

RELEASED: MARCH 1975  
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## NONFERROUS ALLOYS

1. GENERAL  
 This alloy, sometimes referred to as Beta C or more often by combinations of the nominal composition 38-6-44, is an age hardenable, metastable beta alloy. It was developed by the RMI Company (formerly Reactive Metals, Inc.) in 1969. The alloy is formulated by depressing the beta transus with the beta isomorphous elements, molybdenum and vanadium, and the sluggish beta eutectoid element, chromium. It is slightly more beta stabilized than Ti-11.5Mo-6Zr-4.5Sn (Beta III) and less beta stabilized than Ti-13V-11Cr-3Al.
- Beta phase is retained on cooling from above the beta transus (1460F). The alloy can then be heat treated to high strength levels, up to 200 ksi, by aging between 900 to 1100F. Large variations in tensile strength can be obtained by varying the aging temperature and time. A portion of the beta phase transforms to a finely dispersed alpha during aging. It is reported that unlike some of the other beta alloys, 38-6-44 does not develop the brittle omega phase during heat treatment. Also, the alloy does not grain coarsen as rapidly as other beta alloys when heat treated or worked at temperatures above the beta transus.
- The alloy exhibits excellent cold working characteristics, thus it can be manufactured as sheet, foil, tubing, and cold drawn wire and bar with a combination of high strength and ductility. It may be easily hot worked and is through-hardenable in sections up to six inches. The available information indicates it is quite resistant to sustained load crack growth in 3.5 percent NaCl solution. Potential applications include fasteners, springs, torsion bars, and foil to heavy section parts.
- 1.01 Commercial Designation  
 3Al-8V-6Cr-4Mo-4Zr Titanium Alloy.
- 1.02 Alternate Designation  
 RMI-3Al-8V-6Cr-4Mo-4Zr.  
 Tel-Ti-3Al-8V-6Cr-4Mo-4Zr.  
 Ti-3Al-8V-6Cr-4Mo-4Zr.  
 38-6-44.  
 Beta C.
- 1.03 Specifications  
 None
- 1.04 Composition  
 1.041 Producers specified composition, Table 1.041.  
 1.042 The relationship between composition, transformation kinetics, and microstructure has been reviewed (10). The alloy has a total of 18 percent beta stabilizer additions plus 3 percent aluminum, an alpha stabilizer, and 4 percent zirconium, generally a neutral element. In this alloy Zr appears to act more like a beta stabilizer and it is believed to be a constituent of a second phase which is formed upon cooling from above the beta transus (1460 ± 25F) (1). To date this second phase has not been identified, however, it has been established that it is not TiCr<sub>2</sub>. It appears as a randomly dispersed, fine precipitate in the solution annealed microstructure, and possibly may exist at elevated temperatures. It is felt that this second phase inhibits beta grain growth during exposure above the beta transus, thus acting as a ductility enhancer.
- Quenching or air cooling from above the beta transus to room temperature results in the retention of beta in a metastable condition. Recrystallization occurs after short-time annealing at or above the beta transus. The ductile annealed metastable beta phase transforms partially to alpha upon subsequent aging. The alpha phase precipitates both intergranularly and intragranularly when aged over the 800 - 1300F temperature range. This alloy does not develop omega, a brittle phase, during heat treatment.
- 1.05 Heat Treatment
- 1.051 Solution treating and annealing are the same for this alloy. 1500 to 1700F, hold from 15 to 30 minutes, either air cool or water quench (see Tables 1.062 and 1.063). The 1700F temperature is generally recommended for plate or bar, whereas 1500 - 1600F can be used for thin products such as wire, foil, and sheet. The effect of annealing temperature on the tensile properties of cold drawn fastener stock, plate and tubing are shown in Figures 1.0641, 3.0213 and 3.0214. Lower annealing temperatures, specifically 1250F, result in an increase in tensile strength, however a drastic decrease in ductility (see Figure 3.0214). Age. 900 to 1100F, with higher strengths obtainable at the lower temperatures within this range (see Figure 3.0215 to 3.0218).
- 1.052 The selection of aging time for an alloy depends on the combination of properties desired. For this alloy, aging at times beyond 8 hours has an insignificant effect on strength and ductility. Based on a strength-ductility criterion one producer (1) recommends an aging temperature of 900F for 8 hours as offering the best combination of properties (see Figure 3.0217). No information is available on the influence of aging temperature or time on toughness properties.
- 1.053 Hardness  
 The alloy is sufficiently beta stabilized to exhibit deep hardenability. Uniform strength levels in sections up through 6 inches thickness have been reported for both the solution annealed and solution annealed plus aged condition (see Tables 1.062 and 1.063).
- 1.062 Effect of quench rate and specimen location on full section room temperature tensile properties for 6 inch diameter billet in the solution annealed condition. Table 1.062.
- 1.063 Effect of quench rate and specimen location on full section room temperature tensile properties for 6 inch diameter billet in the solution annealed plus aged condition. Table 1.063.
- 1.064 The alloy has excellent cold working characteristics, thus it is possible to manufacture the alloy as foil, sheet, tubing, cold drawn wire and bar with a combination of high strength and ductility. Results (1) from the Olsen cup test show that it has superior formability to numerous titanium alloys. Beta III and Ti-8Mo-8V-2Fe-3Al were not included in this comparison. Cold working prior to aging also enhances the final aged properties. Effect of annealing temperature on tensile properties of 0.312 in round cold drawn fastener stock, Figure 1.0641.
- 1.0642 Effect of cold work on tensile properties of fastener stock in two solution annealed conditions, Figure 1.0642.
- 1.0643 Effect of various aging treatments on the mechanical properties of cold drawn fastener bar, Table 1.0643.
- 1.0644 Effect of aging on mechanical properties of fastener stock cold drawn various percentages, Figure 1.0644.
- 1.0645 Effect of aging temperature on tensile properties of cold worked tubing. Figure 1.0645.
- 1.07 Forms and Conditions Available  
 Plate, sheet, foil, tubing, and cold drawn wire and bar.
- 1.08 Melting and Casting Practice  
 1.081 The composition of the metastable beta alloy Ti-3Al-8V-6Cr-4Mo-4Zr was designed to meet certain specific requirements. The alloy was planned so it would have not only an attractive combination of properties but also that it would be easy to produce using conventional melting practices and readily available raw materials. This alloy can be melted without difficulty when the commercially available master alloys for vanadium (15Al-85V) and molybdenum (30Al-70Mo) are used. Chromium and zirconium can be added in their elemental forms but elemental vanadium is not recommended because of its high cost. Unalloyed molybdenum should not be added because this element (having both a relatively high melting temperature and density) is very difficult to melt into titanium and consistently obtain a

