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NONFERROUS ALLOYS

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

1. GENERAL

This alloy is an age hardenable, metastable beta alloy developed by Crucible Steel Division of Colt Industries under partial sponsorship of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio (Air Force Contract No. AF33(615)-2742). It has exceptional workability and high strength capability. It may be readily hot or cold worked and is through-hardenable in sections up to six inches. Actual and potential applications include fasteners, sheet metal parts, tubing and heavy section parts.

Beta phase is retained on quenching from above 1400F. Omega phase, which also forms on quenching, is stable up to 800F. Yield strengths of up to 220 ksi have been measured in beta + omega structures, the strength level being dependent on the size and volume fraction of the omega phase. Plane strain fracture toughness reaches a minimum value of about 20 ksi$\sqrt{in}$ when the omega particle size exceeds 100 A°. Beta + alpha structures show good combinations of strength (up to F_{ty} = 170 ksi) and fracture toughness (up to K_{Ic} = 60-70 ksi$\sqrt{in}$). Unfortunately, the best combinations are susceptible to stress-corrosion cracking in aqueous solutions containing halide ions. The alloy is castable and weldable.

1.01 Commercial Designation
Beta III Titanium Alloy.

1.02 Alternate Designation
Ti-11.5Mo-6Zr-4.5Sn.

1.03 Specifications
AMS-4977, Bars and Wire (fastener stock)
AMS-4980, Bars and Wire
MIL-T-9047E, Bars and Forging Stock.

1.04 Composition
1.041 AMS and military specified compositions, Table 1.041.

1.05 Heat Treatment
1.051 Solution treat. 1275 to 1450F, hold briefly at temperature (several minutes), cool rapidly. Lower temperatures are used for maximum aging response, higher temperatures for maximum hardenability and solution treated formability. Liquid quenching is generally used, though air cooling is often adequate when solution treated properties are not important. The effect of quench rate from solution temperature on solution treated tensile properties is shown in Figure 3.02136 and Table 3.02125.
1.052 Age. 900 to 1100F, with higher strengths obtainable at the lower temperatures within this range.
1.053 The selection of aging time will depend on the combination of properties desired. At 900F, little additional strengthening is obtained by aging beyond eight hours (see Figure 3.02137), but the best combination of strength and fracture toughness is obtained by aging beyond thirty-two hours (see Section 3.0272). No information is available on the influence of aging time on strength and toughness at higher aging temperatures.

Section 1.06 discusses the aging kinetics as related to hardness. The influence of heatup time on heavy section hardenability is discussed in Section 1.091.

Elevated temperature stability is affected by aging time, as discussed in Section 1.092. When elevated temperature stability is required, eight-hour aging appears adequate in the upper portion of the recommended aging temperature range; times near thirty-two hours may be needed at 900 to 950F.

Aging time has a complicated influence on the stress corrosion cracking susceptibility of this alloy (see Section 2.03).

1.06 Hardness
1.061 The transformation kinetics and associated mechanical behavior of this alloy have been studied by Feeney and Blackburn (15). At aging temperatures below 800F, hardening (or strengthening) is caused by the precipitation of ω-phase (see TTT diagram, Figure 2.0121). The variation of hardness with aging time at 400, 550 and 700F is shown in Figure 1.064. At low aging temperatures, e.g. 400F, the hardness increase is slight and occurs after a rather long initial incubation period (about 120 minutes at 400F). In contrast, aging at temperatures between 500 to 700F commences with a very short (< 2 minutes) incubation period, and a large increase in hardness occurs.

At aging temperatures above 800F, α-phase precipitation is responsible for strengthening. The effect of aging time at 850, 1000 and 1150F on hardness is shown in Figure 1.066. The curves are classical in shape with lower peak hardness at shorter times the higher the aging temperature. Slight overaging is also apparent at each aging temperature. At 1150F, however, there is a marked increase in hardness at times over 100 hours. This secondary hardening far exceeds the initial peak hardness occurring between 5 and 10 minutes.

In the narrow temperature range 800F ± 10F, the α-phase and ω-phase grow simultaneously. Figure 1.065 shows the 800F aging curve bracketed by the 700F and 850F aging curves. It is seen that the aging characteristics at 800F are an apparent compromise between those at the two other aging temperatures.

The influence of prior deformation on the aging response at 700 and 1000F is shown in Figures 1.064 and 1.066, respectively. At the outset of 700F aging the hardness level of deformed stock far exceeds that of undeformed material. The hardness of both increases with aging time and, near peak hardness, the two curves tend to merge. The aging time to achieve peak hardness at 700F is slightly reduced by prior deformation.

As shown in Figure 1.066, the hardness of deformed stock does not increase with aging time at 1000F, but decreases. This contrasts with the response of deformed stock aged at 700F. Further, although the hardness curves for deformed and undeformed stock aged at 1000F merge at longer aging times, there is still a difference of 35 DPN at the peak hardness of the undeformed stock.
1.062 AMS specified hardness for bars and wire, Table 1.062.
1.063 AMS specified hardness for bars and wire for fastener application, Table 1.063.
1.064 Effect of aging time on hardness of specimens aged below 800F, Figure 1.064.
1.065 Effect of aging time on hardness of specimens aged at 800F, Figure 1.065.
1.066 Effect of aging time on hardness of specimens aged above 800F, Figure 1.066.

1.07 Forms and Conditions Available
1.071 The alloy is available in all mill product forms, including foil. Extrusions and tubing are presently available only on a pilot production basis (7).

1.08 Melting and Casting Practice
1.081 Molybdenum is difficult to add to large heats of titanium because of the combined effect of its high melting temperature and density. Zirconium, however, forms a relatively low-melting, low-density master alloy with molybdenum. Attempts to produce this alloy by master-alloy techniques have proven cost-prohibitive. The alloy is now produced using a proprietary vacuum arc melting technique developed by Crucible. Some early production ingots showed evidence of unmelted molybdenum. Modifications to the proprietary melting technique have subsequently been made and ingots are now being produced completely free of unmelted material (4).
1.082 Triple vacuum-arc melted material smooth strength properties are no different than those of double vacuum-arc melted stock (4).

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1.083 Tensile properties of cast-to-size specimens, Table 1.083.

1.09 Special Considerations

1.091 Section size and directionality. Tables 3.0214 thru 3.0216 show the influence of as-quenched section size on the solution treated (water quenched) and aged smooth tensile properties of forged sections up to 6 inches square. The tin content of the bars tested was higher than the normal specification in order to enhance uniform hardenability. The results, however, agree with those for forgings of specified composition in Tables 3.0212 and 3.0213. While the alloy is through-hardenable in 6 inch section (Tables 3.0214 thru 3.0216), an anomaly exists in that higher strengths were obtained in 6 inch section than in 3 or 4 inch section. It is believed that this behavior is related to the effect of heatup time to aging, similar to behavior noted for Ti-13V-11Cr-3Al (14) - the longer the heatup time for a given section, the higher the strength level.

Generally, the reduction in area is observed to decrease with increasing section size. In Table 3.0214 it is noticed that the transverse ductility for bars aged at 900F were particularly low compared with the longitudinal direction. Overaging at 950 or 1000F did not improve this situation (see Tables 3.0215 and 3.0216). Cross forging lessens this directionality, as shown in Table 3.0217 (the edge properties reported should not be weighed heavily because of the limited amount of cold work imparted to those areas).

1.092 Stability. Omega phase forms when solution treated material is aged in the 400 to 800F temperature range (see T-T-T diagram in Figure 2.0121). When well developed, omega phase embrittles the alloy. Stability considerations therefore limit the service temperature for solution treated material to 350 to 400F maximum.

Alpha phase precipitates upon aging at temperatures above 800F, apparently without prior formation of omega. When high strength and/or elevated temperature stability is required, the alloy is aged in the 900 to 1100F range to a stable alpha-beta dispersion. Omega then does not form in subsequent service at lower temperatures. Eight hour aging time is adequate in the upper portion of the recommended range. Times near thirty-two hours may be needed for aging at 900 to 950F. Experience has shown that aging above 1100F leads to instability during subsequent exposure in the omega formation range, e.g. 700F. This is due to the large amount of relatively alloy-lean beta produced at higher aging temperatures (4).

1.093 Composition. Increases in beta stabilizer (Mo and Zr) content above nominal cause modest strength reductions for a given heat treatment (see Table 3.02138). Decreases below nominal may produce creep instability in the maximum strength condition (4).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. Approximately 3200 to 3300F (7).

2.012 Phase changes. Beta transus approximately 1400F (7).

2.0121 Time-temperature-transformation diagram, Figure 2.0121.

2.013 Thermal conductivity.

2.014 Thermal expansion, Figure 2.014.

2.015 Specific heat.

2.016 Thermal diffusivity.

2.02 Other Physical Properties

2.021 Density. 0.183 lb per cu in. 5.10 gr per cu cm (4).

2.022 Electrical properties.

2.0221 Electrical resistivity. 61.3 microhms-inch at 74F for Ti-11.4Mo-5.9Zr-4.3Sn-0.11O.

2.023 Magnetic properties.

2.024 Emittance.

2.025 Damping capacity.

2.03 Chemical Properties

2.031 Corrosion resistance. General. In common with other titanium alloys, Ti-11.5Mo-6Zr-4.5Sn is susceptible to solid salt stress corrosion at elevated temperatures and exhibits delayed failure of cracked specimens at room temperature in aqueous salt environments. No data are available on the stress corrosion cracking susceptibility in organic solvents such as methanol.

2.032 Salt water stress corrosion cracking. According to recent studies by Feeney and Blackburn (15)(21)(22), the as-quenched and omega-phase-strengthened structures (aging between 400 and 800F) appear to be immune to stress corrosion cracking in aqueous halide solutions. This is in contrast to beta + alpha structures (aging above 800F) which show stress corrosion cracking susceptibility the degree to which is dependent upon the aging temperature, applied stress, strain rate, environment and applied electric potential. Figure 2.033 shows the delayed failure characteristics in 3.5 percent NaCl solution of cracked bend specimens aged 100 hours at 900F and tested under open circuit conditions. The data indicate a threshold stress intensity factor of 26 ksi$\sqrt{\text{in}}$. The investigators found no environmental failures under the same conditions for specimens aged at 1150F. This is consistent with the results in Figure 2.034 which show for specimens immersed in 0.6 M KCl at an applied electric potential of -500 mv that the lower the aging temperature (within the beta + alpha field), the lower the threshold stress intensity factor and the higher the subsequent crack growth velocity. Aging time has a complicated influence on the threshold stress intensity factor and subsequent crack growth velocity as shown in Figure 2.035 for specimens aged at 900F and tested in 0.6M KCl at an applied electric potential of -500 mv.

The influence of applied electric potential on the threshold stress intensity factor for specimens immersed in 0.6M KCl aqueous solution is shown in Figure 2.036 which indicates the possibility of cathodic protection for this alloy around -1.5 volts. The influence of potential on crack velocity is shown to be linear in Figure 2.037. This relationship, however, would be expected to vary as a function of heat treatment and specimen orientation. For example, grain size can alter both the slope of this line and its intercept on the potential axis (22).

2.033 Stress corrosion cracking threshold stress intensity factor for failure in 3.5 percent NaCl solution (aqueous) under open circuit conditions (no applied potential), Figure 2.033.

2.034 Effect of aging temperature and stress intensity factor on stress corrosion crack velocity for cracked specimens immersed in 0.6M KCl aqueous solution with -500 mv applied potential, Figure 2.034.

2.035 Effect of aging time and stress intensity factor on stress corrosion crack velocity for cracked specimens immersed in 0.6M KCl aqueous solution with -500 mv applied potential, Figure 2.035.

2.036 Effect of applied electric potential on crack initiation stress intensity factor for cracked specimens immersed in 0.6M KCl aqueous solution, Figure 2.036.

2.037 Effect of applied electric potential on stress corrosion crack velocity for cracked specimens immersed in 0.6M KCl aqueous solution, Figure 2.037.

2.038 Hot salt stress corrosion characteristics of bar, Table 2.038.

2.039 Hot salt stress corrosion characteristics of plate, Table 2.039.

2.0310 Corrosion rates of Ti-11.5Mo-6Zr-4.5Sn and unalloyed titanium in hydrochloric and sulfuric acids, Table 2.0310.

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specified mechanical properties for solution treated bars and wire and bars and wire for fastener application, Table 3.011.

3.012 AMS specified mechanical properties for solution treated and aged bars and wire, Table 3.012.

3.013 AMS specified mechanical properties for solution treated and aged bars and wire for fastener application, Table 3.013.

3.02 Mechanical Properties at Room Temperature

3.021 Tension.

3.0211 Typical stress-strain curves for aged sheet, Figure 3.0211.

3.0212 Variation in tensile properties for hot rolled billet, Table 3.0212.

3.0213 Variation in tensile properties for closed die forging, Table 3.0213.

3.0214 Effect of heat treated section size on tensile properties of unidirectionally forged square bars aged at 900F, Table 3.0214.

3.0215 Effect of heat treated section size on tensile properties of unidirectionally forged square bars aged at 950F, Table 3.0215.

3.0216 Effect of heat treated section size on tensile properties of unidirectionally forged square bars aged at 1000F, Table 3.0216.

3.0217 Effect of cross forging on tensile properties of 3 inch and 6 inch square forged bars aged at 950F, Table 3.0217.

3.0218 Tensile properties of aged bars variously melted and solution treated, Figure 3.0218.

3.0219 Center and mid-radius tensile properties of 1 9/16 inch solution treated bar, Table 3.0219.

3.02110 Tensile property uniformity of 1 inch and 0.5 inch bar, Table 3.02110.

3.02111 Spread of tensile properties for 1/2 inch and 1 9/16 inch diameter bars solution treated at 1350F to 1450F and aged, Figure 3.02111.

3.02112 Effect of 100 hour exposure to elevated temperature with load on room temperature tensile properties of bar, Table 3.02112.

3.02113 Effect of 500 hour exposure to elevated temperature with load on room temperature tensile properties of bar, Table 3.02113.

3.02114 Effect of solution temperature on tensile properties of rod, Figure 3.02114.

3.02115 Spread of tensile properties for rod variously heat treated, Figure 3.02115.

3.02116 Effect of 100 hour exposure at 700F with load on room temperature tensile properties of rod, Table 3.02116.

3.02117 Effect of aging temperature on tensile properties of wire, Figure 3.02117.

3.02118 Tensile properties of seamless tubing, Table 3.02118.

3.02119 Effect of solution temperature on tensile properties of solution treated 0.5 inch plate, Figure 3.02119.

3.02120 Effect of solution temperature on tensile properties of solution treated and aged 0.5 inch plate, Figure 3.02120.

3.02121 Effect of aging temperature on tensile properties of 0.5 inch plate, Figure 3.02121.

3.02122 Effect of aging temperature on tensile properties of 1 inch plate, Figure 3.02122.

3.02123 Tensile properties of heavy plate, Table 3.02123.

3.02124 Tensile properties of double and triple vacuum-arc melted plate, Table 3.02124.

3.02125 Effect of quench rate from solution treatment temperature on tensile properties of plate, Table 3.02125.

3.02126 Effect of hot rolling temperature on tensile properties of plate, Figure 3.02126.

3.02127 Spread of tensile properties for plate variously hot rolled solution treated and aged, Figure 3.02127.

3.02128 Effect of 100 hour exposure to elevated temperature with load on room temperature tensile properties of plate, Table 3.02128.

3.02129 Effect of 500 hour exposure to elevated temperature with load on room temperature tensile properties of plate, Table 3.02129.

3.02130 Tensile properties of hot band, Table 3.02130.

3.02131 Effect of solution temperature on tensile properties of solution treated sheet, Figure 3.02131.

3.02132 Effect of solution temperature on tensile properties of aged sheet, Figure 3.02132.

3.02133 Effect of quench rate from solution treatment temperature on tensile properties of solution treated sheet, (see Figure 3.02136).

3.02134 Effect of aging temperature on tensile properties of hand sheet solution treated at 1350F, Figure 3.02134.

3.02135 Effect of aging temperature on tensile properties of hand sheet solution treated at 1450F, Figure 3.02135.

3.02136 Effect of aging temperature on tensile porperties of sheet solution treated at 1400 or 1450F, Figure 3.02136.

3.02137 Effect of aging time on tensile properties of sheet, Figure 3.02137.

3.02138 Effect of composition (variation in beta-phase-stabilizing element content) on tensile properties of sheet, Table 3.02138.

3.02139 Sheet tensile property variation for electron beam melted ingot, Figure 3.02139.

3.02140 Effect of cold reduction on tensile properties of sheet solution treated at 1350F and water quenched, Figure 3.02140.

3.02141 Effect of cold reduction on tensile properties of sheet solution treated at 1450F and air cooled, Figure 3.02141.

3.02142 Effect of cold reduction on aging response of sheet aged after cold rolling, Figure 3.02142.

3.02143 Effect of cold reduction on aging response of sheet re-solution treated and aged after cold rolling, Figure 3.02143.

3.02144 Spread of tensile properties for sheet variously cold reduced, solution treated and aged, Figure 3.02144.

3.02145 Effect of exposure at 200F with load on room temperature tensile properties of sheet, Table 3.02145.

3.02146 Effect of 100 hour exposure to elevated temperature with load on room temperature tensile properties of sheet aged to medium strength level, Table 3.02146.

3.02147 Effect of 100 hour exposure to elevated temperature with load on room temperature tensile properties of sheet aged to high strength level, Table 3.02147.

3.02148 Effect of 500 hour exposure to elevated temperature with load on room temperature tensile properties of sheet aged to medium strength level, Table 3.02148.

3.02149 Effect of 500 hour exposure to elevated temperature with load on room temperature tensile properties of sheet aged to high strength level, Table 3.02149.

3.02150 Effect of 100 hour exposure to elevated temperature with load on room temperature tensile properties of sheet variously aged, Figure 3.02150.

3.02151 Effect of aging temperature on tensile properties of coil sheet, Figure 3.02151.

3.02152 Tensile properties of foil, Table 3.02152.

3.022 Compression.

3.0221 Typical compressive stress-strain curves for sheet, Figure 3.0221.

3.0222 Compressive yield strength of bar, Table 3.0222.

3.0223 Compressive yield strength of plate, Table 3.0223.

3.0224 Compressive yield strength of sheet, Table 3.0224.

3.023 Impact (see 3.033).

3.024 Bending.

3.025 Torsion and shear.

3.0251 Double shear strength of aged bars variously melted and solution treated, Figure 3.0251.

3.0252 Effect of solution temperature on shear strength of rod, Figure 3.0252.

3.0253 Spread of shear strength for rod aged at different temperatures, Figure 3.0253.

3.0254 Shear strength of sheet, Table 3.0254.

3.026 Bearing.

3.027 Stress concentration.

3.0271 Notch properties.

3.02711 Effect of composition (variation in beta-phase-stabilizing element content) on mild-notch tensile properties of sheet, Table 3.02711.

3.02712 Effect of yield strength level on strength of center fatigue crack sheet specimens, Figure 3.02712.

3.02713 Effect of cold reduction on strength of center fatigue-crack sheet specimens variously heat treated, Figure 3.02713.

3.0272 Fracture toughness.

3.02721 General. The aging response of this alloy is presented in Figure 3.02722 in terms of its yield strength and plane strain fracture toughness. According to a recent study by Feeney and Blackburn (15)(23), the trends observed may be interpreted in light of the alloy's transformation kinetics (see TTT diagram, Figure 2.0121).

The as-quenched β -phase structure contains ω -phase particles < 25 A^{o} in diameter. Aging below 800 F to produce ω -phase particles ≥ 100 A^{o} caused tension specimens to fail in a brittle manner without general yielding. These failures often originated at faint machine markings extensometer marks, and thread roots. Such brittle specimens were therefore tested in compression and are suitably identified in Figure 3.02722.

Only a small increase in yield strength is obtained on aging at 550F, even after 500 hours, at which time the ω-phase particle size is 100 A^{o}. The corresponding decrease in plane strain fracture toughness is marked (a near-linear decrease from 65.9 ksi$\sqrt{in}$ to 9.4 ksi$\sqrt{in}$). At 700F, aging produces a rapid increase in yield strength. The maximum value of 220 ksi is associated with an average particle size of 900A^{o}. The plane strain fracture toughness is reduced to a limiting value of about 20 ksi $\sqrt{in}$ early in the aging cycle and is thus apparently independent of both particle size and yield strength when the ω-phase particle size exceeds 100 A^{o}.

The effect of α-phase precipitation on yield strength and plane strain fracture toughness is typified by the 900F aging curve. It is apparent that the best combination of strength and toughness is obtained by aging beyond 32 hours at 900F, which results in the precipitation of a fine dispersion of α-phase. The low fracture toughness value obtained for specimens aged 0.5 hour at 900F is reproducible and, according to the investigator(15), may be explained by the large mass of the fracture toughness specimen which is responsible for slow heating and slow cooling through the ω-phase transformation region during the aging cycle. Hence the high volume fraction of β-phase may be slightly embrittled by this treatment. The fracture toughness minimum at 8 hours aging is not unexpected as it is associated with maximum strengthening at this aging temperature.

3.02722 Effect of aging time on the plane strain fracture toughness of plate, Figure 3.02722.
3.02723 Plane strain fracture toughness of press forgings, Table 3.02723.
3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Typical stress-strain curves at various temperatures for sheet in longitudinal direction, Figure 3.0311.
3.0312 Typical stress-strain curves at various temperatures for sheet in transverse direction, Figure 3.0312.
3.0313 Effect of test temperature on tensile properties of bar, Figure 3.0313.
3.0314 Effect of test temperature on tensile properties of plate, Figure 3.0314.
3.0315 Effect of test temperature on tensile properties of sheet, Figure 3.0315.
3.032 Compression.
3.0321 Typical compressive stress-strain curves at various temperatures for sheet in longitudinal direction, Figure 3.0321.
3.0322 Typical compressive stress-strain curves at various temperatures for sheet in transverse direction, Figure 3.0322.
3.0323 Effect of test temperature on compressive yield strength of sheet, Figure 3.0323.
3.033 Impact.
3.0331 Charpy-V impact energy for bar at room temperature and -40F, Table 3.0331.
3.0332 Charpy-V impact energy for bar at -40F, Table 3.0332.
3.0333 Effect of aging temperature on -40F impact energy of 0.5 inch plate, Figure 3.0333.
3.0334 Effect of aging temperature on -40F impact energy of 1 inch plate, Figure 3.0334.
3.0335 Effect of hot rolling temperature and cooling rate from the solution treatment temperature on the room temperature and -40F impact energy of 0.5 inch plate, Table 3.0335.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.0372 Fracture toughness.
3.038 Combined properties.

3.04 Creep and Creep Rupture Properties
3.041 100 hour creep deformation for bar (see Table 3.02112).
3.042 500 hour creep deformation for bar (see Table 3.02113).
3.043 100 hour creep deformation for plate, Figure 3.043.
3.044 500 hour creep deformation for plate (see Table 3.02129).
3.045 Smooth stress rupture properties for plate at room temperature and 500F, Table 3.045.
3.046 5 hour mild-notch stress rupture strength for plate, Table 3.046.
3.047 100 hour creep deformation for sheet, Figure 3.047.
3.048 500 hour creep deformation for sheet, Figure 3.048.
3.049 200F creep deformation for sheet, Table 3.049.
3.0410 500 hour mild-notch rupture strength for sheet at room temperature, Table 3.0410.

3.05 Fatigue Properties
3.051 Axial load and rotating beam fatigue properties of bar, Figure 3.051.
3.052 Axial load smooth and mild-notch fatigue properties of bar, Figure 3.052.
3.053 Axial load smooth fatigue properties of plate, Figure 3.053.
3.054 Axial load smooth and mild-notch fatigue properties of sheet, Figure 3.054.

3.06 Elastic Properties
3.061 Poisson's ratio for sheet, Table 3.061.
3.0621 Effect of heat treated section size on elastic modulus of unidirectionally forged square bars aged at 900F,(see Table 3.0214).
3.0622 Effect of test temperature on elastic modulus of bar, Figure 3.0622.
3.0623 Compressive elastic modulus of bar, Table 3.0623.
3.0624 Effect of aging temperature on elastic modulus of plate and sheet, Figure 3.0624.
3.0625 Compressive elastic modulus of plate, Table 3.0625.
3.0626 Effect of solution temperature on elastic modulus of solution treated sheet, Figure 3.0626.
3.0627 Effect of test temperature on elastic modulus of sheet, Figure 3.0627.
3.0628 Effect of test temperature on compressive elastic modulus of sheet, Figure 3.0628.
3.0629 Effect of aging temperature on elastic modulus of coil sheet, Figure 3.0629.
3.06210 Elastic modulus of foil, (see Table 3.02152).
3.0631 Typical compressive tangent modulus at various temperatures for sheet in longitudinal direction, Figure 3.0631.
3.0632 Typical compressive tangent modulus at various temperatures for sheet in transverse direction, Figure 3.0632.

4. FABRICATION

4.01 Formability.
4.011 Cold forming. The cold formability of this alloy is discussed in reference 20. The alloy is more readily cold formed than previously available high strength titanium alloys and is approximately equal in cold formability to half-hard Type 301 stainless steel and A-70 unalloyed titanium. This formability should permit cold forming of many sheet metal parts which would require hot forming alpha-beta grades. The alloy has also been successfully cold shear spun to high reductions.

The alloy exhibits high springback like all titanium alloys. Warm forming may be required when springback cannot be corrected by means of stretch forming or overbending. The alloy can be warm formed at 950-1000F. Inexpensive tooling materials are suitable for forming at such temperatures, in contrast to the high-alloy die materials required for hot forming alpha-beta grades at 1400F. Low temperature forming also minimizes contamination of the surface and subsequent metal removal by pickling. Formed sheet can be simply aged to very high strength levels.

The alloy has been successfully processed to tubing. Tensile properties of tubing are presented in Table 3.02118.

