

1. **GENERAL**
AF 1410 is a further development, under Air Force sponsorship, of the Fe-0.11C-10Ni-8Co-2Cr-1Mo advanced submarine hull steel which has a typical room temperature yield strength and plane strain fracture toughness of 200 ksi and 190 ksi-in.^{1/2} respectively. By raising the Co and C content, the F_{ty} has been increased to a typical of 235 ksi. As might be expected this increase in the strength was accompanied by some loss in fracture toughness, the typical value being about 140 ksi-in.^{1/2} However, this combination of strength and toughness exceeds that of other commercially available steels, and the alloy has been considered as a replacement for titanium in certain aircraft parts. Presently available information shows that AF 1410 is air hardening in sections 3 inch thick, and from metallurgical considerations, satisfactory hardening would be expected in even thicker sections. VIM-VAR melting is presently the preferred practice and care must be taken to keep impurity elements at very low levels. Weldability is good using the CW-GTA process providing high purity wire is used and oxygen contamination is avoided. The K_{IC} value of welds has not been determined. However, from the results of tests on surface cracked specimens, subsized plane strain fracture toughness specimens and Charpy V impact values, it appears that the fracture toughness of the fusion zone and of the heat affected zone is comparable to that of the parent metal. Information on stress corrosion cracking is incomplete and no definite value can be assigned to K_{Isc} for either parent metal or weldments.
- 1.01 Commercial Designation
Unimach 1410
- 1.02 Alternate Designation
AF 1410
- 1.03 Specifications
- 1.031 Rockwell International Corporation, B-1 Division Specification LB0160-184
- 1.04 Composition
Table 1.04
- 1.05 Heat Treatment (See also 4.0313)
General. The steel is austenitized and aged. Quenching from the austenitizing temperature produces a highly dislocated lath martensite having a relatively low yield strength and a high toughness as measured by the Charpy V impact energy (Fig. 3.0235). Aging produces a complex series of changes in the carbide structure which result in a combination of martensite tempering and secondary hardening due to aging. This secondary hardening produces a maximum in the tensile strength at about 900 F (5 hour age time) and a minimum in the impact energy at about 800 F. In a temperature range between 800 and 1000 F the impact energy exhibits a maximum. At aging temperatures above 1000 F both the tensile strength and the impact energy

- decrease rather rapidly (Figs. 3.0234 and 3.0235).
- This steel is subject to austenite reversion during aging. At normal aging temperatures the retained austenite is generally less than one percent by volume. At aging temperatures of 1000 F and higher, large amounts of austenite will be formed (Fig. 2.0121) and these will weaken the matrix.
- 1.051 **Normalize:** 1625 to 1650 F, 1 hour per inch, A. C.
- 1.052 Both single and double austenitizing treatments have been employed. Double austenitizing appears to produce a higher toughness (Table 1.058 and 3.02724). Both the tensile strength and impact energy appear to exhibit a rather flat maximum between 1500 and 1600 F (Figs. 3.0213 and 3.0232).
- 1.0521 **Single austenitizing.** 1475 to 1525 F, 1 hour per inch + 1475 to 1525 F, 1 hour per inch.
- 1.053 **Quenching.** Experience to date indicates that air cooling from the austenitizing temperature will produce tensile strength, toughness and fatigue strength essentially equal to oil or water quenching in section sizes up to 3 inches (Tables 1.057, 1.059 and 3.051).
- 1.054 **Refrigeration.** A refrigeration treatment of -100 F is sometimes applied in order to reduce the amount of retained austenite. There is no evidence that such a treatment has any substantial effect on the mechanical properties (Table 1.057 and 1.058).
- 1.055 **Aging.** 950 F, 4 hours A.C.
- 1.056 **Premachining.** As received material may be given a 1250 F, 8 hour treatment to increase machinability. This treatment is normally followed by austenitizing and aging. (Figs. 3.0216 and 3.0233)
- 1.057 **Tensile strength properties and impact energy for VIM-VAR melt plate quenched in air, oil or water following austenitizing.** Table 1.057
- 1.058 **Effect of various heat treatments on tensile and impact properties of 5/8 inch and 3 inch VIM-VAR Melt Plate.** Table 1.058
- 1.059 **Tensile properties, impact energy and fracture toughness of VIM-VAR Melt 2 inch plate quenched in different media and given a pre-machining heat treatment.** Table 1.059
- 1.06 Hardness
- 1.061 **End quenched hardenability.** Fig. 1.061
- 1.062 **Effect of aging time and temperature on hardness of VIM-VAR Melt Plate.** Fig. 1.062
- 1.07 Forms and Conditions Available
- 1.071 **Sheet, bars, forgings and forging stock.** All products as hot finished, overaged (1250 F, 8 hours A. C.) or to specified heat treatment. (14)
- 1.08 Melting and Casting Practice
- 1.081 **Melting Practice.** Vacuum arc remelting of a vacuum induction melted electrode (VIM-VAR melting). Attempts (1 to 5) (10) have been made to produce this steel by other

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0.16	C
14	Co
10	Ni
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1	Mo

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- melting practices with particular emphasis on electroslag remelting of a vacuum induction melted ingot (VIM-ESR). None of these practices were able to produce material with as high a toughness, as measured by impact energy, as VIM-VAR melting (Tables 1.0814 through 1.08110 also compare Figs. 3.0234 and 3.0236). Variations in the ESR slag composition (Table 1.0812) were investigated in an attempt to improve the toughness and reduce directionality but these were unsuccessful (compare Table 1.0814 with VIM-VAR in Table 1.0815 and compare Table 1.0816 with 1.0817). ESR melts contained excessive amounts of oxygen (Table 1.0813) which contributed to the reduced impact energy of the ESR melted material as compared with VIM-VAR melting. This excess oxygen arises from a slag metal reaction which is apparently impossible to prevent. Normally, oxygen produced in this manner is removed by the addition of deoxidizing elements such as Al and Si. However, in this steel such elements are intentionally controlled to low values in order to achieve high fracture toughness. In addition, ESR melted plate material exhibited slits which apparently result from microvoids in the ingot which are not welded during processing. These microvoids arise from a reaction between alloy carbon and oxygen. The total non metallic content of ESR material was considerably higher than VIM or VFM-VAR melts (Fig. 3.0238).
- 1.0811 Plate and ESR slag compositions for 2000 lb. VIM melt remelted into ESR ingots. Table 1.0811
- 1.0812 Slag compositions used in making ESR remelts. Table 1.0812
- 1.0813 Oxygen levels in ingots produced by various melting practices. Table 1.0813
- 1.0814 Tensile and impact properties of 1-1/4 and 1.4 inch thick plate from VIM-ESR melts. Table 1.0814
- 1.0815 Tensile and impact properties of 1-1/4 inch thick plate from various melting practices. Table 1.0815
- 1.0816 Tensile and impact properties of 3 inch thick plate from VIM and VIM-VAR Melts. Table 1.0816
- 1.0817 Tensile and impact properties of 3 inch thick plate from various melting practices. Table 1.0817
- 1.0818 Tensile and impact properties of 3 inch thick plate from various ADO melting practices. Table 1.0818
- 1.0819 Tensile and impact properties of 1-1/2 and 1-3/4 inch thick upset disks from various melting practices. Table 1.0819
- 1.08110 Tensile and impact properties of 6 inch thick upset disks from various melting practices. Table 1.08110
- 1.09 Special Considerations (See also 1.05 and 4.03)
- 1.091 The toughness of this alloy is especially sensitive to the content of impurity elements including those normally used to deoxidize steel. These elements act to reduce the toughness and are closely controlled by good melting practice. (Figs. 1.094 and 3.0238) Aging temperature in excess of 1000 F result in a loss in toughness and should be avoided (Figs. 3.0234 and 3.0235). Long time exposure to temperatures above about 500 F results in a loss in impact energy. (Fig. 3.0237) The toughness as measured by the impact energy decreases substantially at subzero temperatures and is low at cryogenic temperatures. (Figs. 3.0331 and 3.0332) Effect of sulphur and oxygen content on the impact energy of VIM-VAR and VIM-ESR Melt Alloy. Fig. 1.094
- 1.092
- 1.093
- 1.094
2. PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS
- 2.01 Thermal Properties
- 2.011 Melting range. Liquidus = 2592 F, Solidus = 2462 F
- 2.012 Phase Changes. (14)
 $A_{c1} = 1160 - 1161 F$
 $A_{c3} = 1512 - 1523 F$
 $M_s = 635 \text{ to } 640 F$
 $M_f = 320 \text{ to } 350 F$
- 2.0121 Time temperature transformation diagrams. (Fig. 2.0121)
- 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
- 2.02 Other Physical Properties
- 2.021 Density 0.283 lbs. per cu. inch.
- 2.022 Electrical properties
- 2.023 Magnetic properties
- 2.024 Emittance
- 2.025 Damping capacity
- 2.03 Chemical Environments
- 2.031 General corrosion resistance. The alloy has a general corrosion resistance similar to the maraging steels. It is more resistant than HY 180 and D6ac steels. (7) Fatigue crack growth rates are essentially the same for parent metal tested in air, 3-1/2 percent salt water or in sump tank water. (Figs. 3.056 to 3.059) The fusion zone of CW-GTA welds appear to exhibit a somewhat lower crack growth rate in air and in 3.5 percent NaCl than that characteristic of parent metal. (Compare Figs. 4.03122 and 4.03123 with Fig. 3.056)
- 2.032 Attempts to measure K_{Isc} have been hampered by crack branching. Values as low as 30 ksi-in.^{1/2} have been reported for full heat treated plate in 3.5 percent NaCl. This value is probably quite conservative and considerable additional data will be needed to establish a useful value of K_{Isc} for this alloy.
- 2.04 Nuclear Environments

3.	MECHANICAL PROPERTIES	3.0234	Effect of aging temperature on impact energy of VIM-VAR plate. Fig. 3.0234
3.01	<u>Specified Mechanical Properties</u>	3.0235	Effect of aging temperature on impact energy and yield strength of VIM-VAR plate. Fig. 3.0235
3.011	Fabricators mechanical property specification. Table 3.011	3.0236	Effect of aging temperature on impact energy of three VIM-ESR melts. Fig. 3.0236
3.02	<u>Mechanical Properties at Room Temperature</u>	3.0237	Effect of exposure to elevated temperatures on room temperature Charpy V impact energy of VIM-VAR melt plate. Fig. 3.2037
3.021	<u>Tension-stress/strain diagrams-tension properties.</u>	3.0238	Charpy impact energy for plate as function of total non-metallics as determined with quantitative television microscope. Fig. 3.0238
3.0211	Effect of aging temperature on the tension stress-strain curves of VIM-VAR plate. Fig. 3.0211	3.024	Bending
3.0212	Effect of aging time on tension stress-strain curves of VIM-VAR plate. Fig. 3.0212	3.025	Torsion and shear
3.0213	Effect of austenitizing temperature and refrigeration treatment on tensile strength properties of VIM-VAR melt plate WQ from the austenitizing temperature. Fig. 3.0213	3.026	Bearing
3.0214	Effect of austenitizing temperature and refrigeration treatment on tensile strength properties of VIM-VAR melt plate air cooled from the austenitizing temperature. Figure 3.0214	3.027	Stress concentration
3.0215	Effect of aging time and temperature on tensile properties of VIM-VAR 5/8 inch plate. Fig. 3.0215	3.0271	Notch properties
3.0216	Effect of aging temperature and time on tensile properties of VIM-VAR melt 1 inch plate given a premachining heat treatment. Fig. 3.0216	3.0272	Fracture toughness
3.0217	Effect of exposure to elevated temperature on room temperature tensile properties. Fig. 3.0217	3.02721	General. This alloy was developed to have high fracture toughness. The developmental program goal specified $K_{Ic} = 115 \text{ ksi-in.}^{1/2}$. This goal was exceeded and typical values are in excess of $130 \text{ ksi-in.}^{1/2}$ at room temperature and greater than $100 \text{ ksi-in.}^{1/2}$ at -65 F. Maintaining a high level of fracture toughness requires close attention to alloy purity. (See 1.09)
3.0218	Wing sweep actuator VIM-VAR forging showing test locations and mechanical test specimens cut from these areas. Fig. 3.0218	3.02722	Plane strain fracture toughness of VIM-VAR melt plate tested in two directions at room and low temperature. Table 3.02722
3.0219	Tensile and impact properties for single and double austenitized specimens cut from VIM-VAR melt wing sweep actuator forging. Table 3.0219	3.02723	Plane strain fracture toughness of 3 inch VIM-VAR melt plate. Table 3.02723
3.02110	Tensile and impact properties of single and double austenitized refrigerated specimens cut from VIM-VAR wing sweep actuator forging. Table 3.02110	3.02724	Plane strain fracture toughness values for single and double austenitized specimens cut from VIM-VAR melt wing sweep actuator forging. Table 3.02724
3.02111	Effect of aging temperature on the tensile properties of three VIM-ESR melts. Fig. 3.02111	3.028	Combined properties
3.022	<u>Compression-stress/strain diagrams-compression properties.</u>	3.03	<u>Mechanical Properties at Various Temperatures</u>
3.0221	Compressive yield strength and elastic modulus for single and double austenitized specimens cut from VIM-VAR melt wing sweep actuator forging. Table 3.0221	3.031	<u>Tension-stress/strain diagrams-tension properties</u>
3.0222	Effect of temperature on compression yield strength of VIM-VAR melt plate. See Fig. 3.0322	3.0311	Effect of test temperature on tensile properties of 3/4 inch and 2 inch VIM-VAR melt plate. Fig. 3.0311
3.023	<u>Impact</u>	3.0312	Effect of test temperature on tensile properties of VIM-VAR melt plate exposed at the test temperature. Fig. 3.0312
3.0231	Effect of austenitizing temperatures on impact energy of VIM-VAR melt plate. Fig. 3.0231	3.0313	Effect of low and elevated temperatures on tensile properties of VIM-VAR melt plate. Fig. 3.0313
3.0232	Effect of austenitizing temperature and refrigeration treatment on impact energy of VIM-VAR melt plate air cooled or water quenched from the austenitizing temperature. Fig. 3.0232	3.032	Compression-stress/strain diagrams-compression properties
3.0233	Effect of aging temperature and time on impact energy of VIM-VAR melt plate given a premachining heat treatment. Fig. 3.0233	3.0322	Effect of temperature on the compressive yield strength of VIM-VAR melt plate. Fig. 3.0322
		3.033	Impact
		3.0331	Effect of test temperature on impact energy of three VIM-ESR melts. Fig. 3.0331
		3.0332	Effect of low test temperatures on impact energy of a 300 lb. VIM-VAR melt plate. Fig. 3.0332
		3.034	Bending
		3.035	Torsion and shear
		3.0351	Effect of temperature on shear strength of VIM-VAR melt plate. Fig. 3.0351
		3.036	Bearing
		3.0361	Effect of temperature on bearing yield strength of VIM-VAR melt plate. Fig. 3.0361

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3.0362	Effect of temperature on bearing ultimate strength of VIM-VAR melt plate. Fig. 3.0362
3.037	Stress concentration
3.0371	Notch properties
3.0372	Fracture toughness (See 3.0272)
3.038	Combined properties
3.04	<u>Creep and Creep Rupture Properties</u>
3.041	Creep rupture curve at 800 F for VIM-VAR melt plate. Fig. 3.041
3.05	<u>Fatigue</u>
3.051	Axial load S-N data for VIM-VAR melt plate given a premachining heat treatment and then water or air quenched following austenitizing. Fig. 3.051
3.052	S-N curves at room temperature for VIM-VAR melt plate tested in the transverse direction at several stress concentration factors for R = -1. Fig. 3.052
3.053	S-N curve at room temperature for VIM-VAR melt plate tested in the transverse direction at several stress concentration factors for R = 0.5. Fig. 3.053
3.054	S-N curve at room temperature for VIM-VAR melt plate for several stress concentration factors at R = 0.05. Fig. 3.054
3.055	S-N curve for VIM-VAR melt plate for specimens with ground or ground and shot peened surfaces. Fig. 3.055
3.056	Fatigue crack growth rate for VIM-VAR melt 2-inch plate given a premachining-heat treatment and then water on air quenched following austenitizing. Fig. 3.056
3.057	Fatigue crack growth rate at two frequencies and two R ratios for VIM-VAR plate at room temperature in low humidity air. Fig. 3.057
3.058	Fatigue crack growth rate at two frequencies and two R ratios for VIM-VAR melt plate at room temperature in 3-1/2 percent salt water. Fig. 3.058
3.059	Fatigue crack growth rate at two frequencies for VIM-VAR melt plate at room temperature in sump tank water. Fig. 3.059
3.0510	Fatigue crack growth rate for VIM-VAR plate at -65 F. Fig. 3.0510
3.0511	Effect of stress ratio on fatigue life of various cracked specimens subjected to constant amplitude loading. Fig. 3.0511
3.06	<u>Elastic Properties</u>
3.061	Poisson's ratio
3.062	Modulus of elasticity
3.0621	Elastic modulus in tension for VIM-VAR 1-1/4 inch plate. Table 3.0621 Elastic modulus in compression (see TABLE 3.0221)
3.063	Modulus of rigidity
3.064	Tangent modulus
3.065	Secant modulus

4. FABRICATION

4.01 Forming

General. Only a very limited amount of information is available concerning the forming characteristics of this alloy. One large forging (Fig. 3.0218) has been produced. This closed die forging was forged to final shape after three blocking operations. Semi-finished parts were heated to about 1800 F before final forging. Dies were preheated to 900 F. Forging pressure was 28,000 tons. (6)

4.02 Machining and Grinding

Machinability should be essentially the same as for the maraging steels. A premachining heat treatment of 1250 F, 8 hours A. C. is recommended. (See 1.05)

4.03 Joining4.031 Welding

4.0311

General. The weldment strength and toughness are dependent on the content of impurity elements and on the welding parameters which directly influence the microstructure of the fusion zone (FZ) and the heat affected zone (HAZ). Impurity elements include S, P, O, N, H, and the deoxidizers Al and Si. These elements can form inclusions and second phase particles in the FZ which may act to nucleate voids at relatively low matrix strain. The improvement in FZ impact energy associated with a reduction in impurity elements is evident when comparing CW-GTA welds made with different fillers as shown in Table 4.03112. Gaseous elements can be introduced during welding and these may be in part responsible for the relatively low impact energies shown in Table 4.03112 for the HW-GTA and CW-PA welds. Microstructural changes in the FZ and HAZ during welding are complex and can have a strong influence on the strength and toughness. An excellent description of these changes is given in (12). The final microstructure is a function of the heat input, number of passes and the post weld aging treatment. High heat inputs tend to produce a relatively coarse FZ structure. The as deposited structure is refined by the thermal reversals associated with subsequent passes. These thermal reversals also produce increasing amounts of austenite and temper the carbide structure in both HAZ and FZ. Multiple pass welds may contain as much as eight percent retained austenite after post weld aging. There is no direct evidence that this austenite has a deleterious effect on the toughness. However, the influence of retained austenite will depend on its composition, form and location. Generally, austenite will reduce the strength of the matrix and efforts should be made to keep the amount below six percent by volume.