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

38-6-44

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

38-6-44

- 1.082 homogeneous alloy (12). Titanium castings have not been widely used to date because of processing problems which have both limited the quality and resulted in high production costs. In an attempt to enhance the quality of titanium castings, recent efforts (11) have been directed at demonstrating the use of pyrolytic graphite coated ceramic molds. Results indicate that these molds are suitable for use with alpha-beta titanium alloys in the manufacture of precision investment castings, but not for beta titanium alloys. Casting fluidity of the alpha-beta Ti-6Al-4V and Ti-6Al-2Sn-4Zr-2Mo is superior to the beta alloys, Beta III and Ti-3Al-8V-6Cr-4Zr-4Mo. The tensile properties of the alpha-beta alloys were acceptable in strength, ductility and notch toughness. The beta alloys showed excellent strength but low ductility, which was caused by the formation of a carbide phase during melting (see Figures 1.083 and 1.084). Thus, induction melting in graphite crucibles is recommended for alpha-beta alloys, however, not for beta titanium alloys.
- 1.083 Tensile properties of various cast titanium alloys at room temperature, Figure 1.083.
- 1.084 Tensile properties of various cast titanium alloys at 600F, Figure 1.084.
- 1.09 Special Considerations
- 1.091 The alloy exhibits good to excellent fabrication characteristics in both the cold and hot worked conditions.
- 1.092 Results of a recent investigation (14) show that the beta alloys Ti-3Al-8V-6Cr-4Mo-4Zr, Ti-8Mo-8V-2Fe-3Al, and Beta III are candidate materials for core applications in titanium honeycomb panels. To date only commercially pure titanium, Ti-3Al-2.5V, and Ti-6Al-4V have been used as core materials. The beta alloys offer significant cost reduction potential because of their lower processing costs and a significant increase in strength due to their age hardening characteristics. The 38-6-44 exhibits higher strength properties than the other two beta alloys after various thermal treatments (see Figure 3.0219).
- 1.093 Unlike Beta III, this alloy may be immune to salt water stress corrosion cracking at room temperature (8)(9). (See 2.033).
- 1.094 The alloy is susceptible to rapid hydrogen diffusion during heating, pickling, or chemical milling operations (13). However, because of the much higher solubility of hydrogen in the beta phase (BCC) than in the alpha phase (HCP) of titanium, this alloy has a higher tolerance to hydrogen embrittlement than the alpha or alpha-beta alloys.
- 1.095 Hardenability and quench rate effect. Tables 1.062 and 1.063 show the effect of quench rate and specimen location on full section room temperature tensile properties for 6 inch diameter billet in the solution annealed and solution annealed and aged condition. Uniform strength properties are exhibited by edge, mid radius, and center location specimens for both conditions. Quench rate has no significant effect on strength properties for either condition, however, it does appear to have an effect on ductility for the solution annealed condition.
2. PHYSICAL AND CHEMICAL PROPERTIES
- 2.01 Thermal Properties
- 2.011 Melting range.
- 2.012 Phase change. Beta transus  $1460 \pm 25F$  (See 1.042).
- 2.0121 Time-temperature-transformation diagrams.
- 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. 0.174 lb per cu in, 4.824 gr per cu cm.
- 2.022 Electric properties.
- 2.023 Magnetic properties. Alloy is nonmagnetic.
- 2.024 Emissivity.
- 2.025 Damping capacity.
- 2.03 Chemical Properties
- 2.031 Corrosion resistance. General. Based upon results by Hagemeyer and Gordon (8), this alloy, unlike Beta III, is apparently immune to salt water stress corrosion cracking at room temperature. This immunity has also been found by Czyrkdis and Levy (9), who further report that methanolic solutions provide an extremely aggressive environment for room temperature stress corrosion cracking. No data are available as to its susceptibility to solid salt stress corrosion at elevated temperatures.
- 2.032 Stress corrosion cracking. Results (8) of aging specimens of this alloy at 1050, 1150, and 1250F show no growth of the fatigue precrack after more than 2000 hours submergence in a 3.5 percent sodium chloride solution at a crack tip stress intensity,  $K_{II}$ , equal to the fracture toughness value (see Table 2.0321).
- 2.0321 Effect of aging temperature on stress corrosion cracking in a 3.5 percent sodium chloride environment, Table 2.0321.
- 2.033 Czyrkdis and Levy (9) used the cantilever beam test to determine the alloy's degree of susceptibility to stress corrosion cracking when exposed to various environments. Results are plotted in Figure 2.0331 and can be summarized as follows: (1) The alloy in the aged condition (875F) does not exhibit sustained load crack growth in 3.5 percent NaCl in 166 hours. (If susceptible, failure time for titanium alloys is usually within this time frame), (2) Methanolic solutions provide extremely aggressive environments for SCC and susceptibility is markedly increased in  $CH_3OH + HCl$  solution and (3) the addition of sodium nitrate to the  $CH_3OH + HCl$  solution significantly improves the resistance to SCC. Values for exposure to the various environments are:
- | Environment   | $K_{ISCC} - K_{SI}\sqrt{in}$<br>(166 hrs. exposure). |
|---|--|
| 3.5 percent NaCl                                      | 34.5   |
| $CH_3OH$  | 16   |
| $CH_3OH + 0.5$ percent HCl                            | 6  |
| $CH_3OH + 0.5$ percent HCl<br>+ 0.5 percent Na $Na_3$ | 30   |
- 2.0331 Effect of testing environment on resistance to stress corrosion cracking of plate in the solution treated plus aged condition, Figure 2.0331.
- 2.034 Fractographic analysis of the stress corroded specimens showed that crack extension in all environments cited in 2.033 was transgranular. The alloy exhibits fractographic ductile characteristics (dimple rupture) in air, 3.5 percent NaCl and inhibited  $CH_3OH + HCl$  environments (9).
3. MECHANICAL PROPERTIES
- 3.01 Specific Mechanical Properties
- 3.011 Producers guaranteed minimum mechanical properties for solution annealed condition, Table 3.011.
- 3.012 Producers guaranteed minimum mechanical properties for solution treated plus aged condition, Table 3.012.
- 3.02 Mechanical Properties at Room Temperature
- 3.021 Tension-stress/strain diagrams - tension properties.
- 3.0211 Longitudinal stress-strain curves (see Figure 3.0311).
- 3.0212 Transverse stress-strain curves (see Figure 3.0312).
- 3.0213 Effect of annealing temperature on tensile properties of 1 inch thick hot rolled plate, Figure 3.0213.
- 3.0214 Effect of annealing temperature on the tensile properties of tubing, Figure 3.0214.
- 3.0215 Effect of aging temperature on the tensile properties of plate in the solution annealed condition, Figure 3.0215.
- 3.0216 Effect of aging temperature on tensile properties of annealed tubing, Figure 3.0216.
- 3.0217 Effect of time at various aging temperatures on the tensile properties of forgings, Figure 3.0217.

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- 3.0218 Effect of aging temperature on the tensile properties of beta alloys in foil form, Table 3.0218.
- 3.0219 Effect of thermal exposure treatments prior to aging on the tensile properties of beta alloys in foil form, Figure 3.0219.
- 3.022 Compression-stress/strain diagrams - compression properties.
- 3.0221 Typical longitudinal compressive stress-strain curve for solution treated plus aged condition (see Figure 3.0321).
- 3.0222 Typical transverse compressive stress-strain curve for solution treated plus aged condition (see Figure 3.0322).
- 3.023 Impact.
- 3.024 Bending.
- 3.025 Torsion and shear.
- 3.0251 Effect of solution temperature on the torsion and tensile properties of aged bar, Table 3.0251.
- 3.0252 Effect of aging treatment on the torsion and tensile properties of aged bar, Table 3.0252.
- 3.026 Bearing.
- 3.027 Stress concentration.
- 3.0271 Notch properties.
- 3.0272 Fracture toughness.
- 3.02721 Plane strain fracture toughness properties for the solution treated plus aged condition, Table 3.02721.
- 3.028 Combined properties.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension-stress/strain diagrams - tension properties.
- 3.0311 Longitudinal stress-strain curves at elevated temperatures for the solution treated plus aged condition, Figure 3.0311.
- 3.0312 Transverse stress-strain curves at elevated temperatures for the solution treated plus aged condition, Figure 3.0312.
- 3.0313 Effect of test temperature on tensile properties of bar in the solution annealed condition, Figure 3.0313.
- 3.0314 Effect of test temperature on tensile properties of bar in the solution treated plus aged condition, Figure 3.0314.
- 3.0315 Effect of test temperature on tensile properties of billet in the solution treated plus aged condition, Figure 3.0315.
- 3.0316 Effect of test temperature on the tensile properties of various size tubing, Table 3.0316.
- 3.032 Compression-stress/strain diagrams. Compression properties.
- 3.0321 Longitudinal compressive stress-strain and tangent modulus curves at elevated temperatures for the solution treated plus aged condition, Figure 3.0321.
- 3.0322 Transverse compressive stress-strain and tangent modulus curves at elevated temperatures for the solution treated plus aged condition, Figure 3.0322.
- 3.0323 Effect of test temperature on compressive yield strength of forging in the solution treated plus aged condition, Figure 3.0323.
- 3.033 Impact.
- 3.034 Bending.
- 3.035 Torsion and shear (See Table 3.044)
- 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 Creep rupture curves for billet at 500, 700 and 900F in the solution annealed plus aged condition, Figure 3.041.
- 3.042 Thermal and creep stability data for cold drawn, solution annealed and solution annealed plus aged bar, Table 3.042.
- 3.043 Effect of thermal exposure on tensile properties of various size tubing, Table 3.043.
- 3.044 Effect of various heat treatments on the thermal stability of tensile and shear properties of bar, Table 3.044.
- 3.05 Fatigue Properties
- 3.051 S-N curves at elevated temperatures for smooth and notched specimens in the solution treated plus aged condition at a stress ratio of R = 0.1, Figure 3.051.
- 3.06 Elastic Properties
- 3.061 Poisson's ratio.
- 3.062 Modulus of elasticity (Reference 1).
- |             | Annealed                 | STA                        |
|-------------|--------------------------|----------------------------|
| Orientation | Condition                | Condition                  |
| Tension     | 14 x 10 <sup>3</sup> ksi | 15.4 x 10 <sup>3</sup> ksi |
| Compression | -                        | 14.8 x 10 <sup>3</sup> ksi |
- 3.0621 Effect of test temperature on the modulus of elasticity in tension and compression of billet in the solution treated plus aged condition, Figure 3.0621.
- 3.063 Modulus of rigidity.
- 3.0631 Effect of solution treatment on modulus of rigidity of bar, Table 3.0631.
- 3.0632 Effect of aging treatment on modulus of rigidity of bar, Table 3.0632.
- 3.064 Tangent Modulus.
- 3.0641 Longitudinal tangent modulus at elevated temperatures for the solution treated plus aged condition, Figure 3.0641.
- 3.0642 Transverse tangent modulus at elevated temperatures for the solution treated plus aged condition, Figure 3.0642.
- 3.065 Secant modulus.
4. FABRICATION
- 4.01 Formability  
(See 1.064).
- 4.011 General. The alloy has good hot and cold workability and is highly resistant to cracking during hot working. Hot working is accomplished in the temperature range of 1500F to 1800F with relative insensitivity to workability or subsequent mechanical property variation. Because of its good cold working characteristics, it is possible to manufacture the alloy as sheet, foil, tubing, cold drawn wire and bar with a combination of high strength and ductility.
- 4.02 Machining and Grinding  
Contact Air Force Machinability Data Center, 3980 Rosslyn Drive, Cincinnati, Ohio, 45209.
- 4.03 Welding  
Limited data (1) indicate that the alloy can be welded in the solution annealed condition, but not after solution treating and aging. Welds can be strengthened by aging, however, there is a significant loss in ductility.
- 4.031 Mechanical properties of sheet and plate weldments, Table 4.031.
- 4.04 Heat Treatment
- 4.05 Surface Treatment  
The cleaning procedures established for the first commercial beta alloy, Ti-13V-11Cr-3Al, are particularly applicable for this alloy (13). In addition, even though the beta alloys have a high tolerance to hydrogen embrittlement, caution should be exercised in any chemical cleaning operation which is capable of imparting hydrogen to the metal.

