REVISED: MARCH 1976
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FERROUS ALLOYS

1. GENERAL
Greek Ascoloy is a hardenable, martensitic 13 percent chromium stainless steel, in which additions of nickel and tungsten provide improved mechanical properties and heat resistance over Type 410 stainless steel. It retains corrosion and oxidation resistance up to its maximum recommended service temperature of 1100F, and its creep-rupture properties in this temperature range are equal or superior to those of the austenitic stainless steels. The alloy has good hot-working characteristics and brazability but only fair cold formability and weldability. Its good combination of creep properties and corrosion resistance accounts for its use in compressor blades and vanes and discs in the lower-temperature stages of gas turbines. Other components made from this alloy include rings for jet engines, numerous types of fasteners, and valve parts (5)(6)(7).

1.01 Commercial Designation
Greek Ascoloy

1.02 Alternate Designations
Type 418 Special, AMS 5616, AISI 615, 12-2W (Armco Steel), Unitemp 1415 NW (Universal Cyclops), 436 (Howmet Corp.), Croloy 12-3W (Babcock and Wilcox), UNS S41800.

1.03 Specifications
Table 1.03.

1.04 Composition
Table 1.04.

1.05 Heat Treatment
1.051 Full anneal: 1450F 2 to 4 hours, furnace cool to 800F, air cool to 200F, reheat to 1250F 12 hours, air cool. The resulting hardness is about 225 to 250 BHN (5)(6).
1.052 Subcritical anneal or stress relief: 1300F 4 hours, air cool. This treatment results in a hardness of about 270 to 280 BHN (5)(6).
1.053 Hardening: 1700 to 1900F, oil quench section size larger than 3 inches and air cool or oil quench sections less than 3 inches thick. Preheating at 1200 to 1400F is recommended for parts with large variations in thickness. Exothermic or endothermic furnace atmospheres are recommended to minimize scaling and decarburization (5)(6)(7).
1.054 Temper: 500 to 1250F 2 to 4 hours, air cool. A double temper is recommended for heavy sections or where maximum dimensional stability is required. For parts that are straightened after tempering, a final treatment at 50F lower than the initial tempering temperature is sometimes used to at least partially relieve residual stresses (5)(6)(7).

1.06 Hardness
1.061 Effects of tempering temperature, after two different austenitizing treatments, on room-temperature hardness, Figure 1.061.
1.062 Effects of tempering two hours at various temperatures on hardness, Figure 1.062.
1.063 Hardness range for annealed billets and bars, 240-311 BHN, 23-33 R_C (7).
1.064 Hardness of extrusions in the annealed and hardened-and-tempered conditions, Table 1.064.
1.065 Effects of elevated temperatures on hardness, Figure 1.065.

1.07 Forms and Conditions Available
Greek Ascoloy is available as billets, bars, wire, strip forgings, and investment castings. Other forms, such as extrusions and tubing, can also be produced. It can be furnished annealed, hardened and tempered, hot rolled, cold finished, or cold rolled depending upon the form desired (6)(7)(13).

1.08 Melting and Casting Practice
The alloy is generally air melted in electric-arc furnaces. For applications requiring exceptional quality, it is vacuum remelted by consumable electrode or induction techniques.

1.09 Special Considerations
1.091 Although tempering in the secondary hardening range of about 650 to 950F produces high strength, it also results in reduced notched toughness; therefore tempering in this range is generally not recommended (see Figure 3.0231).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties
2.011 Melting range, 2600 - 2700F (6).
2.012 Phase changes.
2.0121 Time-temperature-transformation diagrams.
2.0122 In the annealed condition, Greek Ascoloy consists of ferrite and carbides; in the hardened condition its structure is martensitic. At temperatures of about 1500F and above the structure is austenitic. The presence of nickel in the alloy prevents the formation of delta ferrite (5).
2.013 Thermal conductivity.
2.014 Thermal expansion, Figure 2.014.
2.015 Specific heat, 0.11 Btu per (lb-F) from 32 to 212F (5).
2.016 Thermal diffusivity.

