	Fe
0.35	C
1.8	Ni
0.8	Cr
0.35	Mo
0.2	V

4335 V Mod

1 GENERAL

This steel is a development of 4330 and 4330 V Mod. The higher carbon content appreciably increases the tensile and yield strengths at low tempering temperatures. The alloy is used primarily in a condition heat treated to F_{ty} = 210 ksi minimum. It is available in the form of sheet, strip, plate, bar, forgings and tubing. It possesses good welding characteristics and the formability of the steel, if spheroidized, is also good.

1.01 Commercial Designation

4335 V Modified.

1.02 Alternate Designations

4335 Modified.
UNS Number: K33517.

1.03 Specifications

1.031 AMS Specifications, Table 1.031.

1.04 Composition

Table 1.04.

1.05 Heat Treatment

1.051 Normalize. 1600 to 1750 F, air cool. Normalizing temperature is frequently kept low (e.g., 1585 to 1615 F, 20 minutes). AMS 6428 gives 1690 to 1710 F.

1.052 Full anneal. 1585 to 1615 F, 1 hour per inch thickness, furnace cool to 1400 F, continue furnace cool at 30 F per hour maximum to 1000 F maximum.

1.053 Spheroidize anneal sheet and plate for maximum formability. 1435 to 1465 F, 10 hours, furnace cool 20 F per hour maximum to 800 F maximum.

1.054 Intermediate anneal to remove strain hardening of cold worked spheroidized sheet. 1200 to 1250 F, 2 to 8 hours.

1.055 Stress relief welded material. 1025 to 1075 F, 30 minutes, furnace cool to 500 F.

1.056 Austenitize. 1600 to 1650 F, 20 minutes per inch thickness, 30 minutes minimum, air cool or oil quench. Below 1600 F, the properties may be irregular. Tensile properties decrease slightly with increasing austenitizing temperatures. Normalizing should precede austenitizing if steel has been previously spheroidized.

1.057 Temper. 400 to 500 F, 2 hours minimum, to obtain F_{ty} = 210 ksi minimum, and 700 F minimum for at least 2 hours to obtain F_{ty} = 190 ksi minimum. AMS specified tensile properties, Table 1.057.

1.058 Alternate heat treatment for sheet. 1635 to 1665 F, 20 minutes, quench in salt bath at 375 to 415 F until metal reaches temperature of 400 to 500 F, hold 2 hours minimum. This treatment produces less distortion than oil quenching.

1.06 Hardness

1.061 End quench hardenability, Figure 1.061.

1.062 Effect of tempering temperature, quenching media and melt method on hardness of sheet, Figure 1.062.

1.063 Rockwell number for extruded bar with typical tempered martensite structure: 50 HRC (35).

1.064 Effect of thickness, melting practice, austenitizing temperature and tempering temperature on hardness of sheet, Table 1.064.

1.065 Effect of below-normal austenitizing temperature on hardness of forging, Figure 1.065.

1.07 Forms and Conditions Available

1.071 Alloy is available in the full commercial range of sizes for sheet, strip, plate, bar, tube and flash-welded rings.

1.072 Bar and forgings are available in the normalized condition. Sheet and plate are available in various annealed conditions.

1.08 Melting and Casting Practice

Electric furnace air melt. Induction and consumable electrode vacuum melts.

1.09 Special Considerations

See 4340.

2 PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. 2645 to 2845 F.

2.012 Phase changes. Transformation temperatures from ferrite to austenite,

A_{c1} = 1310 F
A_{c3} = 1480 F
M_s point = 575 F
M_f point near 360 F.

Determined on specimens with 0.35C (12).

2.0121 Time-temperature-transformation diagram, determined by (12), Figure 2.0121.

2.0122 Time-temperature-transformation diagram, determined by (26), Figure 2.0122.

2.013 Thermal conductivity. 29.2 Btu/ft/hr/ft^2/F.

2.014 Thermal expansion, Figure 2.014.

2.015 Specific heat. 0.16 Btu/lb/F.

2.016 Thermal diffusivity.

2.02 Other Physical Properties

2.021 Density. 0.283 lb/in.^{3}, 7.83 g/cm^3.

2.022 Electrical resistivity.

2.023 Magnetic properties. Alloy is ferromagnetic.

2.024 Emissivity.

2.025 Damping capacity.

2.03 Chemical Properties

Similar to 4340.

2.04 Nuclear Properties

3 MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specifications.

3.0111 AMS specifications for sheet, strip and plate, Table 3.0111.

3.0112 AMS specifications for bars, forgings, stock or billets, Table 3.0112.

3.012 Fabricators' specified mechanical properties, Table 3.012.

3.02 Mechanical Properties at Room Temperature

3.021 Tension.

3.0211 Stress-strain diagrams.

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

3.02111 Stress-strain curve in tension for bar, Figure 3.02111.
3.0212 Effect of austenitizing temperature and time on tensile properties.
3.02121 Effect of austenitizing time and temperature on tensile properties of bar, Figure 3.02121.
3.02122 Effect of austenitizing temperature on tensile properties of sheet, Figure 3.02122.
3.02123 Effect of austenitizing time on tensile properties of sheet, Figure 3.02123.
3.02124 Effect of quenching time at 400 F in salt on tensile properties of sheet, Figure 3.02124.
3.02125 Effect of normalizing and austenitizing temperature on tensile properties of sheet and plate, Figure 3.02125.
3.02126 Effect of below-normal austenitizing temperature on tensile properties of forging, Figure 3.02126.
3.0213 Effect of tempering temperature and time on tensile properties of sheet and plate.
3.02131 Effect of austenitizing and tempering temperatures on tensile properties of sheet, Figure 3.02131.
3.02132 Effect of melting practice and tempering temperature on tensile properties of sheet, Figure 3.02132.
3.02133 Effect of tempering time and temperature and time of austenitizing on tensile properties of sheet and plate austenitized at 1550 F, Figure 3.02133.
3.02134 Effect of tempering time and temperature and time of austenitizing on tensile properties of sheet and plate austenitized at 1600 F, Figure 3.02134.
3.02135 Effect of tempering time and temperature and time of austenitizing on tensile properties of sheet and plate austenitized at 1650 F, Figure 3.02135.
3.02136 Effect of tempering temperature and quenching media and melt method on tensile properties of sheet, Figure 3.02136.
3.02137 Effect of tempering time and quenching media on tensile properties of sheet, Figure 3.02137.
3.02138 Effect of tempering temperature on uniaxial and biaxial tensile stress properties of sheet, Figure 3.02138.
3.0214 Effect of tempering temperature and time on tensile properties of bar.
3.02141 Effect of quenching and tempering temperature on tensile properties of bar, Figure 3.02141.
3.02142 Effect of tempering time and temperature on tensile properties of bar, Figure 3.02142.
3.0215 Size effects on tensile properties.
3.02151 Effect of thickness on tensile properties of sheet and plate, Figure 3.02151.
3.02152 Effect of thickness of sheet from two melting practices and various heat treatments, Table 3.02152.
3.0216 Tensile properties of gun-tube extrusion, Table 3.0216.
3.0217 Tensile properties of forging, Table 3.0217.
3.022 Compression.
3.0221 Stress-strain diagrams.
3.02211 Stress-strain curve in compression for bar, Figure 3.02211.
3.023 Impact.
3.0231 Effect of quenching and tempering temperature on impact strength of bar, Figure 3.0231.
3.0232 Effect of tempering time and temperature on impact strength of bar, Figure 3.0232.
3.0233 Effect of below-normal austenitizing temperature on impact properties of forging, Figure 3.0233.
3.0234 Impact properties of gun-tube extrusion, Table 3.0234.
3.0235 Correlation of Charpy-V shelf energy with dynamic tear shelf energy in comparison to a range of various high-strength steels (37), Figure 3.0235.
3.024 Bending.
3.025 Torsion and shear.
3.0251 Effect of diameter-to-thickness ratio on ultimate shear strength of hollow cylinders, Figure 3.0251.
3.026 Bearing.
3.027 Stress concentration.
3.0271 Notch properties; see also 3.0272 and 3.0371.
3.02711 Effect of tempering temperature on tensile properties and notch strength of plate, Figure 3.02711.
3.02712 Effect of tempering temperature, melting practice and sheet thickness on notch strength of sheet, Figure 3.02712.
3.02713 Effect of stress concentration on notch strength of sheet, Figure 3.02713.
3.02714 Effect of tempering temperature on notch strength of sheet austenitized at 1650 F, Figure 3.02714.
3.02715 Effect of tempering temperature on notch strength of plate austenitized at 1650 F, Figure 3.02715.
3.02716 Effect of tempering time and temperature on notch strength of bar, Figure 3.02716.
3.02717 Effect of quenching and tempering temperature on notch strength of bar, Figure 3.02717.
3.02718 Notch tensile properties of forging, Table 3.02718.
3.0272 Fracture toughness.
3.02721 Effect of austenitizing temperature on notch strength of sheet, Figure 3.02721.
3.02722 Effect of tempering temperature on notch strength of sheet, Figure 3.02722.
3.02723 Effect of tempering temperature on notch strength of sheet austenitized at 1625 F, Figure 3.02723.
3.02724 Effect of tempering temperature on notch strength of plate austenitized at 1625 F, Figure 3.02724.
3.02725 Effect of tempering temperature on notch strength of sheet austenitized at 1650 F, Figure 3.02725.
3.02726 Effect of tempering temperature on notch strength of plate austenitized at 1650 F, Figure 3.02726.
3.02727 Effect of thickness on notch strength of sheet, Figure 3.02727.
3.02728 Fracture-toughness properties of gun-tube extrusion, Table 3.02728.
3.028 Combined properties.

3.03 **Mechanical Properties at Various Temperatures**
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Effect of test temperature on tensile properties of sheet, Figure 3.0312.
3.032 Compression.
3.0321 Stress-strain diagrams.
3.033 Impact.
3.0331 Effect of test temperature on impact strength of plate, Figure 3.0331.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.03711 Effect of test temperature on net fracture stress and fracture appearance of shear-cracked sheet, Figure 3.03711.

3.03712	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.015 inch sheet, Figure 3.03712 (38).
3.03713	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.015 inch sheet, Figure 3.03713 (38).
3.03714	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.015 inch sheet, Figure 3.03714 (38).
3.03715	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.030 inch sheet, Figure 3.03715 (38).
3.03716	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.030 inch sheet, Figure 3.03716 (38).
3.03717	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.030 inch sheet, Figure 3.03717 (38).
3.03718	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.063 inch sheet, Figure 3.03718 (38).
3.03719	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.063 inch sheet, Figure 3.03719 (38).
3.03720	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.063 inch sheet, Figure 3.03720 (38).
3.03721	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.125 inch sheet, Figure 3.03721 (38).
3.03722	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.125 inch sheet, Figure 3.03722 (38).
3.03723	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of air melted, quenched and tempered 0.125 inch sheet, Figure 3.03723 (38).
3.03724	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of consutrode vacuum melted, quenched and tempered 0.015 inch sheet, Figure 3.03724 (38).
3.03725	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of consutrode vacuum melted, quenched and tempered 0.015 inch sheet, Figure 3.03725 (38).
3.03726	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of consutrode vacuum melted, quenched and tempered 0.015 inch sheet, Figure 3.03726 (38).
3.03727	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of consutrode vacuum melted, quenched and tempered 0.063 inch sheet, Figure 3.03727 (38).
3.03728	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of consutrode vacuum melted, quenched and tempered 0.063 inch sheet, Figure 3.03728 (38).
3.03729	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of consutrode vacuum melted, quenched and tempered 0.063 inch sheet, Figure 3.03729 (38).
3.03730	Effect of test temperature on tensile properties, fracture appearance, and net section fracture stress of consutrode vacuum melted, quenched and tempered 0.063 inch sheet, Figure 3.03730 (38).
3.0372	Fracture toughness.
3.038	Combined properties.

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

3.04	**Creep and Creep Rupture Properties**
3.05	**Fatigue Properties**
3.051	S-N curves for bar with various surface treatments, Figure 3.051.
3.052	S-N curves for smooth and notched bar, Figure 3.052.
3.053	Fatigue life at 80 ksi (R = 0) for forging, Figure 3.053.
3.054	Fatigue crack propagation rate of gun-tube extrusion, Table 3.054.
3.06	**Elastic Properties**
3.061	Poisson's ratio. Dynamic bending, 0.303. Static tension, 0.293.
3.062	Modulus of elasticity, 30,000 ksi.
3.063	Modulus of rigidity, 11,000 ksi.
4	**FABRICATION** Similar to 4330 V Mod.
4.01	**Formability** Severe forming of sheet and strip is performed in the spheroidized condition, with the hardness limited to 95 RB maximum.
4.011	Forging range, 2000–2200 F (20).
4.02	**Machining and Grinding** Bar and forgings can be machined in the normalized condition, with additional tempering at 1275 F recommended for best machinability.
4.03	**Welding**
4.031	Flash welding of air melted plate results in reduced joint efficiency when heat treated to maximum strength. Effects of flash welding and tempering temperature on tensile properties and endurance limit of air melted plate, Figure 4.031.
4.032	Flash welding of vacuum melted plate results in better joint efficiency and considerably increased endurance limit. Effect of flash welding and tempering temperature on tensile properties and endurance limit of vacuum melted plate, Figure 4.032.
4.033	Multipass welding technique is required for welding 0.220 inch thick material. A 500 F preheat and a 500 F postheat for 30 minutes results in the optimum as-welded weld ductility (31).
4.034	Tests of welded 0.093 inch sheet, containing weld repairs after heat treatment, show F_{tu} reduced 20 to 30 ksi and F_{ty} reduced 10 to 15 ksi. Fracture toughness of repair weld after heat treatment

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

generally was better than a normal heat-treated weld (32).

4.04 Heat Treatment

4.05 Surface Treatment

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Alloy	4335 V Mod	
Source	AMS	Form
1	5029B	Welding wire
2	6428C	Bars, forgings, forging stock and mechanical tubing
3	6429C	Bars, forgings, mechanical tubing, flash-welded rings, and stock for forging or flash-welded rings (vacuum melt)
4	6430C	Bars, forgings, mechanical tubing, flash-welded rings, and stock for forging or flash-welded rings (special grade)
5	6433C	Sheet, strip and plate (special grade)
6	6434C	Sheet, strip and plate
7	6435C	Sheet, strip and plate (vacuum melt)

TABLE 1.031. AMS SPECIFICATIONS

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

Alloy	4335 V Mod			
Source	AMS (2,6)		AMS (3,4,5,7)	
	Percent		Percent	
Composition	Min	Max	Min	Max
Carbon	0.32[a]	0.38	0.33[b]	0.38
Chromium	0.65	0.90	0.65	0.90
Copper	–	0.35	–	0.35
Manganese	0.60	0.80	0.60	0.90
Molybdenum	0.30	0.40	0.30	0.40
Nickel	1.65	2.00	1.65	2.00
Phosphorus	–	0.025	–	0.010[c]
Silicon	0.15	0.35	0.40	0.60
Sulfur	–	0.025	–	0.010[c]
Vanadium	0.17	0.23	0.17	0.23
Iron	Balance		Balance	

(a) AMS 6434C gives 0.33.
(b) AMS 6430C gives 0.32.
(c) AMS 6430C and AMS 6433C give 0.015.

TABLE 1.04. COMPOSITION

Alloy	4335 V Mod			
Condition	Austenitized 1600–1650 F, 1 hr, OQ			
Source	Form of Product	Temper	F_{tu}, ksi (Min)	F_{ty}, ksi (Min)
AMS 6429C	Bars, forgings, tube (vacuum melted)	400–500 F 2 hr (min)	240	210
AMS 6430C	Bars, forgings, tube (special grade)	700 F 2 hr (min)	205	190
AMS 6433C	Sheet, strip and plate (special grade)	700 F 2 hr (min)	205	190
AMS 6435C	Sheet, strip and plate (vacuum melted)	400–500 F 2 hr (min)	240	210

TABLE 1.057. AMS SPECIFIED TENSILE PROPERTIES

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

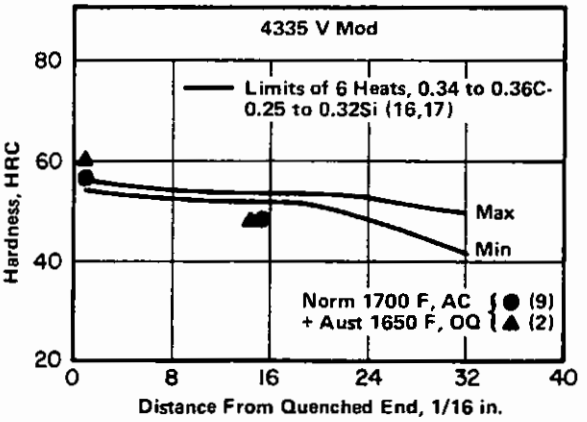


FIGURE 1.061. END QUENCH HARDENABILITY (2,9,16,17)

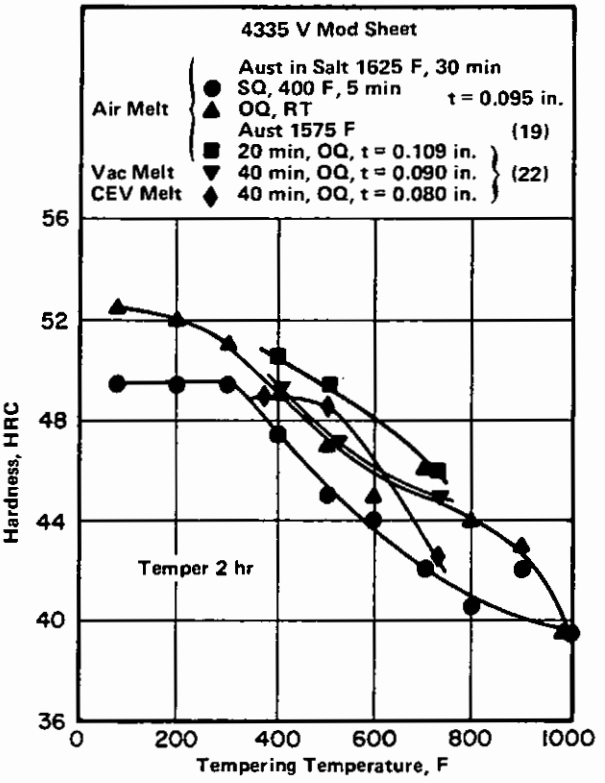


FIGURE 1.062. EFFECT OF TEMPERING TEMPERATURE, QUENCHING MEDIA AND MELT METHOD ON HARDNESS OF SHEET (19,22)

Alloy	4335 V Mod			
Form	Sheet			
		Condition		
Melting Practice	Thickness, in.	Austenitizing Temperature, F(a)	Tempering Temperature, F(b)	Hardness, HRC
Air Melt	0.03	1575	400	49–50
		1575	725	41–43
		1620	400	48–50
	0.063	1575	400	52–54
		1575	725	44–45
		1620	400	48–52
	0.125	1575	400	47–50
		1575	725	42–44
		1620	400	47–51
Consumable Electrode	0.063	1575	400	48–50
		1575	725	43–44
		1620	400	48–50

(a) Austenitized at 1575 F in neutral salt, or in argon at 1620 F, oil quenched.
(b) Tempered for 2 hours and air cooled.