4.0111 Flattening and flaring performance of seamless tubing, Table 4.0111.

4.012 Forging. Forging can be started at temperatures up to 2000F, and minimum temperature is determined solely by equipment power limitations. Finish forging at relatively low temperature (e.g., 1600F) is generally recommended for fine grain size and maximum aged ductility, where equipment limitations permit (7).

4.013 Rollability. The good workability of this alloy, both hot and cold, recommends it for continuous strip processing. At 1700F, the alloy has flow stresses equivalent to Ti-6Al-4V and about 60 percent that for Ti-13V-11Cr-3Al (see Figure 4.0131). It can be processed at reasonable roll loads at temperatures as low as 1400F (see also Figure 4.0131). The roll energy requirement for this alloy is comparable to Type 304 stainless steel (see Figure 4.0132).

The effect of initial and final pass entry temperatures on the tensile properties of sheet is shown in Table 4.0133. The alloy producer recommends an initial pass entry temperature of 1850F (4). Higher temperatures offer no property advantage and would require more conditioning than the 1850F initial entry temperature due to heating contamination, but would provide a safety factor for the mill. Lower initial rolling temperature might cause mill coiling problems. Hot rolling of plate at 1500F appears to produce the best combination of strength and ductility for solution treated or solution treated and aged plate (see Figures 4.0134 and 4.0135).

Figure 4.0136 illustrates the cold rollability of this alloy from 0.195 inch, representing the heaviest practical hot-band gage, down to 0.002 inch foil. It is seen to be somewhat stiffer than commercially pure titanium, requiring about 10-20 percent additional rolling passes at normal roll loads to achieve gage. In terms of cold rollability without edge cracking, this alloy surpasses commercially pure titanium and many commercial alloys. Cold reductions exceeding 90 percent without edge cracking are possible (see Table 4.0137).

4.0131 Hot rollability of Ti-11.5Mo-6Zr-4.5Sn and several other alloys, Figure 4.0131.

4.0132 Energy for hot strip rolling, Figure 4.0132.

4.0133 Effect of hot rolling temperature on tensile properties of hot rolled sheet, Table 4.0133.

4.0134 Effect of hot rolling temperature on tensile properties of solution treated plate, Figure 4.0134.

4.0135 Effect of hot rolling temperature on tensile properties of solution treated and aged plate, Figure 4.0135.

4.0136 Cold rollability, Figure 4.0136.

4.0137 Several cold rolling factors related to reduction limits, Table 4.0137.

4.014 Fasteners. The cold formability of this alloy makes it particularly suitable for aircraft fastener applications. Solution treated rivets can be readily installed by gun driving without fear of cracking due to its low rate of work hardening. Solution treated rivets are suitable only for low strength applications and where service temperatures do not exceed 350F (see stability considerations in Section 1.092).

Where higher strength is required rivets may be readily driven in the overaged condition (1050-1100F). Such rivets can be driven by either squeezing or gun driving, are metallurgically stable up to 800F, and can statistically meet 95 ksi minimum shear strength.

The effect of bucking tool configuration has been recently studied (18). While no effect is observed on the cross tension or lap shear strength of rivet joints (see Table 4.0143 and Figure 4.0144), a significant difference in fatigue strength for joints with or without previous exposure to elevated temperature is shown in Table 4.0146 for flat versus cavity bucking tool configurations.

4.0141 Effect of solution temperature on cold headability of rod, Figure 4.0141.

4.0142 Cross tension and lap shear strength of rivet joints with and without exposure to elevated temperature with load, Table 4.0142.

4.0143 Effect of bucking tool configuration on cross tension strength of rivet joints with and without exposure to elevated temperature, Table 4.0143.

4.0144 Effect of bucking tool configuration and test temperature on lap shear strength of rivet joints with and without previous exposure to elevated temperature, Figure 4.0144.

4.0145 Fatigue strength of riveted lap shear joints, Figure 4.0145.

4.0146 Effect of bucking tool configuration on fatigue strength of riveted lap shear joints with and without previous exposure to elevated temperature, Table 4.0146.

4.02 Machining and Grinding

Contact Air Force Machinability Data Center, 3980 Rosslyn Drive, Cincinnati, Ohio 45209.

4.03 Welding

4.031 Fusion welding. Data shown in Table 4.0311 were obtained on GTA welded sheet prepared for welding by pickling in 2 percent hydrofluoric, 20 percent nitric acid. After pickling, the panels were rinsed in warm water and dried; the sheared panel edges were not dressed in any manner. Welding was manual, single pass, and without addition of filler. Current was 90 ampere at 11 volts. All joints were transverse to the rolling direction. Weld beads were ground flush with the parent metal.

The aged strength of weld joints was about 90 percent that of the aged parent sheet (compare Table 4.0311 with Figure 3.02134). Low-high aging cycles (e.g., 800F, 8 hr + 1050F, 8 hr) produce a fine alpha precipitate and increased aged strength compared with single aging (e.g. 1050F, 8 hr).

Electron beam welding appears to offer no aged strength advantage over GTA welding (compare Tables 4.0311 and 4.0312).

4.0311 Tensile properties of GTA fusion welded sheet, Table 4.0311.

4.0312 Tensile properties of electron-beam fusion welded sheet, Table 4.0312.

4.032 Spot welding. As in the preparation of fusion welds above spot weld specimens for which data are presented in Table 4.0321 were descaled and pickled in nitric-hydrofluoric acid immediately prior to joining. As is general practice for titanium, no inert gas shielding was required during spot welding. This results in only a very superficial oxide film around the weld because the fusion areas are pressed closely together and the weld cycle is short due to the relatively high resistivity of the metal.

Since spot welds develop only a limited fusion area, the spot weld strength may be expected to be influenced by the pre-weld solution temperature. Thus the 1350F pre-weld solution treatment produces higher lap shear strength for unaged, pre-weld aged or post-weld aged welds with one exception - welds post-weld aged at 1000F. With the exception of unaged welds, the cross tension strength of welds pre-weld solution treated at 1450F exceeds that for welds pre-weld solution treated at 1350F. Post-weld high-strength aging treatments at 950 and 1000F are generally unsatisfactory. Only after these aging treatments are weld bond failures observed at the original interface. Only marginal recovery of weld strength is observed in medium strength post-weld aging at 1050F.

4.0321 Cross tension and lap shear strengths of spot welded sheet, Table 4.0321.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

4.04 Heat Treatment

High strength can be produced in this alloy by aging followed by air cooling. Little or no distortion occurs. Resolution treatment prior to aging is recommended for sheet parts where improved ductility and toughness is desired in heavily worked areas. This can be accomplished by heating to 1325-1350F, holding 1-2 minutes, and water quenching or individually air cooling. Some distortion is likely, but to a lesser degree than in heat treatment of other titanium alloys.

4.05 Surface Treating

In common with other titanium alloys, this alloy is susceptible to the embrittling effect of a high-oxygen surface layer. Removal of scale and oxygen-rich surface after heat treatment is recommended. The oxide formed in aging at 900F can be removed by pickling in 25 percent nitric-2 percent hydrofluoric acid at 140-150F. Molten salt descaling prior to pickling is preferred after aging at higher temperatures or after solution treatment and aging. Acid pickling to reduce thickness by 0.0005 inch is adequate after aging, but 0.001-0.002 inch thickness reduction is recommended after solution treatment and aging. Vacuum or inert atmosphere heat treatment does not necessarily eliminate the need for surface removal.

Beta alloys absorb hydrogen quite rapidly, though they are affected less by hydrogen pickup than alpha or alpha-beta alloys. The nitric-hydrofluoric ratio in pickling baths should be maintained at 10-15 to 1 to minimize hydrogen absorption.

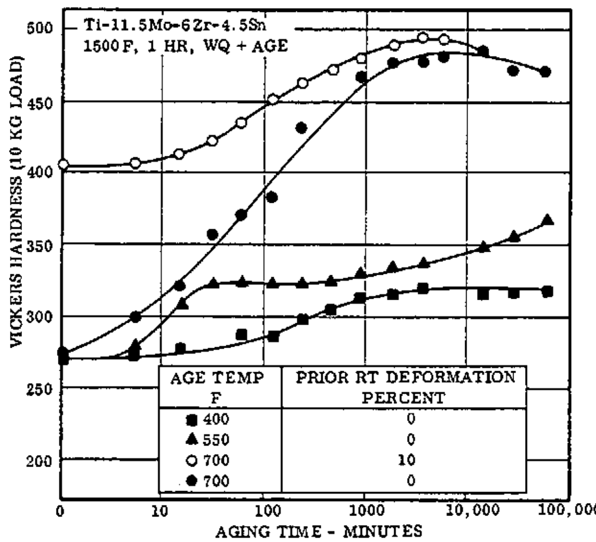


FIG. 1.064 EFFECT OF AGING TIME ON HARDNESS OF SPECIMENS AGED BELOW 800F. (15)

Source	AMS (1)(2) Military (3)	
	Weight Percent	
	Minimum	Maximum
Molybdenum	10.00	13.00
Zirconium	4.50	7.50
Tin	3.75	5.25
Iron	-	0.35
Oxygen	-	0.18
Hydrogen	-	0.0200*
Carbon	-	0.10
Nitrogen	-	0.05
Other Elements (total)	-	0.40
Titanium	Balance	

* Military gives 0.015 max (to be determined on each lot of product as shipped).

TABLE 1.041 AMS AND MILITARY SPECIFIED COMPOSITIONS.

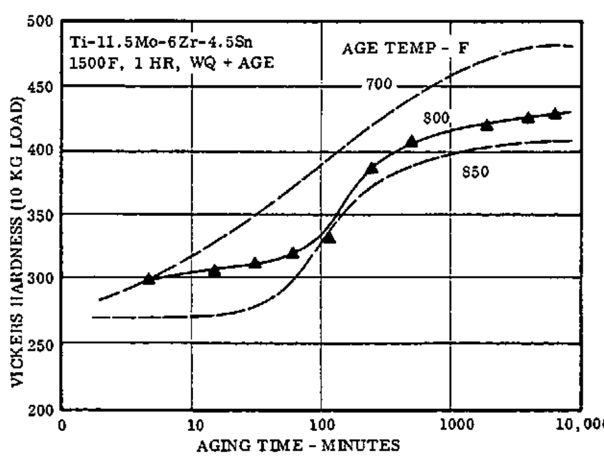


FIG. 1.065 EFFECT OF AGING TIME ON HARDNESS OF SPECIMENS AGED AT 800F. (15)

Source	AMS (2)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	Bars and Wire	
Condition	1300-1450F, 15 min max, WQ	1300-1450F, 15 min max, WQ + 910-940F, 8 hr, AC
Hardness-R_C	30 max	34-45

TABLE 1.062 AMS SPECIFIED HARDNESS FOR BARS AND WIRE.

Source	AMS (1)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	Bars and Wire (Fastener Stock)	
Condition	1275-1350F, 15 min, WQ	1275-1350F, 15 min, WQ + 1050-1100F, 2 hr minimum, AC
Hardness-R_C	30 max	30-38

TABLE 1.063 AMS SPECIFIED HARDNESS FOR BARS AND WIRE FOR FASTENER APPLICATION.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

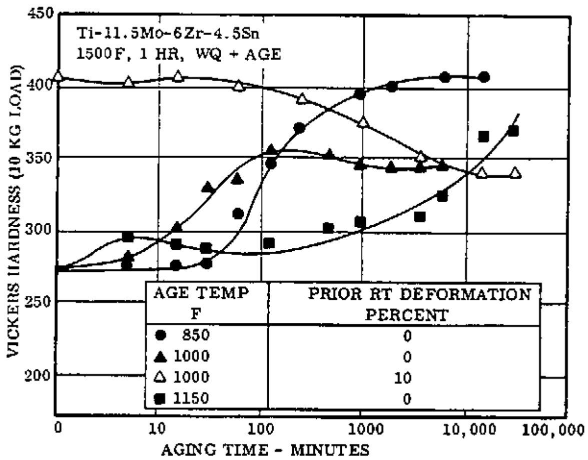


FIG. 1.066 EFFECT OF AGING TIME ON HARDNESS OF SPECIMENS AGED ABOVE 800F. (15)

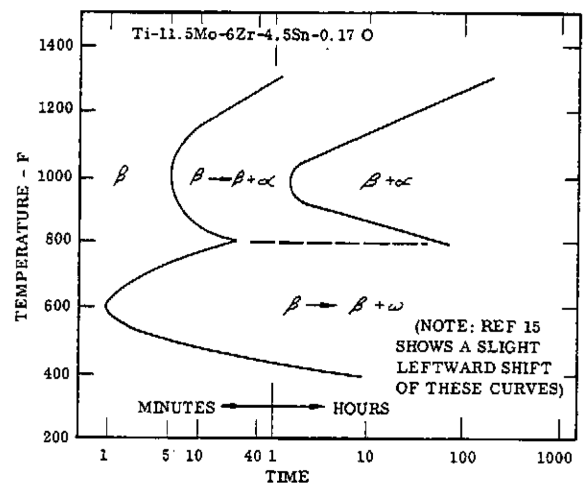


FIG. 2.0121 TIME-TEMPERATURE-TRANSFORMATION DIAGRAM. (10)

Source	(8)				
Alloy	Ti-11.5Mo-6Zr-4.5Sn				
Form	Cast-to-Size Tensile Specimens				
Heat	Condition	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
A(a)	As Cast	121.9	107.7	18.5	61.1
		126.6	115.2	17.0	52.7
	1350F, WQ + 750F, 8 hr	136.1	(d)	-	-
		151.8	(d)	-	-
	1350F, WQ + 900F, 8 hr	191.7	184.1	2.5	4.4
		195.1	180.9	2.5	4.3
	1350F, WQ + 1100F, 8 hr	142.9	135.8	8.0	28.9
		143.2	135.7	6.0	23.9
	1350F, WQ + 750F, 8 hr	149.9	(d)	-	-
	+ 800F, 8 hr	103.3	(d)	-	-
A(b)	As Cast	124.7	114.4	16.8	53.1
		117.1	101.3	19.8	59.8
		118.2	104.4	18.4	60.6
	1400F, 1 hr, WQ + 950F, 8hr	187.4	179.3	2.7	7.9
		193.5	183.7	3.1	7.9
		191.0	179.3	2.4	3.9
		190.0	179.8	2.6	5.4
B(c)	1350F, WQ + 920F, 8 hr	197.0	180.0	6	8
	1350F, WQ + 950F, 8 hr	182.0	164.0	7	15

(a) Cast and tested by investigator No. 1.
(b) Cast and tested by investigator No. 2.
(c) Cast and tested by investigator No. 3.
(d) Specimen failed with less than 0.2 percent plastic deformation.

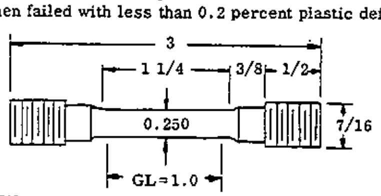


TABLE 1.083 TENSILE PROPERTIES OF CAST-TO-SIZE SPECIMENS.

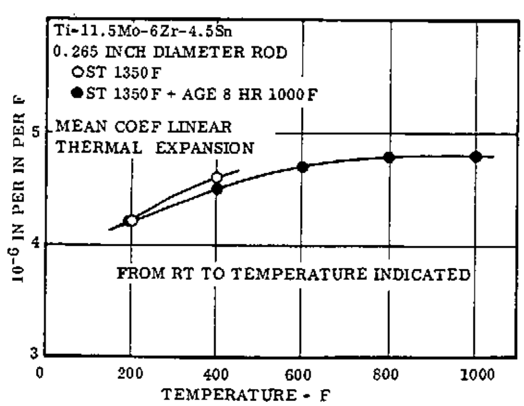


FIG. 2.014 THERMAL EXPANSION. (4)

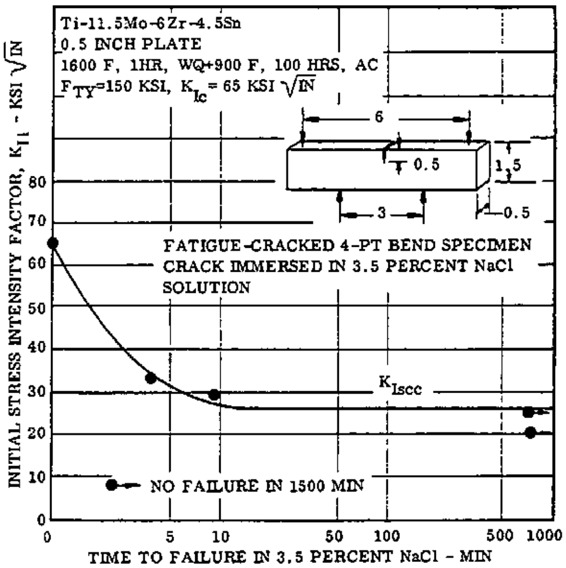


FIG. 2.033 STRESS CORROSION CRACKING THRESHOLD STRESS INTENSITY FACTOR FOR FAILURE IN 3.5 PERCENT NaCl SOLUTION (AQUEOUS) UNDER OPEN CIRCUIT CONDITIONS (NO APPLIED POTENTIAL). (15)(21)(23)

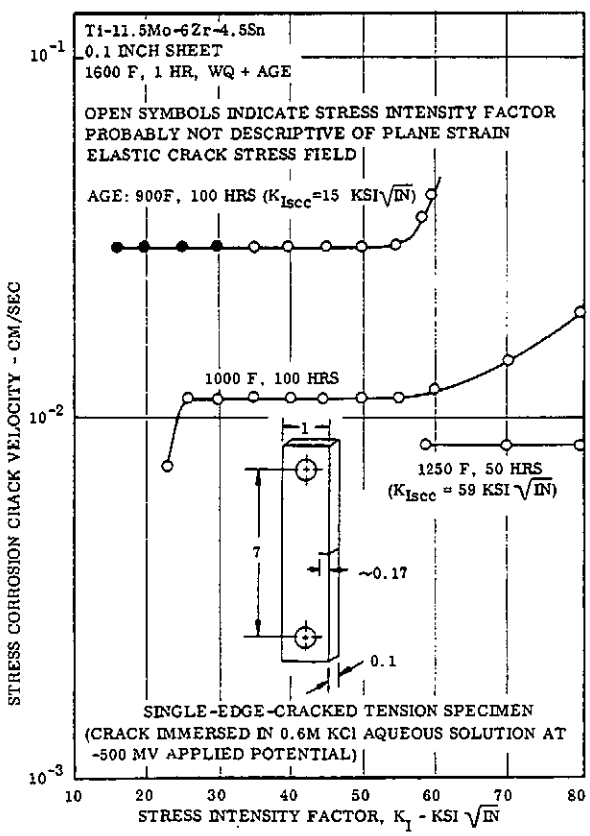


FIG. 2.034 EFFECT OF AGING TEMPERATURE AND STRESS INTENSITY FACTOR ON STRESS CORROSION CRACK VELOCITY FOR CRACKED SPECIMENS IMMERSED IN 0.6M KCl AQUEOUS SOLUTION WITH -500 MV APPLIED POTENTIAL. (15)(22)

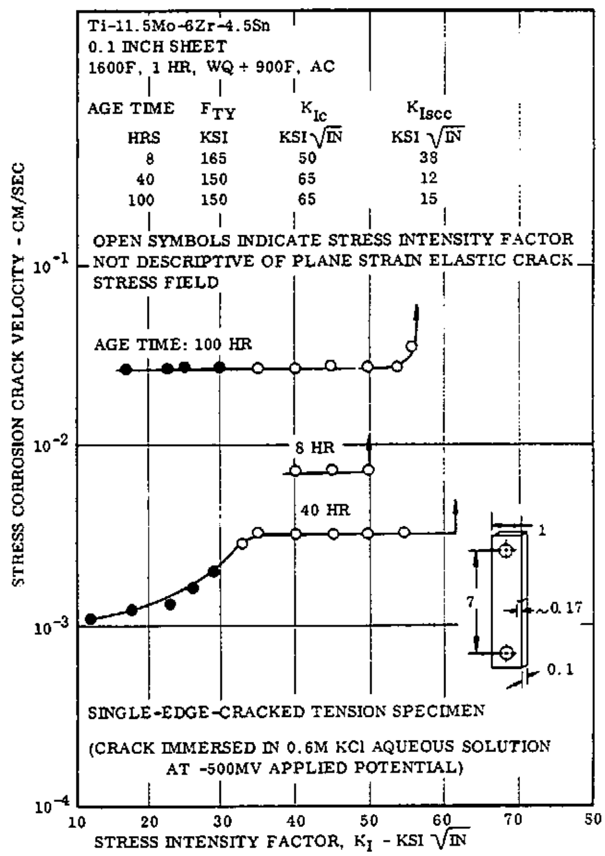


FIG 2.035 EFFECT OF AGING TIME AND STRESS INTENSITY FACTOR ON STRESS CORROSION CRACK VELOCITY FOR CRACKED SPECIMENS IMMERSED IN 0.6M KCl AQUEOUS SOLUTION WITH -500 MV APPLIED POTENTIAL. (15)(22)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

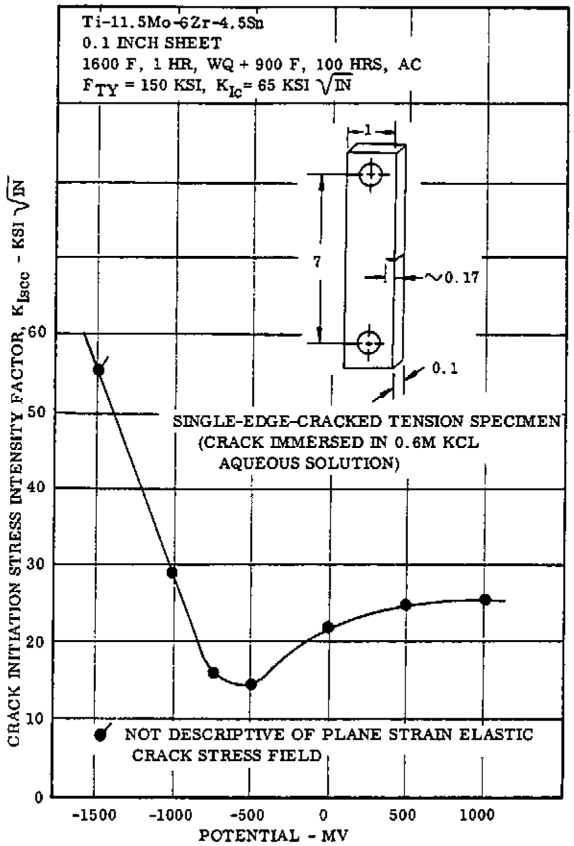


FIG. 2.036 EFFECT OF APPLIED ELECTRIC POTENTIAL ON CRACK INITIATION STRESS INTENSITY FACTOR FOR CRACKED SPECIMENS IMMERSED IN 0.6M KCL AQUEOUS SOLUTION. (15)(21)(22)

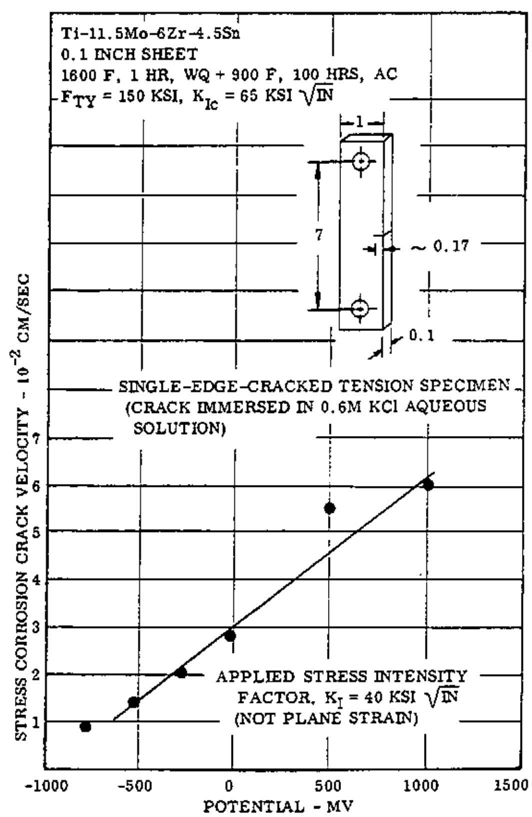


FIG. 2.037 EFFECT OF APPLIED ELECTRIC POTENTIAL ON STRESS CORROSION CRACK VELOCITY FOR CRACKED SPECIMENS IMMERSED IN 0.6M KCl AQUEOUS SOLUTION. (15)(22)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source				(4)				
Alloy				Ti-11.5Mo-6Zr-4.5Sn				
Form				0.5 inch diameter bar				
Condition				1420F, WQ + 950F, 8 hr				
100 hour exposure				Subsequent RT tensile properties				
Temp F	Stress ksi	Permanent Deformation percent	Surface Coating	F_{tu} ksi	F_{ty} ksi	e(4D) percent	RA percent	Salt Attack at Break percent*
Unexposed			none	193.7	181.0	8.0	34.3	0
500	125	0.00	none	200.1	190.0	5.0	16.4	0
500	110	0.10	salt**	196.2	187.6	9.0	31.9	0
500	130	0.01	salt**	199.8	190.8	8.0	28.7	0
500	140	0.36	none	196.9	192.4	11.0	32.5	0
500	140	0.00	salt**	196.4	187.9	8.0	23.8	0
500	150	0.50	salt**	201.2	199.2	3.0	25.7	0
700	90	0.30	none	202.4	191.3	8.0	25.1	0
700	50	0.02	salt**	202.8	191.3	7.0	23.7	0
700	75	0.24	salt**	199.4	192.4	10.0	29.2	0
700	80	0.48	salt**	160.3	-	-	-	15
700	85	0.14	salt**	130.8	-	-	-	20
750	40	0.16	salt**	198.4	187.9	6.0	27.2	0

* Percent of cross section.
** Specimens coated with a slurry of powdered NaCl and water.

TABLE 2.038 HOT SALT STRESS CORROSION CHARACTERISTICS OF BAR.

