEALED BAR (2, p. 12)

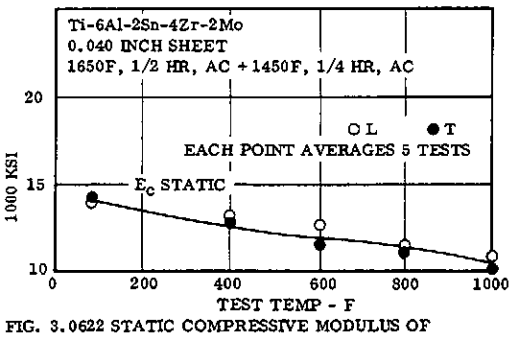


FIG. 3.0622 STATIC COMPRESSIVE MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES FOR DUPLEX ANNEALED SHEET (1, p. 67)

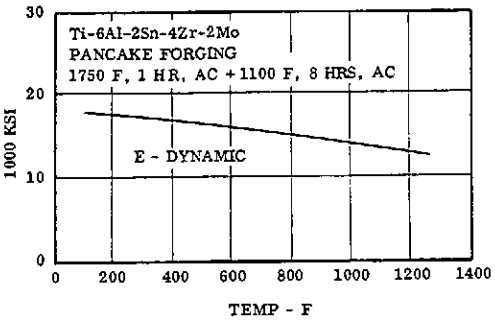


FIG. 3.0626 DYNAMIC TENSILE MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES FOR DUPLEX ANNEALED PANCAKE FORGING. (83)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy			Ti-6Al-2Sn-4Zr-2Mo			
Form			2 1/4 in Square Forged Bar			
Condition			Beta or Alpha-Beta Forged + Duplex Annealed			
150-Hr Exposure at			Subsequent RT Tensile Properties (outside longitudinal)[a]			
Temp F	Stress ksi	Deformation percent	F_{tu} ksi	F_{ty} ksi	e (1-in) percent	RA percent
Alpha-Beta Forged +1750F, 1-Hr, AC + 1100F, 24-Hr, AC						
—	None	—	113.3	135.3	20.0	41.5
850	70	0.25	143.4	134.2	20.0	45.1
900	55	0.28	146.0	134.5	19.0	39.8
950	45	0.29	143.7	132.2	18.0	36.0
1050	30	2.43	147.6	136.0	18.0	33.9
Beta Forged +1750F, 1-Hr, AC +1100F, 24-Hr, AC						
—	None	—	144.0	134.8	20.5	45.5
850	70	0.13	147.3	135.2	15.5	34.2
900	55	0.18	144.8	133.0	16.5	35.1
950	45	0.21	145.6	133.8	16.5	36.7
1050	30	0.52	144.0	133.1	17.5	33.8
Alpha-Beta Forged +1875F (in Beta Field), 1-Hr, AC +1100F, 24-Hr, AC						
—	None	—	139.0	126.4	11.5	29.9
850	70	0.16	138.9	130.4	14.5	26.7
900	55	0.17	146.1	134.6	14.0	23.3
950	45	0.16	146.1	135.2	13.0	23.3
(a) 1050	30	0.25	145.5	136.9	12.5	26.7

(a) Tested after exposure without surface conditioning

TABLE 4.0121 EFFECT OF BETA FORGING AND BETA ANNEALING ON ELEVATED TEMPERATURE STABILITY OF DUPLEX ANNEALED FORGED BAR, (13, pp. 69-70).

Alloy				Ti-6Al-2Sn-4Zr-2Mo			
Form				Forging			
Condition				1750F, 1 Hr, AC + 1100F, 8 Hr, AC			
	1000-Hr Exposure at			Subsequent RT Tensile Properties			
Specimen Grain Structure	Temp F	Stress ksi	Deformation percent	F_{tu} ksi	F_{ty} ksi	e percent	RA percent
Equiaxed (1)	—	None	—	143.5	131.9	17.0	43.4
Transformed (2)	—	None	—	141.1	129.0	13.5	43.0
Equiaxed	800	65	0.195	142.4	131.4	20.0	40.6
Transformed	800	65	0.113	141.3	130.4	17.0	39.8
Equiaxed	900	50	0.250	148.9	134.1	17.0	36.2
Transformed	900	50	0.168	149.4	136.9	18.0	28.1

(1) Sub-transus processed
(2) Beta processed

TABLE 4.0122 EFFECT OF PROCESSED STRUCTURE ON ELEVATED TEMPERATURE STABILITY OF DUPLEX ANNEALED FORGING, (10, p. 12).