TABLE 1.064. EFFECT OF THICKNESS, MELTING PRACTICE, AUSTENITIZING TEMPERATURE AND TEMPERING TEMPERATURE ON HARDNESS OF SHEET (38)

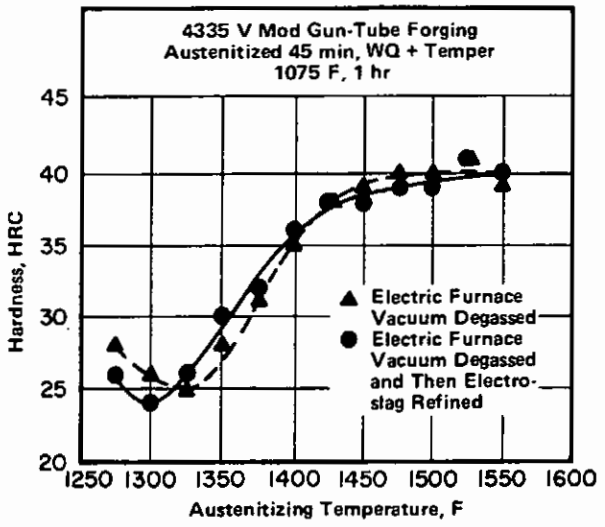


FIGURE 1.065. EFFECT OF BELOW-NORMAL AUSTENITIZING TEMPERATURE ON HARDNESS OF FORGING (33)

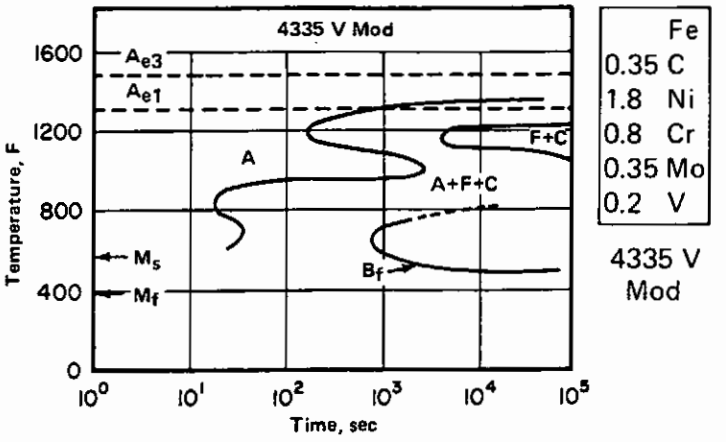


FIGURE 2.0121. TIME-TEMPERATURE-TRANSFORMATION DIAGRAM, DETERMINED BY (12)

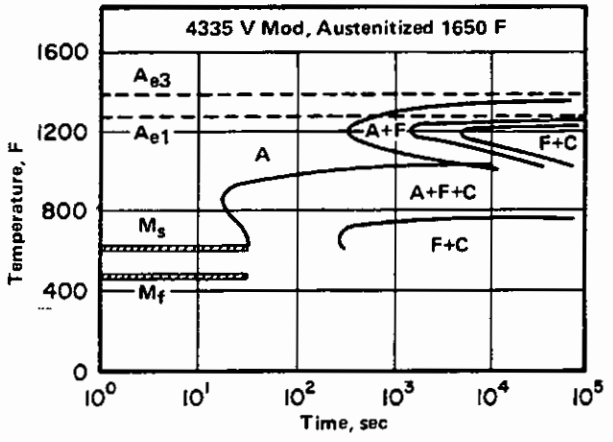


FIGURE 2.0122. TIME-TEMPERATURE-TRANSFORMATION DIAGRAM, DETERMINED BY (26)

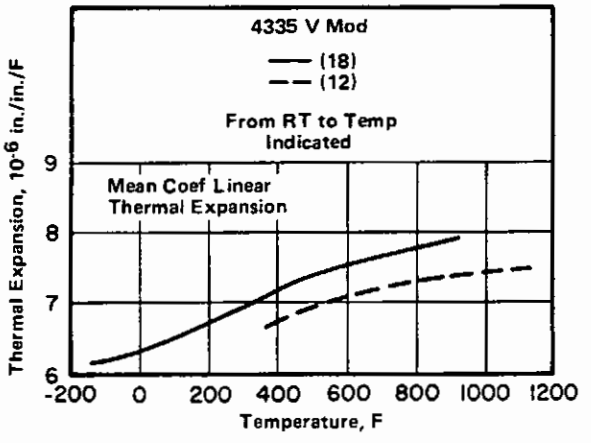


FIGURE 2.014. THERMAL EXPANSION (12,18)

Alloy	4335 V Mod						
Form	Sheet, Strip and Plate						
Condition	1600 to 1650 F, 1 hr, OQ +						
	>700 F, 2 hr				400 to 500 F, 2 hr		
Thickness, in.	≤0.070	>0.070 to 0.249	>0.249 to 0.349	>0.349	≥0.070	≥0.070 to 0.249	>0.349
F_{tu} (Min), ksi	205	205	205	205	240	240	240
F_{ty} (Min), ksi	190	190	190	190	210	210	210
e (2 in.) (Min), percent	5	6	8	10	5	6	8

TABLE 3.0111. AMS SPECIFICATIONS FOR SHEET, STRIP AND PLATE (5,7)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

Alloy	4335 V Mod			
Condition	1600 to 1650 F, 1 hr, OQ + >700 F, 2 hr		400 to 500 F, 2 hr	
Form	Bar	Forgings, Stock, Billets	Bar	Forgings, Stock, Billets
Thickness, in.	Not given			
F_{tu} (Min), ksi		240		205
F_{ty} (Min), ksi		210		190
e (4D) (Min), percent	10 (L)	7 (T)	10 (L)	7 (T)

TABLE 3.0112. AMS SPECIFICATIONS FOR BARS, FORGINGS, STOCK OR BILLETS (3,4)

Alloy	4335 V Mod		
Condition	1625 F, OQ + 400 to 500 F, 2 hr Minimum		
Form	Sheet, Strip, Plate	Bar	Billet
F_{ty} (Min), ksi	–	210	210
L	–	–	–
T	210	–	–
e (2 in.) (Min), percent	–	–	–
L	–	10	–
T	6	–	7

TABLE 3.012. FABRICATORS' SPECIFIED MECHANICAL PROPERTIES (9)

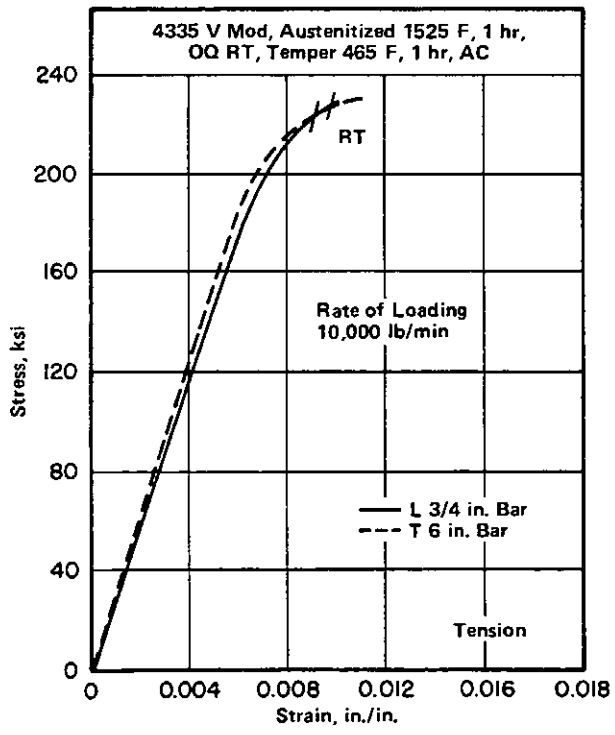


FIGURE 3.02111. STRESS-STRAIN CURVE IN TENSION FOR BAR (24)

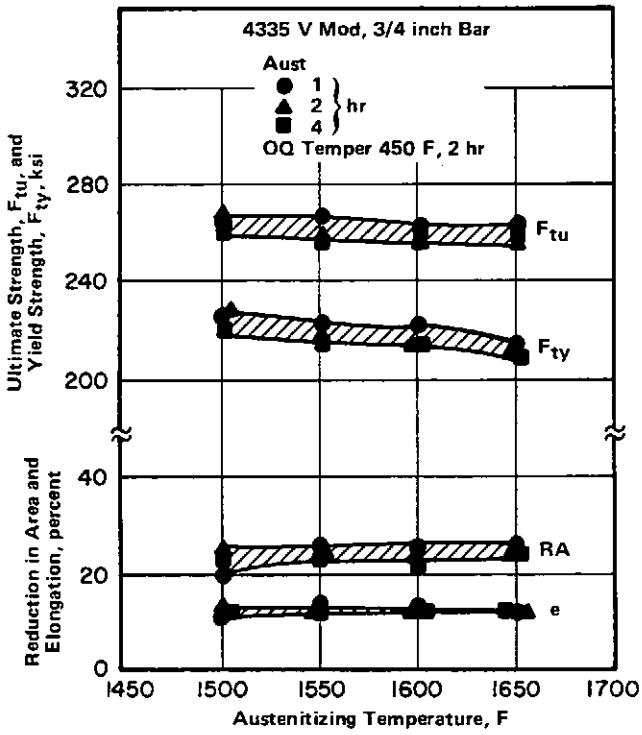


FIGURE 3.02121. EFFECT OF AUSTENITIZING TIME AND TEMPERATURE ON TENSILE PROPERTIES OF BAR (24)

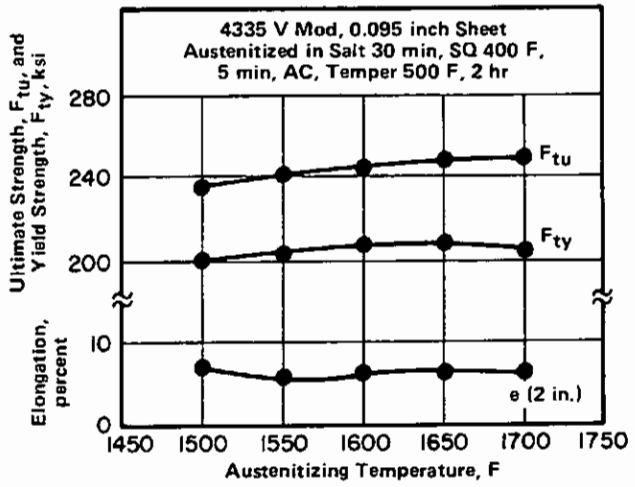


FIGURE 3.02122. EFFECT OF AUSTENITIZING TEMPERATURE ON TENSILE PROPERTIES OF SHEET (19)

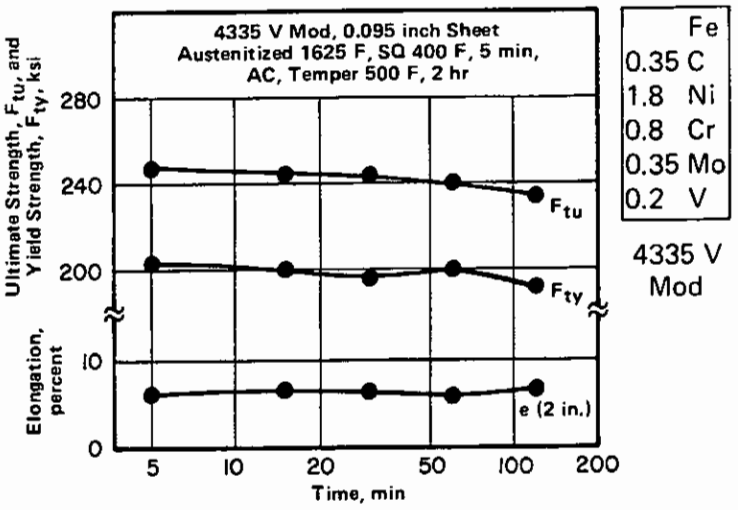


FIGURE 3.02123. EFFECT OF AUSTENITIZING TIME ON TENSILE PROPERTIES OF SHEET (19)

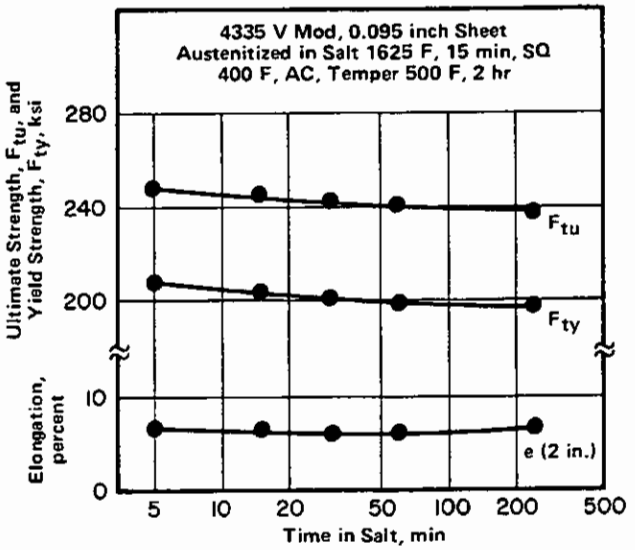


FIGURE 3.02124. EFFECT OF QUENCHING TIME AT 400 F IN SALT ON TENSILE PROPERTIES OF SHEET (19)

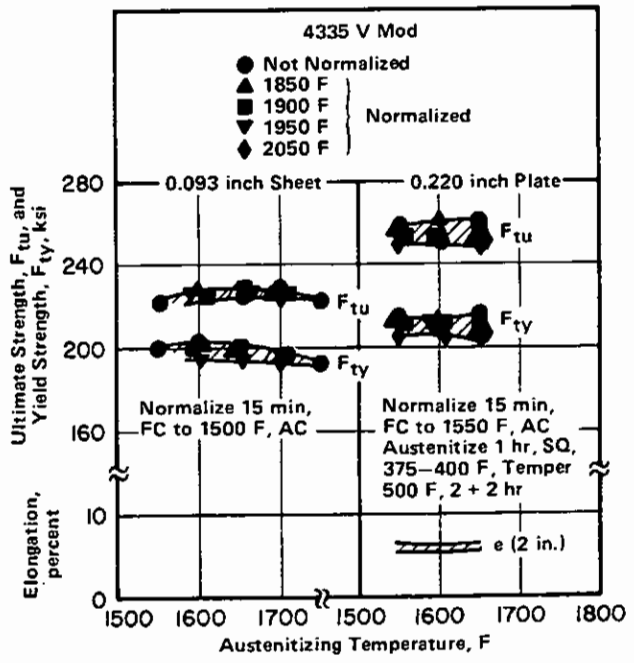


FIGURE 3.02125. EFFECT OF NORMALIZING AND AUSTENITIZING TEMPERATURE ON TENSILE PROPERTIES OF SHEET AND PLATE (21)

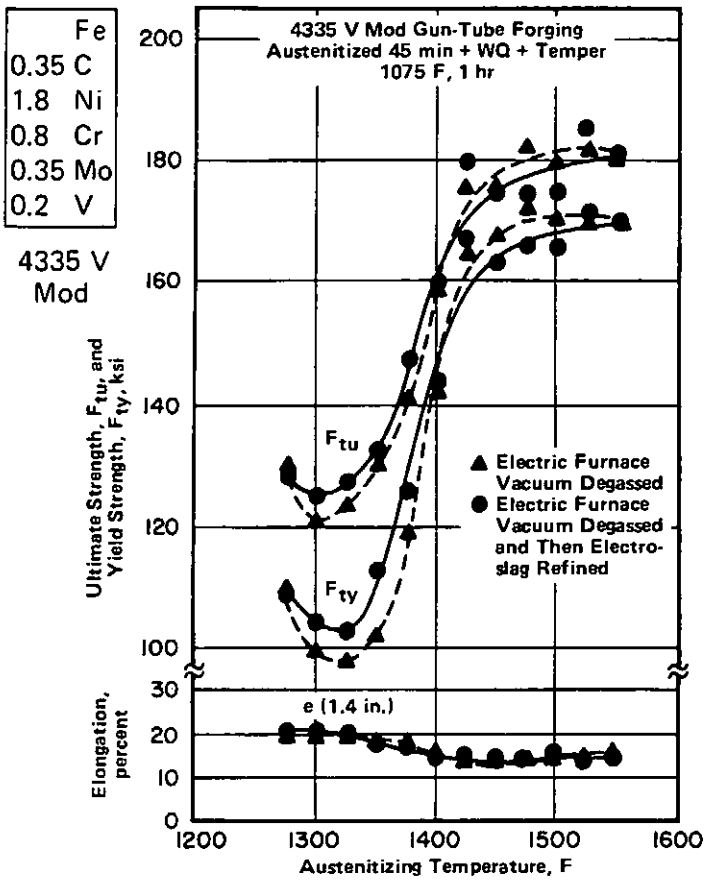


FIGURE 3.02126. EFFECT OF BELOW-NORMAL AUSTENITIZING TEMPERATURE ON TENSILE PROPERTIES OF FORGING (33)

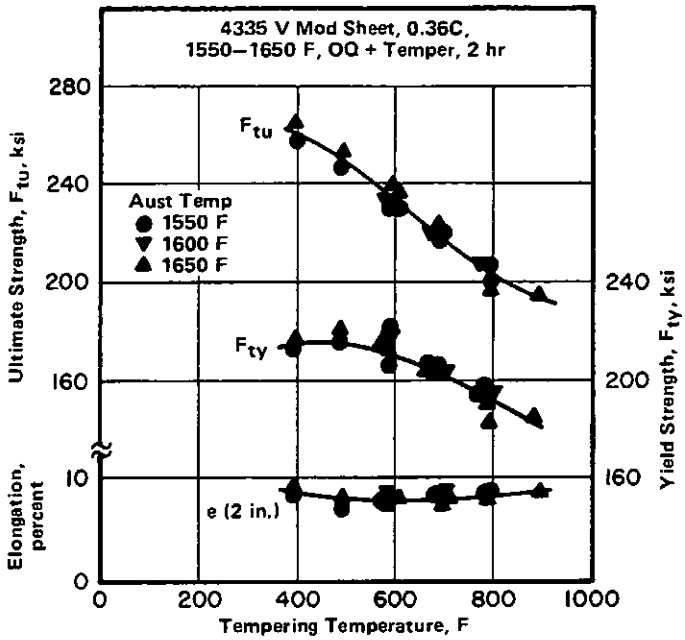


FIGURE 3.02131. EFFECT OF AUSTENITIZING AND TEMPERING TEMPERATURES ON TENSILE PROPERTIES OF SHEET (11)