Source			(4)				
Alloy			Ti-11Mo-5.5Zr-4.5Sn				
Form			0.063 inch sheet				
Condition			ST 1400F + 900F, 8 hr				
650F, 40 ksi Exposure			Subsequent RT Tensile Properties				
Time hr	Permanent Deformation percent	Surface Coating	Ftu ksi	Fty ksi	e(2 in) percent	RA percent	Salt Attack at Break percent*
0	-	None	213.6	197.6	8.0	26.7	0
500	0.05	None	220.2	204.5	5.0	18.9	0
500	0.09	None	222.1	208.1	6.0	22.1	0
500	0.05	Salt	215.5	199.7	5.0	25.4	0
500	<0.01	Salt	223.9	207.6	4.5	9.0	1

* Percent of cross section.

TABLE 2.039 HOT SALT STRESS CORROSION CHARACTERISTICS OF PLATE.

Source	AMS(1)		AMS(2)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	Bars and Wire (Fastener Stock)		Bars and Wire	
Condition	1275-1350F, 15 min, WQ		1300-1450F, 15 min maximum, WQ	
Nominal Diameter or Distance Between Parallel Sides inches	F_{tu} - ksi minimum	F_{ty} - ksi minimum	e(2 in or 4D) percent minimum	RA percent* minimum
1.625	110	90	15	50
1.625 to 3.000	100	90	15	50

* Round specimens.
Longitudinal direction.

TABLE 3.011 AMS SPECIFIED MECHANICAL PROPERTIES FOR SOLUTION TREATED BARS AND WIRE AND BARS AND WIRE FOR FASTENER APPLICATION.

Source		(4)			
Corrosive Medium		Corrosion Rate - mils per year			
		RT		Boiling	
Acid	Weight percent	A70 (a) (500 hr test)	Beta III (b) (1000 hr test)	A70 (a) (48 hr test)	Beta III (b) (48 hr test)
HCl	2	0.034	0.062	297.0	4.28
	3	0.104	0.062	569.0	15.5
	5	7.45	0.078	1393	104.3
	10	26.55	0.164	3155	676.5
	15	-	-	5205	3093
	20	72.0	8.69	-	-
	30	316.5	17.55	-	-
H_2SO_4	1	-	-	456.5	1.80
	3	-	-	1182	15.05
	5	-	-	1830	38.89
	10	-	-	2833	135.1
	15	-	-	4055	241.0

(a) Unalloyed titanium grade A70, mill annealed sheet 0.087 inch thick.
(b) Ti-11.5Mo-6Zr-4.5Sn, ST 1400F, WQ, 0.040 inch thick.

TABLE 2.0310 CORROSION RATES OF Ti-11.5Mo-6Zr-4.5Sn AND UNALLOYED TITANIUM IN HYDROCHLORIC AND SULFURIC ACIDS.

Source	AMS(2)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	Bars and Wire			
Condition	1300-1450F, 15 min maximum, WQ + 910-940F, 8 hr, AC			
Nominal Diameter or Distance Between Parallel Sides inches	F_{tu} - ksi minimum	F_{ty} - ksi minimum	e(2 in or 4D) percent minimum	RA percent* minimum
$\leq$1.625	180	175	8	22
$>$1.625 to 3.000	180	170	4	10

* Round specimens.
Longitudinal direction.

TABLE 3.012 AMS SPECIFIED MECHANICAL PROPERTIES FOR SOLUTION TREATED AND AGED BARS AND WIRE.

Ti	
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source	AMS(1)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	Bars and Wire (Fastener Stock)			
Condition	1275-1350F, 15 min, WQ + 1050-1100F, 2 hr minimum, AC			
Nominal Diameter or Distance Between Parallel Sides inches	F_{tu} - ksi minimum	F_{ty} - ksi minimum	e(2 in or 4D) percent minimum	RA percent* minimum
≤1.625	135	130	12	40
* Round specimens.				

TABLE 3.013 AMS SPECIFIED MECHANICAL PROPERTIES FOR SOLUTION TREATED AND AGED BARS AND WIRE FOR FASTENER APPLICATION.

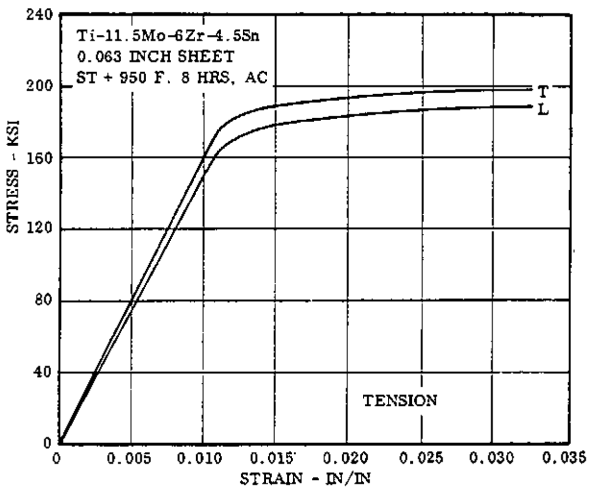


FIG. 3.0211 TYPICAL STRESS-STRAIN CURVES FOR AGED SHEET. (19)

Source	(4)				
Alloy	Ti-11.6Mo-6.5Zr-4.2Sn-0.12O				
Form	3 1/4 inch square billet				
Condition	Hot rolled+1425F, 15 min, WQ+age, 8 hr*				
Age Temp F	Test Location	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
Unaged	Corner	116.0	104.2	21.0	71.4
	Center	108.1	93.0	20.0	61.6
900	Corner	183.9	176.3	6.0	25.6
	Center	186.4	173.6	6.0	13.0
1100	Corner	134.9	127.4	15.0	57.5
	Center	134.3	126.3	14.0	44.9
* Billet solution treated in full section; aging performed on individual test coupons.					

TABLE 3.0212 VARIATION IN TENSILE PROPERTIES FOR HOT ROLLED BILLET.

Source	(11)(17)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn-0.10 O			
Form	Closed Die Press Forging			
Condition	1325F, 1 hr, WQ + 950F, 8 hr, AC*			
Location	F_{tu} - ksi	F_{ty} - ksi	e - percent	RA - percent
1 - Panel transverse	188.0	176.4	5.0	17.4
2 - Panel longitudinal	193.6	185.2	5.0	12.2
3 - Rib longitudinal	192.4	184.0	4.5	10.0
4 - Center surface longitudinal	184.0	183.2	2.5	4.7
5 - Center mid-radius longitudinal	189.2	182.4	2.5	6.2
6 - Center longitudinal	190.8	182.0	4.0	10.8
7 - Center short transverse	183.6	174.0	3.0	10.0
8 - Center longitudinal transverse	180.0	170.0	5.0	13.7
9 - Center transverse end	184.8	173.6	5.5	15.2
10 - Center transverse end	184.5	174.0	4.5	16.5
11 - Center longitudinal end	184.0	173.2	4.0	10.8
* Heat treated in full section.				

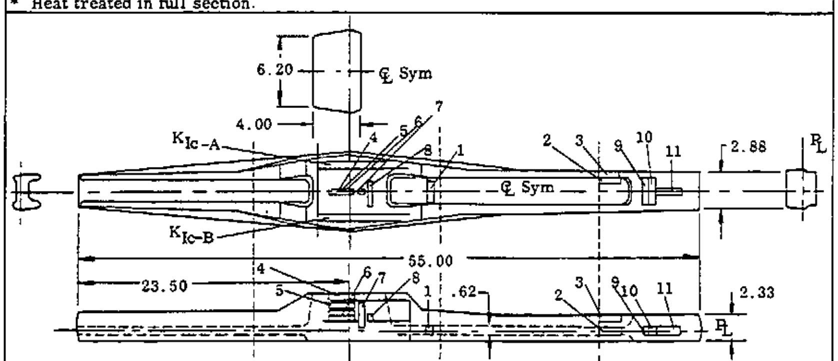


TABLE 3.0213 VARIATION IN TENSILE PROPERTIES FOR CLOSED DIE FORGING.

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

Source	(13)(14)						
Alloy	Ti-11Mo-5Zr-7Sn-0.07 O						
Form	Forged Square Bars						
Condition	1400F, 1 hr, WQ + 900F, 8 hr, AC *						
Bar Size	Test		F_{tu}	F_{ty}	e(4D)	RA	E
in	Direction	Location	ksi	ksi	percent	percent	10^3 ksi
1	Long	Center	191.1	179.8	9.0	29.6	14.2
	Long	Center	188.8	171.2	10.0	29.0	14.9
2	Long	Edge	182.2	175.1	7.0	24.0	14.0
	Long	Center	176.6	168.9	7.0	19.0	12.8
	Long	Edge	187.0	178.9	8.0	22.3	14.2
	Trans	Edge	206.3	200.8	4.0	12.5	-**
	Trans	Center	181.7	175.0	8.0	24.9	-**
	Trans	Edge	190.9	186.3	4.0	11.1	-**
3	Long	Edge	184.1	171.8	8.0	19.6	14.1
	Long	Center	177.4	170.4	9.0	25.3	12.8
	Long	Edge	185.5	178.1	9.0	15.7	13.8
	Trans	Edge	192.8	184.4	6.0	4.0	14.3
	Trans	Center	Broke Before Yield				
	Trans	Edge	191.3	184.9	3.0	3.9	13.9
4	Long	Edge	188.1	183.4	6.0	10.9	14.4
	Long	Mid-Radius	195.2	183.2	7.0	9.1	14.9
	Long	Center	185.7	173.5	6.0	12.8	13.5
	Trans	Edge	Broke Before Yield				
	Trans	Mid-Radius	198.4	191.0	2.0	6.0	14.6
	Trans	Center	192.4	185.6	3.0	4.8	13.2
6	Long	Edge	195.9	190.6	10.0	10.5	14.6
	Long	Mid-Radius	194.1	188.3	6.0	7.8	15.0
	Long	Center	195.2	185.8	6.0	7.8	14.9
	Long	Mid-Radius	196.5	191.5	5.0	11.6	14.7
	Long	Edge	194.5	188.9	8.0	12.3	14.1
	Trans	Edge	202.8	197.2	2.0	4.3	14.6
	Trans	Mid-Radius	201.7	200.0	3.0	3.9	14.5
	Trans	Center	Broke Before Yield				
	Trans	Mid-Radius	206.4	206.0	1.0	2.4	14.3
	Trans	Edge	201.1	200.0	3.0	2.4	14.6

Bars successivly reduced in size from common starting billet.
* Heat treated in full section size.
** Not determined.

TABLE 3.0214 EFFECT OF HEAT TREATED SECTION SIZE ON TENSILE PROPERTIES OF UNIDIRECTIONALLY FORGED SQUARE BARS AGED AT 900F.

Source	(13)(14)					
Alloy	Ti-11Mo-5Zr-7Sn-0.07 O					
Form	Forged Square Bars					
Condition	1400F, 1 hr, WQ + 950F, 8 hr, AC*					
Bar Size	Test		F_{tu}	F_{ty}	e(4D)	RA
in	Direction	Location	ksi	ksi	percent	percent
1	long	center	183.7	172.9	10.0	31.8
2	long	edge	182.9	174.1	8.0	21.1
	long	center	167.0	160.1	17.0	30.7
	long	edge	177.2	170.3	9.0	18.6
	trans	edge	191.4	188.6	6.0	12.5
	trans	center	173.1	-	5.0	12.5
3	long	edge	178.5	171.9	9.0	16.8
	long	center	162.7	154.7	12.0	32.7
	long	edge	178.3	167.7	8.0	14.7
	trans	edge	191.6	183.9	3.0	2.8
	trans	center	167.2	160.4	4.0	3.2
	trans	edge	179.3	174.9	5.0	7.8
4	long	edge	183.9	176.9	10.0	20.0
	long	mid-rad	181.6	172.8	10.0	16.8
	long	center	176.1	166.9	9.0	17.9
	trans	edge	185.0	179.9	3.0	3.6
	trans	mid-rad	185.6	179.0	3.0	4.7
	trans	center	186.8	180.0	3.0	5.1
6	long	edge	187.1	183.1	6.0	12.4
	long	mid-rad	182.2	176.0	7.0	8.6
	long	center	184.3	171.2	10.0	15.7
	long	mid-rad	182.7	176.1	7.0	14.6
	long	edge	182.2	178.5	9.0	12.4
	trans	edge	186.1	-	2.0	2.0
	trans	mid-rad	193.3	187.8	3.0	4.0
	trans	center	191.7	189.5	2.0	2.0
	trans	mid-rad	139.7	-	3.0	2.0
	trans	edge	184.4	183.0	2.0	2.4

Bars successively reduced in size from common starting billet.
* Heat treated in full section size.

TABLE 3.0215 EFFECT OF HEAT TREATED SECTION SIZE ON TENSILE PROPERTIES OF UNIDIRECTIONALLY FORGED SQUARE BARS AGED AT 950F.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source	(13)(14)					
Alloy	Ti-11Mo-5Zr-7Sn-0.07 O					
Form	Forged Square Bars					
Condition	1400F, 1 hr, WQ + 1000F, 8 hr, AC*					
Bar Size in	Test Direction	Test Location	F_{tu} ksi	F_{ty} ksi	e(4D) percent	RA percent
1	long	center	171.7	161.3	13.0	39.3
2	long	edge	171.0	164.1	10.0	11.6
	long	center	159.5	154.6	14.0	31.7
	long	edge	171.3	164.5	10.0	26.9
	trans	edge	172.9	167.8	8.0	15.7
	trans	center	164.1	161.1	10.0	29.9
3	long	edge	168.4	161.1	9.0	15.7
	long	center	155.0	152.8	18.0	51.9
	long	edge	170.6	163.3	8.0	13.8
	trans	edge	170.0	164.6	2.0	5.9
	trans	center	154.4	147.1	7.0	19.7
	trans	edge	176.9	171.8	3.0	2.8
4	long	edge	174.2	167.2	11.0	24.6
	long	mid-rad	171.5	164.4	11.0	14.4
	long	center	167.2	160.1	9.0	24.9
	trans	edge	174.4	169.9	4.0	9.4
	trans	mid-rad	178.9	171.9	4.0	3.0
	trans	center	166.2	159.0	5.0	6.3
6	long	edge	182.4	176.9	7.0	13.3
	long	mid-rad	177.2	169.1	8.0	10.9
	long	center	173.3	164.0	9.0	20.8
	long	mid-rad	178.8	171.2	7.0	10.1
	long	edge	179.0	174.2	8.0	11.2
	trans	edge	175.5	-	2.0	5.5
	trans	mid-rad	152.3	-	1.0	2.4
	trans	center	178.5	174.8	3.0	2.0
	trans	mid-rad	179.9	-	3.0	2.4
	trans	edge	172.7	-	4.0	2.0

Bars successively reduced in size from common starting billet.
* Heat treated in full section size.

TABLE 3.0216 EFFECT OF HEAT TREATED SECTION SIZE ON TENSILE PROPERTIES OF UNIDIRECTIONALLY FORGED SQUARE BARS AGED AT 1000F.

Source	(14)								
Alloy	Ti-11Mo-5Zr-7Sn								
Form	Forged Square Bars								
Condition	1400F, 1 hr, WQ + 950F, 8 hr, AC*								
Direction	Location	F_{tu} - ksi		F_{ty} - ksi		e(4D) - percent		RA - percent	
		(Six inch square forged bar)							
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Longitudinal	Edge	187.1	188.0	183.1	178.7	6.0	2.0	12.4	5.5
	Mid-Radius	182.2	183.0	176.0	173.9	7.0	5.0	8.6	9.4
	Center	184.3	172.1	171.2	160.0	10.0	5.5	15.7	13.5
	Mid-Radius	182.7	170.7	176.1	160.1	7.0	6.5	14.6	17.6
	Edge	182.2	172.4	178.5	160.0	9.0	7.0	12.4	16.8
Transverse	Edge	186.1	188.2	-	181.3	2.0	-	2.0	8.5
	Mid-Radius	193.3	176.9	187.8	171.3	3.0	2.0	4.0	5.4
	Center	191.7	176.9	189.5	169.4	2.0	3.0	2.0	10.5
	Mid-Radius	139.7	187.3	-	180.1	3.0	2.0	2.0	5.5
	Edge	184.4	182.2	183.0	175.1	2.0	2.0	2.4	6.3

Direction	Location	F_{tu} - ksi			F_{ty} - ksi			e(4D) - percent			RA - percent		
		(Three inch square forged bar)											
		(c)	(d)	(e)	(c)	(d)	(e)	(c)	(d)	(e)	(c)	(d)	(e)
Longitudinal	Edge	178.5	180.4	166.1	171.9	173.0	162.2	9.0	-	3.0	16.8	5.9	7.1
	Center	162.7	170.8	166.2	154.7	164.1	158.4	12.0	7.0	7.0	32.7	20.3	28.8
	Edge	178.3	165.1	169.6	167.7	164.1	161.4	8.0	-	5.0	14.7	-	10.4
Transverse	Edge	191.6	189.0	171.0	183.9	182.5	163.7	3.0	-	-	2.8	4.0	5.5
	Center	167.2	179.8	168.3	160.4	173.7	161.9	4.0	8.5	5.0	3.2	14.2	21.1
	Edge	179.3	176.2	170.8	174.9	172.2	162.9	5.0	-	3.0	7.8	4.0	10.2

(a) 6 inch square bar unidirectionally forged 1650F.
(b) 6 inch square x 10 inch long bar press upset 1600F to 6 inch thick, cross forged to 6 inch square x length.
(c) 3 inch square bar unidirectionally forged 1650F.
(d) 3 inch square x 5 inch long bar press upset 1600F to 3 inch thick, cross forged to 3 inch square x length.
(e) 3 inch square x 5 inch long bar press upset 1400F to 3 inch thick, cross forged to 3 inch square x length.
* Heat treated in full section size.

TABLE 3.0217 EFFECT OF CROSS FORGING ON TENSILE PROPERTIES OF 3 INCH AND 6 INCH SQUARE FORGED BARS AGED AT 950F.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

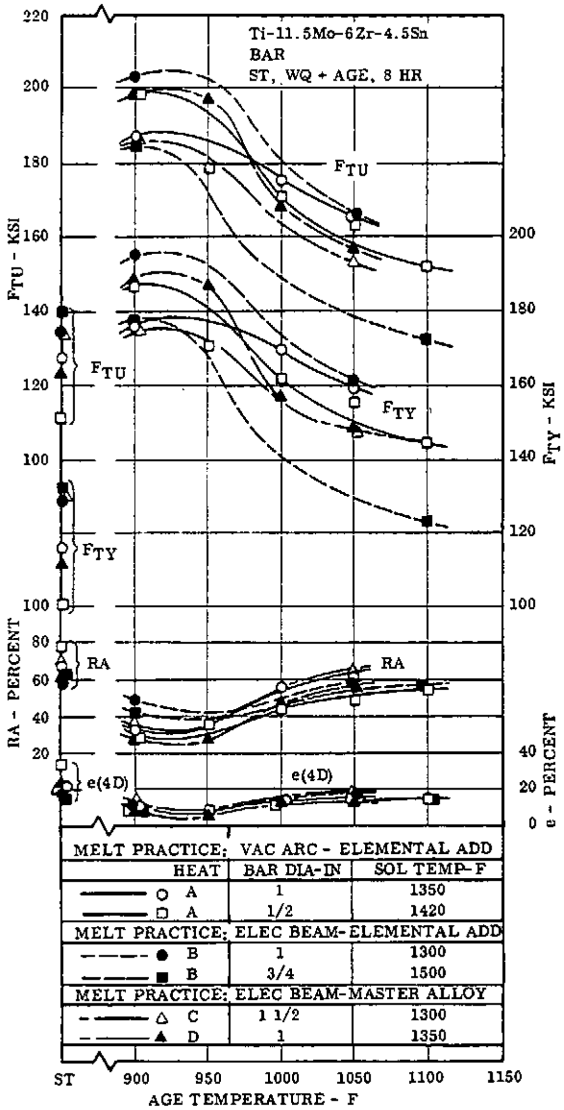


FIG. 3.0218 TENSILE PROPERTIES OF AGED BARS VARIOUSLY MELTED AND SOLUTION TREATED. (4)(7)

Source	(4)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	1 9/16 inch diameter bar			
Condition	1450F, 5 min, WQ			
Location	F_{tu}-ksi	F_{ty}-ksi	e(4D)-percent	RA-percent
Center	130.1	111.1	20.0	70.6
Mid-radius	132.3	110.2	20.0	66.1

TABLE 3.0219 CENTER AND MID-RADIUS TENSILE PROPERTIES OF 1 9/16 INCH SOLUTION TREATED BAR.

Source		(4)			
Alloy		Ti-11.5Mo-6Zr-4.5Sn			
Form		Bar			
Dia - in	Condition	F_{tu} ksi	F_{ty} ksi	e(4D) percent	RA percent
1.0	As hot rolled (a)	117.9	106.2	26.0	79.7
	1350 F, WQ (b)	123.0 - 133.1	108.2 - 125.3	22.0 - 23.0	59.9 - 69.7
	1350 F, WQ+900 F, 8 hr(b)	181.5 - 199.6	167.9 - 191.1	10.0 - 15.0	26.1 - 44.6
0.5	As hot rolled (a)	121.1	108.4	26.0	80.1
	1425 F, WQ (c)	107.0 - 116.5	92.8 - 108.2	32.0 - 38.0	76.2 - 80.3
	1425 F, WQ+900 F, 8 hr(c)	185.9 - 205.8	175.8 - 194.4	9.0 - 11.0	23.8 - 35.0

(a) 3 1/4 in square billet rolled at 1750F to nominal bar size, solution treated, water quenched and centerless ground to final size.
(b) Range for four of sixteen 10-ft lengths randomly sampled.
(c) Range for eight of forty 10-ft lengths randomly sampled.

TABLE 3.02110 TENSILE PROPERTY UNIFORMITY OF 1 INCH AND 0.5 INCH BAR.

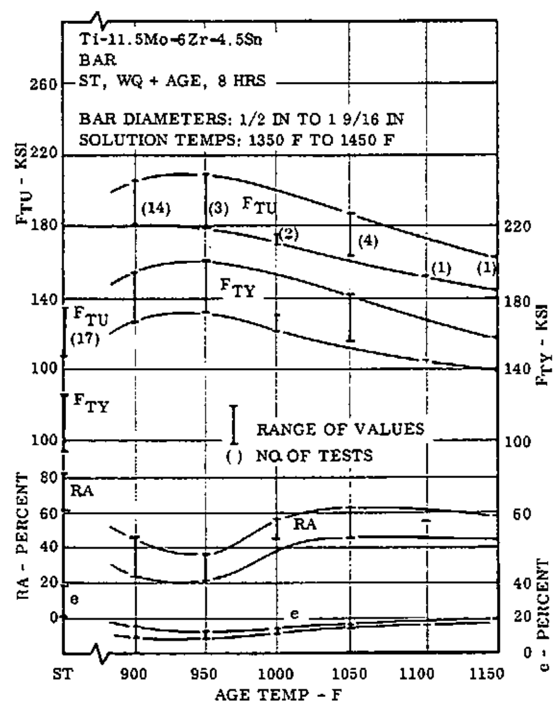


FIG. 3.02111 SPREAD OF TENSILE PROPERTIES FOR 1/2 INCH TO 1 9/16 INCH DIAMETER BARS SOLUTION TREATED AT 1350 F TO 1450 F AND AGED. (4)

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

Source	(4)						
Alloy	Ti-11.5Mo-6Zr-4.5Sn						
Form	1/2 inch diameter bar						
Condition	1425 F, WQ + age, 8 hr						
	100-hr Creep Exposure			Subsequent RT Tensile Properties*			
Age Temp F	Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
900		unexposed		199.6	187.6	9.6	27.2
	500	125	0.11	204.4	192.7	12.0	26.5
	600	105	0.05**	-	-	-	-
	800	15	0.26	212.1	199.1	8.0	19.6
950		unexposed		193.7	181.0	8.0	34.3
	RT	163	0.17**	-	-	-	-
	RT	172	0.11**	-	-	-	-
	500	125	0.00	200.1	190.0	5.0	16.4
	500	140	0.36	196.9	192.4	11.0	32.5
	700	60	0.16	191.1	182.7	10.0	29.5
	700	90	0.30	202.4	191.3	8.0	25.1
1050		unexposed		171.0	163.9	11.0	40.6
	500	110	0.41	162.1	159.1	14.0	54.1
	600	90	0.18	172.8	165.3	12.0	41.3
	800	15	0.02	176.9	165.3	12.0	38.9

* Tests made after creep exposure without surface conditioning.
** Not tensile tested after creep exposure.

TABLE 3.02112 EFFECT OF 100 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF BAR.

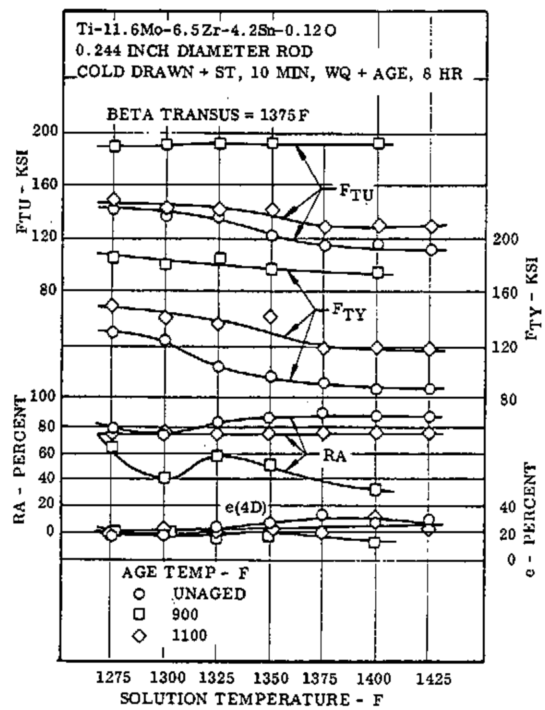


FIG. 3.02114 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF ROD. (4)

Source	(4)						
Alloy	Ti-11.5Mo-6Zr-4.5Sn						
Form	1/2 inch diameter bar						
Condition	1425 F, WQ + age, 8 hr						
	500-hr Creep Exposure			Subsequent RT Tensile Properties*			
Age Temp F	Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
900		unexposed		199.6	187.6	9.6	27.2
	500	125	0.00	210.4	199.9	6.0	21.2
	700	80	0.61	216.2	208.7	7.0	16.7
1050		unexposed		171.0	163.9	11.0	40.6
	500	110	0.00	162.8	156.3	11.0	49.7
	700	60	0.07	171.5	161.0	13.0	43.5

* Tests made after creep exposure without surface conditioning.