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

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Source	(1)	
	Weight Percent	
Element	Minimum	Maximum
Aluminum	3.0	4.0
Vanadium	7.5	8.5
Chromium	5.5	6.5
Molybdenum	3.5	4.5
Zirconium	3.5	4.5
Iron		0.30
Nitrogen		0.03
Carbon		0.05
Oxygen		0.12
Hydrogen		0.020
Other Elements: Each		0.10
Total		0.40

TABLE 1.041 PRODUCERS SPECIFIED COMPOSITION

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Source	(2)					
Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr					
Form	6 in diameter x 6 in long					
Condition	1500F, 15 Min, WQ			1500F, 15 Min, AC		
Location	Edge	Mid Radius	Center	Edge	Mid Radius	Center
F <sub>tu</sub> (ksi)	120	120	117	118	120	120
F <sub>ty</sub> (ksi)	114	113	111	112	113	113
e (1 in) (percent)	16	10	12	15	15	14
RA (percent)	42	22	25	36	31	33
Longitudinal tests.						
Data average of two tests.						

TABLE 1.062 EFFECT OF QUENCH RATE AND SPECIMEN LOCATION ON FULL SECTION ROOM TEMPERATURE TENSILE PROPERTIES FOR 6 IN DIAMETER BILLET IN THE SOLUTION ANNEALED CONDITION.

Source	(2)					
Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr					
Form	6 in diameter x 6 in long					
Condition	1500F, 15 Min., WQ;			1500F, 15 Min., AC;		
	1050F, 12 hrs., AC			1050F, 12 hrs., AC		
Location	Edge	Mid Radius	Center	Edge	Mid Radius	Center
F <sub>tu</sub> (ksi)	176	173	174	173	175	178
F <sub>ty</sub> (ksi)	165	163	164	167	167	168
e (1 in) (percent)	9	10	9	9	9	9
RA (percent)	18	20	18	18	17	16
Longitudinal tests.						
Data average of two tests.						

TABLE 1.063 EFFECT OF QUENCH RATE AND SPECIMEN LOCATION ON FULL SECTION ROOM TEMPERATURE TENSILE PROPERTIES FOR 6 IN DIAMETER BILLET IN THE SOLUTION ANNEALED PLUS AGED CONDITION.

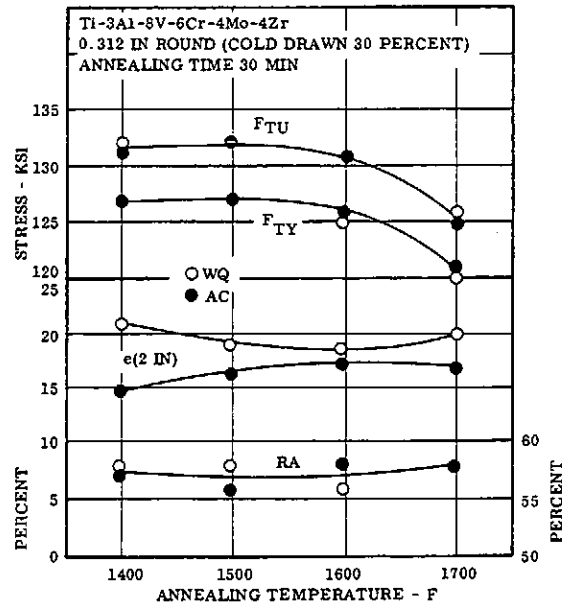


FIG. 1.0641 EFFECT OF ANNEALING TEMPERATURE ON TENSILE PROPERTIES OF 0.312 IN ROUND COLD DRAWN FASTENER STOCK. (1)

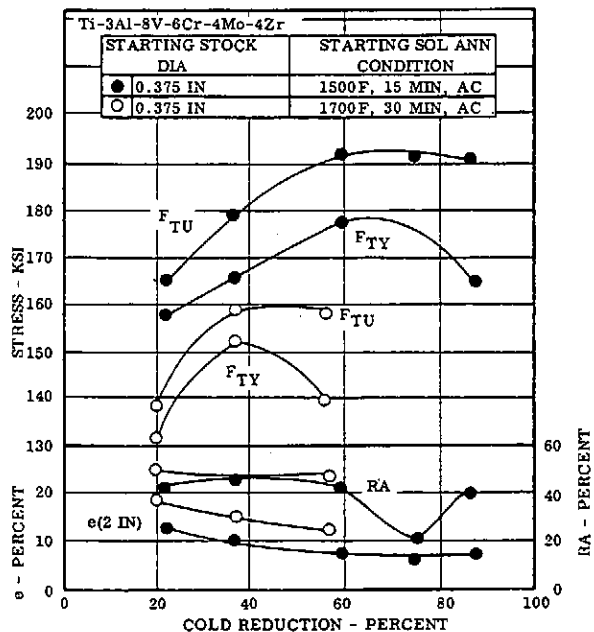
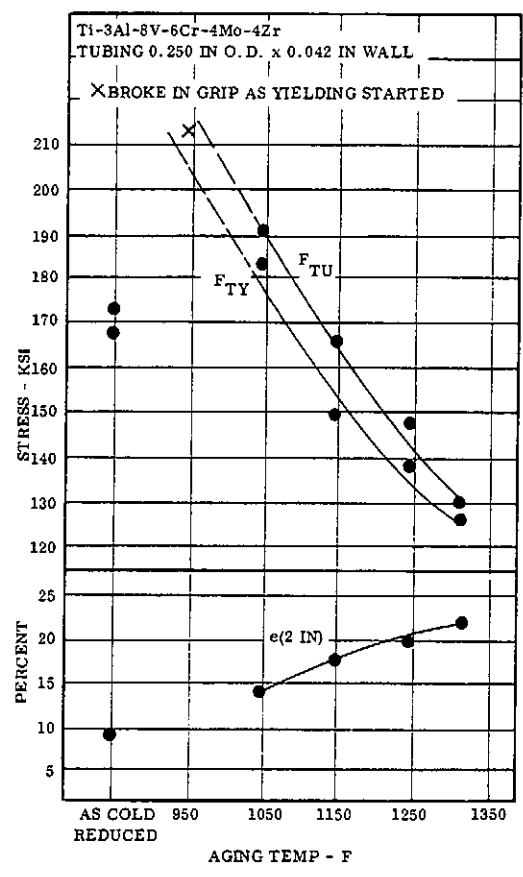


FIG. 1.0642 EFFECT OF COLD WORK ON TENSILE PROPERTIES OF FASTENER STOCK IN TWO SOLUTION ANNEALED CONDITIONS. (3)

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Source	(1)				
Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr				
Form	Bar				
Size (in)	Condition	F <sub>TU</sub> (ksi)	F <sub>TY</sub> (ksi)	e (2 in) (percent)	RA (percent)
0.330	AS CD - 22.5 percent	165	157	13	43
	CD + 800F, 6 hr, AC	242	228	5	17
	CD + 800F, 12 hr, AC	246	234	1	12
	CD + 900F, 6 hr, AC	229	215	5	16
	CD + 900F, 12 hr, AC	223	205	7	18
CD + 1000F + 6 hr, AC	191	177	12	18	
0.510	AS CD - 30 percent	168	160	8	25
	CD + 900F, 6 hr, AC	238	222	5	6
	CD + 950F, 6 hr, AC	228	211	5	6
	CD + 1000F, 4 hr, AC	201	186	10	24

TABLE 1.0643 EFFECT OF VARIOUS AGING TREATMENTS ON THE MECHANICAL PROPERTIES OF COLD DRAWN FASTENER BAR.