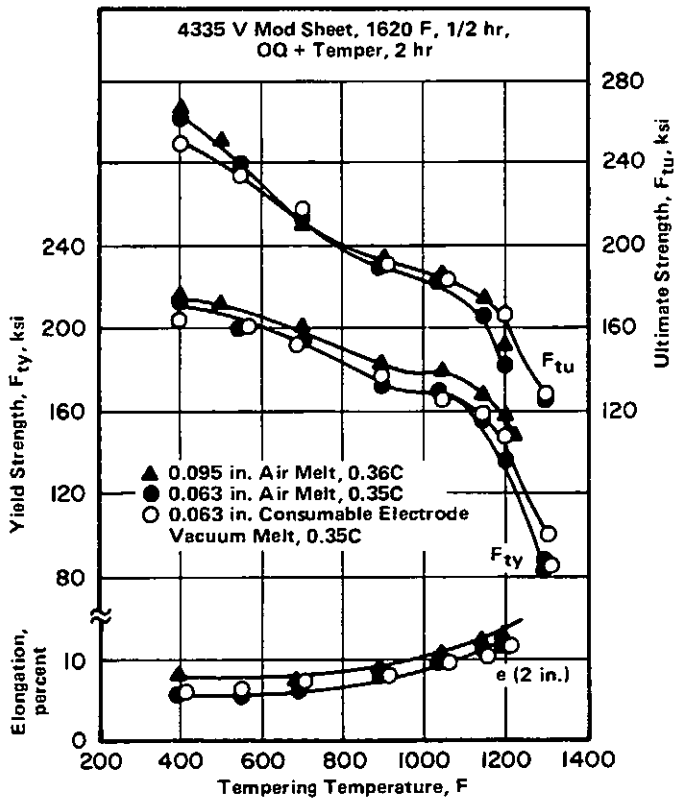


FIGURE 3.02132. EFFECT OF MELTING PRACTICE AND TEMPERING TEMPERATURE ON TENSILE PROPERTIES OF SHEET (13)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

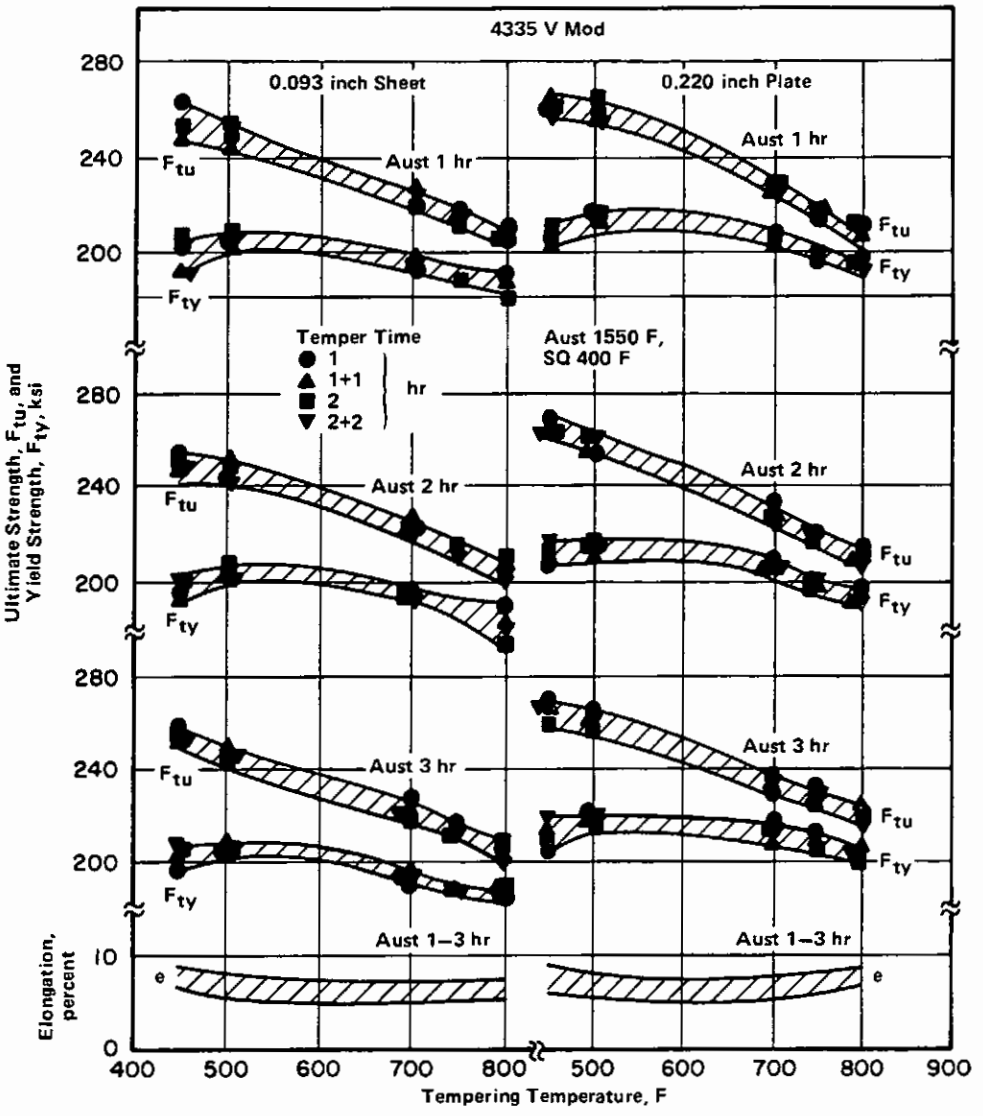


FIGURE 3.02133. EFFECT OF TEMPERING TIME AND TEMPERATURE AND TIME OF AUSTENITIZING ON TENSILE PROPERTIES OF SHEET AND PLATE AUSTENITIZED AT 1550 F (21)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

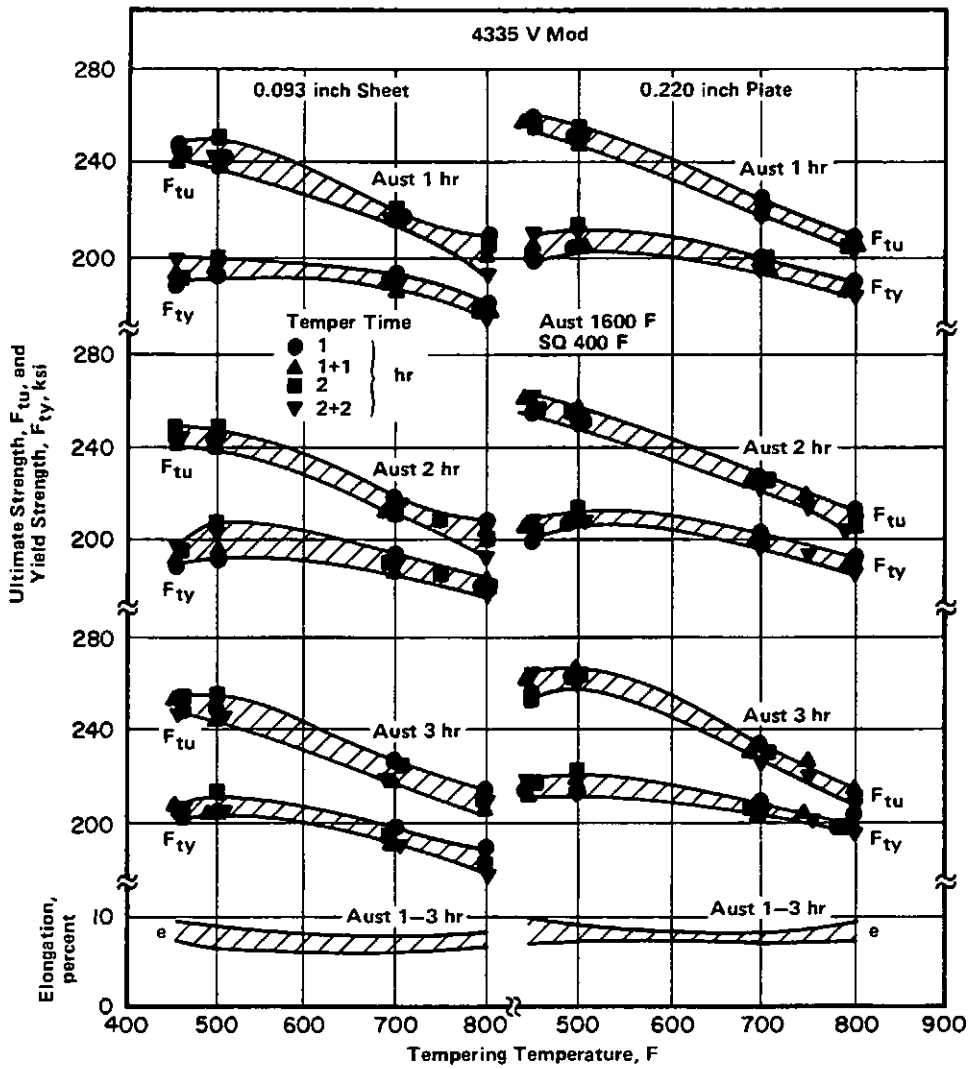


FIGURE 3.02134. EFFECT OF TEMPERING TIME AND TEMPERATURE AND TIME OF AUSTENITIZING ON TENSILE PROPERTIES OF SHEET AND PLATE AUSTENITIZED AT 1600 F (21)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

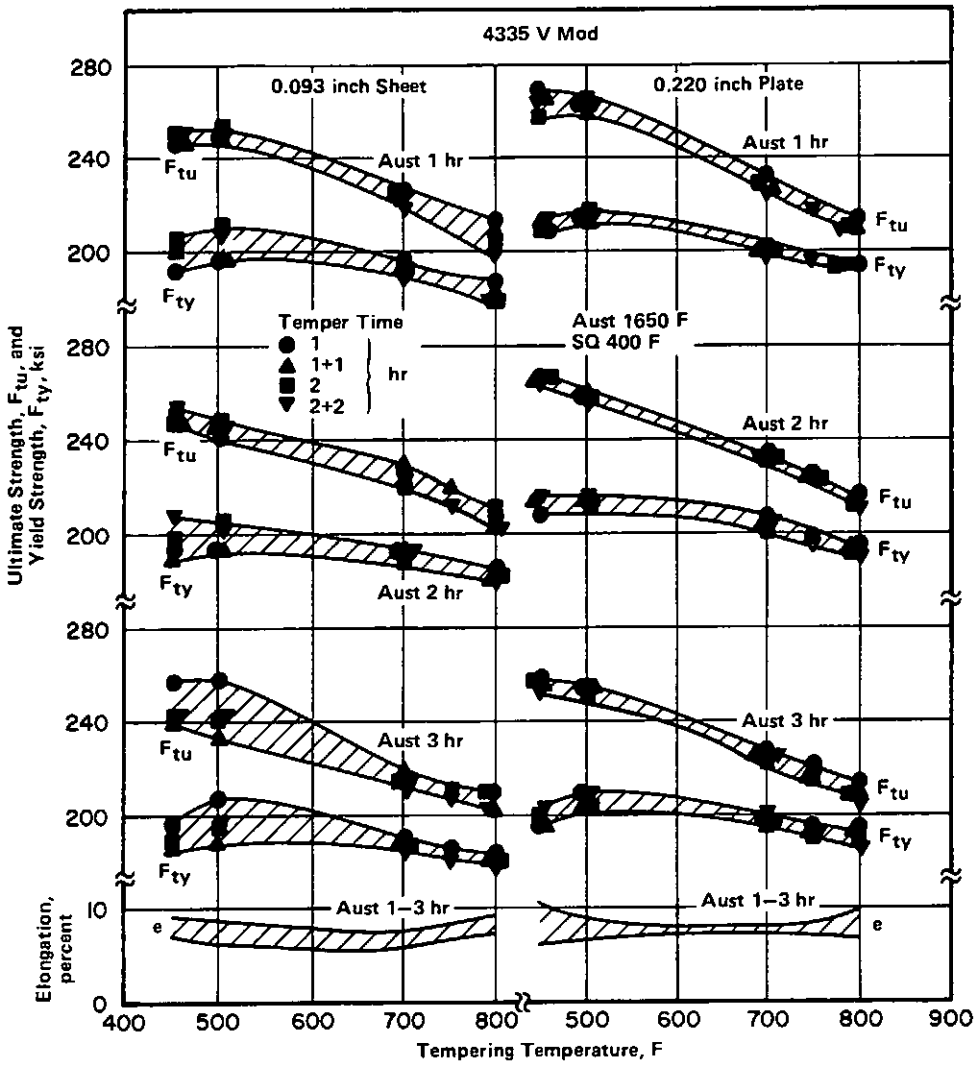


FIGURE 3.02135. EFFECT OF TEMPERING TIME AND TEMPERATURE AND TIME OF AUSTENITIZING ON TENSILE PROPERTIES OF SHEET AND PLATE AUSTENITIZED AT 1650 F (21)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

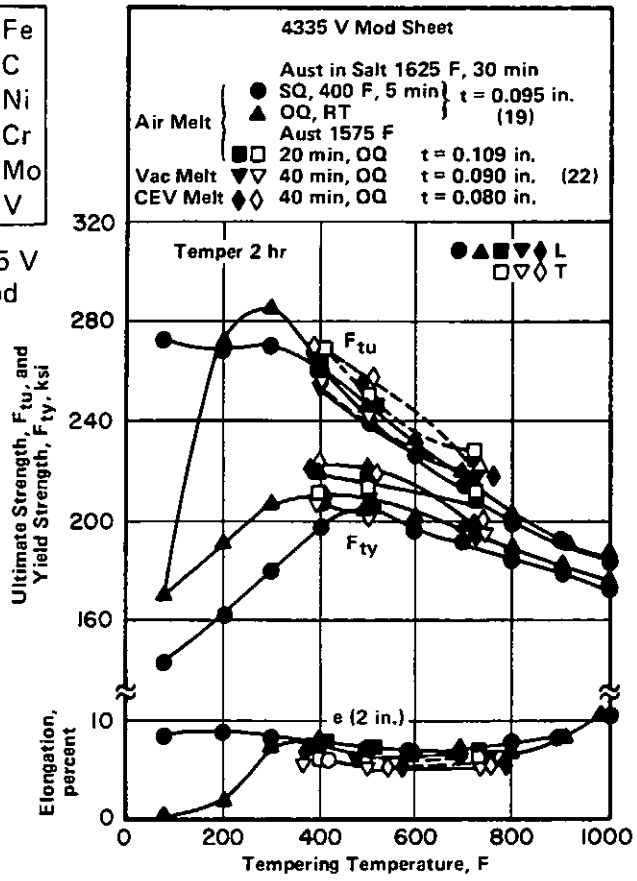


FIGURE 3.02136. EFFECT OF TEMPERING TEMPERATURE AND QUENCHING MEDIA AND MELT METHOD ON TENSILE PROPERTIES OF SHEET (19,22)

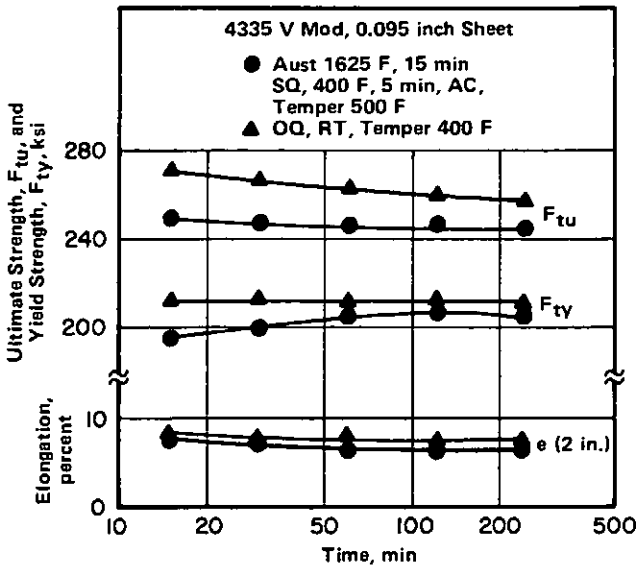


FIGURE 3.02137. EFFECT OF TEMPERING TIME AND QUENCHING MEDIA ON TENSILE PROPERTIES OF SHEET (19)

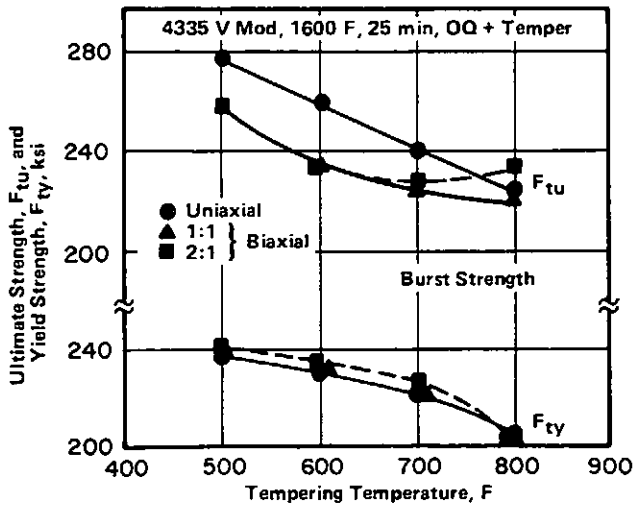


FIGURE 3.02138. EFFECT OF TEMPERING TEMPERATURE ON UNIAXIAL AND BIAXIAL TENSILE STRESS PROPERTIES OF SHEET (28)