TABLE 3.02113 EFFECT OF 500 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF BAR.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source	(4)					
Alloy	Ti-11.5Mo-6Zr-4.5Sn					
Form	0.275 inch diameter rod					
Condition	Cold drawn + 1400F, WQ + 1100F, 8 hr					
100-hr Creep Exposure			Subsequent RT Tensile Properties*			
Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(4D) percent	RA percent
unexposed			147.3	138.9	20.0	71.4
			144.6	136.8	21.4	72.4
700	60	0.09	150.0	138.7	20.0	68.0
		0.07	155.6	141.9	20.0	69.3

* Tests made after creep exposure without surface conditioning.

TABLE 3.02116 EFFECT OF 100 HOUR EXPOSURE AT 700F WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF ROD.

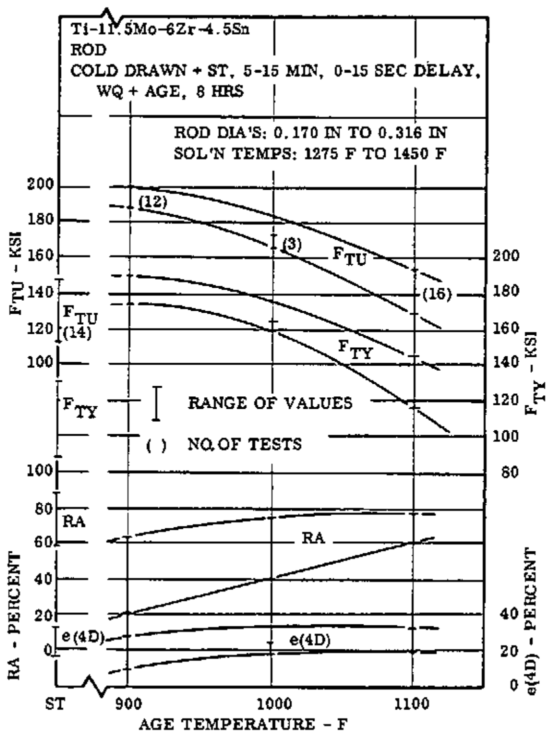


FIG. 3.02115 SPREAD OF TENSILE PROPERTIES FOR ROD VARIOUSLY HEAT TREATED. (4)

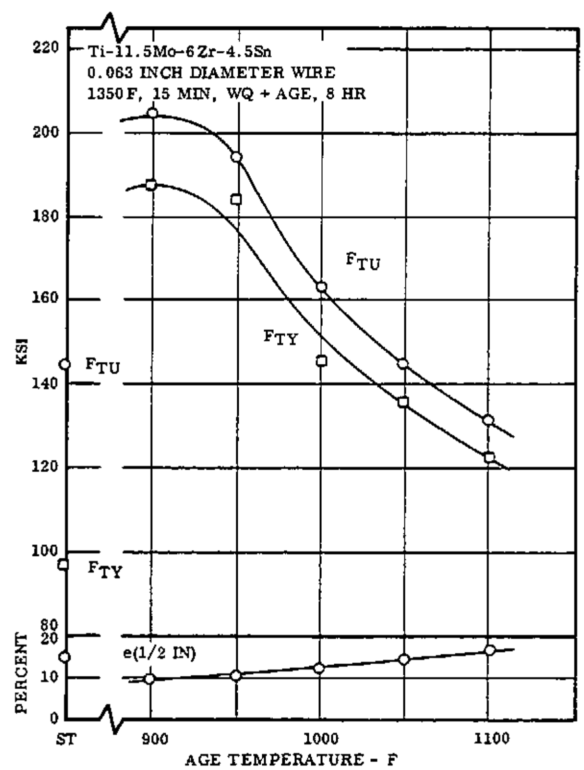


FIG. 3.02117 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF WIRE. (4)

Source		(4)				
Alloy		Ti-11.5Mo-6Zr-4.5Sn				
Form		Seamless Tubing				
Tube Size-in						
OD	Wall t	Condition	F_{tu}(a) ksi	F_{ty} ksi	e(2 in) percent	RA percent
1.5	0.173	As extruded (b)	116.0	99.7	16.0	75.6
			123.9	107.1	18.0	72.0
		As extruded + 950F, 8 hr	200.4(c)	184.3	8.0	18.4
			199.6(c)	183.4	8.0	22.6
1.26	0.120	Mill annealed (d)	143.8	134.1	13.2	42.0
		Mill annealed + pickled	143.4	135.6	13.0	47.5
		Mill annealed + 1350F, WQ	131.3	114.8	13.5	50.9
		Mill annealed + 1350F, WQ + 950F, 8 hr	185.4	176.3	7.5	26.7
		Mill annealed + 1350F, WQ + 1000F, 8 hr	173.7	164.8	9.2	36.5
0.884	0.050	Mill annealed (d)	154.7	141.0	8.5	16.6
		Mill annealed + pickled	151.0	138.2	8.5	24.7
		Mill annealed + 1350F, WQ	117.4	101.2	20.8	36.0
		Mill annealed + 1350F, WQ + 950F, 8 hr	180.4	169.0	6.0	12.3
		Mill annealed + 1350F, WQ + 1000F, 8 hr	169.8	159.8	7.2	15.6
0.5	0.024	As finish cold drawn (e)	162	120	7.0	-
		Cold drawn + 1450F, WQ	122	111	18.0	-
		Cold drawn+1350F, rapid AC+950F, 8 hr	189	183	5.5	-
		Cold drawn+1350F, rapid AC+1000F, 8 hr	184	173	7.5	-
		Cold drawn+1350F, rapid AC+1050F, 8 hr	168	150	9.5	-

(a) Specimens machined from longitudinal sections of tubing subtended by 3/4 inch cords. Specimen uniform section 0.5 inch wide: gage length 2 inches.
(b) 2.8 inch OD x 1.260 inch ID hollow billets canned in mild steel, heated to 1500F, extruded to tube hollow (reduction 7.2:1) and water quenched.
(c) Machined round specimen: uniform section 0.125 inch diameter, gage length 0.5 inch.
(d) Tube hollows cold reduced to finished tubing in a single pass with tube reducers, followed by vacuum anneal: 1350F, 1/2 hr, rapid cool + 1150F, 4 hr, furnace cool to 900F.
(e) 1.02 inch diameter bar gun drilled and cold drawn to finished tubing.

TABLE 3.02118 TENSILE PROPERTIES OF SEAMLESS TUBING.

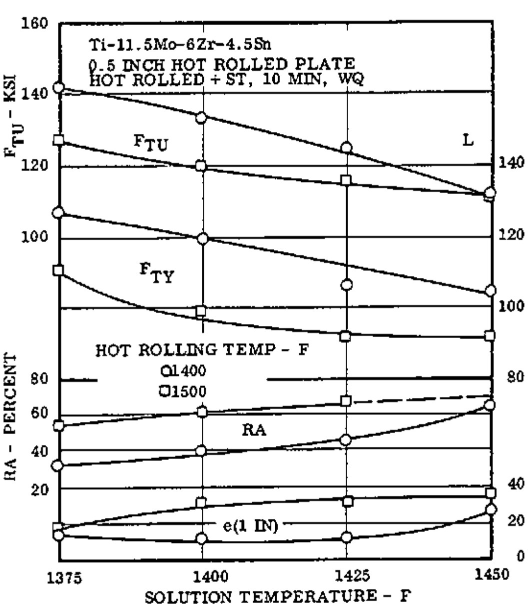


FIG. 3.02119 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED 0.5 INCH PLATE. (4)

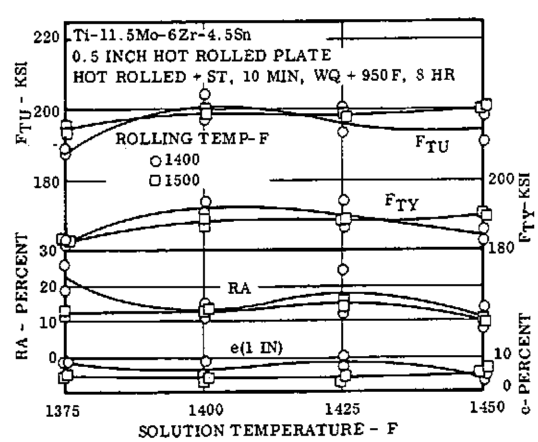


FIG. 3.02120 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED AND AGED 0.5 INCH PLATE. (4)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

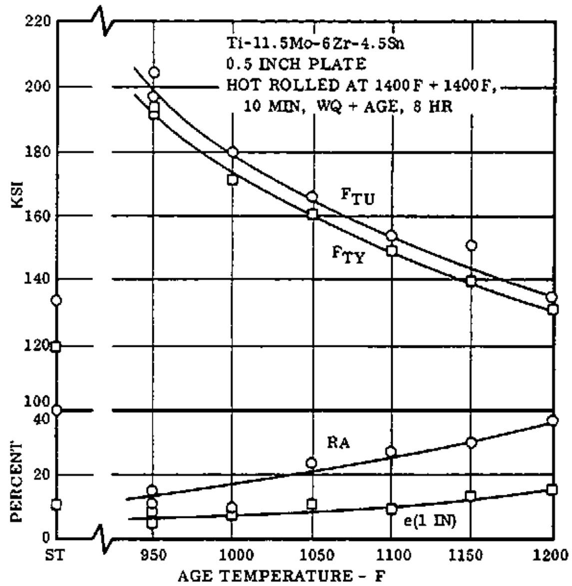


FIG. 3.02121 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF 0.5 INCH PLATE. (4)

Source	(7)					
Alloy	Ti-11.5Mo-6Zr-4.5Sn					
Form	Plate					
Condition	ST, WQ					
Plate Thickness in	Solution Temp F	Test Direction	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
2	1400	L	123.7	106.4	22.3	63.8
		T	119.8	100.7	25.0	65.9
2	1350	T	137.0	128.3	11.0	33.4
0.625	1400	L	132.3	118.8	18.8	50.1
		T	130.3	113.6	16.8	55.4
0.625	1350	L	135.7	125.6	15.3	46.7
		T	132.8	120.3	15.8	51.7
Beta transus ~ 1375 F.						

TABLE 3.02123 TENSILE PROPERTIES OF HEAVY PLATE.

Source	(4)				
Alloy	Ti-11.5Mo-6Zr-4.5Sn				
Form	0.5 inch plate				
Condition	Hot rolled at 1400 F+heat treat				
Heat Treatment	Test Dir	F_{tu} ksi	F_{ty} ksi	e(1 in) percent	RA percent
Double Vacuum-Arc Melted					
1400 F, 10 min, AC	L	140.3	133.9	14.0	37.6
	T	137.9	128.8	8.5	29.2
1400 F, 10 min, WQ	L	127.8	114.3	18.0	51.9
	T	133.0	119.1	12.5	45.0
1400 F, 10 min, WQ+950 F, 8 hr	L	189.9	176.2	6.5	7.5
	T	196.2	187.7	2.5	12.5
1400 F, 10 min, WQ+1050 F, 8 hr	L	164.7	160.9	8.5	16.7
Triple Vacuum-Arc Melted					
1400 F, 10 min, AC	L	146.8	137.8	11.0	29.5
1400 F, 10 min, WQ	L	131.7	113.7	15.0	37.7
	T	132.6	114.9	15.0	41.5
1400 F, 10 min, WQ+950 F, 8 hr	L	193.4	179.4	5.5	9.0
	T	196.2	185.0	4.0	10.5
1400 F, 10 min, WQ+1050 F, 8 hr	L	169.6	157.4	6.7	8.6
	T	172.2	162.5	7.0	14.5

TABLE 3.02124 TENSILE PROPERTIES OF DOUBLE AND TRIPLE VACUUM-ARC MELTED PLATE.

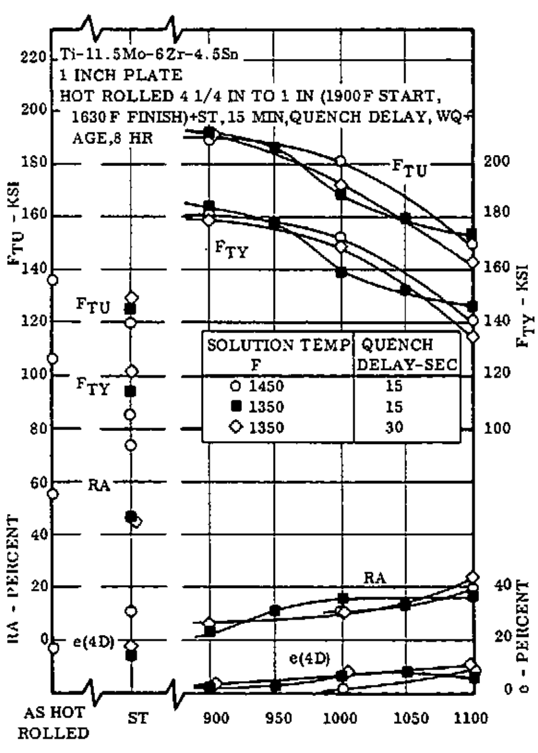


FIG. 3.02122 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF 1 INCH PLATE. (4)

Source	(4)					
Alloy	Ti-11.5Mo-6Zr-4.5Sn					
Form	0.5 inch plate					
Condition	Hot roll + ST, 10 min, Quench					
Hot Roll	Solution Treatment		F_{tu}	F_{ty}	e(1 in)	RA
Temp-F	Temp-F	Quench	ksi	ksi	percent	percent
1800	1450	AC	124.7	111.4	11.1	20.9
	1450	WQ	114.1	96.0	27.5	25.4
1500	1450	AC	135.3	121.7	12.0	36.5
	1450	WQ	114.5	99.4	38.0	65.8
	1400	WQ	119.4	99.1	31.0	61.8
1400	1400	AC	143.5	135.9	12.5	33.6
	1400	WQ	129.8	113.9	16.5	44.9
Each value average two tests, longitudinal specimens.						

TABLE 3.02125 EFFECT OF QUENCH RATE FROM SOLUTION TREATMENT TEMPERATURE ON TENSILE PROPERTIES OF PLATE.

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

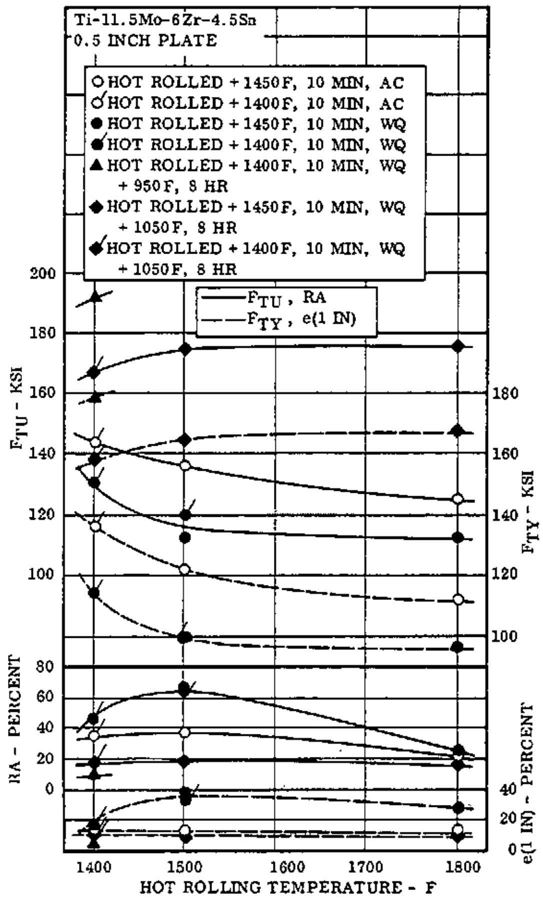


FIG. 3.02126 EFFECT OF HOT ROLLING TEMPERATURE ON TENSILE PROPERTIES OF PLATE. (4)

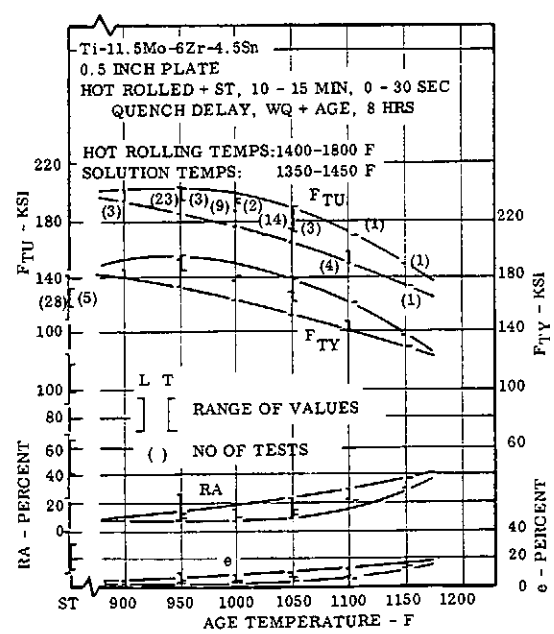


FIG. 3.02127 SPREAD OF TENSILE PROPERTIES FOR PLATE VARIOUSLY HOT ROLLED, SOLUTION TREATED AND AGED. (4)

Source	(4)							
Alloy	Ti-11.5Mo-6Zr-4.5Sn							
Form	0.5 inch plate							
		100 hr Creep Exposure			Subsequent RT Tensile Properties*			
Heat	Condition	Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
A	Hot rolled at 1400F + 1400F, 15 min, WQ + 950F, 8 hr	unexposed			193.3	179.4	5.5	9.0
		500	120	0.11	195.9	185.6	- (a)	- (a)
		500	130	0.18	193.3	190.6	4.0	6.3
		600	100	0.04	196.8	185.7	5.0	8.6
		600	130	0.25	192.4	188.3	3.0	7.4
		700	50	0.04	193.4	180.4	- (a)	- (a)
		700	90	0.14	193.9	183.4	- (b)	- (b)
		800	14	0.07	195.4	182.8	4.0	8.4
		800	27	0.15	195.9	182.2	4.0	5.6
B	Hot rolled + 1350F, 15 min, 15 sec delay, WQ + 950F, 8 hr	unexposed			188.4	175.5	4.0	9.6
		500	120	0.08	187.4	176.2	5.0	7.8
		500	130	0.05	194.9	185.5	3.0	7.0
		600	120	0.13	194.4	183.9	3.0	6.3
		600	130	0.13	200.0	191.8	2.0	2.7
		700	65	0.13	197.9	184.3	3.0	4.0
		800	10	0.12	193.4	179.2	4.0	5.6
		800	20	0.17	195.4	182.5	3.0	7.8
B	Hot rolled + 1350F, 15 min, 15 sec delay, WQ+1000F, 8 hr	unexposed			175.7	163.0	5.0	11.0
		500	110	0.04	178.4	166.7	4.0	7.0
		500	130	0.08	181.9	174.3	1.0	4.0
		600	100	0.10	182.9	170.7	5.0	7.8
		600	120	0.08	182.8	175.4	4.0	9.3
		700	65	0.11	182.3	168.5	4.0	8.7
		700	95	0.20	181.8	171.2	4.0	6.3
		800	10	0.12	184.4	166.9	3.0	7.8
		800	20	0.25	183.4	169.8	4.0	12.4

* Tests made after creep exposure without surface conditioning.
(a) Broke outside gage mark.
(b) Broke at gage mark.

TABLE 3.02128 EFFECT OF 100 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF PLATE.

Source	(4)						
Alloy	Ti-11.5Mo-6Zr-4.5Sn						
Form	0.5 inch plate						
	500 hr Creep Exposure			Subsequent RT Tensile Properties*			
Condition	Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
Hot rolled + 1350F, 15 min, 15 sec delay, WQ + 950F, 8 hr	unexposed			188.4	175.5	4.0	9.6
	500	105	0.05	184.9	174.0	4.0	6.3
	700	50	0.17	193.8	181.3	2.0	5.6
Hot rolled + 1350F, 15 min, 15 sec delay, WQ + 1000F, 8 hr	unexposed			175.7	163.0	5.0	11.0
	500	120	0.11	183.4	174.0	4.0	11.4
	700	55	0.17	183.9	170.4	5.0	10.0

* Tests made after creep exposure without surface conditioning.

TABLE 3.02129 EFFECT OF 500 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF PLATE.

Source	(4)					
Alloy	Ti-11.5Mo-6Zr-4.5Sn					
Form	0.140 inch hot band					
Condition	Location*	Dir	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
As hot rolled	Tail	L	137.8	122.4	4.5	57.6
	Tail	T	146.4	138.0	6.0	37.0
Box annealed 1200F, 8 hr	Head	L	125.6	119.3	10.0	51.5
	Head	T	125.6	115.6	10.0	31.6
	Tail	L	123.6	115.4	15.0	58.7
	Tail	T	132.8	126.6	9.5	30.2
Box annealed 1200F, 8 hr + ST 1350F, 5 min, AC	Head	L	137.5	126.0	12.0	31.2
	Head	T	144.9	136.6	9.5	24.3
	Tail	T	143.8	135.7	9.0	46.3

* Test location in coil.

TABLE 3.02130 TENSILE PROPERTIES OF HOT BAND.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

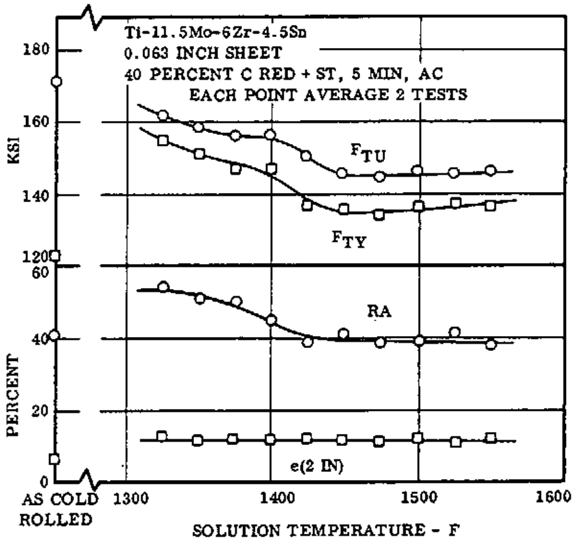


FIG. 3.02131 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED SHEET. (4)

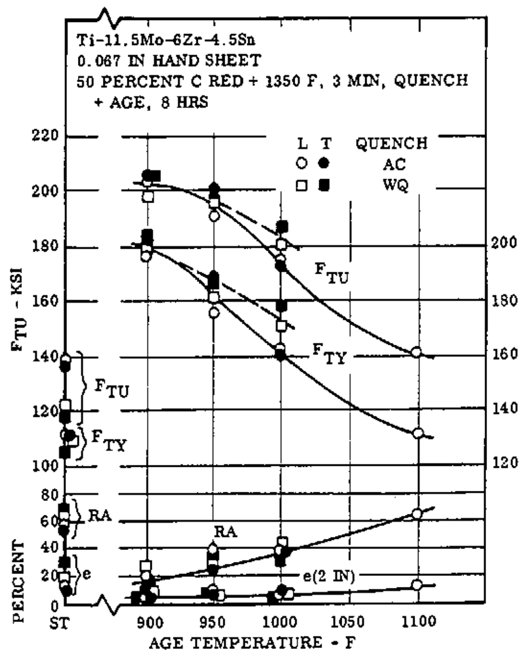


FIG. 3.02134 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF HAND SHEET SOLUTION TREATED AT 1350 F. (4)

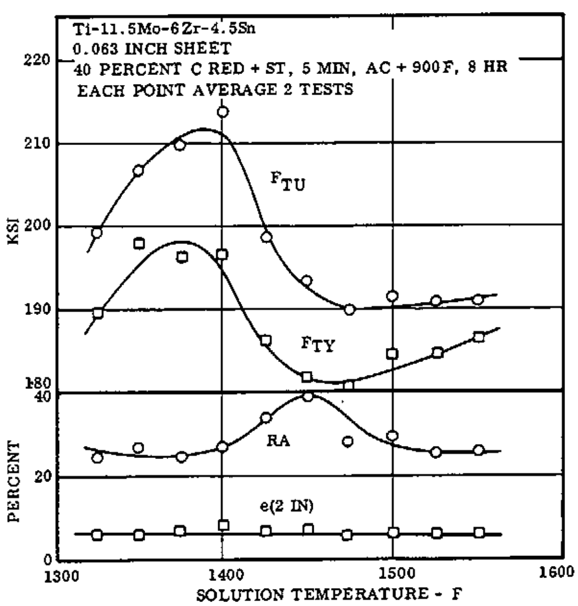


FIG. 3.02132 EFFECT OF SOLUTION TEMPERATURE ON TENSILE PROPERTIES OF AGED SHEET. (4)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

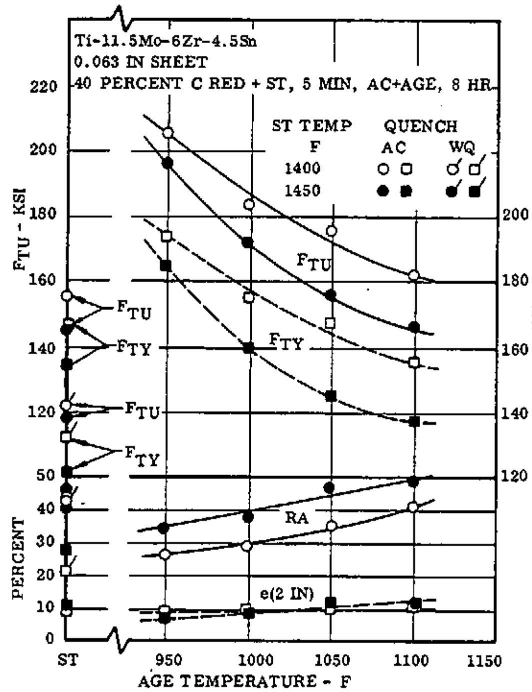


FIG. 3.02136 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF SHEET SOLUTION TREATED AT 1400 OR 1450 F. (4)