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The data available indicate that properly made welds will have smooth tensile and yield strengths somewhat lower than the parent plate (e.g. compare Fig. 3.0216 with Table 4.0318 and see also Fig. 4.03110). On the basis of Charpy V impact energy the toughness of the FZ and HAZ are comparable to the parent plate (e.g. compare Table 4.03113 with Fig. 3.0232). Plane strain fracture toughness (K_{Ic}) values for GTA welds are not available. K_Q values ranged from 97 to 139 ksi-in.^{1/2} for specimens having large irregularities in their fatigue crack fronts (12). The rather low K_{Ic} values for electron beam welds (Table 4.03115) may be associated with a lack of stability in the electron beam which produced a heterogeneous solidification structure. The conventional fatigue of some CW-GTA welds appears to be substantially below that of the plate parent material (e. g. compare Figs. 4.03117 and 4.03118 with Figs. 3.052 to 3.054). This difference may be in part due to the fact that the weld data in question was obtained from specimens of rectangular crosssection while the parent metal data was obtained from specimens of rectangular crosssection while the parent metal data was obtained from specimens with a circular crosssection and in part due to subsurface porosity which characterized the fusion zone of the welded specimens. Welding Conditions: To date the most satisfactory welds in terms of strength and toughness have been made using the CW-GTA process. Typical welding parameters are shown in Table 4.0316. No preheat is necessary and the maximum heat input should not exceed 50 KJ/inch. ment work.

4.0312 Post Weld Heat Treatment: The selection of a post weld age is complicated by the thermal reversals experienced in multipass welding. These produce an aging response different than that characteristic of the parent metal, (compare Fig. 3.0216 with Fig. 4.03110) and may require tailoring the post weld aging to the welding parameters. Present recommendations are for a 950 F, four hour age. (12)

4.0314 Filler wire compositions used in certain weld property studies. Table 4.0314

4.0315 Filler wire compositions used in certain weld property studies. Table 4.0315

4.0316 Weld parameters for automatic pulsed arc CW-GTA welding. Table 4.0316

4.0317 Alternate immersion stress corrosion data in 3.5 percent NaCl for CW-GTA welds in VIM-VAR plate. Table 4.0317

4.0318 Tensile properties at room temperature and -65 F for manual CW-GTA plate butt welds and repair welds with and without bead removal. Table 4.0318

4.0319 Hardness and impact energy as a function of distance from the weld centerline for CW-GTA welds in VIM-VAR plate. Fig. 4.0319

- 4.03110 Fusion zone tensile properties of VIM-VAR melt plate CW-GTA welded with several filler wires and aged for various times at 900 to 950 F. Fig. 4.03110
- 4.03111 Fusion zone charpy impact energy of VIM-VAR plate CW-GTA welded using several filler wires and aged for various times at 900 and 950 F. Fig. 4.03111
- 4.03112 Effects of heat input and filler wire impurities on fusion zone impact energy. Table 4.03112
- 4.03113 Impact energy for GTA weld metal and heat affected zone in VIM-VAR melt 1/2 inch plate. Table 4.03113
- 4.03114 Effect of temperature on fusion zone impact energy of CW-GTA welds in VIM-VAR plate. Fig. 4.03114
- 4.03115 Plane strain fracture toughness of electron beam welds made in VIM-VAR melt plate. Table 4.03115
- 4.03116 Fusion zone fatigue strength of CW-GTA weld in VIM-VAR melt plate. Fig. 4.03116
- 4.03117 S-N curves for GTA Butt Welds in VIM-VAR Melt 1/2 inch plate with bead ground off. Fig. 4.03117
- 4.03118 S-N curves for GTA Butt Welds in VIM-VAR 1/2 inch plate with bead on. Fig. 4.03118
- 4.03119 S-N curves for GTA repaired Butt Welds in VIM-VAR 1/2 inch plate with beads ground off. Fig. 4.03119
- 4.03120 S-N curve for full penetration fillet welded VIM-VAR melt cruciforms with non-symmetrical joints. Fig. 4.03120
- 4.03121 S-N curve for full penetration fillet welded VIM-VAR melt cruciforms with symmetrical joints. Fig. 4.03121
- 4.03122 Fatigue crack growth rate in air and in 3-1/2 percent NaCl for GTA weld in VIM-VAR 1/2 inch plate. Fig. 4.03122
- 4.03123 Fatigue crack growth of fusion zone of CW-GTA welds in VIM-VAR melt plate Fig. 4.03123
- 4.04 Surface Treating
- 4.041 S-N curves for VIM-VAR melt plate for specimens plated by various processes. Fig. 4.041

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Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo		
Form Plate, Bar, Forgings & Reforging Stock		
	Percent	
	Min	Max
C	0.13	0.17
Mn	-	0.10
Si	-	0.10
P	-	0.008
S	-	0.005
Cu	1.80	2.20
Ni	9.50	10.50
Co	13.50	14.50
Mo	0.90	1.10
Ti	-	0.015
Al	-	0.015
O	-	0.0015
N	-	0.0015
Total P+S	-	0.010

TABLE 1.04 COMPOSITION (13)

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo						
Source (8) p 184-186						
Form VIM - VAR 1 inch Plate						
Condition 1250F, 8 Hr AC + 1650F, AC + 1500F, 1 Hr Q + R + 950F, 5 Hr						
Quench Medium	Air		Oil		Water	
	Yes	No	Yes	No	Yes	No
R-Refrigerated at 100F, 1 Hour						
F _{tu} - ksi	246	246	252	252	243	241
F _{ty} - ksi	220	220	229	221	228	223
Charpy V ft. lbs.	47	46	44	44	55	49

TABLE 1.057 TENSILE STRENGTH PROPERTIES & IMPACT ENERGY FOR VIM-VAR MELT PLATE QUENCHED IN AIR, OIL OR WATER FOLLOWING AUSTENITIZING

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo									
Source (11) p 12 & 13									
Form VIM - VAR Plate									
Condition 1650F, AC ⁽¹⁾ + 1250F, 8 Hr AC + A, B, C or D + 950F, 5 Hr AC									
Thickness (in)	5/8				3				Avg. from many heats
	A	B	C	D	A	B	C	D	
Heat Treat ⁽¹⁾⁽²⁾									
F _{tu} - ksi	229	239	235	241	230	244	215	242	243
F _{ty} - ksi	220	225	216	221	223	223	200	223	231
e - percent	16	17	17	17	16	17	18	17	-
R. A. - percent	89	89	70	73	66	70	68	69	-
Charpy V ft. lbs.	67	61	62	83	48	60	43	70	68

1. Time at 1600 or 1500F - 5/8 inch plate. 1 Hr. 3 inch plate. 3 Hrs
 2. A 1500F, WQ
 B 1500F, AC + (-100F)
 C 1500F, Vermiculite cool + (-100F)
 D 1650F, AC + 1500F, AC + (-100F)
 E 1650F, WQ + 1500F, WQ + 950F, 5 Hr AC

TABLE 1.058 EFFECT OF VARIOUS HEAT TREATMENTS ON TENSILE IMPACT PROPERTIES OF 5/8 IN & 3 IN VIM-VAR MELT PLATE

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo			
Source (9) p 6 & 7			
Form VIM - VAR 2 inch Thick Plate			
Condition ⁽²⁾ 1250F, 8 Hr AC ⁽¹⁾ + 1650F, 1 Hr Q + 1525F, 1 Hr Q + (-100F, 1 Hr) + 950F, 5 Hr AC			
Quench Medium	Air	Oil	Water
F _{tu} - ksi	244	254	248
F _{ty} - ksi	214	224	223
e - percent	16	16	16
R. A. percent	69	69	70
Charpy V	51	48	48
ft. - lbs.			
K _{IC} - ksi √in	158	140	146
1. Premachining heat treatment			
2. Heat treated in 2 inch thickness			

TABLE 1.059 TENSILE PROPERTIES, IMPACT ENERGY & FRACTURE TOUGHNESS OF VIM-VAR MELT 2 INCH PLATE QUENCHED IN SEVERAL MEDIA & GIVEN A PREMACHINING HEAT TREATMENT

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo			
Source (10) p 148-9			
Composition VIM - ESR Melt Plate			
Percent	A	D	E
Melt			
C	0.15	0.15	0.16
Co	13.40	13.61	13.76
Ni	9.23	9.66	9.64
Cr	1.46	1.79	1.72
Mo	0.91	1.12	1.07
Mn	0.14	0.15	0.17
Si	< 0.01	< 0.01	< 0.01
Al	< 0.01	< 0.01	< 0.01
Ti	< 0.01	< 0.01	< 0.01
V	< 0.01	< 0.01	< 0.01
S	0.003	0.006	0.007
P	0.010	0.010	0.014
N ppm	13	11	5
O ppm	320	220	88
H ppm	2	2	4
		ESR Slag	
CaF ₂	30	70	70
Al ₂ O ₃	15	22	20
CaO	3	6	8
MgO	2	2	2

TABLE 1.0511 PLATE & ESR SLAG COMPOSITIONS FOR 2000 lb VIM MELT REMELTED INTO ESR INGOTS

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo
AF1410

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo					
Source (1) p 32 (4) p 8					
Melt Practice	VIM-ESR				
Heat	R3	R4	R5	R6	L3616R1
Slag Composition Percent					
CaF ₂	30	55	70	30	30
CaO	40	22	20	40	40
Al ₂ O ₃	30	15	10	30	30
SiO ₂	-	8	-	-	-
Ca ⁽¹⁾	0.032	0.047	0.045	0.14	0.02
Mg	-	-	-	-	0.08
1. Ca added as 30% Ca-Si alloy at 5 minute intervals during melting					

TABLE 1.0812 SLAG COMPOSITIONS USED IN MAKING ESR REMELTS

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo												
Source (1) p 10 & 36 (3) p 10												
Melt Practice	VIM		VIM-VAR ⁽¹⁾				VIM-ESR ⁽²⁾				AOD-ESR ⁽³⁾	AOD-ESR-VAR ⁽³⁾
Heat	L3550	L3614	K-19	K-20	K13	K18	R3	R4	R5	R6	R2	K2
Oxygen ppm	10	12	6	6.5	3.5	4.5	36	53	46	47	28	5
1. K-19 & K-20 from L3550 K13 & K18 from L3614												
2. From L3550												
3. From 3-957 VIM - Argon Oxygen Deoxidized Electric Furnace Heat (AOD)												

TABLE 1.0813 OXYGEN LEVELS IN INGOTS PRODUCED BY VARIOUS MELTING PRACTICES

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo											
Source (2) p 14											
Form 1.25 and 1.4 inch Plate											
Condition 1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F, 5 hours AC											
Melt Practice	VIM-ESR ⁽¹⁾								VIM-ESR ⁽²⁾		
Heat	R3		R4		R5		R6		L3616R1		
Direction	L	T	L	T	L	T	L	T	L	T	
F _{tu} - ksi	249	245	245	241	246	241	253	245	245	249	
F _{ty} - ksi	229	228	230	229	225	225	236	229	233	236	
Charpy V ⁽³⁾	37	28	26	29	36	27	14	13	38	32	
ft. - lbs @ OF											
1. 1.4 inch plate											
2. 1.25 inch plate											
3. L - LT direction T - TL direction											

TABLE 1.0814 TENSILE & IMPACT PROPERTIES OF 1.25 & 1.4 INCH THICK PLATE FROM VIM-ESR MELTS

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo									
Source (2) p. 6 (3) p. 15 (5) p. 3									
Form 1.25 Inch Plate									
Condition 1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F, 5 hour AC									
Melt Practice	VIM-VAR			A1D ⁽¹⁾ -VAR		ARC-ADO-ESR		ARC-ADO-ESR-VAR	
Heat	L3550K20			3-957K11		3-957R2 ⁽³⁾		3-957K2 ⁽³⁾	
Direction	L	T	L	T	L	T	L	T	
F _{tu} - ksi	252	255	232	235	229	218	231	231	
F _{ty} - ksi	232	233	223	222	226	217	220	220	
Charpy v ⁽²⁾ ft-lbs at 0 F	62	59	40	40	46	45	73	41	
1. Argon oxygen deoxidation electric furnace melt. 2. L - LT direction, T - TL direction. 3. See Table 1.0813 for O ₂ content.									

TABLE 1.0815 TENSILE & IMPACT PROPERTIES OF 1.25 THICK PLATE FROM VARIOUS MELTING PRACTICES

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo									
Source (2) p 10									
Form 3 Inch Plate									
Condition 1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F, 5 hours AC									
Melt Practice	VIM			VIM-VAR			VIM-VAR		
Heat	L3550			L3550K19 ⁽¹⁾			L3550K20 ⁽²⁾		
Direction	L	T	ST	L	T	ST	L	T	ST
F _{tu} - ksi	253	261	259	241	250	247	247	247	249
F _{ty} - ksi	239	251	239	227	229	227	226	227	230
RA - percent	64	59	53	72	68	67	70	69	65
e - percent	14	14	13	16	15	14	16	16	15
Charpy v ⁽³⁾ ft - lbs at 0 F	37	36	17	65	61	56	56	50	44
1. VAR stirred 2. VAR not stirred 3. L - LT direction, T - TL direction, ST - SL direction									

TABLE 1.0816 TENSILE & IMPACT PROPERTIES OF 3 INCH THICK PLATE FROM VIM & VIM-VAR MELTS

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo											
Source (2) p 12 & 13 (4) p 9											
Form 3 Inch Plate											
Condition 1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F, 3 hours AC											
Melt Practice	VIM-ESR ^{1,2}						VIM-ESR ⁽²⁾				
Heat	R3		R4		R5		R6		L3616R1		
Direction	L	ST	L	ST	L	ST	L	ST	L	ST	ST
F _{tu} - ksi	251	245	256	240	246	244	246	244	232	234	
F _{ty} - ksi	228	225	239	218	228	229	232	229	223	222	
Charpy v ⁽³⁾ ft - lbs @ 0 F	29	22	31	21	29	23	9	7	33	17	
1. Parent VIM Heat L3550 2. See Table 1.083 for slag composition & deoxidation 3. L - LT direction, T - TL direction, ST - SL direction											

TABLE 1.0817 TENSILE & IMPACT PROPERTIES OF THREE INCH THICK PLATE FROM VARIOUS MELTING PRACTICES

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo							
Source (3) p 15 (5) p 7							
Form 3 Inch Plate							
Condition 1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F 5 hours AC							
Melt Practice	ADO-VAR ⁽¹⁾		ARC-ADO-ESR		ARC-ADO-ESR-VAR		
Heat	3-957K11		3-957-R2 ⁽³⁾		3-957-K2 ⁽³⁾		
Direction	L	ST	L	ST	L	ST	
F _{tu} - ksi	236	239	229	227	231	227	
F _{ty} - ksi	224	226	222	219	222	218	
Charpy v ⁽²⁾ ft - lbs @ 0 F	38	31	42	24	47	28	
1. Argon oxygen deoxidation 2. L-LT direction, T-TL direction, ST-SL direction 3. See Table 1.0813 for O ₂ content							