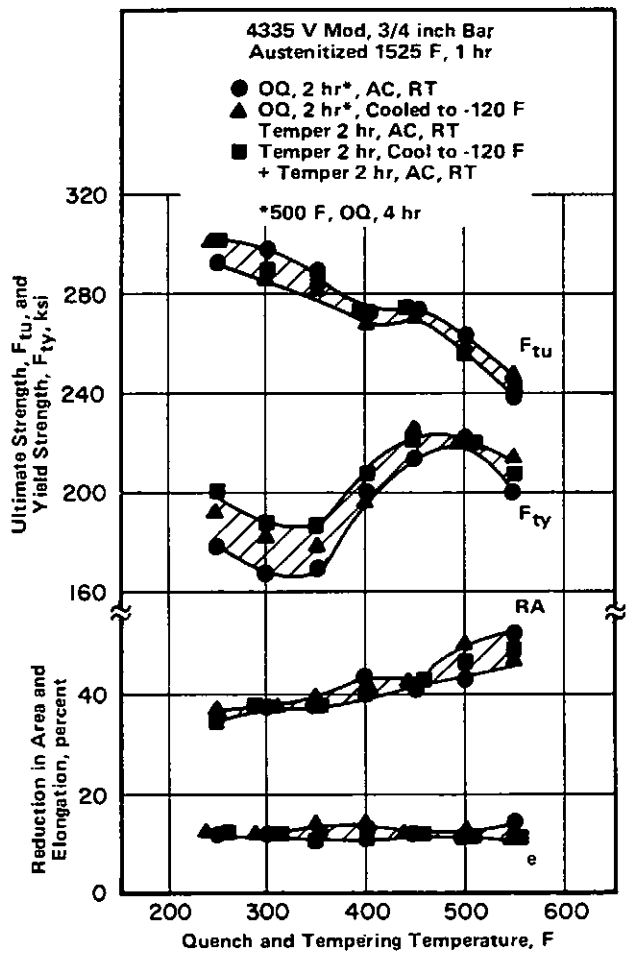


FIGURE 3.02141. EFFECT OF QUENCHING AND TEMPERING TEMPERATURE ON TENSILE PROPERTIES OF BAR (24)

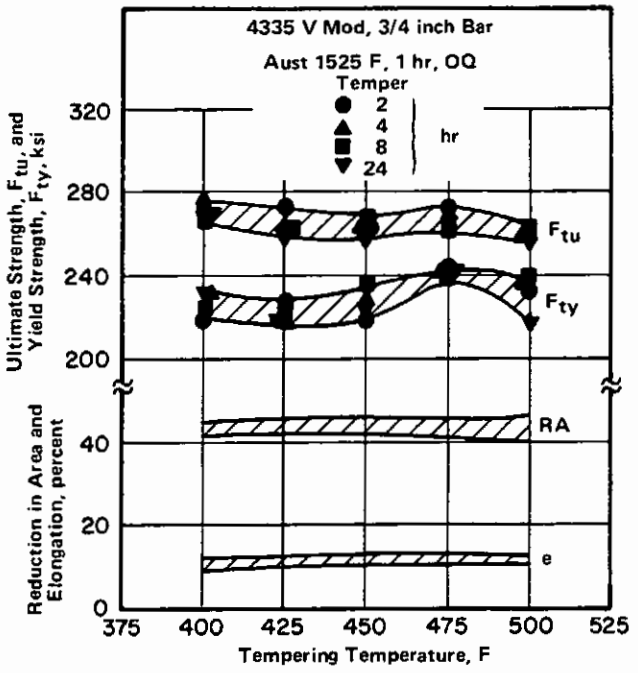
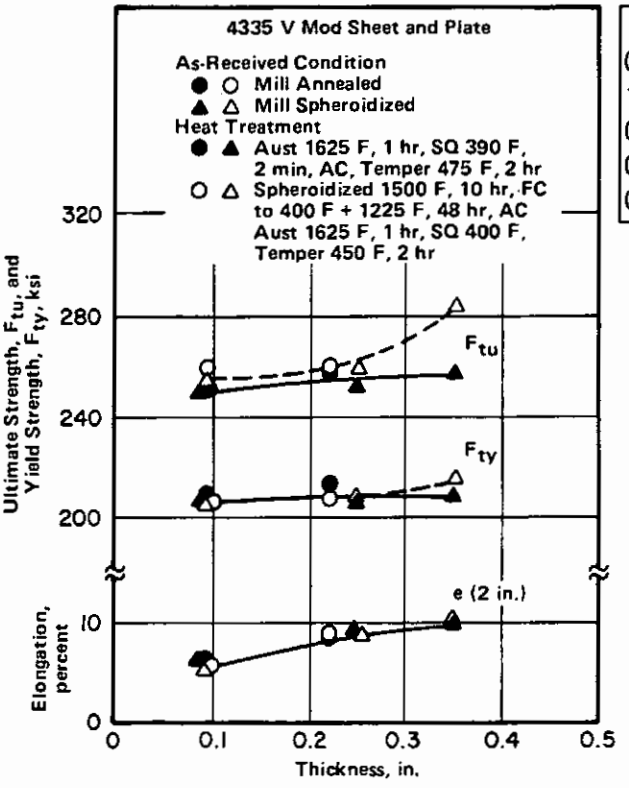


FIGURE 3.02142. EFFECT OF TEMPERING TIME AND TEMPERATURE ON TENSILE PROPERTIES OF BAR (24)



Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

FIGURE 3.02151. EFFECT OF THICKNESS ON TENSILE PROPERTIES OF SHEET AND PLATE (21)

Alloy	4335 V Mod					
Form	Sheet					
Orientation	L					
		Condition				
Melting Practice	Thickness, in.	Austenitizing Temperature, F(a)	Tempering Temperature, F(b)	F_{ty}, ksi	F_{tu}, ksi	Elongation, percent
Air Melt	0.015	1575	400	192	220	2.5
		1575	725	180	193	2
		1620	400	183	217	2.3
	0.03	1575	400	208	251	5
		1575	725	192	211	3.5
		1620	400	189.5	232.5	4
	0.063	1575	400	207	256	7
		1575	725	182	202	5.5
		1620	400	205	254	5.5
		1620(c)	400	204	254	7
	0.125	1575	400	205	254	8
		1575	725	191	209	7.5
		1620	400	196	250	8
Consumable Electrode	0.015	1575	400	185	215	–
		1575	725	173.5	186.5	–
		1620	400	190	229	4
	0.063	1575	400	199	240	6.5
		1575	725	186	205	–
		1620	400	202	248	6.5
		1620(c)	400	201	246	7

(a) Austenitized at 1575 F in neutral salt, or in argon at 1620 F, oil quenched.
(b) Tempered for 2 hours and air cooled.
(c) Transverse specimen.

TABLE 3.02152. EFFECT OF THICKNESS OF SHEET FROM TWO MELTING PRACTICES AND VARIOUS HEAT TREATMENTS (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

Alloy	4335 V Mod			
Form	Hollow Extrusions With Two External Diameters (Approx. 9.5 in. and 7 in.) for 105 mm Gun Tube			
Condition	Austenitized at 1550 F, OD and ID Quenched With Agitated Water, Tempered 1060 F for 4 hr			
Specimen Orientation	T			
Condition	Tube No.	Location	F_{ty} Range[a], ksi	RA Range, percent
Original Heat Treatment (Above)	1	Breech	165.4–168.1	29–36
		Muzzle	162.1–163.4	34–39
	4	Breech	168.7–170.8	35–43
		Muzzle	169.8–171.0	41–48
	8	Breech	167.1–170.1	26–34
		Muzzle	162.3–164.1	26–37
Reheat Treatment[b]	1	Breech	162.6–162.6	42.8–43.6
		Muzzle	158.1–159.6	36.3–40.7
	4	Breech	165.6–165.6	43.6–46.2
		Muzzle	164.1–165.6	44.9–48.6
	8	Breech	172.7–172.7	35.4–38.5
		Muzzle	169.7–169.7	34.0–37.7

(a) Range of values from four specimens.
(b) Austenitized at 1560–1580 F for 3 hours; ID and OD water spray quenched; Tubes 1 and 4 tempered 1100 F for 5 hours, Tube 8 tempered 1080 F for 5 hours.

TABLE 3.0216. TENSILE PROPERTIES OF GUN-TUBE EXTRUSION (36)

Alloy	4335 V Mod			
Form	B-58 Wing, A. O. Smith Pylon Box Forging			
Condition	Austenitized at 1550 F, 30 min, Quenched Into Agitated Molten Salt at 420–435 F for 10 min, Cooled to RT, Tempered 2 hr at 975 F			
Direction	F_{ty}, ksi	F_{tu}, ksi	Elongation, percent	Reduction in Area, percent
L	183.0	188.4	11.4	47.4
T	182.8	189.1	9.3	33.3

TABLE 3.0217. TENSILE PROPERTIES OF FORGING (34)

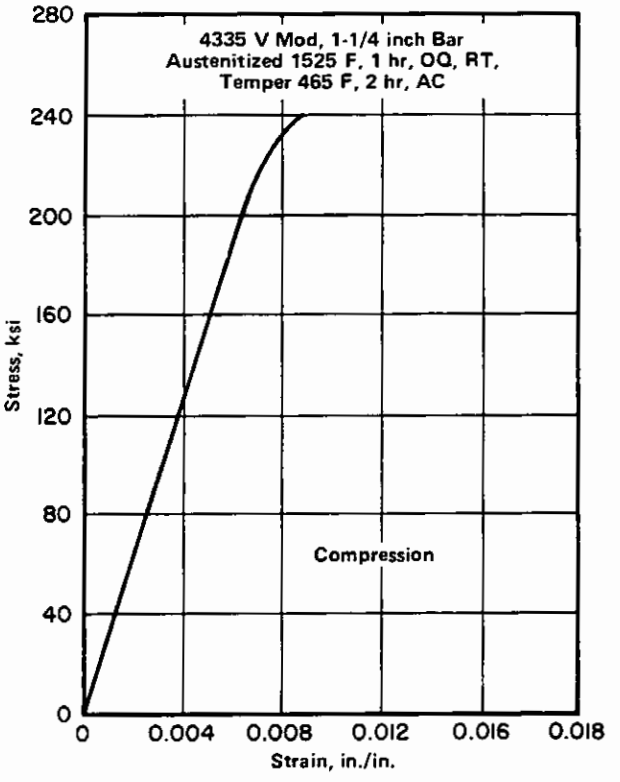


FIGURE 3.02211. STRESS-STRAIN CURVE IN COMPRESSION FOR BAR (24)

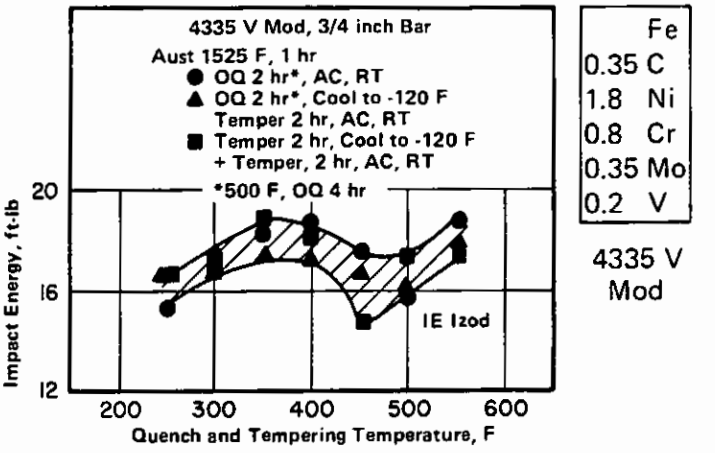


FIGURE 3.0231. EFFECT OF QUENCHING AND TEMPERING TEMPERATURE ON IMPACT STRENGTH OF BAR (24)

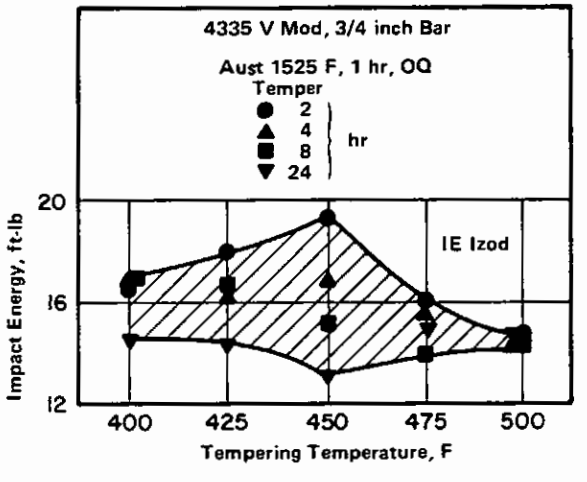


FIGURE 3.0232. EFFECT OF TEMPERING TIME AND TEMPERATURE ON IMPACT STRENGTH OF BAR (24)

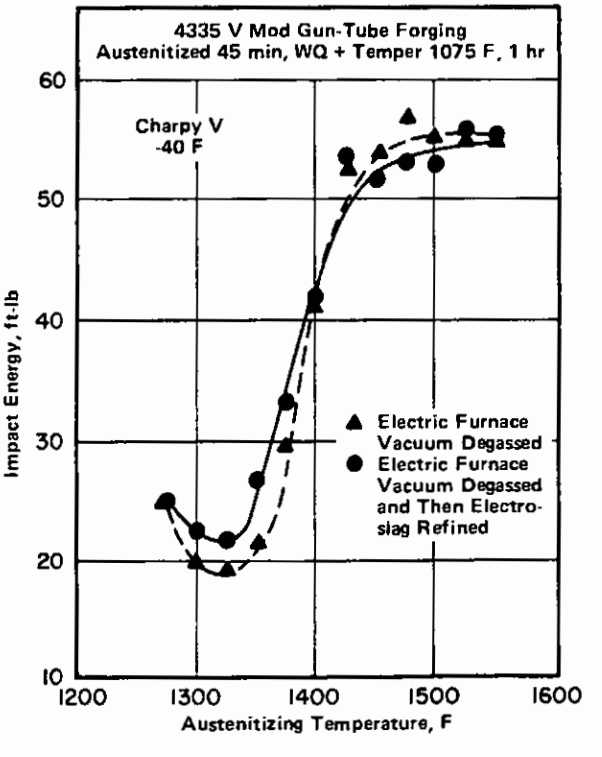


FIGURE 3.0233. EFFECT OF BELOW-NORMAL AUSTENITIZING TEMPERATURE ON IMPACT PROPERTIES OF FORGING (33)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

Alloy	4335 V Mod		
Form	Hollow Extrusions With Two External Diameters (Approx. 9.5 in. and 7 in.) for 105 mm Gun Tube		
Condition	Austenitized at 1550 F, OD and ID Quenched With Agitated Water, Tempered 1060 F for 4 hr		
Specimen Orientation	T		
Condition	Tube No.	Location	Charpy V-Notch Range[a] at -40 F, ft-lb
Original Heat Treatment (Above)	1	Breech	15–16
		Muzzle	17–18
	4	Breech	17–20
		Muzzle	19–20
	8	Breech	16–17
		Muzzle	15.5–16
Reheat Treatment[b]	1	Breech	18.3–20.0
		Muzzle	17.5–17.5
	4	Breech	21–22
		Muzzle	23–23
	8	Breech	14.5–14.5
		Muzzle	15.5–15.5

(a) Range of values from four specimens.
(b) Austenitized at 1560–1580 F for 3 hours; ID and OD water spray quenched; Tubes 1 and 4 tempered 1100 F for 5 hours, Tube 8 tempered 1080 F for 5 hours.

TABLE 3.0234. IMPACT PROPERTIES OF GUN-TUBE EXTRUSION (36)

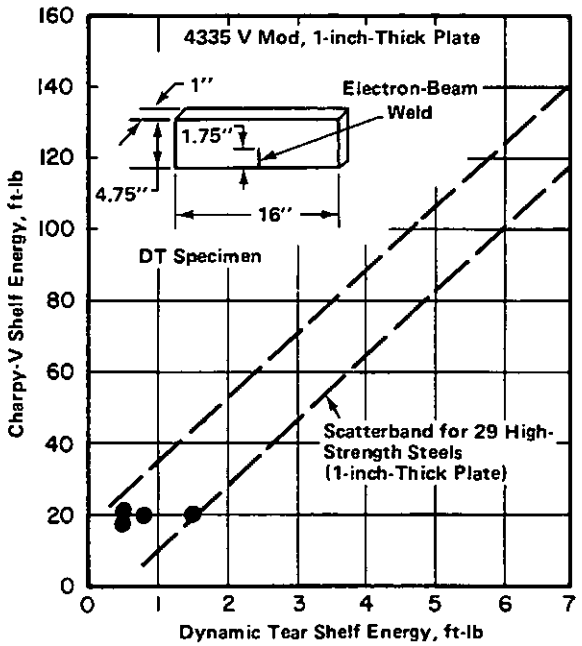


FIGURE 3.0235. CORRELATION OF CHARPY-V SHELF ENERGY WITH DYNAMIC TEAR SHELF ENERGY IN COMPARISON TO A RANGE OF VARIOUS HIGH-STRENGTH STEELS (37)

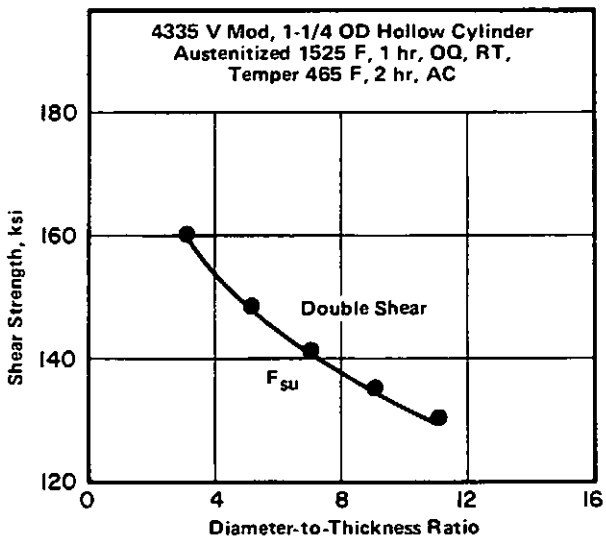


FIGURE 3.0251. EFFECT OF DIAMETER-TO-THICKNESS RATIO ON ULTIMATE SHEAR STRENGTH OF HOLLOW CYLINDERS (24)

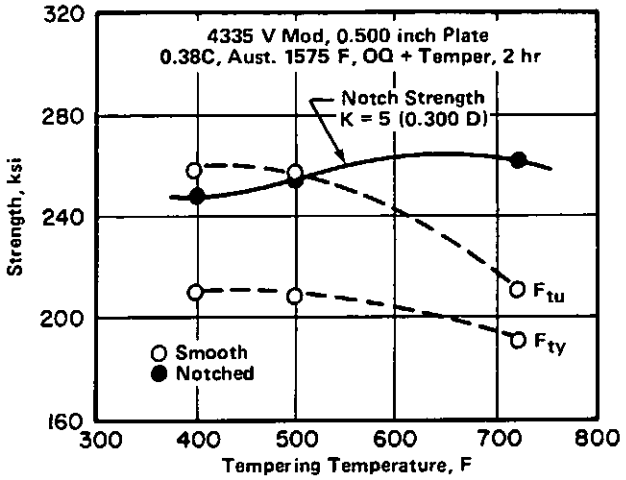


FIGURE 3.02711. EFFECT OF TEMPERING TEMPERATURE ON TENSILE PROPERTIES AND NOTCH STRENGTH OF PLATE (8)

