

1 **GENERAL**  
 T-250 (MS 250) is a maraging steel which contains no cobalt. Cobalt has been considered as a strategic element because of uncertain supply coupled with a high and volatile price. The strength of the cobalt-free alloy is essentially equal to that of the conventional cobalt-containing 250 grade maraging steel. This equivalent strength has been obtained by a substantial increase in the titanium content and the alloy properties are significantly influenced by variations in titanium within the specified composition limits. T-250 maintains many of the desirable characteristics of the cobalt-containing alloy including excellent hot- and cold-formability, simple heat treatment with very small dimensional change, high fracture toughness, and good weldability.

Applications to date have been primarily in the production of relatively small rocket motor cases by high-cold-reduction shear forming. Demonstration projects have shown that very large cases (e.g., solid rocket motor case segments for the Space Shuttle) can be successfully produced by the same processes.

1.01 **Commercial Designations**  
 Maraging T-250 and Maraging MS 250.

1.02 **Alternate Designations**  
 Maraging Free-Co.

1.03 **Specifications**  
 MIS 36275 Steel Bar, billet and forgings; AMS 6518 and AMS 6591A.

1.04 **Composition**  
 1.041 Composition, Table 1.04.

1.05 **Heat Treatment**  
 1.051 Homogenize: 1800 F to 2000 F. Used under special circumstances to control retained austenite and dissolve precipitated phases (e.g., see 4.03).  
 1.052 Solution treat (solution anneal or anneal). This treatment is designed to take into solution the strengthening phases which precipitate on aging. It also produces a soft structure and for that reason has been called solution anneal or anneal. Normally 1475 to 1525 F, 1 hr per inch with 1/2 hr minimum. Higher annealing temperatures may be used but can result in large grain sizes (see also Code 1220).

1.053 Aging: 800 F to 1000 F, depending on the strength level desired. Normally 875 to 925 F, 3 to 4 hrs, which gives the highest strengths. (See also Code 1220.)

1.06 **Hardness**  
 1.061 Hardness of 3 inch diameter bars in the annealed condition and after aging, Table 1.061.  
 1.062 Effect of aging temperature on hardness of bar of two titanium contents, Figure 1.062.

1.07 **Forms and Conditions Available**  
 Bar, billet, plate, sheet, forgings and wire.

1.08 **Melting and Casting Practice**  
 Close control of raw material is required to insure low carbon and residual element content. Electric furnace melting plus argon/oxygen decarbonization (AOD) followed by double vacuum melting (VIM/VAR) is recommended.

1.09 **Special Considerations**  
 1.091 Effect of composition. The tensile and yield strength are significantly influenced by variations in the titanium content within the ranges given in the AMS Specifications. Increased titanium raises these strength properties (see Figure 3.0212) and reduces the fracture toughness (see Figure 3.02722). A discussion of the effects of the alloying elements is given in (3).

1.092 Hydrogen embrittlement. The alloy is very susceptible to hydrogen embrittlement. Hydrogen embrittlement studies (8) show that tensile samples with hydrogen contents of about 18 ppm exhibit large reductions in strength and negligible ductility. A high degree of embrittlement is also observed when tested in 10 ksi hydrogen gas (8). Hydrogen is rapidly absorbed into the lattice structure and the alloy should not be used under cathodic conditions. (See also 4.03.)

1.093 Stress corrosion in salt solutions appears to be accelerated by tempering at 850 F and below (8).

2 **PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS**

2.01 **Thermal Properties**

2.011 Melting range: 2615 to 2740 F (20).  
 2.012 Phase changes. There is considerable hysteresis in the thermal expansion on heating and cooling. The exact nature of this behavior will depend on variations in composition within the specified limits. On cooling from a completely austenitic condition, martensite transformation starts at about 400 F and is complete at about 250 F. This martensite is a heavily dislocated lath structure. Aging primarily produces very fine Ni<sub>3</sub>Ti needle-like particles which are coherent with the matrix. Increasing the aging temperature increases the size of these particles. Aging at 900 F results in a uniform distribution of particles which form a Widmanstatten pattern (19).

Reheating the aged material results in austenite reversion starting at about 1000 F. Complete solution of the Ni<sub>3</sub>Ti is normally complete at about 1500 F.

2.012 A uniform shrinkage of about 0.001 in./in. occurs on solution annealing and on aging (2).  
 2.012 Linear expansion curves showing the MS and start of austenite reversion, Figure 2.0121.  
 2.0121 Time-temperature transformation diagram.  
 2.013 Thermal conductivity.  
 2.014 Thermal expansion.  
 2.0141 Mean coefficient of linear thermal expansion, Figure 2.0141.  
 2.015 Specific heat.  
 2.016 Thermal diffusivity.

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18 Ni
3 Mo
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Fe
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2.02	<b>Other Physical Properties</b>	2.0321	$K_{ISCC}$ results for plate and forging exposed to artificial seawater and to 100% R.H. air, Table 2.0321.
2.021	Density: 0.286 lb/in. <sup>3</sup> (19).	2.0322	Crack-growth data for T-250 ring forging in artificial seawater and in 100% R.H. air, Figure 2.0322.
2.022	Electrical properties.	2.0323	$K_{ISCC}$ data showing the effects of applied potential in a 3.5% NaCl solution using a small, step-loaded slow bend test, Table 2.0323.
2.023	Magnetic properties.	2.04	<b>Nuclear Environments</b>
2.024	Emittance.	3	<b>MECHANICAL PROPERTIES</b>
2.025	Damping capacity.	3.01	<b>Specified Mechanical Properties</b> AMS and MIS Specified Mechanical Properties, Table 3.01.
2.03	<b>Chemical Environments</b>	3.02	<b>Mechanical Properties at Room Temperature</b>
2.031	General corrosion. Limited general corrosion information indicates the alloy is superior to 4340 but may be somewhat inferior to the cobalt-containing grade in long-term exposures in salt atmospheres.	3.021	Tension – stress-strain diagrams – tension properties.
2.0311	General corrosion resistance for several alloys, Table 2.0311.	3.0211	Stress strain curve for aged bar, Figure 3.0211.
2.032	Stress corrosion. The tendency for stress corrosion cracking has been measured using a variety of test methods (e.g., ASTM G30 for U-bend specimens, ASTM G38 for C-ring specimens and ASTM G 49 for direct-tension specimens). While these types of tests are useful in comparing the general response of various alloys to a given environment, the results are difficult to use in structural life prediction or in fracture control programs. Preferably, the stress corrosion resistance should be measured using a fracture mechanics approach, which can yield both crack growth rates in a corrosive environment as well as a $K_{ISCC}$ value below which cracks should be stable in this environment. This type of information should be emphasized in evaluation of high strength alloys. Unfortunately, there is, as yet, no ASTM standard method for determining $K_{ISCC}$ and various procedures have been used to determine this value. The information that follows is derived from test methods which are generally acceptable.	3.0212	Effect of titanium content on tensile yield strength, Figure 3.0212.
		3.0213	Tensile properties and hardness of annealed alloy from various sources, Table 3.0213.
		3.0214	Mechanical properties of various forms in the aged condition, Table 3.0214.
		3.0215	Effect of solution temperature and resolution treatment on tensile properties of bar, Figure 3.0215.
		3.0216	Effect of aging temperature on tensile properties of bar of two titanium contents, Figure 3.0216.
		3.0217	Tensile strength properties of bar aged for 3 or 12 hours at various temperatures, Figure 3.0217.
		3.0218	Effect of aging temperature on tensile properties of bar, showing effects of inclusions on ductility, Figure 3.0218.
		3.0219	Effect of cold reduction on the tensile properties of unaged 1.26 percent titanium alloy, Figure 3.0219.
		3.02110	Effect of cold reduction on tensile properties of aged 1.26 percent titanium alloy, Figure 3.02110.
		3.02111	Effect of cold reduction on tensile properties of unaged 1.43 percent titanium alloy, Figure 3.02111.
		3.02112	Effects of cold reduction on tensile properties of aged 1.43 percent titanium alloy, Figure 3.02112.
		3.02113	Tensile properties at various stages of fabrication of a small solid propellant rocket motor case, Table 3.02113.
		3.02114	Tensile properties of a large shear-formed cylinder from a demonstration project, Table 3.02114.
		3.02115	Statistical summary of tensile properties derived from tests on 59 heats, Table 3.02115.
		3.022	Compression – stress-strain diagrams – compression properties.
		3.023	Impact.
		3.0231	Effect of solution temperature and resolution treatment on impact energy for bar, Figure 3.0231.
		3.0232	Effect of aging temperature on impact energy of bar given a double solution treatment, Figure 3.0232.
		3.0233	Effect of test temperature and exposure temperature on the impact energy for bar, Figure 3.0233.
		3.024	Bending.
		3.025	Torsion and shear.
		3.026	Bearing.

T-250 steel, like other high strength steels, is susceptible to stress corrosion cracking in chloride solutions and in high humidity air. The crack growth rates of these steels will increase and the  $K_{ISCC}$  values decrease with increasing strength level and with increasing cathodic potential.

$K_{ISCC}$  values have been reported for both plate and for large ring forgings of T-250 steel. From the limited data available (Table 2.0321), an estimate of  $K_{ISCC}$  is between 18 to 21 ksi  $\sqrt{\text{in.}}$  at a yield-strength level of 250 ksi for alternate immersion in 3.5% NaCl or in 100% R.H. air. This range is somewhat lower than the 29 ksi  $\sqrt{\text{in.}}$  reported for the cobalt-containing grade at the same yield-strength level. It should be noted that the interpretation of these values is complicated by the lack of information on the free corrosion potentials in the media used.

The influence of cathodic potential on the  $K_{ISCC}$  of T-250 at several strength levels is shown in Table 2.0323. As expected, the  $K_{ISCC}$  decreases with the strength level at a constant applied potential. However, it should be noted that the potential of -1.2 volts is a very severe condition unlikely to be encountered during service. Reducing the negative potential to -0.8 volts results in a large increase in the measured values of  $K_{ISCC}$ . To apply data of this type to structural life prediction it would be necessary to know the service potential.