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo		
Forge		Anneal Treatment	Beta Recrystallization percent	Average Grain Diameter[2] inch
Temp	Reduction			
2300F	One 50%	None	5	
2300F	One 50%	2300F, 1/2 hr	75	
2300F	One 50%	2300F, 1 hr	75	
2300F	Two 50%[1]	None	50	
2300F	Two 50%	1900F, 1 hr	95	
2300F	Two 50%	2300F, 1 hr	100	0.55
2200F	One 50%	None	3	
2200F	One 50%	2200F, 1/2 hr	75	
2200F	One 50%	2200F, 1 hr	75	
2200F	Two 50%	None	40	
2200F	Two 50%	1900F, 1 hr	95	
2200F	Two 50%	2200F, 1 hr	100	0.049
2100F	One 50%	None	1	
2100F	One 50%	2100F, 1/2 hr	75	
2100F	One 50%	2100F, 1 hr	75	
2100F	Two 50%	None	30	
2100F	Two 50%	1900F, 1 hr	95	
2100F	Two 50%	2100F, 1 hr	100	0.049
2000F	One 50%	None	0	
2000F	One 50%	2000F, 1/2 hr	75	
2000F	One 50%	2000F, 1 hr	75	
2000F	Two 50%	None	10	
2000F	Two 50%	1900F, 1 hr	95	
2000F	Two 50%	2000F, 1 hr	100	0.047

(1) Reheated 1/2-hr at forging temperature between successive 50% forging reductions.
(2) Determined by counting the number of grain boundaries intersecting a line 3-inches in length. Initial, as-cast grain diameter of ingot was 0.27 inch.

TABLE 4.0123 HIGH TEMPERATURE FORGING AND RECRYSTALLIZATION RESULTS, (86).

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo	
Forge		Anneal Treatment	Beta Recrystallization percent
Temp	Reduction		
1950F	30%	None	0
1950F	30%	1900F, 1 hr	5
1950F	30%	1950F, 1 hr	70
1950F	30%	2000F, 1 hr	80
1950F	50%	None	0
1950F	50%	1900F, 1 hr	5
1950F	50%	1950F, 1 hr	90
1950F	50%	2000F, 1 hr	95
1900F	30%	None	0
1900F	30%	1900F, 1 hr	5
1900F	30%	1950F, 1 hr	90
1900F	30%	2000F, 1 hr	90
1900F	50%	None	0
1900F	50%	1900F, 1 hr	10
1900F	50%	1950F, 1 hr	95
1900F	50%	2000F, 1 hr	95
1850F	30%	None	0
1850F	30%	1900F, 1 hr	5
1850F	30%	1950F, 1 hr	90
1850F	30%	2000F, 1 hr	90
1850F	50%	None	0
1850F	50%	1900F, 1 hr	20
1850F	50%	1950F, 1 hr	95
1850F	50%	2000F, 1 hr	95
1800F	30%	None	0
1800F	30%	1900F, 1 hr	95
1800F	30%	1950F, 1 hr	95
1800F	30%	2000F, 1 hr	95
1800F	50%	None	0
1800F	50%	1900F, 1 hr	95
1800F	50%	1950F, 1 hr	95
1800F	50%	2000F, 1 hr	95

TABLE 4.0124 LOWER TEMPERATURE FORGING AND RECRYSTALLIZATION RESULTS, (86).