Ti  
3 Al  
8 V  
6 Cr  
4 Mo  
4 Zr

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FIG. 1.0645 EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF COLD WORKED TUBING. (5)

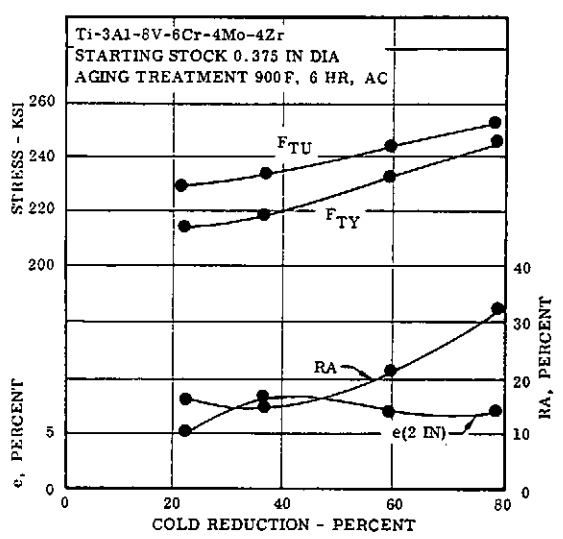


FIG. 1.0644 EFFECT OF AGING ON MECHANICAL PROPERTIES OF FASTENER STOCK COLD DRAWN VARIOUS PERCENTAGES. (3)

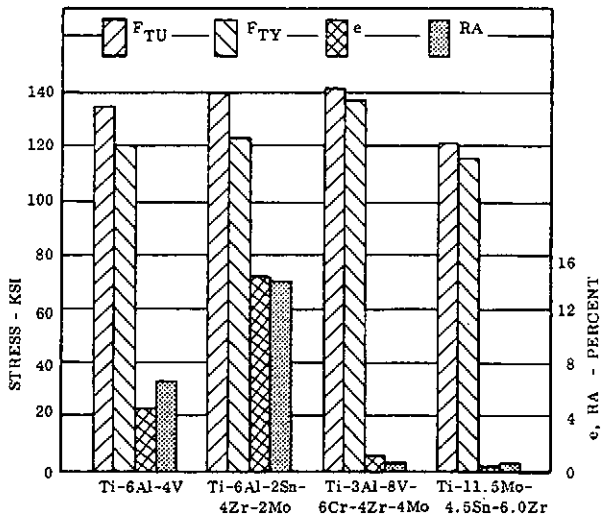


FIG. 1.083 TENSILE PROPERTIES OF VARIOUS CAST TITANIUM ALLOYS AT ROOM TEMPERATURE. (11)

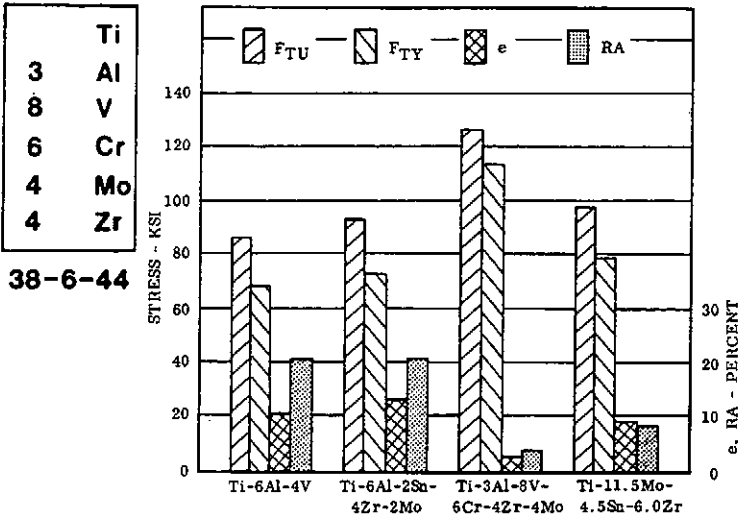


FIG. 1.084 TENSILE PROPERTIES OF VARIOUS CAST TITANIUM ALLOYS AT 600F. (11)

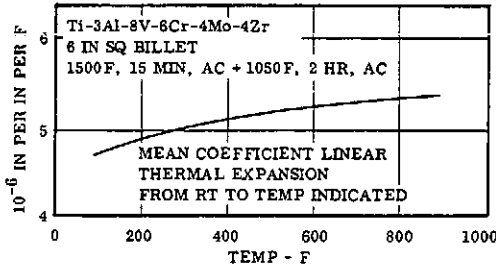


FIG. 2.014 THERMAL EXPANSION. (6)

Source	(8)
Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr
Form	1.25 in thick plate
Condition	1700F, 1 hr, AC, age 8 hr, VAC
Environment	3.5 percent NaCl in distilled water
Aging Temperature (F)	Stress Corrosion Cracking
	$K_{ISCC}$ KSI $\sqrt{IN}$
1050	> 47 (a)
1150	> 55 (a)
1250	> 50 (a)

(a) No crack growth took place, thus the value of  $K_{ISCC}$  is reported as being greater than maximum value of  $K_I$  tested. Specimens used were a bolt loaded, constant deflection WOL type, containing a fatigue crack W of 2.55 in and B of 0.80 in. Orientation L-T.

TABLE 2.0321 EFFECT OF AGING TEMPERATURE ON STRESS CORROSION CRACKING IN A 3.5 PERCENT SODIUM CHLORIDE ENVIRONMENT.

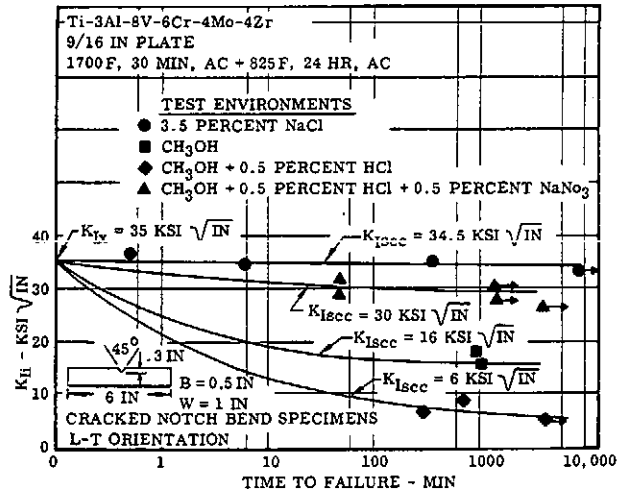


FIG. 2.0331 EFFECT OF TESTING ENVIRONMENT ON RESISTANCE TO STRESS CORROSION CRACKING OF PLATE IN THE SOLUTION TREATED PLUS AGED CONDITION. (9)

NOTE:  $K_{I\alpha}$  EQUALS THE AIR VALUE.

Source	(2)							
Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr							
Condition	Sol. ann - 1500F, 15 - 30 min, AC							
Form	Sheet and Strip		Plate		Bar and Forged Billet			
Thickness-in.	to 0.070	>0.070 to 0.187	to 2	>2 to 4	0.50 to 1.50	>1.50 to 3.00	>3.00 to 9.00	
$F_{tu}$ (ksi)	125	125	125	120	125	120	125	
$F_{ty}$ (ksi)	120	120	120	115	120	115	120	
e (2 in) (percent)	8 (a)	8	10	8	10	10	10 (d)	
				6 (b)		6(b)		
				3 (c)				
RA (percent)					30	25	25	
						20(b)		

(a) Gauges < 0.030 inch  
 (b) Transverse Direction  
 (c) Short transverse direction  
 (d) Results based on forged samples 3:1 minimum upset

TABLE 3.011 PRODUCERS GUARANTEED MINIMUM MECHANICAL PROPERTIES FOR SOLUTION ANNEALED CONDITION.

NONFERROUS ALLOYS

Source	(2)						
Type	Ti-3Al-8V-6Cr-4Mo-4Zr						
Condition	STA: Sol. ann 1500 - 1700F, 1 hr., AC; Age 850 to 1000F, 24 hr, AC						
Form	Sheet and Strip	Plate		Bar and Billet			
Thickness - in	All gauges	to 2	>2 to 4	0.50 to 1.50	>1.50 to 3.00	>3.00 to 6.00	>3.00 to 9.00(a)
F <sub>tu</sub> (ksi)	180	180	180	190	180	170	180
F <sub>ty</sub> (ksi)	170	170	170	180	170	160	170
e (2 in) (percent)	6	8	8	8	8	6	10
RA (percent)			6(b)	15	6(b)	3(b)	15
					15(a)	5(b)	20

(a) Results based on forged samples 3:1 minimum upset.  
 (b) Transverse direction.

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

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TABLE 3.012 PRODUCERS GUARANTEED MINIMUM MECHANICAL PROPERTIES FOR SOLUTION TREATED PLUS AGED CONDITION.

