	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

1 **GENERAL**

4340 is a low alloy steel with excellent hardenability because of its appreciable contents of carbon, nickel, chromium, and molybdenum. As a result, quench-and-temper heat treatments develop excellent combinations of strength and toughness uniformly over a wide range of section sizes. These characteristics make the alloy attractive for many critical applications from -200 to 900 F, particularly in heavy sections for which leaner alloy steels are not capable of developing uniformly high properties. Some of the current applications include gears, pinions, crankshafts, piston rods, landing gear, bolts, and other fasteners. Because of its high hardenability, its weldability is inferior to that of steels with lower contents of carbon and other alloying elements. Consequently, it is not normally recommended for applications in which high weld joint efficiently is essential. Nevertheless, with proper precautions it can be welded with arc and gas welding processes and with the electron beam technique.

1.01 Commercial Designation

4340.

1.02 Alternate Designations

AISI 4340, SAE 4340, E 4340, 4340 H, and UNS G43400.

1.021 The E 4340 designation indicates electric furnace melted.

1.022 The 4340 H designation indicates that the steel is made within strict hardenability limits; consequently, wider composition limits are allowed for individual alloying elements.

1.03 Specifications

Specifications, Table 1.03.

1.04 Composition

Composition, Table 1.04.

1.05 Heat Treatment

1.051 Normalize, 1550 to 1700 F, air cool (30) (33) (69) (70) (76).

1.052 Temper after normalize for improved machinability and toughness, 800 to 1200 F 1/2 hr minimum, air cool.

1.053 Anneal, 1450 to 1575 F, air cool (30) (33) (76).

1.054 Spheroidize anneal, 1275 F hold 2 hr, increase to 1325 F hold 2 hr, cool to 1200 F hold 6 hr, furnace cool to 1100 F, air cool. Alternative schedule, 1375 F several hours, cool to room temperature (33) (76).

1.055 Stress relief, 1100 to 1250 F, air cool (33) (69) (76).

1.056 Harden, 1475 to 1600 F, oil-quench to about 150 F. For sections greater than about 3 inch in diameter, better uniformity is obtained by water-quenching, but the risks of distortion and quench cracks are greatly increased. A modified technique called martempering, which minimizes distortion and cracking, consists of quenching into hot salt at 450 to 525 F, holding until the parts are uniform in temperature which requires about 2 to 6 minutes, and then air cooling. Sections up to about 4 inch in diameter can be fully hardened in this manner (30) (33) (69) (70) (76).

1.057 Temper after hardening, 350 to 450 F or 750 to 1200 F, air cool or water-quench. Tempering in the range 450 to 750 F is not recommended because tempered martensite embrittlement, common to most low alloy steels, occurs in that range. The 4340 alloy is resistant to temper embrittlement which occurs in some low alloy steels in the range 800 to 1100 F. In order to minimize quench cracking, 4340 parts should be placed in the tempering furnace shortly after the quench operation while they are between 150 F and ambient temperature (30) (33) (69) (70) (76).

1.06 Hardness

1.061 Effect of tempering temperature on hardness, Figure 1.061.

1.062 Effect of bar diameter on surface hardness for various heat treated conditions, Figure 1.062.

1.063 Effect of bar diameter on as-quenched hardness at various depths in bar, Figure 1.063.

1.064 Effect of temperatures from 80 F to -423 F on hardness of bar heat treated to a hardness level of R_C 51, Figure 1.064.

1.065 End-quench hardenability, Figure 1.065.

1.07 Forms and Conditions Available

1.071 Wrought products including bars, rods, plates, sheets, tubes, and billets are available in the annealed, normalized or spheroidized condition. Forgings and castings are available in any heat treated condition.

1.08 Melting and Casting Practice

1.081 The 4340 alloy is generally air melted in basic electric, basic open hearth, or basic oxygen furnaces. For some applications requiring exceptional quality, it is induction or consumable electrode remelted in vacuum or electroslag refined.

1.09 Special Considerations

1.091 Most of the common electroplating processes including chromium, cadmium, nickel, copper, silver, and zinc tend to induce some degree of hydrogen embrittlement in 4340 steel that has been heat treated to tensile strength (F_{tu}) levels above 180 ksi. Most acid pickling processes can also induce hydrogen embrittlement at high strength levels. One exception is nitric acid pickling at concentrations above 1.0N. Anodic cleaning processes and alkaline descaling are nonhydrogen embrittling. Baking 2 to 6 hr at 375 F normally relieves hydrogen embrittlement resulting from electroplating or acid pickling (4) (5).

1.0911 Adding rare-earths such as cerium and lanthanum to 4340 tends to minimize or prevent hydrogen embrittlement (12).

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

1.09111 Effects of cerium content on delayed fracture in air of 0.5-inch thick precracked specimens that have been cathodically charged with hydrogen, Figure 1.09111.

1.092 Like other martensite and ferrite steels, 4340 undergoes a transition from ductile to brittle behavior at low temperatures; the transition temperature varies with the heat treatment and the degree of stress concentration. (See Figures 3.0331 through 3.0339, 3.03711 through 3.03715, and Figure 3.03721.)

1.093 Increasing contents of sulfur and phosphorus are detrimental to the notch toughness of 4340. (See Figures 3.0237, 3.02724, 3.02727, 3.0337, and 3.0338). Treatment of the molten alloy with rare-earths minimizes the adverse effects of sulfur (see Figure 3.0338).

1.094 Surface decarburization, which can occur during high temperature processing or during heat treatment, is detrimental to fatigue properties, particularly at the higher strength levels. For optimum fatigue properties, decarburization should be prevented, for example, by controlling the atmosphere during heat treatment, or by removing critical decarburized areas by machining.

1.095 Thin sections tend to air harden; that is, they may become hard and brittle (similar to the as-oil-quenched properties rather than the usual normalized properties) when air cooled from temperatures above 1400 F. Tempering restores toughness and ductility and reduces hardness of air hardened materials just as it does for oil-quenched material.

1.096 For quenched-and-tempered 4340, fracture toughness increases with increasing austenitizing temperatures when subsequent tempering temperatures are below 600 F (see Figures 3.02723, 3.02724, and 3.02725 and Table 3.02726). On the other hand, impact properties, as well as other measures of ductility, decrease with increasing austenitizing temperatures (see Figures 3.0234, 3.0235, and 3.0236). Because the reason for this anomaly is not presently understood, the use of unusually high austenitizing temperatures to obtain high fracture toughness is not generally practiced.

2 PHYSICAL AND ENVIRONMENTAL EFFECTS

2.01 **Thermal Properties**

2.011 Melting range, about 2740 F (31) (32).

2.012 Phase changes.

2.0121 Time-temperature-transformation diagram, Figure 2.0121.

2.0122 Upon heating under equilibrium conditions, transformation from pearlite or martensite to austenite starts at 1335 F (A_c1) and is complete at 1425 F (A_c3) (69).

2.0123 Upon slow cooling under equilibrium conditions, the transformation from austenite to pearlite starts at 1310 F (A_r3) and is complete at 1210 F (A_r1) (69).

2.0124 Upon rapid quenching from the austenitic condition, the transformation to martensite starts at 570 F (Ms) and is complete at 400 F (Mf)(34).

2.013 Thermal conductivity, Figure 2.013.

2.014 Thermal expansion, Figure 2.014.

2.015 Specific heat, 0.107 Btu/lb ft (31) (32).

2.016 Thermal diffusivity.

2.02 **Other Physical Properties**

2.021 Density, 0.283 lb/in.^{3} (31) (32).

2.022 Electrical properties.

2.0221 Electrical properties from room temperature to 1100 F, Figure 2.0221.

2.023 Magnetic properties. Alloy is ferromagnetic.

2.024 Emittance.

2.025 Damping capacity.

2.03 **Chemical Environment**

2.031 Since the alloy is susceptible to rusting, it should be protected by means of paint, electroplate, anode, or other suitable corrosion inhibitor for long time exposures in moist, marine, or other corrosive environments.

2.032 An exhaustive study, including laboratory salt spray tests and alternate immersions in salt solutions, as well as outdoor exposures in urban and seacoast environments, showed that 4340 has good resistance to stress-corrosion when heat treated to strength levels below 180 ksi, which requires tempering temperatures above 950 F. The resistance decreases with increasing tensile strength above the 180 ksi level. Also, the susceptibility is greater when stresses are applied in the short transverse and long transverse directions, rather than in the longitudinal direction (13).

2.0321 Threshold stress intensity factor (K_{Iscc}) for stress-corrosion cracking of plate in aerated 3 percent aqueous sodium-chloride solution at various corresponding levels of tensile strength and critical stress intensity factor (K_{Ic}), Table 2.0321.

2.0322 Effect of variations in yield strength on threshold stress intensity factor for stress-corrosion crack growth in 3.5 percent solution of sodium-chloride in water, Figure 2.0322.

2.0323 Effect of yield strength on resistance to stress-corrosion cracking of heat treated 4340 in aqueous salt solutions, Figure 2.0323.

2.0324 Effect of increasing yield strength, induced by decreasing tempering temperature or by increasing amounts of cold rolling up to 50 percent reduction, on resistance to stress-corrosion cracking in an environment of hydrogen-sulfide (H_2S) gas at 50 psig at room temperature, Figure 2.0324.

2.0325 Effect of cold working and stress relief on resistance to stress-corrosion cracking in an environment of hydrogen-sulfide (H_2S) gas at 50 psig at room temperature, Figure 2.0325.

2.0326 Time to stress-corrosion failure of quenched-and-tempered plate in distilled water at various temperatures, Figure 2.0326.

2.0327 Effect of temperature on resistance to stress-corrosion cracking in an environment of dry hydrogen gas at 80 psig, Figure 2.0327.

2.0328 Effect of temperature on resistance to stress-corrosion cracking in an environment of hydrogen-sulfide gas at 50 psig, Figure 2.0328.

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

2.0329 Effect of gas pressure on resistance to stress-corrosion cracking in environments of hydrogen and hydrogen-sulfide gases at room temperature, Figure 2.0329.

2.03210 Effect of cerium additions on time to stress-corrosion failure in an aqueous 3.5-percent sodium-chloride solution, Figure 2.03210.

2.03211 Effect of a brief prestress of precracked specimens on the threshold stress intensity (K_{Iscc}) for stress-corrosion cracking in 3.5 percent aqueous sodium-chloride solution, Figure 2.03211.

2.04 **Nuclear Environment**

2.041 In general, nuclear irradiation tends to cause the hardness and strength of low alloy steels to increase and the ductility and toughness to decrease. Quenched and tempered material is affected somewhat less than normalized or annealed material.

3 MECHANICAL PROPERTIES

3.01 **Specified Mechanical Properties**
Specified mechanical properties, Table 3.01.

3.02 **Mechanical Properties at Room Temperature**

3.021 Tension – Stress-strain diagrams – Tension properties.

3.0211 Room temperature tensile stress-strain curves for bar heat treated to various strength levels, Figure 3.0211.

3.0212 Complete tensile stress-strain curves at room temperature for tube in two different conditions, Figure 3.0212.

3.0213 Effect of tempering temperature on tensile properties of oil-quenched bar, Figure 3.0213.

3.0214 Effect of tempering temperature on tensile properties of normalized bar, Figure 3.0214.

3.0215 Effect of section size on tensile properties of bar in several heat treated conditions, Figure 3.0215.

3.0216 Effect of strain rate on tensile properties of oil-quenched-and-tempered bar at room temperature, Figure 3.0216.

3.0217 Effect of strain rate on the ultimate tensile strength and elongation of bar in various heat treated conditions, Figure 3.0217.

3.0218 Tensile properties for different orientations in forging, Table 3.0218.

3.0219 Effects of various tempering temperatures on tensile properties of electroslag remelted plate after conventional oil-quenching and after martempering, Table 3.0219.

3.02110 Comparison of tensile properties of air induction melted cross rolled plate of normal purity with those of high purity plate produced by vacuum induction melting followed by vacuum arc remelting, Table 3.02110.

3.02111 Effects of cold working and stress relief on room temperature tensile properties of oil-quenched-and-tempered forgings, Figure 3.02111.

3.02112 Effects of tempering temperature and 10 percent cold reduction and aging at 400 F on tensile properties of oil-quenched bar, Figure 3.02112.

3.02113 Effects of cold working and aging on tensile properties of bar that had previously been oil-quenched-and-tempered at 1000 F, Figure 3.02113.

3.02114 Effects of cold working and aging on tensile properties of bar that had been previously oil-quenched-and-tempered at 1150 F, Figure 3.02114.

3.02115 Effects of cold work by hydrostatic extrusion and of retempering on tensile properties of bar that had been previously oil-quenched-and-tempered, Table 3.02115.

3.02116 Effect of cerium additions on room temperature tensile properties, Figure 3.02116.

3.02117 Tensile properties of annealed bar, Table 3.02117.

3.02118 Comparison of room temperature tensile properties in two heat treated conditions of cast keel block and wrought plate made from the same air induction melted heat, Table 3.02118.

3.022 Compression – Stress-strain diagrams – Compression properties.

3.0221 Room temperature stress-strain curve in compression for bar heat treated to F_{tu} = 260 ksi, Figure 3.0221.

3.0222 Relationship between compressive yield strength and tensile strength, Figure 3.0222.

3.023 Impact.

3.0231 Effect of tempering temperature on impact properties of oil-quenched bar at room temperature, Figure 3.0231.

3.0232 Effect of tempering temperature on impact properties of normalized bar at room temperature, Figure 3.0232.

3.0233 Effects of tempering temperature and melting practice on impact properties at room temperature, Figure 3.0233.

3.0234 Effects of tempering temperature and austenitizing temperature and resulting grain size on impact properties at room temperature of bar that had been air melted and vacuum degassed, Figure 3.0234.

3.0235 Effects of tempering temperature after two different austenitizing treatments on impact properties at room temperature of air melted and electroslag refined forgings, Figure 3.0235.

3.0236 Effect of austenitizing temperature on the room temperature impact properties of oil-quenched-and-tempered vacuum arc remelted plate, Figure 3.0236.

3.0237 Effects of tempering temperature and phosphorus content on impact properties at room temperature of plate that had been vacuum induction melted, Figure 3.0237.

3.0238 Comparison of room temperature Charpy V-notch impact properties in two heat treated conditions of cast keel block and wrought plate made from the same induction melted heat, Table 3.0238.

3.024 Bending.

3.025 Torsion and shear.

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

3.0336 Effect of low temperatures on the impact properties of bar heat treated to two levels of hardness, Figure 3.0336.

3.0337 Effects of temperature and phosphorus content on impact properties of plate that have been vacuum induction melted, Figure 3.0337.

3.0338 Effects of rare-earth treatment and variations in sulfur content on impact transition curves of vacuum induction melted plate in two heat treated conditions, Figure 3.0338.

3.0339 Comparison of impact properties over a range of temperatures for quenched-and-tempered and normalized-and-tempered 4340, Figure 3.0339.

3.03310 Impact properties at various temperatures for different orientations in forgings, Table 3.03310.

3.03311 Comparison of low temperature impact properties of air induction melted cross rolled plate of normal purity with those of high purity plate produced by vacuum induction melting followed by vacuum arc remelting, Figure 3.03311.

3.034 Bending.

3.035 Torsion and shear.

3.0351 Effect of low temperatures on shear strength of bar quenched and tempered to two levels of hardness, Figure 3.0351.

3.036 Bearing.

3.037 Stress concentration.

3.0371 Notch properties.

3.03711 Effect of temperatures from 80 to −200 F on ratio of notched tensile strength to tensile strength of bar heat treated to two levels of hardness, Figure 3.03711.

3.03712 Effect of temperatures from 80 to −423 F on ratio of notched tensile strength to tensile strength of plate heat treated to a hardness level of R_C 36, Figure 3.03712.

3.03713 Effect of low temperatures on notched strength of bar heat treated to F_{tu} = 270 ksi, Figure 3.03713.

3.03714 Effect of low temperatures on tensile strength and crack strength of sheet in three heat treated conditions, Figure 3.03714.

3.03715 Effect of temperatures from −300 to 300 F on tensile strength and crack strength of vacuum induction melted and vacuum induction remelted bar heat treated to F_{tu} = 265 ksi, Figure 3.03715.

3.0372 Fracture toughness.

3.03721 Effect of temperatures from −100 to 200 F on fracture toughness of plate heat treated to two different strength levels, Figure 3.03721.

3.03722 Fracture toughness at 75 and −200 F of plate heat treated to a room temperature tensile strength level of 275 ksi, Table 3.03722.

3.038 Combined properties.

3.04 Creep and Creep Rutpure Properties

3.041 Stress-rupture properties at 900 - 1100 F of normalized-and-tempered smooth and notched bar, Figure 3.041.

3.05 Fatigue Properties

3.051 Fatigue life of bar at room temperature and at −320 F, Figure 3.051.

3.052 Effect of specimen sizes from 1/8- to 1-inch diameter on fatigue life of bar, Figure 3.052.

3.053 Fatigue life of bare and coated bar in environments of air and 3.5 percent aqueous sodium-chloride solution, Figure 3.053.

3.054 Constant-life fatigue curves at 80 F for smooth and notched bar heat treated to F_{tu} = 260 ksi, Figure 3.054.

3.055 Constant-life fatigue curves at 80 F for smooth and notched bar heat treated to F_{tu} = 150 ksi, Figure 3.055.

3.056 Constant-life fatigue curves at 600 F for smooth and notched bar heat treated to F_{tu} = 150 ksi, Figure 3.056.

3.057 Constant-life fatigue curves at 1000 F for smooth and notched bar heat treated to F_{tu} = 150 ksi, Figure 3.057.

3.058 Fatigue crack-growth rate in air of air melted and electroslag refined forgings that have been oil-quenched and tempered at two different temperatures, Figure 3.058.

3.059 Fatigue crack-growth rate of plate at various strength levels in air and in aerated 3 percent aqueous sodium-chloride solution, Figure 3.059.

3.0510 Effects of various environments and a sodium-borate, sodium-nitrite inhibitor on fatigue crack-growth rate of plate heat treated to two strength levels, Figure 3.0510.

3.0511 Fatigue crack-growth rates for plate tested at room temperature in air at three levels of relative humidity, Figure 3.0511.

3.0512 Fatigue crack-growth rates for plate tested at room temperature in distilled water at three frequencies and in argon at one frequency, Figure 3.0512.

3.0513 Effects of tempering temperature and stress-intensity range on fatigue crack-growth rate in air, Figure 3.0513.

3.06 Elastic Properties

3.061 Poisson's ration, 0.3 (74).

3.062 Modulus of elasticity.

3.0621 Effect of temperatures from −423 to 1200 F on modulus of elasticity, Figure 3.0621.

3.063 Modulus of rigidity, 11.2 x 10^3 ksi (74).

3.064 Tangent modulus.

3.0641 Tangent modulus curves in compression at room and elevated temperatures, Figure 3.0641.

3.065 Secant modulus.

3.0651 Secant modulus curves in compression at room and elevated temperatures, Figure 3.0651.

4 FABRICATION

4.01 Forming

4.011 Although the cold formability of 4340 is inferior to that of steels with lower carbon and alloy contents, it can be cold formed to a limited extent. Optimum formability is obtained in the spheroidize annealed condition.

4.012 Forging and other hot working operations can readily be conducted on 4340 in the temperature range of 1950 to 2250 F. Because of its relatively high alloy content, somewhat more

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

force is required than for hot working plain carbon or lower alloy steels. Slow cooling, preferably in a furnace, is recommended after hot work (32) (33) (70).

4.02 Machining and Grinding

4.021 Type 4340 can be machined without difficulty in the annealed and cold drawn conditions. Based on a 100 percent machinability rating for cold rolled B1112 steel, the rating for 4340 is 55 percent in the cold drawn condition and 45 percent in the annealed condition. Machining is more difficult for quenched-and-tempered material; the difficulty increases with increasing hardness. Good machinability is obtained by normalizing and tempering at 1200 F (32) (33).

4.03 Joining

4.031 When fusion welded, 4340 is susceptible to underbead cracking, heat affected zone embrittlement, and thermal stress cracking unless proper precautions and controls are exercised. Proper procedures include the use of low hydrogen electrodes, preheat and interpass temperatures of at least 550 F, and postweld stress relief at 1100 to 1200 F immediately after welding followed by slow cooling. Full quench-and-temper heat treatment after welding is necessary to develop optimum properties in weldments. Type 4340 can be successfully welded by the electron beam method (33) (70) (75).

4.04 Surface Treating

4.041 (See Code 1203, 4140 steel, section 4.04.)

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0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

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52 "Elevated-Temperature Tensile Properties of SAE 4340 Steel Heat Treated to 260,000 – 280,000 psi Ultimated Tensile Strength", ER 9145-4 (May 3, 1957).

53 Sachs, G. and Klier, E. P., "Survey of Low-Alloy Aircraft Steels Heat-Treated to High Strength Levels", WADC TR 53-254, Pt. 5 (September 1954).

54 McGee, R. L., Campbell, J. E., Carlson, L. R., and Manning, G. K., "The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures", WADC TR 58-386 (November 1958).

55 Banerjee, B. R. and Hauser, J. T., "Research and Application Engineering to Determine the Effect of Processing Variables on Crack Propagation of High-Strength Steels and Titanium", ASD-TDR-62-1034, Pt. 1 (April 1963).

56 Banerji, S. K., McMahon, C. J., and Feng, H. C., "Intergranular Fracture in 4340-Type Steels: Effects of Impurities and Hydrogen", Metallurgical Transactions, Vol. 9A (February 1978).

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

57 Hemirl, G. J., and Hughes, P. J., "Structural Efficiencies of Various Aluminum, Titanium and Steel Alloys at Elevated Temperatures", NACA TN 2975 (July 1953).

58 Hesbur, M. G., Abraham, K. P., and Prasad, Y.V.R.K., "Effects of Electroslag Refining on the Fracture Toughness and Fatigue Crack Propagation Rates in Heat Treated AISI 4340 Steel", Engineering Fracture Mechanics, Vol. 13 (1980).

59 AMS 5331 C (November 15, 1972).

60 AMS 6359 D (July 15, 1980).

61 AMS 6414 C (April 15, 1980).

62 AMS 6415 J (October 10, 1979).

63 Alloy Cross Index, Battelle Columbus Laboratories (1982).

64 Unified Numbering System, SAE-ASTM (1977).

65 Unterweiser, P. M. and Penzenik, "Worldwide Guide to Equivalent Irons and Steels", ASM.

66 Arnessen, J. E., Personal Communication, Pratt and Whitney Aircraft Corp. (May 7, 1959).

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68 Ritchie, R. O. and Horn, R. M., "Further Considerations on the Inconsistency in Toughness Evaluation of AISI 4340 Steel Austenitized at Increasing Temperatures", Metallurgical Transactions, Vol. 9A (March 1978).

69 Mechanical Properties of Steel, Republic Steel Corp. (1961).

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71 Khan, K. H. and Wood, W. E., "The Effect of Step Quenching on the Microstructure and Fracture Toughness of AISI 4340 Steel", Metallurgical Transactions, Vol. 9A (July 1978).

72 Horn, R. M. and Ritchie, R. O., "Mechanisms of Tempered Martensite Embrittlement in Low-Alloy Steels", Metallurgical Transactions, Vol. 9A (August 1978).

73 Floreen, S., "The Fracture Toughness of Cast High-Strength Steels", Trans. ASME, Journal of Engineering Materials and Technology, Vol. 99 (January 1977).

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75 Stout, R. D. and Doty, W. D., "Weldability of Steels", Welding Research Council (1971).

76 Metals Handbook, Ninth Edition, Vol. 4, American Society for Metals (1981).

77 Crooker, T. W., "Optimizing Crack-Growth Resistance in Engineering Alloys", Naval Research Laboratory Report 8110 (April 18, 1977).

78 Kula, E. B. and Anctil, A. A., "Tempered Martensite Embrittlement and Fracture Toughness in SAE 4340 Steel", Journal of Materials, Vol. 4 (December 1969).