TABLE 1.0818 TENSILE & IMPACT PROPERTIES OF THREE INCH THICK PLATE FROM VARIOUS ADO MELTING PRACTICES

Fe
 0.16 C
 14 Co
 10 Ni
 2 Cr
 1 Mo

AF1410

Alloy									Fe-0.16C-14Co-10Ni-2Cr-1Mo								
Source									(3) p 30 (5) p 13								
Form									1 1/2 & 1 3/4 Inch Thick Upset Disks								
Condition									1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F, 5 hours AC								
Melt Practice			VIM-VAR ⁽²⁾			VIM-ESR ⁽³⁾			ARC-AOD-VAR ⁽²⁾			ACR-AOD ⁽¹⁾ ESR ⁽³⁾					
Heat			L3614K18			L3614R1			3-957K11			3-957R2					
Direction		R		T		R		T		R		T					
F _{tu} - ksi		249		246		245		246		236		241					
F _{ty} - ksi		232		232		234		232		223		224					
RA percent		63		67		60		61		65		64					
Charpy V		45		46		34		32		33		37					
ft-lbs at OF																	

1. Argon oxygen deoxidation electric furnace heat
 2. 1 3/4 inch thick
 3. 1 1/2 inch thick
 4. R - RT direction, T - TR direction

TABLE 1.0818 TENSILE & IMPACT PROPERTIES OF 1 1/2 & 1 3/4 INCH THICK UPSET DISKS FROM VARIOUS MELTING PRACTICES

Alloy													Fe-0.16C-14Co-10Ni-2Cr-1Mo												
Source													(3) p 28 (5) p 11												
Form													6 inch Thick Upset Disks												
Condition													1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950, 5 hours AC												
Melt Practice			VIM-VAR			VIM-ESR			ARC-AOD ⁽¹⁾ VAR			ARC-AOD-ESR													
Heat			L3614K18			L3614R1			3-957K11			3-957R2													
Direction		R		T		ST		R		T		ST		R		T		ST							
F _{tu} - ksi		230		229		229		236		239		239		240		230		236							
F _{ty} - ksi		215		212		211		222		223		221		219		211		215							
RA percent		68		69		68		50		58		61		62		64		63							
Charpy V ⁽²⁾		44		44		43		20		25		26		28		28		29							
ft-lbs at OF																									

1. Argon oxygen deoxidation electric furnace heat
 2. R - RT direction, T - TR direction, ST - ST direction

TABLE 1.08110 TENSILE & IMPACT PROPERTIES OF 6 INCH THICK UPSET DISKS FROM VARIOUS MELTING PRACTICES

Alloy						Fe-0.16C-14Co-10Ni-2Cr-1Mo					
Form						Plate, Bar, Forgings & Reforging Stock					
Melting						VIM-VAR					
Condition						1600 to 1650F, 1 hr AC + 1500 to 1550F, 1 hr. AC + (-90 to -110F, 1 hr) + 940 to 960F, 5 hr. AC					
Thickness (inches)	F _{tu} (min)	F _{ty} (min)	c(min)	R. A. (min)	K _{1c} ⁽¹⁾ (min)						
	ksi	ksi	2 in. %	%	ksi - √in						
t < 1.00	235	220	12	60	-						
1.00 < t < 1.50	235	215	12	60	-						
1.50 < t < 2.00	235	210	12	60	130						
2.00 < t < 2.50	235	200	12	60	130						
2.50 < t ²											

1. Applies to product 1.5 inch thick or over. For thinner products report K_{1c}. WL orientation
 2. As negotiated with supplier

TABLE 3.011 FABRICATORS MECHANICAL PROPERTY SPECIFICATION (13)

Alloy																	Fe-0.16C-14Co-10Ni-2Cr-1Mo																
Source																	11(p 17)																
Form																	Wing Sweep Actuator Forging VIM-VAR Melt																
Condition																	Forging Heat Treat: 1650F, 1 hour AC + 1250F, 5 hours AC																
Specimen Heat Treat		1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F, 5 hours AC								1500F, 1/2 hour AC + (-100F, 1/2 hour) + 950F, 5 hours AC																							
Location ⁽¹⁾	F _{tu} - ksi	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8																
	F _{ty} - ksi	252	256	246	234	244	255	237	243	256	229	233	231	252	235	230	253																
	e - percent	17	18	18	17	17	17	17	17	17	17	17	16	17	16	16	15																
	RA percent	73	73	75	75	74	72	77	72	68	67	68	66	66	67	68	63																
	Charpy V ft-lbs	80	94	82	-	84	-	-	83	50	53	56	-	50	-	-	51																

1. For location in forging, see Fig. 3.0218

TABLE 3.0219 TENSILE & IMPACT PROPERTIES FOR SINGLE & DOUBLE AUSTENITIZED SPECIMENS CUT FROM VIM-VAR MELT WING SWEEP ACTUATOR FORGING

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo

AF1410

Alloy		Fe-0.16C-14Co-10Ni-2Cr-1Mo	
Source		(11) p 20	
Form ⁽¹⁾		Wing Sweep Actuator Forging (Location 1) VIM-VAR Melt	
Condition		Forging Heat Treat: 1650F, 1 hour AC + 1250F, 8 hours AC	
Specimen	1650F, 1/2 hr AC + 1500F, 1/2 hr AC	1500F, 1/2 hr AC + (-100F, 1/2 hr) +	
Heat Treat	+ (-100F, 1/2 hr) + 950F, 5 hrs AC	950F, 5 hrs AC	
F _{tu} - ksi	254		256
F _{ty} - ksi	228		237
e - percent	17		17
RA - percent	72		68
Charpy V ft - lbs	64		59

1. For specimen location see Fig. 3.0218

TABLE 3.02110 TENSILE & IMPACT PROPERTIES OF SINGLE & DOUBLE AUSTENIZED & REFRIGERATED SPECIMENS CUT FROM VIM-VAR MELT WING SWEEP ACTUATOR FORGING

Alloy		Fe-0.16C-14Co-10Ni-2Cr-1Mo							
Source		(11) p 23							
Form		Wing Sweep Actuator Forging VIM-VAR Melt							
Condition		Forging Heat Treat: 1650F, 1 hour AC + 1250F, 8 hours AC							
Specimen	1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ	1500F, 1/2 hour AC + (-100F, 1/2 hour)				+ 950F, 5 hours AC			
Heat Treat	- 950F, 5 hours AC	+ 950F, 5 hours AC							
Forging Test Location ⁽¹⁾		1	2	3	4	1	2	3	4
F _{cy} - ksi		256	255	260	259	250	234	250	234
E _c - 1000 ksi		30.1	29.8	29.3	28.7	31.1	29.9	30.5	28.3

1. For test locations see Fig. 3.0218

TABLE 3.0221 COMPRESSIVE YIELD STRENGTH & ELASTIC MODULUS FOR SINGLE & DOUBLE AUSTENIZED SPECIMENS CUT FROM VIM-VAR MELT WING SWEEP ACTUATOR FORGING

Alloy		Fe-0.16C-14Co-10Ni-2Cr-1Mo			
Source		(8) p 79			
Form		VIM-VAR 2 Inch Plate			
Condition		1650F, 1 hour WQ + 1500F, 1 hour WQ + 950F, 5 hours AC			
Direction		LT		TL	
Temp - F		RT	-65	RT	-65
K _{IC} - ksi √in		140	110	137	111
F _{ty} - ksi		228	236	228	249

TABLE 3.02722 PLANE STRAIN FRACTURE TOUGHNESS OF VIM-VAR MELT PLATE TESTED IN TWO DIRECTIONS AT ROOM AND LOW TEMPERATURE

Alloy		Fe-0.16C-14Co-10Ni-2Cr-1Mo					
Source		(11) p 24 (15)					
Form		Wing Sweep Actuator Forging VIM-VAR Melt					
Condition		Forging Heat Treat: 1650F, 1 hour AC + 1250F, 8 hours AC					
Specimen	1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ	1500F, 1/2 hour AC + (-100F, 1/2 hour)			+ 950F, 5 hours AC		
Heat Treat	+ 950F, 5 hours AC	+ 950F, 5 hours AC					
Location ⁽¹⁾		5			1	5	
F _{ty} - ksi		228			237	233	
K _{IC} - ksi √in ⁽²⁾		196 ⁽³⁾			151	154	

1. For location see Figure 3.0218

2. Specimen 1.5 inch thick

3. K_Q

TABLE 3.02724 PLANE STRAIN FRACTURE TOUGHNESS VALUES FOR SINGLE & DOUBLE AUSTENIZED SPECIMENS CUT FROM VIM-VAR MELT WING SWEEP ACTUATOR FORGING

Alloy		Fe-0.16C-14Co-10Ni-2Cr-1Mo		
Source		(3) p 19, p 15		
Form		VIM-VAR 3 Inch Plate		
Condition		1650F, 1 hour WQ + 1500F, 1 hour WQ + 950F, 5 hours AC		
Direction		LT	TL	SL
K _{IC} - ksi √in		154	142	136
F _{ty} - ksi		233	230	230

TABLE 3.02723 PLANE STRAIN FRACTURE TOUGHNESS OF 3 INCH VIM-VAR MELT PLATE

Alloy		Fe-0.16C-14Co-10Ni-2Cr-1Mo	
Source		(5) p 16	
Form		VIM-VAR 1 1/4 Inch Plate	
Condition		1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + 950F, 5 hours AC	
Direction		L	T
E-1000 ksi		29.3	29.4

TABLE 3.0621 ELASTIC MODULUS IN TENSION FOR VIM-VAR 1 1/4 INCH PLATE

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo				
Source (12) p 24				
Form Filler Wire 0.062 inch Diameter				
Heat	VE 798	VE 799	VE 800	VE 717
C	0.18	0.15	0.16	0.16
Co	14.34	13.76	14.06	14.30
Ni	10.35	9.82	9.99	9.94
Cr	1.92	1.90	1.94	2.13
Mo	1.04	1.00	1.06	0.93
Si	0.16	< 0.01	0.16	0.11
Al	0.015	0.025	0.031	0.028
V	0.029	< 0.01	< 0.01	0.015
Mn	< 0.05	< 0.05	< 0.05	< 0.03
Ti	< 0.01	< 0.01	< 0.01	< 0.01
S	0.007	0.005	0.005	0.007
P	< 0.001	< 0.001	< 0.001	0.006
O	37 ppm	52 ppm	74 ppm	28 ppm
N	3 ppm	4 ppm	2 ppm	4 ppm
H	1 ppm	1 ppm	2 ppm	1 ppm

TABLE 4.0314 FILLER WIRE COMPOSITIONS USED IN CERTAIN WELD PROPERTY STUDIES

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo		
Source (8) p 64		
Form Filler Wire		
Heat	L3616K13	TLA2606
C	0.17	0.15
Co	13.98	13.76
Ni	10.10	9.82
Cr	1.91	1.90
Mo	0.97	1.00
Si	0.04	< 0.01
Al	0.003	0.025
Mn	0.06	< 0.05
Ti	0.004	< 0.01
S	0.001	0.005
P	0.004	< 0.001
O	300 ppm	520 ppm
N	200 ppm	400 ppm

TABLE 4.0315 FILLER WIRE COMPOSITIONS USED IN CERTAIN WELD PROPERTY STUDIES

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo		
Source (12) p 12		
Plate thickness, inch	1/2	1 1/8
Weld groove	40° Double J	40° Double U
Electrode diameter, inch	1/8	1/8
Electrode type	W - 2 Th	W - 2 Th
Wire diameter, inch	0.062	0.062
Total passes	11 - 16	29 - 30
Interpass, F	100 - 150	100 - 160
Back up gas, cu ft per hour	A, 10 - 12	A, 10 - 12
Torch gas, percent	75 He - 25 A	75 He - 25 A
Flowrate, cu ft per hour	60	60
Pulsed arc	200-5 } or { 200-15	200-15
Current, amp - secs	160-15 } or { 160-5	160-5
Arc voltage	14 or 13	13
Arc travel, inch per min.	4	4
Heat input, Kj per inch	35.7 or 37.1	37.1 - 38.5
Deposition Rate - lbs per hour	1.1	1.1

TABLE 4.0316 WELD PARAMETERS FOR AUTOMATIC PULSED ARC CW-GTA WELDING

Alloy Fe-0.16C-14Co-10Ni-2Cr-1Mo		
Source (12) p 48		
Form 1 1/8 inch Plate		
Condition	1650F, 1 hour WQ + 1500F, 1 hour WQ + CW-GTA Weld ⁽¹⁾ + 950F, 4 hours WQ	
Test Condition	Alternate Immersion (10 min. in 3.5% NaCl) + 50 min. Air Dry) at 165 ksi. Specimen Axis Normal to Weld	
Specimen No.	Failure Time, Hours	Remarks
4c4	488	Crack initiated in HAZ
4c6	199	Failed at tool mark in head radius
1. Weld wire heat VE799 (Table 4.0314). See Table 4.0316 for welding parameters.		

TABLE 4.0317 ALTERNATE IMMERSION STRESS CORROSION DATA IN 3.5% NaCl FOR CW-GTA WELDS IN VIM-VAR PLATE

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo

AF1410

Fe-0.16C-14Co-10Ni-2Cr-1Mo								
Form VIM VIM-VAR 1/2 inch Plate (Rectangular Cross-section Specimens)								
Source (8) p 125 & 126								
Condition 1650F, 1 hour WQ + 1500F, 1 hour WQ + Weld - 950F, 5 hours AC								
Weld Double U Groove, Manual, Stringer Bead CW-GTA Butt Welds, 0.062 Matching Filler With Argon Shield								
Surface Condition	Weld Bead On		Bead Ground Off		Single Repair Bead Ground off		Multiple Repair Bead Ground off	
Test Temp F	RT	-65 ⁽¹⁾	RT	-65	RT	-65	RT	-65
F _{tu} - ksi ⁽²⁾	248	255	232	256	236	254	239	254
F _{ty} - ksi	230	-	220	-	219	-	204	-
e(2 in.) percent	12.5	21	12	12	9	11	9	10

1. Specimens failed in parent metal
2. Welds normal to applied load

TABLE 4.0318 TENSILE PROPERTIES AT ROOM TEMPERATURE AND -65F FOR MANUAL CW-GTA PLATE BUTT WELDS AND REPAIR WELDS WITH AND WITHOUT BEAD REMOVAL

Fe-0.16C-14Co-10Ni-2Cr-1Mo											
Source (12) p 33											
Form 1/2 inch Plate VIM-VAR Melt											
Condition 1650F, 1/2 hour WQ + 1500F, 1/2 hour WQ + Weld											
Weld ⁽¹⁾ Process	Filler ⁽³⁾ Wire	Heat Input KJ per in.	Deposition Rate, lbs per hr	Fusion Zone Impurities						Fusion Zone C _{avg} (ft-lbs) ⁽⁴⁾	
				Al	Si	S	P	O	N	As Deposit	Aged ⁽²⁾
CW-GTA	VE717	33.2	1.1	0.086	0.21	0.007	0.006	59	5	35.4	24.4
	VE799	37.1	1.1	0.025	<0.01	0.005	0.001	52	4	40.4	47.3
HW-GTA	VE717	33.8	5.6	0.061	0.20	0.003	0.006	195	62	18.3	16.2
CW-PA	VE717	93.6	3.4	0.095	0.22	0.006	0.007	90	102	23	13.3

1. CW-GTA Cold wire gas tungsten arc
HW-GTA Hot wire GTA
CW-PA Cold wire plasma arc
2. Age 950F, 5 hours
3. For wire composition see Table 4.0314
For weld parameters see Table 4.0316
4. LT orientation, L in weld direction

TABLE 4.03112 EFFECTS OF HEAT INPUT AND FILLER WIRE IMPURITIES ON FUSION ZONE IMPACT ENERGY

Fe-0.16C-14Co-10Ni-2Cr-1Mo		
Source 8 (p 131)		
Form VIM-VAR 1/2 inch Plate		
Condition 1650F, 1 hour WQ + 1500F, 1 hour WQ + Weld + 950F, 5 hours AC		
Weld Location Manual Stringer Bead CW-GTA Butt Welds ⁽¹⁾ Weld HAZ		
Charpy v ⁽¹⁾ ft-lbs		
Average	49.7	44.5
Std. Dev.	5.0	5.6

1. See Table 4.0318 for tensile properties & weld parameters

TABLE 4.03113 IMPACT ENERGY FOR GTA WELD METAL & HAZ IN VIM-VAR MELT 1/2 INCH PLATE

Fe-0.16C-14Co-10Ni-2Cr-1Mo		
Source (7) p 84		
Form VIM-VAR 1 1/2 inch Plate		
Condition Electron Beam Weld		
Specimen No.	E97	E98
K _{1c} - ksi √in.	71.1	72.5
F _{ty} - ksi	230	230