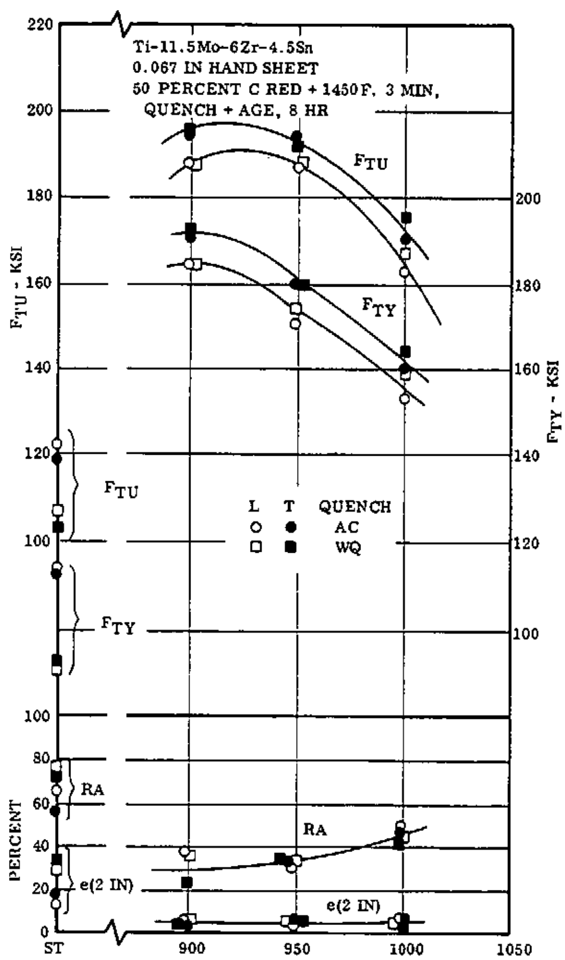


FIG. 3.02135 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF HAND SHEET SOLUTION TREATED AT 1450 F. (4)

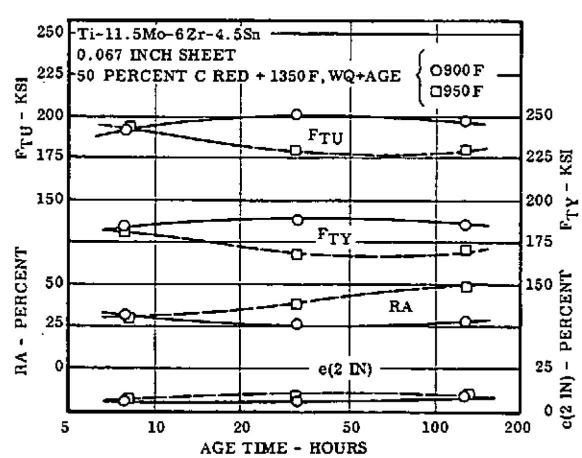


FIG. 3.02137 EFFECT OF AGING TIME ON TENSILE PROPERTIES OF SHEET. (4)

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

Source								(4)				
Alloy								See Compositions Below				
Form								0.063 inch sheet				
Condition								40 percent c red + 1400 F, 5 min, AC + age, 8 hr				
Composition - weight percent								Age Temp	F_{tu}	F_{ty}	e(2 in)	RA
Ti	Mo	Zr	Sn	Fe	C	O	N	F	ksi	ksi	percent	percent
								As ST (1)	155.3	146.2	9.0	44.3
Bal	10.8	5.8	4.4	0.08	0.06	0.15	0.010	950 (1)	205.2	193.7	8.0	26.0
								1050 (1)	175.2	167.3	9.8	35.2
								As ST (2)	144.1	138.3	11.5	41.6
									145.2	139.9	12.5	37.9
Bal	12.2	6.7	4.1	0.03	0.04	0.14	0.013	950 (2)	193.9	180.8	9.5	31.0
									195.2	185.5	8.5	30.0
								1050 (2)	167.2	158.7	8.0	34.8
									166.4	157.0	9.0	35.5
(1) Specimen orientation not given.												
(2) longitudinal specimen direction.												

TABLE 3.02138 EFFECT OF COMPOSITION (VARIATION IN BETA-PHASE-STABILIZING ELEMENT CONTENT) ON TENSILE PROPERTIES OF SHEET.

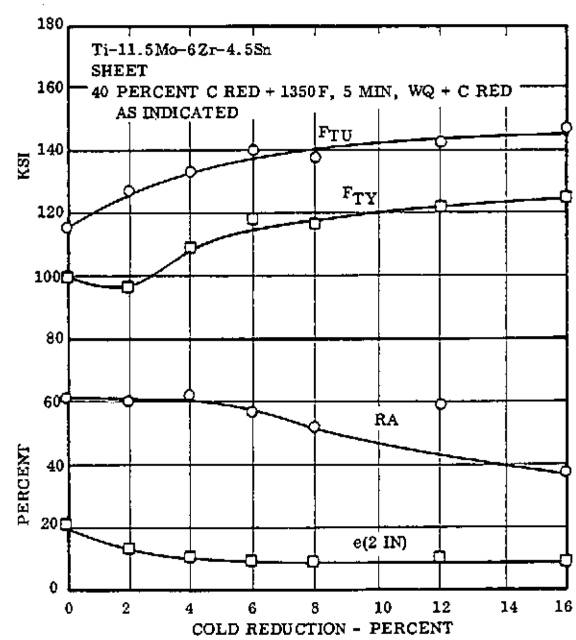


FIG. 3.02140 EFFECT OF COLD REDUCTION ON TENSILE PROPERTIES OF SHEET SOLUTION TREATED AT 1350F AND WATER QUENCHED. (4)

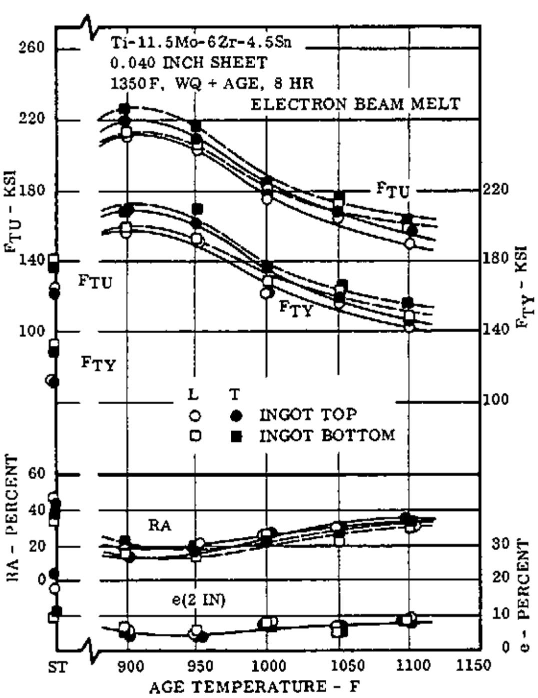


FIG. 3.02139 SHEET TENSILE PROPERTY VARIATION FOR ELECTRON BEAM MELTED INGOT. (7)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

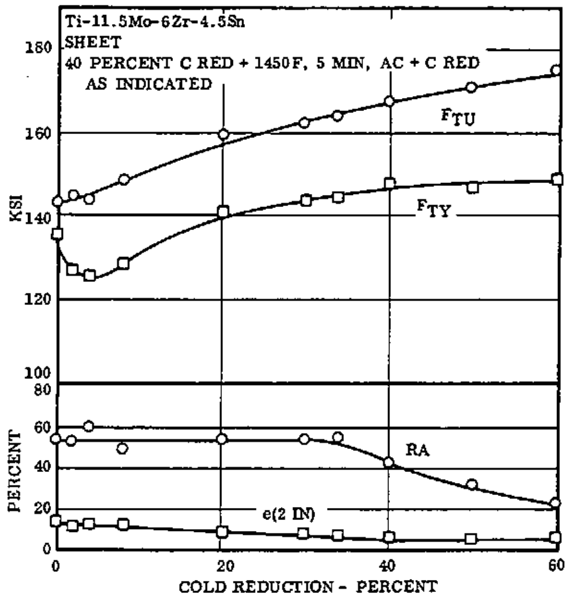


FIG. 3.02141 EFFECT OF COLD REDUCTION ON TENSILE PROPERTIES OF SHEET SOLUTION TREATED AT 1450F AND AIR COOLED. (4)

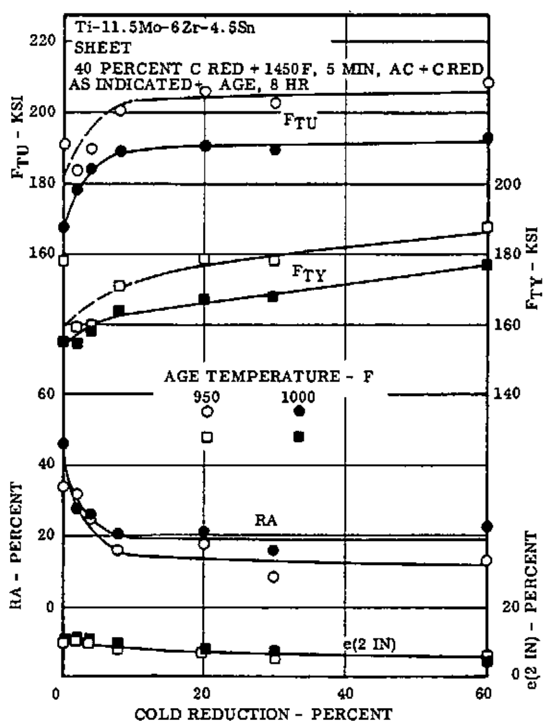


FIG. 3.02142 EFFECT OF COLD REDUCTION ON AGING RESPONSE OF SHEET AGED AFTER COLD ROLLING. (4)

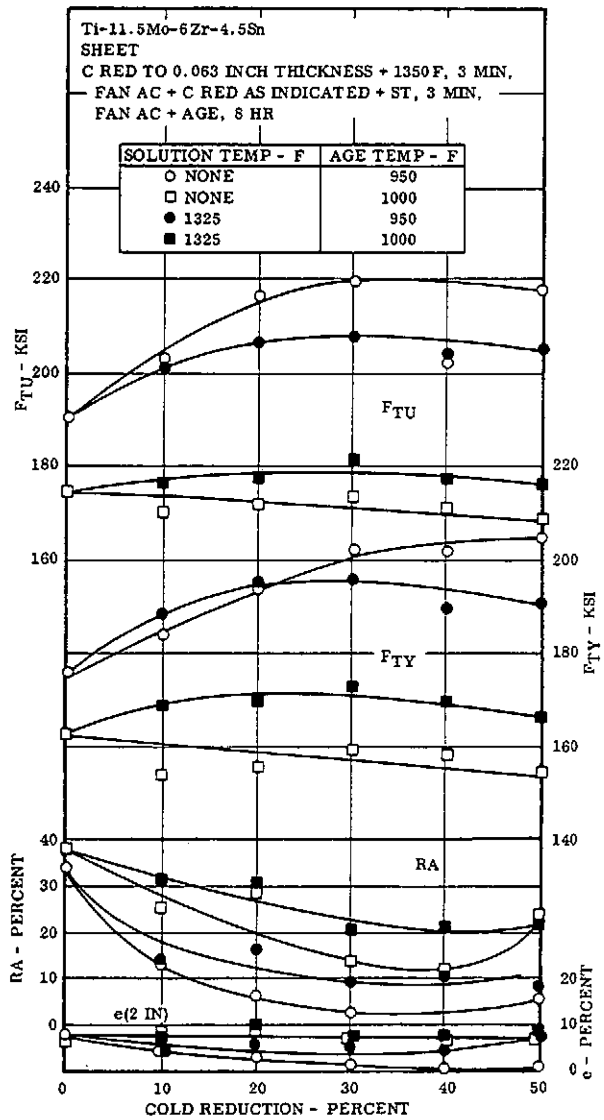


FIG. 3.02143 EFFECT OF COLD REDUCTION ON AGING RESPONSE OF SHEET RESOLUTION TREATED AND AGED AFTER COLD ROLLING. (4)

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

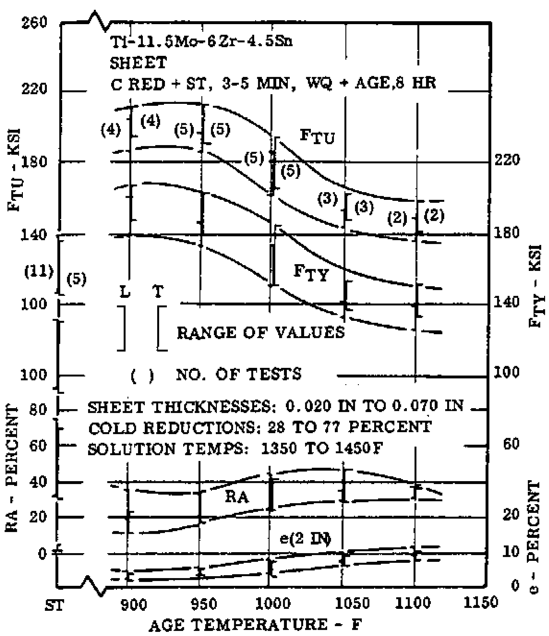


FIG. 3.02144 SPREAD OF TENSILE PROPERTIES FOR SHEET VARIOUSLY COLD REDUCED, SOLUTION TREATED AND AGED. (4)

Source	(4)						
Alloy	Ti-11.5Mo-6Zr-4.5Sn						
Form	0.063 inch sheet						
	200F Creep Exposure			Subsequent RT Tensile Properties			
Condition	Stress ksi	Time hr	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
50 percent c red + 1350F, AC	unexposed			144.5	135.0	8.0	43.1
	unexposed			145.5	136.9	8.0	43.0
	109	762	0.08	144.0	138.4	7.5	42.7
	109	1000	0.03	147.5	143.2	8.0	37.4
50 percent c red + 1350F, AC + 1100F, 8 hr	unexposed			143.8	137.8	8.5	58.1
	unexposed			144.5	138.6	8.5	42.2
	111	1000	0.09	143.3	140.0	9.5	54.8
	111	1000	0.78	147.3	144.8	9.5	42.7
Test made after creep exposure without surface conditioning.							

TABLE 3.02145 EFFECT OF EXPOSURE AT 200F WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET.

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

Source		(4)							
Alloy		Ti-11.5Mo-6Zr-4.5Sn							
Form		Sheet							
Heat	Sheet Thickness in	Condition	100 hr Creep Exposure			Subsequent RT Tensile Properties (a)			
			Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
A	0.063	40 percent c red + 1400F, 5 min, AC + 1050F, 8 hr	unexposed (b)			175.2	167.3	9.7	35.2
			500	115	0.08	181.0	175.5	8.5	55.1
			500	130	0.16	182.1	178.6	8.5	56.2
			600	100	0.11	173.8	166.2	7.5	47.0
			600	115	0.19	179.9	176.0	9.0	52.6
			700	55	0.10	183.1	176.2	7.5	44.8
			700	75	0.15	181.2	175.2	7.5	35.5
			700	85	0.17	186.6	179.4	8.5	47.4
			800	13	0.10	184.7	177.3	9.0	42.4
			800	23	0.16	183.6	171.7	7.5	37.9
B	0.063	40 percent c red + 1400F, 5 min, AC + 1050F, 8 hr	unexposed			167.2	158.7	8.0	34.8
			unexposed			166.4	157.0	9.0	35.5
			500	115	0.18	174.9	171.3	5.5	40.2
			500	130	0.12	174.8	170.6	5.0	48.6
			600	100	0.11	172.5	165.0	5.5	45.0
			600	115	0.21	180.2	175.0	5.5	45.6
			700	55	0.12	179.9	(c)	4.3	45.4
			700	75	0.15	175.9	168.8	5.0	39.7
			800	13	0.04	178.6	169.0	5.5	40.2
			800	23	0.16	175.4	163.6	5.5	41.3
C	0.067	50 percent c red + 1350F, AC + 1000F, 8 hr	unexposed			178.0	164.5	4.5	34.9
			unexposed			170.6	159.7	7.5	39.4
			500	90	0.13	172.9	163.8	8.0	40.6
			500	110	0.15	172.9	168.3	4.0	35.2
			600	70	0.12	174.1	164.2	8.0	43.5
			600	90	0.19	173.0	164.1	9.0	50.9
			700	45	0.09	178.1	166.6	3.5	39.5
			800	12	0.00	176.5	163.7	8.5	35.5
			800	22	0.10	181.1	168.4	7.0	23.2
C	0.067	50 percent c red + 1450F, AC + 1000F, 8 hr	unexposed			162.1	156.5	5.5	50.9
			unexposed			163.1	150.3	8.0	47.6
			500	120	0.21	169.7	167.3	6.5	40.4
			700	75	0.11	176.6	167.2	4.0	36.8

(a) Tests made after creep exposure without surface conditioning.
(b) Unexposed values average two tests.
(c) Not determined.

TABLE 3.02146 EFFECT OF 100 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET AGED TO MEDIUM STRENGTH LEVEL.

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

Source		(4)							
Alloy		Ti-11.5Mo-6Zr-4.5Sn							
Form		Sheet							
			100 hr Creep Exposure			Subsequent RT Tensile Properties(a)			
Heat	Sheet Thickness in	Condition	Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
A	0.063	40 percent c red + 1400F, 5 min, AC + 900F, 8 hr	unexposed(b)			213.6	197.6	8.0	26.7
			500	130	0.07	214.6	206.4	4.0	19.1
			500	140	0.14	219.3	212.3	7.0	22.9
			600	90	0.07	214.6	202.2	4.5	21.9
			600	115	0.14	219.2	210.2	6.5	26.0
			600	130	0.16	217.6	208.7	6.0	27.5
			700	60	0.11	219.8	206.0	5.0	21.9
			700	75	0.16	217.4	207.7	3.5	14.9
			700	90	0.22	222.2	209.1	5.0	(c)
B	0.063	40 percent c red + 1400F, 5 min, AC + 950F, 8 hr	unexposed			193.9	180.8	9.5	31.0
			unexposed			195.2	185.5	8.5	30.0
			500	130	0.07	199.2	191.8	5.5	42.8
			500	150	0.35	202.4	200.0	4.0	38.0
			600	90	0.05	201.0	190.8	5.0	27.8
			600	115	0.16	202.1	195.4	5.5	33.3
			700	35	0.05	202.3	186.2	5.0	22.5
			700	75	0.17	206.4	197.5	5.5	30.2
			800	10	0.04	205.2	192.4	7.0	25.3
			800	23	0.20	204.4	192.6	5.5	30.7
C	0.067	50 percent c red + 1350F, AC + 900F, 8 hr	unexposed			200.9	196.8	4.5	25.9
			unexposed			204.5	194.9	3.0	11.1
			500	110	0.06	200.9	191.5	3.5	17.0
			500	140	0.31	203.6	203.6	3.5	14.7
			600	90	0.05	200.4	192.7	3.5	18.9
			600	115	0.13	202.7	198.4	2.5	15.6
			700	60	0.05	214.7	203.2	2.5	16.0
			700	75	0.02	219.7	217.9	(c)	(c)
			800	10	0.11	205.8	193.8	4.5	10.2
			800	20	0.37	204.5	195.4	2.5	14.9
C	0.067	50 percent c red + 1350F, AC +950F, 8 hr	unexposed			188.9	172.8	7.0	30.9
			unexposed			191.4	177.8	7.5	35.6
			700	75	0.24	203.7	192.5	4.5	19.4
C	0.067	50 percent c red + 1350F, WQ + 900F, 8 hr	unexposed(b)			191.4	184.0	6.0	30.4
			700	70	0.33	216.3	213.9	5.0	7.2
C	0.067	50 percent c red + 1350F, WQ + 950F, 8 hr	unexposed(b)			192.5	179.9	7.0	31.1
			700	70	0.04	196.5	185.8	6.5	27.9
C	0.067	50 percent c red + 1450F, AC + 900F, 8 hr	unexposed			186.6	185.8	4.0	36.6
			unexposed			188.3	183.3	5.0	(c)
			500	120	0.27	199.3	197.3	3.0	9.0
C	0.067	50 percent c red + 1450F, AC + 950F, 8 hr	unexposed			184.6	169.8	5.5	33.5
			unexposed			188.2	172.5	4.0	25.2
			500	120	0.08	193.0	157.9	18.5	33.3
			700	75	0.24	199.5	189.2	4.0	24.6

(a) Tests made after creep exposure without surface conditioning.
(b) Unexposed values average two tests.
(c) Not determined.

TABLE 3.02147 EFFECT OF 100 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET AGED TO HIGH STRENGTH LEVEL.

Source	(4)								
Alloy	Ti-11.5Mo-6Zr-4.5Sn								
Form	Sheet								
			500 hr Creep Exposure			Subsequent RT Tensile Properties(a)			
Heat	Sheet Thickness in	Condition	Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
A	0.063	40 percent c red + 1400F, 5 min, AC + 1050F, 8 hr	unexposed(b)			175.2	167.3	9.7	35.2
			500	110	0.08	181.2	176.0	8.0	41.8
			500	125	0.19	187.2	183.9	4.0	46.7
			600	80	0.09	184.4	179.7	7.5	33.8
			600	100	0.16	183.6	177.0	9.0	49.2
			700	30	0.09	185.5	179.0	8.0	49.4
			700	50	0.15	190.4	179.6	6.5	46.7
			800	10	0.14	185.1	175.0	8.0	48.2
			800	15	0.21	183.7	177.3	6.5	32.0
B	0.067	50 percent c red + 1350F, AC + 1000F, 8 hr	unexposed			178.0	164.5	4.5	34.9
			unexposed			170.6	159.7	7.5	39.4
			500	110	0.27	159.3	155.3	9.0	35.4
			700	50	0.75	185.3	165.8	4.0	25.9

(a) Tests made after creep exposure without surface conditioning.
(b) Unexposed values average two tests.

TABLE 3.02148 EFFECT OF 500 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET AGED TO MEDIUM STRENGTH LEVEL.

Source	(4)								
Alloy	Ti-11.5Mo-6Zr-4.5Sn								
Form	Sheet								
			500 hr Creep Exposure			Subsequent RT Tensile Properties(a)			
Heat	Sheet Thickness in	Condition	Temp F	Stress ksi	Permanent Deformation percent	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
A	0.063	40 percent c red + 1400F, 5 min, AC + 900F, 8 hr	unexposed(b)			213.6	179.6	8.0	26.7
			500	110	0.08	219.1	204.8	6.5	23.7
			500	115	0.07	219.5	207.4	6.0	24.8
			500	125	0.10	217.3	208.9	4.5	20.2
			600	90	0.12	218.2	205.4	5.5	20.0
			600	100	0.11	220.3	189.8	5.0	19.8
			600	110	0.20	219.3	215.1	4.0	18.7
			700	30	0.06	221.0	216.5	5.5	11.6
			700	40	0.14	225.2	207.4	6.0	21.7
			700	50	0.16	214.2	200.0	6.0	18.3
			800	5	0.13	222.6	209.1	6.0	12.2
			800	7	0.13	222.2	209.2	6.0	19.6
			800	15	0.22	219.4	206.8	5.0	18.9
B	0.067	50 percent c red + 1350F, AC + 900F, 8 hr	unexposed			200.9	196.8	4.5	25.9
			unexposed			204.5	194.9	3.0	11.1
			500	120	0.18	199.1	188.5	6.0	20.8

(a) Tests made after creep exposure without surface conditioning.
(b) Unexposed values average two tests.

TABLE 3.02149 EFFECT OF 500 HOUR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET AGED TO HIGH STRENGTH LEVEL.