2.02 Other Physical Properties
2.021 Density, 0.284 lb per cu in, 7.86 gr per cu cm (6)(7)(8).
2.022 Electrical properties.
2.0221 Electrical properties at various temperatures, Table 2.0221.
2.023 Magnetic properties, ferromagnetic.
2.0231 Magnetic permeability after tempering at 700 to 900F, Table 2.0231.
2.024 Emittance.
2.025 Damping capacity.

2.03 Chemical Properties
2.031 The resistance to general corrosion and to rusting of Greek Ascoloy, which is optimum in the hardened and tempered condition, is similar to that of Type 410 stainless steel and other 12 percent chromium stainlesses (see Types 403, 410, 416, Code 1401) (6)(7).
2.032 Its resistance to stress corrosion and to hydrogen embrittlement is superior to that of Type 410. Tempering in the secondary hardening range of about 650 to 950F reduces resistance to stress-corrosion cracking (5)(7).
2.033 The alloy resists oxidation up to 1500F for continuous service and to 1300F for intermittent service. It has good resistance to oxidizing acids but not to reducing acids. It also resists sulfur gases over its entire service temperature range (6)(7).

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties
Table 3.01.

3.02 Mechanical Properties at Room Temperature
3.021 Tension- stress/strain diagrams-tension properties.
3.0211 Effects of tempering temperature, after two different austenitizing treatments, on tensile properties, Figure 3.0211.
3.0212 Effects of tempering temperature on tensile properties of bars of various diameters and carbon content, Figure 3.0212.
3.0213 Tensile properties of extrusions in the annealed and the hardened-and-tempered conditions, Table 3.0213.
3.0214 Ranges of tensile properties for annealed billets and bars, Table 3.0214.
3.022 Compression- stress/strain diagrams - compression properties.

Fe
13 Cr
3 W
2 Ni

GREEK ASCOLOY

3.023 Impact.
3.0231 Effects of tempering temperature, after two different austenitizing treatments, on room temperature impact properties, Figure 3.0231.
3.0232 Effect of tempering temperature on charpy keyhole impact properties, Figure 3.0232.
3.0233 Room temperature Izod impact strength of annealed bar, 50-90 ft lb (7).
3.024 Bending.
3.025 Torsion and shear.
3.026 Bearing.
3.027 Stress concentration.
3.0271 Notch properties.
3.0272 Fracture toughness.
3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures
3.031 Tension - stress/strain diagrams - tension properties.
3.0311 Effects of elevated temperatures on tensile properties of bar austenitized at two temperatures and tempered at 1050F, Figure 3.0311.
3.0312 Effects of elevated temperatures on tensile properties of bar austenitized at two temperatures and tempered at 1200F, Figure 3.0312.
3.0313 Effects of temperature on tensile properties of bar of various diameters and carbon contents, Figure 3.0313.
3.032 Compression - stress/strain diagrams - compression properties.
3.033 Impact.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.0372 Fracture toughness.
3.038 Combined properties.

3.04 Creep and Creep Rupture Properties
3.041 Creep-rupture curves for bar with three different heat treatments, Figure 3.041.
3.042 Stresses required to produce 0.1 and 1 percent creep deformation in 100 and 150 hours at temperatures from 700 to 1100F, Figure 3.042.
3.043 Creep-rupture curves for bar at 600 to 1200F, Figure 3.043.
3.044 Creep-rupture curves for notched bar at 600 to 1200F, Figure 3.044.
3.045 Creep-rupture curves for smooth and notched sheet at 1050 to 1200F, Figure 3.045.

3.05 Fatigue Properties
3.051 Effects of temperature on the fatigue endurance limit at 10^7 cycles for bar heat treated to two hardness levels, Figure 3.051.

3.06 Elastic Properties
3.061 Poisson's ratio.
3.062 Modulus of elasticity.
3.0621 Modulus of elasticity at various temperatures, Table 3.0621.
3.063 Modulus of rigidity.

4. FABRICATION

4.01 Forming
4.011 Since Greek Ascoloy is not as soft as Type 410 stainless in the annealed condition, it requires somewhat greater pressures for cold forming. Although it does not work harden as much as 18-8 type stainless, intermediate anneals may be required, depending upon the degree and nature of the deformation. Severely cold-formed parts should be annealed or stress relieved (5)(6)(7).
4.012 The alloy can be hot worked by any of the conventional methods, such as forging, rolling, and extrusion. Hot working should be done in the range 2150 to 1700F: working below 1700F tends to cause cracking. Large sections should be heated at 1200 to 1400F prior to heating to hot-working temperatures in order to prevent strain cracking. Also to prevent strain cracking after hot work, the material should be cooled slowly in Sil-O-Cel or some other insulating material, or stress relieved at 1300F, or fully annealed, which produces optimum machinability (5)(6)(7).