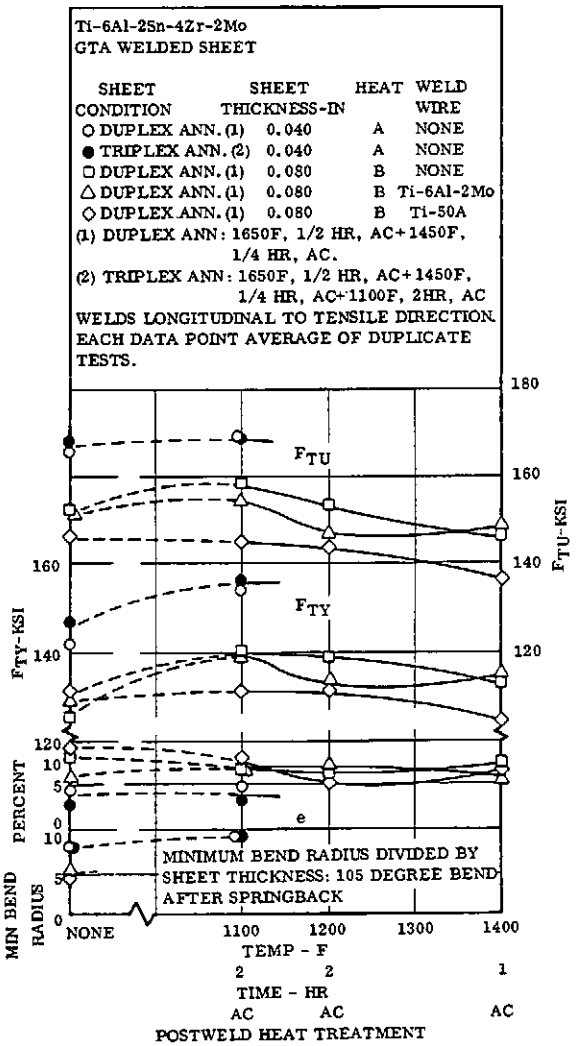


FIG. 4.036 EFFECT OF HEAT TREATMENT AND FILLER WIRE COMPOSITION ON ROOM TEMPERATURE TENSILE AND BEND PROPERTIES OF WELDED SHEET. (13, P.34)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti·6·2·4·2

Alloy	Ti-6Al-2Sn-4Zr-2Mo						
Form	GTA Welded Sheet						
Sheet Condition	Sheet Thickness Inch	Heat	Weld Wire	Postweld Heat Treatment	F_{ty} ksi (1)	Weld NTS ksi (2)	HAZ NTS ksi (2)
Duplex Ann (3)	0.040	A	None	None	142	116	116
Triplex Ann (4)	0.040	A	None	None	146	122	121
Duplex Ann (3)	0.040	A	None	1100F, 2 hr, AC	154	112	106
Triplex Ann (4)	0.040	A	None	1100F, 2 hr, AC	155	104	118
Duplex Ann (3)	0.080	B	None	None	125	134	---
Duplex Ann (3)	0.080	B	None	1200F, 2 hr, AC	138	128	---
Duplex Ann (3)	0.080	B	None	1400F, 1 hr, AC	132	122	---
Duplex Ann (3)	0.080	B	Ti-6Al-2Mo	None	128	134	---
Duplex Ann (3)	0.080	B	Ti-50A	None	129	146	---

(1) Welds longitudinal to tensile direction.
(2) Welds transverse to tensile direction (see illustration below).
(3) Duplex Ann: 1650F, ½ hr, AC + 1450F, ¼ hr, AC.
(4) Triplex Ann: 1650F, ½ hr, AC + 1450F, ½ hr, AC + 1100F, 2 hr, AC.
All values average duplicate tests.

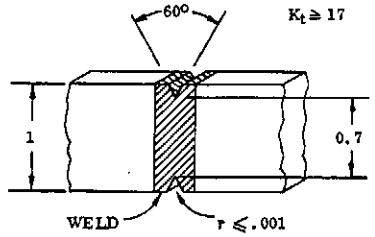


TABLE 4.037 EFFECT OF HEAT TREATMENT ON ROOM TEMPERATURE SHARP NOTCH TENSILE PROPERTIES OF WELDED SHEET. (13, pp.34,35)