Fe
18 Ni
3 Mo
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Al

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3.027 Stress concentration.  
 3.0271 Effect of stress concentration on the ultimate tensile strength of bar, Figure 3.0271.  
 3.0272 Fracture toughness.  
 3.02721 Plane strain fracture toughness of various forms in the aged condition from several commercial heats, Table 3.02721. 4.02  
 3.02722 Effect of aging temperature on plane strain fracture toughness of bar of two titanium contents, Figure 3.02722.  
 3.028 Combined properties. 4.03  
 3.03 **Mechanical Properties at Various Temperatures** 4.031  
 3..031 Tension – stress-strain diagrams – tensile properties.  
 3.0311 Stress strain curves at elevated temperatures for heavily cold worked and aged alloy, Figure 3.0311.  
 3.0312 Effect of test temperature on tensile properties of bar, Figure 3.0312.  
 3.0313 Effect of test temperature and exposure temperature on tensile properties of solution treated and aged bar, Figure 3.0313.  
 3.033 Compression – stress-strain diagrams – tensile properties.  
 3.034 Bending.  
 3.035 Torsion and shear.  
 3.036 Bearing. 4.032  
 3.037 Stress concentration.  
 3.0371 Fracture toughness.  
 3.038 Combined properties.  
 3.04 **Creep and Creep Rupture Properties**  
 3.05 **Fatigue Properties**  
 3.051 Rotating beam fatigue strength for aged bar given several solution treatments, Figure 3.051.  
 3.052 Fatigue crack growth rate for plate, Figure 3.052.  
 3.06 **Elastic Properties**  
 3.061 Poisson's ratio.  
 3.062 Modulus of elasticity:  $27.64 \times 10^6$  psi (20).  
 3.063 Modulus of rigidity.  
 3.064 Tangent modulus.  
 3.065 Secant modulus.  
 4 **FABRICATION**  
 4.01 **Formability**  
 4.011 Hot working. The alloy has excellent hot workability as evidenced by the tensile data at temperatures above 1400 F (Figure 4.0111). Titanium and molybdenum have a tendency to segregate (banding) and for this reason proper homogenization is required before forging or welding. The required homogenization is normally applied by the alloy producer using proprietary processes. Hot forging and pressing are usually done in the temperature range between 2000 and 2150 F, finishing at 1500 to 1750 F. Finishing above 1750 F can result in undesirably large prior austenite grain size.  
 4.0111 Effect of test temperature on the tensile strength and ductility of bar, Figure 4.0111. 4.0321  
 4.012 Cold forming. In the solution annealed condition very large cold reductions can readily be obtained without cracking (e.g., cold rolling up to 80 reduction without intermediate anneals) (4). Similar 4.0322

results have been obtained in shear forming of large cylinders (see Table 3.02114). Aging of cold-formed material can give tensile strengths above 300 ksi (see Figures 3.02110 and 3.02112).

**Machining and Grinding**  
 In the solution-annealed condition, the machinability is comparable to 4340 at the same hardness level. Dimensional stability is such that machining prior to aging is possible in most applications.

**Joining**  
 General. Present information indicates the alloy is readily weldable using the electron beam or GTA processes. No preheat should be employed beyond that necessary to avoid condensation of moisture and interpass temperatures must be held below the MS with 200 to 250 F being recommended. The alloy is very susceptible to hydrogen embrittlement and care should be taken to employ low-hydrogen filler wire (4 to 5 ppm) and to take suitable precautions to avoid hydrogen contamination from other sources. Weldability studies have not been completed and the information in this chapter should be supplemented by reference to the alloy supplier and/or INCO.  
 Electron beam welding. Large thin-walled shear-formed cylinders (Table 4.0321) have been successfully electron-beam welded with the welds exhibiting 96 percent joint efficiency (compare Table 4.0321 with Table 3.02114). Investigations (5,6,7) of electron beam welding of 3/4 inch thick plate have suggested several practically useful conclusions, some of which require further study. Microfissuring in the HAZ appears to be related to banding in the parent metal and to be associated with dark etching bands in the aged weld HAZ microstructure of plate welded in the 1500 F solution annealed condition (5). The effects of the microfissuring on the tensile properties and fracture toughness of weldments has not been clearly established. However, microfissuring cannot be considered an innocuous condition. Homogenization (preweld treatment) of a banded plate (1.44 percent titanium) at 2000 F resulted in a coarse prior austenite grain size but eliminated the microfissures. However, it produced relatively low impact energies in the HAZ for post-weld solution annealing at 1500 F plus aging, or post-weld aging alone (Table 4.0324). The low impact energies appeared to be associated with precipitations due to the weld thermal cycle. These precipitations were located at prior austenite grain boundaries and were thought to be associated with the coarse grained austenite (5). Postweld homogenization at 2000 F resulted in HAZ impact values essentially equal to those of the weld and increased tensile strength and ductility (see Table 4.0324). A preweld homogenization at 1800 F appeared to be effective in producing satisfactory HAZ impact values and resulted in a much finer grain size than the 2000 F treatment (Table 4.0325).  
 Tensile properties of transverse weld specimens taken from EB-welded large shear-formed cylinders, Table 4.0321.  
 Welding conditions and specimen orientation for electron-beam plate welds, Figure 4.0322.

Fe
18 Ni
3 Mo
Ti
Al

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- 4.0323 Hardness variations across electron-beam welded plate after several postweld heat treatments (see Figure 4.0322 for welding conditions), Figure 4.0323. 6 O'Donnell, D. B., and Bishel, B. A., "Gas Tungsten Welding of INCO MS 250 With Matching Filler Metal", *ibid.* (December 17, 1987).
- 4.0324 Transverse tensile and impact properties of electron-beam welded plate showing the effects of pre- and postweld heat treatments, Table 4.0324. 7 O'Donnell, D. B., "Fusion Welding of MS 250 Using Elevated Post Weld Anneals for Strength Improvements", *ibid.* (May 27, 1988).
- 4.0325 Tensile and impact properties of electron-beam welded plate showing the effects of preweld heat treatments on grain size and HAZ toughness, Table 4.0325. 8 Hibner, E. L., and Crum, J. R., "INCO Alloy MS 250 Corrosion Testing", *ibid.* (May 1, 1988).
- 4.0326 Plane strain fracture toughness of electron beam welds, Table 4.0326. 9 Hickey, C. S., "Mechanical Property Characterization of Vascomax T-250 Maraging Steels: Recent Developments and Applications", R. K. Wilson, Editor, *Minerals, Metals and Materials Society* (1988), p 73.
- 4.033 GTA welding. The alloy may be readily joined by GTA welding in the solution-annealed or in the aged condition. Filler wire of T-250 composition (Table 4.0331) was used to make GTA welds in solution-annealed 7/8 inch thick plate given a postweld treatment of 1500 F 1/2 hr plus a 900 F, 4 hr age (Table 4.0332). Joint efficiencies of approximately 86 percent were obtained. A postweld homogenization of 2000 F or 1800 F (Table 4.0332) resulted in joint efficiencies of approximately 98 percent. Solution treated and aged or aged weld-metal tensile strengths are well below those of the parent metal (Table 4.0332). These low weld-metal strength values are probably associated with retained austenite. Development of high joint efficiencies in GTA welds made in conventionally solution-annealed and aged plate will require the development of a higher strength filler wire. 10 Personal communication from Louie Coffee, INCO, Huntington, WV to W. F. Brown, Jr. (1989).
- 4.0331 Welding conditions for GTA welds in 7/8 inch plate, Table 4.0331. 11 Aerospace Materials Specification, AMS 6519A (April 4, 1987).
- 4.0332 Transverse and all weld-metal tensile properties of GTA welds in 1.36 percent titanium plate showing the effects of pre- and postweld heat treatments, Table 4.0332. 12 Aerospace Materials Specification, AMS 6518 (June 1, 1986).
- 4.04 **Surface Treating** 13 Military Specification: Steel Bar, Billet and Forgings, Cobalt Free Maraging Steel, MIS 36275 (June 17, 1983).
- 4.041 Nitriding. Preliminary information indicates that nitriding should be carried out at 900 F for 10 to 20 hr. This is below the industry standard of 975 F but reflects the overaging of maraging steels which can occur at this temperature for long time exposures (23). 14 Personal communication from A. M. Bayer, Teledyne Vasco to W. F. Brown, Jr. (1989).
- 4.042 Corrosion resistant coatings are required for long time exposures in normal atmospheres. 15 Lampson, F. K., "Free-CO Cobalt Free Maraging Steel Stinger Motor Case Fabrication Development", The Marquart Company, U.S. Army Missile Command, TR RK-CR-83-12 (1983).
- 16 Lampson, F. K., "Manufacturing Methods Interim Report for Cobalt-Free (Free-CO) Maraging Steel Rocket Motor Components", The Marquart Co., U.S. Army Missile Command, TR RK-CR-83-14 (1983).
- 17 Burnette, T. D., and Lampson, F. K., "Fabrication and Delivery of Cobalt Free (Free-CO) Maraging Steel Rocket Motor Components", The Marquart Co., U.S. Army Missile Command, TR RK-CR-84-5 (1984).
- 18 Lampson, F. K., and Wood, J. L., *ibid.*, TR RK-CR-83-12 (1982).
- 19 Siebein, K. N., "Microstructural Characterization of a Cobalt Free Maraging Steel, Vascomax T-250", U.S. Army Materials Technology Laboratory, Report MTL-TR-87-12 (1987).
- 20 INCO Alloy MS 250, INCO Alloys International, Huntington, WV (1986).
- 21 VascoMax T-200/T-250/T-300, Data Sheets, Teledyne Vasco, Latrobe, PA (1985).
- 22 Personal communication from W. B. Austin, Hercules Inc., McGregor, TX (November 14, 1989).
- 23 Martin, J. M., "Nitriding INCO Alloy MS 250", INCO International Inc., Huntington, WV (September 1, 1986).
- 24 Scanlon, J. F., and Hickey, C. F., "Stress Corrosion Cracking of Maraging Steels", U.S. Army Materials Technology Laboratory, Watertown, MA; presented at 1989 Tri-Service Corrosion Conference.
- 25 Emanuelson, R. H., "Stress Corrosion Cracking Characteristics and Constant Extension Rate Tests on T-250 Maraging Steel and D6AC Low Alloy Steel", projects sponsored by Thiokol Corp., Wasatch Operations, at Babcock & Wilcox, Alliance Research Center (1988).
- 26 LRA Laboratories, Irvine, CA, "Reports on Stress Corrosion Cracking of T-250 Maraging Steel and D6AC Steel", prepared for Thiokol Corp., Wasatch Operations (1988).