4.02 Machining and Grinding
4.021 Because of its higher annealed hardness, Greek Ascoloy does not machine as easily as Type 410 stainless: however, because of its lower work-hardening it does machine better than Type 18-8 stainlesses. Based on 100 percent machinability for resulfurized B 1112 steel, annealed Greek Ascoloy is rated at 55 percent (5)(6).

4.03 Joining
4.031 Greek Ascoloy can be welded by fusion or resistance methods, but weldability is not considered good because of its susceptibility to strain cracking. Since the alloy is air hardening, preheat and interpass temperatures of 400 to 600F and postweld annealing or tempering above 1000F are recommended. Subsequently, weldments may be hardened and tempered to obtain desired properties. Optimum weld ductility is obtained with austenitic filler rods such as Type 310 stainless, but optimum strength is obtained with Greek Ascoloy filler metal (5)(6)(7).
4.032 High-strength brazed joints for elevated-temperature applications can be made in Greek Ascoloy by brazing in hydrogen at 1800 to 1850F, preferably with a filler metal of 82 Au - 18 Ni. Other acceptable filler metals are 58.5 Cu-31.5 Mn-10 Co for service temperatures up to 1000F and 54 Ag-25Pd-21Cu for service temperatures up to 800F. For optimum properties the brazed assembly should be furnace cooled to about 1700F, then rapidly cooled, and finally tempered (12).
4.033 In an evaluation of the effects of simulated service conditions on arc-welded and brazed Greek Ascoloy compressor blades and vanes and compressor discs, no deterioration in tensile properties and no corrosion in the welded and brazed joints occurred in four hours exposure to temperatures up to 800F at stresses of 90 percent of F_{ty} in a sea-salt atmosphere. The welded joints had been made by the tungsten-inert-gas method with Greek Ascoloy filler metal, and the weldments were hardened and tempered. The brazed joints were made in a hydrogen atmosphere at 1800F with an 82 Au-18Ni braze alloy and were tempered at 1050F (11).

4.04 Surface Treatment
4.041 Because of its good resistance to oxidation and corrosion, protective surface treatments and coatings are not normally needed.
4.042 Preferred methods for removal of hot-work and heat-treat scales are either mechanical techniques such as sand or vapor blasting, or immersion in a molten caustic bath followed by light acid pickling. Somewhat less effective is acid pickling alone in either 10 percent nitric acid or 20 percent hydrocholoric acid at about 130F; some scrubbing of the surface may subsequently be required to complete the scale removal. After acid pickling of hardened and tempered parts, baking at 400F is recommended as a precaution against hydrogen embrittlement (5).

Alloy	Greek Ascoloy	
Source	Form	Specification
(1)	Sheet, strip, plate	AMS 5508 B
(2)	Bars, forgings, tubing	AMS 5616 E
(3)	Welding wire	AMS 5817 A
(4)	Investment castings	AMS 5354 B

TABLE 1.03 SPECIFICATIONS

Alloy	Greek Ascoloy			
Form	Wrought		Cast	
Source	AMS 5508 B (1) AMS 5616 E (2) AMS 5817 A (3)		AMS 5354 B (4)	
	Min	Max	Min	Max
Carbon	0.15	0.20	0.12	0.20
Manganese	-	0.50	-	1.0
Silicon	-	0.50	-	1.0
Phosphorus	-	0.040	-	0.04
Sulfur	-	0.030	-	0.03
Chromium	12.00	14.00	12.0	14.0
Nickel	1.80	2.20	1.8	2.2
Tungsten	2.50	3.50	2.5	3.5
Molybdenum	-	0.50	-	0.50
Aluminum	-	0.15	-	-
Copper	-	0.50	-	0.50
Tin	-	0.05	-	-
Iron	Balance		Balance	