Alloy	Ti-6Al-2Sn-4Zr-2Mo						
Form	GTA Welded 0.040 inch Sheet						
Sheet Condition	Postweld Heat Treatment	150 hour Exposure at: Temp F	Stress ksi	Deformation percent	Subsequent RT Tensile Properties F_{tu} ksi	F_{ty} ksi	e (1-in) percent
Duplex Ann (1)	None	None			166	142	4.5
Triplex Ann (2)	None	None			168	146	3.0
Duplex Ann (1)	1100F, 2 hr, AC	None			170	154	5.0
Triplex Ann (2)	1100F, 2 hr, AC	None			170	155	3.0
Duplex Ann (1)	None	800	65	0.209	182	163	3.5
Triplex Ann (2)	None	800	65	0.185	172	155	2.5
Duplex Ann (1)	1100F, 2 hr, AC	800	65	0.088	168	156	3.5
Triplex Ann (2)	1100F, 2 hr, AC	800	65	0.092	174	160	4.0
Duplex Ann (1)	None	900	45	0.452	180	164	4.0
Triplex Ann (2)	None	900	45	0.510 (3)	173	160	1.5
Duplex Ann (1)	1100F, 2 hr, AC	900	45	0.177	173	160	2.5
Triplex Ann (2)	1100F, 2 hr, AC	900	45	0.199	177	163	3.0
Duplex Ann (1)	None	1000	25	0.706 (3)	181	168	3.0
Triplex Ann (2)	None	1000	25	0.610	174	164	2.0
Duplex Ann (1)	1100F, 2 hr, AC	1000	25	0.407	172	162	2.0
Triplex Ann (2)	1100F, 2 hr, AC	1000	25	0.356	174	163	2.0

(1) Duplex Ann: 1650F, ½ hr, AC + 1450F, ¼ hr, AC.
(2) Triplex Ann: 1650F, ½ hr, AC + 1450F, ¼ hr, AC + 1100F, 2 hr, AC.
(3) Single values: all others average of duplicate tests.
Welds longitudinal to tensile direction, tested in as-exposed condition.

TABLE 4.038 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF WELDED SHEET GIVEN VARIOUS HEAT TREATMENTS. (13, p. 36)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy		Ti-6Al-2Sn-4Zr-2Mo			
Form		GTA Welded 0.040 inch Sheet			
Sheet Condition	Postweld Heat Treatment	Test Temp F	F_{tu} ksi	F_{ty} ksi	e (2-in) percent
Duplex Ann (1)	None	RT (3)	166	142	4.5
Triplex Ann (2)	None	RT (3)	168	146	3.0
Duplex Ann (1)	1100F, 2 hr, AC	RT (3)	170	154	5.0
Triplex Ann (2)	1100F, 2 hr, AC	RT (3)	170	155	3.0
Duplex Ann (1)	None	600 (4)	110	87	7.0
Triplex Ann (2)	None	600 (4)	118	92	7.0
Duplex Ann (1)	1100F, 2 hr, AC	600 (4)	120	96	7.5
Triplex Ann (2)	1100F, 2 hr, AC	600 (4)	117	91	7.5
Duplex Ann (1)	None	800 (4)	114	85	8.5
Triplex Ann (2)	None	800 (4)	111	87	8.0
Duplex Ann (1)	1100F, 2 hr, AC	800 (4)	120	95	7.5
Triplex Ann (2)	1100F, 2 hr, AC	800 (4)	112	89	7.5

(1) Duplex Ann: 1650F, ½ hr, AC + 1450F, ¼ hr, AC.
(2) Triplex Ann: 1650F, ½ hr, AC + 1450F, ¼ hr, AC + 1100F, 2 hr, AC.
(3) Welds longitudinal to tensile direction.
(4) Welds transverse to tensile direction.
All values average duplicate tests.

TABLE 4.039 ELEVATED TEMPERATURE TENSILE PROPERTIES OF WELDED SHEET. (30, pp. 7,5)