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo				
Forms					
Bar, Billets, Forgings, and Tubing	Sheet, Strip, and Plate	Castings	Wire	Bolting Material	General
AMS 6414 C AMS 6415 J ASTM A322 ASTM A519 ASTM A304 ASTM A646	AMS 6359 D ASTM A505 Fed. QQ-S-627	AMS 5331 C MIL-S-22141	ASTM A547	ASTM A320	MIL-S-8844B MIL-S-16974 MIL-S-5000 SAE J404j SAE J412h SAE J770c

TABLE 1.03. SPECIFICATIONS (59-65)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo					
Form	Wrought 4340 (61)[a]		Wrought 4340H(33)		Castings(59)	
	Percent		Percent		Percent	
Composition	Min	Max	Min	Max	Min	Max
C	0.38	0.43	0.37	0.44	0.38	0.46
Mn	0.60	0.90	0.55	0.90	0.60	1.00
Si	0.15	0.35	0.15	0.30	0.50	0.90
P	–	0.015	–	0.035	–	0.025
S	–	0.015	–	0.040	–	0.025
Cr	0.70	0.90	0.65	0.95	0.65	1.00
Ni	1.65	2.00	1.55	2.00	1.65	2.00
Mo	0.20	0.30	0.20	0.30	0.30	0.45
Cu	–	0.35	–	–	–	0.35

(a) The other AMS specifications for wrought 4340 (references 60 and 62) allow 0.025 percent maximum phosphorus and sulfur; whereas most ASTM and SAE specifications allow 0.035 percent maximum phosphorus and 0.040 percent maximum sulfur for wrought 4340.

TABLE 1.04. COMPOSITION

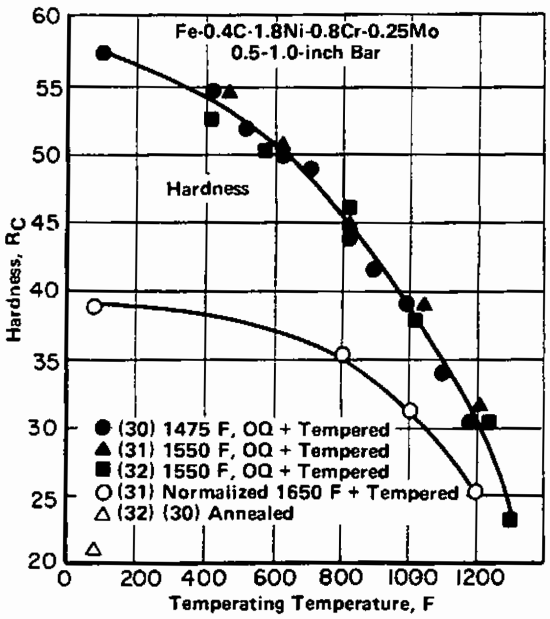


FIGURE 1.061. EFFECT OF TEMPERING TEMPERATURE ON HARDNESS (30, 31, 32)

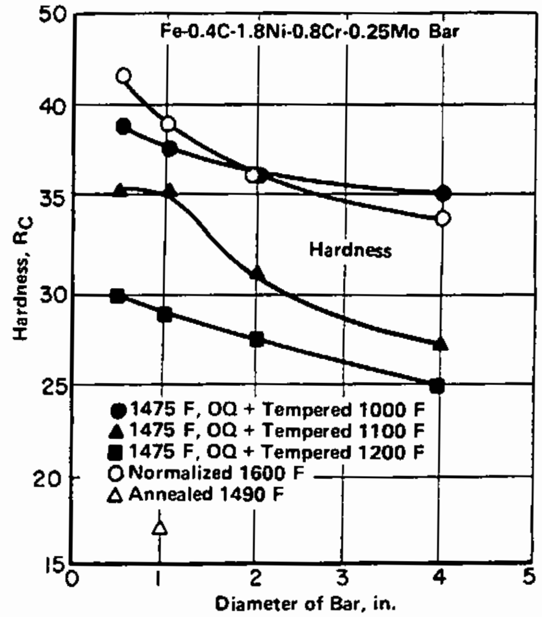


FIGURE 1.062. EFFECT OF BAR DIAMETER ON SURFACE HARDNESS FOR VARIOUS HEAT TREATED CONDITIONS (30)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

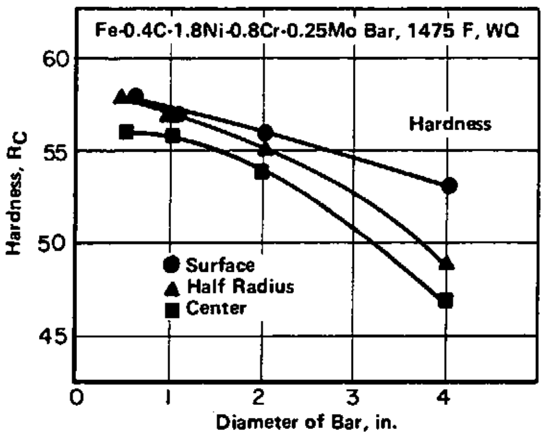


FIGURE 1.063. EFFECT OF BAR DIAMETER ON AS-QUENCHED HARDNESS AT VARIOUS DEPTHS IN BAR (30)

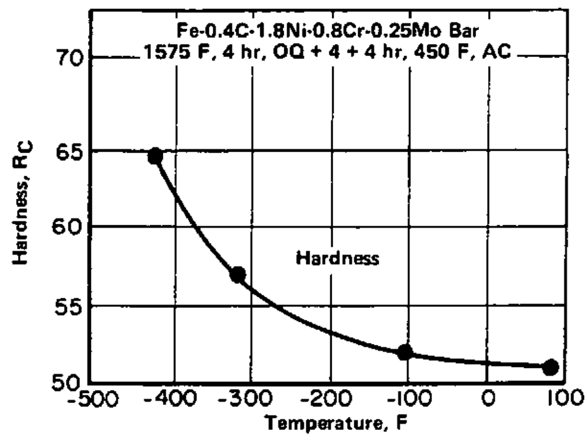


FIGURE 1.064. EFFECT OF TEMPERATURES FROM 80 F TO -423 F ON HARDNESS OF BAR HEAT TREATED TO A HARDNESS LEVEL OF RC 51 (31)

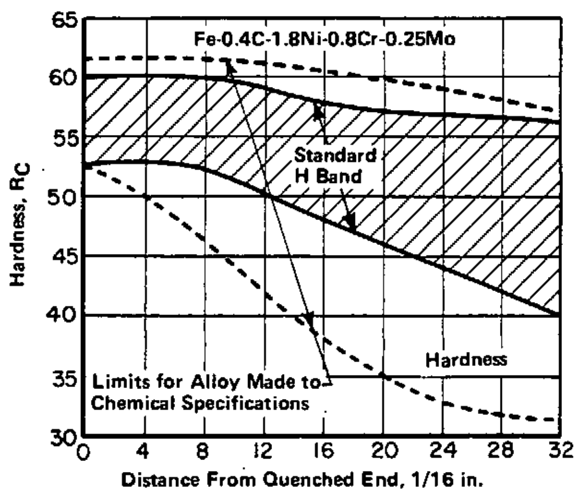


FIGURE 1.065. END-QUENCH HARDENABILITY (33)

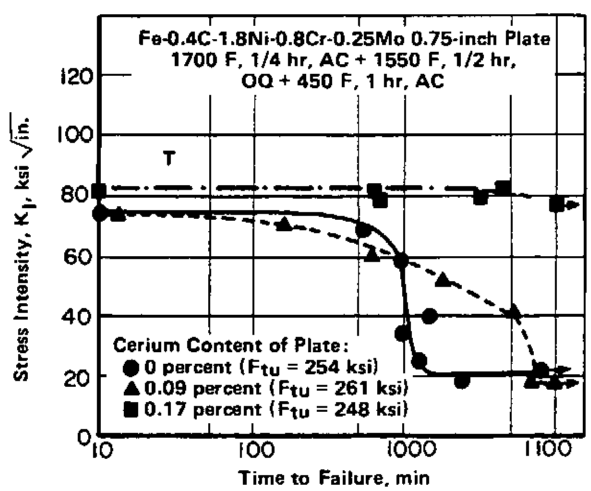


FIGURE 1.09111. EFFECTS OF CERIUM CONTENT ON DELAYED FRACTURE IN AIR OF 0.5-INCH THICK PRECRACKED SPECIMENS THAT HAVE BEEN CATHODICALLY CHARGED WITH HYDROGEN (12)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

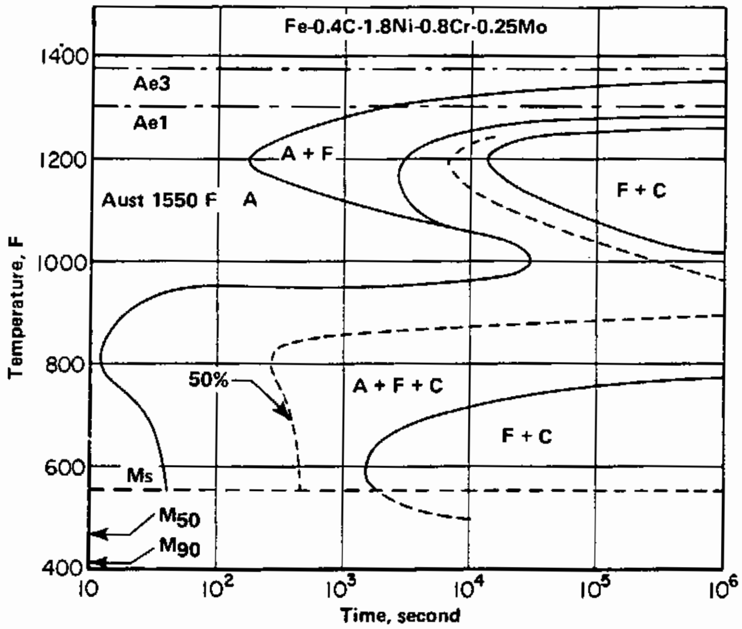


FIGURE 2.0121. TIME-TEMPERATURE-TRANSFORMATION DIAGRAM (34)

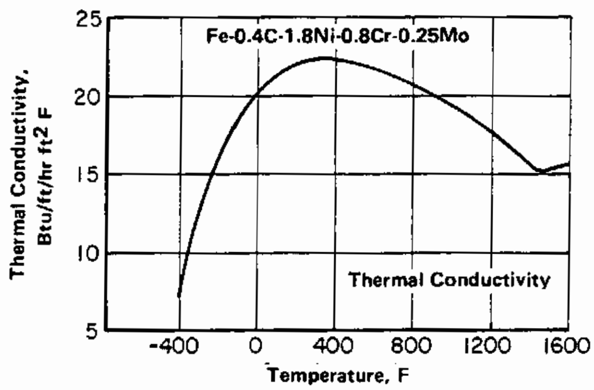


FIGURE 2.013. THERMAL CONDUCTIVITY (37)

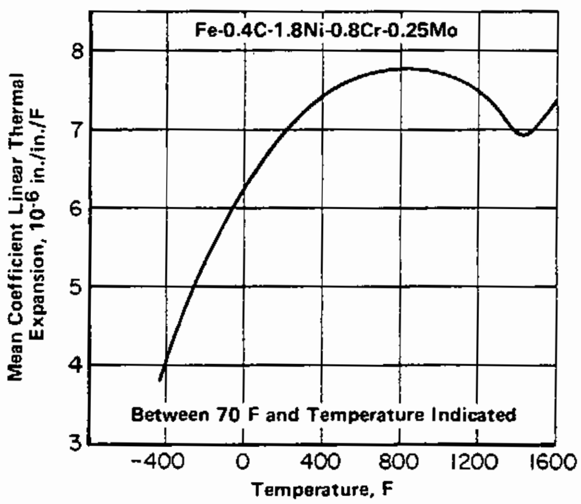


FIGURE 2.014. THERMAL EXPANSION (37)

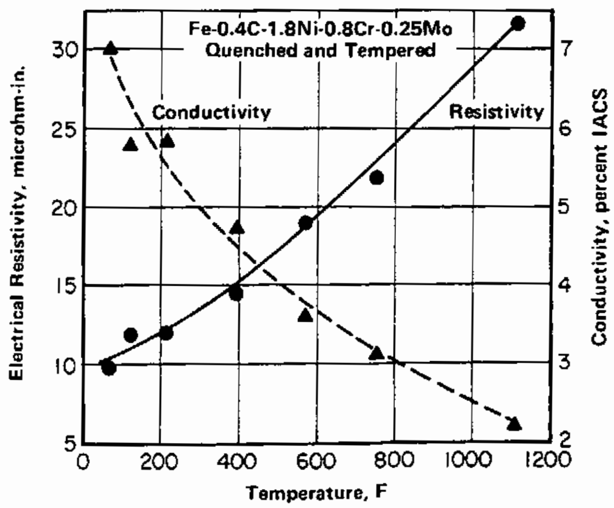


FIGURE 2.0221. ELECTRICAL PROPERTIES FROM ROOM TEMPERATURE TO 1100 F (31, 32, 33)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo		
Form	1-inch Plate		
Condition	1600 F 1 hr. AC + 1550 F 1 hr. OQ + Temper 1 hr. AC		
Temper, F	F_{tu}, ksi	K_{Ic}, ksi √in.	K_{Iscc}, ksi √in.
1200	145	>141	111
950	195	104	26
400	285	56	10.5

Note: K_{Ic} and K_{Iscc} specimens, cantilever bending, 1.0 in. thick. T-L direction.

TABLE 2.0321. THRESHOLD STRESS INTENSITY FACTOR (K_{Iscc}) FOR STRESS-CORROSION CRACKING OF PLATE IN AERIATED 3 PERCENT AQUEOUS SODIUM-CHLORIDE SOLUTION AT VARIOUS CORRESPONDING LEVELS OF TENSILE STRENGTH AND CRITICAL STRESS INTENSITY FACTOR (K_{Ic}) [1]

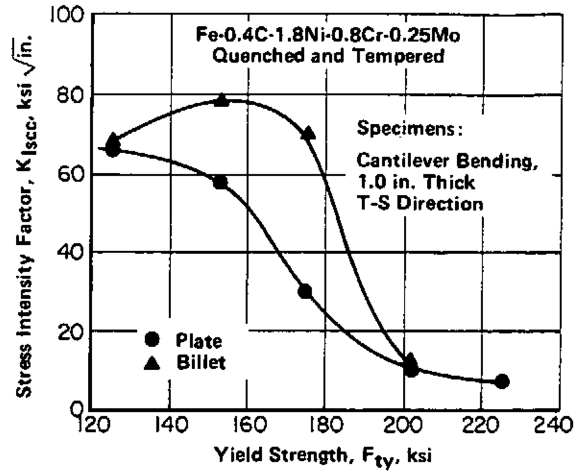


FIGURE 2.0322. EFFECT OF VARIATIONS IN YIELD STRENGTH ON THRESHOLD STRESS INTENSITY FACTOR FOR STRESS-CORROSION CRACK GROWTH IN 3.5 PERCENT SOLUTION OF SODIUM CHLORIDE IN WATER (13)

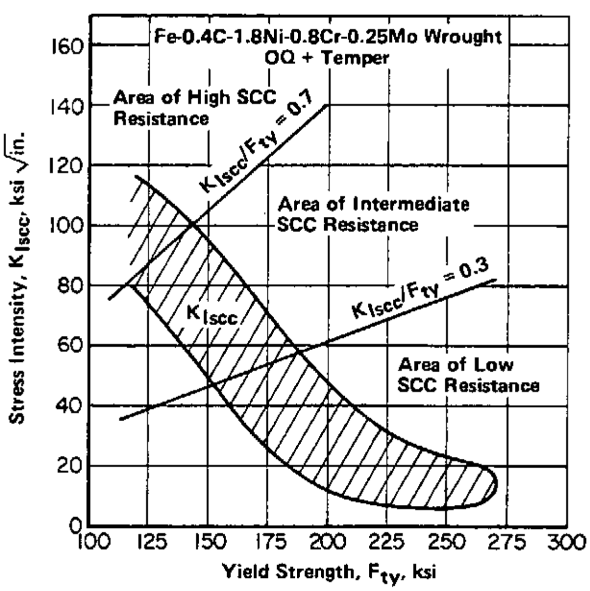


FIGURE 2.0323. EFFECT OF YIELD STRENGTH ON RESISTANCE TO STRESS-CORROSION CRACKING (SCC) OF HEAT TREATED 4340 IN AQUEOUS SALT SOLUTIONS (19)

Note: Shaded range summarizes data from a number of test programs.

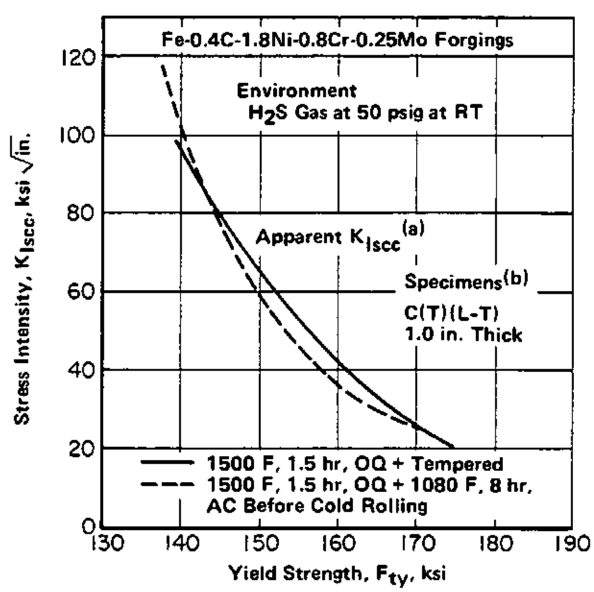


FIGURE 2.0324. EFFECT OF INCREASING YIELD STRENGTH, INDUCED BY DECREASING TEMPERING TEMPERATURE OR BY INCREASING AMOUNTS OF COLD ROLLING UP TO 50 PERCENT REDUCTION ON RESISTANCE TO STRESS-CORROSION CRACKING IN AN ENVIRONMENT OF HYDROGEN-SULFIDE (H_2S) GAS AT 50 PSIG AT ROOM TEMPERATURE (21)

Notes: (a) The term "apparent K_{Iscc}" is used to distinguish between results developed under rising load conditions and results obtained by means of long-time, constant-load or constant-displacement tests.
(b) ASTM Standardization News, May 1982, p 31-32, provides "Standard Designation Code for Fracture Specimens, Loading, and Orientations".

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

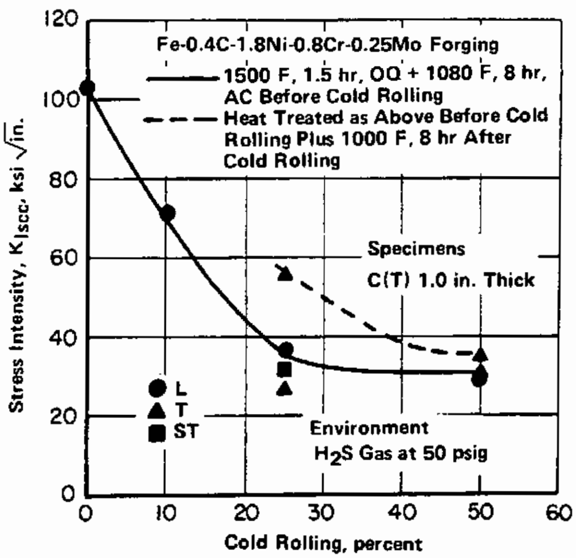


FIGURE 2.0325. EFFECT OF COLD WORKING AND STRESS RELIEF ON RESISTANCE TO STRESS-CORROSION CRACKING IN AN ENVIRONMENT OF HYDROGEN-SULFIDE (H_2S) GAS AT 50 PSIG AT ROOM TEMPERATURE (21)

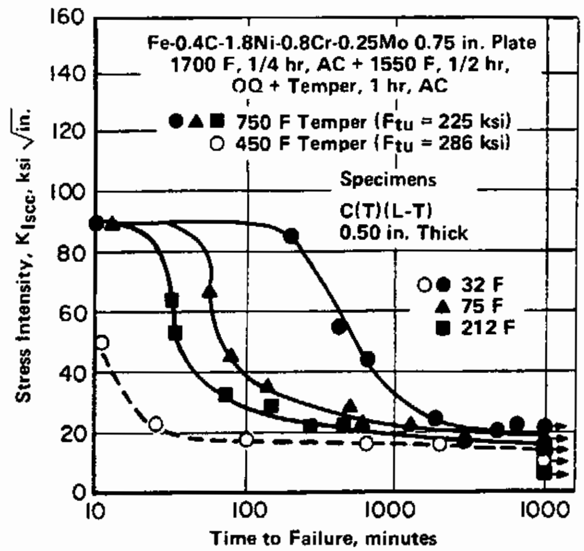


FIGURE 2.0326. TIME TO STRESS-CORROSION FAILURE OF QUENCHED-AND-TEMPERED PLATE IN DISTILLED WATER AT VARIOUS TEMPERATURES (14)

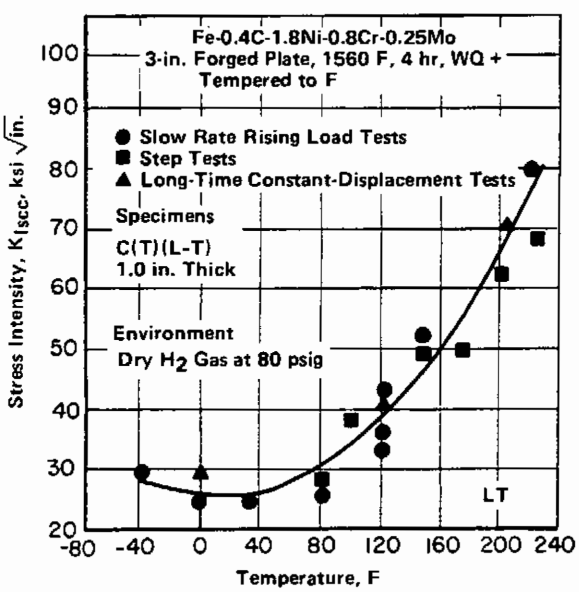


FIGURE 2.0327. EFFECT OF TEMPERATURE ON RESISTANCE TO STRESS-CORROSION CRACKING IN AN ENVIRONMENT OF DRY HYDROGEN GAS AT 80 PSIG (41)

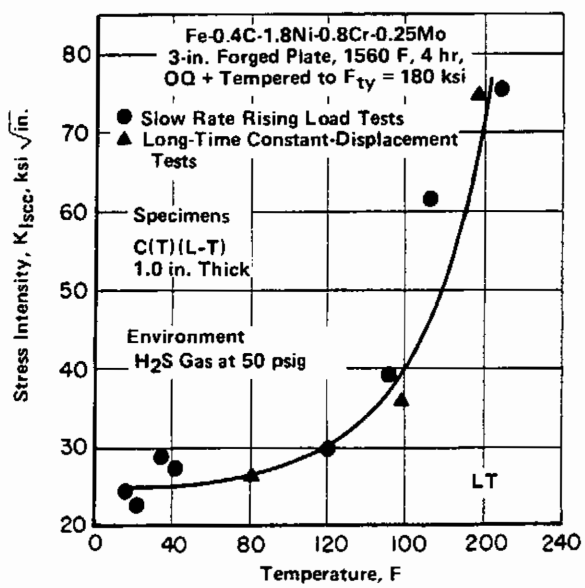


FIGURE 2.0328. EFFECT OF TEMPERATURE ON RESISTANCE TO STRESS-CORROSION CRACKING IN AN ENVIRONMENT OF HYDROGEN-SULFIDE GAS AT 50 PSIG (41)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

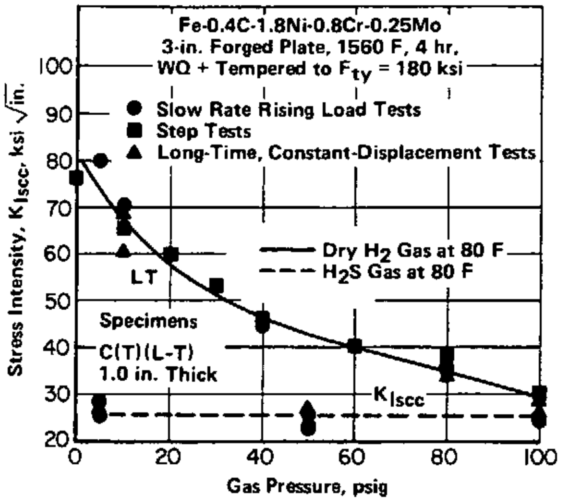


FIGURE 2.0329. EFFECT OF GAS PRESSURE ON RESISTANCE TO STRESS-CORROSION CRACKING IN ENVIRONMENTS OF HYDROGEN AND HYDROGEN-SULFIDE GASES AT ROOM TEMPERATURE (41)