TABLE 4.03115 PLANE STRAIN FRACTURE TOUGHNESS OF ELECTRON BEAM WELDS MADE IN VIM-VAR MELT PLATE

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

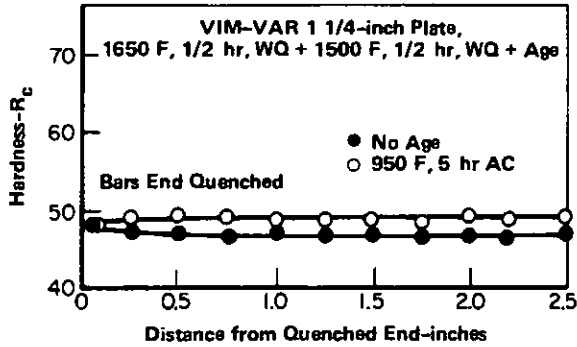


FIGURE 1.061. END QUENCH HARDENABILITY (5) P. 18

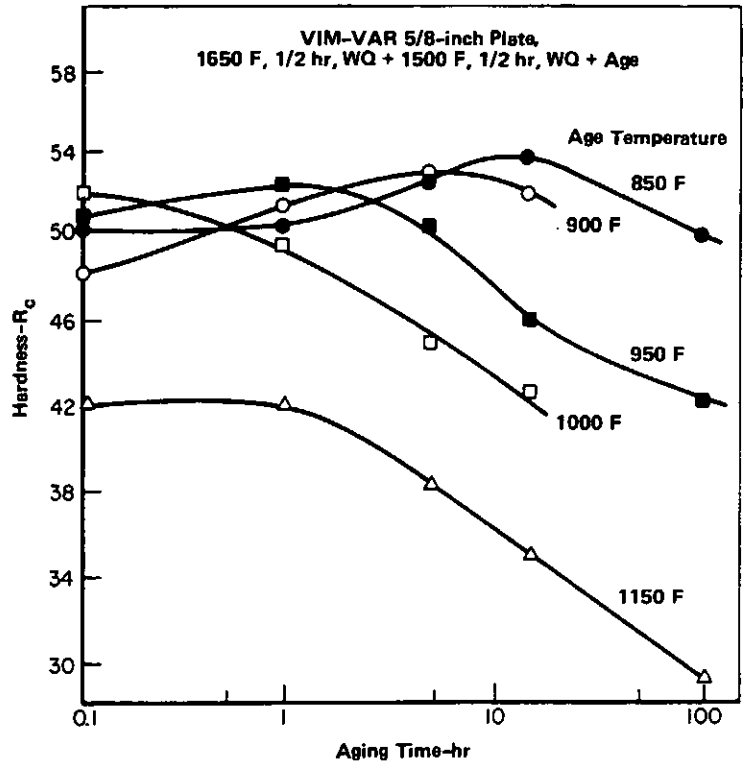


FIGURE 1.062. EFFECT OF AGING TIME AND TEMPERATURE ON HARDNESS OF VIM-VAR MELT PLATE (7) P. 53

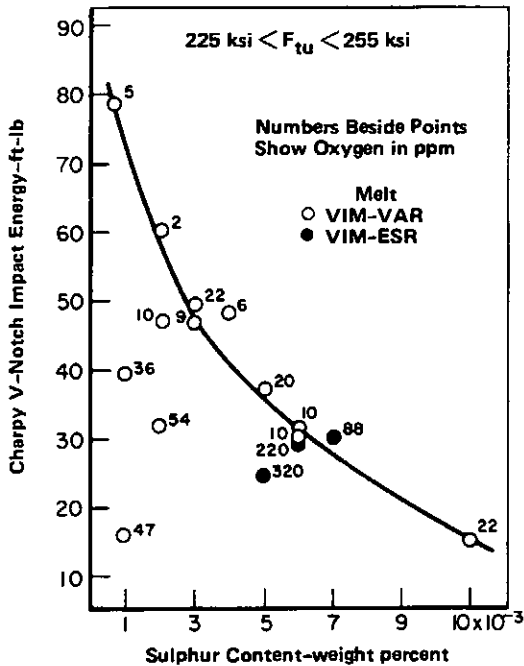


FIGURE 1.094. EFFECT OF SULPHUR AND OXYGEN CONTENT ON THE IMPACT ENERGY OF VIM-VAR AND VIM-ESR MELT ALLOY (12) P. 28

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo
AF1410	

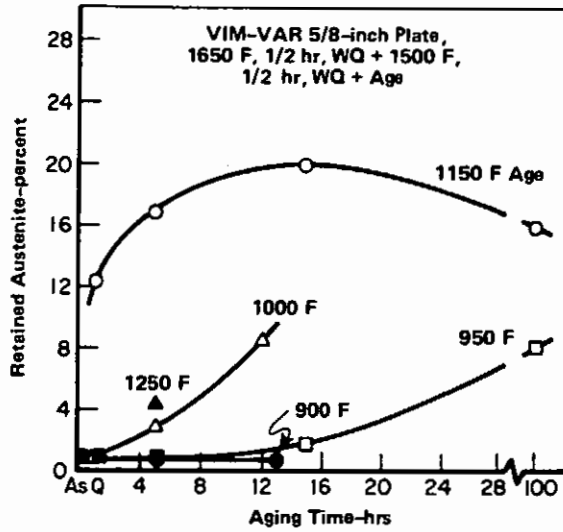


FIGURE 2.0121. EFFECT OF AGING TIME AND TEMPERATURE ON AMOUNT OF RETAINED AUSTENITE IN VIM-VAR MELT PLATE (7) P. 60

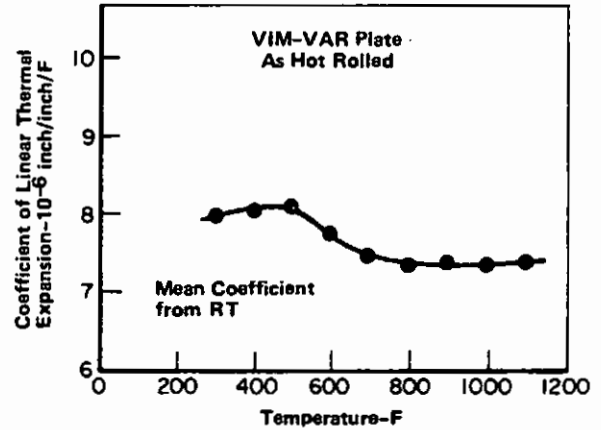


FIGURE 2.0141. MEAN COEFFICIENT OF LINEAR THERMAL EXPANSION (5) P. 17

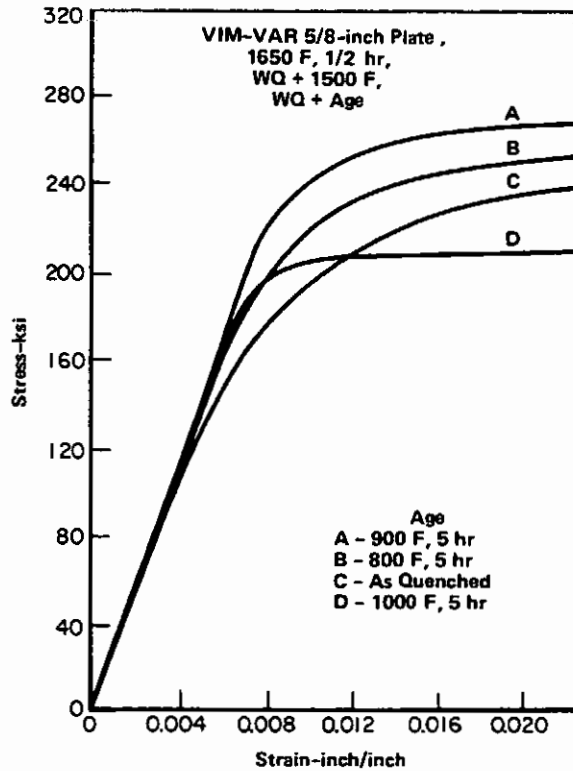


FIGURE 3.0211. EFFECT OF AGING TEMPERATURE ON TENSION STRESS STRAIN CURVES OF VIM-VAR PLATE (7) P. 94

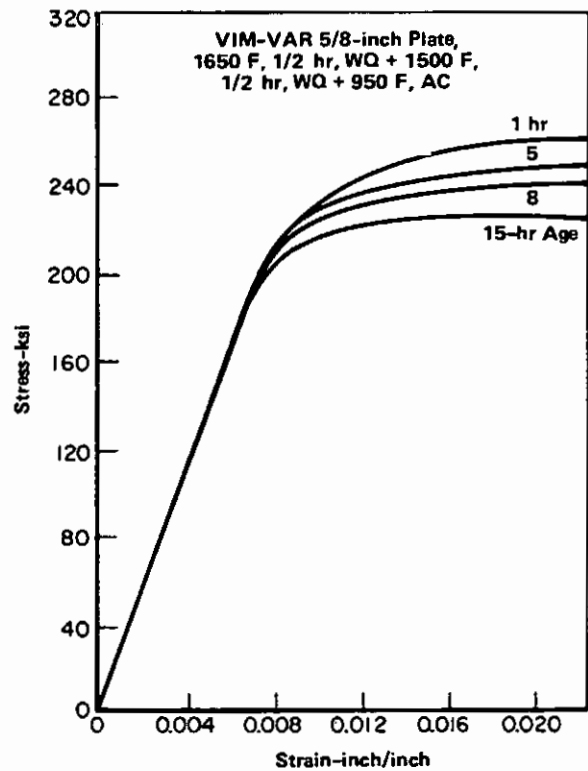


FIGURE 3.0212. EFFECT OF AGING TIME ON TENSION STRESS STRAIN CURVES FOR VIM-VAR PLATE (7) P. 42

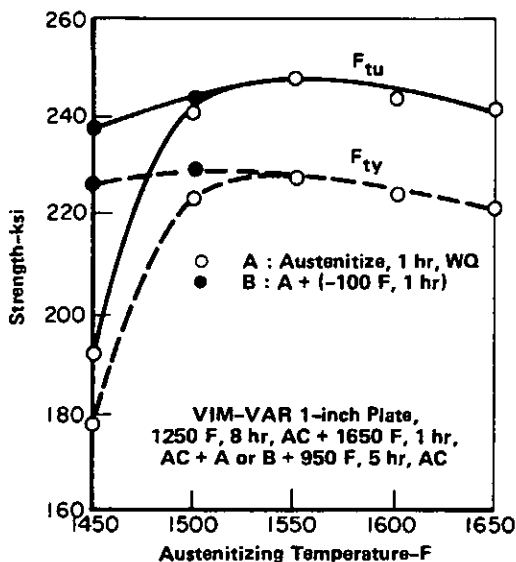


FIGURE 3.0213. EFFECT OF AUSTENITIZING TEMPERATURE AND REFRIGERATION TREATMENT ON PROPERTIES OF VIM-VAR WATER QUENCH PLATE (8) P. 189, 192

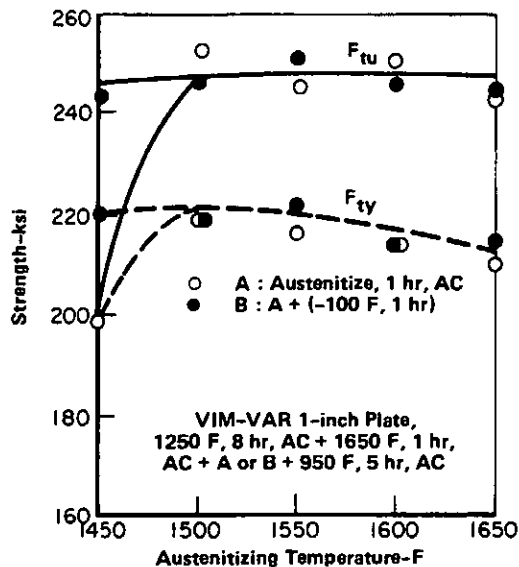


FIGURE 3.0214. EFFECT OF AUSTENITIZING TEMPERATURE AND REFRIGERATION TREATMENT ON TENSILE PROPERTIES OF AIR COOLED VIM-VAR PLATE (8) P. 187, 190

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

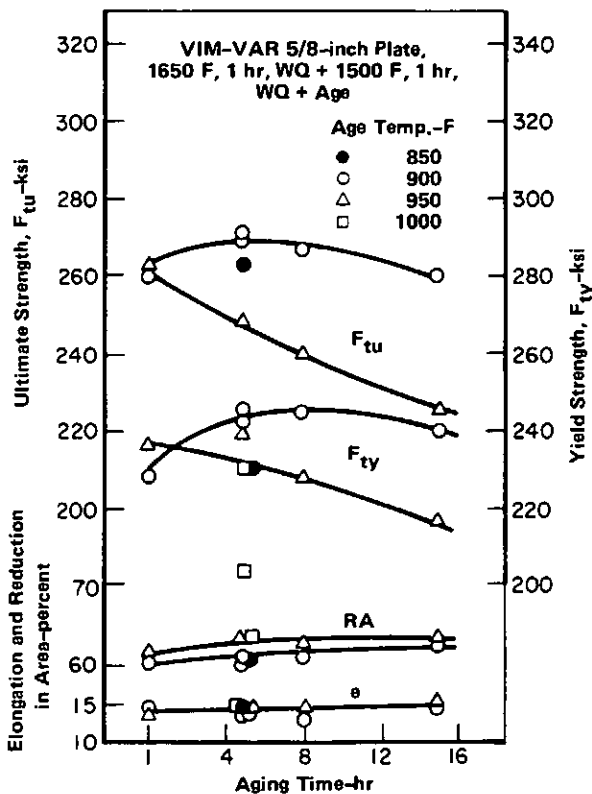


FIGURE 3.0215. EFFECT OF AGING TIME AND TEMPERATURE ON TENSILE PROPERTIES OF VIM-VAR 5/8-INCH PLATE (9) P. 40

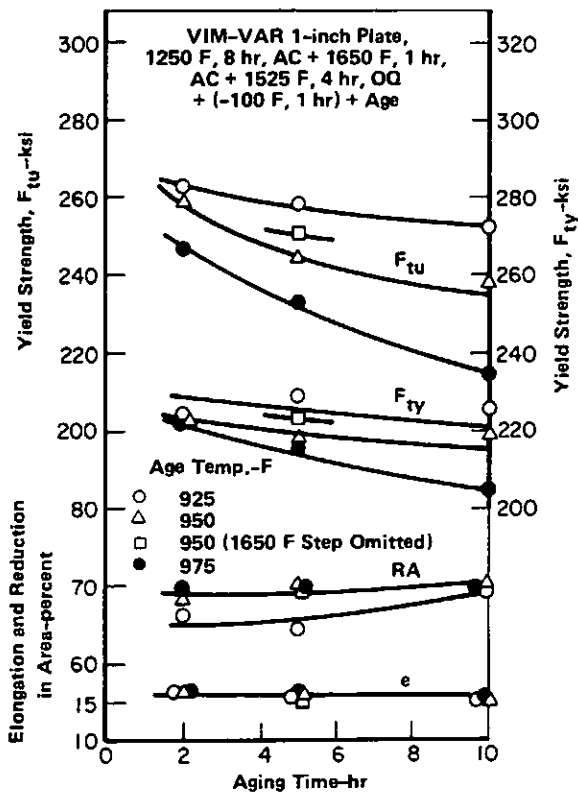


FIGURE 3.0216. EFFECT OF AGING ON TENSILE PROPERTIES OF VIM-VAR 1-INCH PLATE GIVEN A PRE-MACHINING HEAT TREATMENT (9) P. 2

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo
AF1410	

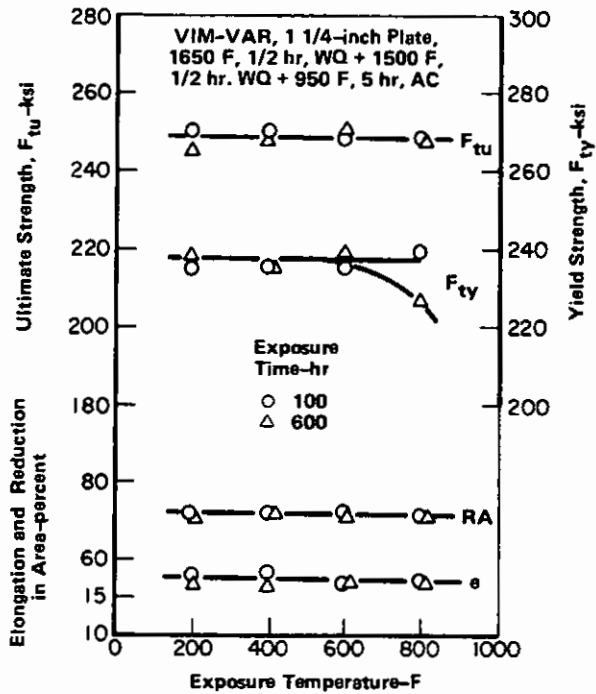


FIGURE 3.0217. EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES (6) P. 14