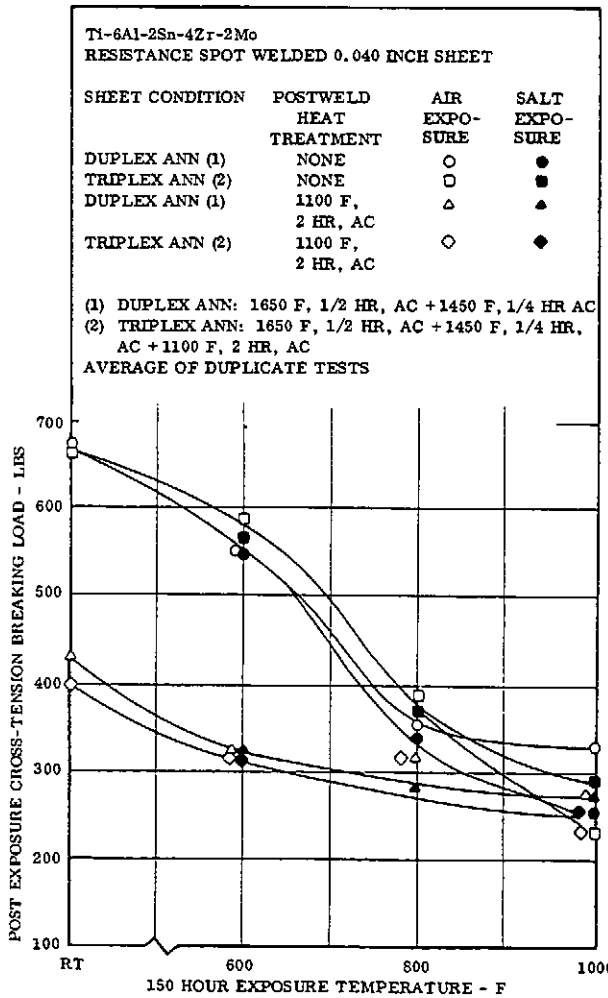


FIG. 4.0310 EFFECT OF HEAT TREATMENT AND THERMAL EXPOSURE, WITH AND WITHOUT A SALT ENVIRONMENT, ON ROOM TEMPERATURE CROSS-TENSION STRENGTH OF SINGLE RESISTANCE SPOT WELDS (30, p. 13)

Alloy	Ti-6Al-2Sn-4Zr-2Mo		
Form	Resistance Spot Welded 0.040 inch Sheet		
		Breaking Load - Lbs (3)	
Sheet Condition	Postweld Heat Treatment	Shear-Tension	Cross-Tension
Duplex Ann (1)	None	2190	670
Triplex Ann (2)	None	2080	660
Duplex Ann (1)	1100F, 2 hr, AC	1660	440
Triplex Ann (2)	1100F, 2 hr, AC	1650	400

(1) Duplex Ann: 1650F, ½ hr, AC + 1450F, ½ hr, AC.
(2) Triplex Ann: 1650F, ½ hr, AC + 1450F, ½ hr, AC + 1100F, 2 hr, AC
(3) Average of triplicate tests.

TABLE 4.0311 ROOM TEMPERATURE SHEAR-TENSION AND CROSS-TENSION STRENGTHS OF SINGLE RESISTANCE SPOT WELDS GIVEN VARIOUS HEAT TREATMENTS. (13, p. 38)

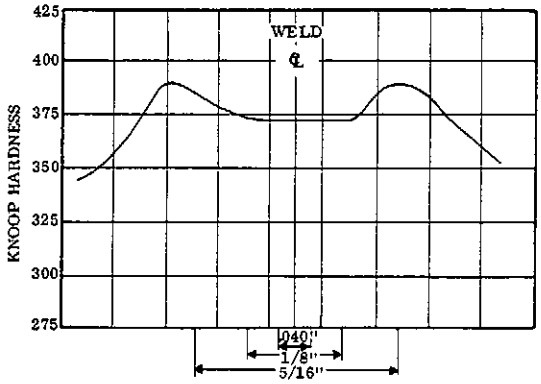


FIG. 4:0314 MICROHARDNESS OF WELD CROSS SECTION IN 0.025 INCH THICK Ti-6Al-2Sn-4Zr-2Mo SHEET. (27 p 33)

Ti
6 Al
2 Sn
4 Zr
2 Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo			
Form	GTA Welded Sheet			
			Ratio: Minimum Bend Radius to Sheet Thickness (1)	
			Weld Cooling Rate	
Sheet Condition	Sheet Thickness inch	Heat	Slow	Fast (2)
Triplex Ann (3)	0.038	A	10.0	10.0
Duplex Ann (4)	0.080	A	7.8	9.4
Duplex Ann (4)	0.125	A	7.0	> 8.0
Triplex Ann (3)	0.050	B	10.0	12.5
Duplex Ann (4)	0.025	C	7.5	10.0
Duplex Ann (4)	0.025	D	10.0	11.0
Triplex Ann (3)	0.025	D	7.5	10.0
Triplex Ann (3)	0.040	D	10.9	>12.5
Duplex Ann (4)	0.060	D	10.0	12.5
Duplex Ann (4)	0.080	D	9.4	10.2
Triplex Ann (3)	0.080	D	10.9	>12.5

(1) Weld transverse to bend axis.
(2) Copper chill fixtures employed.
(3) Triplex Ann: 1650F, ½ hr, AC + 1450F, ½ hr, AC + 1100F, 2 hr, AC
(4) Duplex Ann: 1650F, ½ hr, AC + 1450F, ½ hr, AC.