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

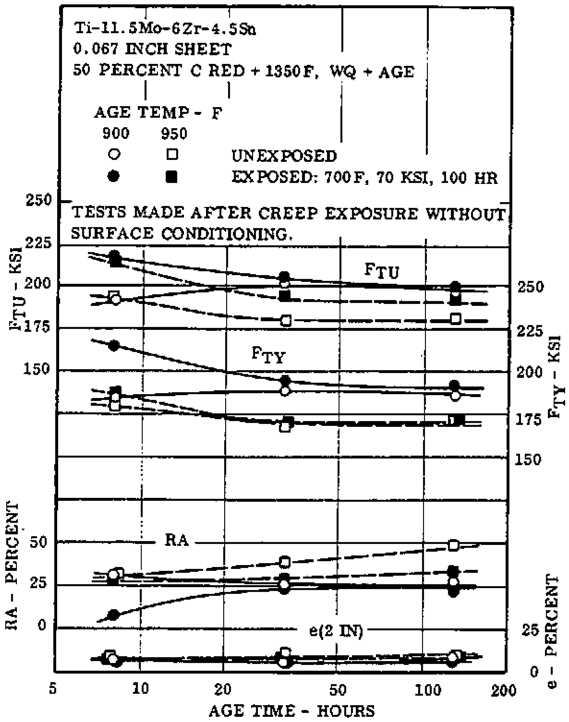


FIG. 3.02150 EFFECT OF 100 HR EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET VARIOUSLY AGED. (4)

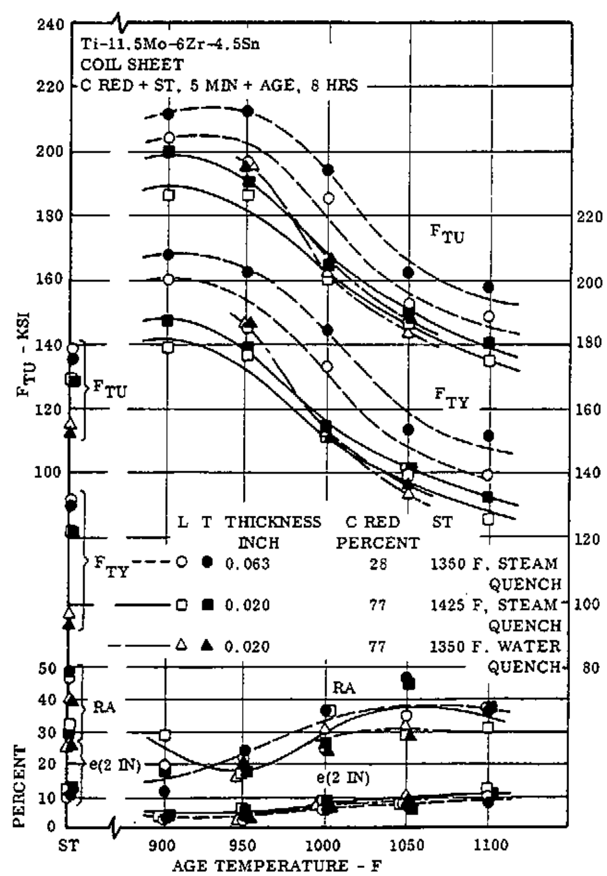


FIG. 3.02151 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF COIL SHEET. (4)

Source	(4)							
Alloy	Ti-11.5Mo-6Zr-4.5Sn							
Form	Foil							
Condition	1450F in Argon, AC + Age, 8 hr in Vacuum (2 x 10^{-5} mm Hg)							
				Tensile Properties (b)				
Foil Gage in	Age Temp F	Deskin(a)	Test Dir	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent	E Static 1000 ksi
0.010(c)	unaged	No	L	143.7	134.2	10.8	28.6	11.5
		S	L	144.8	135.8	9.8	30.0	11.9
		No	T	143.7	139.8	7.5	27.5	11.2
		S	T	141.3	137.1	8.0	37.2	12.6
	950	No	L	201.2	191.5	3.2	10.0	15.6
		S	L	174.7	162.0	4.5	22.0	15.5
		A	L	173.0	164.0	5.5	22.8	16.1
	1000	No	L	158.0	156.0	4.5	24.0	15.8
		S	L	168.4	161.0	4.0	22.4	15.7
		A	L	157.0	149.7	5.5	25.5	16.8
0.005(c)	unaged	No	L	152.1	137.0	10.0	-	11.2
		S	L	151.5	141.0	8.0	-	12.8
		No	T	153.7	148.6	5.7	-	12.8
		S	T	151.7	139.5	9.2	-	12.6
	950	No	L	203.3	190.6	2.5	-	16.9
		S	L	185.0	177.6	3.3	-	15.1
		A	L	187.8	178.1	3.5	-	15.8
	1000	No	L	170.8	167.0	4.0	-	15.4
		S	L	170.8	163.3	3.0	-	16.2
		A	L	175.5	165.0	5.0	-	16.2
0.0035(d)	950	No	L	194.1	180.3	4.2	-	16.1
		S	L	162.6	153.6	4.0	-	14.5
		A	L	177.1	165.1	5.0	-	15.6
	1000	No	L	161.1	151.7	3.5	-	15.1
		S	L	166.9	161.2	8.0	-	16.1
		A	L	166.9	156.9	4.5	-	16.6
0.002(e)	unaged	No	L	141.6	133.2	8.5	-	10.2
		S	L	145.6	144.3	6.0	-	10.8
		No	T	145.0	138.4	6.2	-	11.5
		S	T	144.4	140.7	6.2	-	11.0
	950	No	L	227.3	213.3	2.0	-	18.4
		S	L	242.8	232.9	1.7	-	17.3
		A	L	178.8	168.0	1.0	-	15.0
	1000	No	L	170.0	168.0	(f)	-	17.4
		A	L	186.7	177.0	4.0	-	17.9

(a) Deskin acid pickle: S = 0.0005 in after ST, A = 0.0005 in after aging.
(b) Average of duplicate tests.
(c) Cold reduced from 0.020 in strip.
(d) Produced by cold reducing solution treated 0.010 in foil.
(e) Produced by cold reducing solution treated 0.005 in foil.
(f) Failed at gage mark.

TABLE 3.02152 TENSILE PROPERTIES OF FOIL.

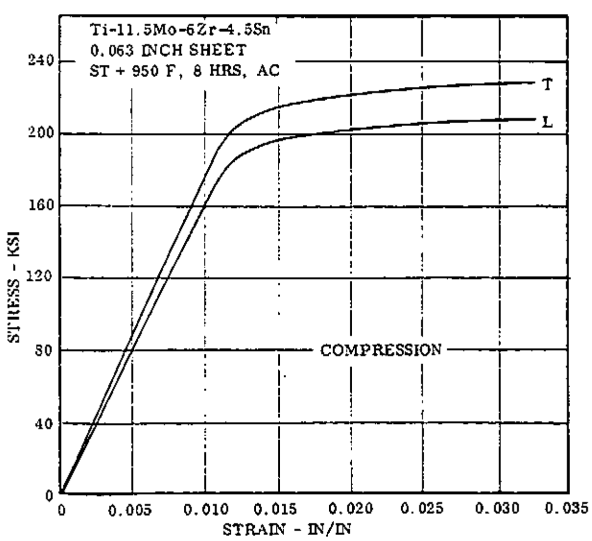


FIG. 3.0221 TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR SHEET. (19)

Source	(4)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	1/2 inch diameter bar	
Condition	1420F, WQ + age, 8 hr	
Age Temp-F	F_{ty} - ksi	F_{cy} - ksi*
As ST	99.9	119.2
		112.2
900	187.6	203.2
		194.3
1000	155.6	162.8

* Specimens 0.5 inch diameter x 1.250 inch height.

TABLE 3.0222 COMPRESSIVE YIELD STRENGTH OF BAR.

Source	(4)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	0.5 inch plate	
Condition	Hot rolled 1.1 in to 0.5 in + 1350F, 15 min, 15 sec delay, WQ + Age, 8 hr	
Age Temp F	F_{ty} - ksi	F_{cy}* - ksi
Unaged	105.6	123.6 124.1
950	175.5	188.2 184.2
1000	163.0	169.0 170.5
* Compression specimens 0.5 inch diameter by 1.250 inch height.		

TABLE 3.0223 COMPRESSIVE YIELD STRENGTH OF PLATE.

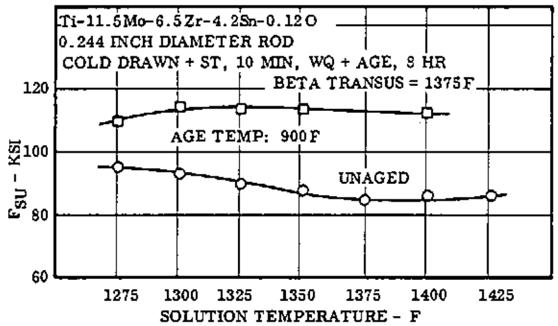


FIG. 3.0252 EFFECT OF SOLUTION TEMPERATURE ON SHEAR STRENGTH OF ROD. (4)

Ti	
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source	(19)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	0.063 inch sheet	
Condition	ST + 950F, 8 hr, AC	
Test Direction	F_{ty} - ksi	F_{cy} - ksi
L	175	195
T	185	211

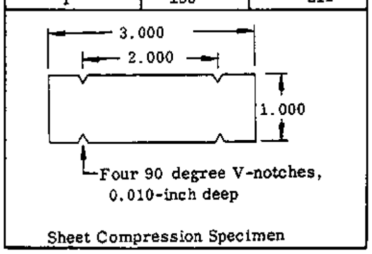


TABLE 3.0224 COMPRESSIVE YIELD STRENGTH OF SHEET.

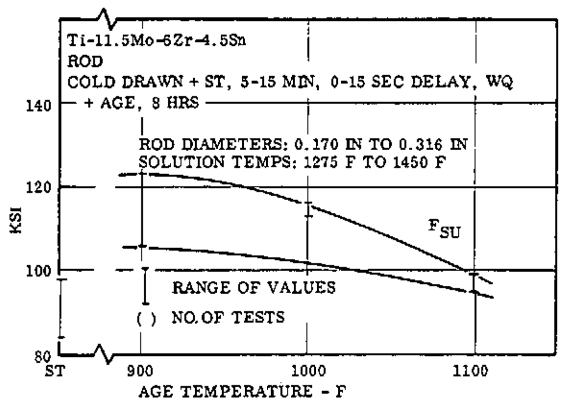


FIG. 3.0253 SPREAD OF SHEAR STRENGTH FOR ROD AGED AT DIFFERENT TEMPERATURES. (4)

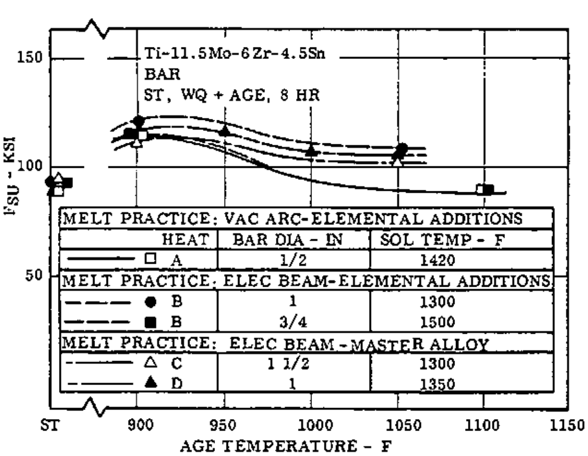


FIG. 3.0251 DOUBLE SHEAR STRENGTH OF AGED BARS VARIOUSLY MELTED AND SOLUTION TREATED. (7)

Source	(19)
Alloy	Ti-11.5Mo-6Zr-4.5Sn
Form	0.063 inch sheet
Condition	ST + 950F, 8 hr, AC
Test Direction	F_{su} - ksi
L	117
T	118

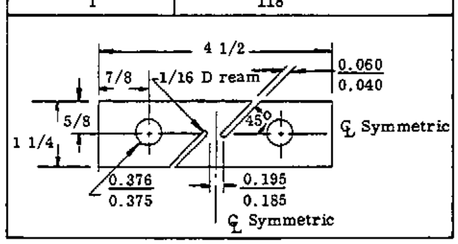
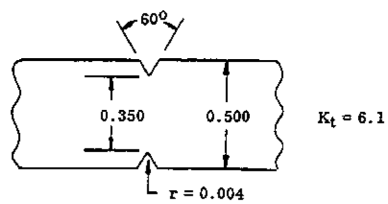


TABLE 3.0254 SHEAR STRENGTH OF SHEET.

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

Source								(4)		
Alloy								See Compositions Below		
Form								0.063 inch Sheet		
Condition								40 percent c red + 1400F, 5 min, AC + age, 8 hr		
Composition - weight percent										
Ti	Mo	Zr	Sn	Fe	C	O	N	Age Temp - F	F_{TY} - ksi	NTS* - ksi
Bal	10.8	5.8	4.4	0.08	0.06	0.15	0.010	900	196.3	212.0 199.4
								1050	167.3	197.8 198.4
Bal	12.2	6.7	4.1	0.03	0.04	0.14	0.013	950	183.1	201.4 214.0
								1050	157.8	185.7 183.3



* No load crosshead speed 0.05 in/min

TABLE 3.02711 EFFECT OF COMPOSITION (VARIATION IN BETA-PHASE-STABILIZING ELEMENT CONTENT) ON MILD-NOTCH TENSILE PROPERTIES OF SHEET.

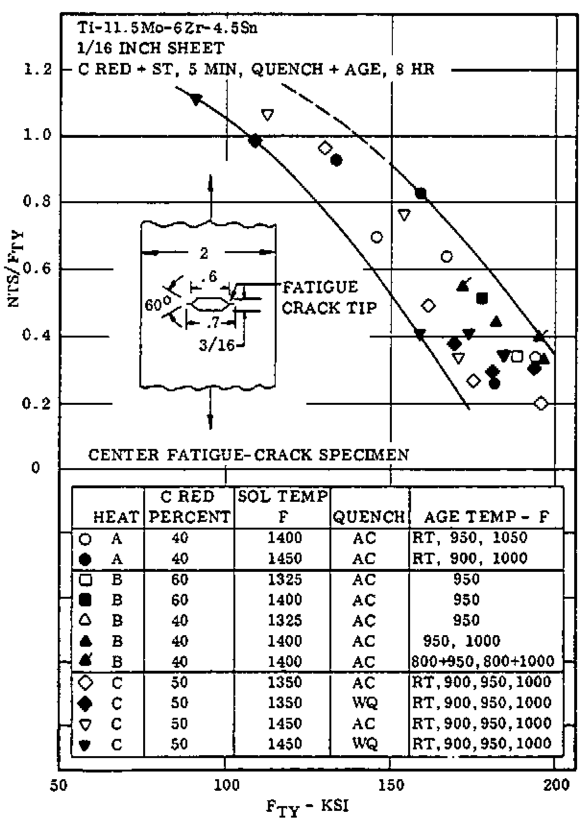


FIG. 3.02712 EFFECT OF YIELD STRENGTH LEVEL ON STRENGTH OF CENTER FATIGUE-CRACK SHEET SPECIMENS. (4)

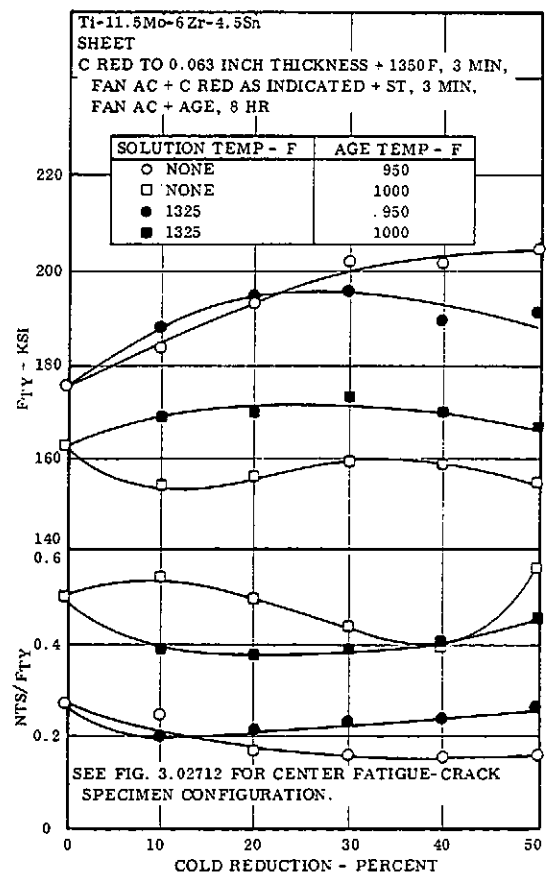


FIG. 3.02713 EFFECT OF COLD REDUCTION ON STRENGTH OF CENTER FATIGUE-CRACK SHEET SPECIMENS VARIOUSLY HEAT TREATED. (4)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

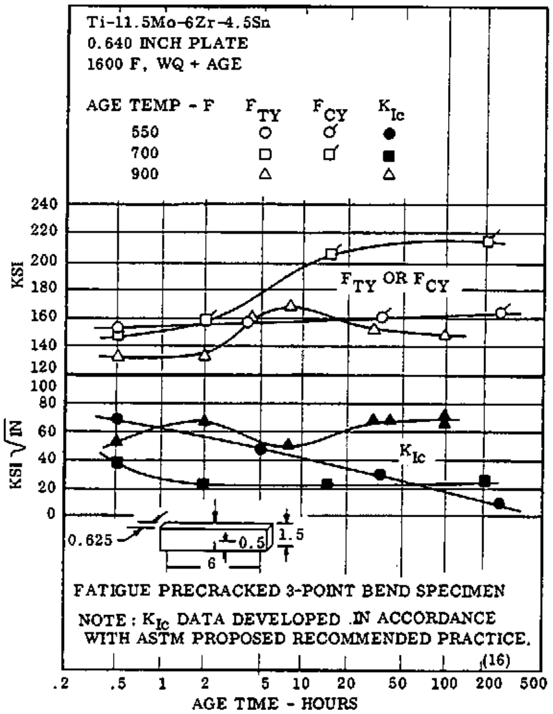


FIG. 3.02722 EFFECT OF AGING TIME ON THE PLANE STRAIN FRACTURE TOUGHNESS OF PLATE. (15)

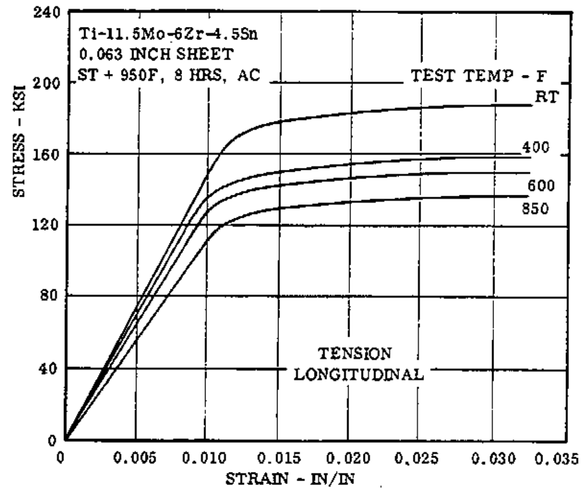


FIG. 3.0311 TYPICAL STRESS-STRAIN CURVES AT VARIOUS TEMPERATURES FOR SHEET IN LONGITUDINAL DIRECTION. (19)

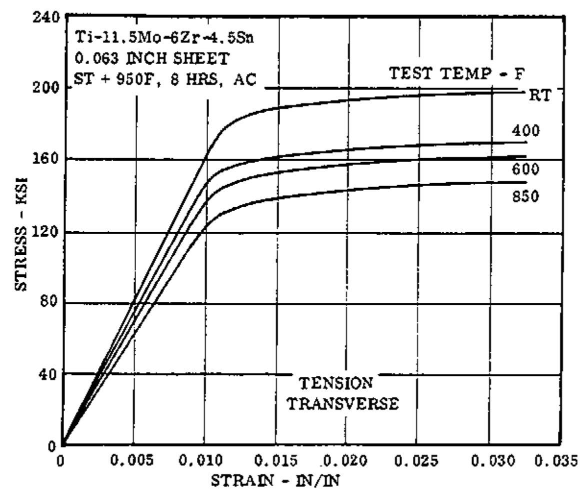
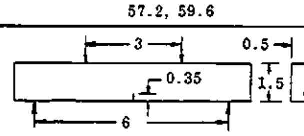
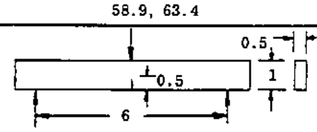


FIG. 3.0312 TYPICAL STRESS-STRAIN CURVES AT VARIOUS TEMPERATURES FOR SHEET IN TRANSVERSE DIRECTION. (19)

Source	(11)	(12)(14)
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	Closed Die Press Forging*	Press Forged 3 inch Square
Condition	1325F, 1 hr, WQ + 950F, 8 hr, AC**	1400F, 1 hr, WQ + 950F, 8 hr, AC**
F_{ty} - ksi	182	165
K_{Ic} - ksi $\sqrt{in}$	57.2, 59.6	58.9, 63.4
Fatigue-Cracked Bend Specimens		

* See Table 3.0213 for forging configuration and specimen locations (specimens K_{Ic} -A and K_{Ic} -B).
** Heat treated in full section.

TABLE 3.02723 PLANE STRAIN FRACTURE TOUGHNESS OF PRESS FORGINGS.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

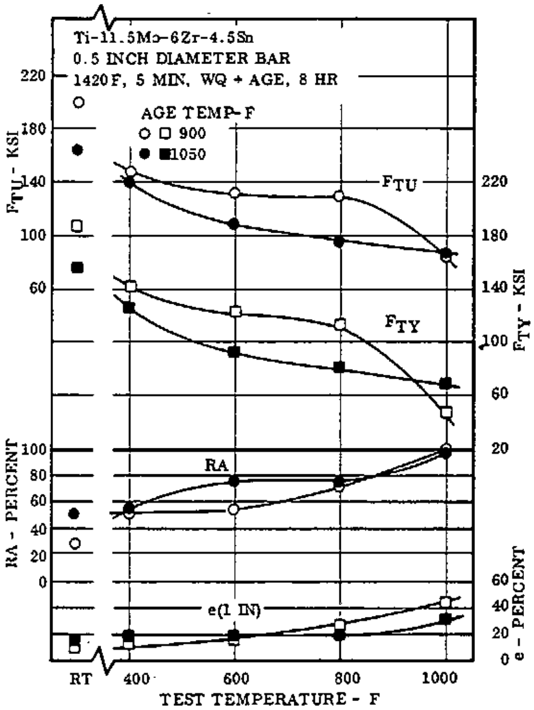


FIG. 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF BAR. (4)

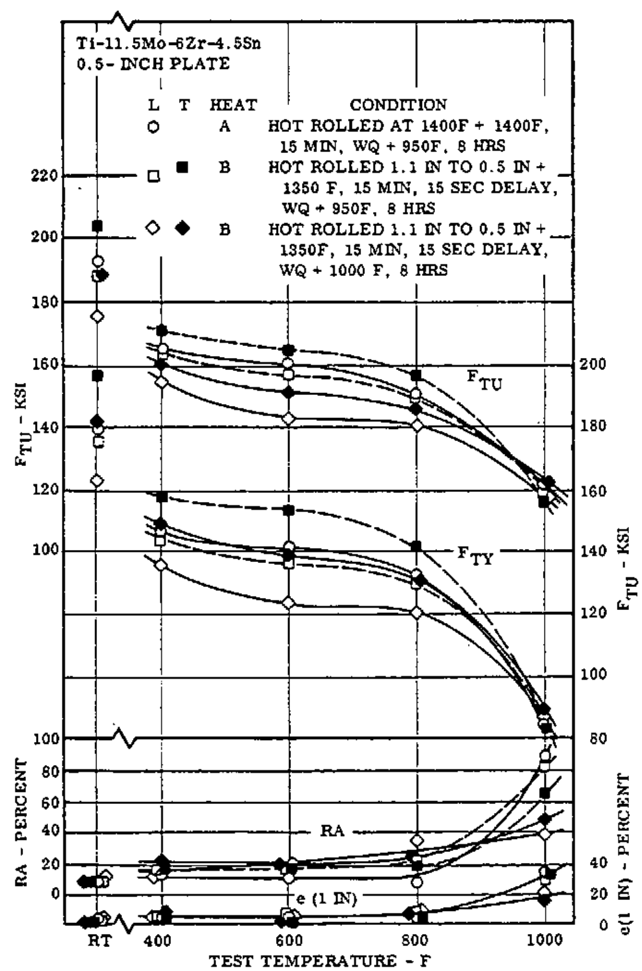


FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF PLATE. (4)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

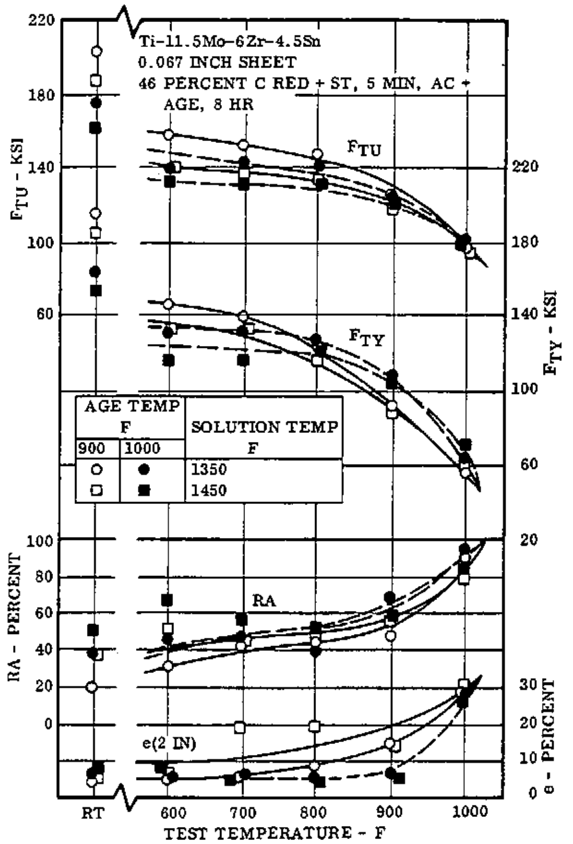


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET. (4)

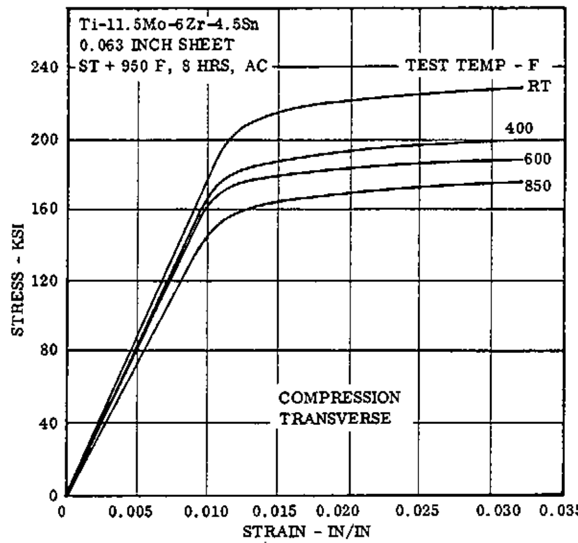


FIG. 3.0322 TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT VARIOUS TEMPERATURES FOR SHEET IN TRANSVERSE DIRECTION. (19)

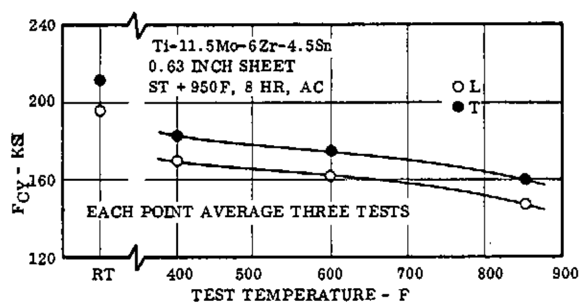


FIG. 3.0323 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF SHEET. (19)

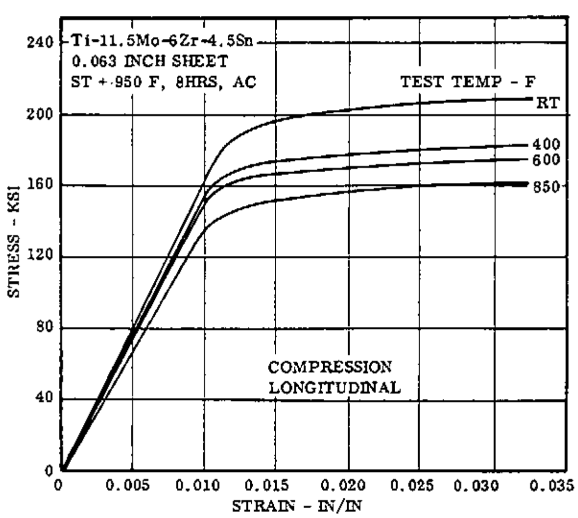


FIG. 3.0321 TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT VARIOUS TEMPERATURES FOR SHEET IN LONGITUDINAL DIRECTION. (19)

Source	(4)		
Alloy	Ti-11.5Mo-6Zr-4.5Sn		
Form	1 9/16 inch dia bar		
Condition	Test Temp F	F_{ty} ksi	IE, Charpy-V ft-lb
1350F, WQ + 900F, 8 hr	RT -40	176.3	14.5 13.0
1350F, WQ + 1050F, 8 hr	RT -40	159.3	13.5 10.5
Mid-radius properties			

TABLE 3.0331 CHARPY-V IMPACT ENERGY FOR BAR AT ROOM TEMPERATURE AND -40F.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source		(4)		
Alloy		Ti-11.5Mo-6Zr-4.5Sn		
Form		Bar		
Heat	Dia inch	Condition	F_{ty} at RT ksi	IE, Charpy-V at -40F ft-lb
A	1 9/16	1450F, WQ	111.1*	25*
		1450F, WQ + 950F, 8 hr	184.8	6
		1450F, WQ + 1050F, 8 hr	158.0	10
B	1	1350F, WQ + 900F, 8 hr	176.3	13
		1350F, WQ + 1050F, 8 hr	159.3	10.5

* Center; all other values mid-radius.