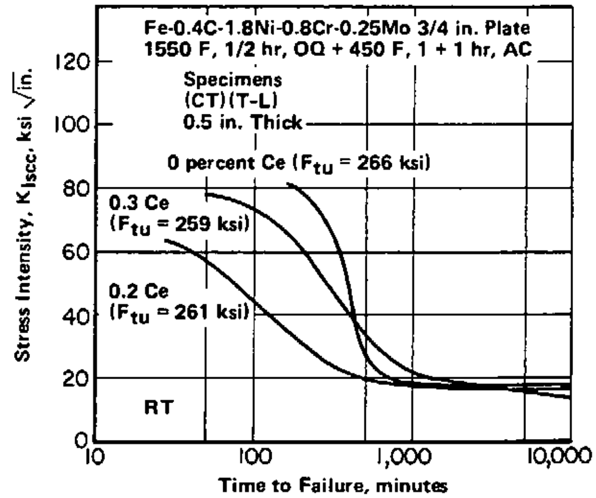


FIGURE 2.03210. EFFECT OF CERIUM ADDITIONS ON TIME TO STRESS-CORROSION FAILURE IN AN AQUEOUS 3.5 PERCENT SODIUM-CHLORIDE SOLUTION (20)

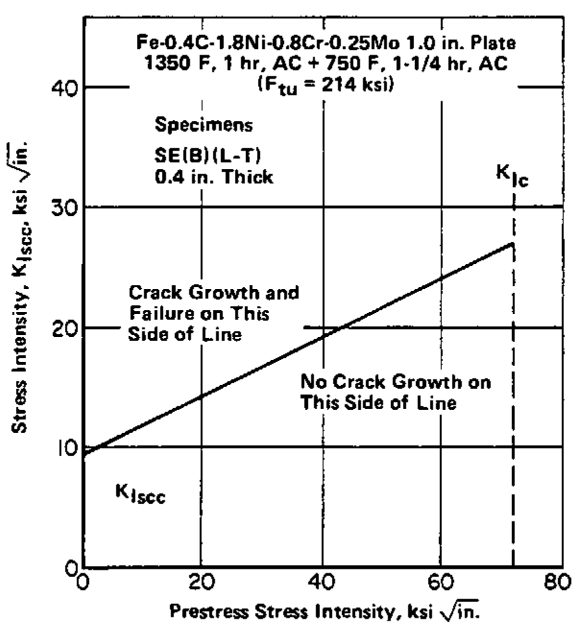


FIGURE 2.03211. EFFECT OF A BRIEF PRESTRESS OF PRECRACKING SPECIMENS ON THE THRESHOLD STRESS INTENSITY (K_{Iscc}) FOR STRESS-CORROSION CRACKING IN 3.5 PERCENT AQUEOUS SODIUM-CHLORIDE SOLUTION (15)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

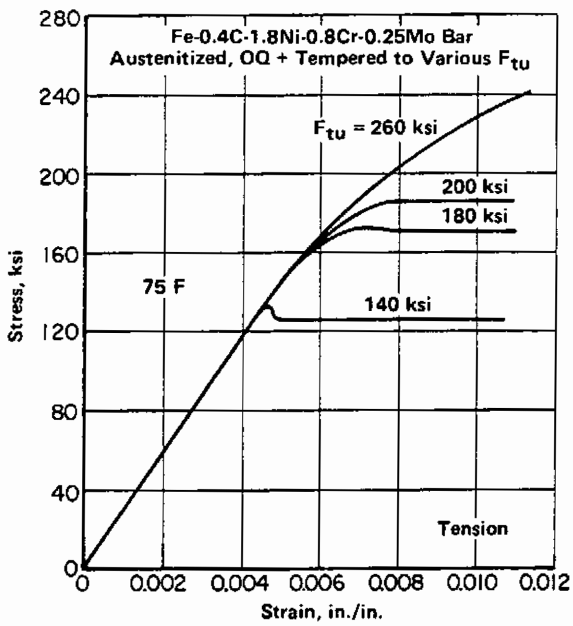


FIGURE 3.0211. ROOM TEMPERATURE TENSILE STRESS-STRAIN CURVES FOR BAR HEAT TREATED TO VARIOUS STRENGTH LEVELS (37)

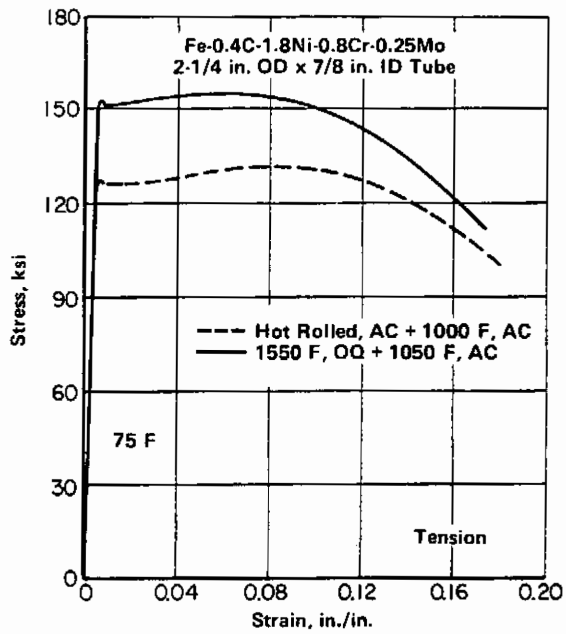


FIGURE 3.0212. COMPLETE TENSILE STRESS-STRAIN CURVES AT ROOM TEMPERATURE FOR TUBE IN TWO DIFFERENT CONDITIONS (7)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo							
Source	Form	Condition	F_{ty}, ksi (Min)	F_{tu}, ksi (Min)	e (2 inch), percent (Min)	RA, percent (Min)	Hardness (Min)	Hardness (Max)
AMS 6415 J (62)	Bars							
	<0.501-inch diam	Cold Finished		125 Max				
	>0.500-inch diam	Hot Finished					–	235 BHN
	>0.500-inch diam	Cold Finished					–	255 BHN
	Tubing	Hot Finished					–	99 R_B
		Cold Finished					–	25 R_C
AMS 6359 D (60)	Sheet and Strip	Annealed or Hot Rolled					–	98 R_B
	Plate	Annealed or Hot Rolled					–	25 R_C
AMS 6414 C (61)	Forgings	Normalized and Tempered					–	269 BHN
	Bars, Tubes, and Forgings	1500 F, OQ + 475 F, AC + 475 F, AC						
	Longitudinal		217	260	10	30		
	Transverse		217	260	–	25(a)		
AMS 5331 C (59)	Castings	Annealed					–	286 BHN
		1500 F, OQ + 800 F, AC + 800 F, AC	180	200	5	–	44 R_C	49 R_C

(a) Lower values of percent elongation allowed for cross-sectional areas greater than 100 $in.^2$

TABLE 3.01. SPECIFIED MECHANICAL PROPERTIES

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

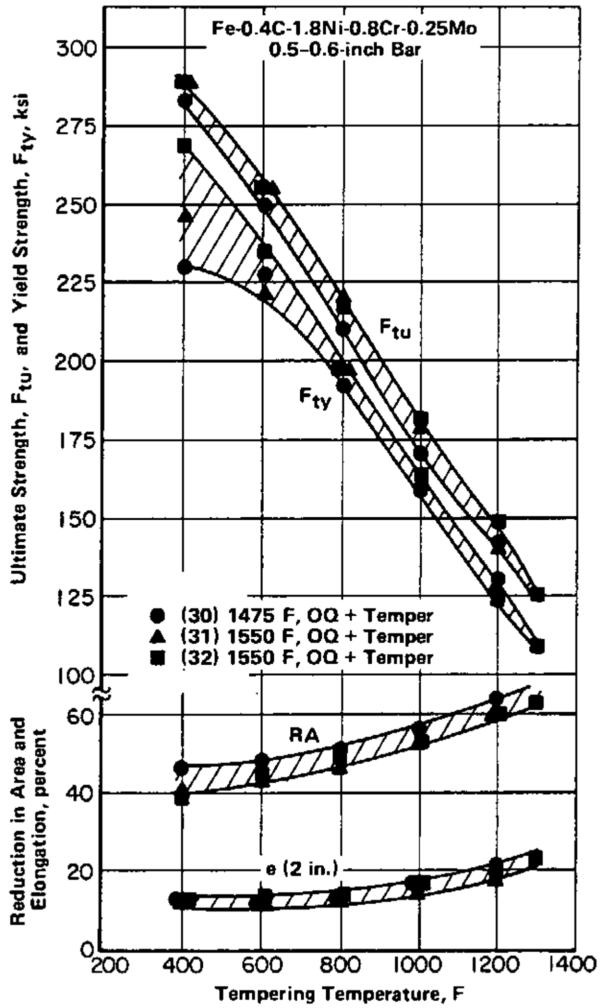


FIGURE 3.0213. EFFECT OF TEMPERING TEMPERATURE ON TENSILE PROPERTIES OF OIL-QUENCHED BAR (30, 31, 32)

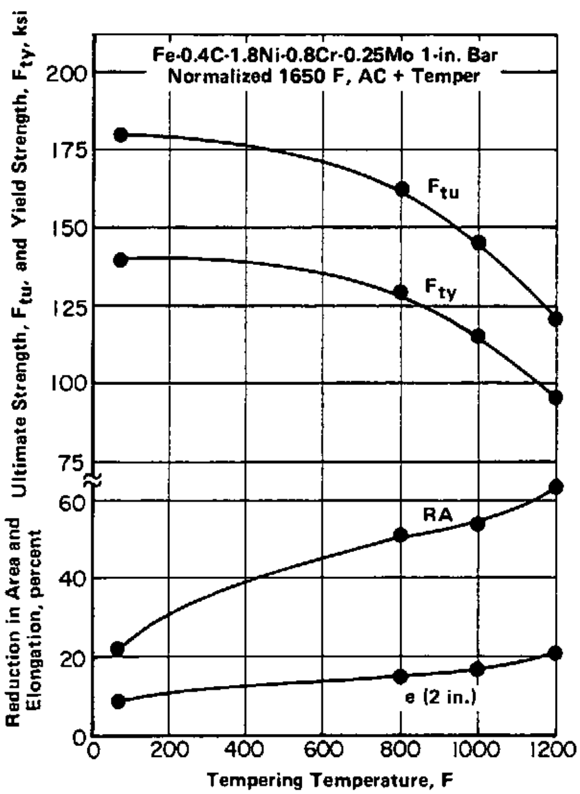


FIGURE 3.0214. EFFECT OF TEMPERING TEMPERATURE ON TENSILE PROPERTIES OF NORMALIZED BAR (31, 32)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

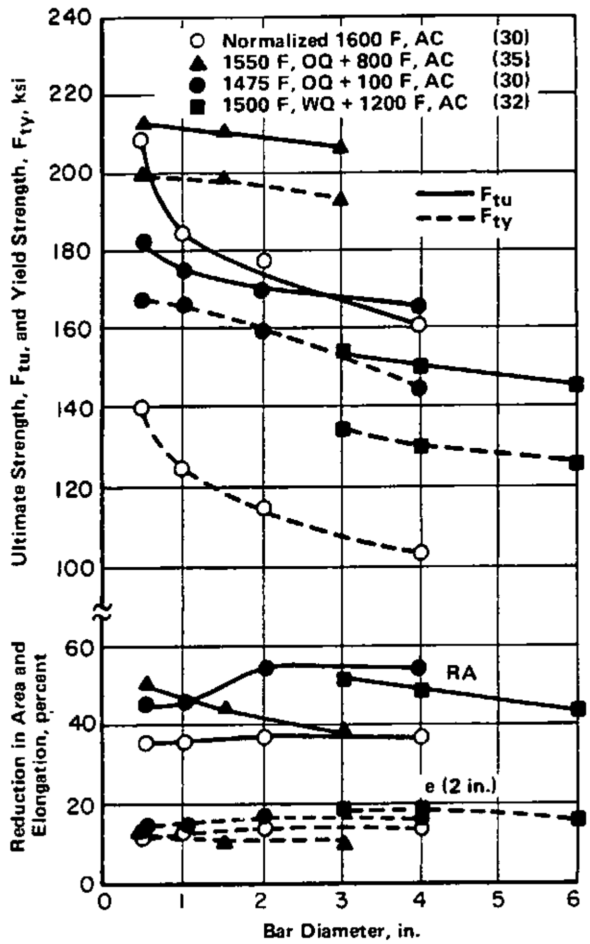


FIGURE 3.0215. EFFECT OF SECTION SIZE ON TENSILE PROPERTIES OF BAR IN SEVERAL HEAT TREATED CONDITIONS (30, 32, 35)

(Tests specimens taken from bars greater than 1 in. in diameter and taken at half radius.)

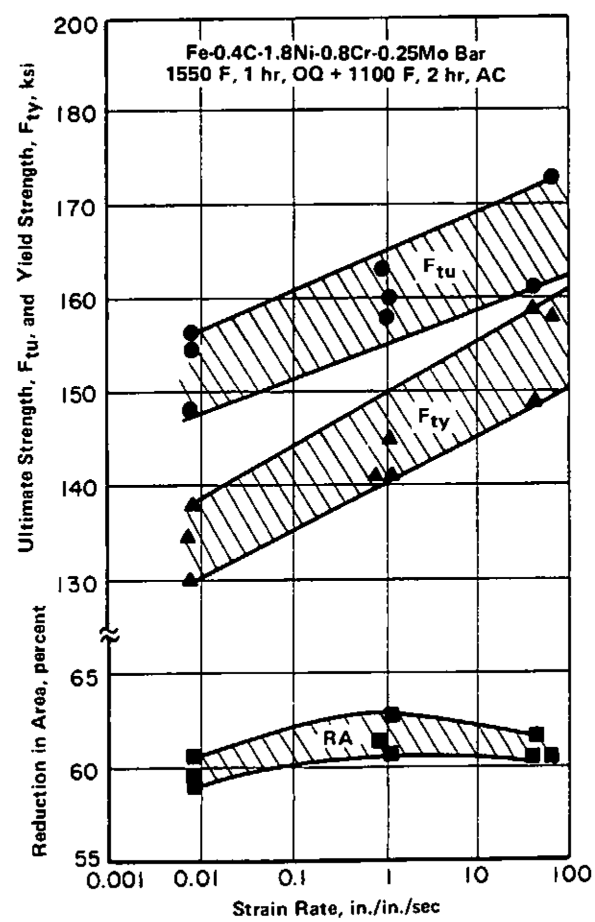


FIGURE 3.0216. EFFECT OF STRAIN RATE ON TENSILE PROPERTIES OF OIL-QUENCHED-AND-TEMPERED BAR AT ROOM TEMPERATURE (18)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

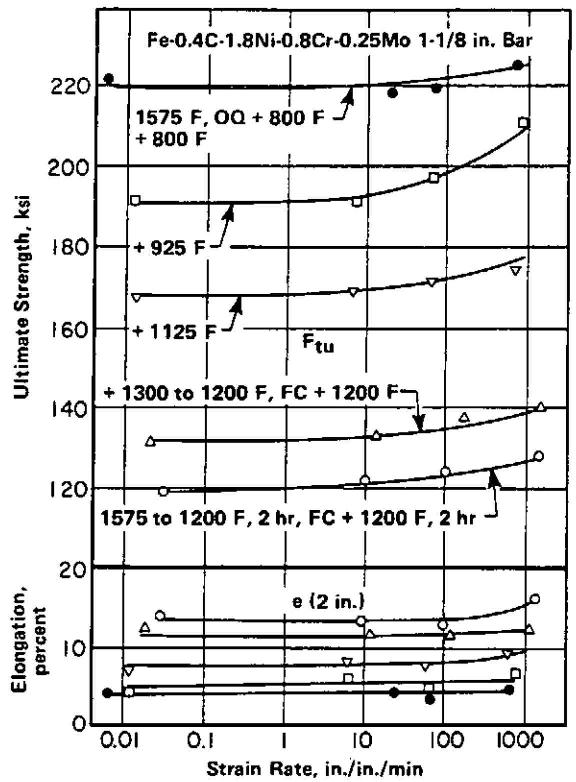
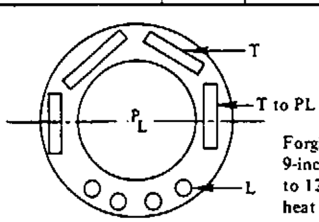


FIGURE 3.0217. EFFECT OF STRAIN RATE ON THE ULTIMATE TENSILE STRENGTH AND ELONGATION OF BAR IN VARIOUS HEAT TREATED CONDITIONS (43)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo			
Form	Forging			
Condition	Oil-Quenched and Tempered to R_C 41			
Orientation	F_{ty}, ksi	F_{tu}, ksi	e (2 inch), percent	RA, percent
Longitudinal	180	191	14.6	48.9
Transverse	181	191	8.2	17.1
Transverse to P_L	176	188	4.6	9.8



Forging section 12-inch OD x 9-inch ID x 48-inch long. Forged to 12-inch diam, bored, and then heat treated.

TABLE 3.0218. TENSILE PROPERTIES FOR DIFFERENT ORIENTATIONS IN FORGING (33)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo				
Form	1-1/2-inch Plate				
Condition	1550 F 1 hr. OQ + Temper 3 hr. AC				
Temper, F	Orien-tation	F_{ty}, ksi	F_{tu}, ksi	e (4D), percent	RA, percent
300	L	227.3	340.0	10.0	37.4
		228.0	307.6	11.8	41.3
375	L	226.6	318.0	13.7	38.1
	T	216.4	283.1	13.0	45.2
450	L	236.5	295.7	12.7	43.5
	T	228.5	273.5	14.0	44.3
500	L	241.2	286.4	11.2	44.0
Condition	1550 F 1 hr. Salt Q at 450 F 5 Min. AC + Temper 3 hr. AC				
375	L	229.0	325.1	12.3	37.8
450	L	239.9	309.2	10.0	36.1

TABLE 3.0219. EFFECTS OF VARIOUS TEMPERING TEMPERATURES ON TENSILE PROPERTIES OF ELECTROSLAG REMELTED PLATE AFTER CONVENTIONAL OIL-QUENCHING AND AFTER MARTEMPERING (27)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

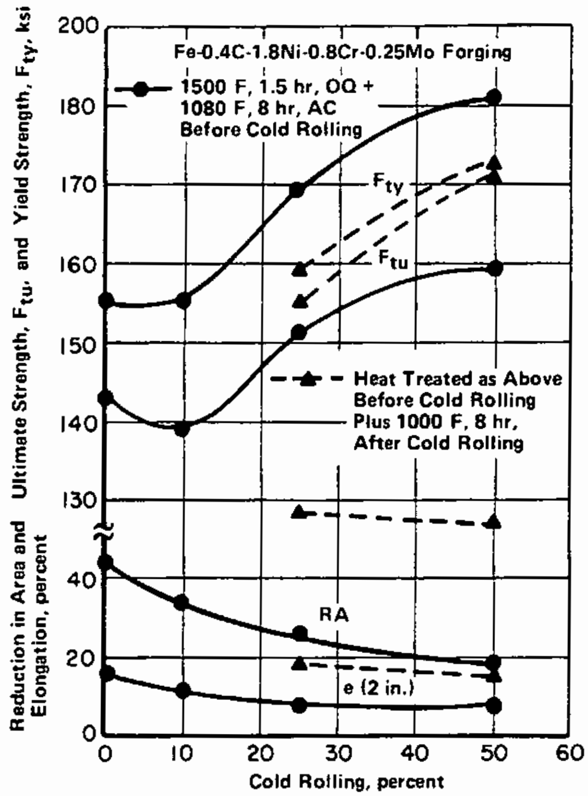


FIGURE 3.02111. EFFECTS OF COLD WORKING AND STRESS RELIEF ON ROOM TEMPERATURE TENSILE PROPERTIES OF OIL-QUENCHED-AND-TEMPERED FORGINGS (21)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo				
Form	1-inch Plate, Cross Rolled				
Condition	1650 F 1 hr, OQ + 1525 F 1 hr, OQ + 475 F 8 hr, AC				
Purity	Orientation	F_{ty}, ksi	F_{tu}, ksi	e (2 inch), percent	RA, percent
Normal	L	219	259	11.6	43.3
	T	221	260	10.0	39.7
High	L	210	247	11.6	45.4
	T	209	248	12.4	51.2

Note. Chemical Analyses

Purity	C	Mn	P	S	Si	Ni	Cr	Mo	Cu
Normal	0.40	0.71	0.010	0.011	0.27	1.80	0.82	0.25	0.006
High	0.40	0.29	<0.0003	0.0008	0.007	1.79	0.75	0.27	0.002

(Cont)	Co	O	Al	N	Ti	As	Sb	Sn
Normal	0.008	0.0016	0.034	0.008	0.005	<0.002	<0.0004	<0.002
High	0.023	0.0010	0.002	0.002	<0.002	<0.002	<0.0004	<0.002

TABLE 3.02110. COMPARISON OF TENSILE PROPERTIES OF AIR INDUCTION MELTED CROSS ROLLED PLATE OF NORMAL PURITY WITH THOSE OF HIGH PURITY PLATE PRODUCED BY VACUUM INDUCTION MELTING FOLLOWED BY VACUUM ARC REMELTING (8)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

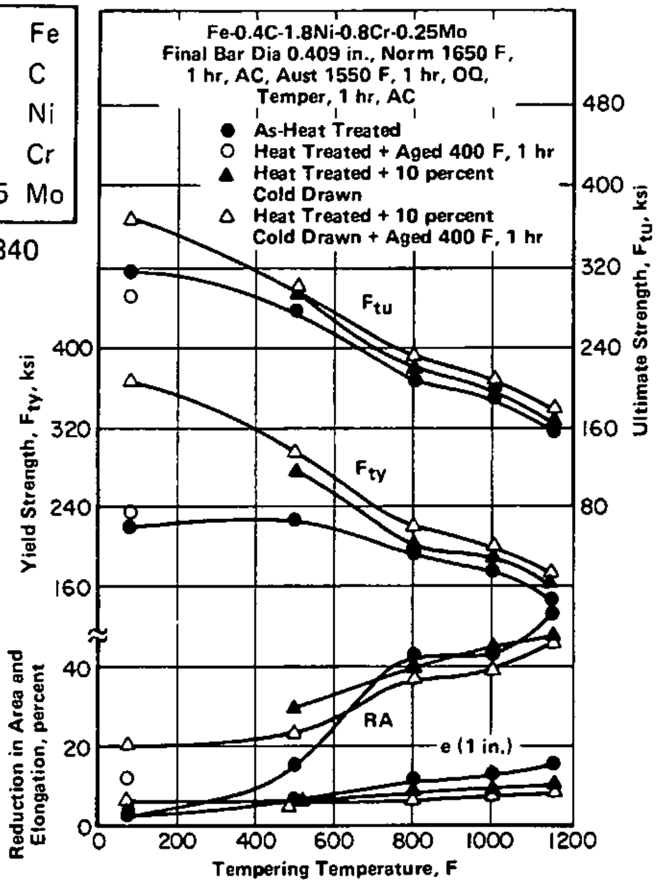


FIGURE 3.02112. EFFECTS OF TEMPERING TEMPERATURE AND 10 PERCENT COLD REDUCTION AND AGING AT 400 F ON TENSILE PROPERTIES OF OIL-QUENCHED BAR (42)