TABLE 4.0312 MINIMUM BEND RADII OF DUPLEX AND TRIPLEX ANNEALED SHEET OF VARIOUS THICKNESSES FROM SEVERAL HEATS, WELDED AND COOLED AT TWO DIFFERENT RATES FROM THE WELD CYCLE. (30, p. 20)

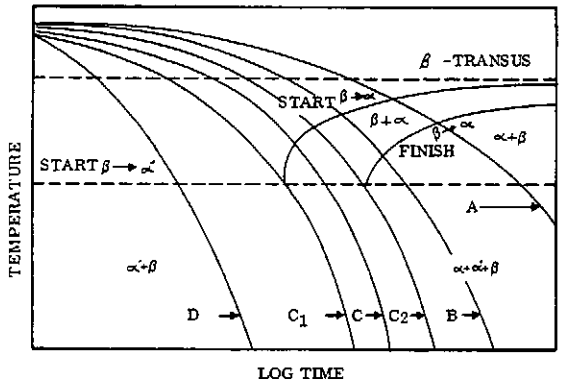


FIG. 4.0313 HYPOTHETICAL COOLING CURVES A, B, C_2, C C_1 AND D, SUPERIMPOSED ON SCHEMATIC CONTINUOUS-COOLING-TRANSFORMATION (CCT) DIAGRAM FOR AN ALPHA-LEAN BETA TITANIUM ALLOY. (27, p 21)

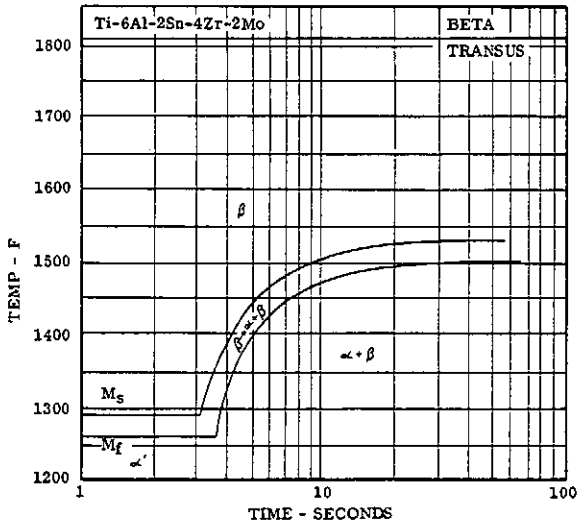
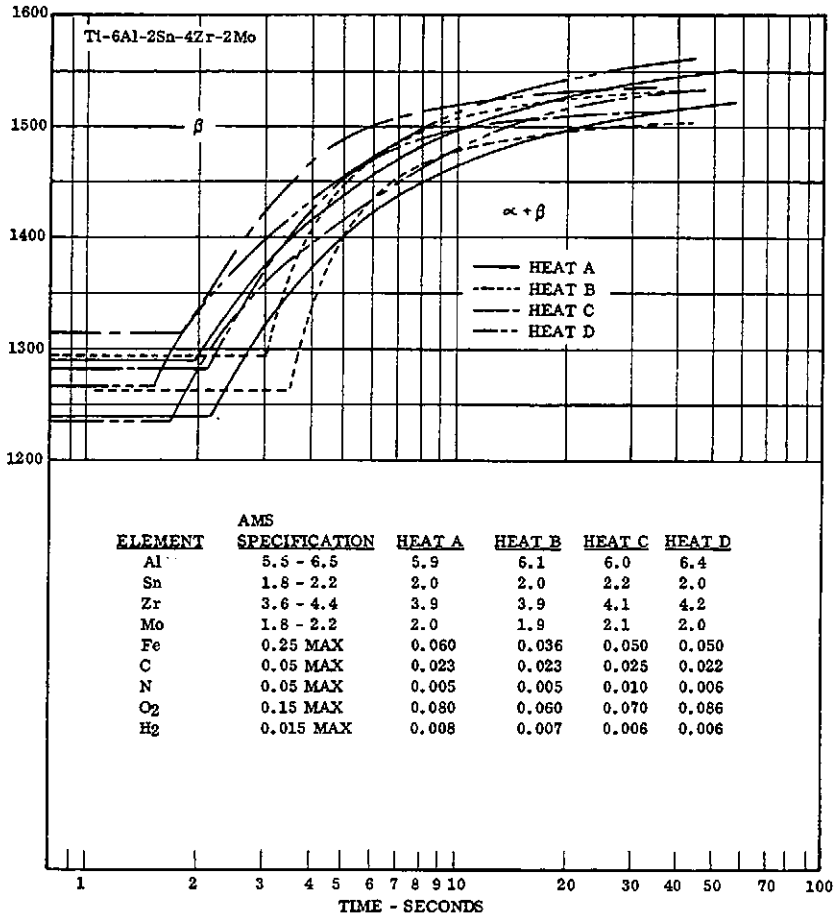