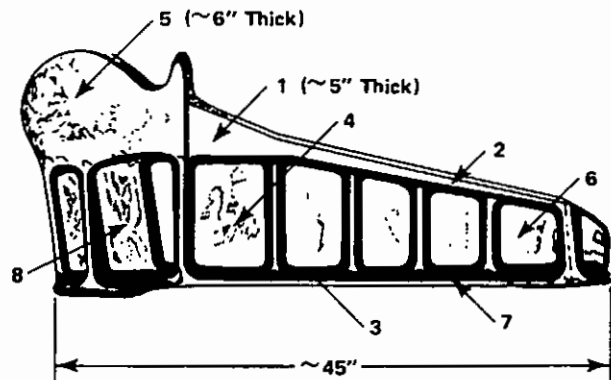


FIGURE 3.0218. WING SWEEP ACTUATOR VIM-VAR FORGING SHOWING CRITICAL TEST LOCATIONS AND MECHANICAL TEST SPECIMENS CUT FROM THESE AREAS (11) P. 15

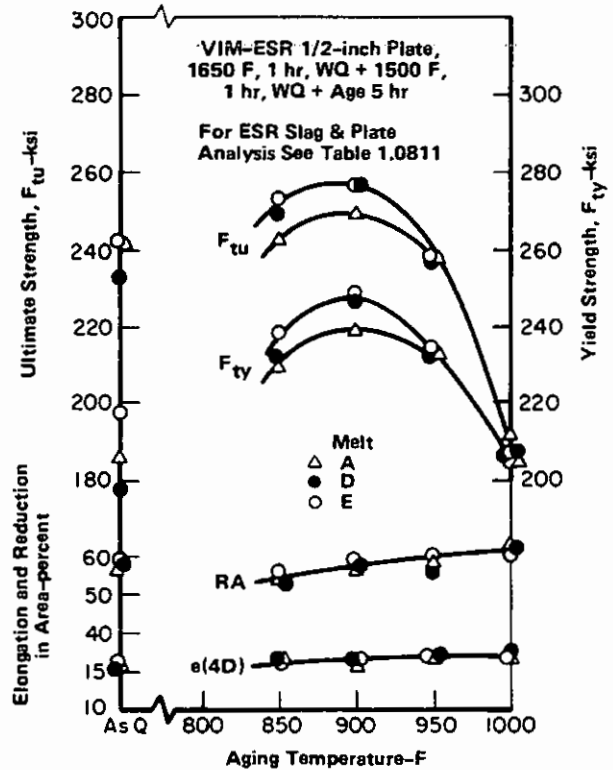


FIGURE 3.02111. EFFECT OF AGING TEMPERATURE ON THE TENSILE PROPERTIES OF THREE VIM-ESR MELTS (10) P. 20

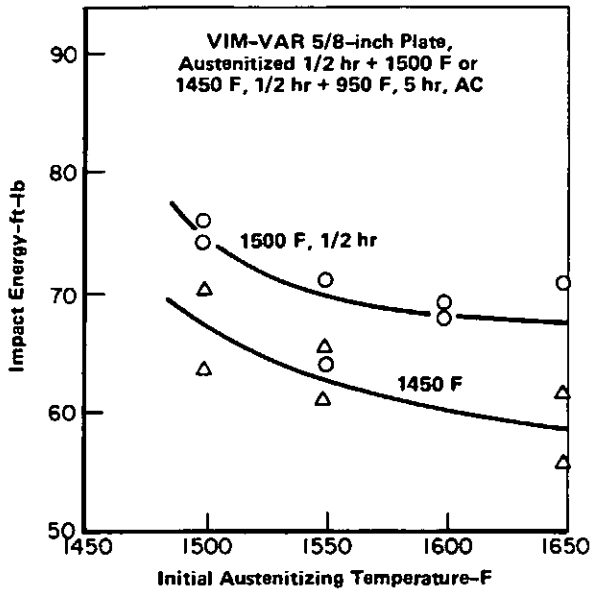


FIGURE 3.0231. EFFECT OF AUSTENITIZING TEMPERATURES ON IMPACT ENERGY OF VIM-VAR MELT PLATE (3) P. 21

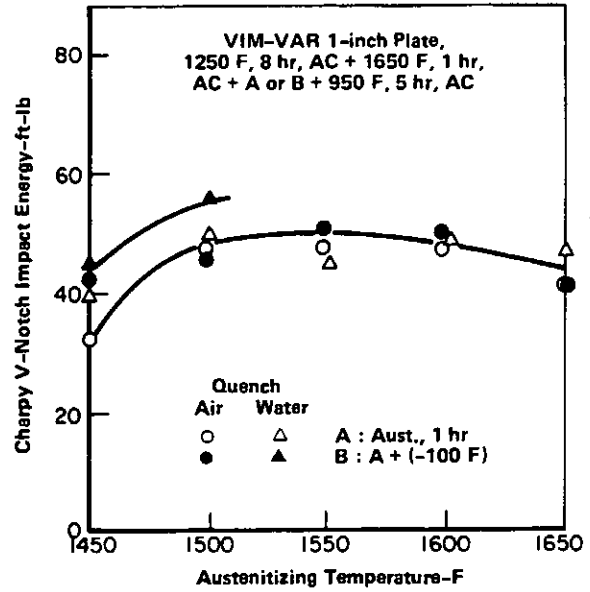


FIGURE 3.0232. EFFECT OF AUSTENITIZING TEMPERATURE AND REFRIGERATION TREATMENT ON IMPACT ENERGY OF VIM-VAR MELT PLATE AIR COOLED OR WATER QUENCHED FROM THE AUSTENITIZING TEMPERATURE (8) P. 193, 195

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo
AF1410	

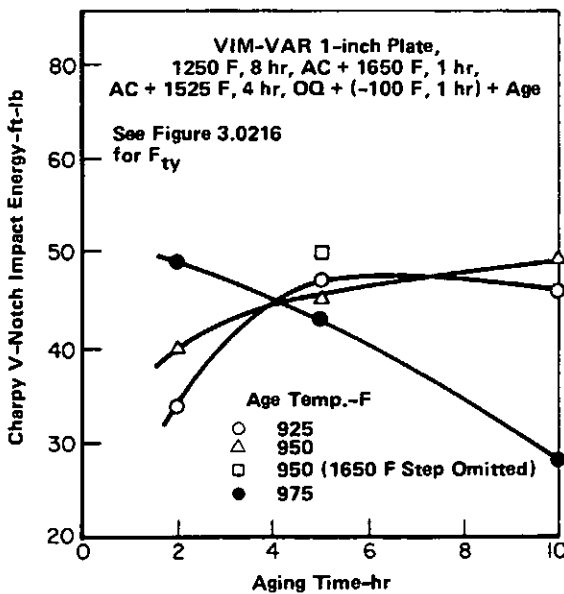


FIGURE 3.0233. EFFECT OF AGING TEMPERATURE AND TIME ON IMPACT ENERGY OF VIM-VAR MELT 1-INCH PLATE GIVEN A PRE-MACHINING HEAT TREATMENT (9) P. 2

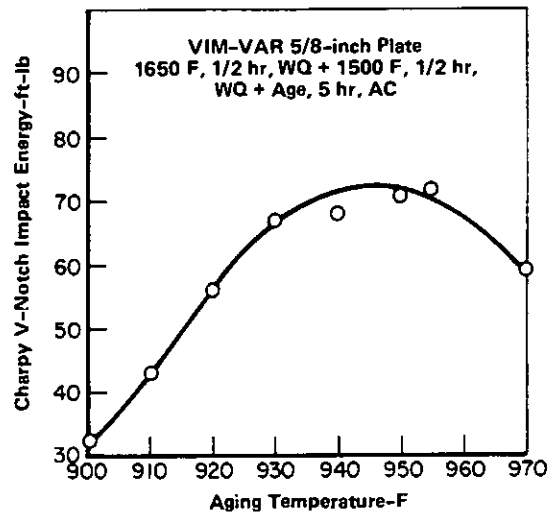


FIGURE 3.0234. EFFECT OF AGING TEMPERATURE ON IMPACT ENERGY OF VIM-VAR PLATE (2) P. 31

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo
AF1410

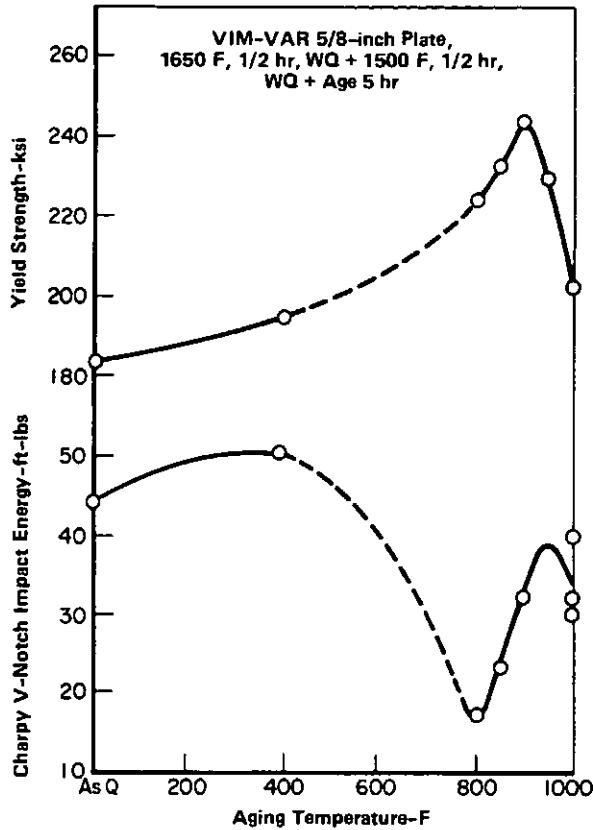


FIGURE 3.0235. EFFECT OF AGING TEMPERATURE ON IMPACT ENERGY AND YIELD STRENGTH OF VIM-VAR PLATE (7) P. 46

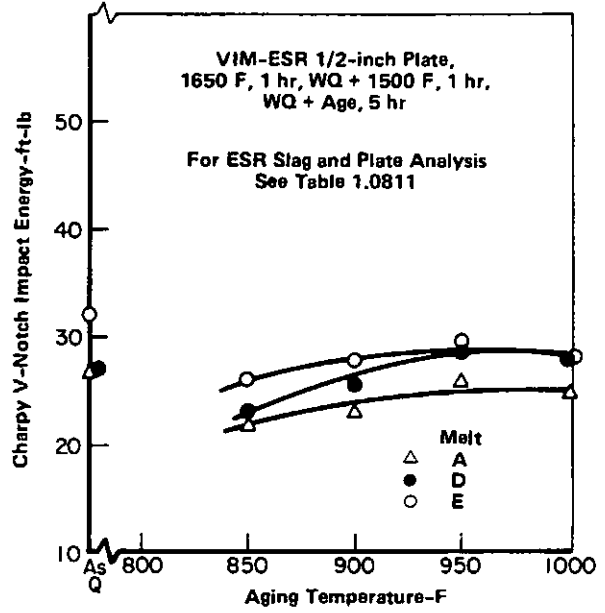


FIGURE 3.0236. EFFECT OF AGING TEMPERATURE ON IMPACT ENERGY OF THREE VIM-ESR MELTS (10) P. 20

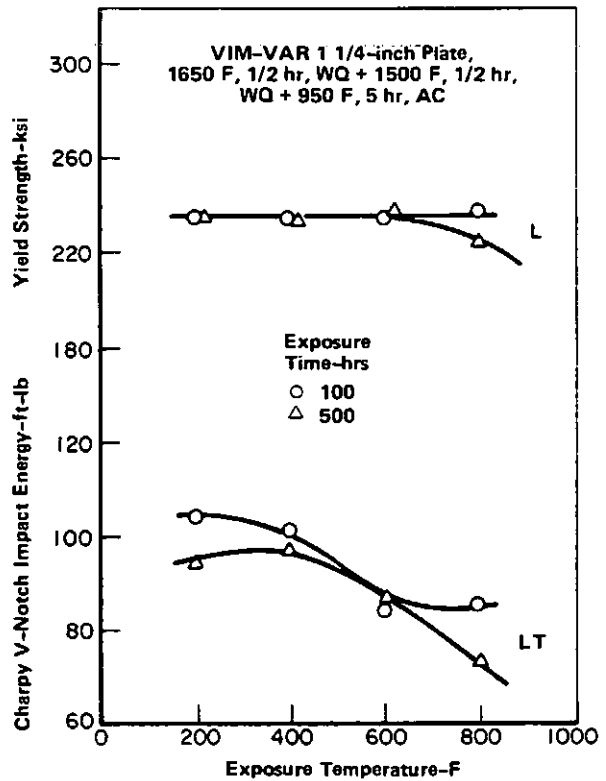


FIGURE 3.0237. EFFECT OF EXPOSURE TO ELEVATED TEMPERATURES ON ROOM TEMPERATURE-CHARPY V IMPACT ENERGY AND TENSILE YIELD STRENGTH OF VIM-VAR MELT PLATE (6) P. 13, 14

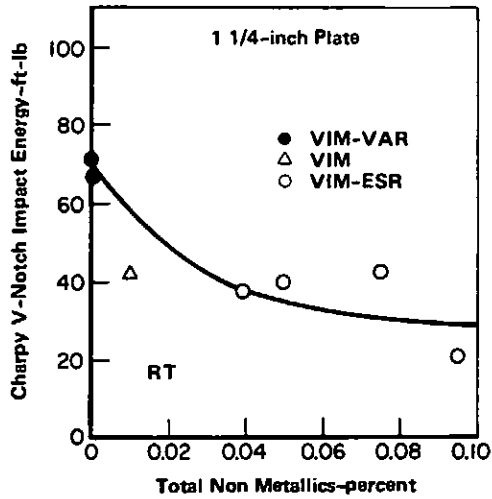
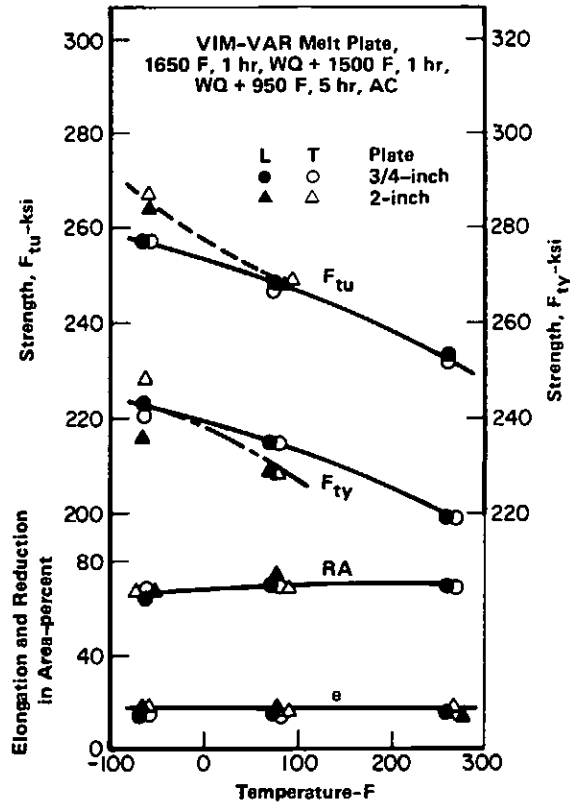


FIGURE 3.0238. CHARPY IMPACT ENERGY FOR PLATE AS FUNCTION OF TOTAL NON-METALLICS AS DETERMINED WITH QUANTITATIVE TELEVISION MICROSCOPE (2) P. 19



Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo
AF1410

FIGURE 3.0311. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF 3/4-INCH AND 2-INCH-VIM-VAR-MELT-PLATE (8) P. 73 & 74

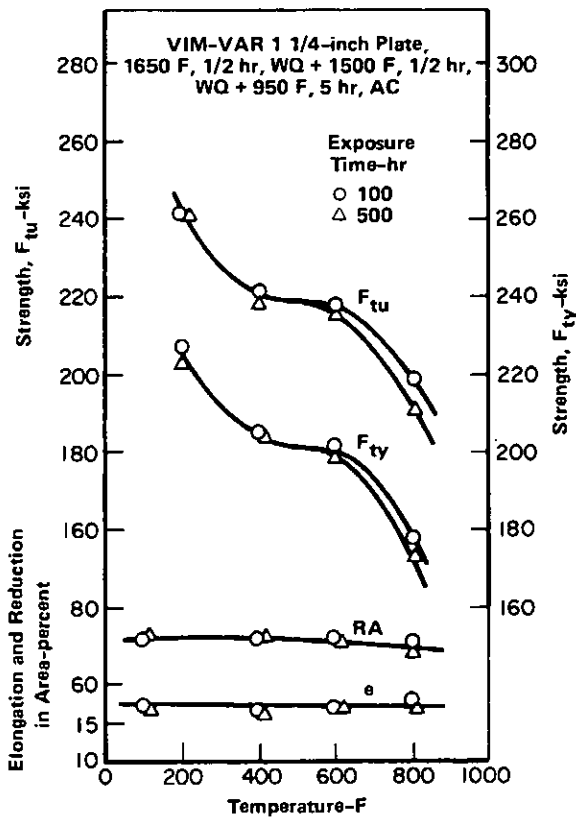


FIGURE 3.0312. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF VIM-VAR MELT PLATE EXPOSED AT THE TEST TEMPERATURE (6) P. 14