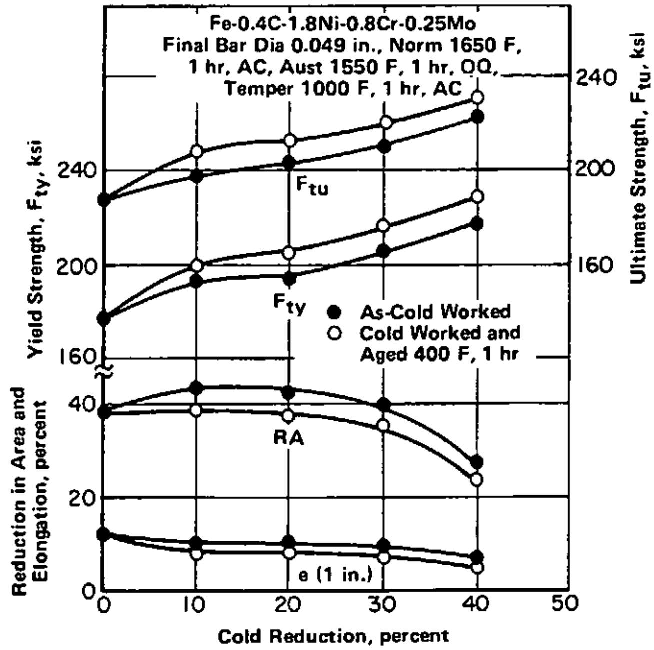


FIGURE 3.02113. EFFECTS OF COLD WORKING AND AGING ON TENSILE PROPERTIES OF BAR THAT HAD PREVIOUSLY BEEN OIL-QUENCHED-AND-TEMPERED AT 1000 F (42)

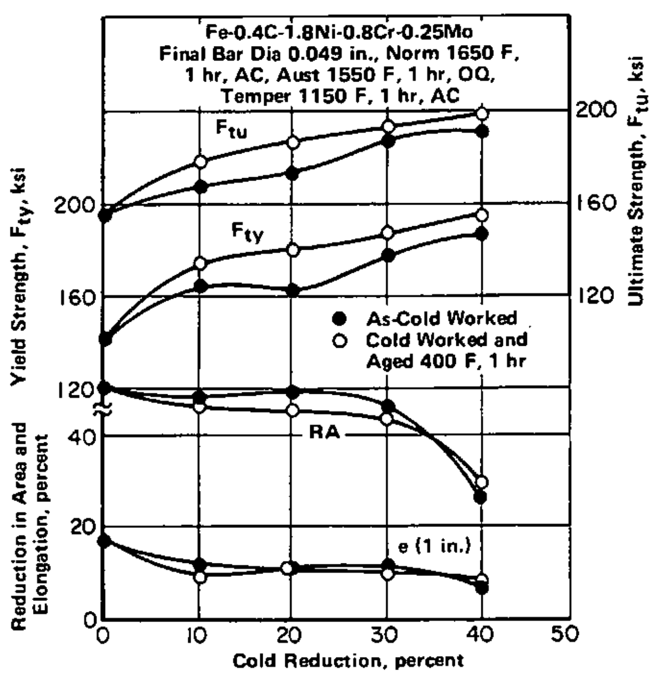


FIGURE 3.02114. EFFECTS OF COLD WORKING AND AGING ON TENSILE PROPERTIES OF BAR THAT HAD BEEN PREVIOUSLY OIL-QUENCHED-AND-TEMPERED AT 1150 F (42)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo					
Form	Bar					
Condition			Tensile Properties			
1550 F 1 hr, OQ + Following			F_{ty}, ksi	F_{tu}, ksi	e (2 inch), percent	RA, percent
Temper	CW, percent	Retemper				
800 F 1 hr (R_C 44)	–	–	197.5	208.5	14.0	54.5
	50 (R_C 47)	–	229.0	239.0	8.6	46.7
	50 (R_C 47)	400 F 1 hr (R_C 49)	258.7	269.2	10.0	48.1
900 F 1 hr (R_C 42)	–	–	182.0	188.6	15.3	56.2
	50 (R_C 43)	–	211.0	229.0	9.3	48.9
	50 (R_C 43)	400 F 1 hr (R_C 46)	227.0	240.0	10.0	48.3
	67	–	225.0	246.5	7.9	43.9
	67	400 F 1 hr	233.8	257.0	8.5	41.2

TABLE 3.02115. EFFECT OF COLD WORK BY HYDROSTATIC EXTRUSION AND OF RETEMPERING ON TENSILE PROPERTIES OF BAR THAT HAD BEEN PREVIOUSLY OIL-QUENCHED AND TEMPERED (26)

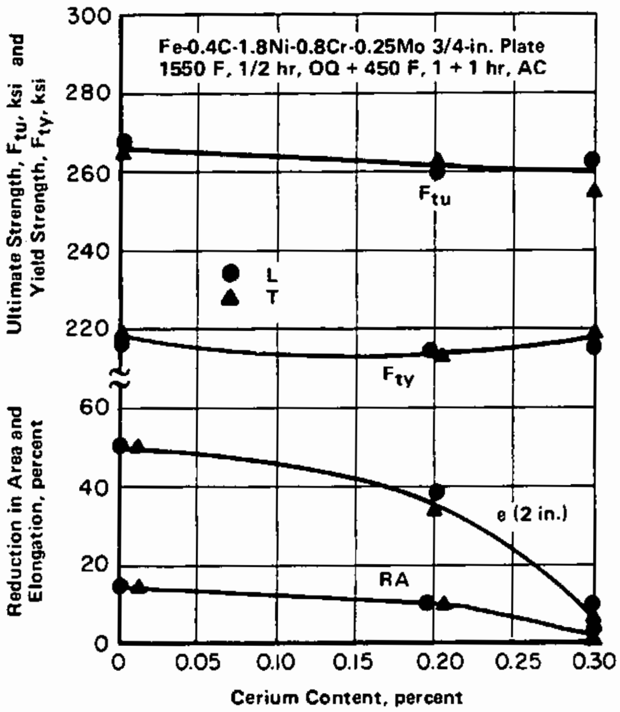


FIGURE 3.02116. EFFECT OF CERIUM ADDITIONS ON ROOM TEMPERATURE TENSILE PROPERTIES (20)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo
Form	Bar
Condition	Annealed: 1490 F, FC 20 F per hr to 670 F, AC
F_{ty}, ksi	68.5
F_{tu}, ksi	108.0
e (2 inch), percent	22.0
RA, percent	49.9

TABLE 3.02117. TENSILE PROPERTIES OF ANNEALED BAR (30)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo			
Condition	1600 F, OQ + Temper 1 hr, AC			
Temper, F	600		905	
Form	Cast	Plate	Cast	Plate
F_{ty}, ksi	211	220	174	181
F_{tu}, ksi	239	236	186	195
e (2 inch), percent	8	9	8	9
RA, percent	21	25	29	39

TABLE 3.02118. COMPARISON OF ROOM TEMPERATURE TENSILE PROPERTIES IN TWO HEAT TREATED CONDITIONS OF CAST KEEL BLOCK AND WROUGHT PLATE MADE FROM THE SAME AIR INDUCTION MELTED HEAT (73)

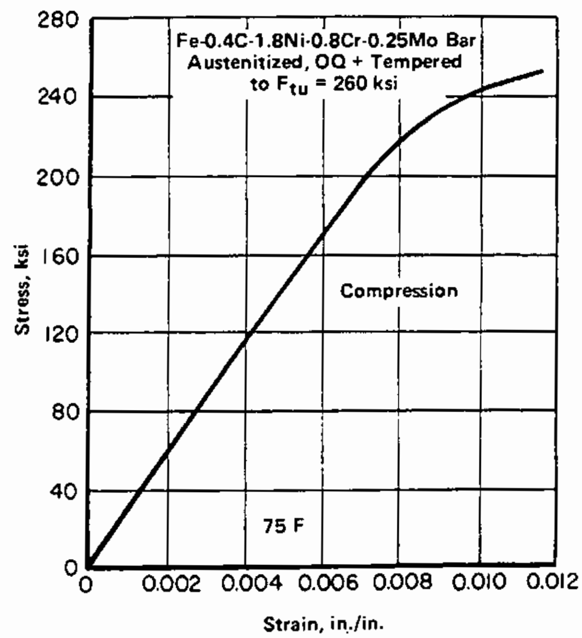


FIGURE 3.0221. ROOM TEMPERATURE STRESS-STRAIN CURVE IN COMPRESSION FOR BAR HEAT TREATED TO F_{tu} = 260 KSI (37)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

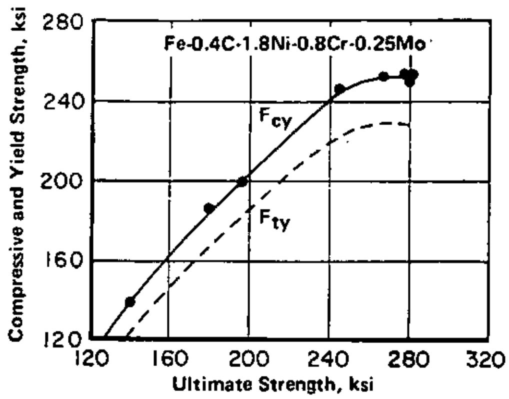


FIGURE 3.0222. RELATIONSHIP BETWEEN COMPRESSIVE YIELD STRENGTH AND TENSILE STRENGTH (44)

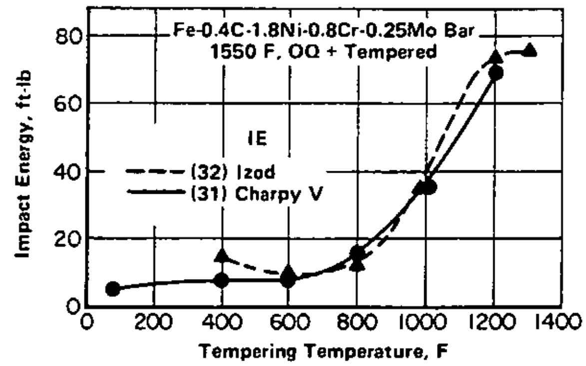


FIGURE 3.0231. EFFECT OF TEMPERING TEMPERATURE ON IMPACT PROPERTIES OF OIL-QUENCHED BAR AT ROOM TEMPERATURE (31, 32)

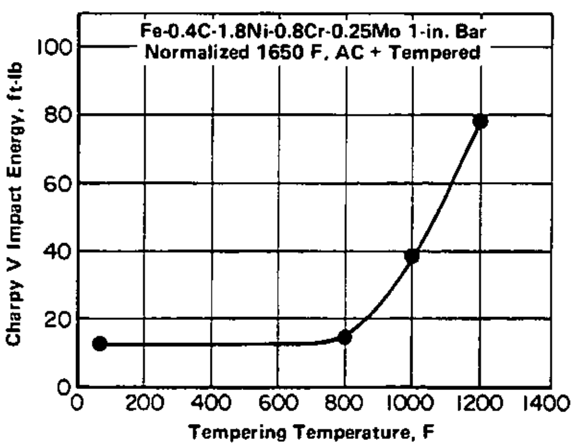


FIGURE 3.0232. EFFECT OF TEMPERING TEMPERATURE ON IMPACT PROPERTIES OF NORMALIZED BAR AT ROOM TEMPERATURE (31, 32)

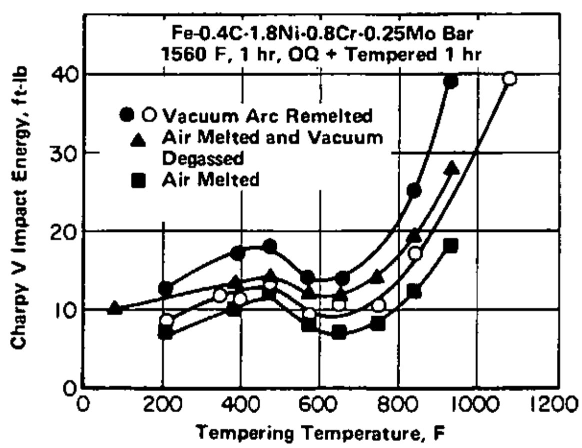


FIGURE 3.0233. EFFECTS OF TEMPERING TEMPERATURE AND MELTING PRACTICE ON IMPACT PROPERTIES AT ROOM TEMPERATURE (56)

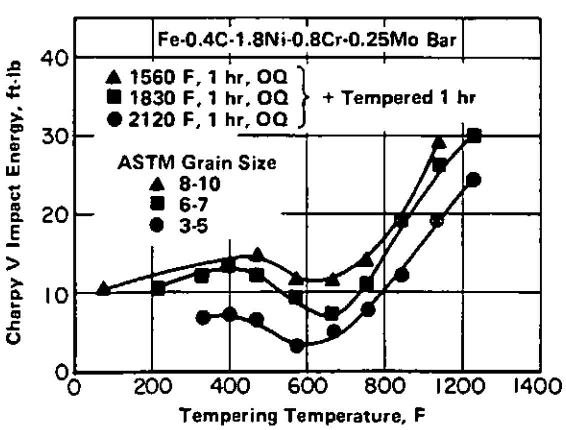


FIGURE 3.0234. EFFECTS OF TEMPERING TEMPERATURE AND AUSTENITIZING TEMPERATURE AND RESULTING GRAIN SIZE ON IMPACT PROPERTIES AT ROOM TEMPERATURE OF BAR THAT HAD BEEN AIR MELTED AND VACUUM DEGASSED (56)

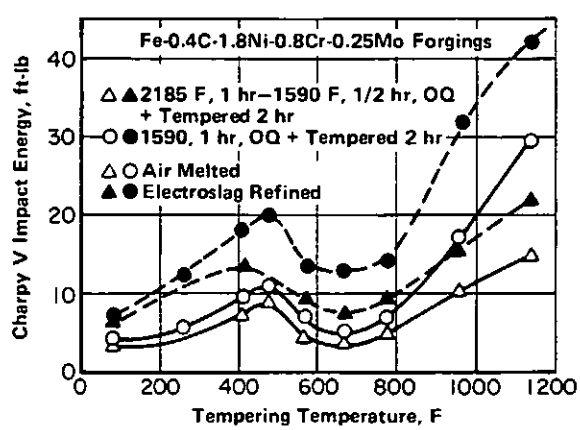


FIGURE 3.0235. EFFECTS OF TEMPERING TEMPERATURE AFTER TWO DIFFERENT AUSTENITIZING TREATMENTS ON IMPACT PROPERTIES AT ROOM TEMPERATURE OF AIR MELTED AND ELECTROSLAG REFINED FORGINGS (58)

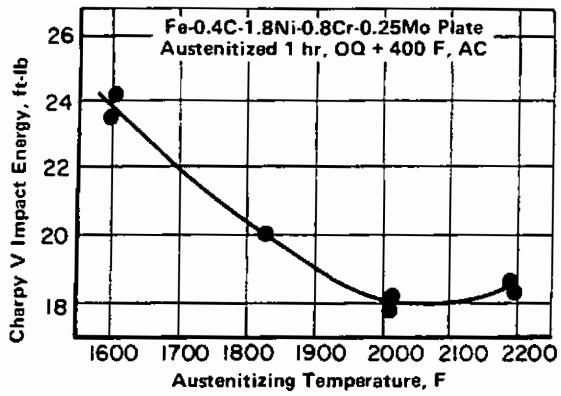
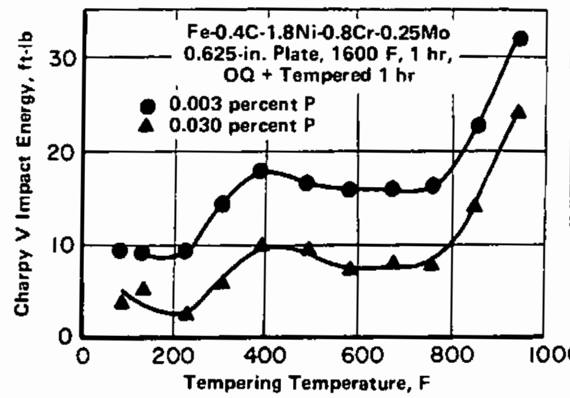


FIGURE 3.0236. EFFECT OF AUSTENITIZING TEMPERATURE ON THE ROOM TEMPERATURE IMPACT PROPERTIES OF OIL-QUENCHED-AND-TEMPERED VACUUM ARC REMELTED PLATE (68)



	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

FIGURE 3.0237. EFFECTS OF TEMPERING TEMPERATURE AND PHOSPHORUS CONTENT ON IMPACT PROPERTIES AT ROOM TEMPERATURE OF PLATE THAT HAD BEEN VACUUM INDUCTION MELTED (57)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo			
Condition	1600 F, OQ + Temper 1 hr, AC			
Temper, F	600		905	
Form	Cast	Plate	Cast	Plate
Impact, ft-lb	9.2	10.5	19.9	17.7

TABLE 3.0238. COMPARISON OF ROOM TEMPERATURE CHARPY V-NOTCH IMPACT PROPERTIES IN TWO HEAT TREATED CONDITIONS OF CAST KEEL BLOCK AND WROUGHT PLATE MADE FROM THE SAME INDUCTION MELTED HEAT (73)

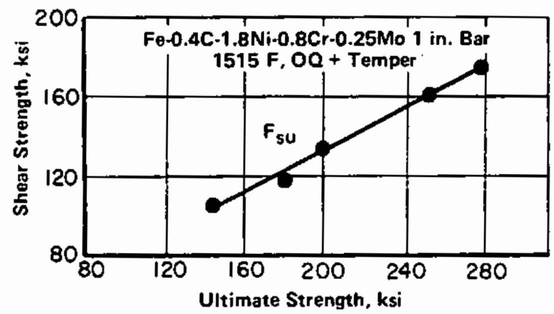


FIGURE 3.0251. RELATIONSHIP BETWEEN SHEAR STRENGTH IN TORSION AND ULTIMATE TENSILE STRENGTH (45)

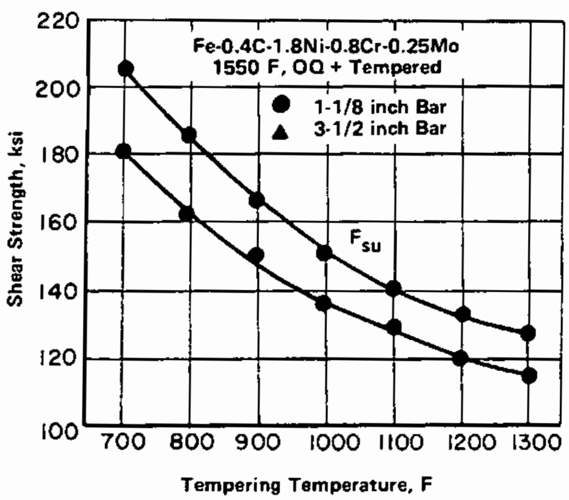


FIGURE 3.0252. EFFECT OF TEMPERING TEMPERATURE ON SHEAR STRENGTH IN TORSION OF OIL-QUENCHED BAR OF TWO DIFFERENT SIZES (32)

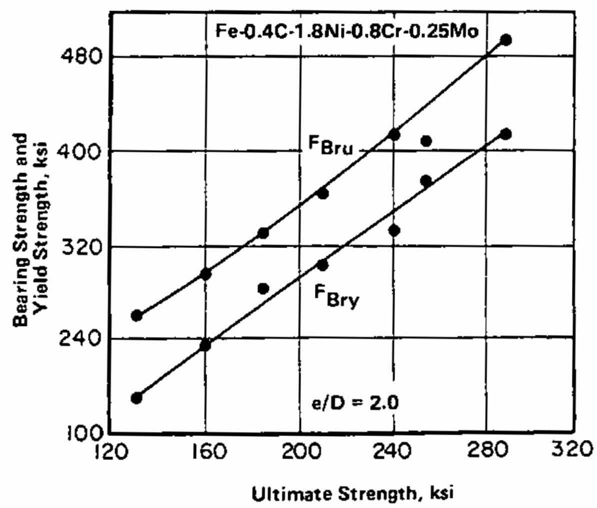


FIGURE 3.0261. RELATIONSHIP BETWEEN BEARING PROPERTIES AND ULTIMATE TENSILE STRENGTH (44)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

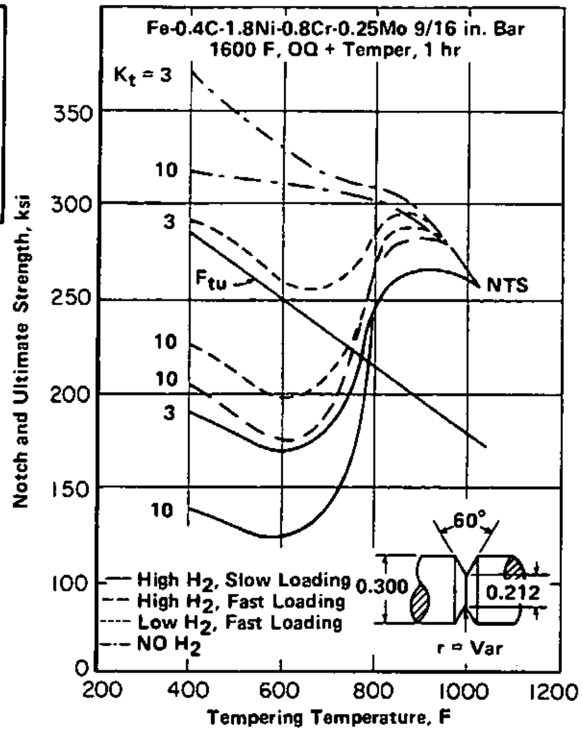


FIGURE 3.02711. EFFECTS OF TEMPERING TEMPERATURE, HYDROGEN CONTENT, STRESS CONCENTRATION, AND RATE OF LOADING ON THE NOTCHED TENSILE STRENGTH OF BAR (46)

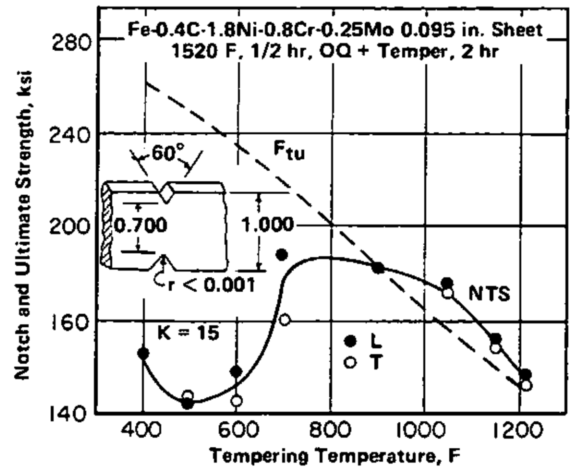


FIGURE 3.02712. EFFECT OF TEMPERING TEMPERATURE ON SHARP-NOTCH STRENGTH OF SHEET (47)

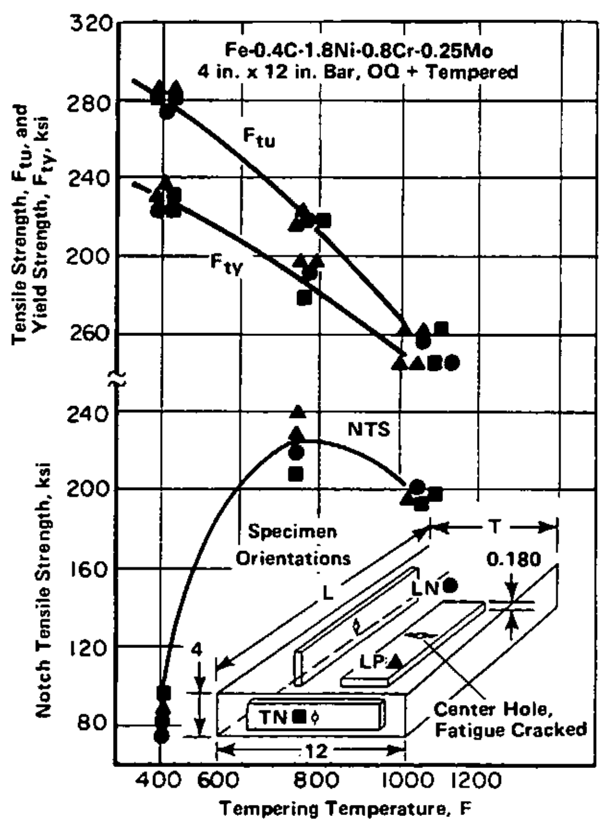


FIGURE 3.02713. EFFECT OF TEMPERING TEMPERATURE AND SPECIMEN ORIENTATION ON CRACK STRENGTH OF BAR (48)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