TABLE 3.0332 CHARPY-V IMPACT ENERGY FOR BAR AT -40F.

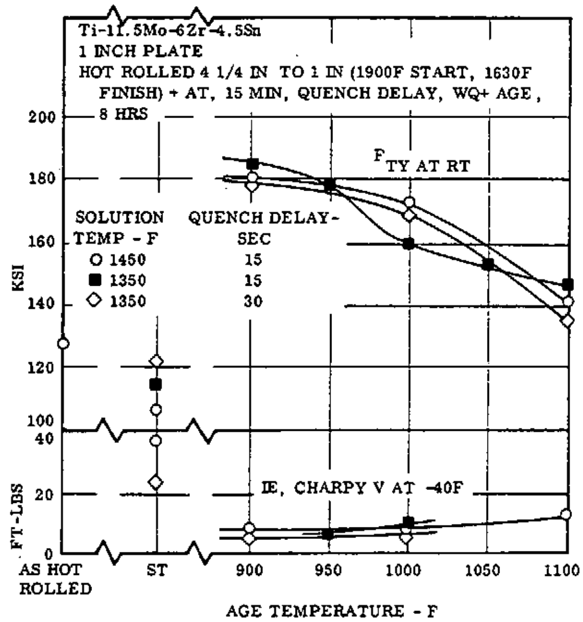


FIG. 3.0334 EFFECT OF AGING TEMPERATURE ON -40F IMPACT ENERGY OF 1 INCH PLATE. (4)

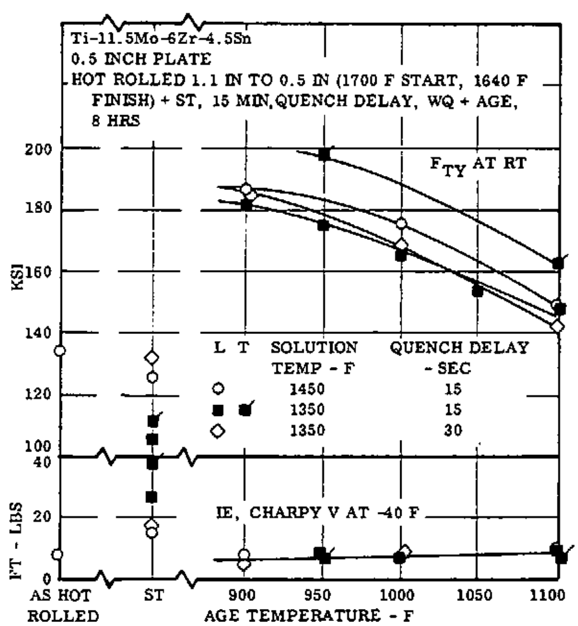


FIG. 3.0333 EFFECT OF AGING TEMPERATURE ON -40 F IMPACT ENERGY OF 0.5 INCH PLATE. (4)

Source	(4)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	0.5 inch plate			
Condition	Hot rolled + heat treated			
Hot Rolling Temp F	Heat Treatment	Test Temp F	F_{ty} ksi	IE, Charpy-V ft-lb
1800	1450F, 10 min, AC	RT	111.4	5
		-40		5
	1450F, 10 min, WQ	RT	96.0	7
		-40		6
1500	1450F, 10 min, AC	RT	121.7	11
		-40		9
	1450F, 10 min, WQ	RT	99.4	23
		-40		17
	1400F, 10 min, WQ	RT	99.1	16
		-40		16
1400	1400F, 10 min, AC	RT	135.9	12
		-40		10
	1400F, 10 min, WQ	RT	113.9	27
		-40		20
1400	1400F, 10 min, WQ + 950F, 8 hr	RT	178.3	9
		-40		7
1800	1450F, 10 min, WQ + 1050F, 8 hr	RT	166.8	5
		-40		3
1500	1450F, 10 min, WQ + 1050F, 8 hr	RT	164.7	10
		-40		9
1400	1400F, 10 min, WQ + 1050F, 8 hr	RT	157.2	10
		-40		8

All values average duplicate tests.

TABLE 3.0335 EFFECT OF HOT ROLLING TEMPERATURE AND COOLING RATE FROM THE SOLUTION TREATMENT TEMPERATURE ON THE ROOM TEMPERATURE AND -40F IMPACT ENERGY OF 0.5 INCH PLATE.

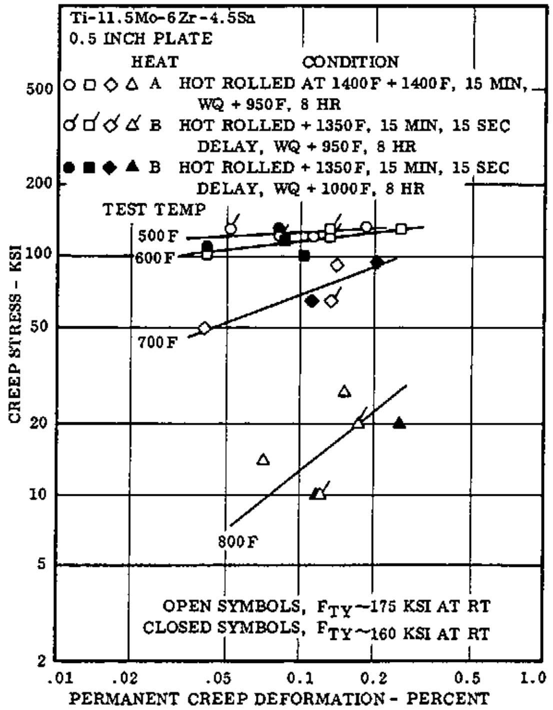


FIG. 3.043 100 HOUR CREEP DEFORMATION FOR PLATE. (4)

Source	(4)		
Alloy	Ti-11.5Mo-6Zr-4.5Sn		
Form	0.5 inch plate		
Condition	Hot rolled + 1350F, 15 min, 15 sec delay, WQ + Age, 8 hr		
Age Temp F	Test Temp F	F_{ty} ksi	5 hr mild notch stress rupture strength* - ksi
950	RT	175.5	190.0
	500	140.0	210.0
1000	RT	163.0	215.0
	500	129.4	204.4

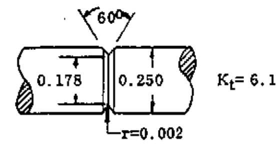


TABLE 3.046 5 HOUR MILD-NOTCH STRESS RUPTURE STRENGTH FOR PLATE.

Ti	
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source	(4)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	0.5 inch plate			
Condition	Hot rolled + 1350F, 15 min, 15 sec delay, WQ + age, 8 hr			
			Smooth Stress Rupture Properties	
Age Temp F	Test Temp F	F_{ty} ksi	Stress ksi	Time to Failure hours
950	RT	175.5	186	9.6
	RT		183	>1604
	500	140.0	160	>1250
1000	RT	163.0	168	4.1
	RT		165	>1416
	500	129.4	145	>1251

TABLE 3.045 SMOOTH STRESS RUPTURE PROPERTIES FOR PLATE AT ROOM TEMPERATURE AND 500F.

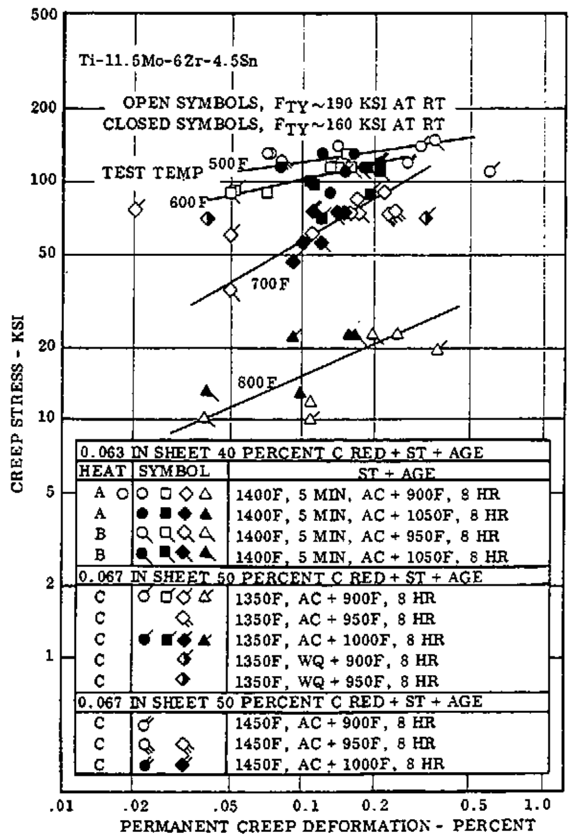


FIG. 3.047 100 HR CREEP DEFORMATION FOR SHEET. (4)

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

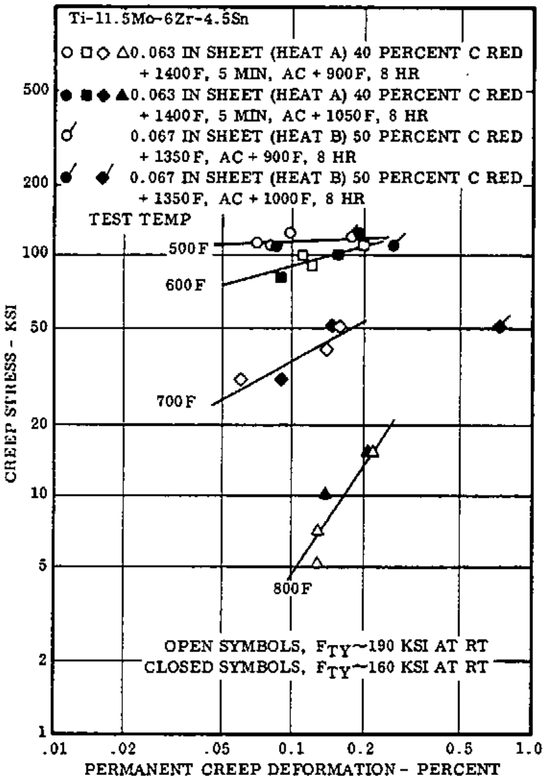


FIG. 3.048 500 HOUR CREEP DEFORMATION FOR SHEET.(4)

Source	(4)		
Alloy	Ti-11.5Mo-6Zr-4.5Sn		
Form	0.063 inch sheet		
Condition	200F Creep Exposure		Permanent Creep Deformation - percent
	Stress ksi	Time hours	
50 percent C Red+1350F, AC	109	762	0.08
	109	1000	0.03
50 percent C Red + 1350F, AC + 1100F, 8 hr	111	1000	0.09
	111	1000	0.78

TABLE 3.049 200F CREEP DEFORMATION FOR SHEET.

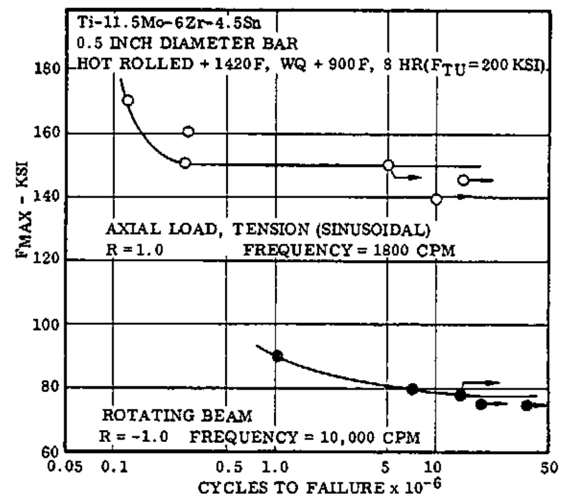


FIG. 3.051 AXIAL LOAD AND ROTATING BEAM FATIGUE PROPERTIES OF BAR. (4)

Source	(4)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	0.063 inch sheet	
Condition	40 percent C Red + 1400F, 5 min, AC + age, 8 hr	
Age Temp F	F_{ty} ksi	500 hr, RT Mild Notch* Rupture Strength - ksi
900	196.3	190.0
1050	167.3	182.0
* See Table 3.02711 for specimen configuration.		

TABLE 3.0410 500 HOUR MILD-NOTCH RUPTURE STRENGTH FOR SHEET AT ROOM TEMPERATURE.

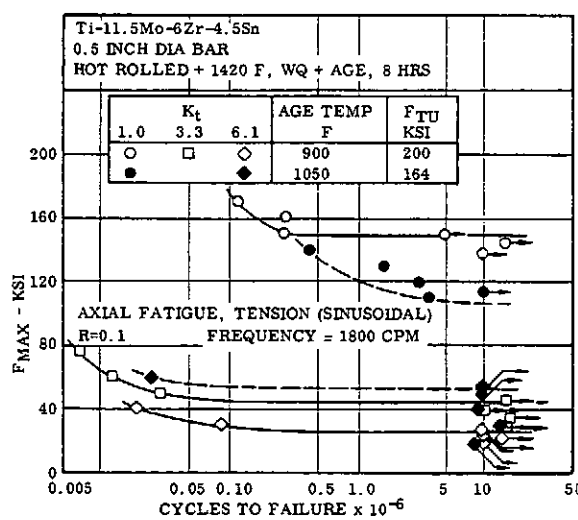


FIG. 3.052 AXIAL LOAD SMOOTH AND MILD NOTCH FATIGUE PROPERTIES OF BAR. (4)(7)

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

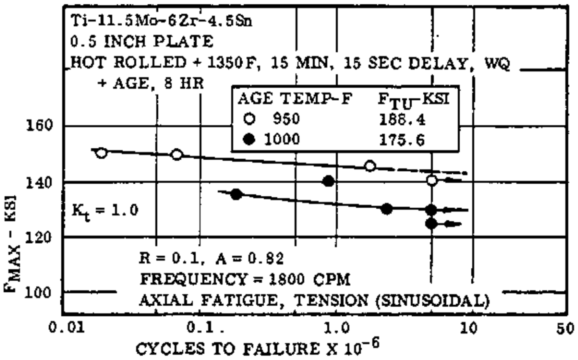


FIG. 3.053 AXIAL LOAD SMOOTH FATIGUE PROPERTIES OF PLATE. (4)

Source	(7)
Alloy	Ti-11.5Mo-6Zr-4.5Sn
Form	0.063 inch sheet
Condition	Poisson's Ratio, μ
1450F, WQ	0.382
1350F, WQ	0.368, 0.359
1350F, WQ + 900F, 8 hr, AC	0.312, 0.313
1350F, WQ + 1100F, 8 hr,AC	0.335, 0.325
All specimens longitudinal.	

TABLE 3.061 POISSON'S RATIO FOR SHEET.

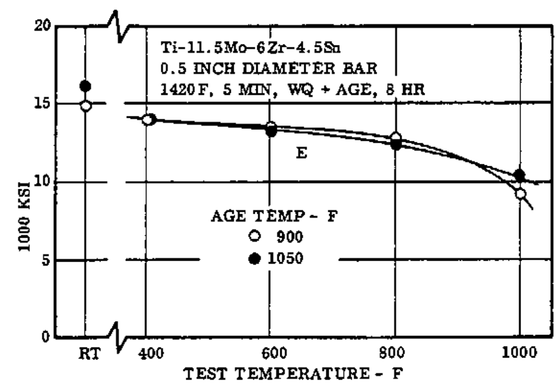


FIG. 3.0622 EFFECT OF TEST TEMPERATURE ON ELASTIC MODULUS OF BAR. (4)

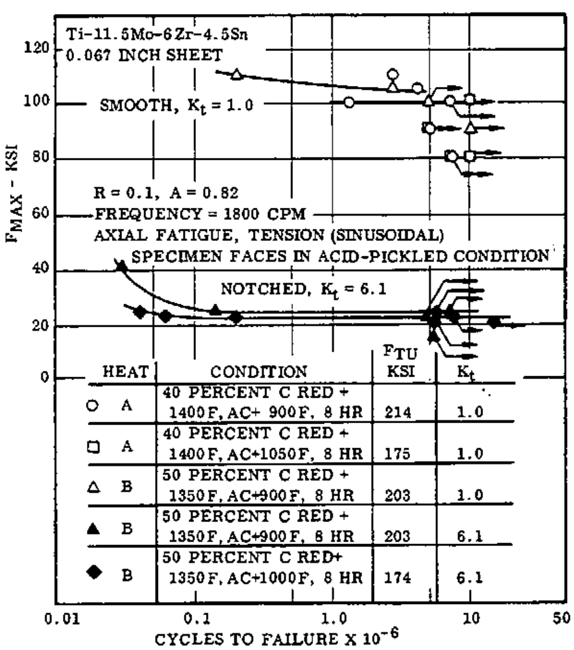


FIG. 3.054 AXIAL LOAD SMOOTH AND MILD-NOTCH FATIGUE PROPERTIES OF SHEET. (4)

Source	(4)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	0.5 inch plate	
Condition	Hot rolled 1.1 in to 0.5 in + 1350F, 15 min, 15 sec delay, WQ + age, 8 hr	
Age Temp - F	E - 10^3 ksi	E_c * - 10^3 ksi
Unaged	11.5	12.0 11.8
950	15.8	16.7 17.0
1000	15.9	15.8 15.8
* Compression specimens 0.5 inch diameter by 1.250 inch height.		

TABLE 3.0625 COMPRESSIVE ELASTIC MODULUS OF PLATE.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

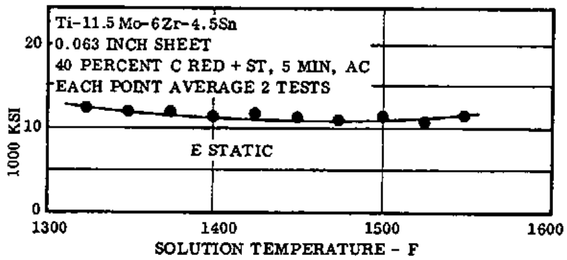


FIG. 3.0626 EFFECT OF SOLUTION TEMPERATURE ON ELASTIC MODULUS OF SOLUTION TREATED SHEET. (4)

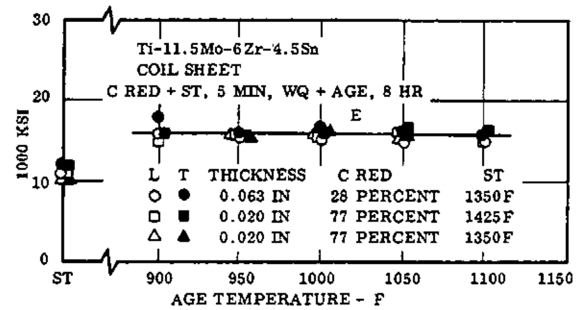


FIG. 3.0629 EFFECT OF AGING TEMPERATURE ON ELASTIC MODULUS OF COIL SHEET. (4)

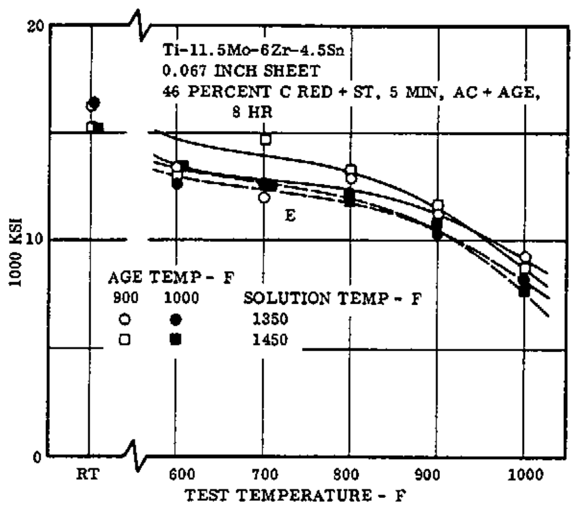


FIG. 3.0627 EFFECT OF TEST TEMPERATURE ON ELASTIC MODULUS OF SHEET. (4)

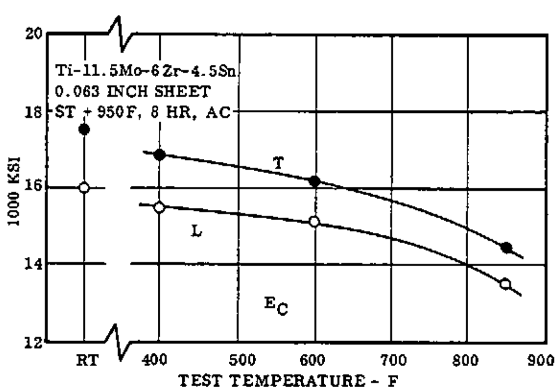


FIG. 3.0628 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE ELASTIC MODULUS OF SHEET. (19)

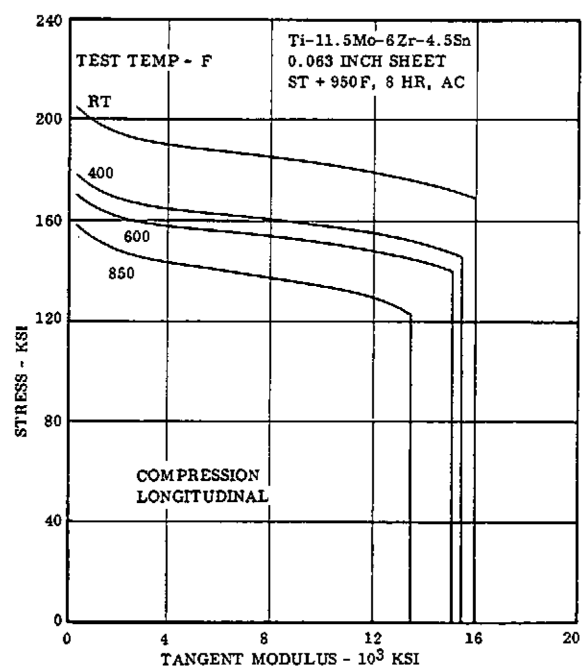


FIG. 3.0631 TYPICAL COMPRESSIVE TANGENT MODULUS AT VARIOUS TEMPERATURES FOR SHEET IN LONGITUDINAL DIRECTION. (19).