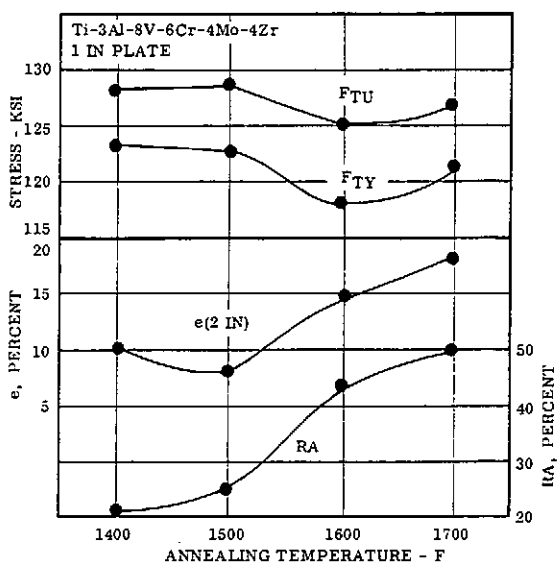


FIG. 3.0213 EFFECT OF ANNEALING TEMPERATURE ON TENSILE PROPERTIES OF 1 IN THICK HOT ROLLED PLATE. (1)

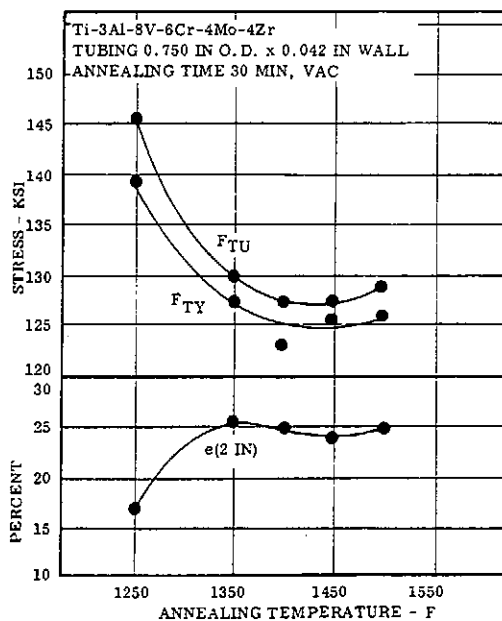


FIG. 3.0214 EFFECT OF ANNEALING TEMPERATURE ON THE TENSILE PROPERTIES OF TUBING. (5)

Ti  
3 Al  
8 V  
6 Cr  
4 Mo  
4 Zr

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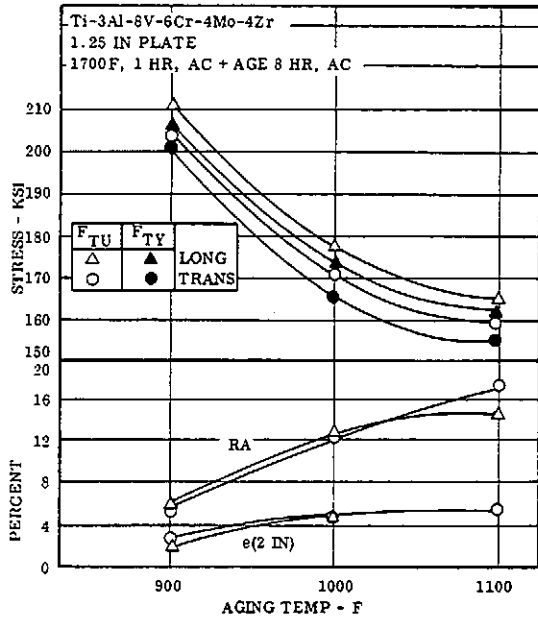


FIG. 3.0215 EFFECT OF AGING TEMPERATURE ON THE TENSILE PROPERTIES OF PLATE IN THE SOLUTION ANNEALED CONDITION. (8)

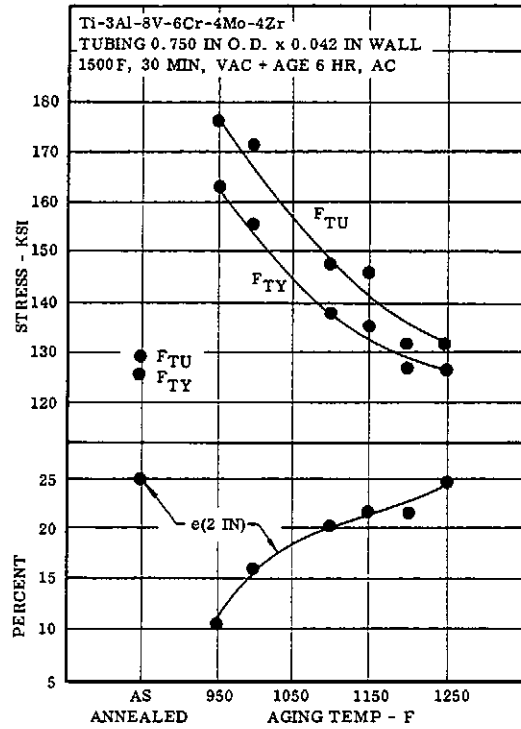


FIG. 3.0216 EFFECT OF AGING TEMPERATURE ON THE TENSILE PROPERTIES OF ANNEALED TUBING. (5)

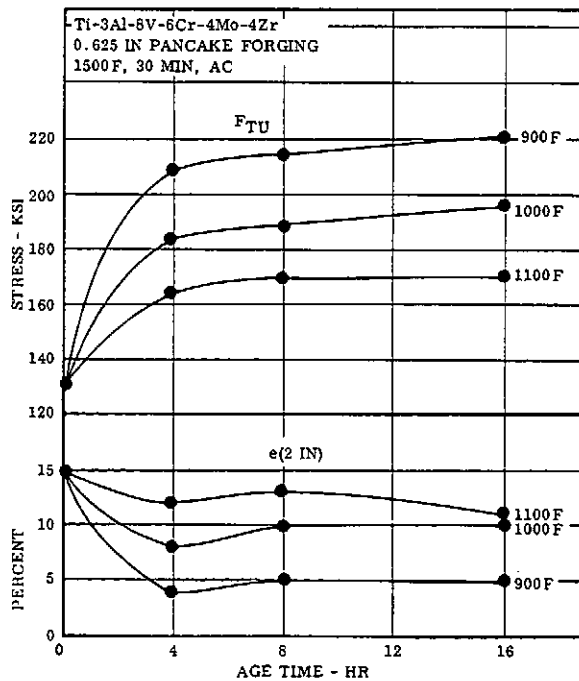


FIG. 3.0217 EFFECT OF TIME AT VARIOUS AGING TEMPERATURES ON THE TENSILE PROPERTIES OF FORGING. (1)

NONFERROUS ALLOYS

Source	(14)					
Form	0.003 in. Foil					
Condition	1500F, 15 min, FC + age, 8 hr, AC					
Alloys	Ti-3Al-3V-6Cr-4Mo-4Zr	Ti-11.5Mo-4.5Sn-6.0Zr	Ti-8Mo-8V-2Fe-3Al			
Aging Temperature	950F	1000F	950F	1000F	950F	1000F
F <sub>tu</sub> (ksi)	193	174	187	180	193	182
F <sub>ty</sub> (ksi)	180	163	172	166	175	-
e (2 in.) (percent)	6.9	3.4	5.0	3.0	5.0	4.0

TABLE 3.0218 EFFECT OF AGING TEMPERATURE ON THE TENSILE PROPERTIES OF BETA ALLOYS IN FOIL FORM.

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

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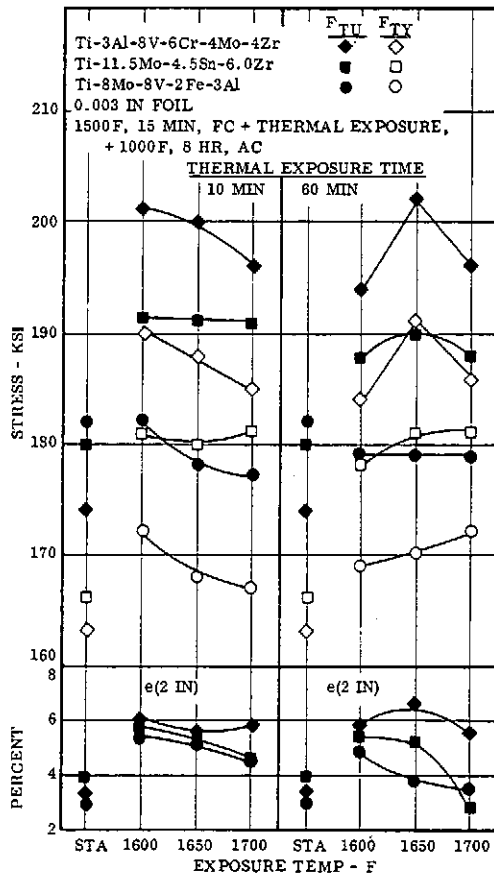


FIG. 3.0219 EFFECT OF THERMAL EXPOSURE TREATMENTS PRIOR TO AGING ON THE TENSILE PROPERTIES OF BETA ALLOYS IN FOIL FORM. (14)

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

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Solution Treatment (c)	(12)									
	Ti-3Al-8V-6Cr-4Mo-4Zr									
	2.625 in diameter bar									
Torsion Properties(d)	Long Tensile Properties					45° Tensile Properties				
	F <sub>st</sub> (ksi)	F <sub>sty</sub> (ksi)	F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (percent)	RA (percent)	F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (percent)	RA (percent)
1400F, 30 min. AC (a)	148	134	214	205	6	13	211	201	2	3
1500F, 30 min. AC (a)	160	140	212	203	7	15	213	202	3	5
	164	140	212	203	7	15	213	202	3	5
1700F, 30 min. AC +	166	133	211	200	4	6	209	197	4	4
1500F, 30 min. AC(a)	162	132	204	194	4	6	200	190	5	8
1700F, 30 min. AC +	171	138	204	192	5	7	213	205	5	8
1500F, 30 min. AC(b)										

(a) Laboratory heat treatment.  
 (b) Production heat treatment  
 (c) Solution treatment followed by aging at 900F, 24 hours. AC.  
 (d) Based on gage dimensions of 1.375 in diameter and 9.5 in length.