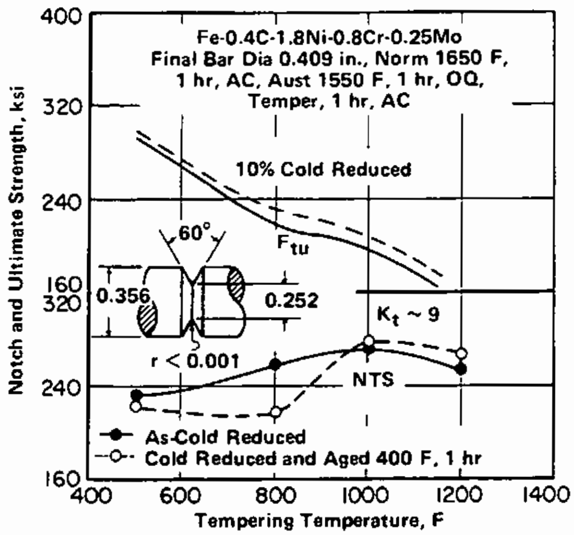


FIGURE 3.02714. EFFECT OF TEMPERING TEMPERATURE ON SHARP-NOTCH STRENGTH OF BAR COLD REDUCED 10 PERCENT AFTER TEMPERING (42)

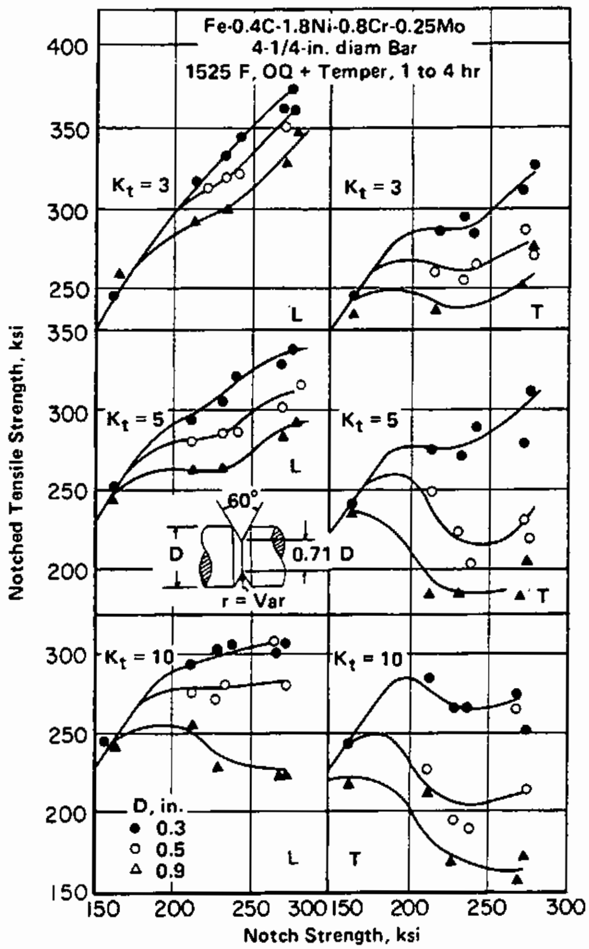


FIGURE 3.02715. RELATIONSHIP BETWEEN ULTIMATE TENSILE STRENGTH (F_{tu}) AND NOTCHED TENSILE STRENGTH (NTS) FOR VARIOUS SIZE TEST BARS, STRESS CONCENTRATIONS, AND ORIENTATIONS (49)

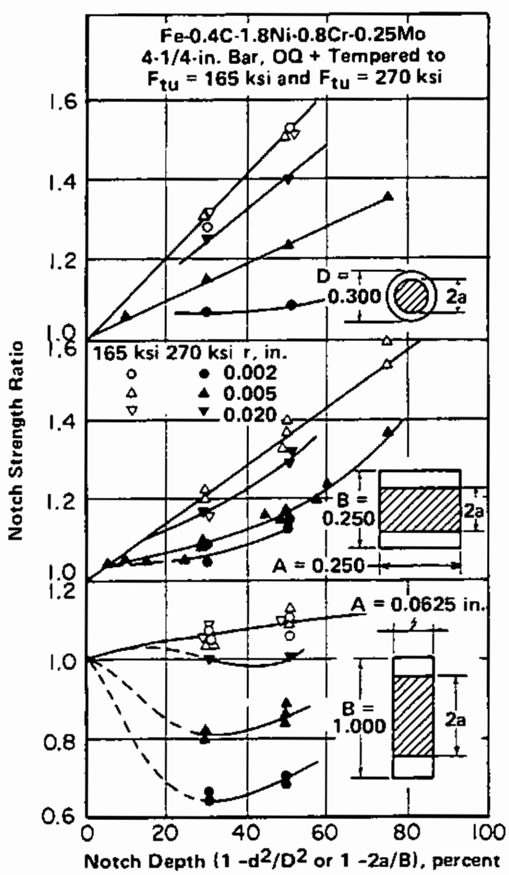


FIGURE 3.02716. EFFECT OF SPECIMEN CROSS SECTION, NOTCH ROOT RADIUS, AND NOTCH DEPTH ON NOTCH STRENGTH RATIO OF BAR (50)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

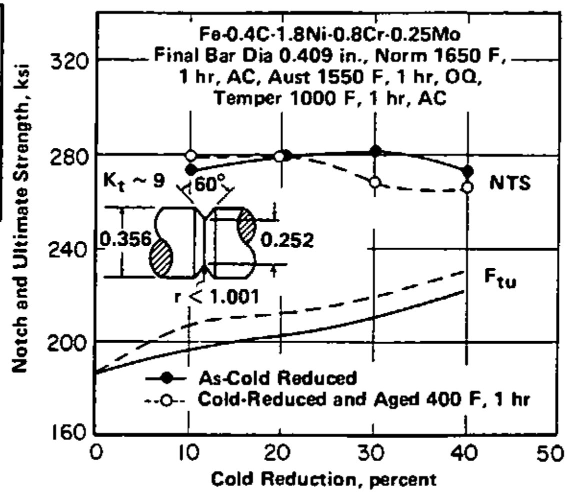


FIGURE 3.02717. EFFECT OF COLD WORKING ON SHARP-NOTCH STRENGTH OF BARS PREVIOUSLY OIL-QUENCHED-AND-TEMPERED AT 1000 F (42)

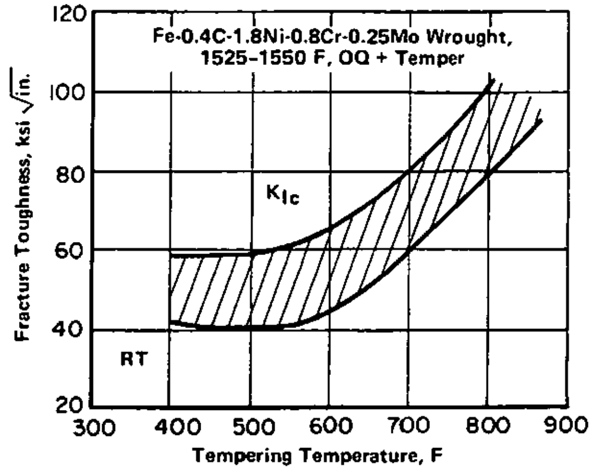


FIGURE 3.02721. EFFECT OF TEMPERING TEMPERATURE ON RANGE OF FRACTURE TOUGHNESS RESULTING FROM NORMAL VARIATIONS IN MELTING AND PROCESSING PRACTICES, CHEMICAL COMPOSITION, AND IMPURITY CONTENT (11)

Note: Shaded range summarizes data gathered from a number of sources.

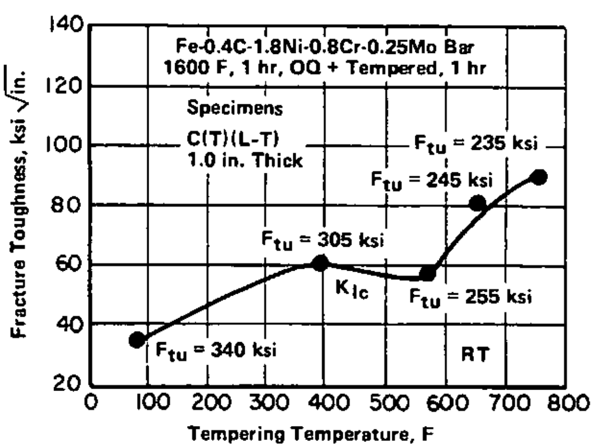


FIGURE 3.02722. EFFECT OF TEMPERING TEMPERATURE ON THE FRACTURE TOUGHNESS OF AIRCRAFT-QUALITY (VACUUM ARC REMELTED) BAR (72)

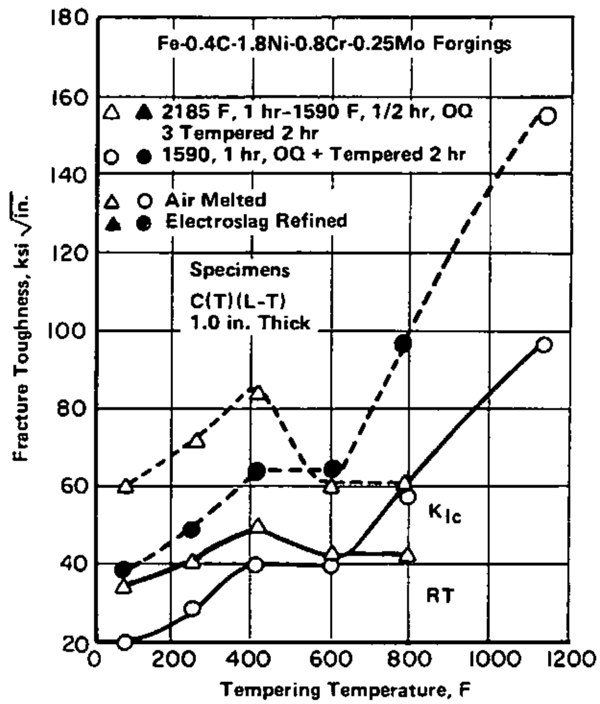


FIGURE 3.02723. EFFECTS OF TEMPERING TEMPERATURE AFTER TWO DIFFERENT AUSTENITIZING TREATMENTS ON FRACTURE TOUGHNESS AT ROOM TEMPERATURE OF AIR MELTED AND ELECTROSLAG REFINED FORGINGS (58)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

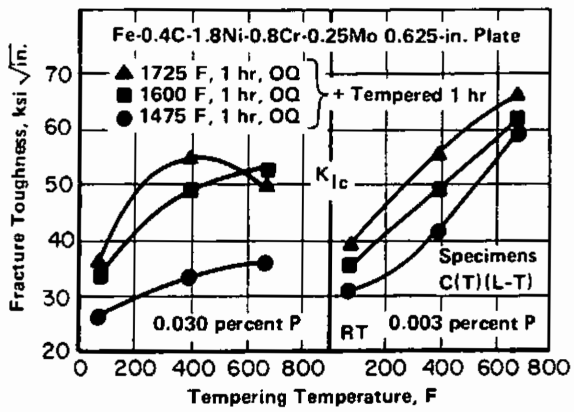


FIGURE 3.02724. EFFECTS OF TEMPERING AND AUSTENITIZING TEMPERATURES AND PHOSPHORUS CONTENT ON ROOM TEMPERATURE FRACTURE TOUGHNESS OF PLATE THAT HAS BEEN VACUUM INDUCTION MELTED (57)

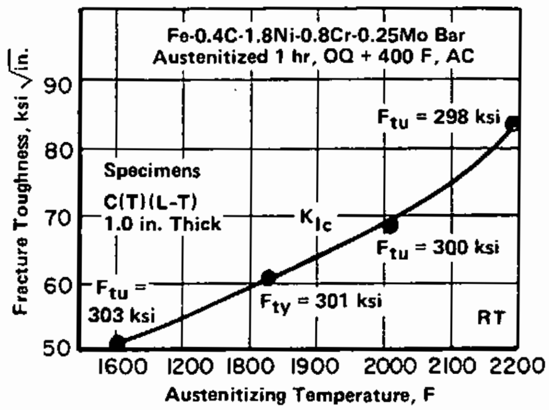


FIGURE 3.02725. EFFECT OF AUSTENITIZING TEMPERATURE ON THE ROOM TEMPERATURE FRACTURE TOUGHNESS OF OIL-QUENCHED-AND-TEMPERED VACUUM-ARC REMELTED PLATE (68)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo
Form	Plate
Condition	K_{Ic}, ksi √in.
2190 F 1 hr, OQ + 390 F 1 hr, AC	89.1
2190 F 1 hr — 2010 F 10 min. OQ + 390 F 1 hr, AC	86.0
2190 F 1 hr — 2010 F 1/2 hr. OQ + 390 F 1 hr. AC	68.0
2190 F 1 hr — 2010 F 1 hr. OQ + 390 F 1 hr. AC	67.0
2190 F 1 hr — 1600 F 1/2 hr. OQ + 390 F 1 hr. AC	60.9

Notes: K_{Ic} specimens, C(T)(L-T), 1.0 in. thick.
F_{ty} approximately 220 ksi for all conditions.

TABLE 3.02726. EFFECTS OF VARIOUS STEP-QUENCHING TREATMENTS ON FRACTURE TOUGHNESS OF AIRCRAFT-QUALITY PLATE INITIALLY AUSTENITIZED AT 2190 F AND SUBSEQUENTLY TEMPERED AT 390 F (71)

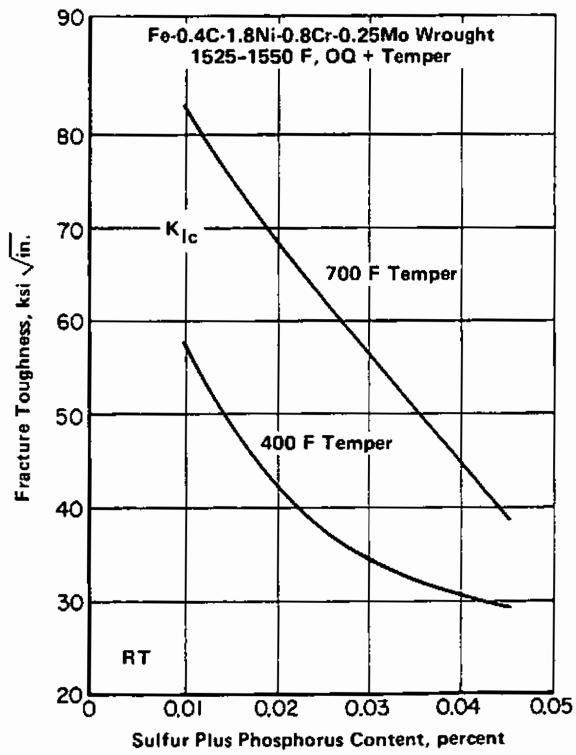


FIGURE 3.02727. EFFECT OF SULFUR PLUS PHOSPHORUS CONTENT ON THE FRACTURE TOUGHNESS (17, 78)

Note: Curves summarize averages of data gathered from a number of sources.

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo			
Condition	1600 F, OQ + Temper 1 hr. AC			
Temper, F	600		905	
Form	Cast	Plate	Cast	Plate
K_{Ic}, ksi √in.	60	55	104	80

Notes: Specimens, C(T)(T-L) [(T-L) direction applies to plate].
See Table 3.02118 for tensile properties.

TABLE 3.02728. COMPARISON OF ROOM TEMPERATURE FRACTURE TOUGHNESS IN TWO HEAT TREATED CONDITIONS OF CAST KEEL BLOCK AND WROUGHT PLATE MADE FROM THE SAME INDUCTION MELTED HEAT (73)

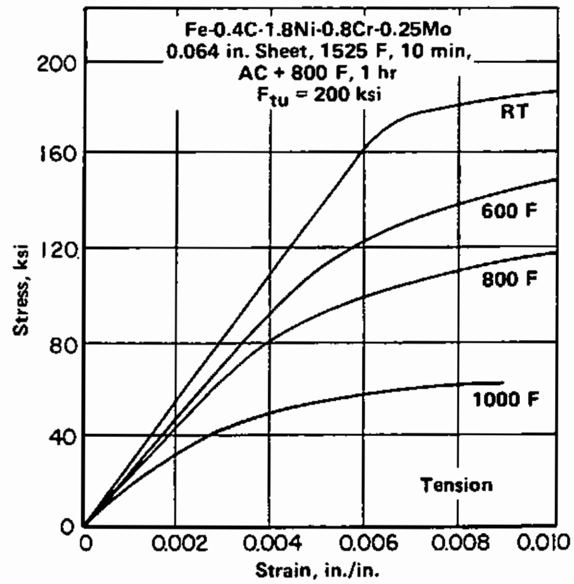


FIGURE 3.0311. TENSILE STRESS-STRAIN CURVES AT ROOM TEMPERATURE AND ELEVATED TEMPERATURES FOR SHEET HEAT TREATED TO F_{tu} = 200 KSI (51)

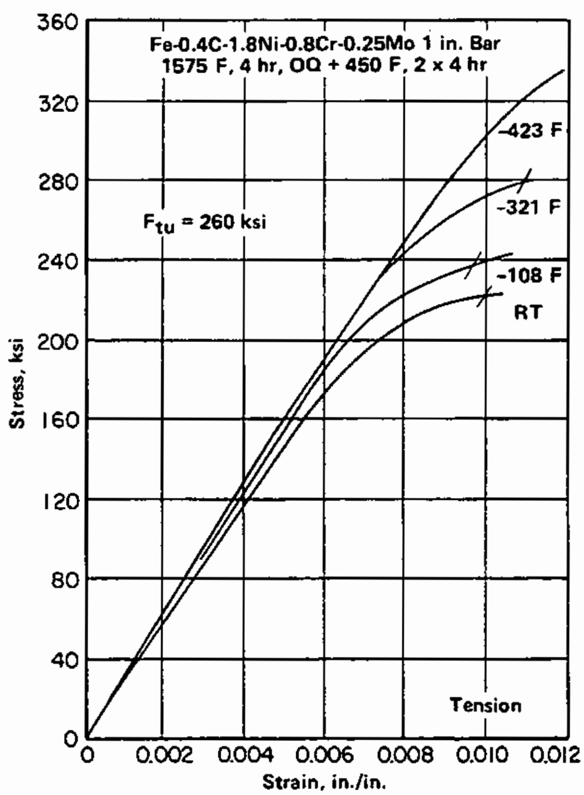


FIGURE 3.0312. TENSILE STRESS-STRAIN CURVES AT ROOM TEMPERATURE AND LOW TEMPERATURES FOR BAR HEAT TREATED TO F_{tu} = 270 KSI (52)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

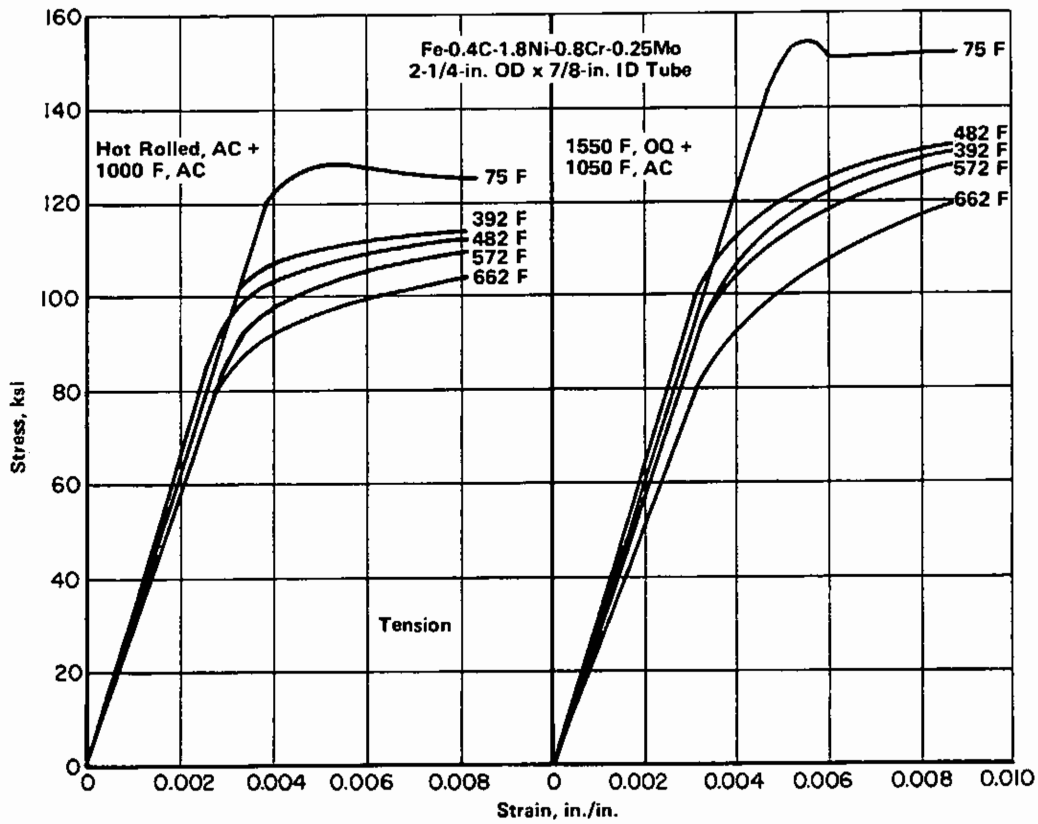


FIGURE 3.0313. TENSILE STRESS-STRAIN CURVES AT VARIOUS TEMPERATURES FOR TUBE IN TWO DIFFERENT CONDITIONS (7)

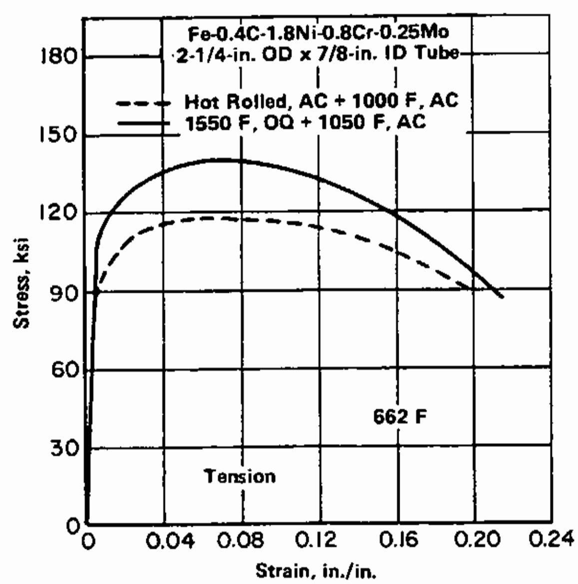


FIGURE 3.0314. COMPLETE TENSILE STRESS-STRAIN CURVES AT 662 F FOR TUBE IN TWO DIFFERENT CONDITIONS (7)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