#### REFERENCES

- 1 Henery, R. J., "New Concepts in Maraging Steels", Teledyne Vasco, Latrobe, PA (1982).
- 2 VascoMax T-250 Data Sheet, *ibid.* (1985).
- 3 Floreen, S., and Bayer, A. W., "Development and Characterization of Cobalt Free Maraging Steels", AIME Met. Trans., to be published (1990).
- 4 Coffee, L. G., and Smith, D. F., "Processing, Metallurgical and Physical Property Characteristics of INCO Alloy MS 250", Laboratory Report, INCO Alloys International, Huntington, WV (May 12, 1988).
- 5 O'Donnell, D. B., and Bishel, B. A., "Electron Beam Weld Fracture Toughness and Weldability Progress Report on INCO Alloy MS 250", Laboratory Report, INCO Alloys International, Huntington, WV (May 12, 1988).

27 Personal communication from Eldon Bott, Thiokol Corp., Brigham City, UT, to W. F. Brown, Jr., January 1990.

28 Raymond, L., and Crumly, W. R., "Accelerated Low Cost Test Method for Measuring the Susceptibility of HY-Steels to Hydrogen Embrittlement", p 477, Proceedings of the First International Conference on Current Solutions to Hydrogen Problems in Steels, ASM, Washington, DC (November, 1982).

Fe
18 Ni
3 Mo
Ti
Al

T-250 Maraging

Alloy	T-250 Maraging			
	Composition			
	Weight, percent			
Form	Bars, Forgings, Tubing and Rings		Sheet, Strip and Plate(a)	
	Min	Max	Min	Max
Carbon	-	0.03	-	0.03
Manganese	-	0.10	-	0.10
Silicon	-	0.10	-	0.10
Phosphorous	-	0.010	-	0.010
Sulphur	-	0.010	-	0.010
Nickel	18.00	20.00	18.00	20.00
Molybdenum	2.75	3.25	2.75	3.25
Titanium	1.30	1.45	1.20	1.60
Aluminum	0.05	0.15	0.05	0.15
Chromium	-	0.50	-	0.50
Cobalt	-	0.50	-	0.50
Copper	-	0.50	-	0.50

(a) Same as MIS 36275 (13) for bar, billet and forgings except no copper is specified in MIS 36275.

Alloy	T-250 Maraging	
Form	3-inch Diameter Bar	
Number of Bars	6	6
Heat Treatment	1500 F, 1 hr, AC	1500 F, 1 hr, AC 900 F, 3 hr
Hardness, HRC		
Mean	29.4	49.5
Std Dev	0.71	0.45

TABLE 1.061. HARDNESS OF 3 INCH DIAMETER BARS IN ANNEALED CONDITION AND AFTER AGING (16, TABLE 3)

TABLE 1.04. AMS AND MIS SPECIFICATIONS FOR VARIOUS FORMS (11,12)

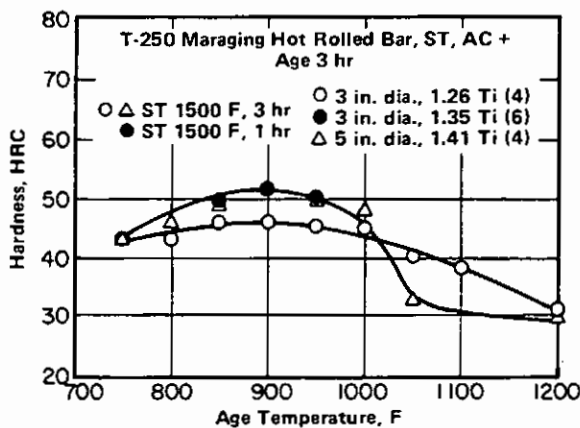


FIGURE 1.062. EFFECT OF AGING TEMPERATURE ON HARDNESS OF BAR OF TWO TITANIUM CONTENTS (4, TABLE 3), (9, TABLE 2)

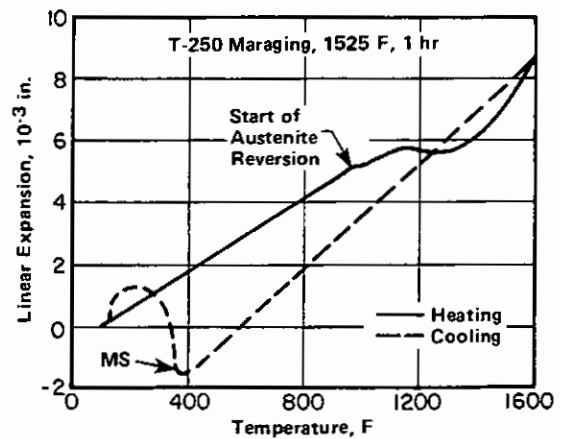


FIGURE 2.0121. LINEAR EXPANSION CURVES SHOWING THE MS AND START OF AUSTENITE REVERSION (4, FIGURE 4)

Fe
18 Ni
3 Mo
Ti
Al

T-250  
Maraging

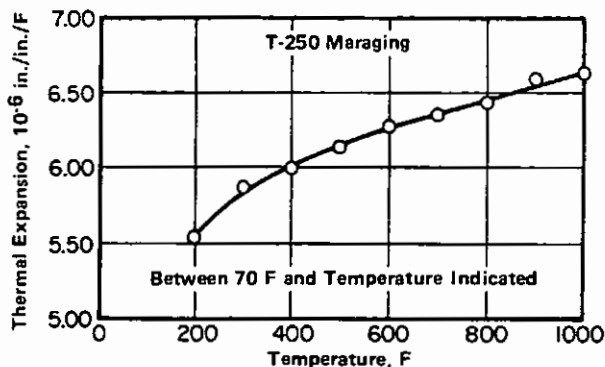


FIGURE 2.0141. MEAN COEFFICIENT OF LINEAR THERMAL EXPANSION (20, TABLE 3)

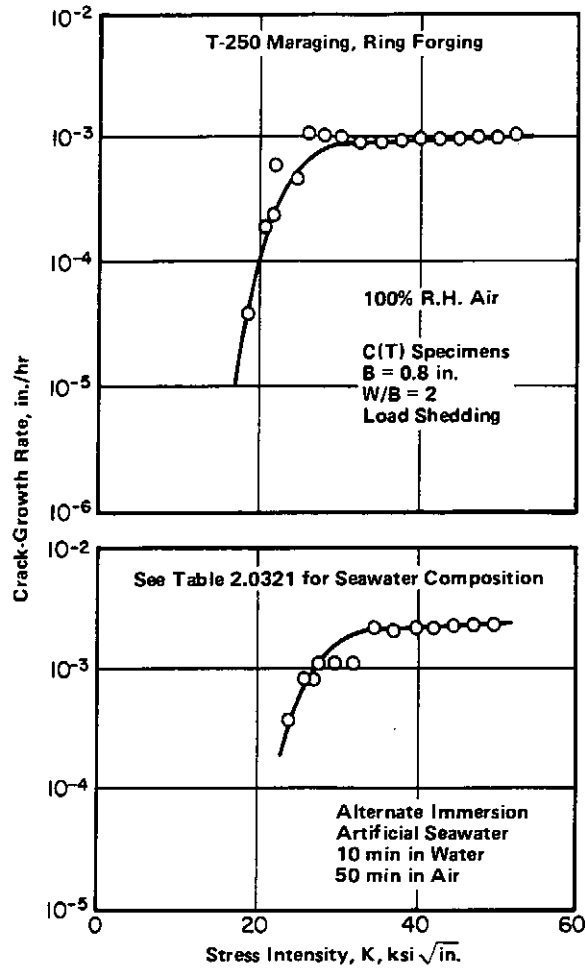
Form	1/16 inch Sheet								
Environment	3.5 percent NaCl, 75 F, for 500 hr			Sea Water-Splash/Spray for 150 Days			Kurie Beach (25 meters) for 153 Days		
Alloy <sup>(a)</sup>	T-250	18Ni 300	4340	T-250	18Ni 300	4340	T-250	18Ni 300	4340
Corrosion Rate, mils/yr	1.11	1.29	1.58	0.62	0.38	1.41	0.99	0.47	1.77

TABLE 2.0311. GENERAL CORROSION RESISTANCE FOR SEVERAL ALLOYS (8, TABLES 2 AND 3)

Alloy	T-250		C-250 <sup>(a)</sup>	
	(24)	(25)	(25)	(24)
Source	3/4 inch Plate	Ring Forging 156 in. OD x 2-1/2 in. Wall	Ring Forging 156 in. OD x 2-1/2 in. Wall	5/8 inch Plate
Heat Treat	1500 F, 1 hr, AC + 900 F, 4 hr	1500 F, 1 hr, AC + 910 F, 6 hr	1500 F, 1 hr, AC + 910 F, 6 hr	1500 F, 1 hr, AC + 900 F, 3 hr
Specimen Thickness, in.	1/2	0.8	0.8	1/2
F <sub>tu</sub> , ksi	-	267	267	-
F <sub>ty</sub> , ksi	249	250	250	250
Method	CB <sup>(b)</sup>	CT Load Shedding <sup>(c)</sup>	CT Load Shedding <sup>(c)</sup>	CB <sup>(b)</sup>
Environment	3.5% NaCl	Alt. Immersion 10 min Seawater 50 min Air <sup>(d)</sup>	100% R.H.	3.5% NaCl
Duration, hr	1000	-	-	1000
K <sub>Isc</sub> , ksi √in.	21	18 to 20 <sup>(e)</sup>	Approx. 20 <sup>(e)</sup>	29

- (a) Cobalt containing maraging steel.
- (b) Cantilever bend constant load.
- (c) Compact tension; computer load control.
- (d) Artificial Seawater: 41.953 gm/liter of ASTM D1141-52 artificial sea salt.
- (e) See also Figure 2.0322.