TABLE 3.0251 EFFECT OF SOLUTION TEMPERATURE ON THE TORSION AND TENSILE PROPERTIES OF AGED BAR.

Aging Treatment	(12)					
	Ti-3Al-8V-6Cr-4Mo-4Zr					
	2.625 in diameter bar					
Torsion Properties(a)	45° Tensile Properties					
	F <sub>st</sub> (ksi)	F <sub>sty</sub> (ksi)	F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (percent)	RA (percent)
900F, 12 hr. AC	162	132	206	192	4	6
900F, 24 hr. AC	167	134	205	191	5	7
925F, 8 hr. AC	162	129	205	192	4	6
950F, 8 hr. AC	159	127	200	187	5	6

(a) See (d) Table 3.0251

TABLE 3.0252 EFFECT OF AGING TREATMENT ON THE TORSION AND TENSILE PROPERTIES OF AGED BAR.

Source		(6)(7)	
Alloy		Ti-3Al-8V-6Cr-4Mo-4Zr	
Condition		STA: 1500F, 15 min. AC + 1050F, 12 hr. AC	
Test temp.		RT	
Form		Billet (6) (F <sub>ty</sub> = 167 ksi) Forging (7) (F <sub>ty</sub> = 168 ksi)	
Orientation		Plane strain fracture toughness	
		K <sub>IC</sub> - ksi√in	
L-T	53(a)		-
L-T	60(b)		-
L-T	-		53
Bend specimen - 3 point loading			
Data average of three or more tests			
Thickness, B = 0.50 inch (6)			
B = 0.75 inch (7)			
Testing procedure and data conform to ASTM E399			
(a) Specimens from outside location of billet.			
(b) Specimens from middle location of billet.			

TABLE 3.02721 PLANE STRAIN FRACTURE TOUGHNESS PROPERTIES FOR THE SOLUTION TREATED PLUS AGED CONDITION.

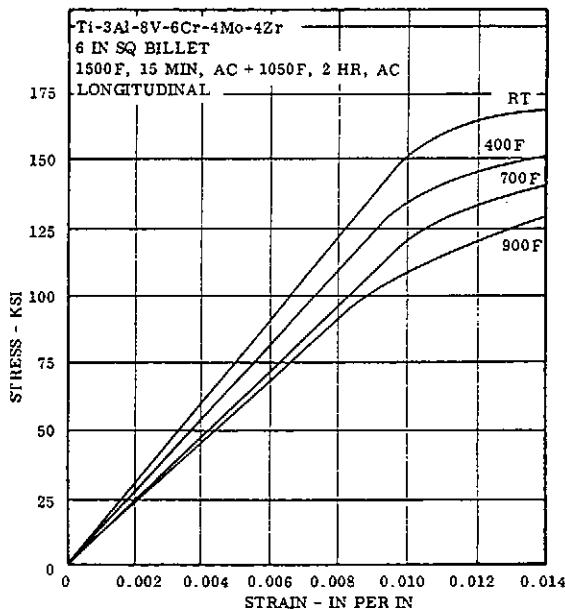


FIG. 3.0311 LONGITUDINAL STRESS-STRAIN CURVES AT ELEVATED TEMPERATURES FOR THE SOLUTION TREATED PLUS AGED CONDITION. (6)

NONFERROUS ALLOYS

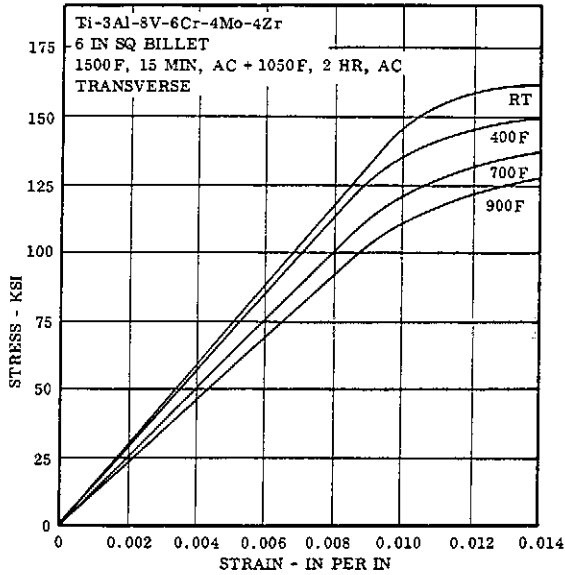
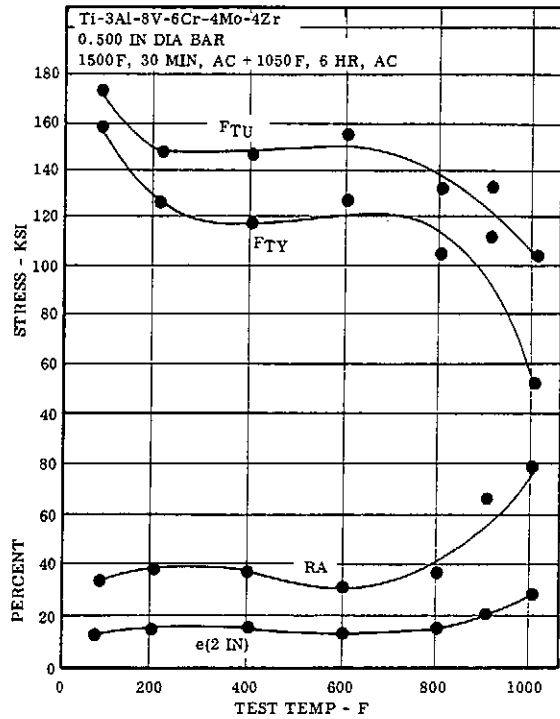


FIG. 3.0312 TRANSVERSE STRESS-STRAIN CURVES AT ELEVATED TEMPERATURES FOR THE SOLUTION TREATED AGED CONDITION. (6)



3	Ti
8	Al
6	V
4	Cr
4	Mo
4	Zr

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FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF BAR IN THE SOLUTION TREATED PLUS AGED CONDITION. (1)

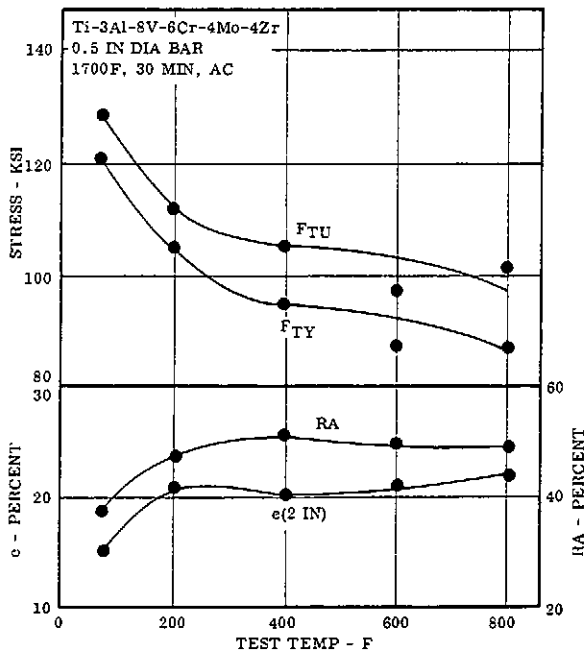


FIG. 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF BAR IN THE SOLUTION ANNEALED CONDITION. (1)

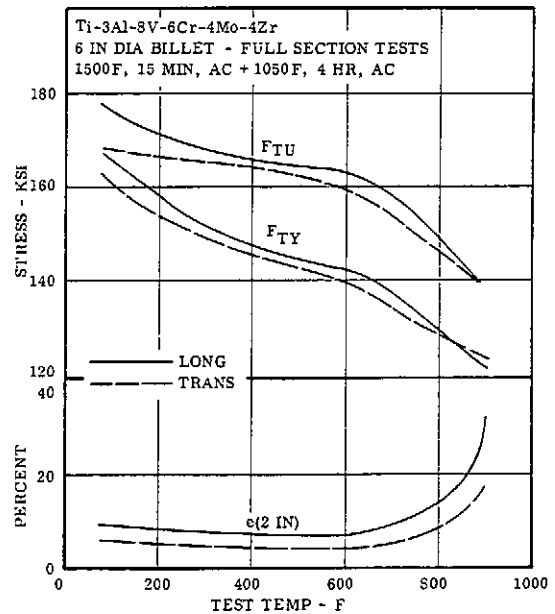


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF BILLET IN THE SOLUTION TREATED PLUS AGED CONDITION. (1)