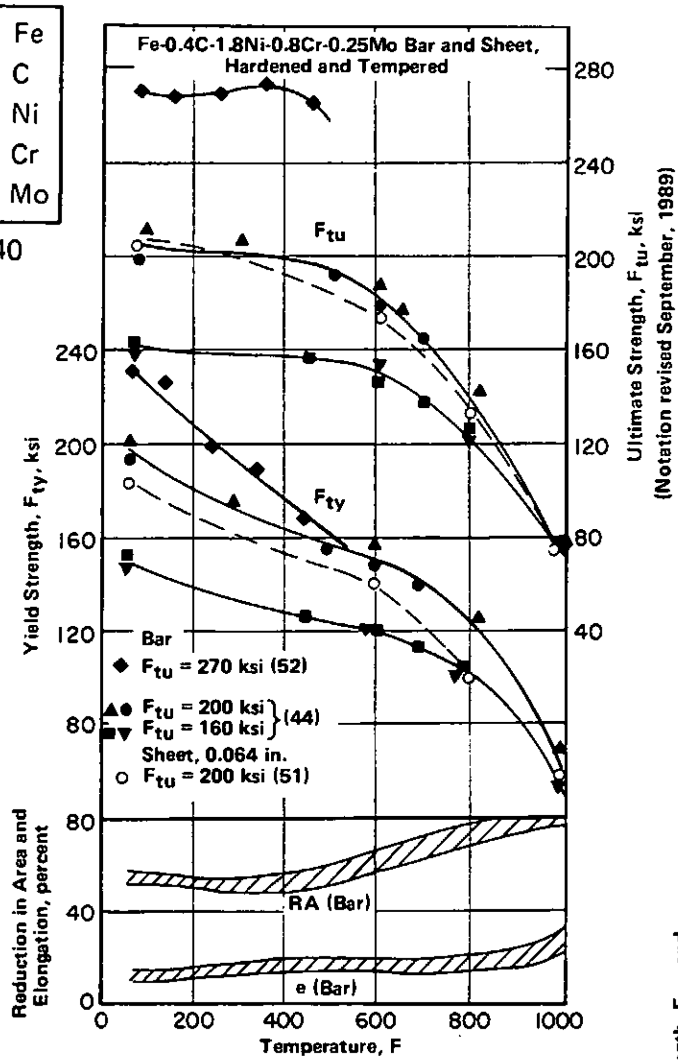


FIGURE 3.0315. EFFECT OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF BAR AND SHEET HEAT TREATED TO VARIOUS STRENGTH LEVELS (44, 51, 52)

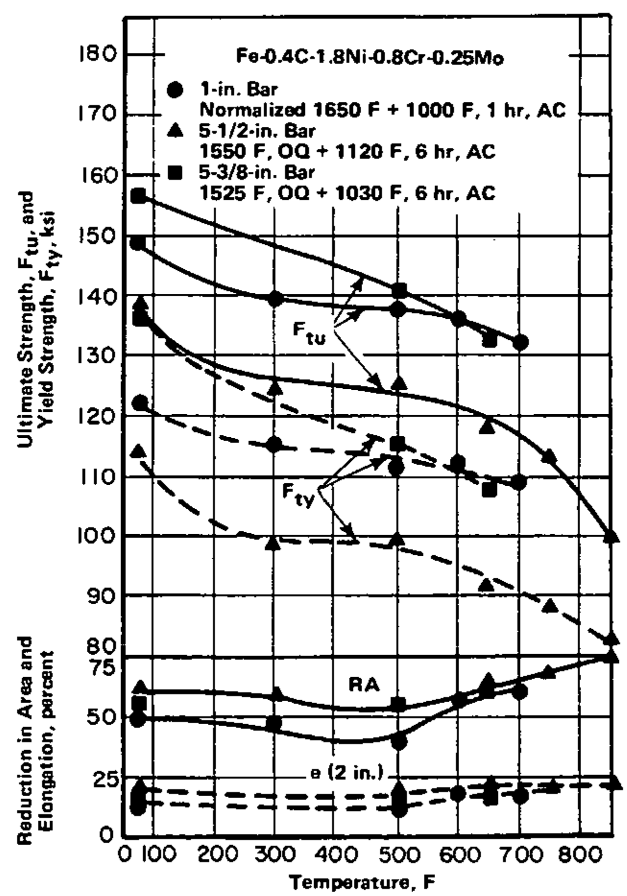


FIGURE 3.0316. EFFECT OF ELEVATED TEMPERATURES UP TO 850 F ON TENSILE PROPERTIES OF BAR IN VARIOUS HEAT TREATED CONDITIONS (7)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

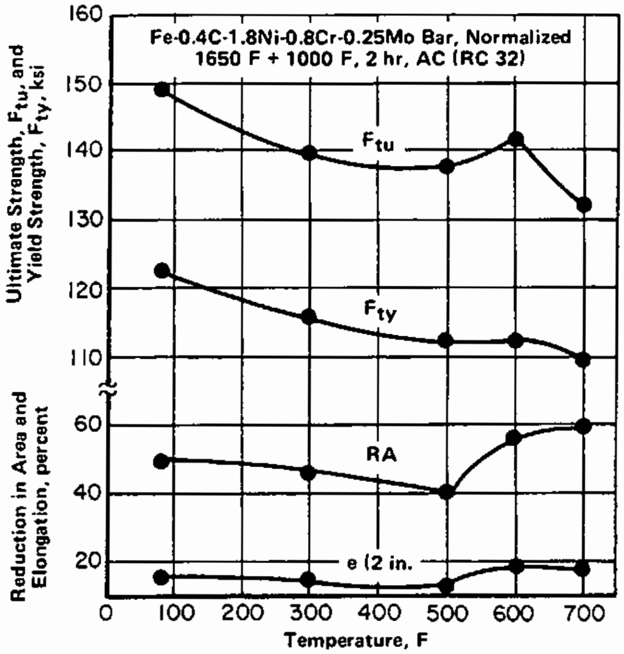


FIGURE 3.0317. EFFECT OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF BAR NORMALIZED AND TEMPERED TO A HARDNESS LEVEL OF RC 32 (31)

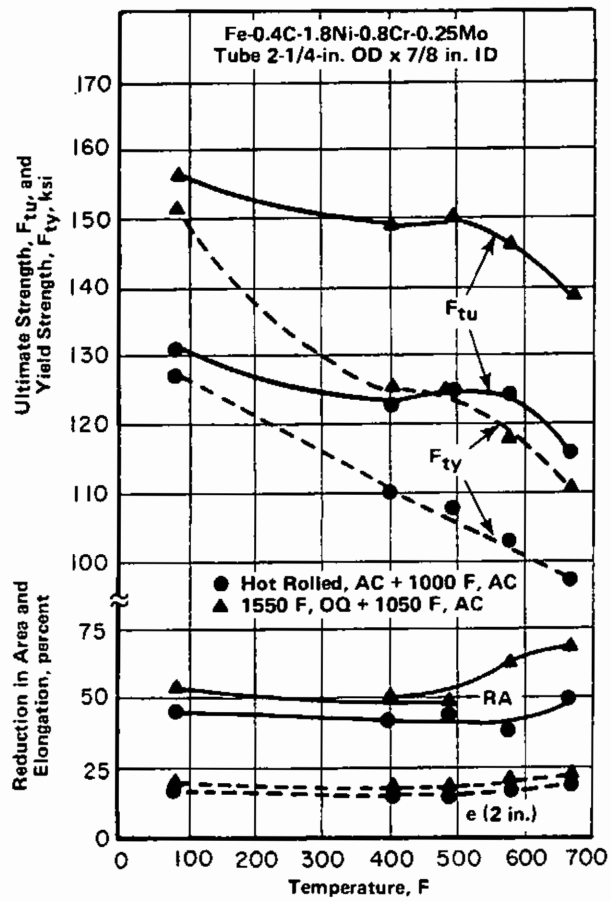


FIGURE 3.0318. EFFECT OF ELEVATED TEMPERATURES UP TO 662 F ON TENSILE PROPERTIES OF TUBE IN TWO DIFFERENT CONDITIONS (7)

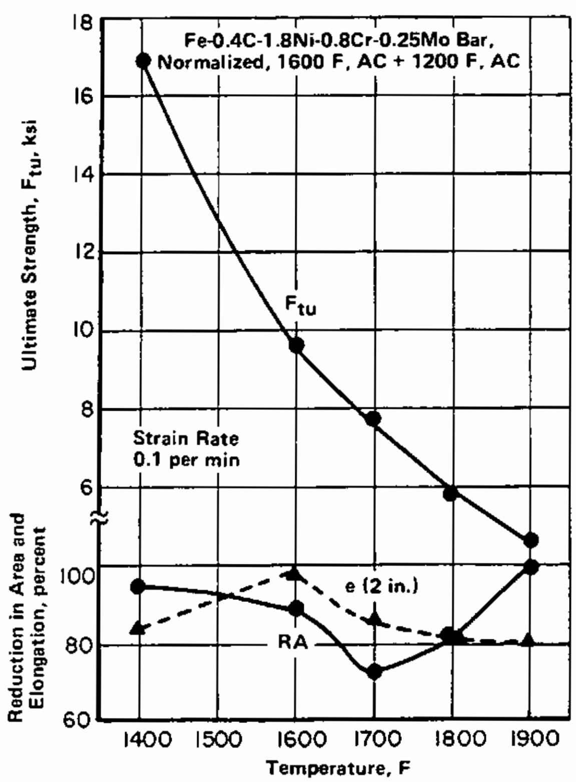


FIGURE 3.0319. EFFECT OF TEMPERATURES FROM 1400 F TO 1900 F ON TENSILE PROPERTIES OF NORMALIZED-AND-TEMPERED BAR (31)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

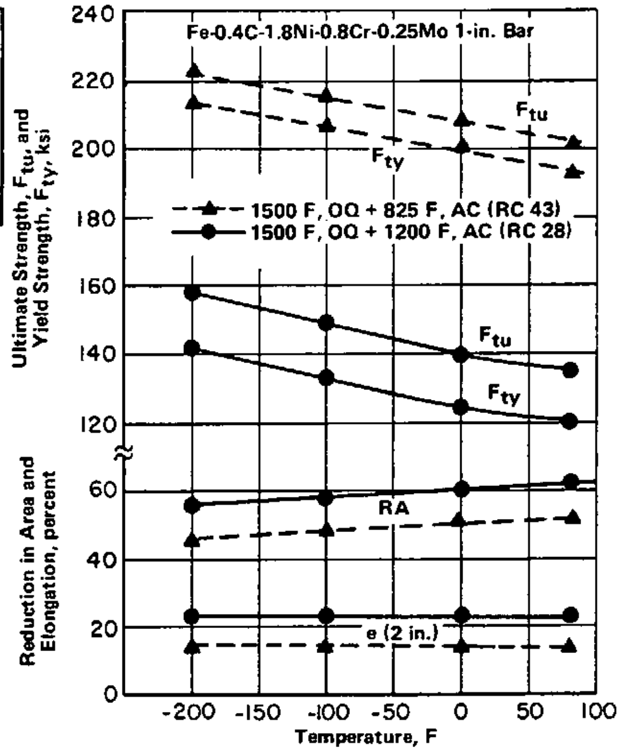


FIGURE 3.03110. EFFECT OF TEMPERATURES FROM 80 TO -200 F ON THE TENSILE PROPERTIES OF BAR QUENCHED AND TEMPERED TO TWO LEVELS OF HARDNESS (23)

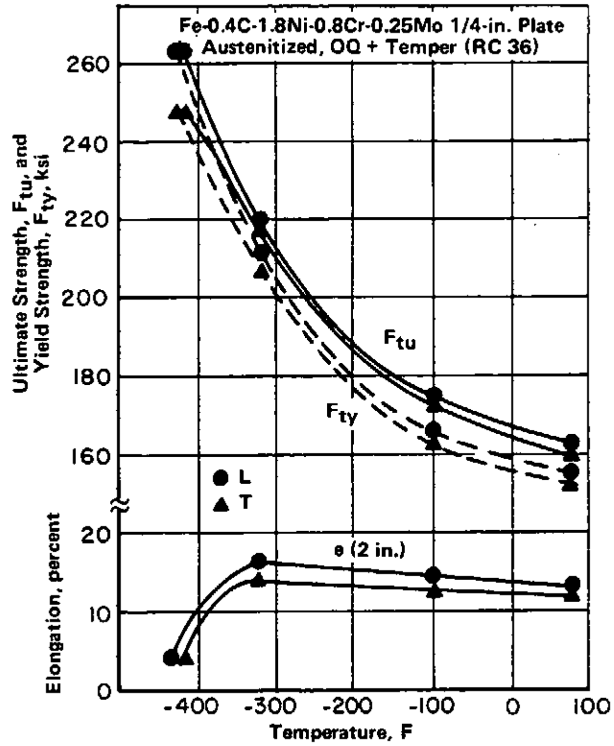


FIGURE 3.03111. EFFECT OF TEMPERATURES FROM 80 TO -423 F ON THE TENSILE PROPERTIES OF PLATE QUENCHED AND TEMPERED TO A HARDNESS LEVEL OF RC 36 (25)

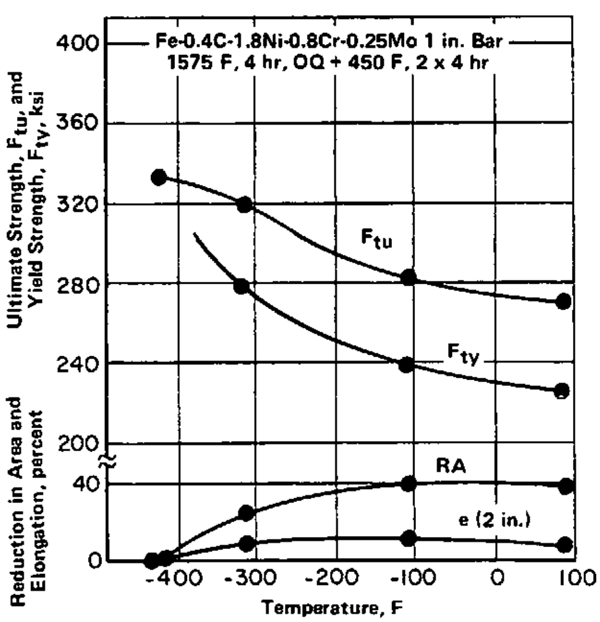


FIGURE 3.03112. EFFECT OF TEMPERATURES FROM 80 TO -423 F ON THE TENSILE PROPERTIES OF BAR QUENCHED AND TEMPERED TO F_{tu} = 270 KSI (31)

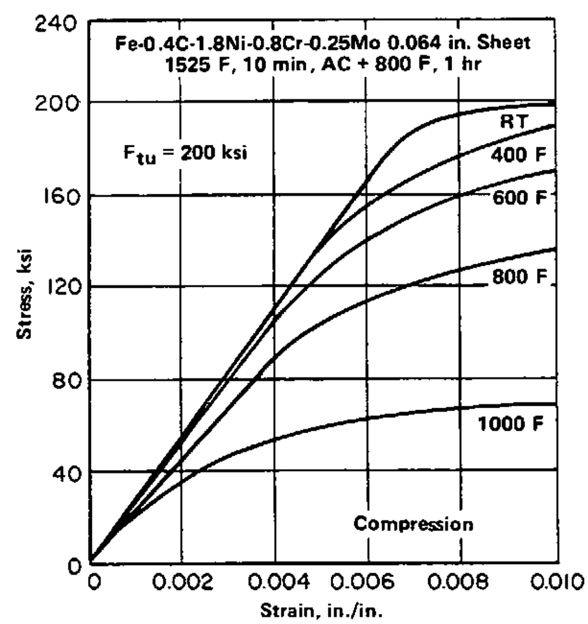


FIGURE 3.0321. STRESS-STRAIN CURVES IN COMPRESSION AT ROOM AND ELEVATED TEMPERATURES FOR SHEET HEAT TREATED TO F_{tu} = 200 KSI (51)

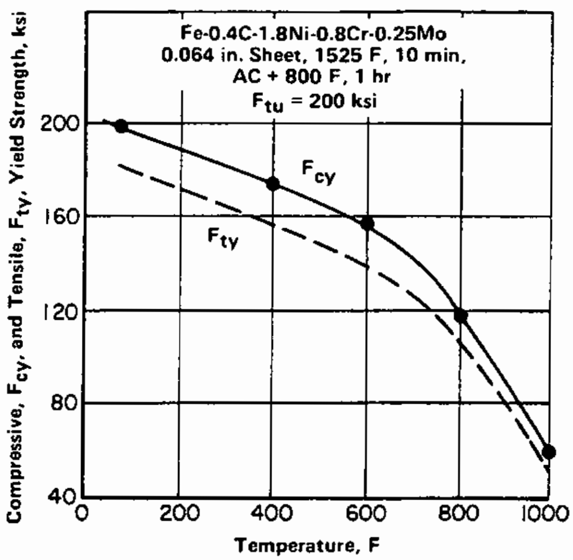


FIGURE 3.0322. EFFECT OF ELEVATED TEMPERATURES ON COMPRESSIVE YIELD STRENGTH OF SHEET HEAT TREATED TO F_{tu} = 200 KSI (51)

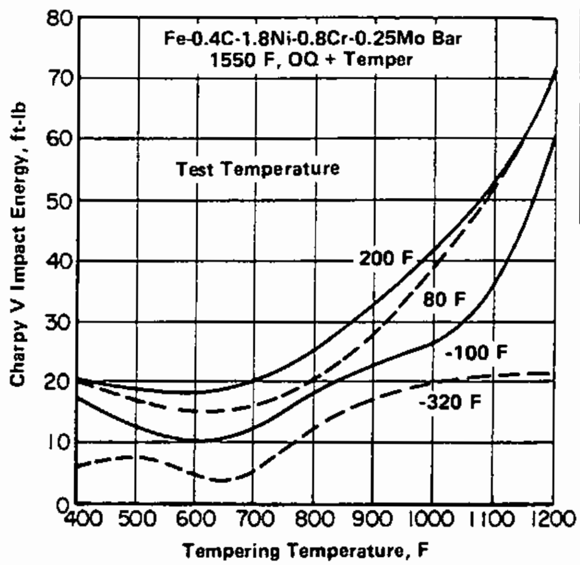


FIGURE 3.0331. EFFECTS OF TEMPERING TEMPERATURE AND TEST TEMPERATURE ON IMPACT PROPERTIES OF OIL-QUENCHED BAR (53)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

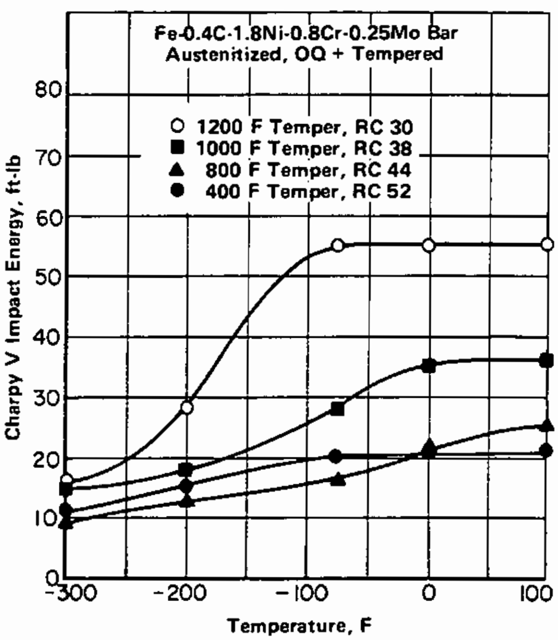


FIGURE 3.0332. EFFECT OF TEMPERATURES FROM 100 F TO -300 F ON IMPACT PROPERTIES OF OIL-QUENCHED BAR TEMPERED AT 400 TO 1200 F (38)

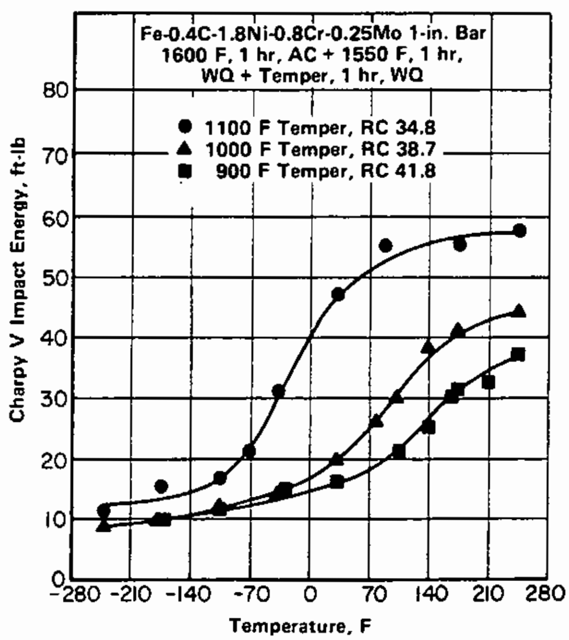


FIGURE 3.0333. EFFECT OF TEMPERATURES FROM 245 F TO -240 F ON IMPACT PROPERTIES OF WATER-QUENCHED BAR TEMPERED AT 900 TO 1100 F (3)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

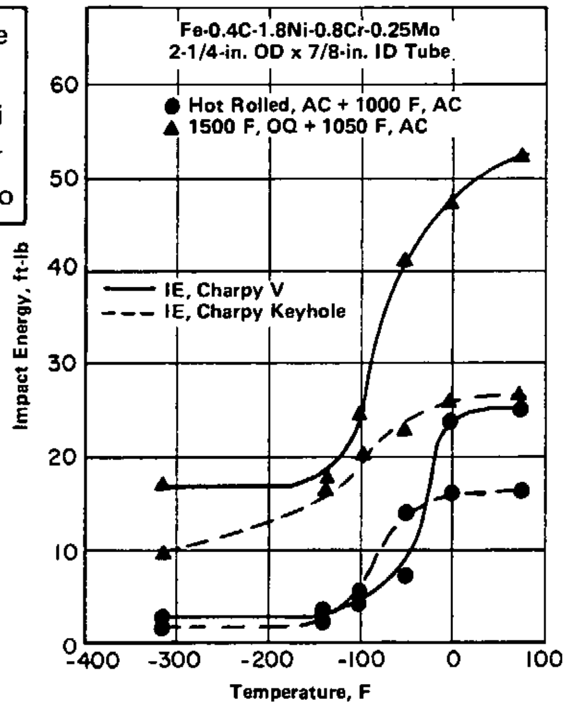


FIGURE 3.0334. EFFECT OF LOW TEMPERATURES ON IMPACT PROPERTIES OF TUBE IN TWO DIFFERENT CONDITIONS (7)

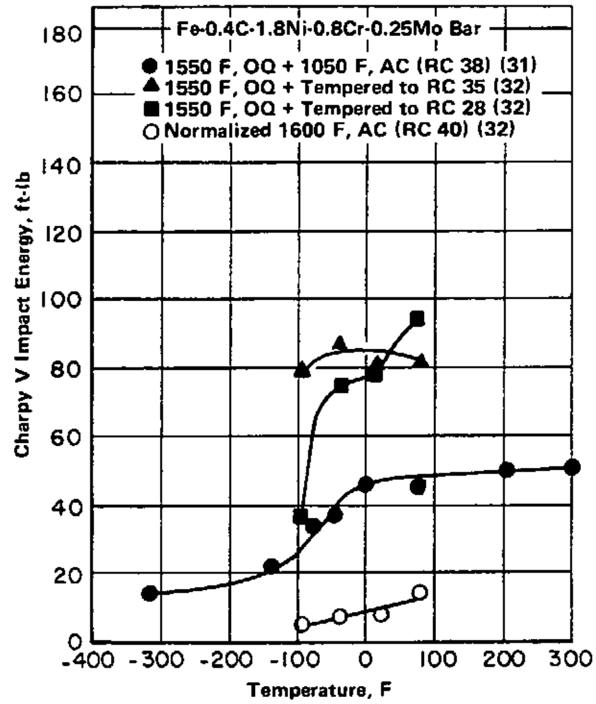


FIGURE 3.0335. EFFECT OF TEMPERATURE ON IMPACT PROPERTIES OF BAR IN VARIOUS HEAT TREATED CONDITIONS (31, 32)

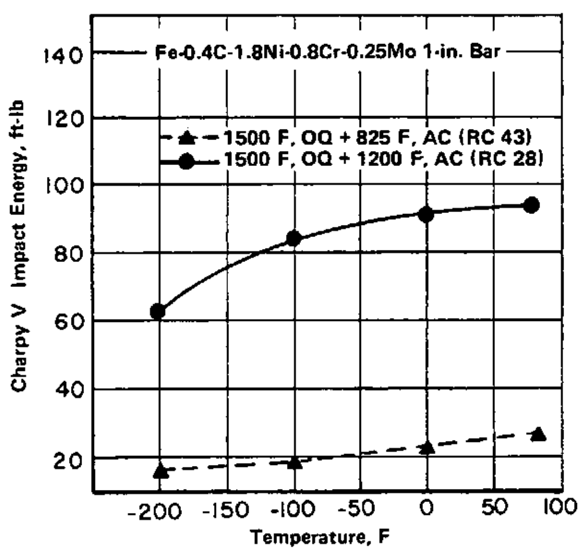


FIGURE 3.0336. EFFECT OF LOW TEMPERATURES ON THE IMPACT PROPERTIES OF BAR HEAT TREATED TO TWO LEVELS OF HARDNESS (23)