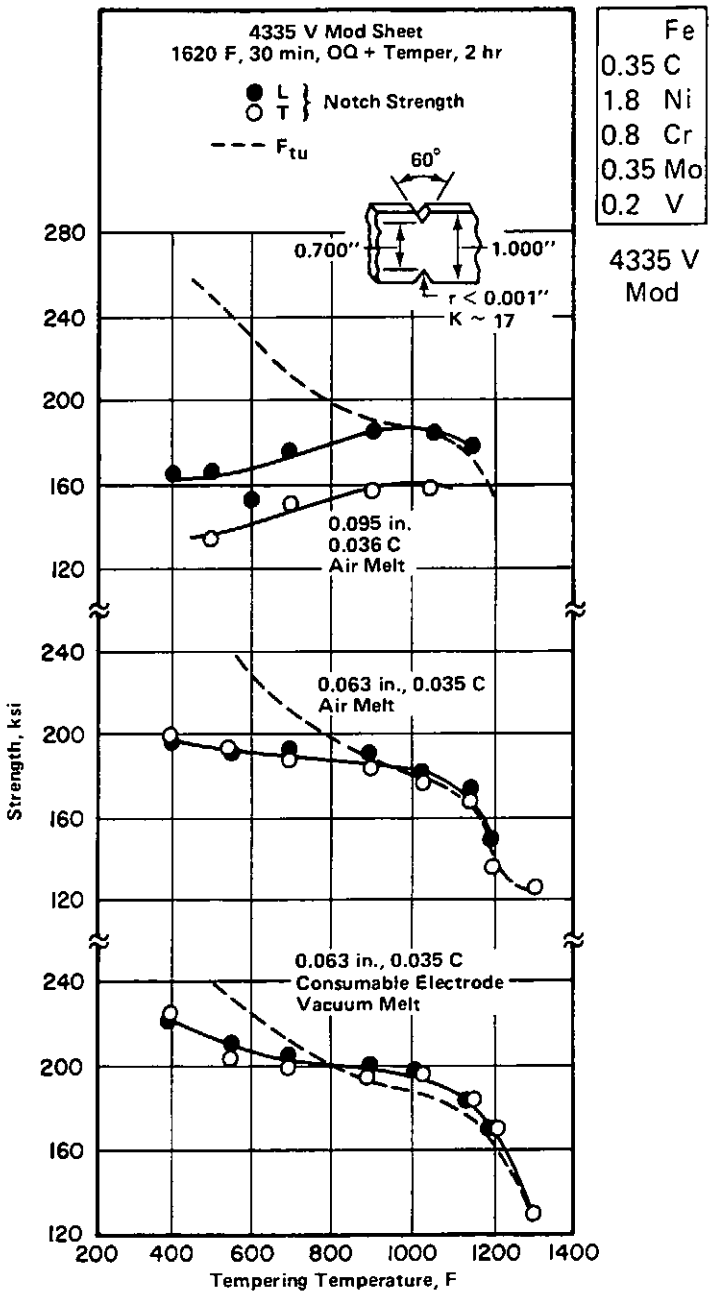


FIGURE 3.02712. EFFECT OF TEMPERING TEMPERATURE, MELTING PRACTICE AND SHEET THICKNESS ON NOTCH STRENGTH OF SHEET (13)

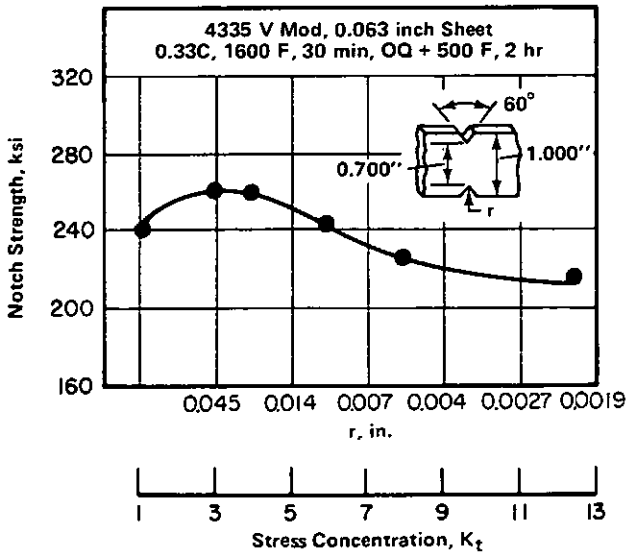


FIGURE 3.02713. EFFECT OF STRESS CONCENTRATION ON NOTCH STRENGTH OF SHEET (14)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

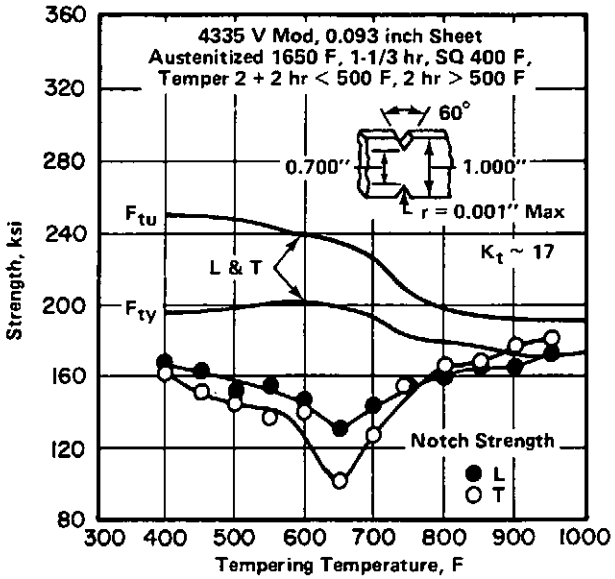


FIGURE 3.02714. EFFECT OF TEMPERING TEMPERATURE ON NOTCH STRENGTH OF SHEET AUSTENITIZED AT 1650 F (21)

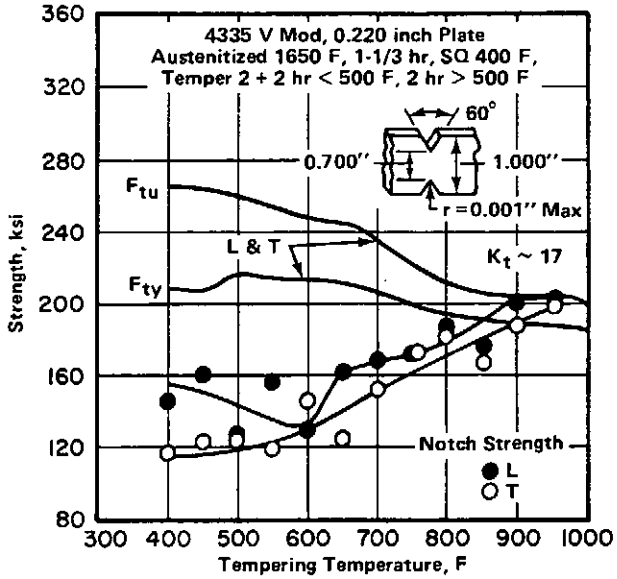


FIGURE 3.02715. EFFECT OF TEMPERING TEMPERATURE ON NOTCH STRENGTH OF PLATE AUSTENITIZED AT 1650 F (21)

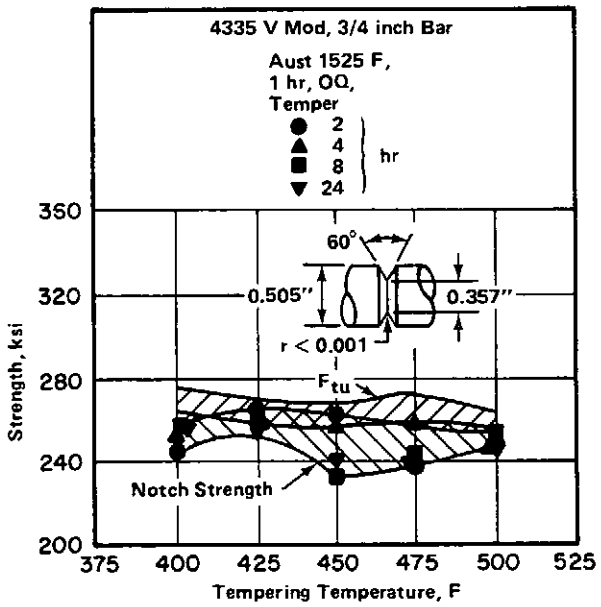


FIGURE 3.02716. EFFECT OF TEMPERING TIME AND TEMPERATURE ON NOTCH STRENGTH OF BAR (24)

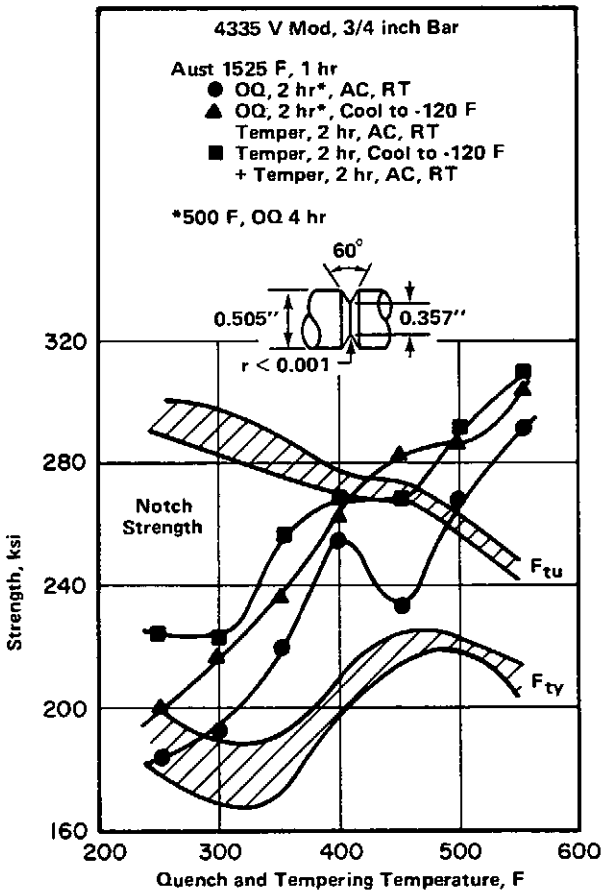


FIGURE 3.02717. EFFECT OF QUENCHING AND TEMPERING TEMPERATURE ON NOTCH STRENGTH OF BAR (24)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

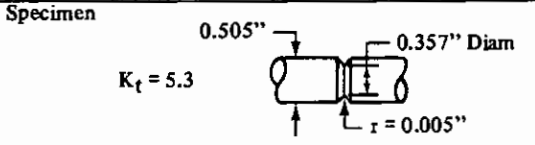
Alloy	4335 V Mod	
Form	B-58 Wing, O. A. Smith Pylon Box Forging	
Condition	Austenitized 1550 F, 30 min, Quench Into Agitated 420–435 F Molten Salt, 10 min, Cooled to RT, Tempered 2 hr at 975 F	
Specimen		
Direction	Notch Strength, ksi	Notch Strength-Ultimate Strength Ratio
Long.	268.4	1.42
L. Trans.	262.2	1.39

TABLE 3.02718. NOTCH TENSILE PROPERTIES OF FORGING (34)

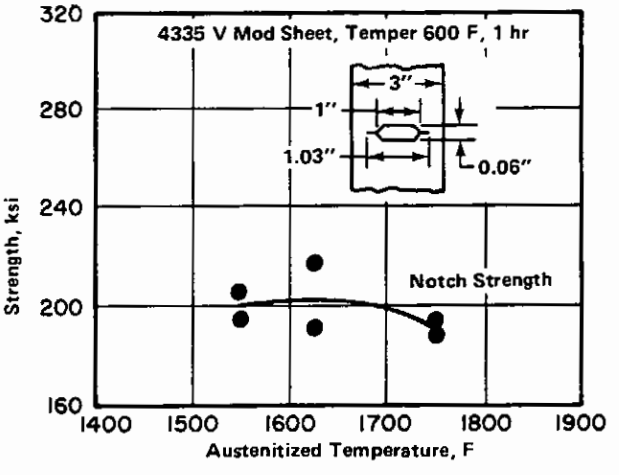


FIGURE 3.02721. EFFECT OF AUSTENITIZING TEMPERATURE ON NOTCH STRENGTH OF SHEET (29)

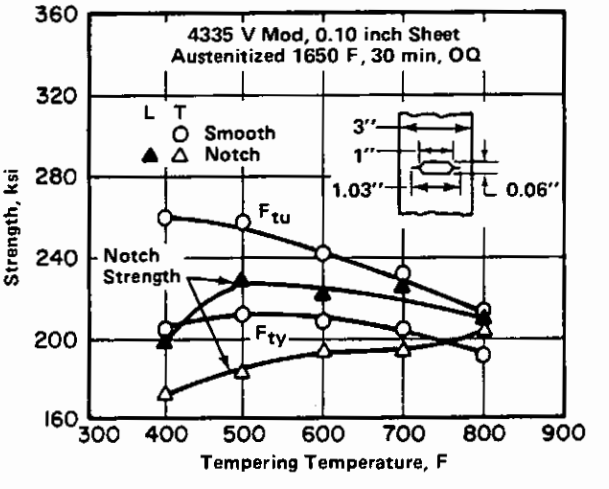


FIGURE 3.02722. EFFECT OF TEMPERING TEMPERATURE ON NOTCH STRENGTH OF SHEET (30)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

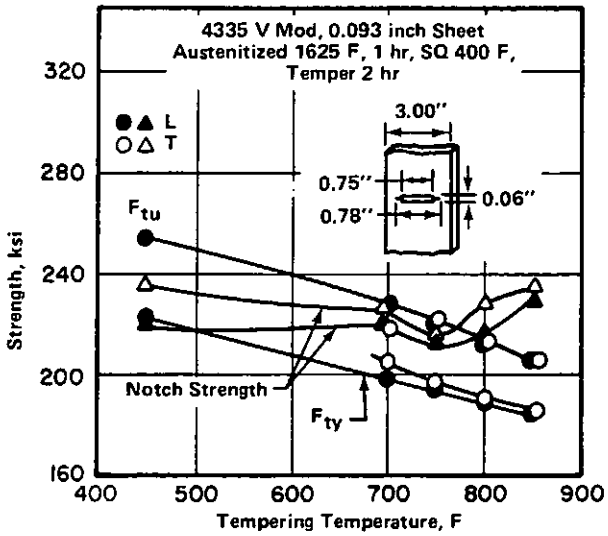


FIGURE 3.02723. EFFECT OF TEMPERING TEMPERATURE ON NOTCH STRENGTH OF SHEET AUSTENITIZED AT 1625 F (21)

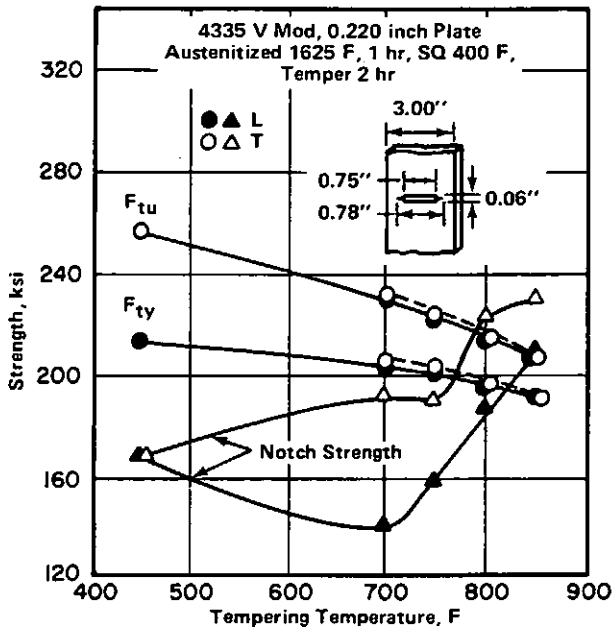


FIGURE 3.02724. EFFECT OF TEMPERING TEMPERATURE ON NOTCH STRENGTH OF PLATE AUSTENITIZED AT 1625 F (21)

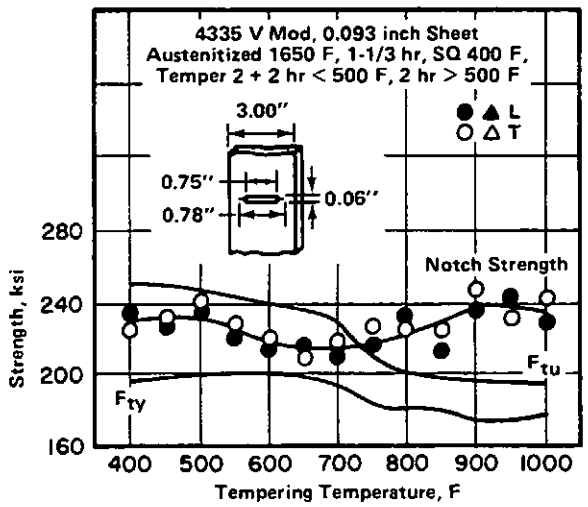


FIGURE 3.02725. EFFECT OF TEMPERING TEMPERATURE ON NOTCH STRENGTH OF SHEET AUSTENITIZED AT 1650 F (21)

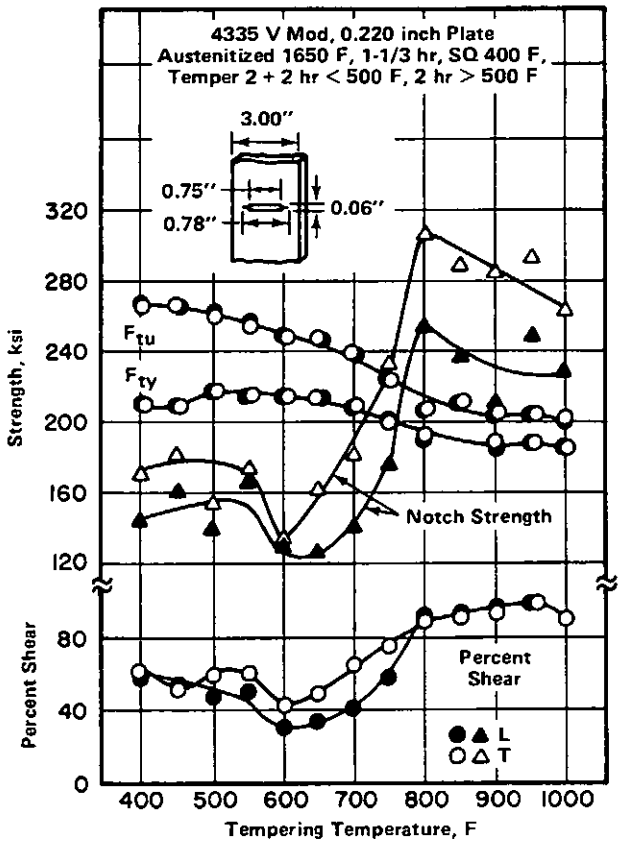


FIGURE 3.02726. EFFECT OF TEMPERING TEMPERATURE ON NOTCH STRENGTH OF PLATE AUSTENITIZED AT 1650 F (21)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

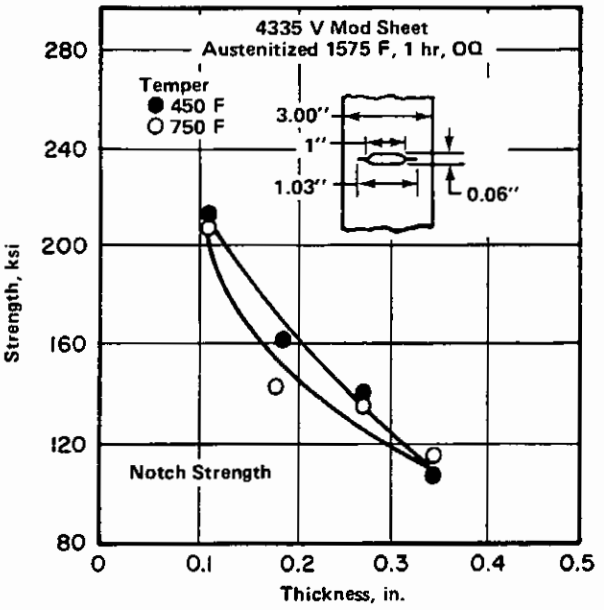


FIGURE 3.02727. EFFECT OF THICKNESS ON NOTCH STRENGTH OF SHEET (30)

Alloy	4335 V Mod	
Form	Hollow Extrusions With Two External Diameters (Approx. 9.5 in. and 7 in.) for 105 mm Gun Tube	
Condition	Austenitized at 1550 F, OD and ID Quenched With Agitated Water, Tempered 1060 F for 4 hr	
Specimen and Orientation	C Shape, T-S	
	K_{Ic}, ksi $\sqrt{in.}$	
Location	Average(a)	Range
Breech End of Extrusion	109.3	106.4–112.1
Muzzle End of Extrusion	97.4	94.1–102.3
Mid-Length of Breech	113.3	109.1–116.4
Mid-Length of Muzzle	95.6	92.4– 97.7

(a) Average of six specimens, two from each of three extrusions.