<p>3 8 6 4 4</p> <p>Ti Al V Cr Mo Zr</p> <p>38-6-44</p>	Source	(5)			
	Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr			
	Form	Tubing			
	Condition	Sol. ann. 1500F - 1.5 hr - vacuum cooled			
	Tubing size (in)	Test temp (F)	F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (2 in) (percent)
	0.750 OD x 0.042 wall	RT	127	122	20
		450	107	103	34
		650	103	91	31
	0.540 OD x 0.030 wall	RT	129	125	18
		450	105	100	28
650		99	88	30	
0.375 OD x 0.025 wall	RT	137	130	14	
	450	108	100	16	
	650	102	90	21	
Data are average of two tests					

TABLE 3.0316 EFFECT OF TEST TEMPERATURE ON THE TENSILE PROPERTIES OF VARIOUS SIZE TUBING

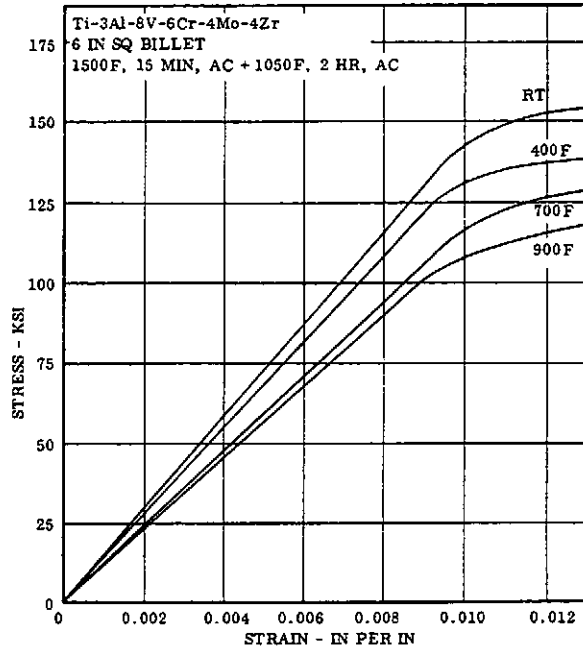


FIG. 3.0322 TRANSVERSE COMPRESSIVE STRESS-STRAIN CURVES AT ELEVATED TEMPERATURES FOR THE SOLUTION TREATED PLUS AGED CONDITION. (6)

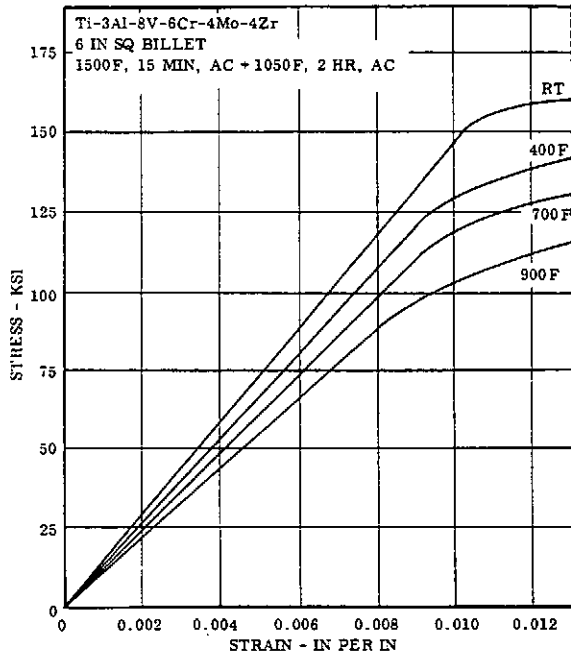


FIG. 3.0321 LONGITUDINAL COMPRESSIVE STRESS-STRAIN CURVES AT ELEVATED TEMPERATURES FOR THE SOLUTION TREATED PLUS AGED CONDITION. (6)

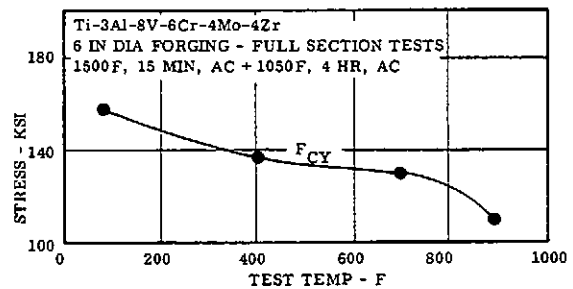
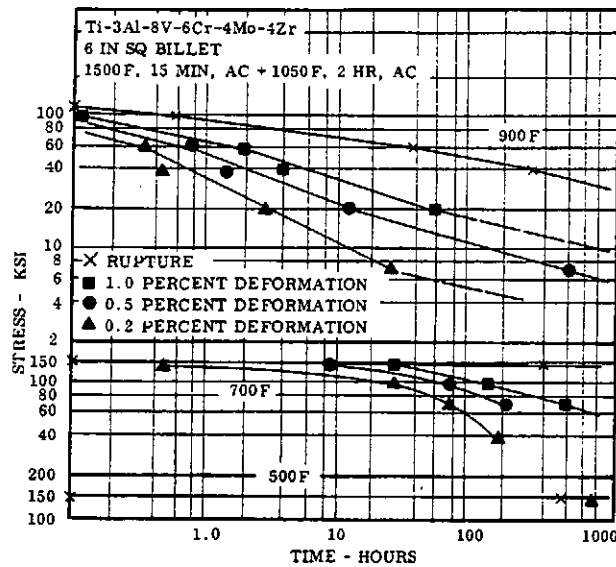


FIG. 3.0323 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF FORGING IN THE SOLUTION TREATED PLUS AGED CONDITION. (1)

NONFERROUS ALLOYS



Ti
3 Al
8 V
6 Cr
4 Mo
4 Zr

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FIG. 3.041 CREEP RUPTURE CURVES FOR BILLET AT 500, 700 AND 900F IN THE SOLUTION ANNEALED PLUS AGED CONDITION. (6)

Source		(3)(4)								
Alloy		Ti-3Al-8V-6Cr-4Mo-4Zr								
Form		Bar								
Bar Dia. (in)	Condition	Thermal Exposure	Tensile Properties							
			Before Exposure				After Exposure			
			F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (2 in) (percent)	RA (percent)	F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (2 in) (percent)	RA (percent)
0.330	As CD - 22.5 percent As Sol Ann -1550F	500F-40 ksi-100 hr.	165	157	13	43	164	151	12	50
0.330		500F-0 ksi-25 hr.	130	128	16	49	131	129	19	47
		500F-0 ksi-100 hr.					131	128	16	49
		500F-40 ksi-25 hr.					132	129	19	48
		500F-40 ksi-100 hr.					133	128	18	50
0.500	As Sol ann 1500F; Age 1050F, 6 hr.	500F-40 ksi-200 hr.					130	127	18	48
		600F-40 ksi-100 hr.					138	133	23	48
		600F-80 ksi-1107 hr(a)	174	160	13	35	174	162	14	31
		700F-75 ksi-212 hr(b)					180	166	12	30
		800F-30 ksi-72 hr (c)					181	165	15	29

(a) Total creep deformation 0.126 percent.  
 (b) Total creep deformation 0.234 percent.  
 (c) Total creep deformation 0.250 percent.

TABLE 3.042 THERMAL AND CREEP STABILITY DATA FOR COLD DRAWN, SOLUTION ANNEALED AND SOLUTION ANNEALED PLUS AGED BAR.

Source		(5)					
Alloy		Ti-3Al-8V-6Cr-4Mo-4Zr					
Form		Tubing					
Condition		Sol. ann. 1500F - 1.5 hr - vacuum cooled					
Thermal Exposure		500F - 0 ksi - 100 hr.					
Tubing Size (in)		Tensile Properties					
		Before Exposure			After Exposure		
		F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (2 in) (percent)	F <sub>tu</sub> (ksi)	F <sub>ty</sub> (ksi)	e (2 in) (percent)
0.750 OD x 0.042 wall		127	122	20	128	125	18
0.540 OD x 0.030 wall		129	125	18	124	121	15
0.375 OD x 0.025 wall		137	130	14	135	132	17

TABLE 3.043 EFFECT OF THERMAL EXPOSURE ON TENSILE PROPERTIES OF VARIOUS SIZE TUBING.