FIG. 4.0315 CONTINUOUS-COOLING-TRANSFORMATION (CCT) DIAGRAM FOR Ti-6Al-2Sn-4Zr-2Mo. (27, p 28)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2



ELEMENT	AMS SPECIFICATION	HEAT A	HEAT B	HEAT C	HEAT D
Al	5.5 - 6.5	5.9	6.1	6.0	6.4
Sn	1.8 - 2.2	2.0	2.0	2.2	2.0
Zr	3.6 - 4.4	3.9	3.9	4.1	4.2
Mo	1.8 - 2.2	2.0	1.9	2.1	2.0
Fe	0.25 MAX	0.060	0.036	0.050	0.050
C	0.05 MAX	0.023	0.023	0.025	0.022
N	0.05 MAX	0.005	0.005	0.010	0.006
O_2	0.15 MAX	0.080	0.060	0.070	0.086
H_2	0.015 MAX	0.008	0.007	0.006	0.006

FIGURE 4.0316 EFFECT OF COMPOSITIONAL VARIATIONS WITHIN SPECIFICATION ON CONTINUOUS-COOLING-TRANSFORMATION (CCT) DIAGRAM FOR Ti-6Al-2Sn-4Zr-2Mo (27, pp. 24, 25, 26 and 27)

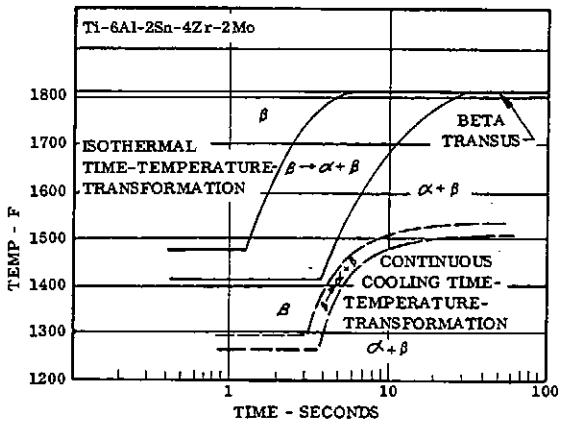


FIG. 4.0317 COMPARISON OF CONTINUOUS-COOLING-TRANSFORMATION (CCT) DIAGRAM AND ISOTHERMAL-TRANSFORMATION (TTT) DIAGRAM FOR Ti-6Al-2Sn-4Zr-2Mo ALLOY. (27, p. 28)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