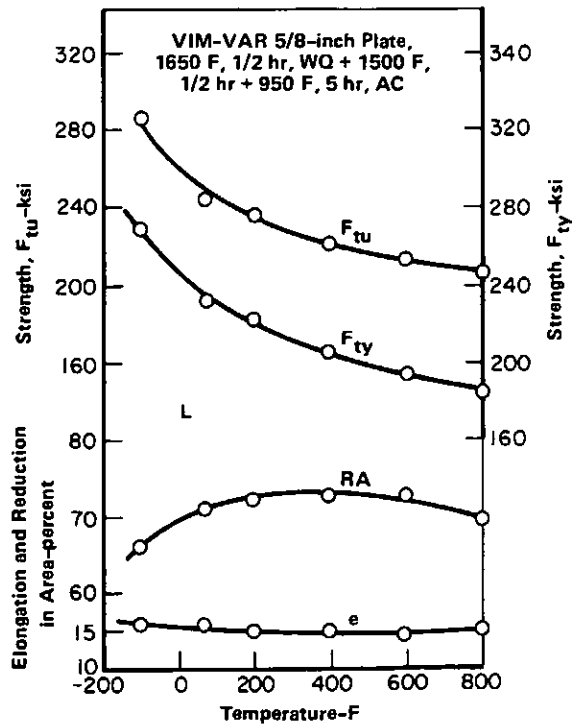


FIGURE 3.0313. EFFECT OF LOW AND ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF VIM-VAR MELT PLATE (4) P. 15

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo
AF1410	

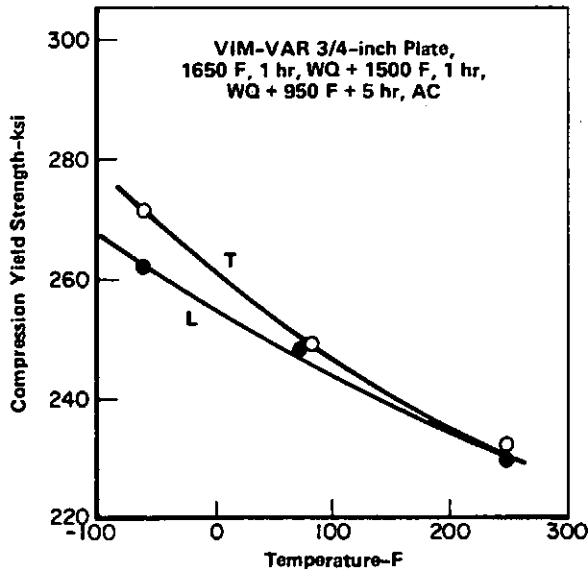


FIGURE 3.0322. EFFECT OF TEMPERATURE ON COMPRESSION YIELD STRENGTH OF VIM-VAR MELT PLATE (8) P. 75

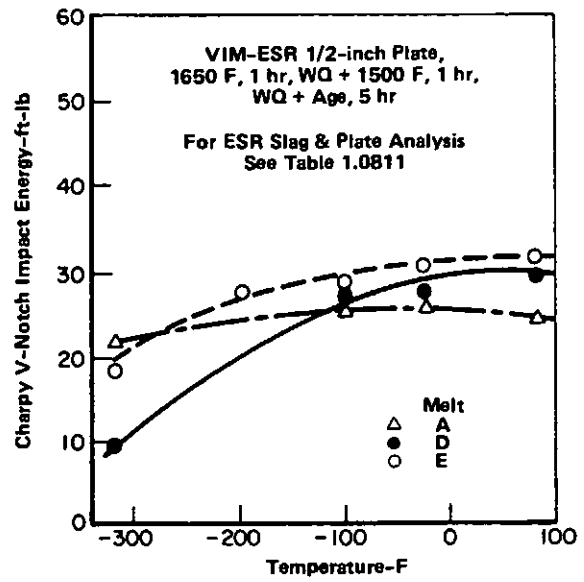


FIGURE 3.0331. EFFECT OF TEST TEMPERATURE ON IMPACT ENERGY OF THREE VIM-ESR MELTS (10) P. 22

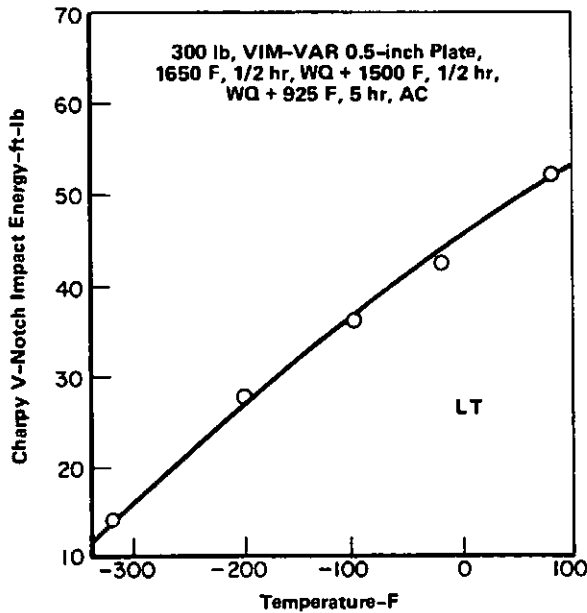


FIGURE 3.0332. EFFECT OF LOW TEST TEMPERATURES ON IMPACT ENERGY OF A 300-LB VIM-VAR MELT PLATE (7) P. 35

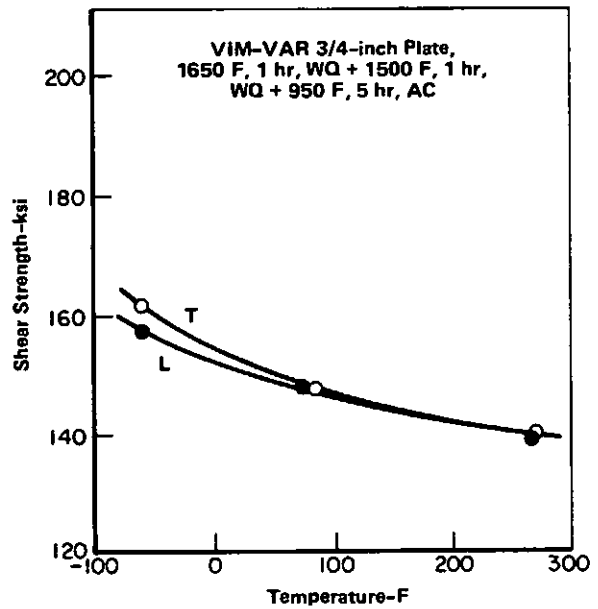


FIGURE 3.0351. EFFECT OF TEMPERATURE ON SHEAR STRENGTH OF VIM-VAR MELT PLATE (8) P. 76

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

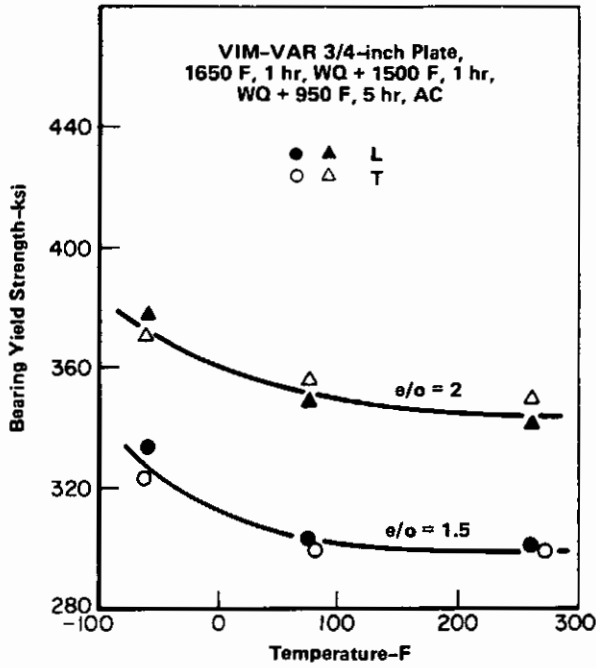


FIGURE 3.0361. EFFECT OF TEMPERATURE ON BEARING YIELD STRENGTH OF VIM-VAR MELT PLATE (8) P. 78

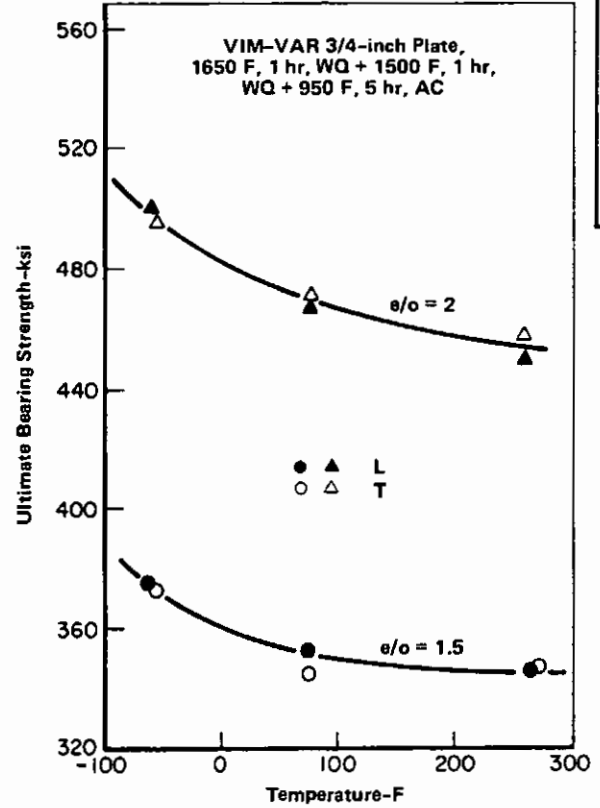


FIGURE 3.0362. EFFECT OF TEMPERATURE ON BEARING ULTIMATE STRENGTH OF VIM-VAR MELT PLATE (8) P. 78

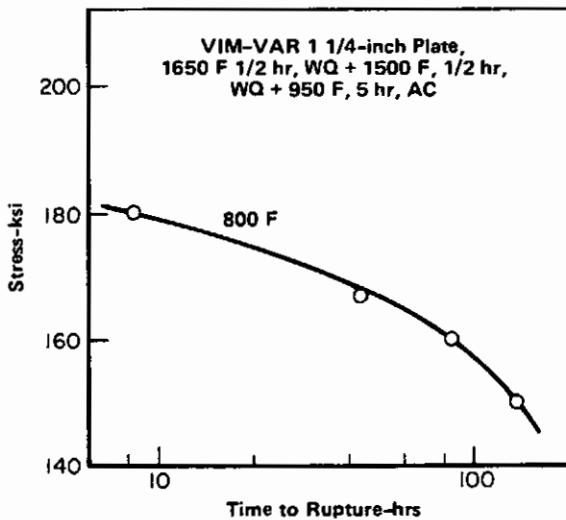


FIGURE 3.041. CREEP RUPTURE CURVE AT 800 F FOR VIM-VAR MELT PLATE (11) P. 27

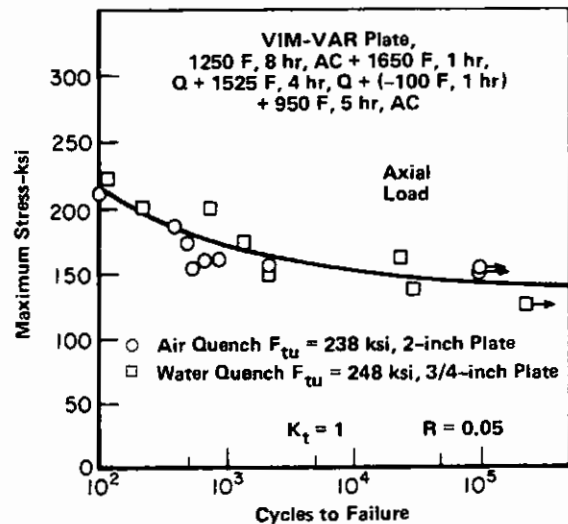


FIGURE 3.051. AXIAL LOAD S-N DATA FOR VIM-VAR MELT PLATE GIVEN A PREMACHINING HEAT TREATMENT AND THEN WATER OR AIR QUENCHED FOLLOWING AUSTENITIZING (9) P. 11

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

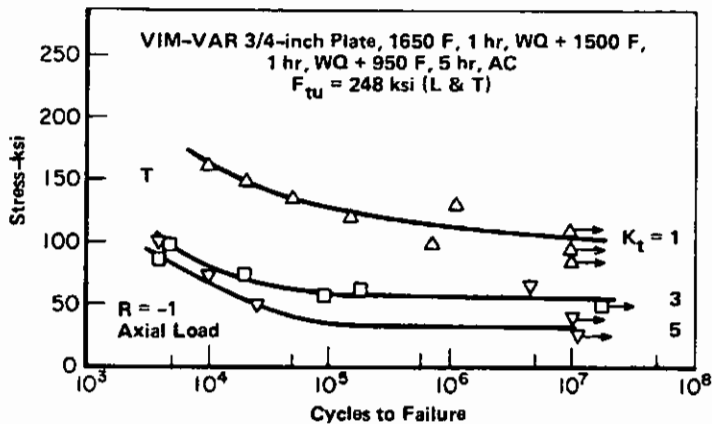


FIGURE 3.052. S-N CURVES AT ROOM TEMPERATURE FOR VIM-VAR MELT PLATE TESTED IN TRANSVERSE DIRECTION AT SEVERAL STRESS CONCENTRATION FACTORS $R = -1$ (8) P. 87, 91, 95

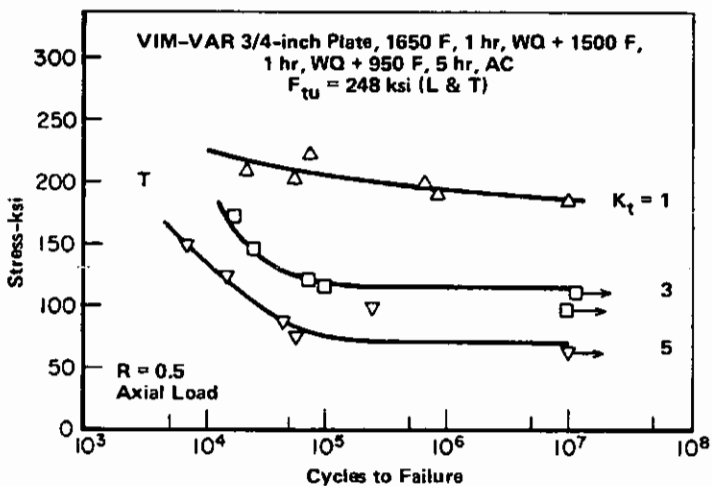


FIGURE 3.053. S-N CURVES AT ROOM TEMPERATURE FOR VIM-VAR MELT PLATE TESTED IN TRANSVERSE DIRECTION AT SEVERAL STRESS CONCENTRATION FACTORS $R = 0.5$ (8) P. 86, 90, 94

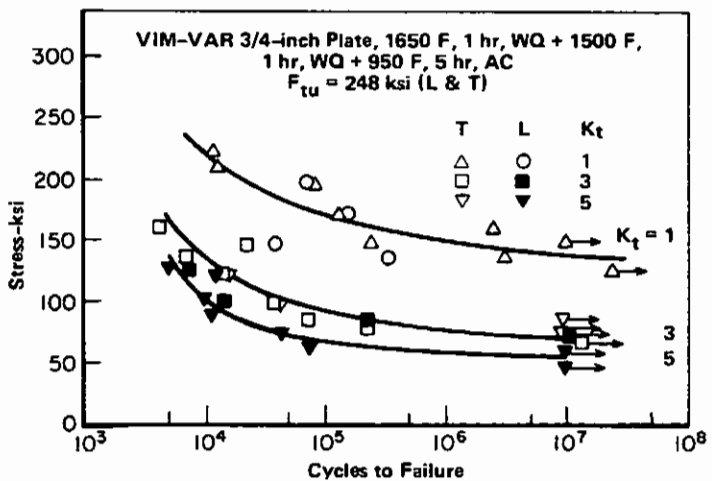


FIGURE 3.054. S-N CURVE AT ROOM TEMPERATURE FOR VIM-VAR MELT PLATE FOR SEVERAL STRESS CONCENTRATION FACTORS AT $R = 0.05$ (8) P. 84, 85, 88, 89, 92, 93