TABLE 3.02728. FRACTURE-TOUGHNESS PROPERTIES OF GUN-TUBE EXTRUSION (36)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

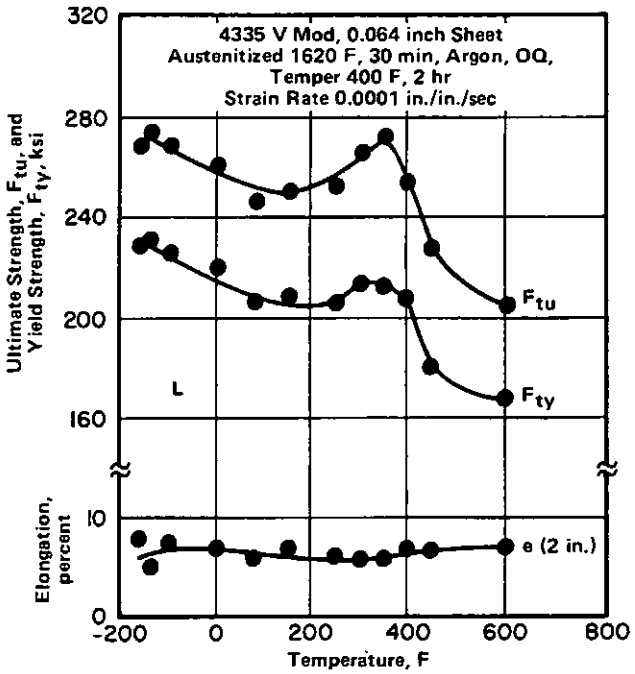


FIGURE 3.0312. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET (23)

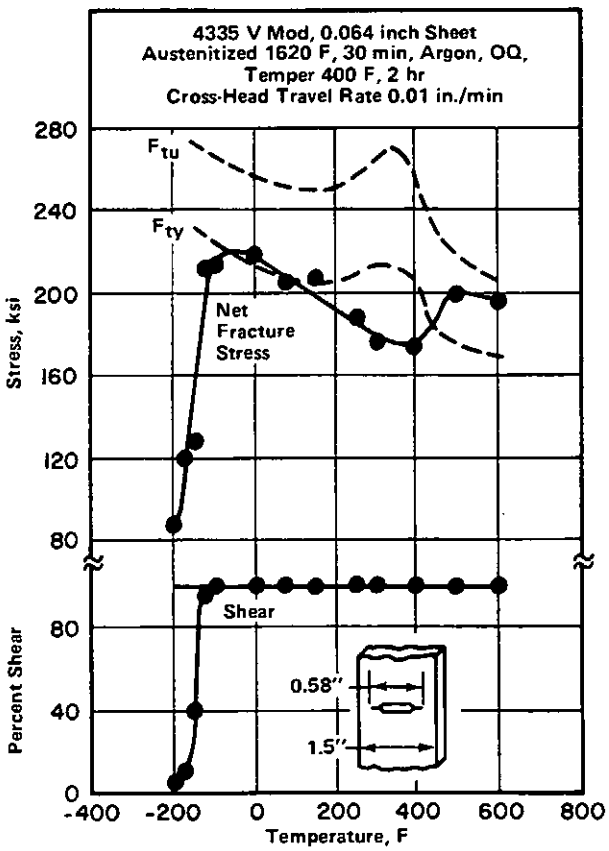


FIGURE 3.03711. EFFECT OF TEST TEMPERATURE ON NET FRACTURE STRESS AND FRACTURE APPEARANCE OF SHEAR CRACKED SHEET (23)

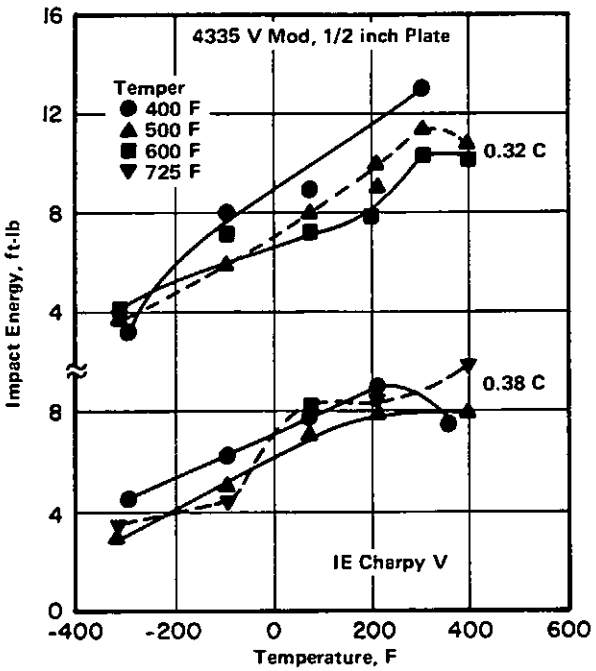


FIGURE 3.0331. EFFECT OF TEST TEMPERATURE ON IMPACT STRENGTH OF PLATE (27)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

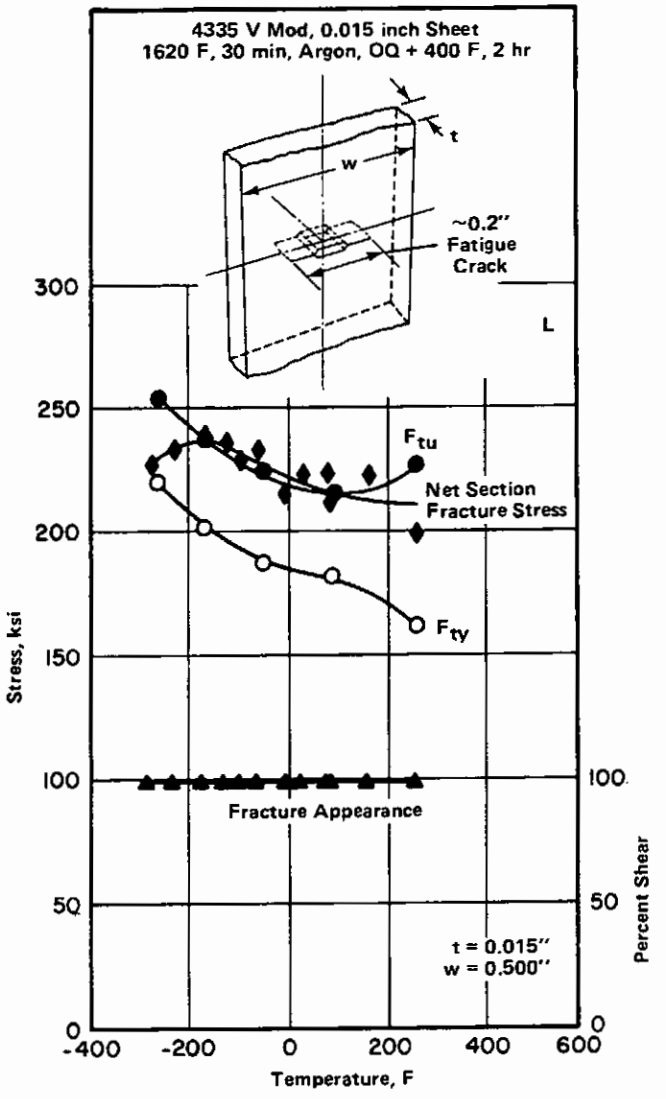


FIGURE 3.03712. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.015 INCH SHEET (38)

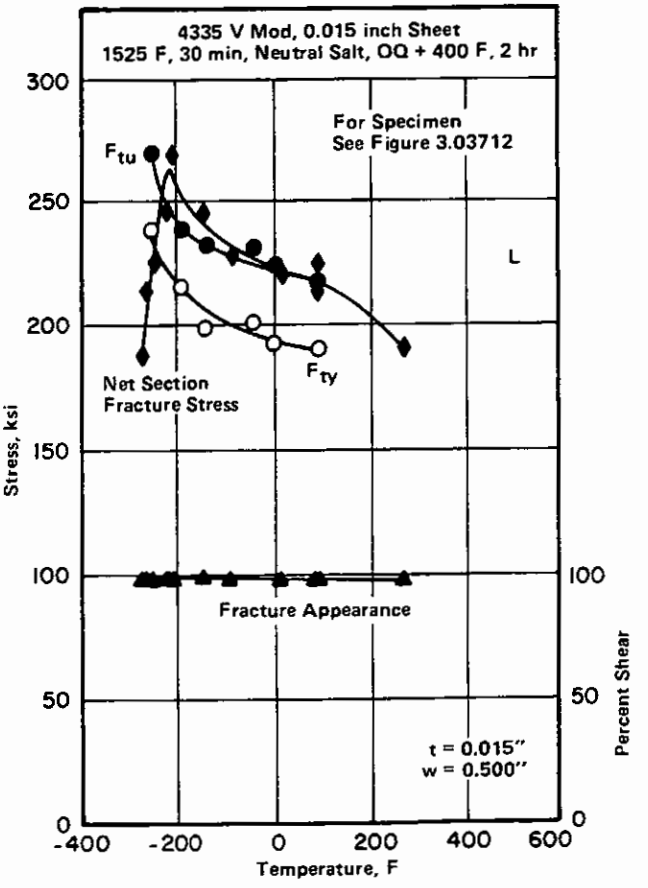


FIGURE 3.03713. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.015 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

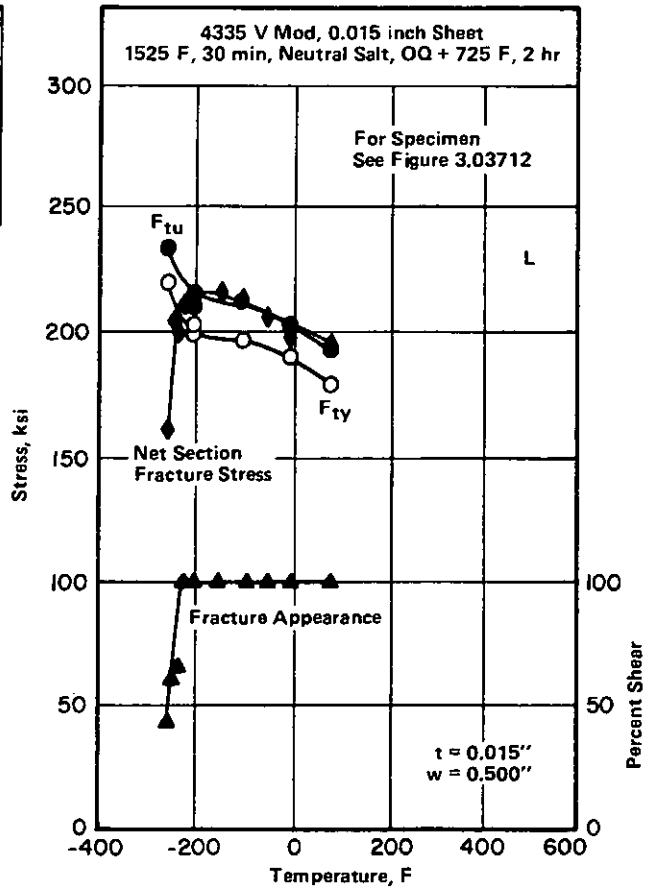


FIGURE 3.03714. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.015 INCH SHEET (38)

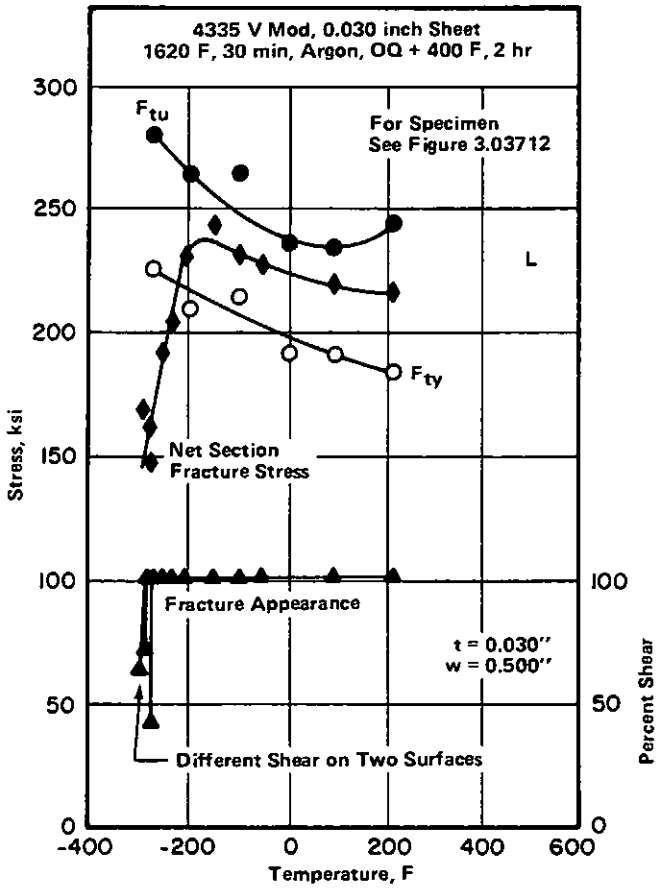


FIGURE 3.03715. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.030 INCH SHEET (38)

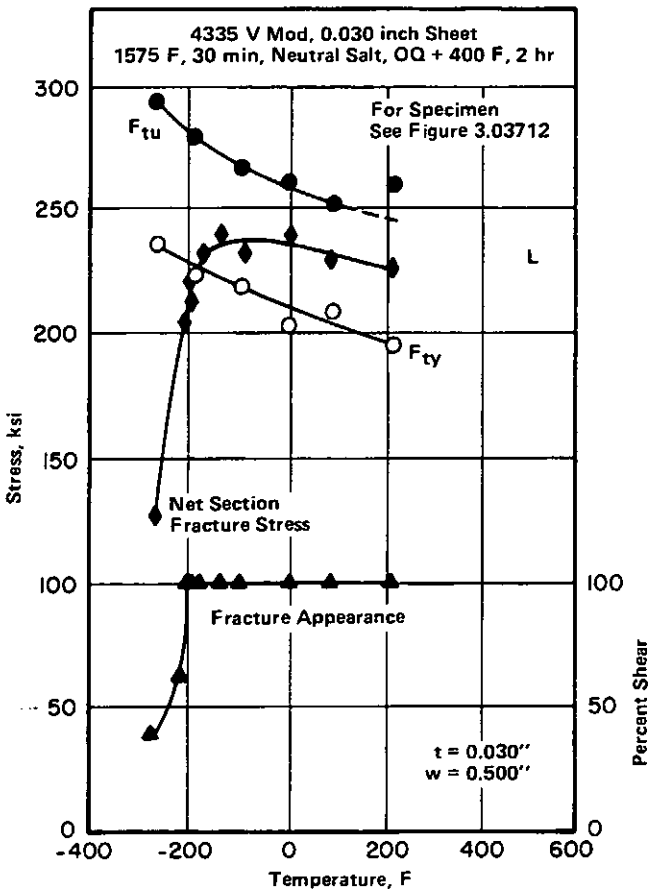


FIGURE 3.03716. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.030 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

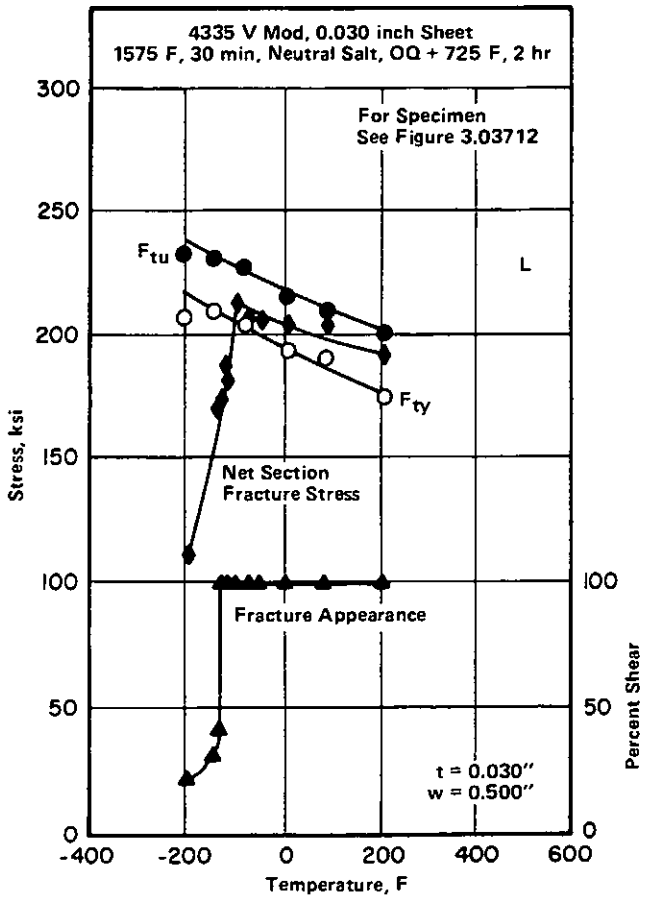


FIGURE 3.03717. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.030 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