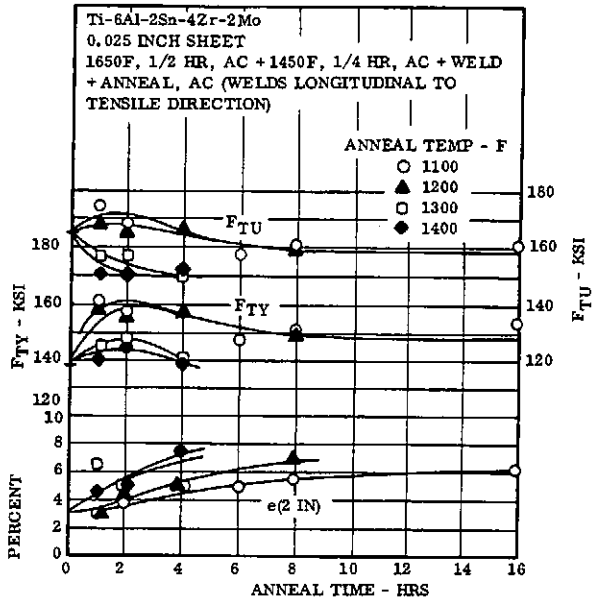


FIG. 4.0318 EFFECT OF POSTWELD ANNEAL TEMPERATURE AND TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF WELDED DUPLEX ANNEALED 0.025 INCH SHEET (30, p.25)

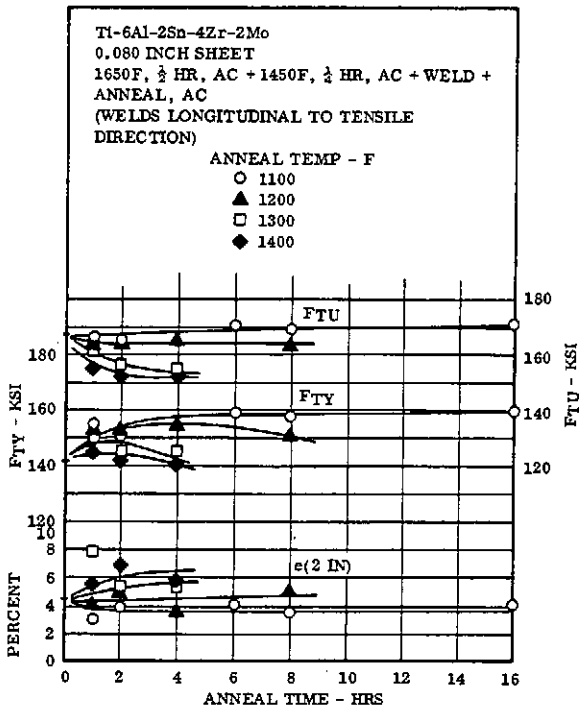


FIG. 4.0319 EFFECT OF POSTWELD ANNEAL TEMPERATURE AND TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF WELDED DUPLEX ANNEALED 0.080 INCH SHEET (30, p. 25)

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

Alloy	Ti-6Al-2Sn-4Zr-2Mo					
Form	Welded Sheet					
Condition	1650F, ½ Hr, AC + 1450F, ½ Hr, AC + Weld + Anneal, 2 Hr, AC					
Postweld Anneal Temp - F	RT Tensile Properties (1)					
	Unexposed			Exposed 150 Hr at 1000F		
	F_{tu} - ksi	F_{ty} - ksi	e (2-in) - %	F_{tu} - ksi	F_{ty} - ksi	e (2-in) - %
0.025 inch Sheet						
As Welded	164.3	138.8	3.0	167.1	157.9	2.8
1100	168.5	157.2	3.8	167.8	160.9	2.5
1200	165.1	155.3	4.5	165.8	158.8	3.0
1300	157.1	147.5	5.0	159.0	151.4	4.0
1400	150.0	144.8	5.0	155.4	150.6	4.0
0.080 inch Sheet						
As Welded	165.6	141.6	4.3	175.3	153.4	3.0
1100	164.5	150.2	3.8	173.6	165.1	2.3
1200	163.0	152.8	4.8	170.2	160.9	2.3
1300	155.6	145.0	5.3	165.6	156.0	5.5
1400	152.0	141.5	6.8	162.4	152.8	3.8

(1) Welds longitudinal to tensile direction.

TABLE 4.0320 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF WELDED DUPLEX ANNEALED SHEET POSTWELD ANNEALED FOR TWO HOURS AT VARIOUS TEMPERATURES. (30, p.25)

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	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti-6-2-4-2

	Ti
6	Al
2	Sn
4	Zr
2	Mo

Ti·6·2·4·2

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