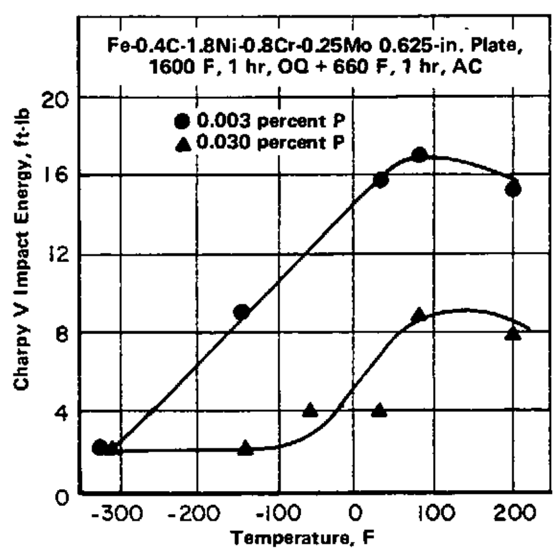


FIGURE 3.0337. EFFECTS OF TEMPERATURE AND PHOSPHORUS CONTENT ON IMPACT PROPERTIES OF PLATE THAT HAVE BEEN VACUUM INDUCTION MELTED (57)

Fe	
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

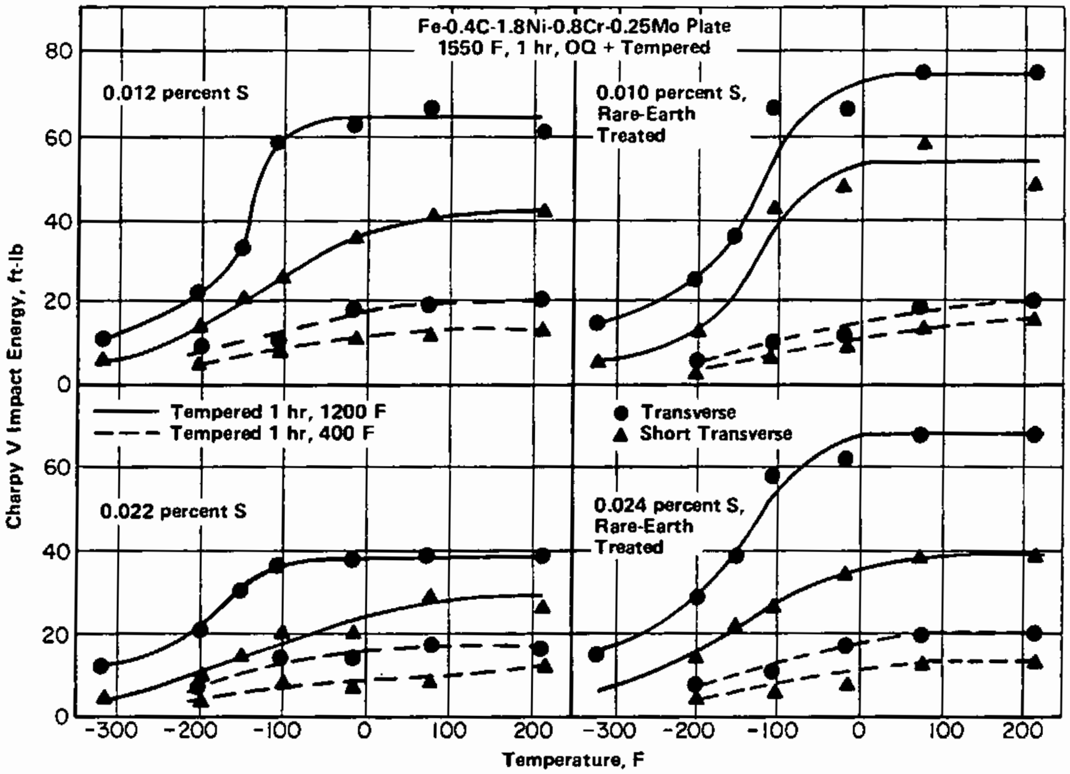


FIGURE 3.0338. EFFECTS OF RARE-EARTH TREATMENT AND VARIATIONS IN SULFUR CONTENT ON IMPACT TRANSITION CURVES OF VACUUM INDUCTION MELTED PLATE IN TWO HEAT TREATED CONDITIONS (9)

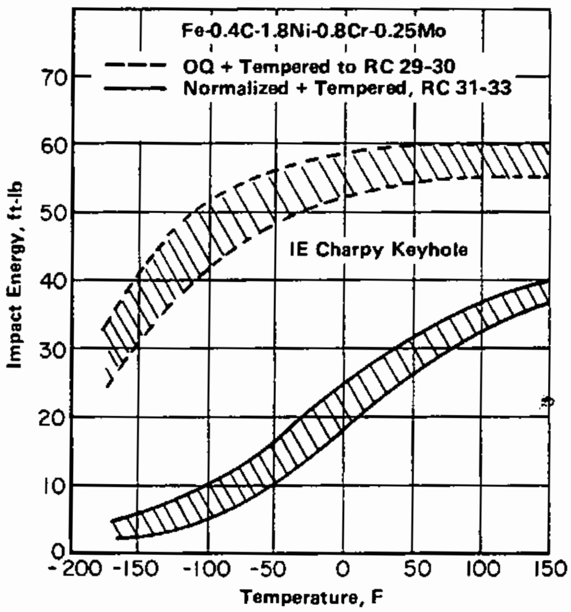
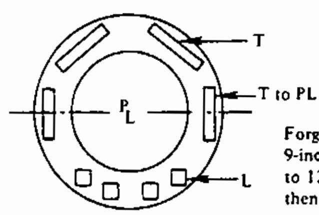


FIGURE 3.0339. COMPARISON OF IMPACT PROPERTIES OVER A RANGE OF TEMPERATURES FOR QUENCHED-AND-TEMPERED AND NORMALIZED-AND-TEMPERED 4340 (33)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo		
Form	Forging		
Condition	Oil-Quenched and Tempered to R_C 41		
	Charpy V-Notch Impact, ft-lb		
Orientation	68 F	32 F	- 65 F
Longitudinal	27.5	20.0	17.3
Transverse	15.5	14.5	11.3
Transverse to P_L	10.9	9.6	8.6



Forging section 12-inch ID x 9-inch OD x 48-inch long. Forged to 12-inch diam, bored, and then heat treated.

TABLE 3.03310. IMPACT PROPERTIES AT VARIOUS TEMPERATURES FOR DIFFERENT ORIENTATIONS IN FORGINGS (33)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo			
Form	1-inch Plate, Cross Rolled			
Condition	1650 F 1 hr, OQ + 1525 F 1 hr, OQ + 475 F 8 hr, AC			
		Charpy V-Notch IE, ft-lb		
Purity	Orientation	72 F	0 F	-80 F
Normal	L	12	10	9
	T	11	10	8
High	L	14	11	8
	T	14	11	9

Note: Chemical Analyses

Purity	C	Mn	P	S	Si	Ni	Cr	Mo	Cu
Normal	0.40	0.71	0.010	0.011	0.27	1.80	0.82	0.25	0.006
High	0.40	0.29	<0.0003	0.0008	0.007	1.79	0.75	0.27	0.002

(Cont)	Co	O	Al	N	Ti	As	Sb	Sn
Normal	0.008	0.0016	0.034	0.008	0.005	<0.002	<0.0004	<0.002
High	0.023	0.0010	0.002	0.002	<0.002	<0.002	<0.0004	<0.002

TABLE 3.03311. COMPARISON OF LOW TEMPERATURE IMPACT PROPERTIES OF AIR INDUCTION MELTED CROSS ROLLED PLATE OF NORMAL PURITY WITH THOSE OF HIGH PURITY PLATE PRODUCED BY VACUUM INDUCTION MELTING FOLLOWED BY VACUUM ARC REMELTING (8)

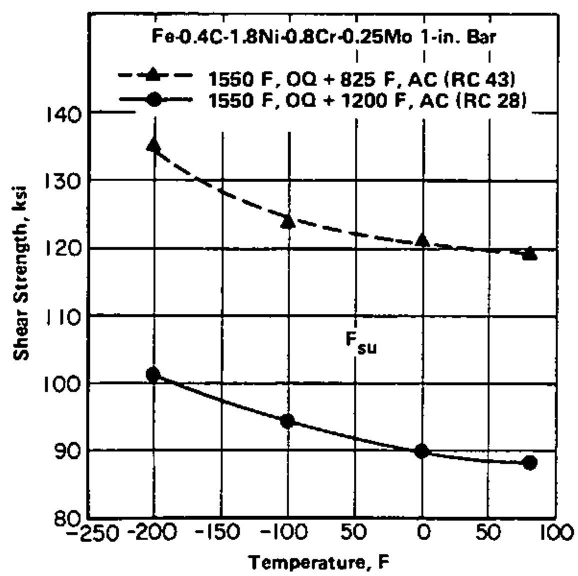


FIGURE 3.0351. EFFECT OF LOW TEMPERATURES ON SHEAR STRENGTH OF BAR QUENCHED AND TEMPERED TO TWO LEVELS OF HARDNESS (23)

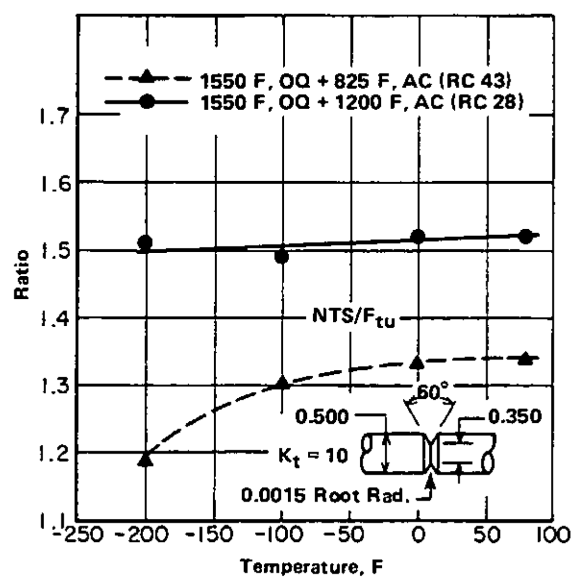


FIGURE 3.03711. EFFECT OF TEMPERATURES FROM 80 TO -200 F ON RATIO OF NOTCHED TENSILE STRENGTH TO TENSILE STRENGTH OF BAR HEAT TREATED TO TWO LEVELS OF HARDNESS (23)

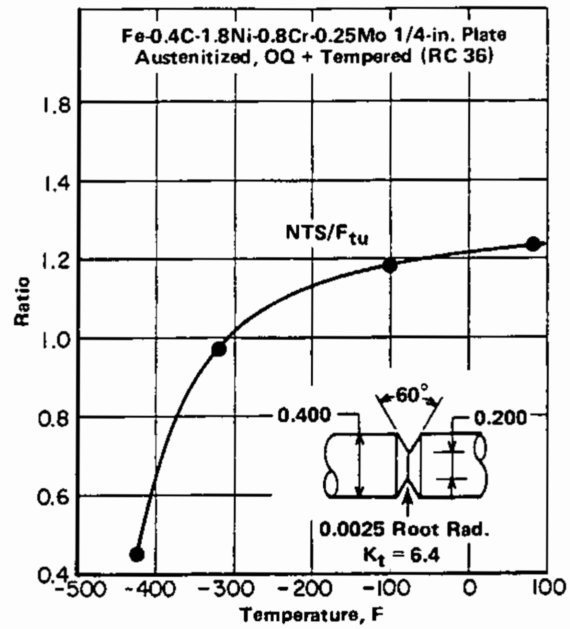


FIGURE 3.03712. EFFECT OF TEMPERATURES FROM 80 TO -423 F ON RATIO OF NOTCHED TENSILE STRENGTH TO TENSILE STRENGTH OF PLATE HEAT TREATED TO A HARDNESS LEVEL OF RC 36 (25)

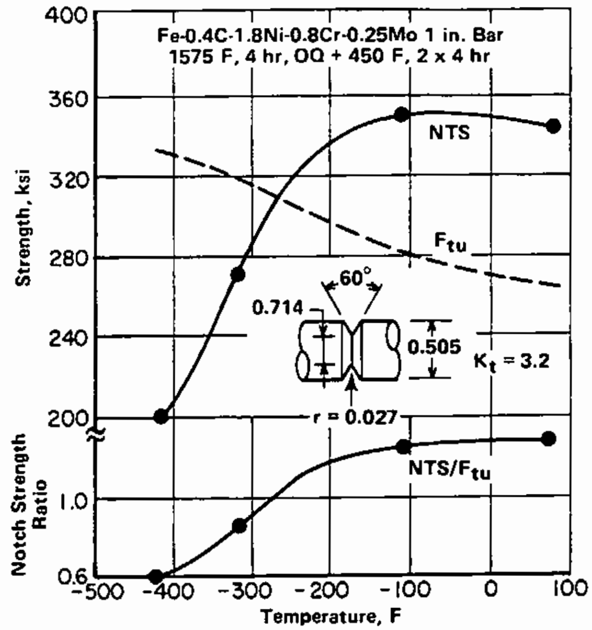


FIGURE 3.03713. EFFECT OF LOW TEMPERATURES ON NOTCHED STRENGTH OF BAR HEAT TREATED TO F_{tu} = 270 KSI (54)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

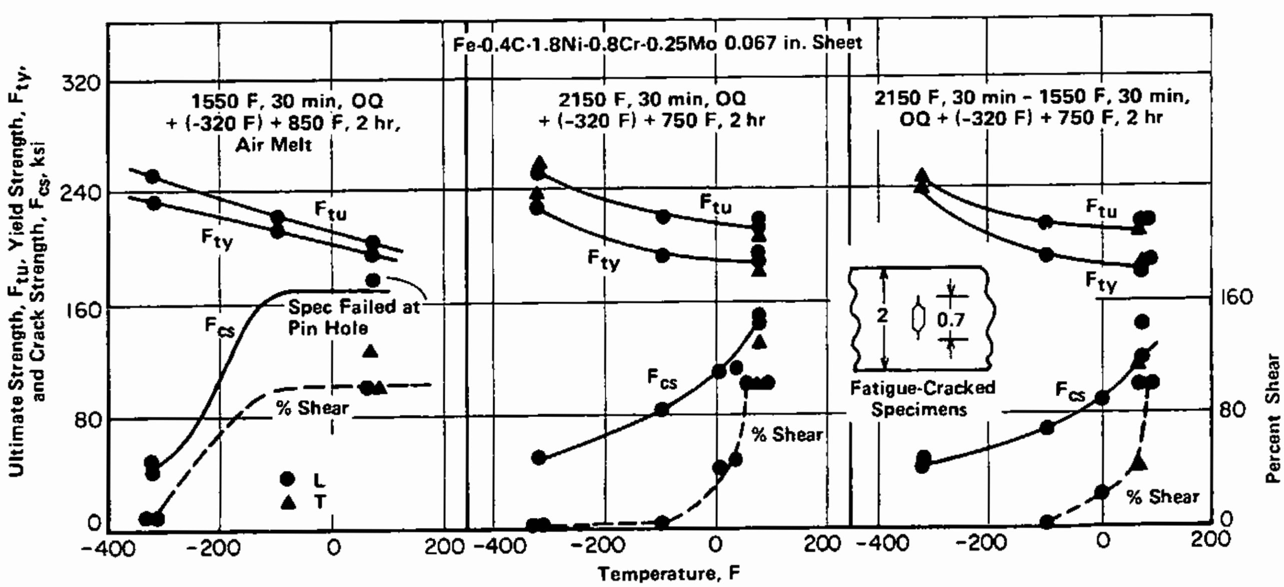


FIGURE 3.03714. EFFECT OF LOW TEMPERATURES ON TENSILE STRENGTH AND CRACK STRENGTH OF SHEET IN THREE HEAT TREATED CONDITIONS (55)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

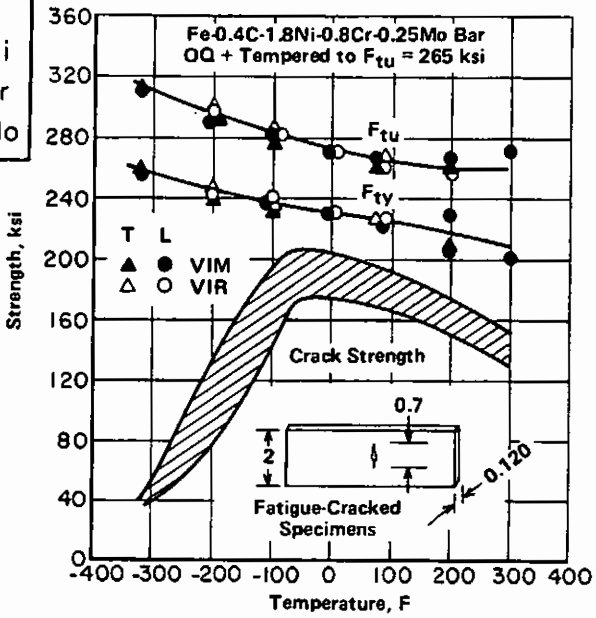


FIGURE 3.03715. EFFECT OF TEMPERATURES FROM -300 TO 300 F ON TENSILE STRENGTH AND CRACK STRENGTH OF VACUUM INDUCTION MELTED AND VACUUM INDUCTION REMELTED BAR HEAT TREATED TO F_{tu} = 265 KSI (55)

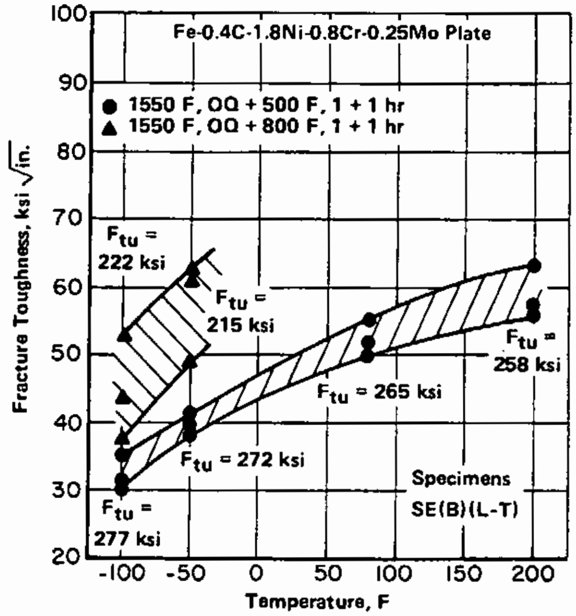


FIGURE 3.03721. EFFECT OF TEMPERATURES FROM -100 TO 200 F ON FRACTURE TOUGHNESS OF PLATE HEAT TREATED TO DIFFERENT STRENGTH LEVELS (40)

Alloy	Fe-0.4C-1.8Ni-0.8Cr-0.25Mo		
Form	1-inch Plate		
Condition	1550 F 1 hr, OQ + 400 F 3 + 3 hr, AC		
		Temp, F	
Property	Orientation(a)	75	-200
F_{ty}, ksi	L	214	225
F_{tu}, ksi	L	275	294
e (2 inch), percent	L	10	3
K_{Ic}, ksi √in.	L-S	72.6	40.1
	L-T	72.1	41.6
	T-S	–	40.6

Note: K_{Ic} specimens, M(T)(LS&LT), 0.25 in. thick.

TABLE 3.03722. FRACTURE TOUGHNESS AT 75 AND -200 F OF PLATE HEAT TREATED TO A ROOM TEMPERATURE TENSILE STRENGTH LEVEL OF 275 KSI (22)

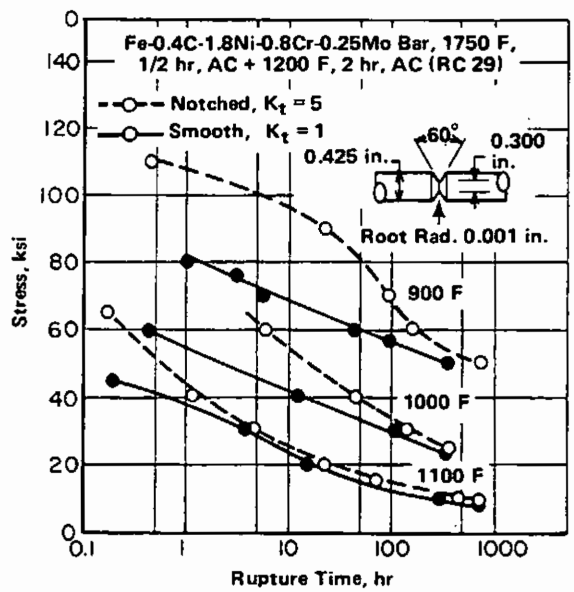


FIGURE 3.041. STRESS-RUPTURE PROPERTIES AT 900-1100 F OF NORMALIZED-AND-TEMPERED SMOOTH AND NOTCHED BAR (39)

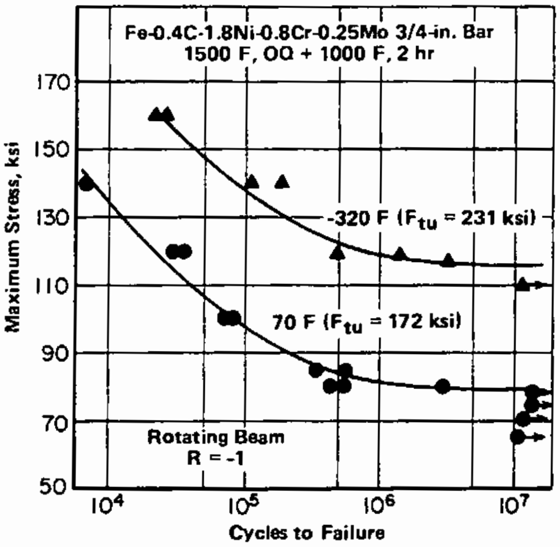


FIGURE 3.051. FATIGUE LIFE OF BAR AT ROOM TEMPERATURE AND AT -320 F (2)

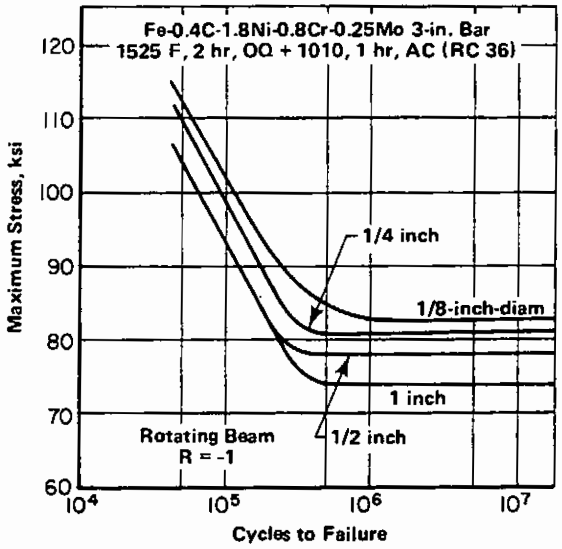


FIGURE 3.052. EFFECT OF SPECIMEN SIZES FROM 1/8 INCH TO 1 INCH DIAMETER ON FATIGUE LIFE OF BAR (28)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

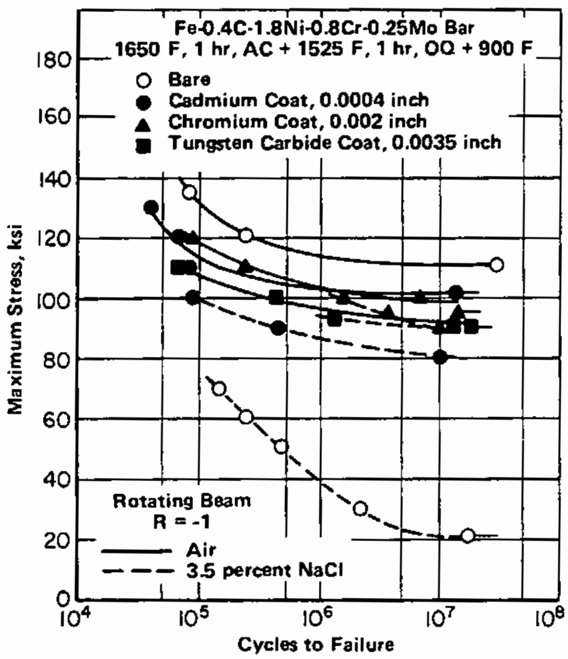


FIGURE 3.053. FATIGUE LIFE OF BARE AND COATED BAR IN ENVIRONMENTS OF AIR AND 3.5 PERCENT AQUEOUS SODIUM-CHLORIDE SOLUTION (10)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