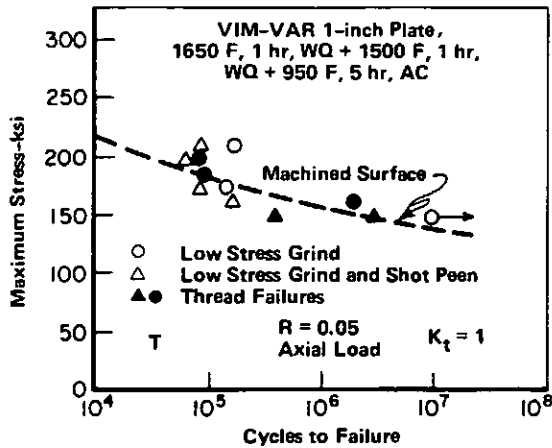


FIGURE 3.055. S-N CURVES FOR VIM-VAR MELT PLATE FOR SPECIMENS WITH GROUND OR GROUND AND SHOT PEENED SURFACES (8) P. 120

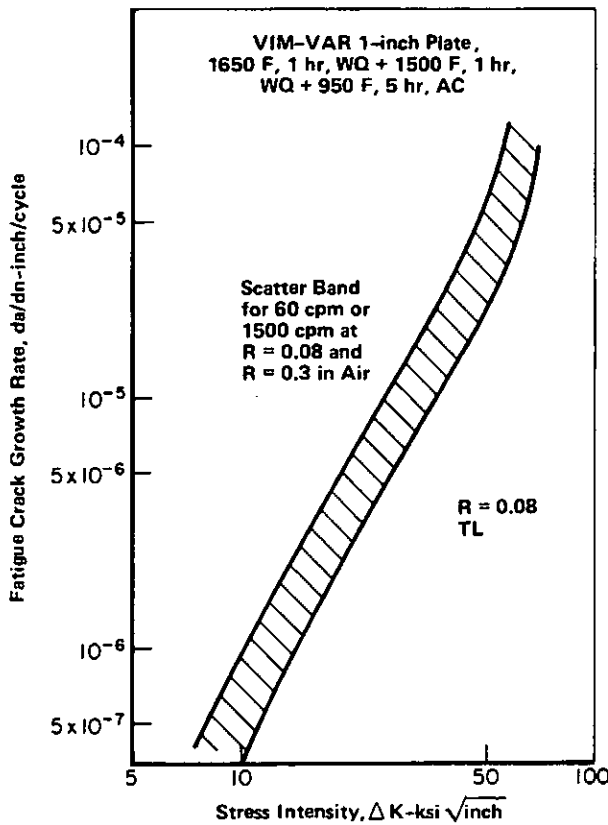


FIGURE 3.057. FATIGUE CRACK GROWTH RATE AT TWO FREQUENCIES AND TWO R RATIOS, FOR VIM-VAR PLATE AT ROOM TEMPERATURE IN LOW HUMIDITY AIR (9)

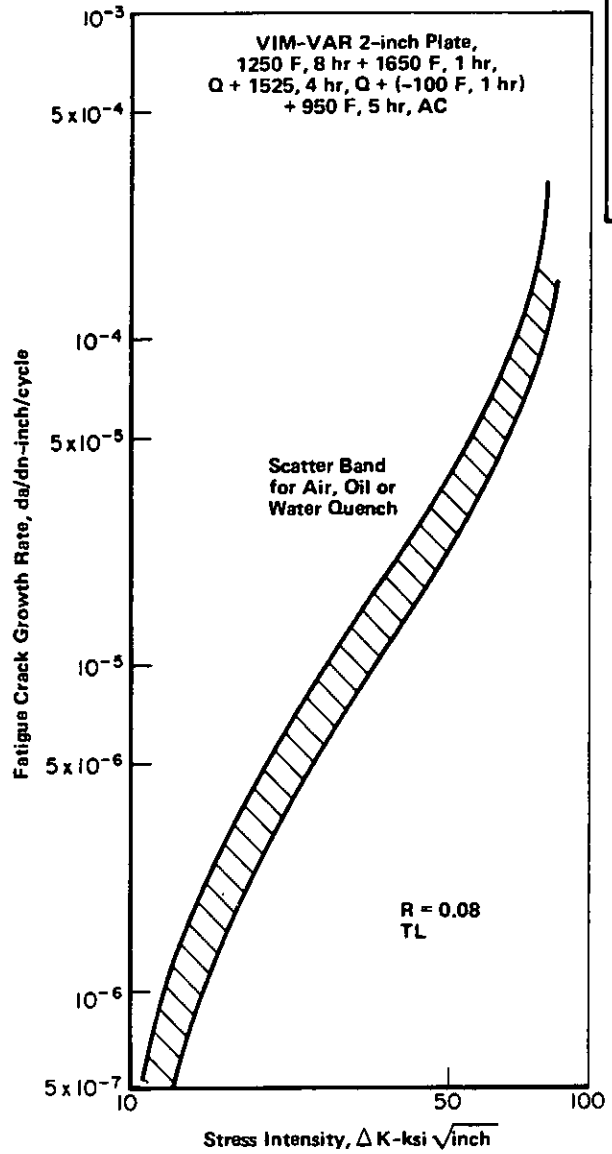


FIGURE 3.056. FATIGUE CRACK GROWTH RATE FOR VIM-VAR MELT 2-INCH PLATE GIVEN A PREMACHINING HEAT TREATMENT AND THEN WATER OR AIR QUENCHED FOLLOWING AUSTENITIZING (9) P. 9

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo
AF1410

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo

AF1410

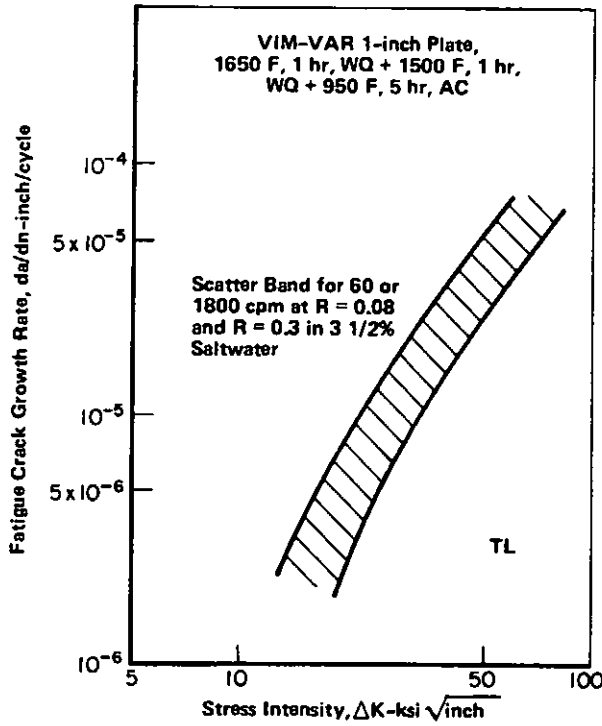


FIGURE 3.058. FATIGUE CRACK GROWTH RATE AT TWO FREQUENCIES AND TWO R RATIOS FOR VIM-VAR MELT PLATE AT ROOM TEMPERATURE IN 3 1/2% SALTWATER (8) P. 100, 111

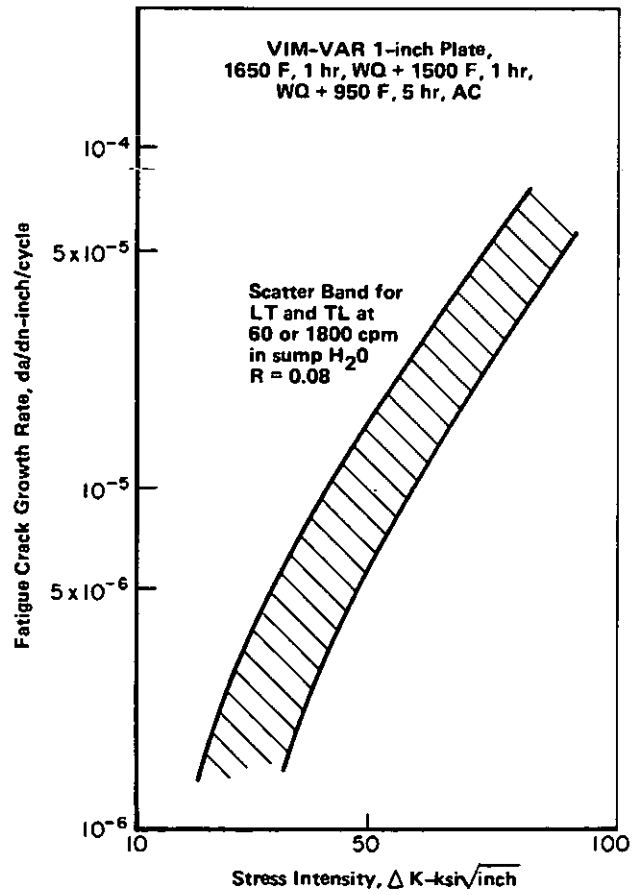


FIGURE 3.059. FATIGUE CRACK GROWTH RATE AT TWO FREQUENCIES FOR VIM-VAR MELT PLATE AT ROOM TEMPERATURE IN SUMP TANK WATER (8) P. 112

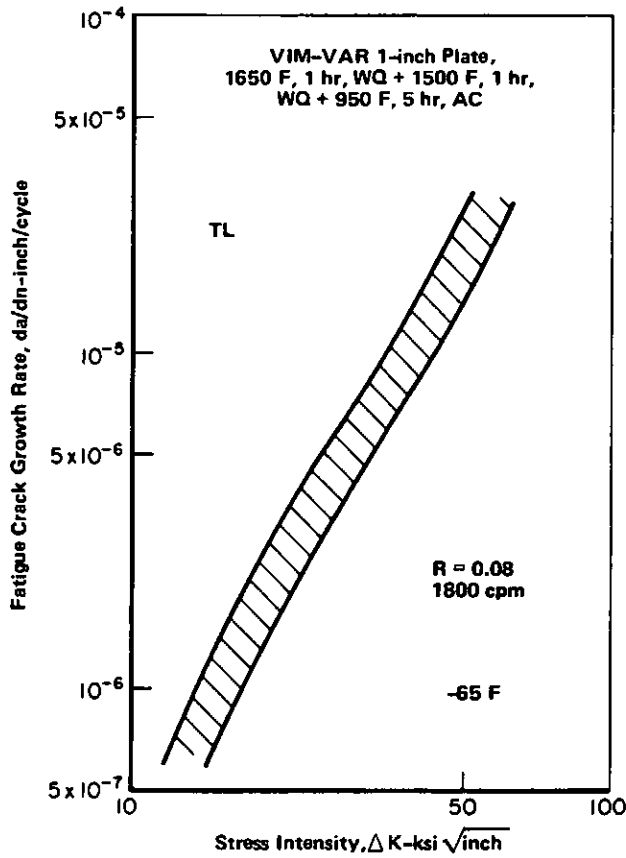


FIGURE 3.0510. FATIGUE CRACK GROWTH RATE FOR VIM-VAR PLATE AT -65F (8) P. 113

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

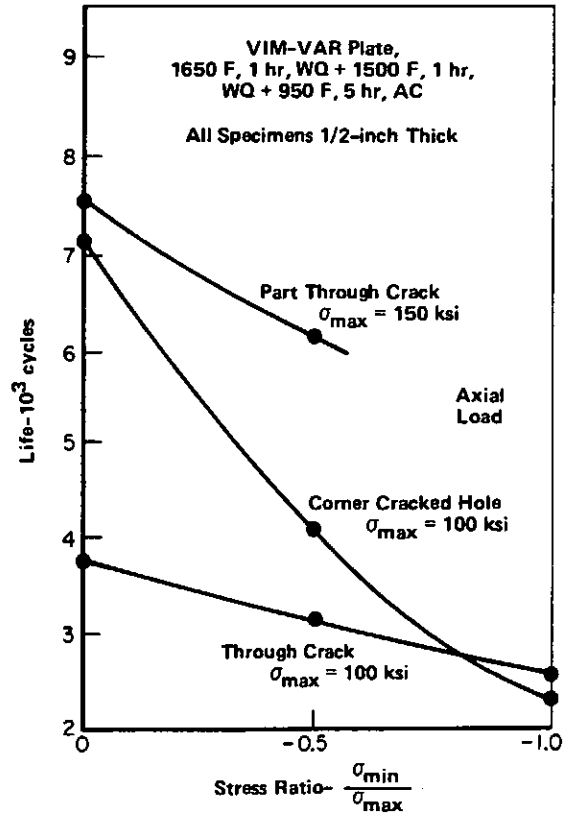


FIGURE 3.0511. EFFECT OF STRESS RATIO ON FATIGUE LIFE OF VARIOUS CRACKED SPECIMENS SUBJECTED TO CONSTANT AMPLITUDE LOADING (8) P. 178

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo
AF1410

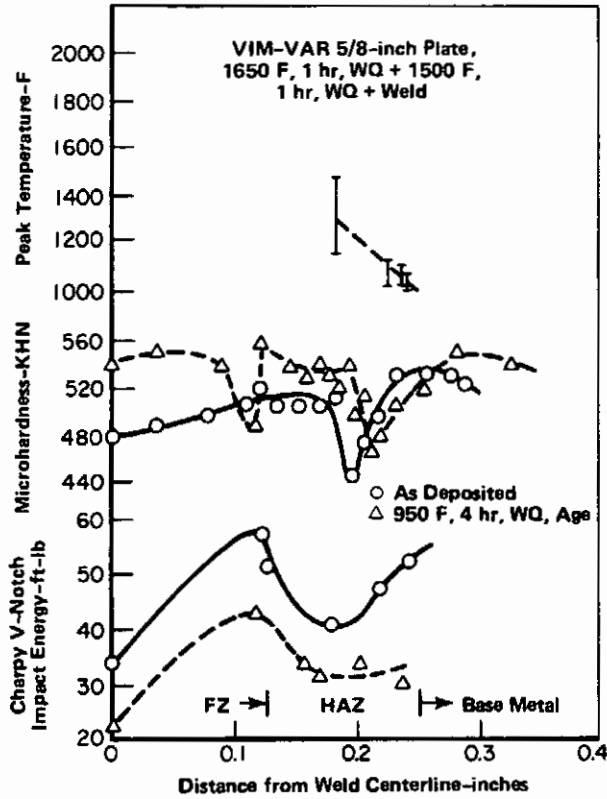


FIGURE 4.0319. HARDNESS AND IMPACT ENERGY AS A FUNCTION OF DISTANCE FROM WELD CENTERLINE FOR CW-GTA WELDS IN VIM-VAR PLATE (12) P. 69

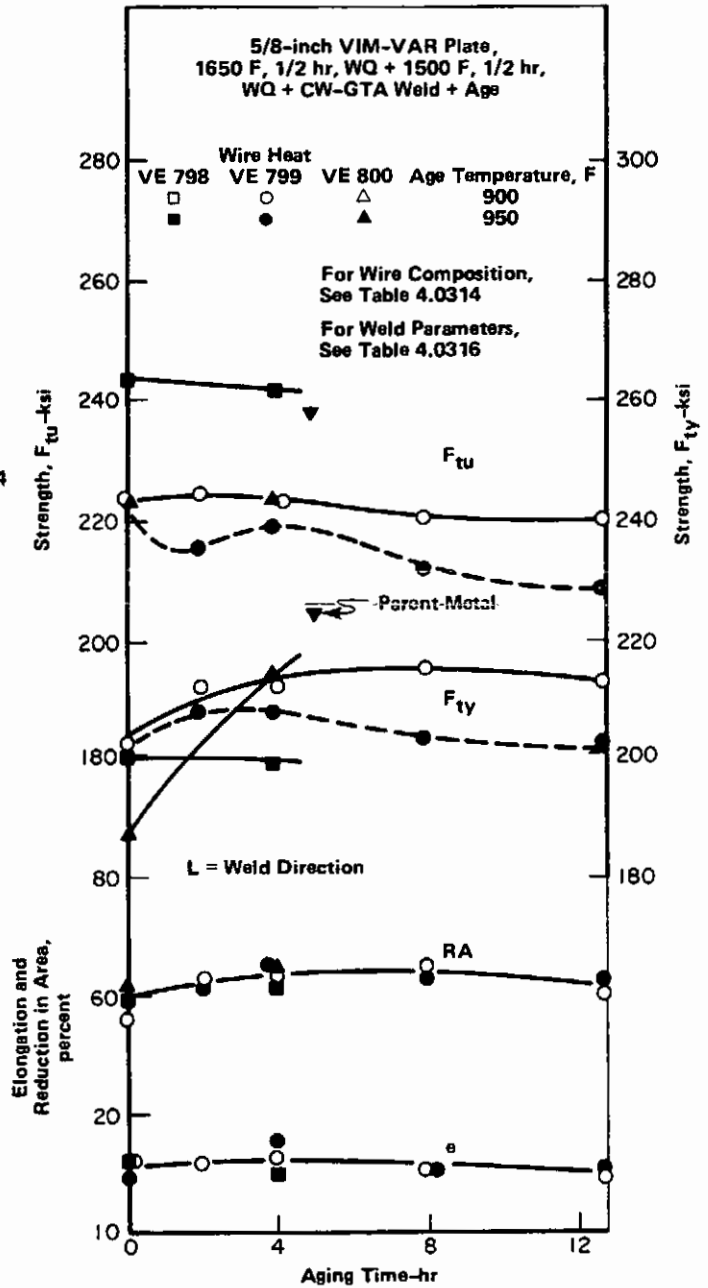


FIGURE 4.03110. FUSION ZONE TENSILE PROPERTIES OF VIM-VAR MELT PLATE CW-GTA WELDED WITH SEVERAL FILLER WIRES AND AGED FOR VARIOUS TIMES AT 900 AND 950 F (12) P. 35