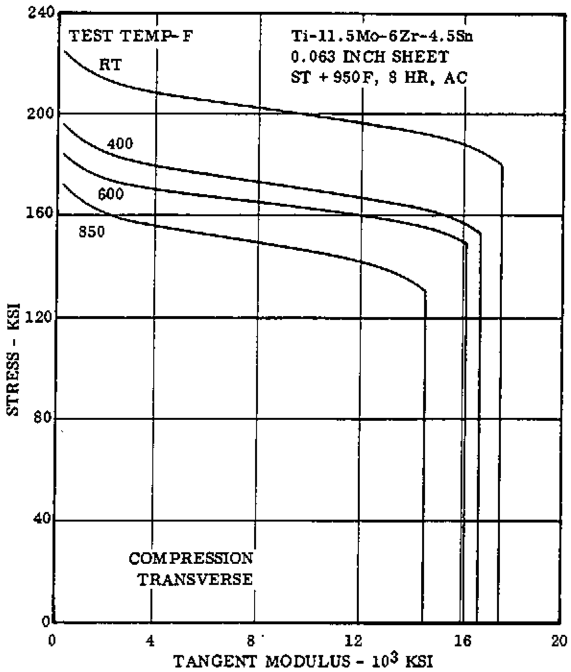


FIG. 3.0632 TYPICAL COMPRESSIVE TANGENT MODULUS AT VARIOUS TEMPERATURES FOR SHEET IN TRANSVERSE DIRECTION. (19)

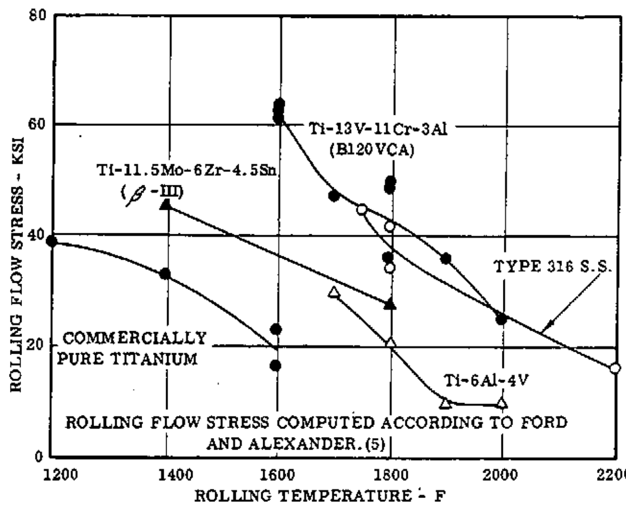


FIG. 4.0131 HOT ROLLABILITY OF Ti-11.5Mo-6Zr-4.5Sn AND SEVERAL OTHER ALLOYS. (4)

Source	(4)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	Seamless Tubing			
Tube Size in		Condition	Flattening Test (a) OD_f/t	Flaring Test (b) percent
OD	Wall t			
1.5	0.173	As extruded (c)	3.7	-
1.26	0.120	Mill annealed (d)	9.0	13.5
		Mill annealed + pickled	8.1	12.0
		Mill annealed+1350F, WQ	7.0	32.3
0.884	0.050	Mill annealed (d)	11.8	16.3
		Mill annealed + pickled	12.2	15.7
		Mill annealed + 1350F, WQ	6.6	27.8

(a) Flattening performance - ratio: height (outside diameter) at failure/wall thickness.
(b) Flaring performance - percentage increase in outside diameter at the location of failure.
(c) 2.8 inch O D x 1.260 inch I D hollow billets canned in mild steel, heated to 1500F, extruded to tube hollow (reduction 7.2:1) and water quenched.
(d) Tube hollows cold reduced to finished tubing in a single pass with tube reducers, followed by vacuum anneal: 1350F, 1/2 hr, rapid cool + 1150F, 4 hr, furnace cool to 900F.

TABLE 4.0111 FLATTENING AND FLARING PERFORMANCE OF SEAMLESS TUBING.

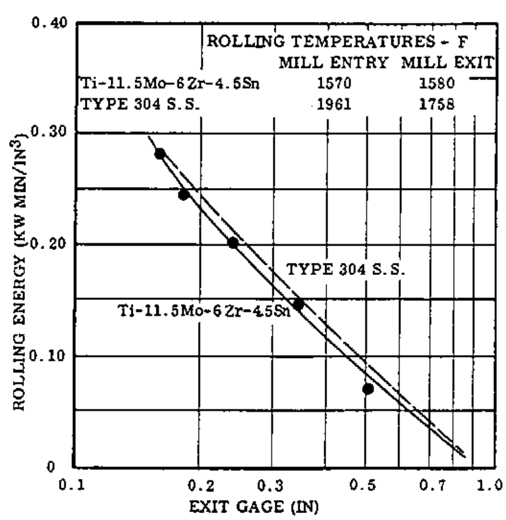


FIG. 4.0132 ENERGY FOR HOT STRIP ROLLING. (4)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source		(4)				
Alloy		Ti-11.5Mo-6Zr-4.5Sn				
Form		0.195 inch hot rolled sheet				
Hot Rolling Temp - F (a)						
Start	Finish(b)	Heat Treatment	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent
1925	1550	As-hot rolled, AC	133.3	121.9	10.0	29.7
1850	1475		145.5	134.6	7.0	38.2
1775	1400		152.4	143.4	6.0	27.1
1925	1550	1450F, 5 min, AC	125.6	111.6	11.0	42.1
1850	1475		131.8	118.7	12.0	50.0
1775	1400		131.6	121.0	10.0	46.0
1925	1550	1450F, 5 min, WQ	112.7	93.4	27.0	54.9
1850	1475		117.3	99.0	26.5	61.2
1775	1400		116.3	97.8	27.0	52.3
1925	1550	1450F, 5 min, WQ + 1000F, 8 hr	193.8	187.5	5.0	19.9
1850	1475		189.6	182.1	3.5	20.6
1775	1400		178.5	170.0	6.0	26.5
(a) Initial slab thickness: 2.5 inches. Reduction per pass: 22.5 percent.						
(b) Temperature at final pass entry.						
Results for 0.135 inch sheet essentially the same.						

TABLE 4.0133 EFFECT OF HOT ROLLING TEMPERATURE ON TENSILE PROPERTIES OF HOT ROLLED SHEET.

Source	(4)	
Alloy	Ti-11.5Mo-6Zr-4.5Sn	
Form	1/2 inch dia bar	
Condition	1420F, WQ + age, 8 hr	
Age Temp - F	E_t - 1000 ksi	E_c - 1000 ksi*
Unaged	9.9	11.1
		11.7
900	14.8	16.2
		16.0
1050	15.7	15.4
* Specimens 0.5 inch dia x 1.250 inch height.		

TABLE 3.0623 COMPRESSIVE ELASTIC MODULUS OF BAR.

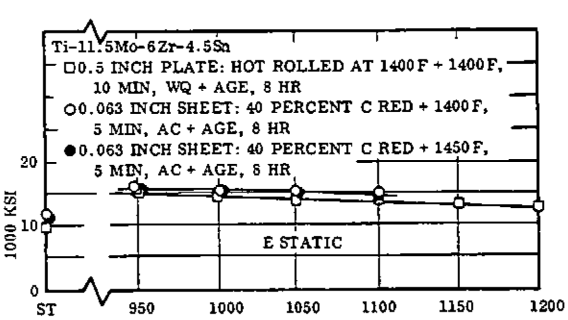


FIG. 3.0624 EFFECT OF AGING TEMPERATURE ON ELASTIC MODULUS OF PLATE AND SHEET. (4)

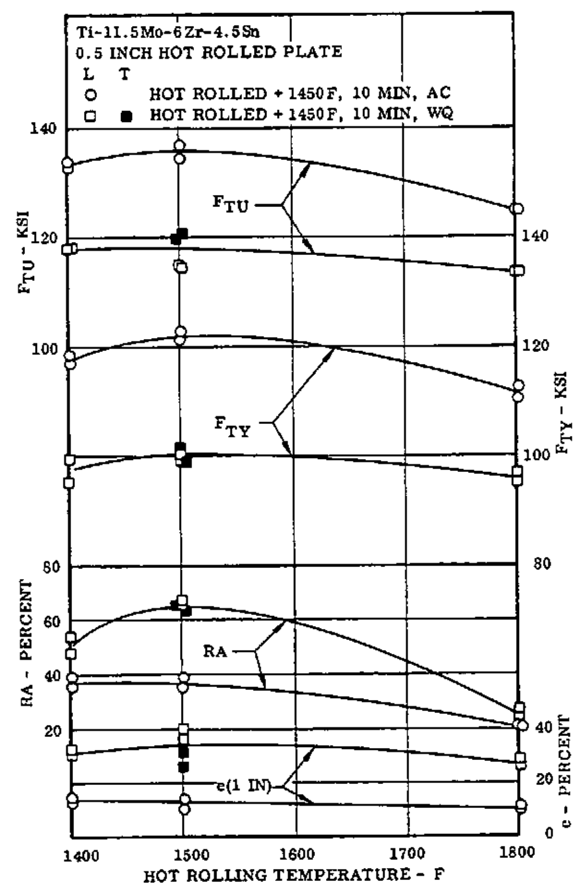


FIG. 4.0134 EFFECT OF HOT ROLLING TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED PLATE. (4)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

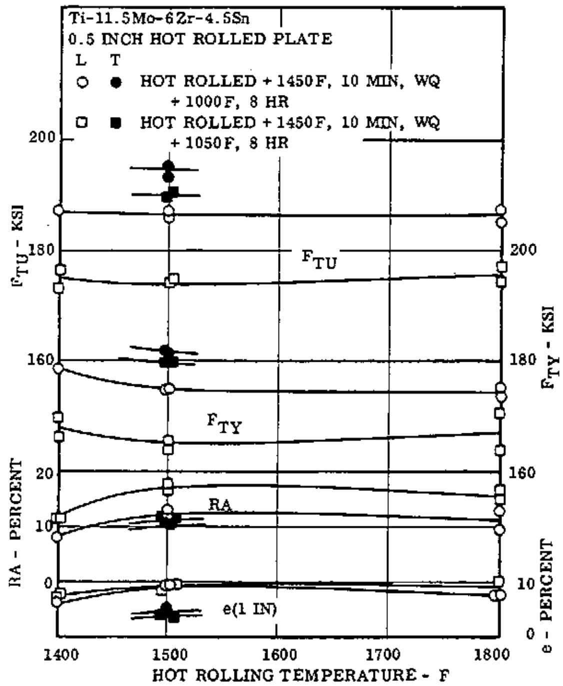


FIG. 4.0135 EFFECT OF HOT ROLLING TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED AND AGED 0.5 INCH PLATE. (4)

Source	(4)		
Alloy	Deformation Banding Limit percent	Cold Work Without Edge Cracking percent	Ratio: Roll Diameter to Min Practical Thickness
Ti-11.5Mo-6Zr-4.5Sn	none	>90	250
Ti Commercially Pure	none	50	300
Ti-13V-11Cr-3Al	none	40	250
Ti-6Al-4V	20	20	250
Ti-8Al-1Mo-1V	<20	10	-

TABLE 4.0137 SEVERAL COLD ROLLING FACTORS RELATED TO REDUCTION LIMITS.

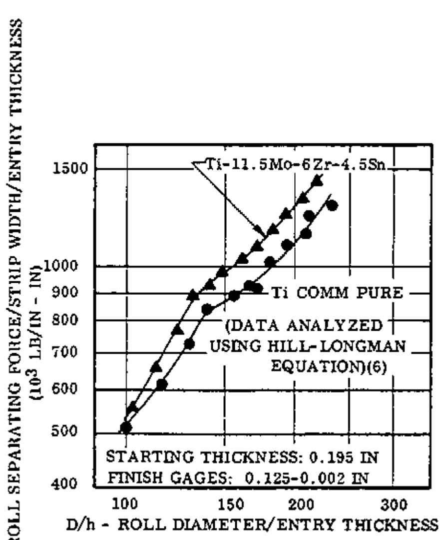


FIG. 4.0136 COLD ROLLABILITY. (4)

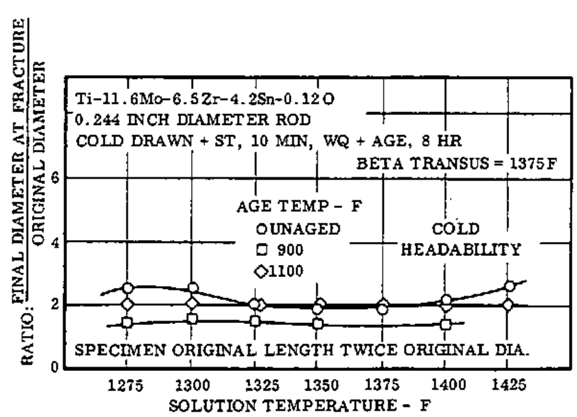


FIG. 4.0141 EFFECT OF SOLUTION TEMPERATURE ON COLD HEADABILITY OF ROD. (4)

Ti
11.5 Mo
6 Zr
4.5 Sn

BETA III

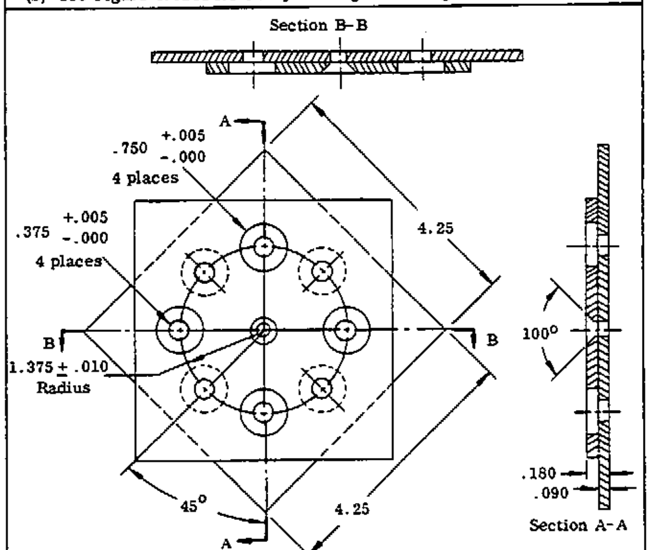
Source	(4)						
Alloy	Ti-11.5Mo-6Zr-4.5Sn						
Form	Rivet Joints (a)						
Type (b) of Test	Ratio (c): Rivet Tail Protrusion to Dia	Cold Head Ratio D_f/D_i	Rivet Joint Exposure			Ultimate Strength ksi	Type(d) of Failure
			Temp F	Stress ksi	Time hr		
Lap Shear	1	1.45	-	-	-	107.0	S
	1	1.45	-	-	-	101.0	S
	1	1.45	500	50	100	110.0	S
	1	1.45	700	25	100	112.0	S
Cross Tension	1/2	1.30	-	-	-	73.0	H
	1/2	1.30	-	-	-	96.0	T
	1/2	1.30	500	-	100	73.0	H
	1/2	1.30	700	-	100	55.0	H
	1	1.45	-	-	-	62.2	H
	1	1.45	-	-	-	78.0	H
	1	1.45	500	-	100	73.5	H
	1	1.45	700	-	100	67.0	H

(a) Ti-6Al-4V sheet (0.067 inch thick) joined with a Ti-11.5Mo-6Zr-4Sn rivet 0.124 inch diameter.
(b) Specimen configurations same as those for spot weld tests shown in Table 4.0321.
(c) Ti-11.5Mo-6Zr-4.5Sn mill solution treated rod aged 1100F, 8 hr and machined to rivet. Rivet head countersunk with 82° included angle. Rivet head protrusion about 0.003 inch.
(d) Type of failure: S = shear, H = countersunk head, T = bucktail.

TABLE 4.0142 CROSS TENSION AND LAP SHEAR STRENGTH OF RIVET JOINTS WITH AND WITHOUT EXPOSURE TO ELEVATED TEMPERATURE WITH LOAD.

Source	(18)		
Alloy	Ti-11.5Mo-6Zr-4.5Sn		
Form	Rivet Joint (a)		
Condition	ST + head forged + 1275F, 10 min, WQ + 1050F, 8 hr, AC + press cold bucked (1.35 Bucktail Expansion)		
Bucking Tool Configuration (b)	Rivet Joint Expansion		Cross Tension Strength ksi
	Temp - F	Time - hr	
Flat	Unexposed		65.9
Cavity	Unexposed		57.2
Flat	550	500	67.8
Cavity	550	500	66.9

(a) Ti-6Al-4V sheet (0.090 inch thick) joined with a Ti-11.5Mo-6Zr-4.5Sn rivet 0.250 inch diameter. See Figure 4.0144 for rivet configuration.
(b) See Figure 4.0144 for cavity bucking tool configuration.



1/4 inch diameter rivet cross tension coupon

TABLE 4.0143 EFFECT OF BUCKING TOOL CONFIGURATION ON CROSS TENSION STRENGTH OF RIVET JOINTS WITH AND WITHOUT EXPOSURE TO ELEVATED TEMPERATURE.

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

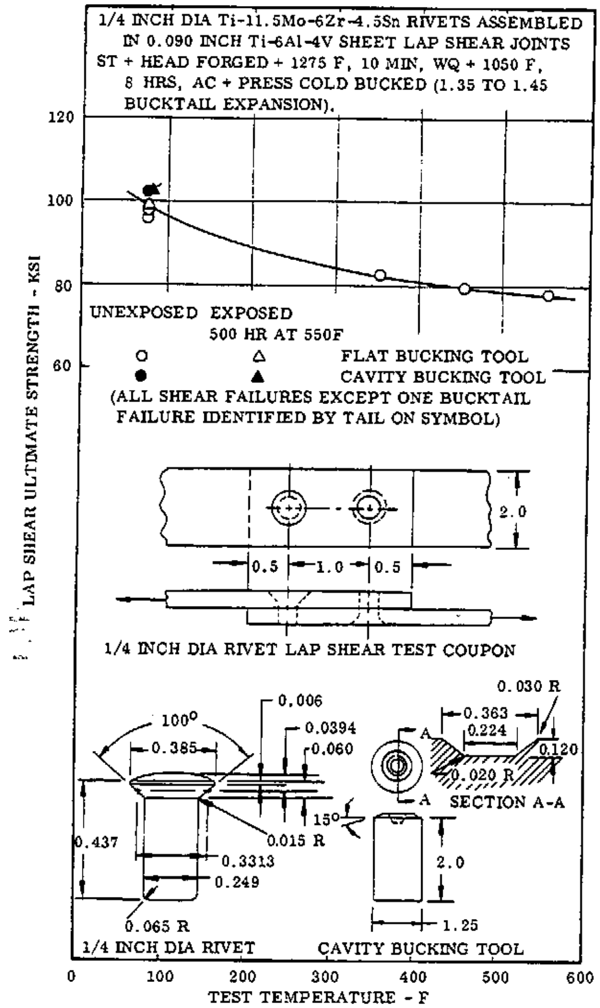


FIG. 4.0144 EFFECT OF BUCKING TOOL CONFIGURATION AND TEST TEMPERATURE ON LAP SHEAR STRENGTH OF RIVET JOINTS WITH AND WITHOUT PREVIOUS EXPOSURE TO ELEVATED TEMPERATURE. (18)

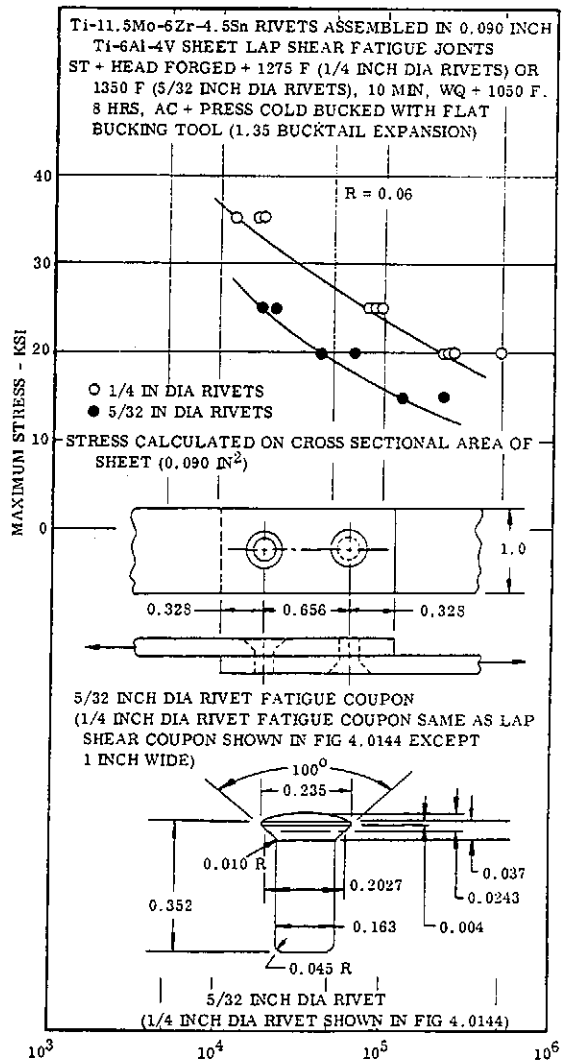


FIG. 4.0145 FATIGUE STRENGTH OF RIVETED LAP SHEAR JOINTS. (18)

	Ti
11.5	Mo
6	Zr
4.5	Sn

BETA III

Source	(4)(9)						
Alloy	Ti-11.5Mo-6Zr-4.5Sn						
Form	GTA fusion welded 0.067 inch sheet*						
Condition	50 percent CRed + 1350F, 5 min, AC + weld with or without 8 hr pre-weld or post-weld aging						
Test Dir	Pre-Weld Aging Temp - F	Post-Weld Aging Temp - F	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	RA percent	Location of Break**
L	-	-	106.5	89.3	12.0	49.4	-
	950	-	112.1	99.6	20.0	48.0	-
	1100	-	113.3	100.4	17.0	56.1	-
T	-	-	109.2	95.3	2.5	20.6	W
	950	-	116.5	106.6	6.8	54.0	W
	1100	-	111.2	100.0	6.3	53.2	W
T	-	950	167.6	164.9	1.0	9.1	W
	-	950	190.0	160.1	4.0	24.7	P
	-	1000	150.2	144.0	3.0	26.9	W
	-	800 + 1000	157.4	151.3	2.0	15.9	W
	-	1050	139.3	131.1	3.0	25.4	W
	-	800 + 1050	155.4	147.7	3.0	21.9	HAZ
	-	1100	128.3	121.5	3.0	25.0	W
	-	800 + 1100	123.6	116.8	4.5	25.7	W

* GTA welded in argon-filled tank without filler metal additions.
** Location of break: W = weld fusion zone, P = parent metal, HAZ = heat affected zone.
Note: See Figure 3.02134 for parent sheet properties.

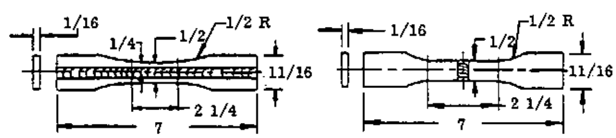


TABLE 4.0311 TENSILE PROPERTIES OF GTA FUSION WELDED SHEET.

Source	(18)		
Alloy	Ti-11.5Mo-6Zr-4.5Sn		
Form	Rivet Joint(a)		
Condition	ST + head forged + 1275F, 10 min, WQ + 1050F, 8 hr, AC + press cold bucked (1.35 bucktail expansion)		
Bucking Tool Configuration (b)	Rivet Joint Exposure Temp - F	Rivet Joint Exposure Time - hr	Cycles to Failure at F_{max} = 35 ksi, R = .06
Flat	unexposed		19, 800
Flat	unexposed		14, 600
Flat	unexposed		19, 200
Flat	550	500	18, 500
Flat	550	500	22, 900
Flat	550	500	18, 700
Cavity	unexposed		155, 400
Cavity	unexposed		345, 800
Cavity	unexposed		309, 900
Cavity	550	500	251, 200

(a) Ti-6Al-4V sheet (0.090 inch thick) joined with Ti-11.5Mo-6Zr-4.5Sn rivets 0.250 inch diameter. See Figure 4.0144 for rivet configuration.
(b) See Figure 4.0144 for cavity bucking tool configuration.
(c) Rivet fatigue coupon same as lap shear coupon shown in Figure 4.0144 except 1 inch wide.
All failures through rivet holes in sheet material.

TABLE 4.0146 EFFECT OF BUCKING TOOL CONFIGURATION ON FATIGUE STRENGTH OF RIVETED LAP SHEAR JOINTS WITH AND WITHOUT PREVIOUS EXPOSURE TO ELEVATED TEMPERATURE.

Source	(25)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	Electron-beam fusion welded 0.02 inch sheet			
Condition	F_{tu} ksi	F_{ty} ksi	e(2 in) percent	Location of Break
Parent metal: ST + 950F age	196	181	4.2	Parent metal
ST + weld + 950F age	174	162	4.9	Parent metal
ST + 950F age + weld	137	136	1.7	Weld fusion zone
ST + weld + ST + 950F age	174	163	4.0	Two in parent metal Three in weld fusion zone

TABLE 4.0312 TENSILE PROPERTIES OF ELECTRON-BEAM FUSION WELDED SHEET.

Source	(4)			
Alloy	Ti-11.5Mo-6Zr-4.5Sn			
Form	Spot Welded 0.067 inch Sheet			
Condition	46 percent C Red + ST, 5 min, AC + spot weld with or without 8 hr pre-weld or post-weld aging			
Pre-Weld Solution Temp F	Pre-Weld Aging Temp F	Post-Weld Aging Temp F	Cross Tension Maximum Load lb	Lap Shear Maximum Load lb
1350	-	-	3190 NP	5540 N
			2550NP	5360 NP
1450	-	-	2540 N	4750 PN
			2950 N	4825 N
1350	900	-	2260 P	6075 HP
			2470 P	6075 N
1450	900	-	2580 HP	5750 N
			2640 P	5700 N
1350	950	-	2270 P	6175 N
			2450 P	6100 HP
1450	950	-	2620 HP	6050 N
			2570 N	6050 N
1350	1000	-	2720 P	6125 HP
			2540 P	5925 HP
1450	1000	-	2720 NP	5700 N
			2605 HP	5700 N
1350	-	950	650 W	2800 WN
			675 N	2875 N
1450	-	950	730 WN	2650 WN
			700 WN	3050 N
1350	-	1000	810 W	3650 NP
			970 N	3475 N
1450	-	1000	830 W	3875 N
			960 N	3050 W
1350	-	1050	1100 N	4220 N
1450	-	1050	1145 N	4200 N

Sheet descaled before spot welding.
Post-weld aged specimens tested without removal of surface oxidation.
Spot weld failure code:
- P = Failure through parent metal
- HP = Failure through heat affected zone and parent metal
- NP = Failure through weld nugget and parent metal
- N = Pulled weld nugget
- WN = Failure partially through pulled weld nugget and partially through prior spot weld interface.
- W = Failure through prior spot weld interface

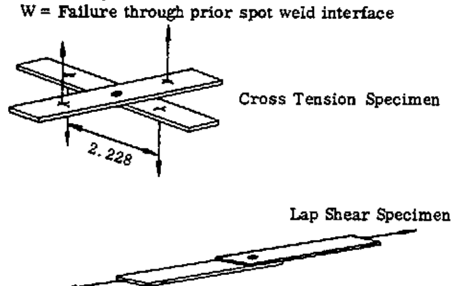


TABLE 4.0321 CROSS TENSION AND LAP SHEAR STRENGTHS OF SPOT WELDED SHEET.

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