TABLE 2.0321. K<sub>Isc</sub> RESULTS FOR PLATE AND FORGING EXPOSED TO ARTIFICIAL SEAWATER AND TO 100% R.H. AIR (24,25)



Fe
18 Ni
3 Mo
Ti
Al

T-250  
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FIGURE 2.0322. CRACK-GROWTH DATA FOR T-250 RING FORGING IN ARTIFICIAL SEAWATER AND IN 100% R.H. AIR (25)

Alloy	T-250 Maraging					
Test Method	Step Load Slow Bend <sup>(a)</sup>					
Test Environment	3.5% NaCl					
Form	1/2 and 1 inch Plate (T)					Ring Forging (T) (See Table 2.0321)
Solution Treat	1500 F, 1 hr, AC + Age					
Age	3 hr, 1200 F + 900 F, 3 hr	1000 F, 3 hr	950 F, 3 hr	900 F, 3 hr	910 F, 6 hr	910 F, 6 hr
F <sub>ty</sub> , ksi	192	234	242	242	264	264
Applied Potential, volts	-1.2	-1.2	-1.2	-0.8	-1.2	-0.8
K <sub>Isc</sub> , ksi√in.	30	14	12	33	10	22

(a) Charpy-size specimen with sharp notch and deep side grooves (see Ref. 28).

TABLE 2.0323. K<sub>Isc</sub> DATA SHOWING THE EFFECTS OF APPLIED POTENTIALS IN A 3.5% NaCl SOLUTION USING A SMALL STEP LOADED SLOW BEND TEST (26)

Fe
18 Ni
3 Mo
Ti
Al

T-250  
Maraging

Alloy		T-250 Maraging			
Source		AMS 6591A (11)		AMS 6518 (12)	
Condition		1475-1725 F, 1-2 hr, AC + 890-910 F, 4-6 hr		1475-1525 F, AC + 890-910 F, 4-6 hr	
Form		Bars, Forgings, Tubing and Rings		Sheet, Strip and Plate	
Thickness, in.		<4		4-10 inc. <sup>(c)</sup>	
Direction		L	T	L	T
F <sub>tu</sub> , ksi		255	255	250	250
F <sub>ty</sub> , ksi		245	245	240	240
RA, percent		45	35	30	20
e, percent		6	4	5	3
F <sub>tu</sub> , ksi, Annealed		160 (Max) <sup>(b)</sup>			
Hardness, Aged		48 HRC (Min)			
Hardness, Annealed		321 HBN <sup>(b)</sup>			

- (a) Specified elongation varies widely with thickness and gage length; see Specification for details.
- (b) Thickness 0.5 inch or greater.
- (c) Same as MIS 36275 (13) except MIS gives e = 6 percent for L and does not specify RA.

TABLE 3.01. AMS AND MIS SPECIFIED MECHANICAL PROPERTIES

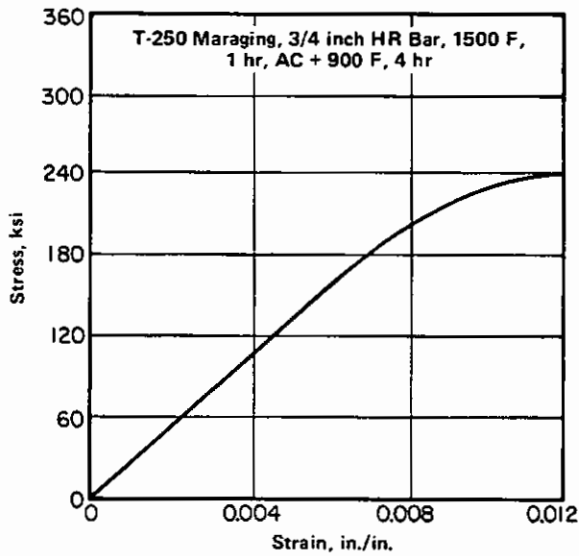


FIGURE 3.0211. STRESS STRAIN CURVE FOR AGED BAR (14)

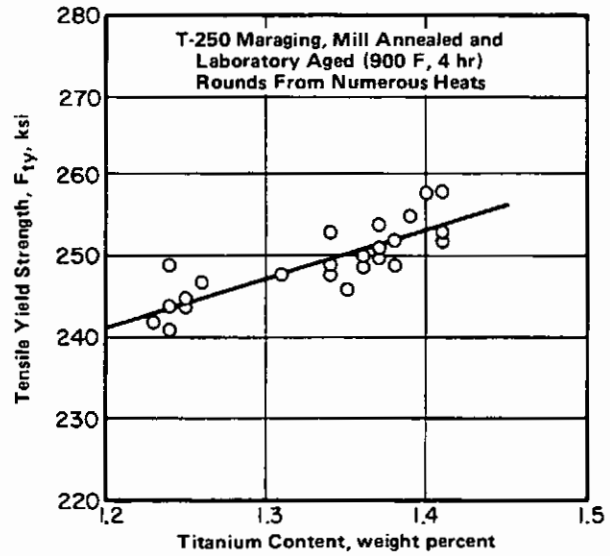


FIGURE 3.0212. EFFECT OF TITANIUM CONTENT ON TENSILE YIELD STRENGTH (4, FIGURE 3)

Alloy	T-250 Maraging		
Form	All		
Condition	Solution Anneal (1500 F)		
Reference	(2)	(21)	(20)
Hardness, HRC	27/29	30/32	32
F <sub>tu</sub> , ksi	140	140	155
F <sub>ty</sub> , ksi	100	95	110
e, percent	21	16	16
RA, percent	92	70	71

Fe
18 Ni
3 Mo
Ti
Al

T-250 Maraging

TABLE 3.0213. TENSILE PROPERTIES AND HARDNESS OF ANNEALED ALLOY FROM VARIOUS SOURCES

Alloy	T-250 Maraging							
Condition	Solution Annealed + 900 F, 3 hr							
Form	5/8 in. Rd.	2 in. Rd.	3 in. Rd.	6 in. Sq.	6 in. Sq.	0.2 in. Sheet	0.25 in. Sheet	
Direction	Long.	Long.	Long.	Long.	Trans.	Trans.	Long.	
Hardness, HRC	51	51	50	51	50	50	51	
F <sub>tu</sub> , ksi	266	259	266	260	260	262	260	
F <sub>ty</sub> , ksi	258	253	260	254	254	254	252	
e, percent	12	11	10	11	9	7	8	
RA, percent	59	58	52	56	46	54	62	

TABLE 3.0214. MECHANICAL PROPERTIES OF VARIOUS FORMS IN THE AGED CONDITION (21)

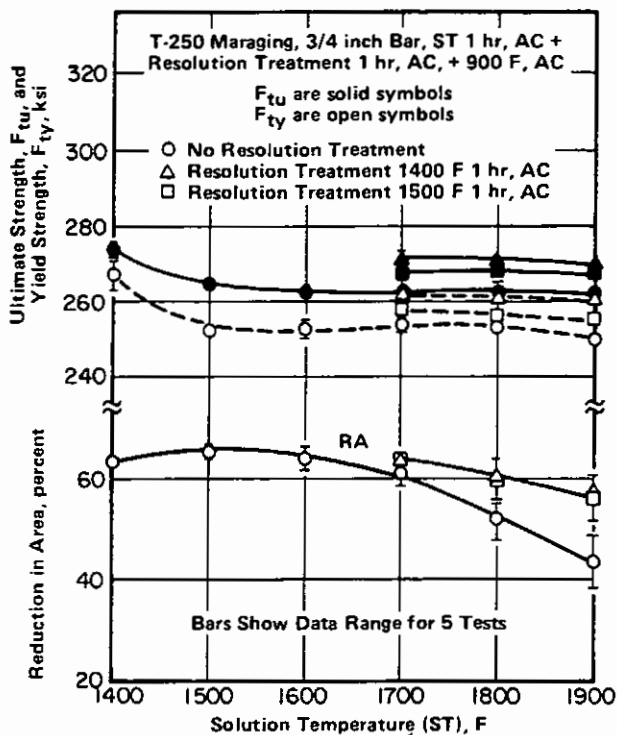


FIGURE 3.0215. EFFECT OF SOLUTION TEMPERATURE AND RESOLUTION TREATMENT ON TENSILE PROPERTIES OF BAR (1, APP. 4 AND 5)

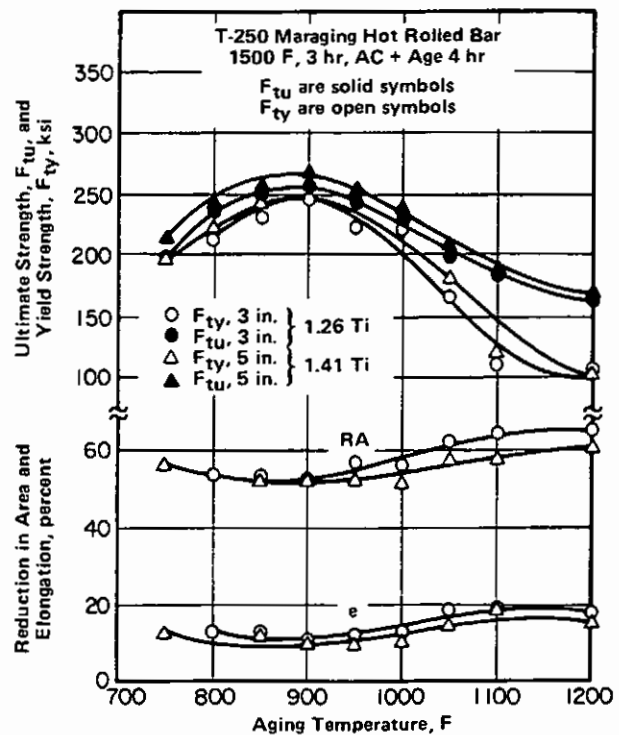


FIGURE 3.0216. EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF BAR OF TWO TITANIUM CONTENTS (4, TABLE 3)