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo

AF1410

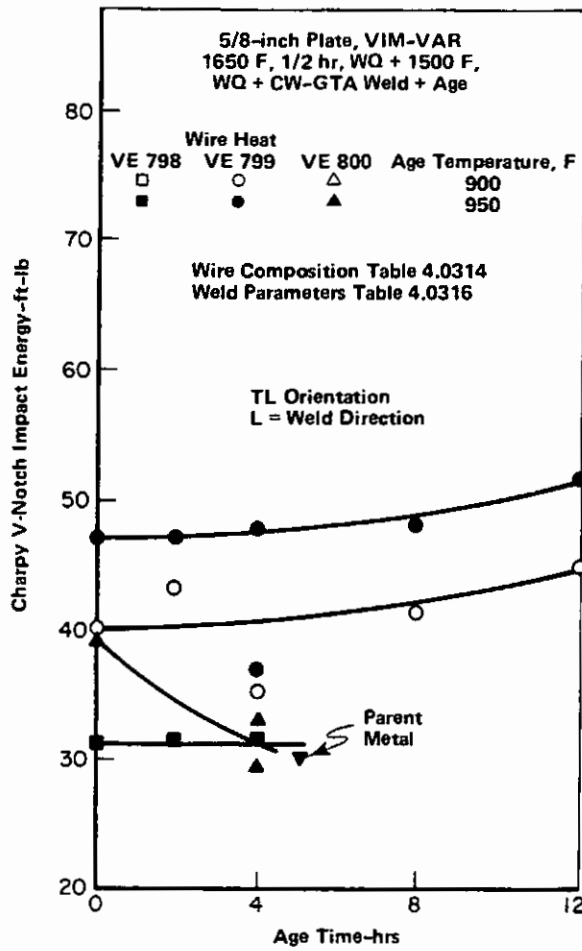


FIGURE 4.03111. FUSION ZONE CHARPY IMPACT ENERGY OF VIM-VAR MELT PLATE CW-GTA WELDED USING SEVERAL FILLER WIRES AND AGED FOR VARIOUS TIMES AT 900 AND 950 F (12) P. 38

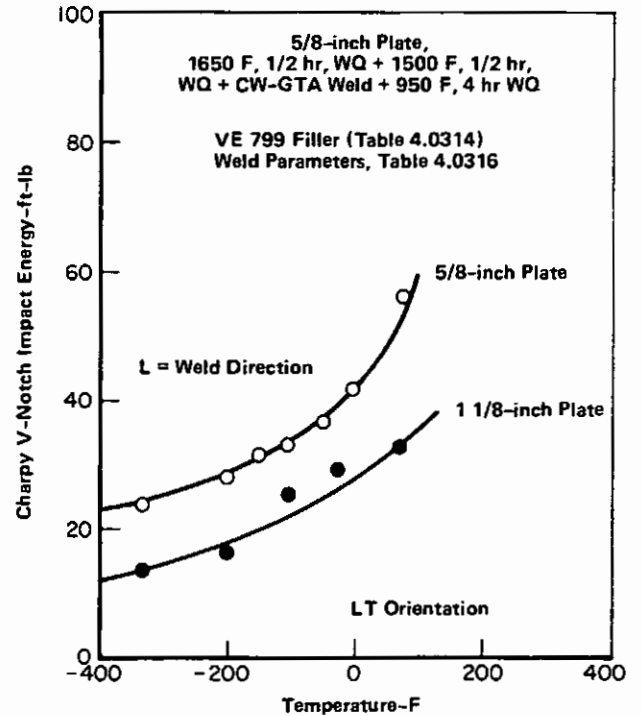


FIGURE 4.03114. EFFECT OF TEMPERATURE ON FUSION ZONE IMPACT ENERGY OF CW-GTA WELDS IN VIM-VAR PLATE (12) P. 83

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo
AF1410

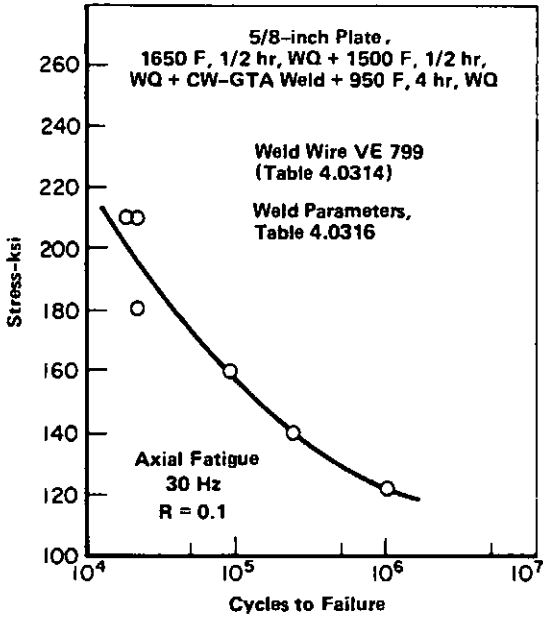


FIGURE 4.03116. FUSION ZONE FATIGUE STRENGTH OF CW-GTA WELD IN VIM-VAR MELT PLATE (12) P. 44

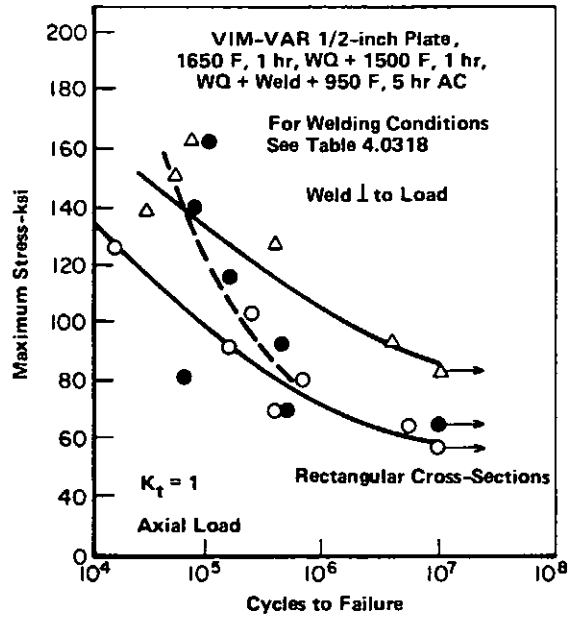


FIGURE 4.03117. S-N CURVES FOR GTA BUTT WELDS IN VIM-VAR MELT 1/2-INCH PLATE WITH WELD BEAD GROUND OFF (8) P. 145-146

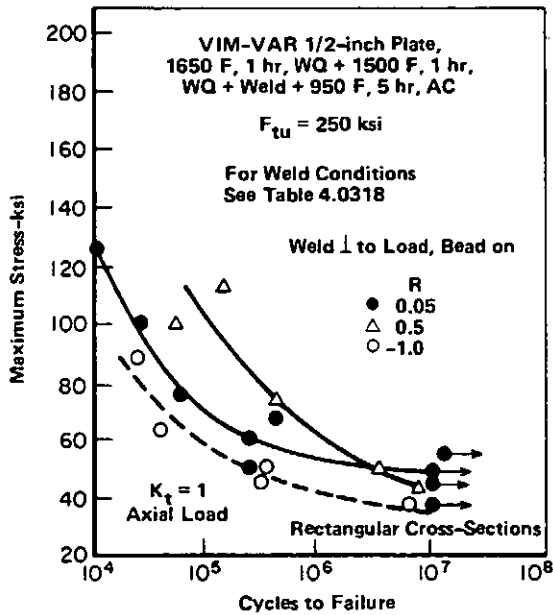


FIGURE 4.03118. S-N CURVES FOR GTA BUTT WELDS IN VIM-VAR 1/2-INCH PLATE WITH WELD BEAD ON (8) P. 135, 138, 139

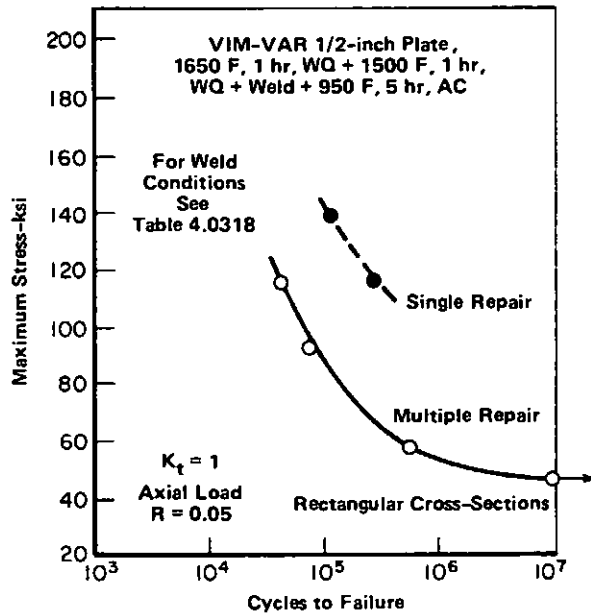


FIGURE 4.03119. S-N CURVES FOR GTA REPAIRED BUTT WELDS IN VIM-VAR 1/2-INCH PLATE WITH BEAD GROUND OFF (8) P. 144-146

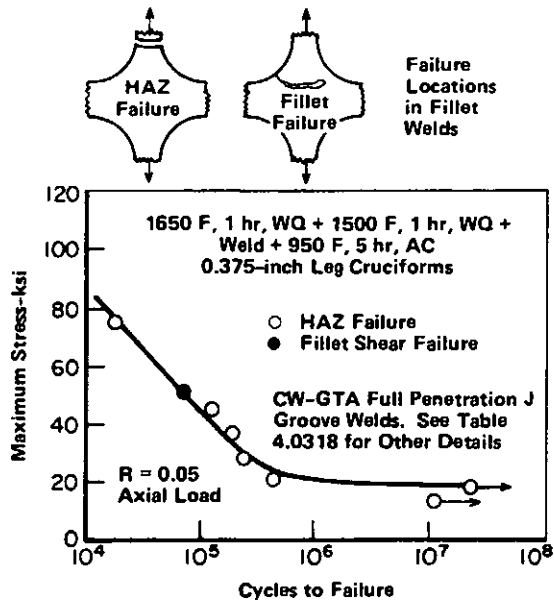


FIGURE 4.03120. S-N CURVE FOR FULL PENETRATION FILLET WELDED VIM-VAR MELT CRUCIFORMS WITH NONSYMMETRICAL JOINTS (8) P. 163

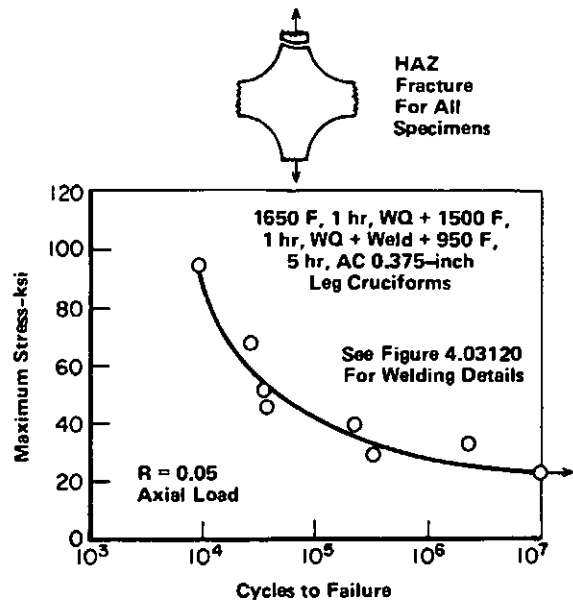


FIGURE 4.03121. S-N CURVE FOR FULL PENETRATION FILLET WELDED VIM-VAR MELT CRUCIFORMS WITH SYMMETRICAL JOINTS (8) P. 161

Fe
0.16 C
14 Co
10 Ni
2 Cr
1 Mo

AF1410

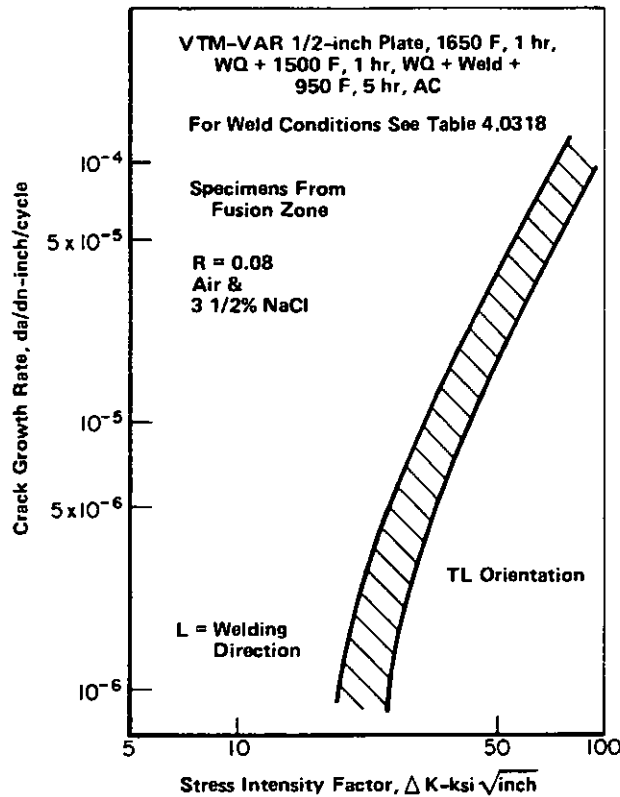


FIGURE 4.03122. FATIGUE CRACK GROWTH RATE IN AIR AND IN 3.5% SALTWATER FOR GTA WELD IN VIM-VAR 1/2-INCH PLATE (8) P. 167

	Fe
0.16	C
14	Co
10	Ni
2	Cr
1	Mo

AF1410

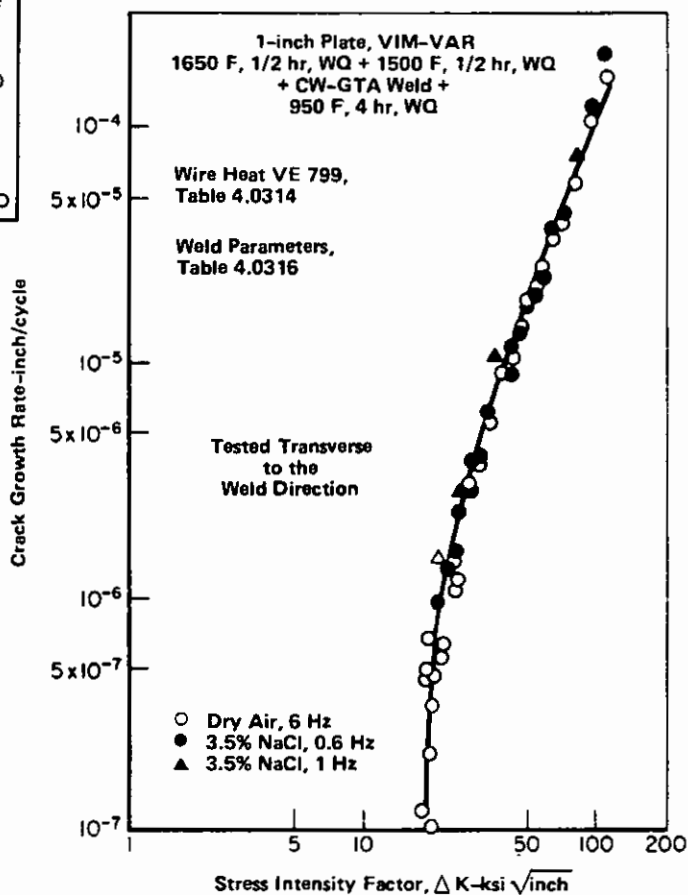


FIGURE 4.03123. FATIGUE CRACK GROWTH OF FUSION ZONE OF CW-GTA WELDS IN VIM-VAR MELT PLATE (12) P. 46 & 47

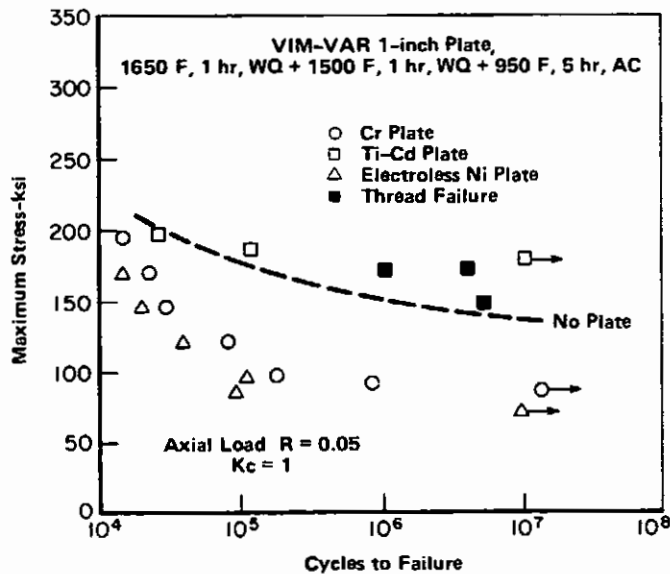


FIGURE 4.041. S-N CURVES FOR VIM-VAR MELT PLATE FOR SPECIMENS PLATED BY VARIOUS PROCESSES (8) P. 121