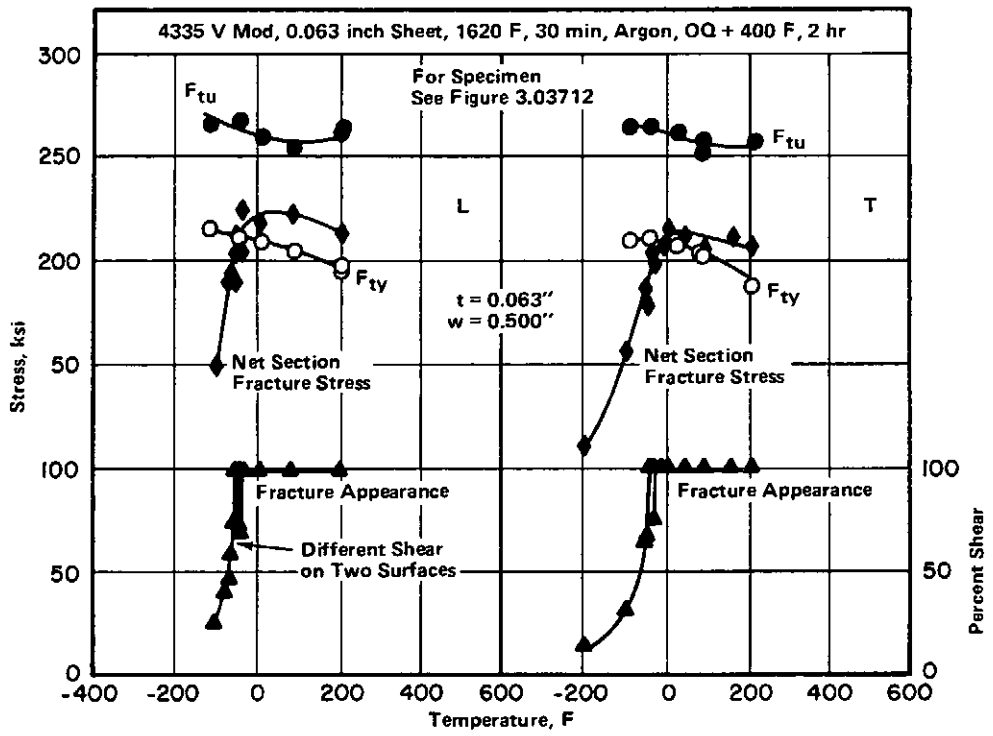


FIGURE 3.03718. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.063 INCH SHEET (38)

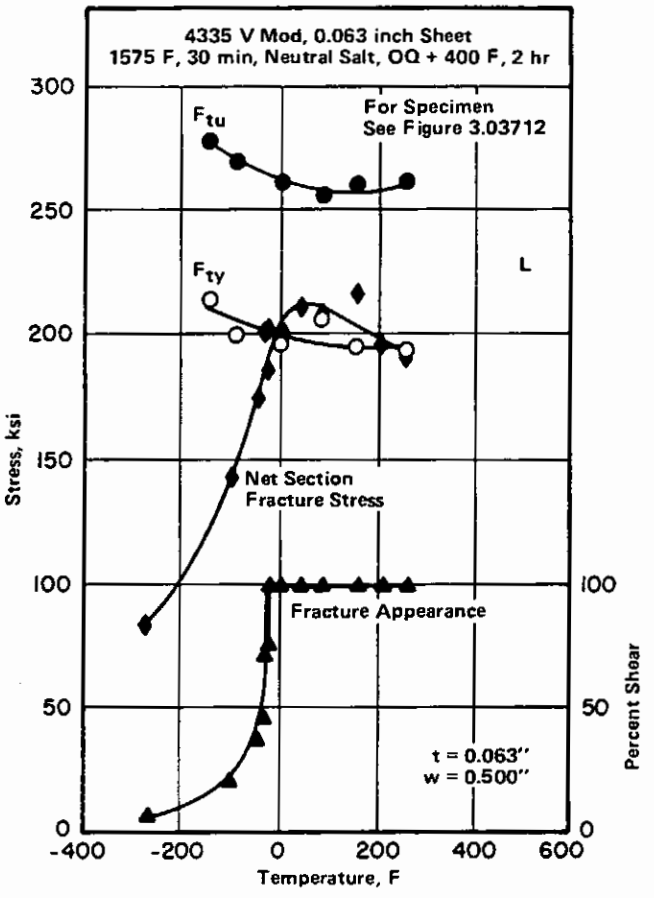


FIGURE 3.03719. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.063 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

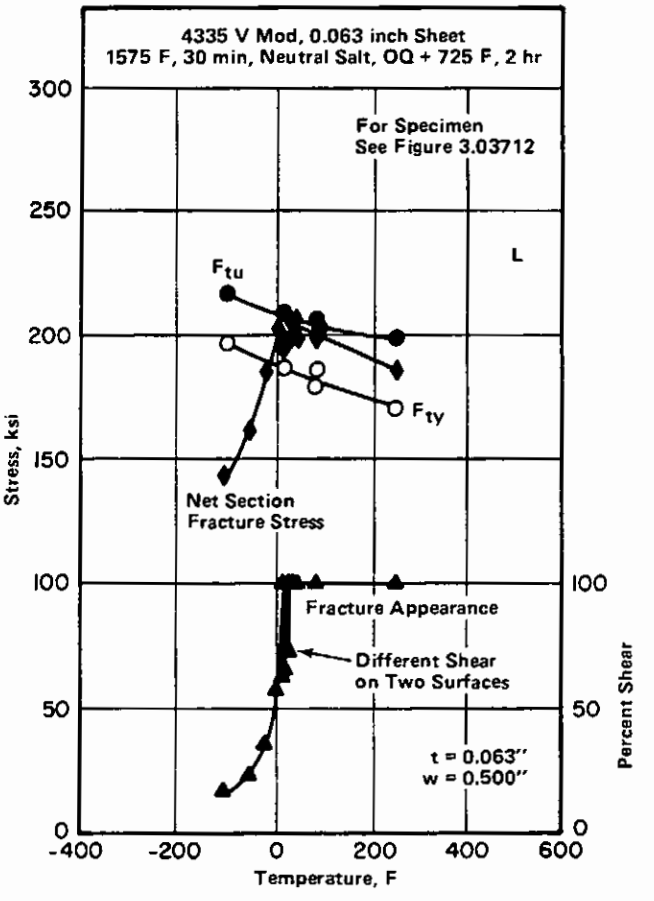


FIGURE 3.03720. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.063 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

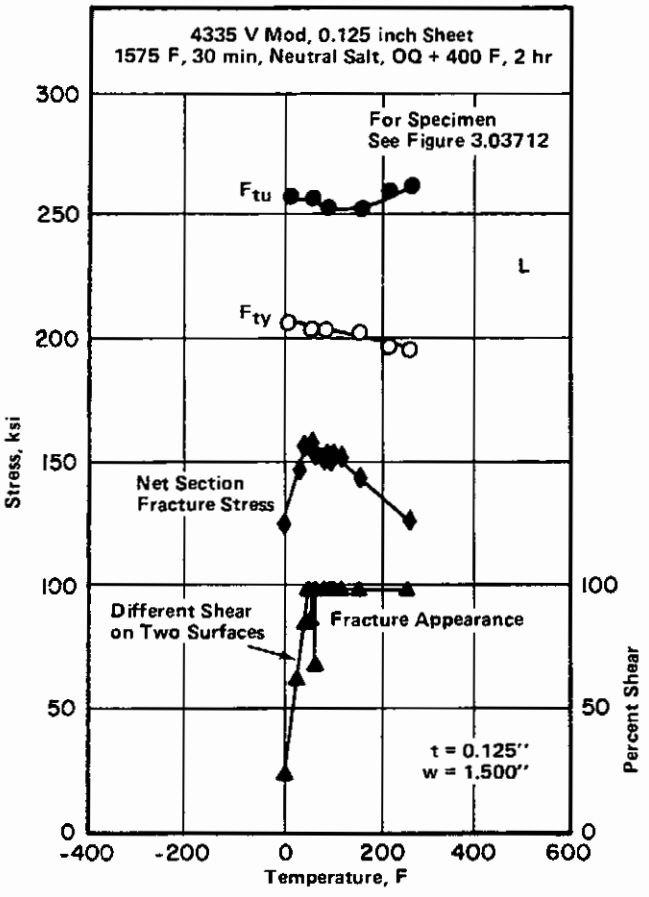


FIGURE 3.03721. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.125 INCH SHEET (38)

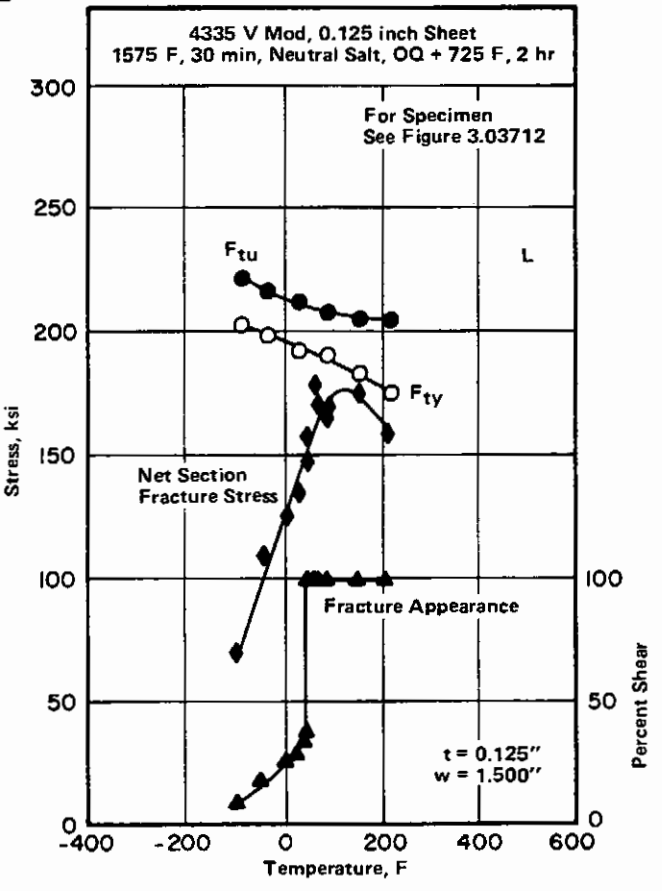


FIGURE 3.03722. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.125 INCH SHEET (38)

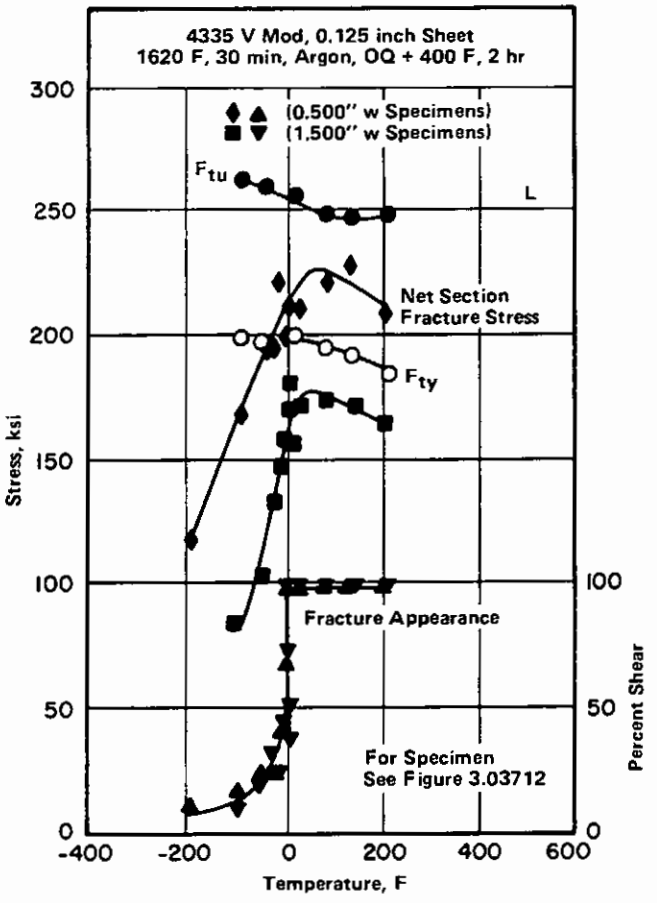


FIGURE 3.03723. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF AIR MELTED, QUENCHED AND TEMPERED 0.125 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

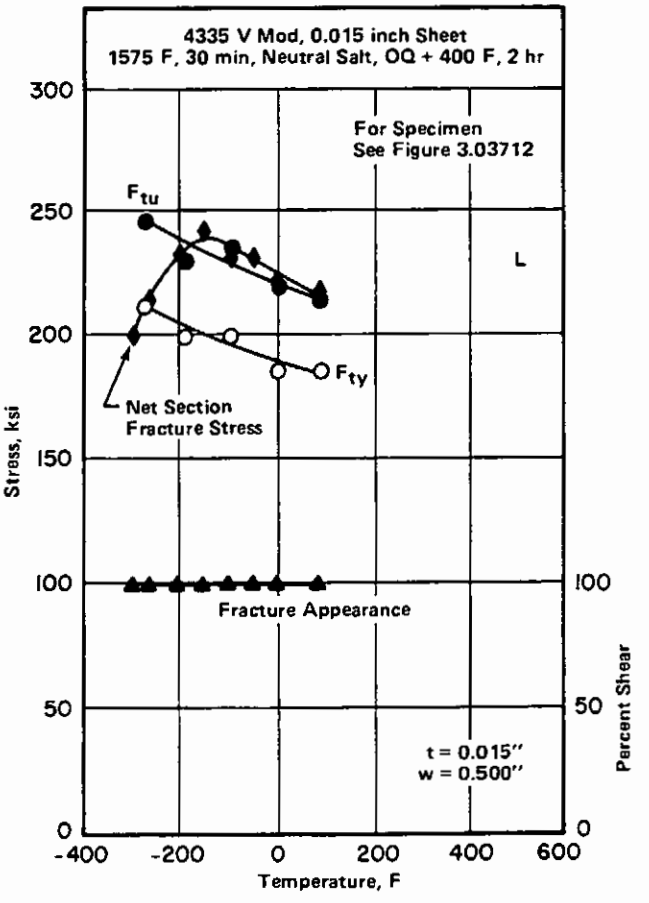


FIGURE 3.03724. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF CONSUTRODE VACUUM MELTED, QUENCHED AND TEMPERED 0.015 INCH SHEET (38)

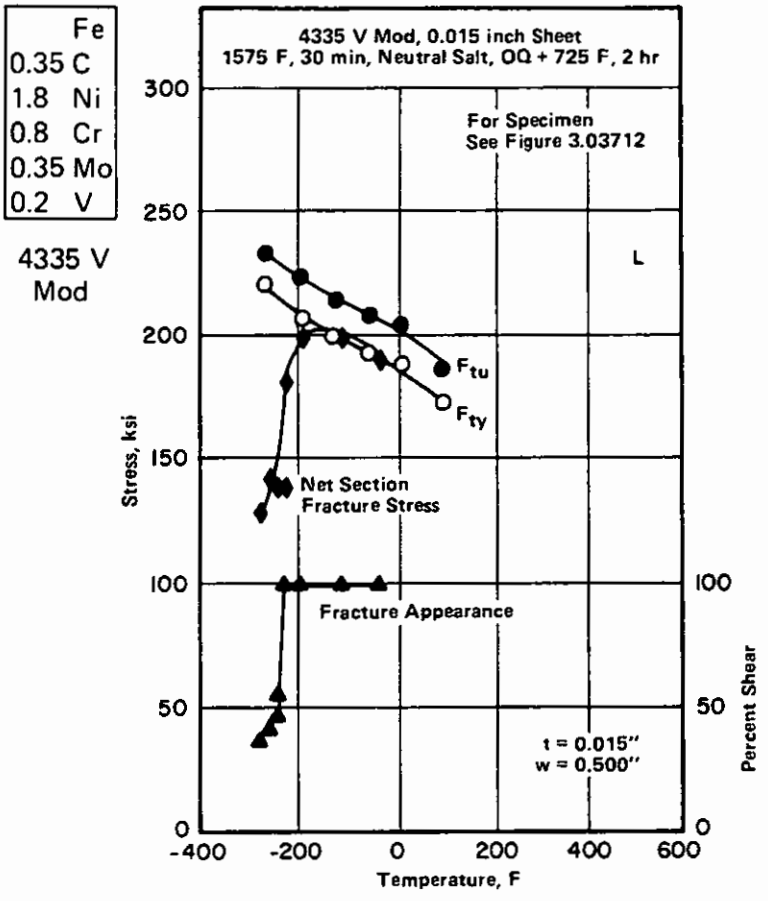


FIGURE 3.03725. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF CONSUTRODE VACUUM MELTED, QUENCHED AND TEMPERED 0.015 INCH SHEET (38)