TABLE 1.04 COMPOSITION

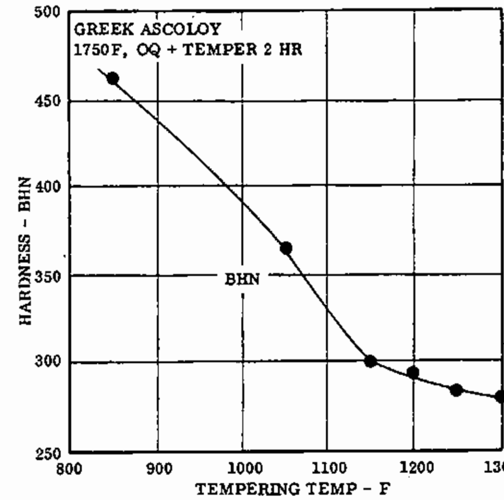

FIG. 1.062 EFFECT OF TEMPERING TWO HOURS AT VARIOUS TEMPERATURES ON HARDNESS. (6)

	Fe
13	Cr
3	W
2	Ni

GREEK ASCOLOY

Alloy	Greek Ascoloy
Form	0.75 in x 3-1/8 in extruded flat
Source	(10)
Condition	BHN
Ann. 1450F, 2 hr.	331
Ann. 1600F, FC to 1100F	290
1800F, AC + temper 700F	429

TABLE 1.064 HARDNESS OF EXTRUSIONS IN THE ANNEALED AND THE HARDENED-AND-TEMPERED CONDITIONS

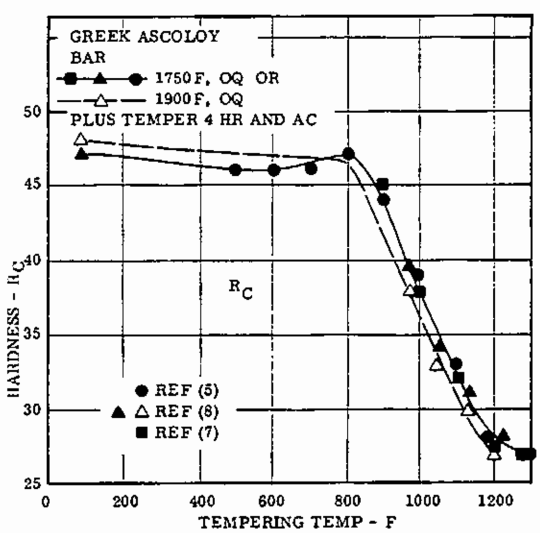

FIG. 1.061 EFFECTS OF TEMPERING TEMPERATURE, AFTER TWO DIFFERENT AUSTENITIZING TREATMENTS, ON ROOM TEMPERATURE HARDNESS. (5)(7)(8)

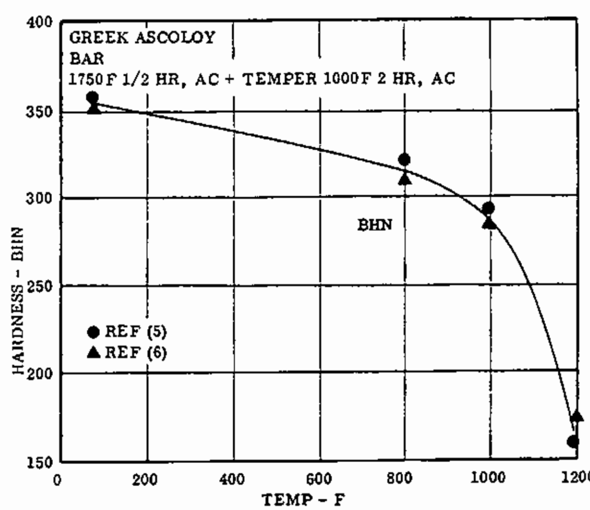

FIG. 1.065 EFFECTS OF ELEVATED TEMPERATURES ON HARDNESS. (5)(6)