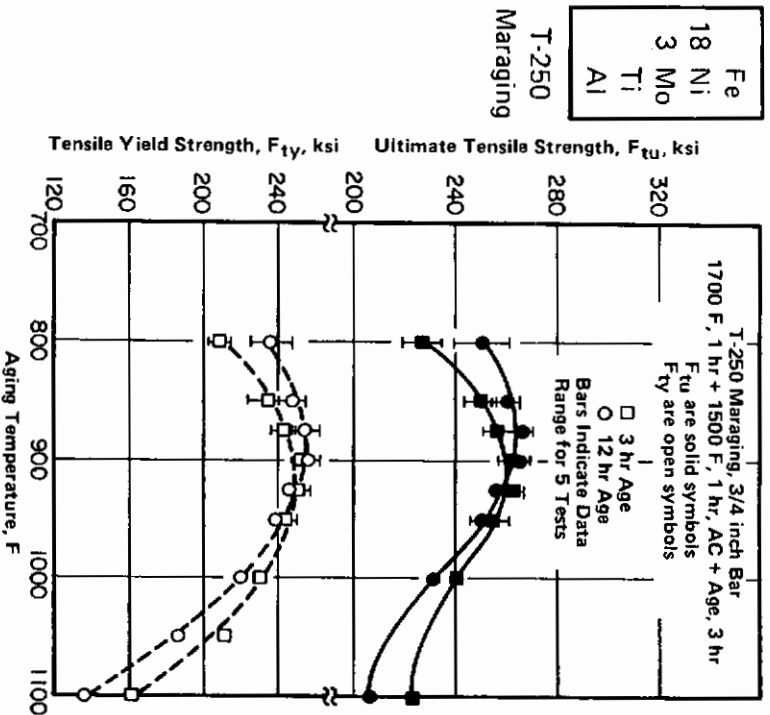


FIGURE 3.0217. TENSILE STRENGTH PROPERTIES OF BAR AGED FOR 3 OR 12 HOURS AT VARIOUS TEMPERATURES (1, APP. 1)

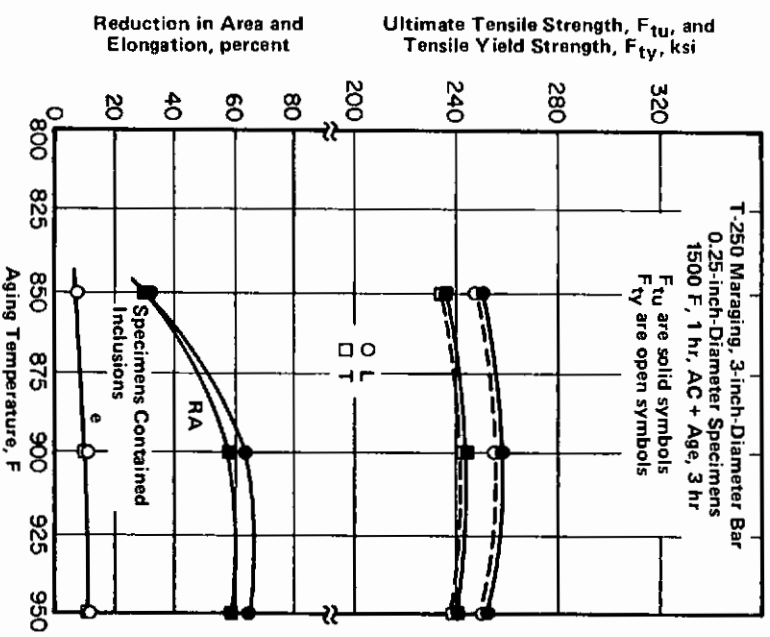


FIGURE 3.0218. EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF BAR, SHOWING EFFECTS OF INCLUSIONS ON DUCTILITY (9, TABLE 6)

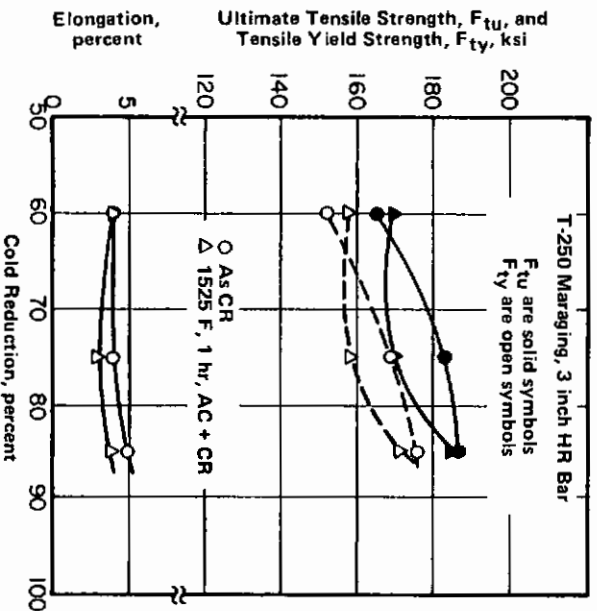


FIGURE 3.0219. EFFECT OF COLD REDUCTION ON TENSILE PROPERTIES OF UNAGED 1.26 PERCENT TITANIUM ALLOY (10)

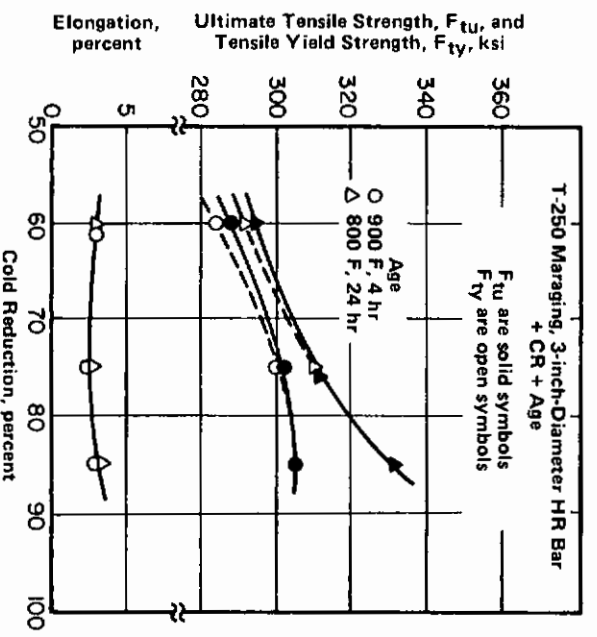


FIGURE 3.02110. EFFECT OF COLD REDUCTION ON TENSILE PROPERTIES OF AGED 1.26 PERCENT TITANIUM ALLOY (10)

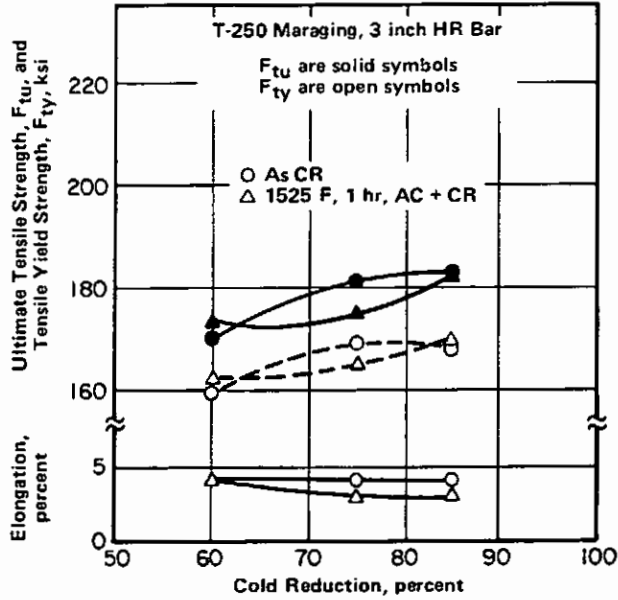


FIGURE 3.02111. EFFECT OF COLD REDUCTION ON TENSILE PROPERTIES OF UNAGED 1.43 PERCENT TITANIUM ALLOY (10)

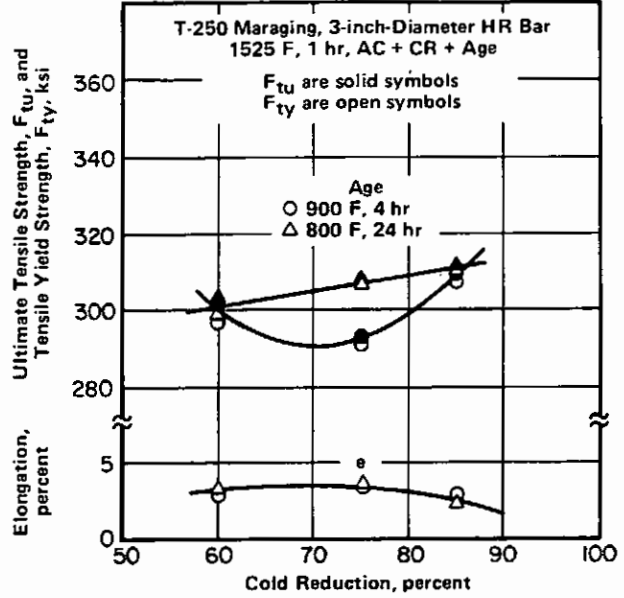


FIGURE 3.02112. EFFECTS OF COLD REDUCTION ON TENSILE PROPERTIES OF AGED 1.43 PERCENT TITANIUM ALLOY (10)

Fe  
18 Ni  
3 Mo  
Ti  
Al  
T-250  
Maraging

Alloy	T-250 Maraging			
	As Received	Forged	2nd Shear Form <sup>(b)</sup>	Final Shear Form
Form	2 in. Dia Bar	0.65	0.175	0.023
Thickness, in. <sup>(a)</sup>				
Heat Treat <sup>(c)</sup>	ST + 900 F, 4 hr	ST	52% Reduction ST	75% Reduction 900 F, 4 hr
$F_{ty}$ , ksi				
No. of Tests	4	2	1	7
Mean	253	122	124	296
Std Dev	2.39	-	-	7.27
$F_{tu}$ , ksi				
No. of Tests	4	2	2	-
Mean	261	154	174	-
Std Dev	2.12	-	-	-
$e$ , percent				
No. of Tests	4	-	2	5
Mean	11.4	18	15	2.2
Std Dev	0.48	-	-	0.45
RA, percent				
No. of Tests	4	2	2	-
Mean	56	55	55	-
Std Dev	1.97	-	-	-

(a) Except as indicated, thickness refers to cylindrical wall of motor case.

(b) Shear preform had 0.36 inch wall.

(c) ST = solution treat 1500 F, 1 hr, AC.