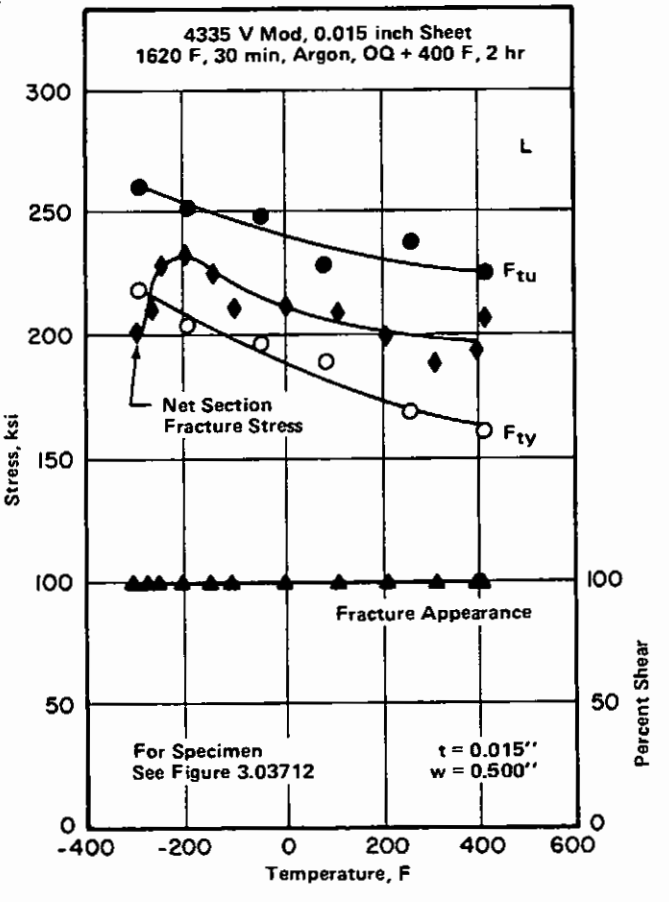


FIGURE 3.03726. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF CONSUTRODE VACUUM MELTED, QUENCHED AND TEMPERED 0.015 INCH SHEET (38)

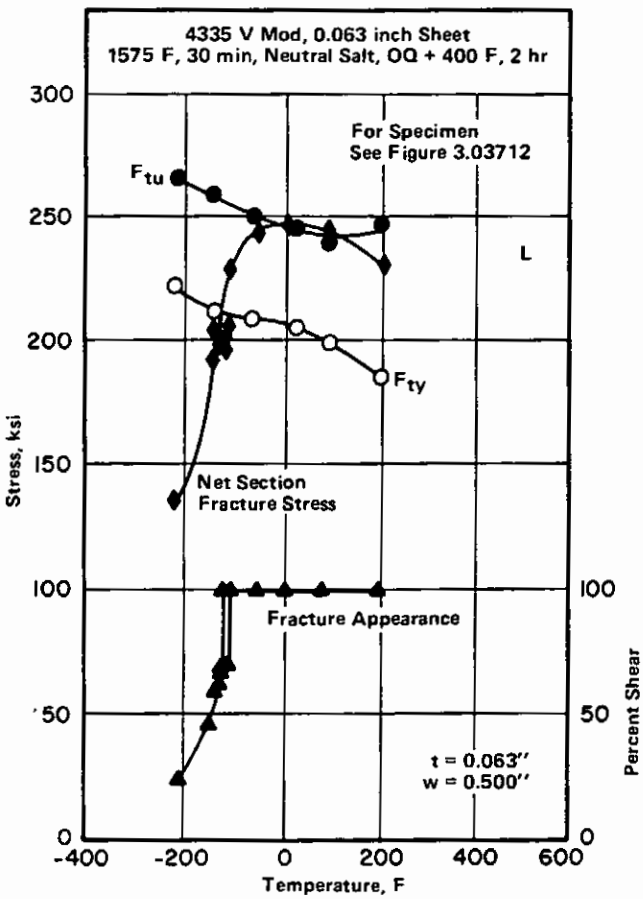


FIGURE 3.03727. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF CONSUTRODE VACUUM MELTED, QUENCHED AND TEMPERED 0.063 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

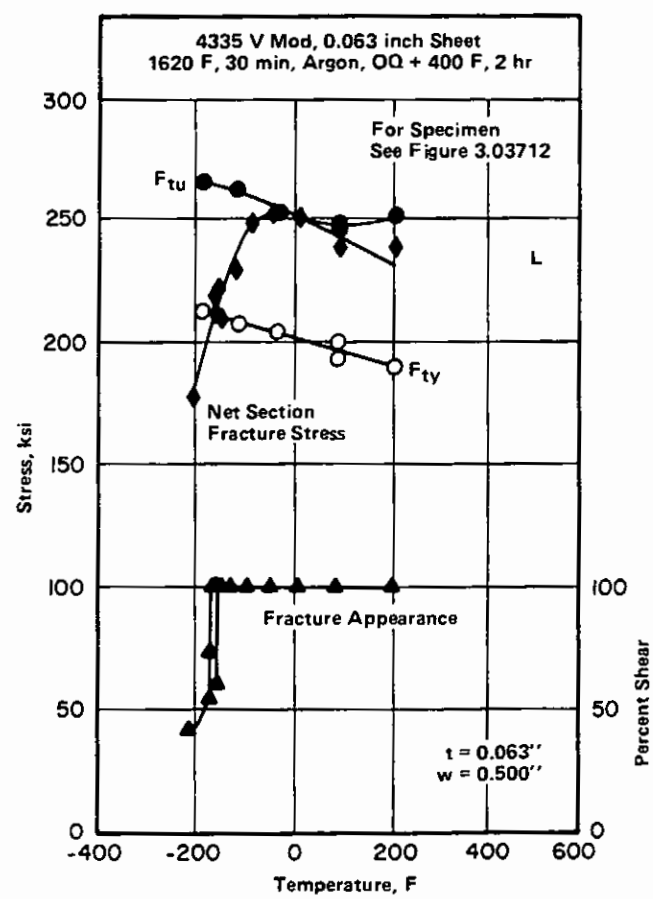


FIGURE 3.03728. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF CONSUTRODE VACUUM MELTED, QUENCHED AND TEMPERED 0.063 INCH SHEET (38)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

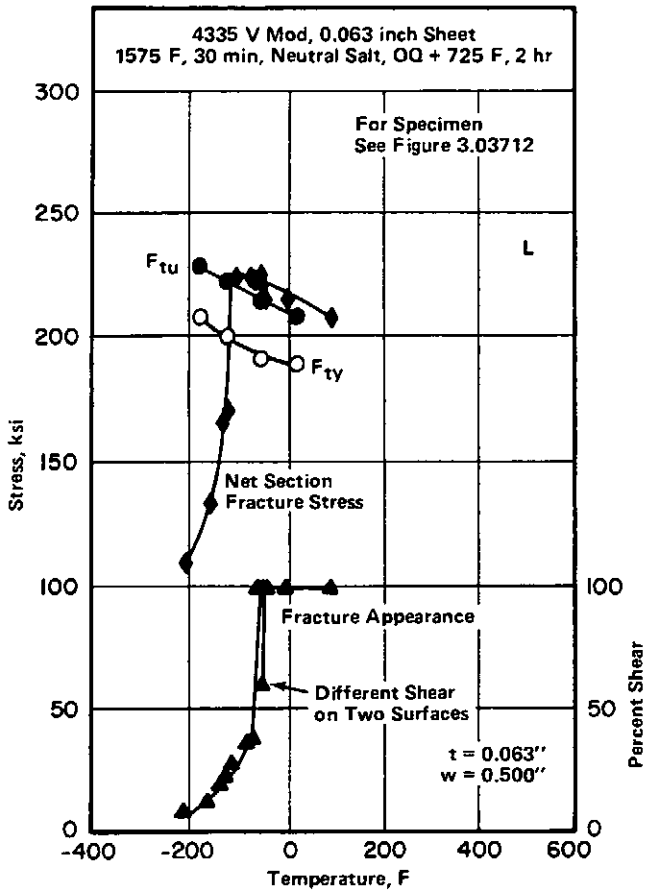


FIGURE 3.03729. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF CONSUTRODE VACUUM MELTED, QUENCHED AND TEMPERED 0.063 INCH SHEET (38)

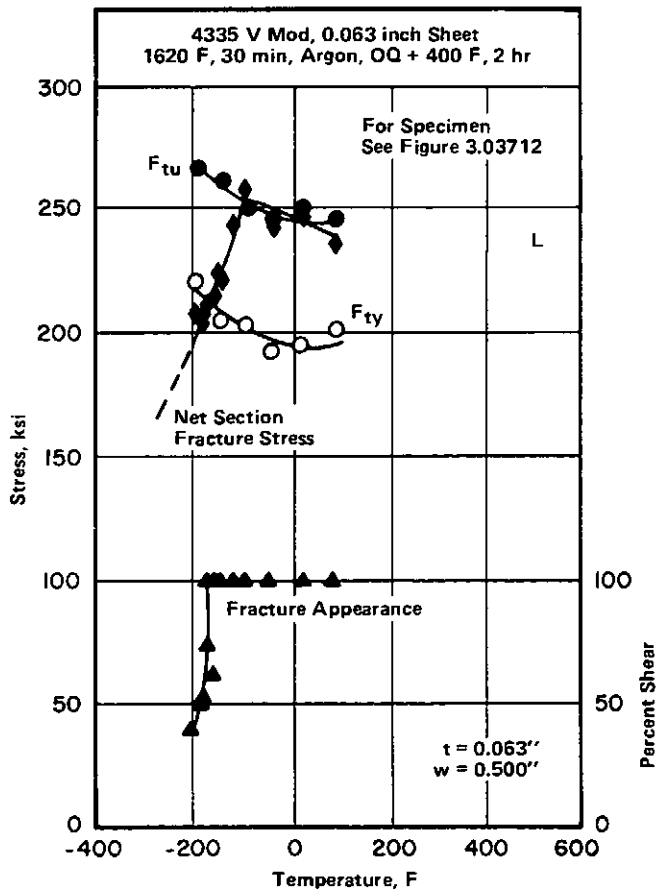


FIGURE 3.03730. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES, FRACTURE APPEARANCE, AND NET SECTION FRACTURE STRESS OF CONSUTRODE VACUUM MELTED, QUENCHED AND TEMPERED 0.063 INCH SHEET (38)

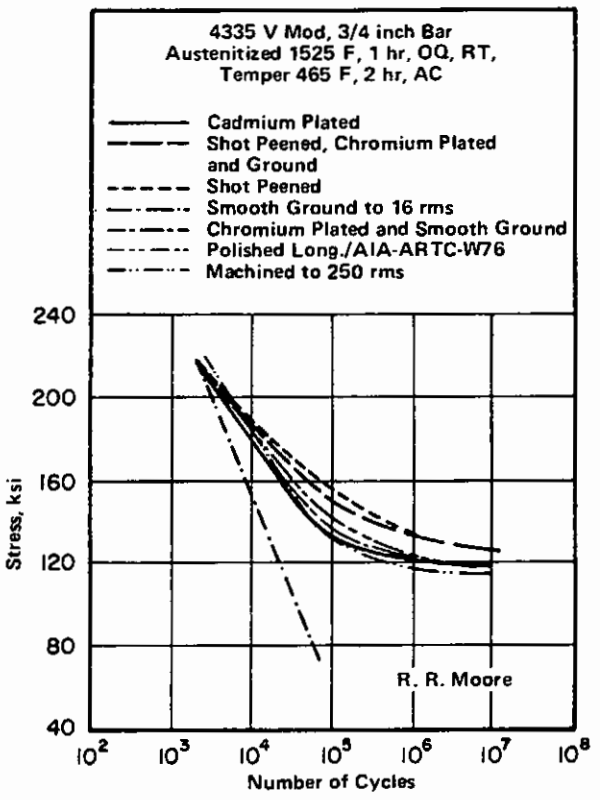
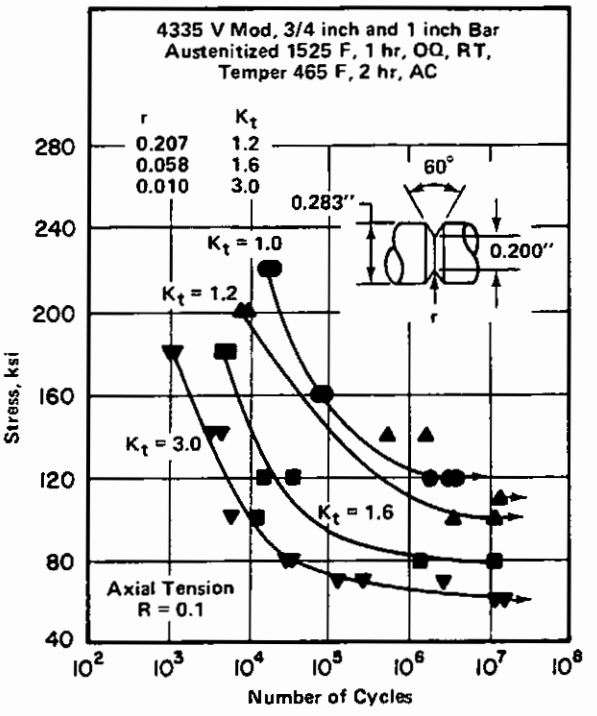


FIGURE 3.051. S-N CURVES FOR BAR WITH VARIOUS SURFACE TREATMENTS (24)



Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

FIGURE 3.052. S-N CURVES FOR SMOOTH AND NOTCHED BAR (25)

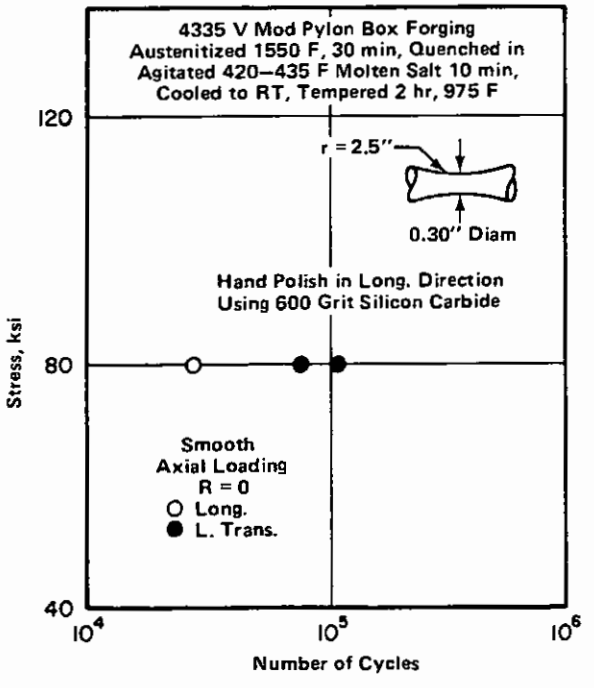


FIGURE 3.053. FATIGUE LIFE AT 80 KSI (R = 0) FOR FORGING (34)

Fe
0.35 C
1.8 Ni
0.8 Cr
0.35 Mo
0.2 V

4335 V Mod

Alloy	4335 V Mod	
Form	Hollow Extrusions With Two External Diameters (Approx. 9.5 in. and 7 in.) for 105 mm Gun Tube	
Condition	Austenitized at 1550 F (Time Unspecified), OD and ID Quenched With Agitated Water, Tempered 1060 F for 4 hr	
Specimen and Orientation	C Shape, T-S	
Location	Applied ΔK, ksi $\sqrt{in.}$	da/dN[(a)], in./cycle
Breech End of Extrusion	27.3	5.05×10^{-6}
Mid-Length of Breech	27.3	5.75×10^{-6}
Muzzle End of Extrusion	35.1	10.8×10^{-6}

(a) Average of two specimens, one from each of two extrusions.

TABLE 3.054. FATIGUE CRACK PROPAGATION RATE OF GUN-TUBE EXTRUSION (36)

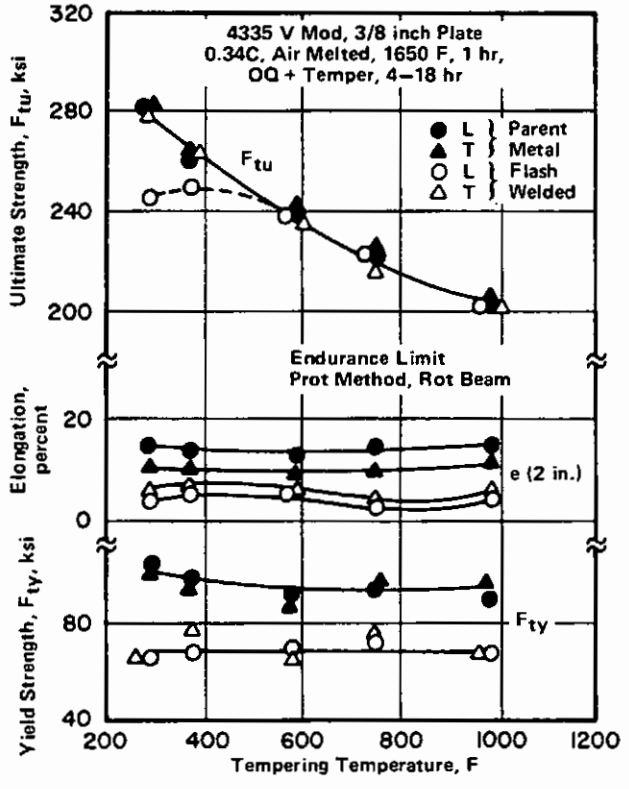


FIGURE 4.031. EFFECT OF FLASH WELDING AND TEMPERING TEMPERATURE ON TENSILE PROPERTIES AND ENDURANCE LIMIT OF AIR MELTED PLATE (15)

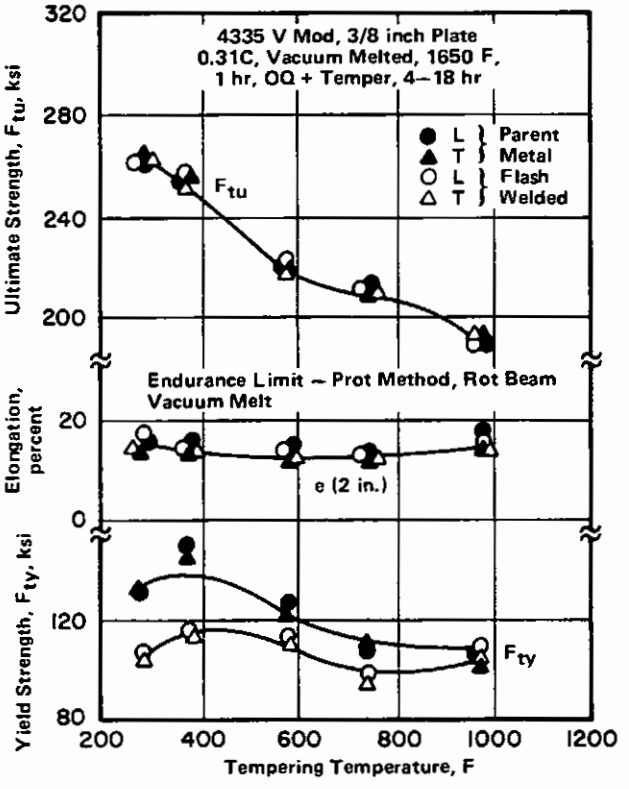


FIGURE 4.032. EFFECT OF FLASH WELDING AND TEMPERATURE ON TENSILE PROPERTIES AND ENDURANCE LIMIT OF VACUUM MELTED PLATE (15)