Ti  
3 Al  
8 V  
6 Cr  
4 Mo  
4 Zr

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Condition before Exposure	Room Temp. Tensile and Shear Properties									
	Before Exposure					After Exposure				
	$F_{tu}$ (ksi)	$F_{ty}$ (ksi)	e (2 in) (percent)	RA (percent)	Shear (ksi)	$F_{tu}$ (ksi)	$F_{ty}$ (ksi)	e (2 in) (percent)	RA (percent)	Shear (ksi)
1500F-15 min-AC	131	130	16	49	92	136	130	15	39	95
1500F-15 min-AC	129	127	16	49	91	136	129	15	44	95
1500F-15 min-AC	220	208	8	17	127	227	210	7	10	125
800F-6 hrs, AC	216	204	8	18	123					125
1500F-15 min-AC	210	187	7	21	121	212	198	8	17	124
900F-6 hr-AC					119	209	197	9	16	124
1500F-15 min-AC	178	162	15	38	111	172	157	15	41	110
1000F-6 hr-AC	180	167	16	40	110	173	159	17	37	110
1500F-15 min-AC	163	151	15	50	104	160	149	20	42	105
1050F-6 hr-AC	161	153	13	49	102	161	147	20	44	105
1500F-15 min-AC						147	139	21	45	100
1150F-6 hr-AC						149	138	20	46	99
1500F-15 min-AC	135	129	18	48	91	134	127	20	46	91
1250F-6 hr-AC	136	130	16	49	92	138	131	13	39	92

TABLE 3.044 EFFECT OF VARIOUS HEAT TREATMENTS ON THE THERMAL STABILITY OF TENSILE AND SHEAR PROPERTIES OF BAR.

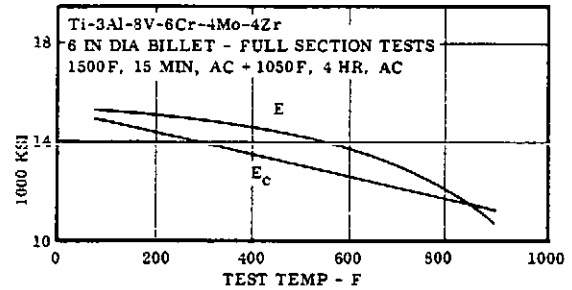


FIG. 3.0621 EFFECT OF TEST TEMPERATURE ON THE MODULUS OF ELASTICITY IN TENSION AND COMPRESSION OF BILLET IN THE SOLUTION TREATED PLUS AGED CONDITION. (1)

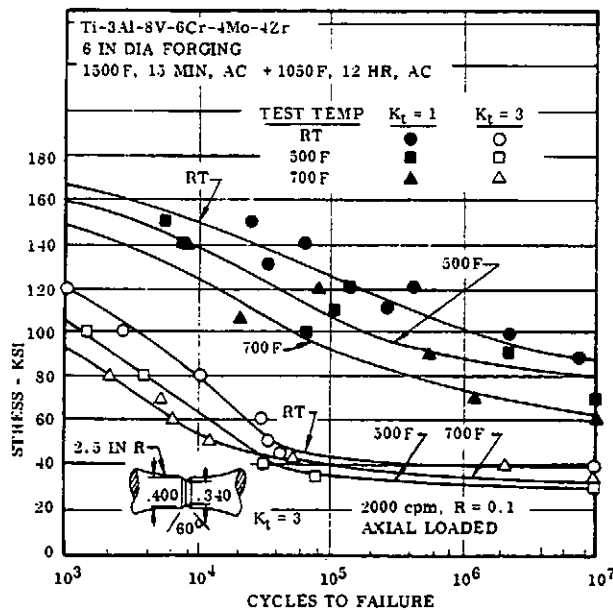


FIG. 3.051 S-N CURVES AT ELEVATED TEMPERATURES FOR SMOOTH AND NOTCHED SPECIMENS IN THE SOLUTION TREATED PLUS AGED CONDITION AT A STRESS RATIO OF R = 0.1. (6)

Solution Treatment	Modulus of Rigidity, $G \times 10^6$ psi	
	(a)	(b)
1400F, 30 min, AC (c)	6.08	6.04
1500F, 30 min, AC (c)	5.94	5.82
1700F, 30 min, AC +	6.05	6.30
1500F, 30 min, AC (c)		6.30
1700F, 30 min, AC +		6.25
1500F, 30 min, AC (d)		

TABLE 3.0631 EFFECT OF SOLUTION TREATMENT ON MODULUS OF RIGIDITY OF BAR.

NONFERROUS ALLOYS

Source	(12)
Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr
Form	2.625 in diameter bar
Condition	Production anneal 1700F, 30 min, AC; 1500F, 30 min, AC + age
Aging Treatment	Modulus of Rigidity G x 10 <sup>6</sup> psi (a)
900F-12 hr-AC	5.95
900F-24 hr-AC	6.28
925F-8 hr-AC	5.91
950F-8 hr-AC	6.04
(a) Statistically determined from torsion test data	

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

TABLE 3.0632 EFFECT OF AGING TREATMENT ON MODULUS OF RIGIDITY OF BAR.

38-6-44

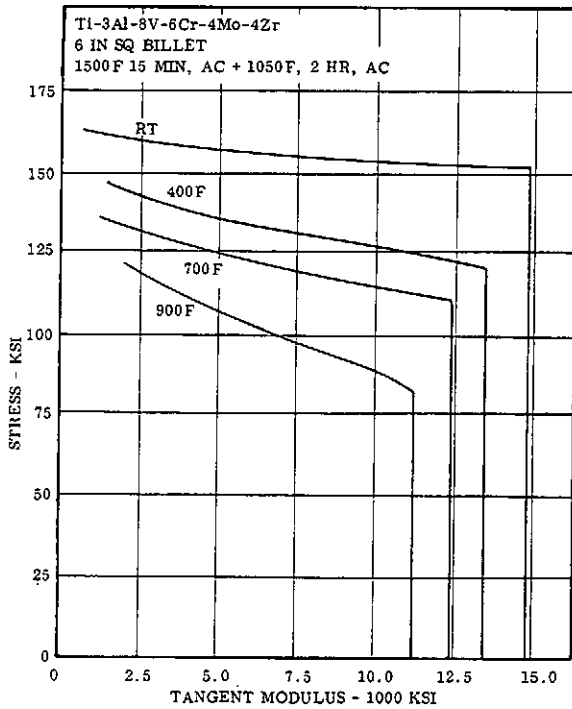


FIG. 3.0641 LONGITUDINAL TANGENT MODULUS AT ELEVATED TEMPERATURES FOR THE SOLUTION TREATED PLUS AGED CONDITION. (6)

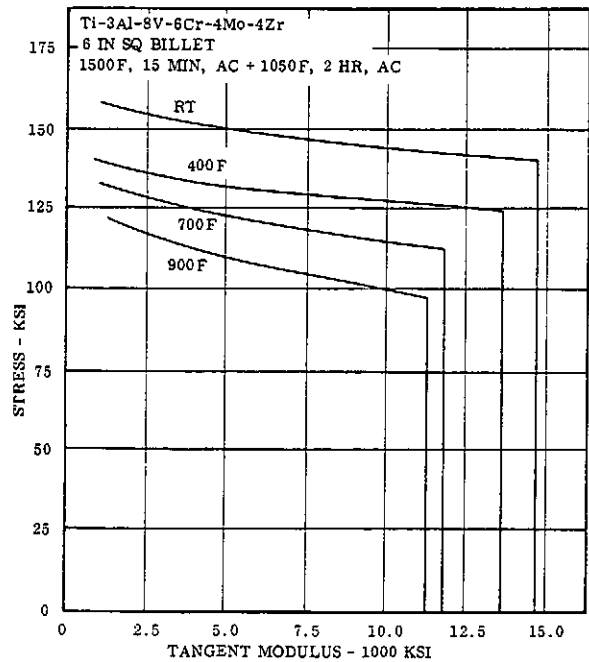


FIG. 3.0642 TRANSVERSE TANGENT MODULUS AT ELEVATED TEMPERATURES FOR THE SOLUTION TREATED PLUS AGED CONDITION. (6)

Source	(1)									
Alloy	Ti-3Al-8V-6Cr-4Mo-4Zr									
Form	Sheet - 0.085 inch and Plate - 0.500 inch									
Condition	F <sub>tu</sub> (ksi)		F <sub>ty</sub> (ksi)		e (percent)		RA (percent)		Failure Site	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1500F, 15 min, AC	126	-	113	-	13	-	-	-	-	-
1500F, 15 min, AC + weld	119	119	113	109	7	10	-	28	WM	WM
1500F, 15 min, AC + weld + 1100F, 2 hr, AC	-	152	-	144	-	6	-	9	-	WM
(a) Sheet (b) Plate Gas tungsten-arc (GTA) weld process. Ti-3Al-8V-6Cr-4Mo-4Zr filler metal used. WM - weld metal. Data average of two tests.										

TABLE 4.031 MECHANICAL PROPERTIES OF SHEET AND PLATE WELDMENTS.

	Ti
3	Al
8	V
6	Cr
4	Mo
4	Zr

38-6-44

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