TABLE 3.02113. TENSILE PROPERTIES AT VARIOUS STAGES OF FABRICATION OF A SMALL SOLID PROPELLANT ROCKET MOTOR CASE (12, FIGURE 10 AND TABLE 5)

Fe
18 Ni
3 Mo
Ti
Al

T-250  
Maraging

Alloy	T-250 Maraging			
Form	Shear-Formed Cylinders			
Fabrication	8 inch RCS Forged and Punched at 2150 F + Ring Rolled (16 inch OD x 1/8 inch ID x 14 inch Long) Finish at 1750 F + 1650 F, 1 hr, AC, Machine Shear Preform With 0.45 inch Wall + Spin to 22-33 inch Long With Thickness Indicated. Specimens Longitudinal.			
Thickness, in.	0.100	0.119	0.137	0.143
Shear Form Reduction, percent	76	74	77	68
Heat Treatment After Shear Form	1500 F, 1 hr, AC, + 900 F, 4 hr	900 F, 4 hr	1500 F, 1 hr, AC, 900 F, 4 hr	900 F, 4 hr
F <sub>ty</sub> , ksi Mean(a)	259	268	259	266
Std Dev	1.6	3 Tests	1.9	0.8
F <sub>tu</sub> , ksi Mean	268	275	269	273
Std Dev	2.1	1.3	0.96	0.5
e, percent Mean	6	4.3	7.8	6
Std Dev	0	0.5	0.5	0

(a) Four tests unless indicated.

TABLE 3.02114. TENSILE PROPERTIES OF A LARGE SHEAR-FORMED CYLINDER FROM A DEMONSTRATION PROJECT (18, TABLE 12)

Alloy	T-250 Maraging			
Form	3 inch Diameter Rounds			
Heat Treatment	1500 F, 1 hr, AC + 900 F, 3 hr			
No. of Heats	59			
	Avg	s(a)	Min	Max
F <sub>tu</sub> , ksi	257.8	4.6	250	265.8
F <sub>ty</sub> , ksi	251.0	4.6	232.8	260.2
Elongation, percent	11.2	0.7	10	13.0
Reduction of Area, percent	56.9	2.0	52	61.0

(a) S: sample standard deviation.

TABLE 3.02115. STATISTICAL SUMMARY OF TENSILE PROPERTIES DERIVED FROM TESTS ON 59 HEATS (27)

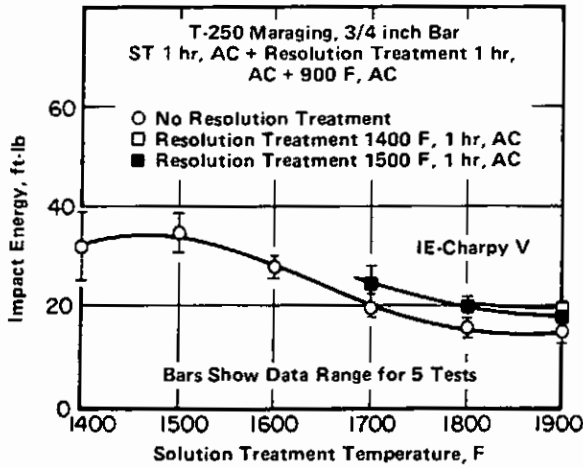


FIGURE 3.0231. EFFECT OF SOLUTION TREATMENT TEMPERATURE AND RESOLUTION TREATMENT ON IMPACT ENERGY FOR BAR (1, APP. 4 AND 5)

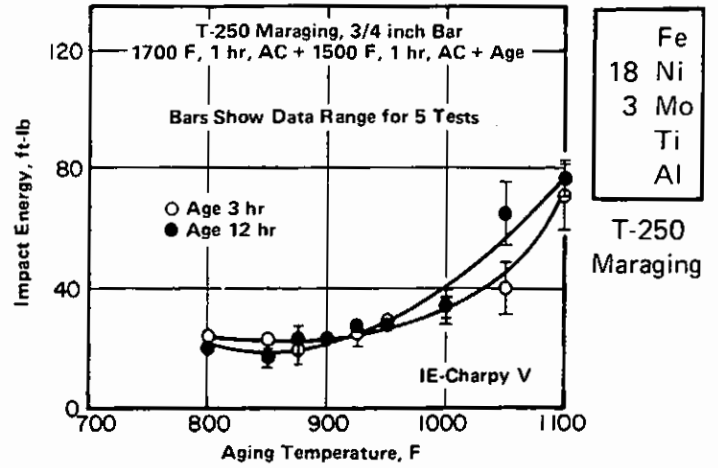


FIGURE 3.0232. EFFECT OF AGING TEMPERATURE ON IMPACT ENERGY OF BAR GIVEN A DOUBLE SOLUTION TREATMENT (1, APP. 1 AND 3)

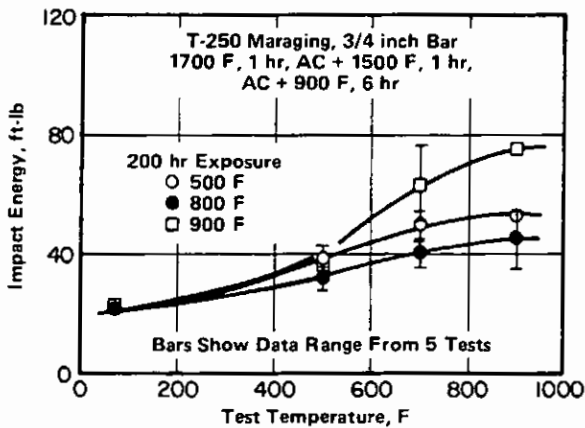


FIGURE 3.0233. EFFECT OF TEST TEMPERATURE AND EXPOSURE TEMPERATURE ON IMPACT ENERGY FOR BAR (1, APP. 6)

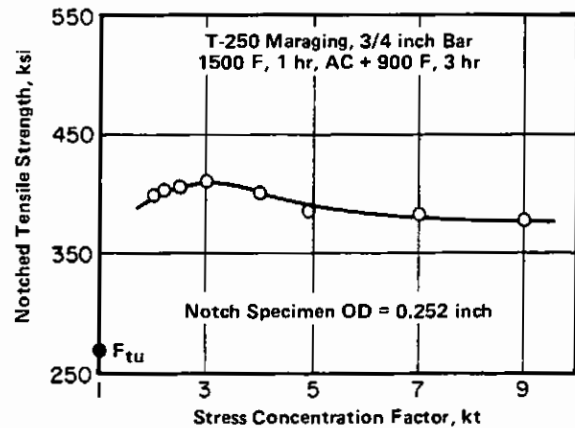


FIGURE 3.0271. EFFECT OF STRESS CONCENTRATION ON THE ULTIMATE TENSILE STRENGTH OF BAR (21, FIGURE 2)

Alloy	T-250 Maraging				
Condition	Bend Specimens; 1500 F, 1 hr, AC + 900 F, 3 hr				
Form	0.25 in. Sheet	0.5 in. Plate	2 in. Round	3 in. Round	8 in. Square
$K_{Ic}$ , ksi $\sqrt{\text{in.}}$	89	99	112	98	95

TABLE 3.02721. PLANE STRAIN FRACTURE TOUGHNESS OF VARIOUS FORMS IN THE AGED CONDITION FROM SEVERAL COMMERCIAL HEATS (21, FIGURE 7)

Fe  
18 Ni  
3 Mo  
Ti  
Al  
T-250  
Maraging

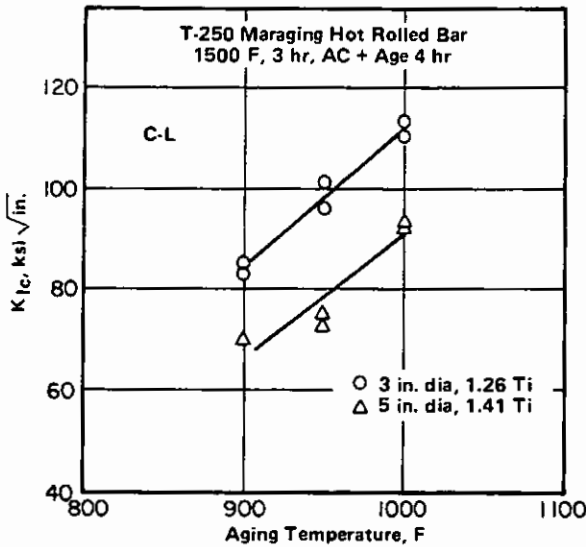


FIGURE 3.0272. EFFECT OF AGING TEMPERATURE ON PLANE STRAIN FRACTURE TOUGHNESS OF BAR OF TWO TITANIUM CONTENTS (4, TABLE 3)

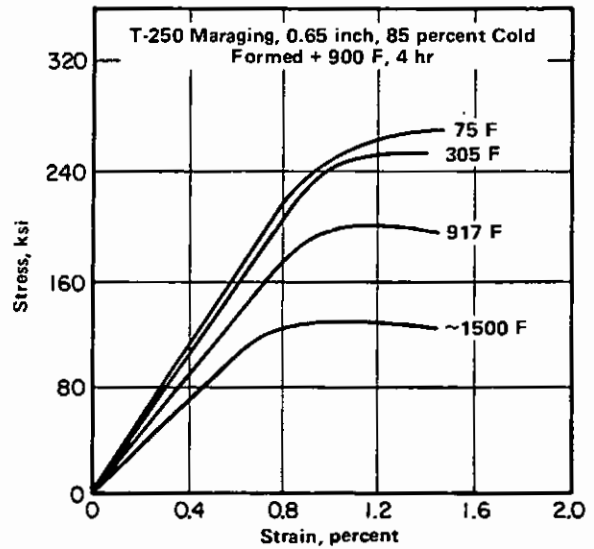


FIGURE 3.0311. STRESS-STRAIN CURVES AT ELEVATED TEMPERATURES FOR HEAVILY COLD WORKED AND AGED ALLOY (22)