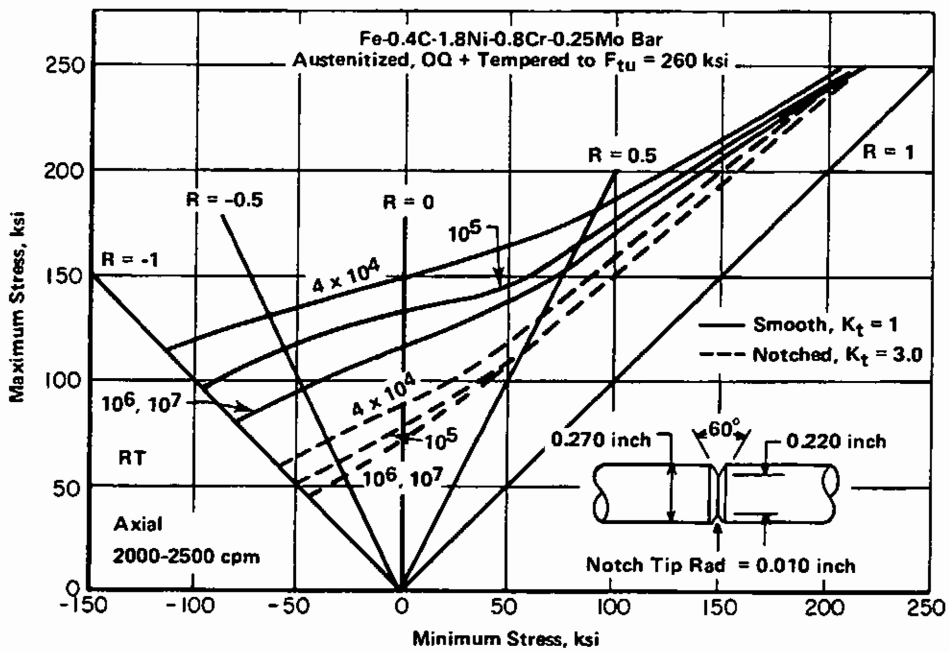


FIGURE 3.054. CONSTANT-LIFE FATIGUE CURVES AT 80 F FOR SMOOTH AND NOTCHED BAR HEAT TREATED TO F_{tu} = 260 KSI (37)

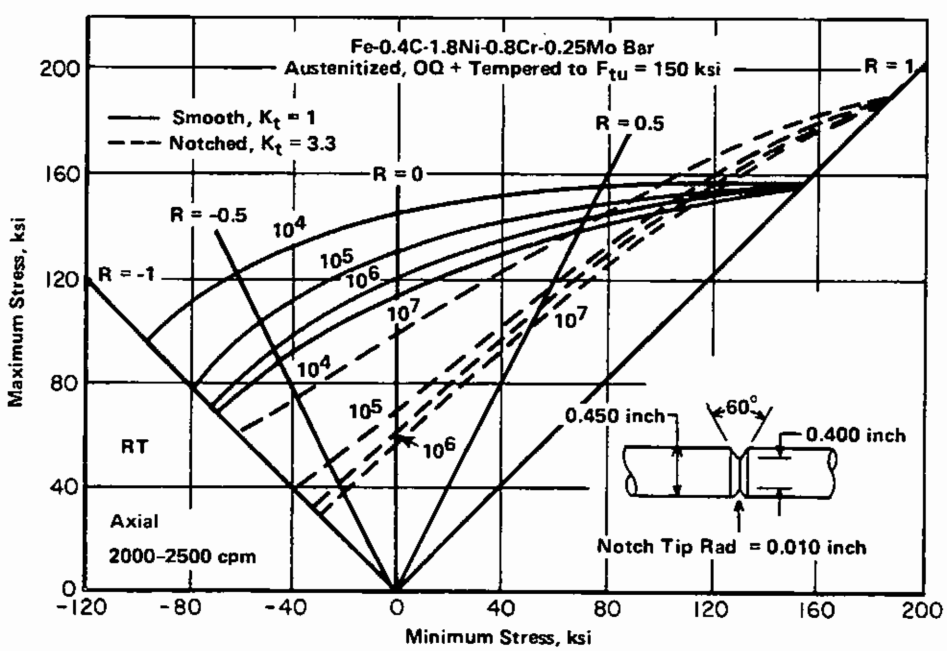


FIGURE 3.055. CONSTANT-LIFE FATIGUE CURVES AT 80 F FOR SMOOTH AND NOTCHED BAR HEAT TREATED TO F_{tu} = 150 KSI (37)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

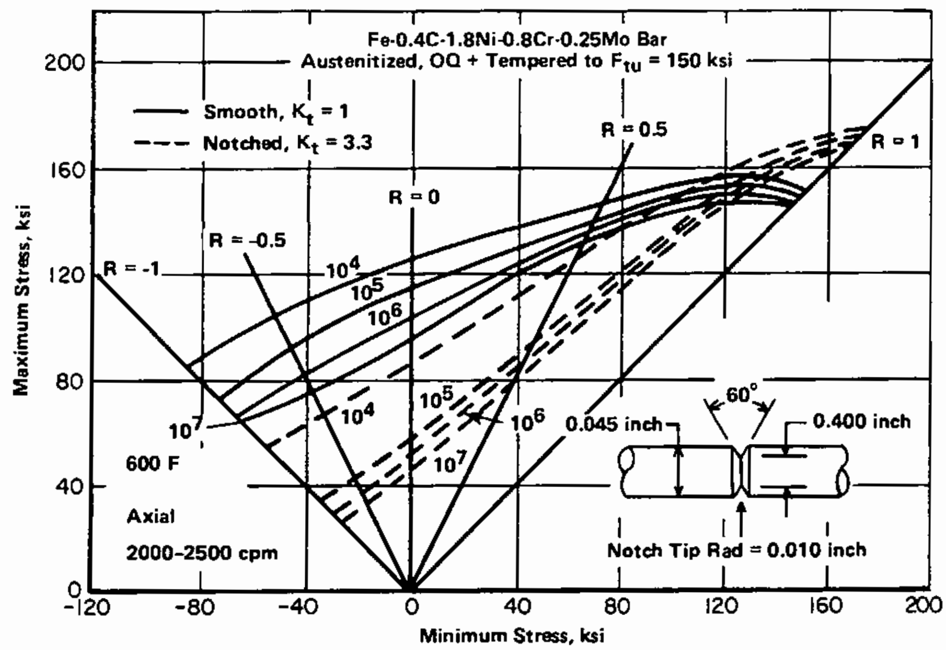


FIGURE 3.056. CONSTANT-LIFE FATIGUE CURVES AT 600 F FOR SMOOTH AND NOTCHED BAR HEAT TREATED TO F_{tu} = 150 KSI (37)

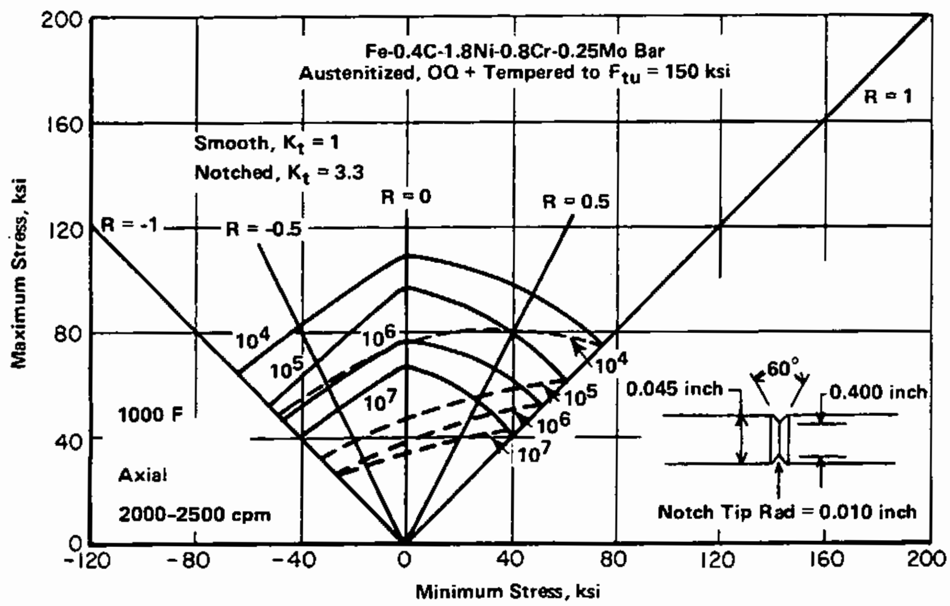


FIGURE 3.057. CONSTANT-LIFE FATIGUE CURVES AT 1000 F FOR SMOOTH AND NOTCHED BAR HEAT TREATED TO F_{tu} = 150 KSI (37)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

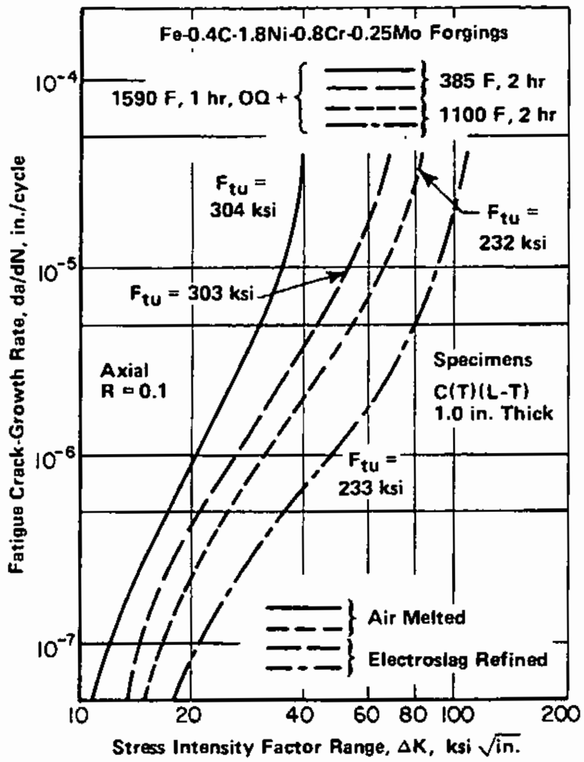


FIGURE 3.058. FATIGUE CRACK-GROWTH RATE IN AIR OF AIR-MELTED AND ELECTROSLAG REFINED FORGINGS THAT HAVE BEEN OIL-QUENCHED AND TEMPERED AT TWO DIFFERENT TEMPERATURES (58)

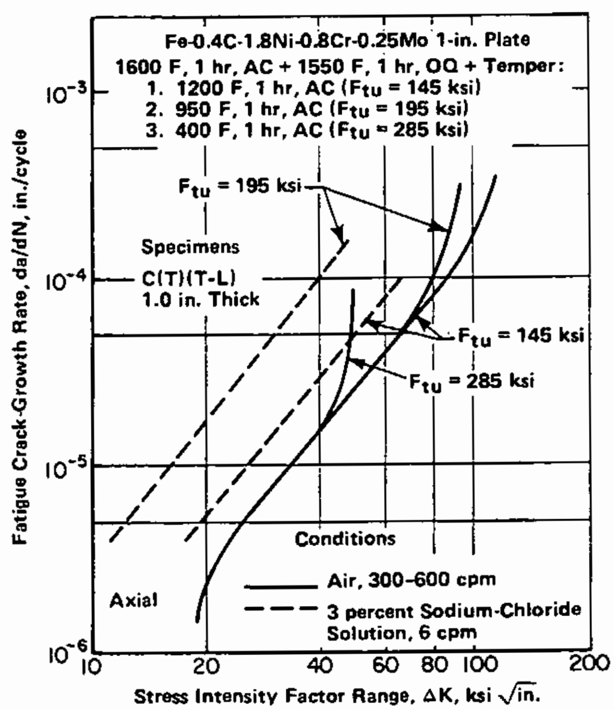


FIGURE 3.059. FATIGUE CRACK-GROWTH RATE OF PLATE AT VARIOUS STRENGTH LEVELS IN AIR AND IN AERATED 3 PERCENT AQUEOUS SODIUM-CHLORIDE SOLUTION (1)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

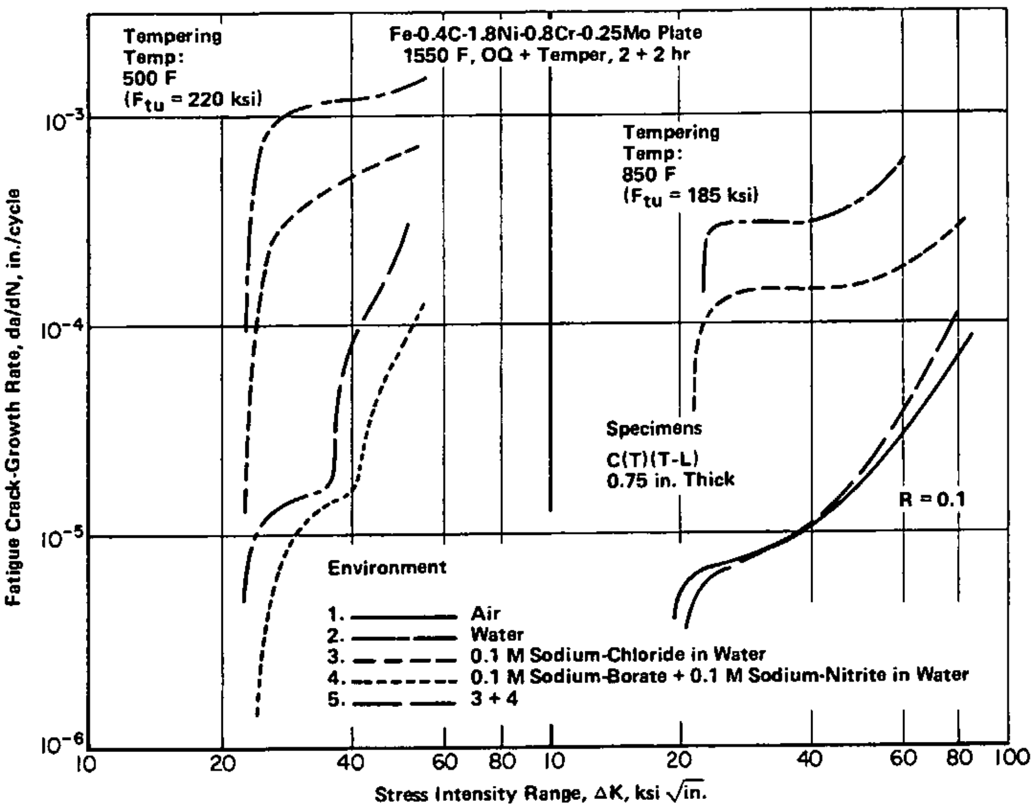


FIGURE 3.0510. EFFECTS OF VARIOUS ENVIRONMENTS AND A SODIUM-BORATE, SODIUM-NITRITE INHIBITOR ON FATIGUE CRACK-GROWTH RATE OF PLATE HEAT TREATED TO TWO STRENGTH LEVELS (29)

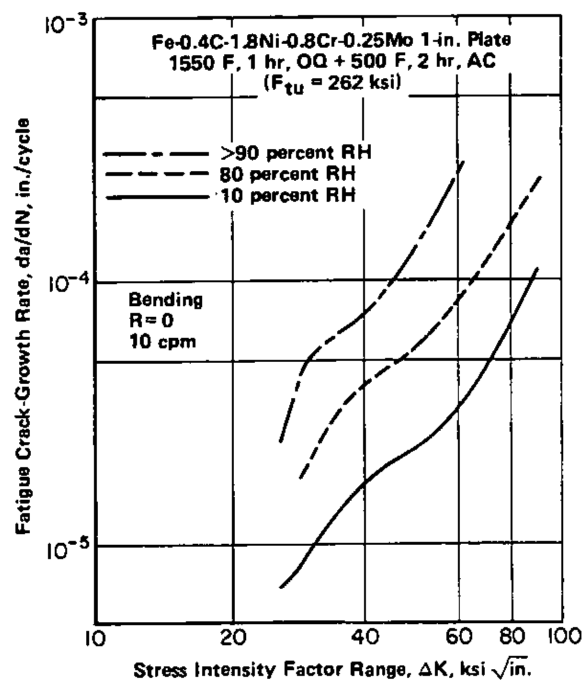


FIGURE 3.0511. FATIGUE CRACK-GROWTH RATES FOR PLATE TESTED AT ROOM TEMPERATURE IN AIR AT THREE LEVELS OF RELATIVE HUMIDITY (16, 36)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

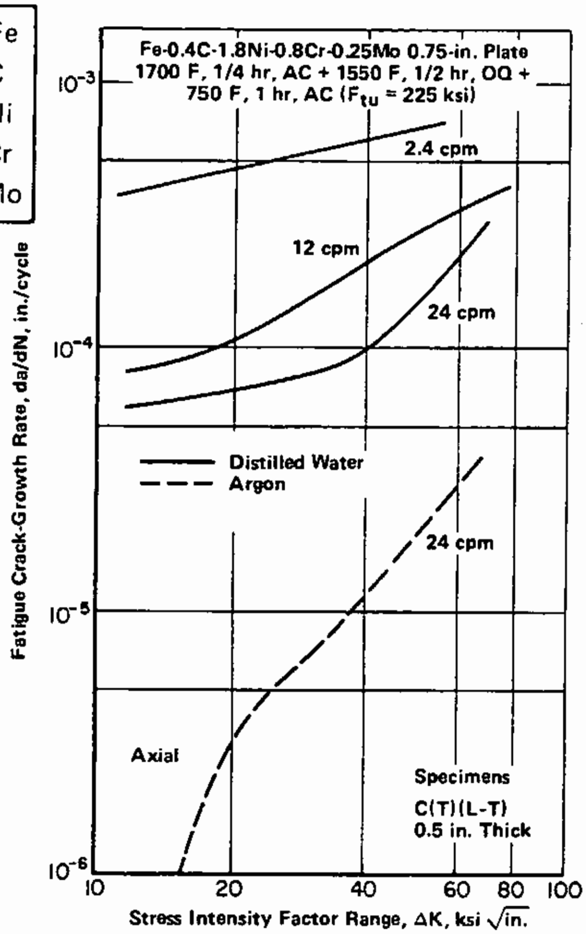


FIGURE 3.0512. FATIGUE CRACK-GROWTH RATES FOR PLATE TESTED AT ROOM TEMPERATURE IN DISTILLED WATER AT THREE FREQUENCIES AND IN ARGON AT ONE FREQUENCY (14)

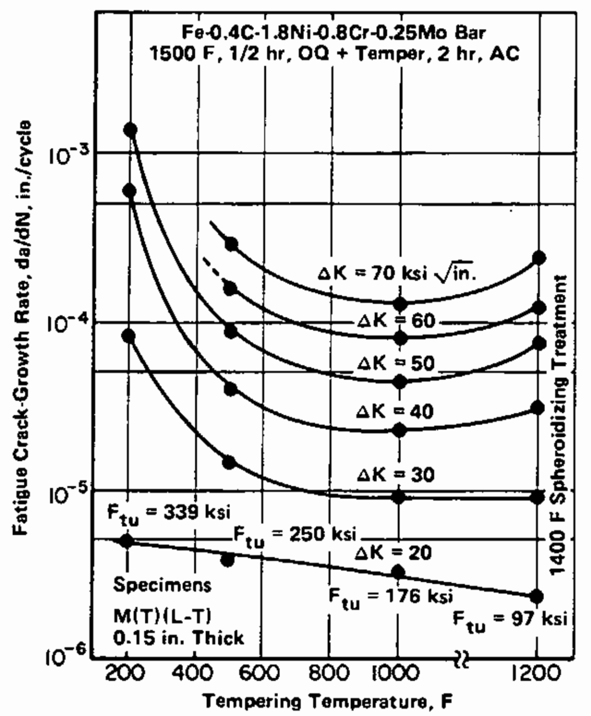


FIGURE 3.0513. EFFECTS OF TEMPERING TEMPERATURE AND STRESS-INTENSITY RANGE ON FATIGUE CRACK-GROWTH RATE IN AIR (19)

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340

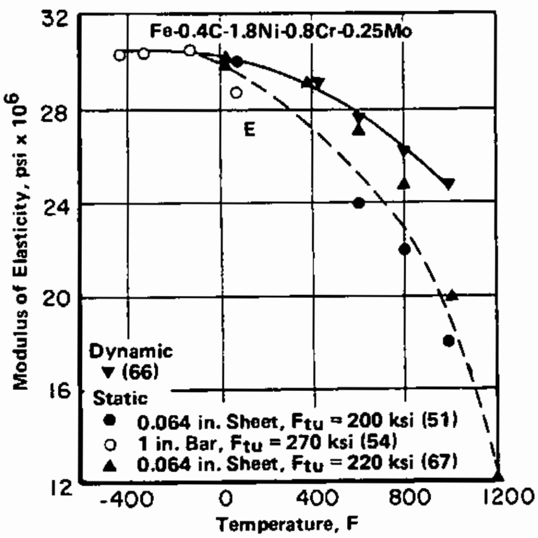


FIGURE 3.0621. EFFECT OF TEMPERATURES FROM -423 TO 1200 F ON MODULUS OF ELASTICITY (51, 54, 66, 67)

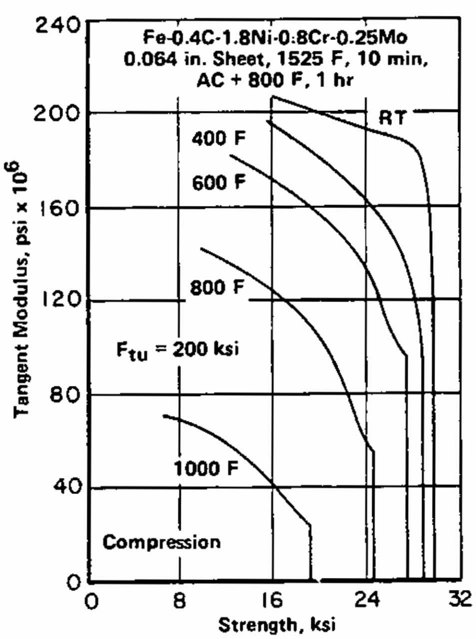


FIGURE 3.0641. TANGENT MODULUS CURVES IN COMPRESSION AT ROOM AND ELEVATED TEMPERATURES (51)

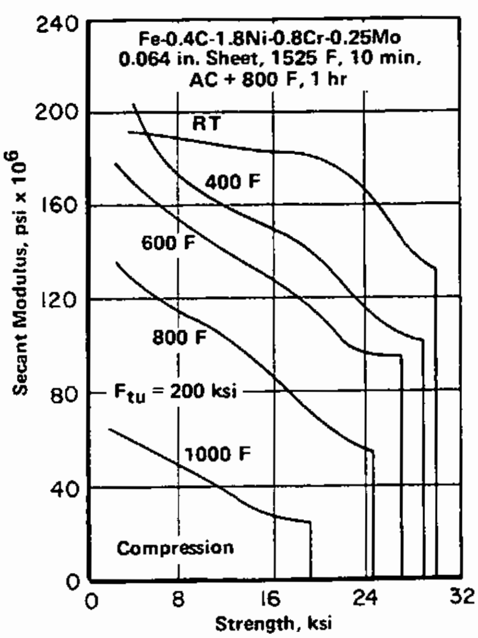


FIGURE 3.0651. SECANT MODULUS CURVES IN COMPRESSION AT ROOM AND ELEVATED TEMPERATURES (51)