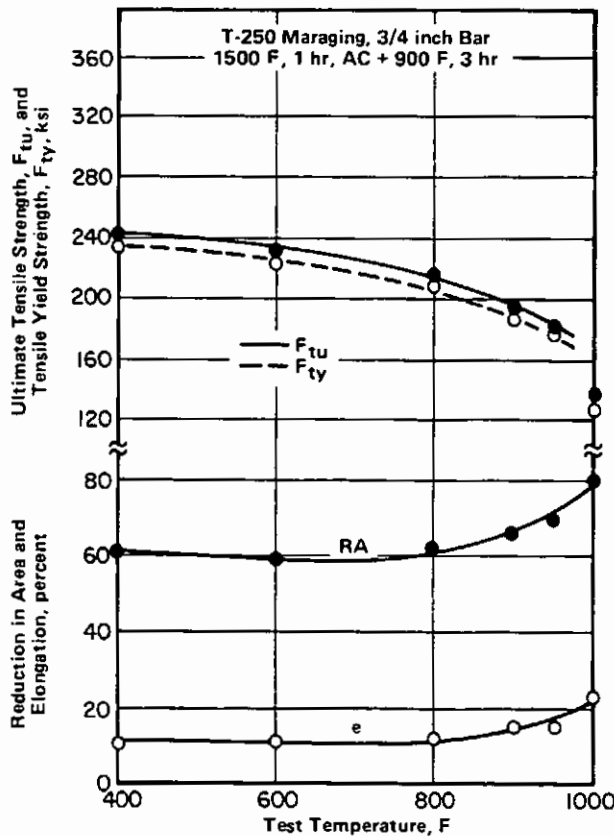


FIGURE 3.0312. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF BAR (21, FIGURE 1)

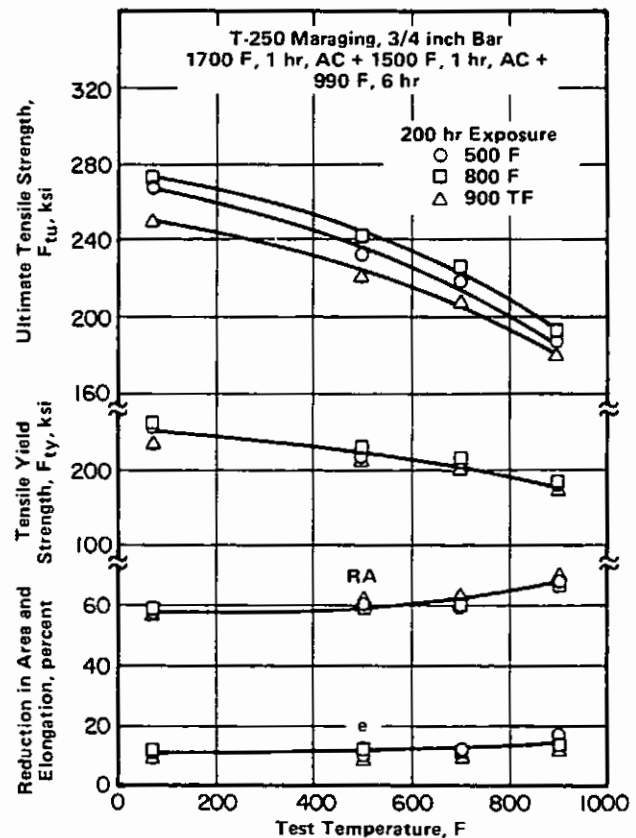


FIGURE 3.0313. EFFECT OF TEST TEMPERATURE AND EXPOSURE TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED AND AGED BAR (1, APP. 6)

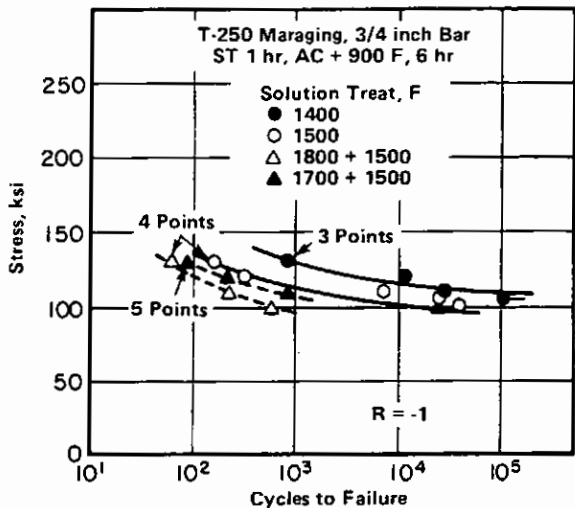
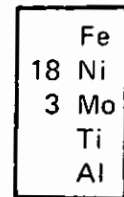


FIGURE 3.051. ROTATING BEAM FATIGUE STRENGTH FOR AGED BAR GIVEN SEVERAL SOLUTION TREATMENTS (14)



T-250  
Maraging

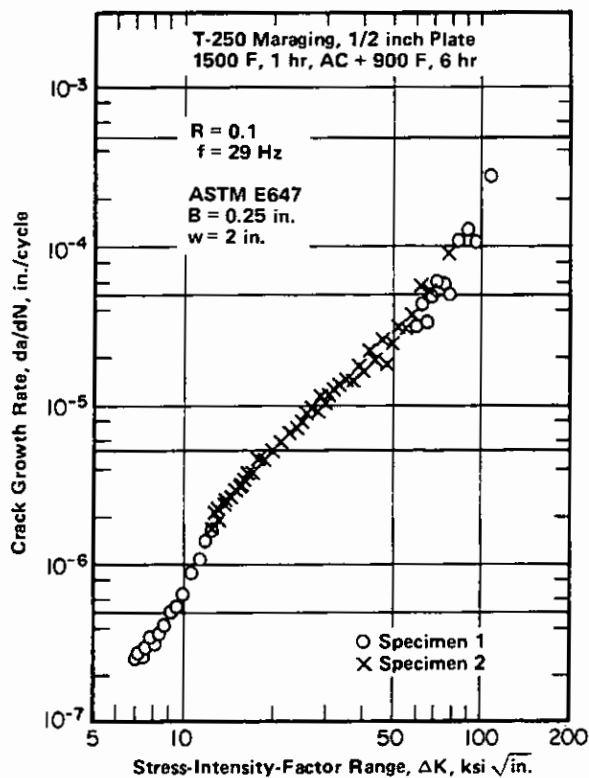


FIGURE 3.052. FATIGUE CRACK GROWTH RATE FOR PLATE (27)

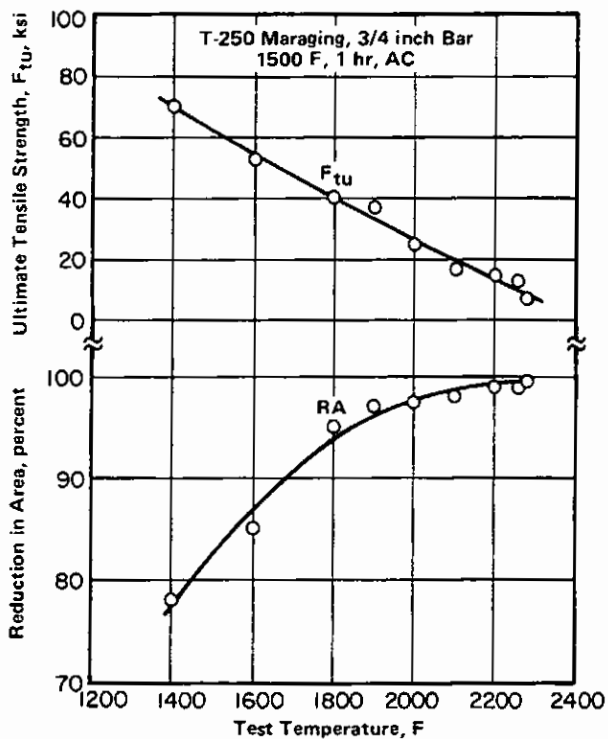


FIGURE 4.0111. EFFECT OF TEST TEMPERATURE ON THE TENSILE STRENGTH AND DUCTILITY OF BAR (4, FIGURE 1)

Fe
18 Ni
3 Mo
Ti
Al

T-250  
Maraging

Alloy		T-250 Maraging			
Form	Transverse EB Weld Specimens From Shear Formed Cylinders				
Fabrication	See Table 3.02114 for Fabrication and Parent Metal Properties				
Shear Forming Reduction, percent	76	74	77	68	
Thickness, in.	0.100	0.119	0.137	0.149	
Heat Treat After Weld	1500 F, 1 hr, AC, 900 F, 4 hr	900 F, 4 hr	1500 F, 1 hr, AC, 900 F, 4 hr	900 F, 4 hr	
Failure Location	Weld area	-	Weld area	Weld area	
F <sub>ty</sub> , ksi					
Mean(a)	249	259	249	257	
Std Dev	0.8	2.4	0.5	1.4	
F <sub>tu</sub> , ksi					
Mean	268	263	257	261	
Std Dev	2.1	2.4	0.5	1.7	
e, percent					
Mean	6	2	1.8	2.2	
Std Dev	0	0	0.5	0.5	

(a) Four tests per condition.

TABLE 4.0321. TENSILE PROPERTIES OF TRANSVERSE WELD SPECIMENS TAKEN FROM EB-WELDED LARGE SHEAR-FORMED CYLINDERS (18, TABLE 12)

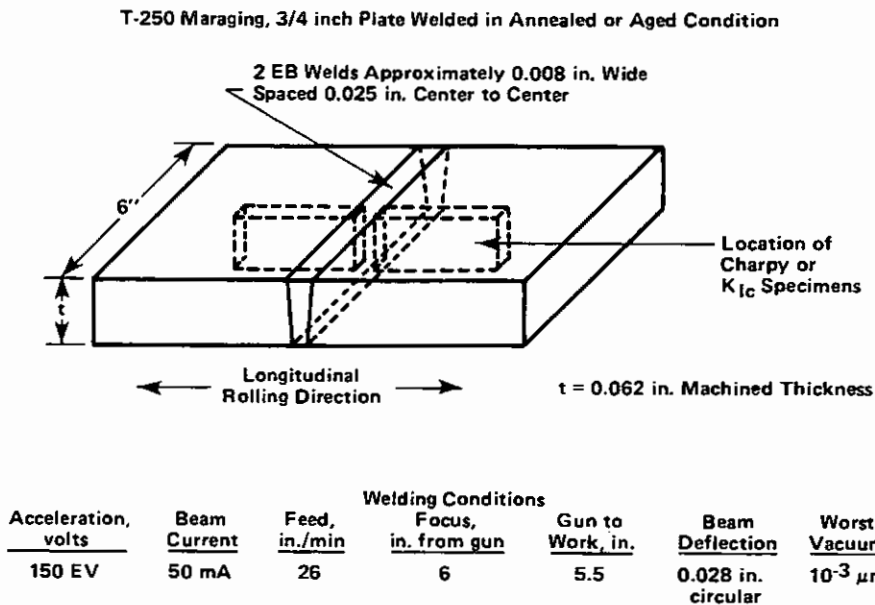
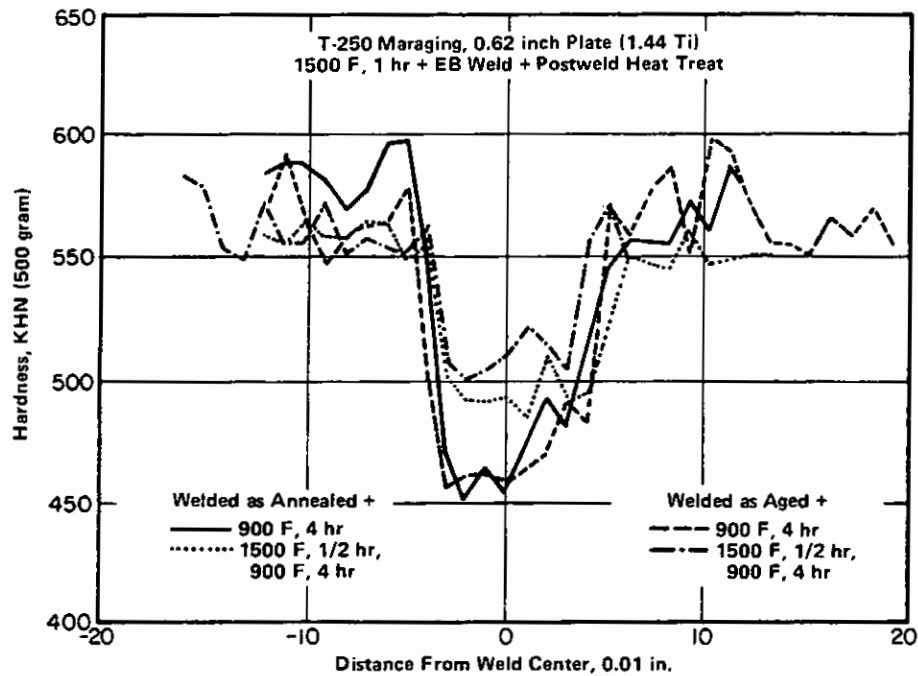


FIGURE 4.0322. WELDING CONDITIONS AND SPECIMEN ORIENTATION FOR ELECTRON-BEAM PLATE WELDS (5)



Fe  
18 Ni  
3 Mo  
Ti  
Al

T-250  
Maraging

FIGURE 4.0323. HARDNESS VARIATION ACROSS EB WELDED PLATE AFTER SEVERAL POSTWELD HEAT TREATMENTS (SEE FIGURE 4.0322 FOR WELDING CONDITIONS) (5)

Alloy	T-250 Maraging									
Form	3/4 inch Plate With Double Electron Beam Welds									
1.44 Ti Parent Metal	Heat Treated: 1500 F, 1/2 hr + 900 F, 4 to 8 hr									
Tensile Properties	$F_{tu} = 271$ ksi, $F_{ty} = 258$ ksi, $e = 12$ percent, $RA = 56$ percent									
Welding Conditions	See Figure 4.0322									
Preweld Heat Treat	2000 F, 1 hr, AC <sup>(a)</sup>								1500 F, 1/2 hr, AC <sup>(b)</sup>	
Postweld Heat Treat	1500 F, 1/2 hr, AC + 900 F, 4 hr		900 F, 4 hr		2000 F, 1 hr, AC + 900 F, 4 hr		2000 F, 1 hr, AC, 1500 F, 1/2 hr, AC, 900 F, 4 hr		1500 F, 1/2 hr, AC + 900 F, 4 hr	
Location	Weld	HAZ	Weld	HAZ	Weld	HAZ	Weld	HAZ	Weld	HAZ
Charpy V, ft-lb <sup>(c,d)</sup>	16	10	15	8	13	14	15	15	15	16
	19	7	15	9	14	14	15	17	16	17
$F_{tu}$ , ksi <sup>(e)</sup>	238		232		268		271		250	
$F_{ty}$ , ksi	228		224		251		258		241	
e, percent	6		6		10		10		6	
RA, percent	37		36		50		48		36	

- (a) Prior austenite G.S. approximately 2.5.
- (b) Prior austenite G.S. approximately 8.
- (c) Charpy values from 1.36 percent Ti heat.
- (d) For Charpy specimen orientation see Figure 4.0322.
- (e) Tensile values from 1.47 percent Ti heat.

TABLE 4.0324. TRANSVERSE TENSILE AND IMPACT PROPERTIES OF ELECTRON-BEAM WELDED PLATE SHOWING THE EFFECTS OF PRE- AND POSTWELD HEAT TREATMENTS (5, TABLES 3 AND 4)

Fe
18 Ni
3 Mo
Ti
Al

T-250  
Maraging

Alloy		T-250 Maraging					
Form		3/4 inch Plate With Double Electron Beam Welds					
Welding Conditions		See Figure 4.0322					
Preweld Heat Treat		1500 F, 1/2 hr, AC		2000 F, 1 hr, AC		1800 F, 1 hr, AC	
Approx. Prior Austenite G.S.		8		2.5		4-5	
Postweld Heat Treat		1500 F, 1/2 hr, AC, 900 F, 4 hr		1500 F, 1/2 hr, AC, 900 F, 4 hr		1500 F, 1 hr, AC, 900 F, 4 hr	
Location		Weld	HAZ	Weld	HAZ	Weld	HAZ
Charpy V, ft-lb(b,c)		15	16	16	10	13.7(a)	18.5(a)
		16	17	19	7		
F <sub>tu</sub> , ksi(d,e)		250		238			
F <sub>ty</sub> , ksi		241		228			
e, percent		6		6			
RA, percent		36		37			

- (a) Average of three test results.  
 (b) Charpy values from a 1.36 percent Ti heat.  
 (c) For Charpy specimen orientation, see Figure 4.0322.  
 (d) Tensile values from a 1.44 percent Ti heat.  
 (e) For base metal properties, see Table 4.0324.

TABLE 4.0325. TENSILE AND IMPACT PROPERTIES OF ELECTRON-BEAM WELDED PLATE SHOWING THE EFFECTS OF PREWELD HEAT TREATMENTS ON GRAIN SIZE AND HAZ TOUGHNESS (7, TABLE 3)

Alloy		T-250 Maraging							
Form		Electron Beam Welds in 0.62 inch 1.44 percent Ti Plate							
Welding Conditions and Specimen Orientation		See Figure 4.0322							
Preweld Heat Treat		1500 F, 1/2 hr, AC							
Postweld Heat Treat		900 F, 4 hr		1500 F, 1/2 hr, AC + 900 F, 4 hr		1000 F, 4 hr		1500 F, 1/2 hr, AC + 1000 F, 4 hr	
		Weld	HAZ	Weld	HAZ	Weld	HAZ	Weld	HAZ
F <sub>ty</sub> , ksi		235	-	241	-	-	-	-	-
K <sub>Ic</sub> , ksi $\sqrt{\text{in.}}$		90	83	67	68	(a)	79	(a)	86
		76	72	73	66	(a)	88	(a)	82

- (a) Toughness too high for specimen thickness.

TABLE 4.0326. PLANE STRAIN FRACTURE TOUGHNESS OF ELECTRON BEAM WELDS (5, TABLES 3 AND 5)

Alloy	T-250 Maraging
Filler Wire Composition, weight percent	C-0.01, Ti-1.44, Mo-3.03 (Hydrogen-13 ppm)
Polarity	Straight
Electrode	1/8 inch Tungsten 1 percent Thoriated
Current, amps	180-210
Filler Metal	0.093 inch diameter MS 250
Shielding Gas	Argon (30 ft <sup>3</sup> /hr)
Arc Length, V	13-16
Maximum Interpass Temp	220-250 F

Fe
18 Ni
3 Mo
Ti
Al

T-250 Maraging

TABLE 4.0331. WELDING CONDITIONS FOR GTA WELDS IN 7/8 INCH PLATE (6, TABLE 4)

Alloy	T-250 Maraging				
Form	7/8 inch Plate, GTA Welds				
1.36% Ti Parent Metal	Heat Treated: 1500 F, 1/2 hr + 900 F, 4 hr				
Tensile Properties	F <sub>TU</sub> = 276 ksi, F <sub>TY</sub> = 265 ksi, e = 7.5 percent, RA = 38 percent				
Welding Conditions	See Table 4.0331				
Specimen Type	Transverse to Weld Unless Noted				
Preweld Heat Treat	1500 F, 1 hr, AC				
Postweld Heat Treat	None	900 F, 4 hr	1500 F, 1/2 hr, AC + 900 F, 4 hr	2000 F, 1 hr, AC + 900 F, 4 hr	1800 F, 1 hr, AC + 900 F, 4 hr
F <sub>TU</sub> , ksi	163	237	233	272	267
F <sub>TY</sub> , ksi	143	226	226	255	253
e, percent	5	7	2(a)	7.5	7.5
RA, percent	52	36	12	-	-
Preweld Heat Treat	900 F, 4 hr				
F <sub>TU</sub> , ksi	203	234	234		
F <sub>TY</sub> , ksi	169	221	226		
e, percent	7.5	7.5	7		
RA, percent	34	36	38		
Specimen Type	All Weld Metal				
F <sub>TU</sub> , ksi	193	228	234		
F <sub>TY</sub> , ksi	121	198	213		
e, percent	9.5	13	11		
RA, percent	26	49	45		

(a) Small defect on fracture surface.

TABLE 4.0332. TRANSVERSE AND ALL WELD METAL TENSILE PROPERTIES OF GTA WELDS IN 1.36 PERCENT TITANIUM PLATE SHOWING THE EFFECTS OF PRE- AND POSTWELD HEAT TREATMENTS (6, TABLE 2)