	Fe
13	Cr
3	W
2	Ni

GREEK ASCOLOY

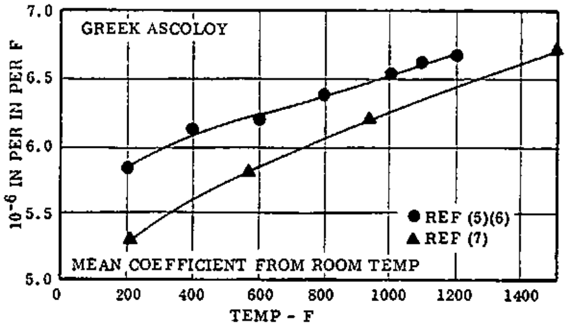

FIG. 2.014 THERMAL EXPANSION. (5)(6)(7)

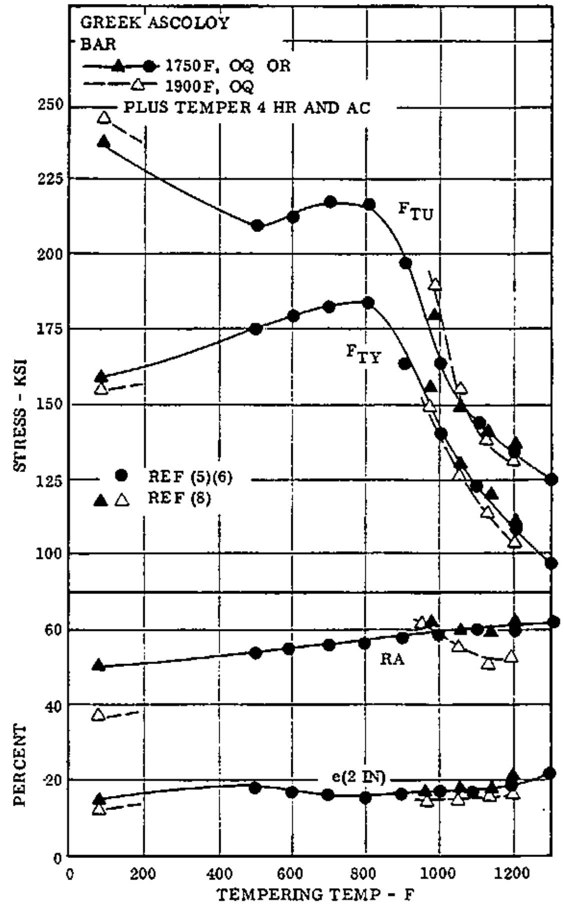

FIG. 3.0211 EFFECTS OF TEMPERING TEMPERATURE, AFTER TWO DIFFERENT AUSTENITIZING TREATMENTS, ON TENSILE PROPERTIES. (5)(6)(8)

Alloy	Greek Ascoloy		
Condition	Quenched and tempered		
Source	(5)		
	Electrical Conductivity		Electrical Resistivity
Temp, F	Percent IACS	Megohms per in^3	Microhm-in
77	2.12	0.0322	31.0
700	2.80	0.0411	24.3
800	2.84	0.0419	23.9
900	2.86	0.0422	23.7

TABLE 2.0221 ELECTRICAL PROPERTIES AT VARIOUS TEMPERATURES

Alloy	Greek Ascoloy	
Condition	Quenched and tempered	
Source	(5)	
Tempering	Magnetic Permeability	
Temp, F	at 100 Oersteds	Maximum
700	85	85
800	75	92
900	93	100

TABLE 2.0231 MAGNETIC PERMEABILITY AFTER TEMPERING AT 700 TO 900F

Alloy	Greek Ascoloy							
			F_{ty} (ksi)	F_{tu} (ksi)		e (4D)	Hardness	
Source	Form	Condition	min	min	max	min	R_C (min)	BHN (max)
AMS 5508 B (1)	Sheet, strip, plate	Annealed	-	-	150	10	-	-
	Sheet, strip, plate	1800F, AC	-	-	-	-	42	-
AMS 5616 E (2)	Bars, welded rings	Annealed	-	-	-	-	-	311
	Tubing	Ann. and cold finished	-	-	-	-	-	311
	Wire	Ann. and cold finished	-	-	155	-	-	-
	Bars, tube, forgings	1750F, OQ	-	-	-	-	45	-
AMS 5817 A (3)	Weld metal deposit 1/4 inch thick	1800F, AC	-	-	-	-	42	-
AMS 5354 B (4)	Investment cast	1750F, AC	-	-	-	-	45	-
		1750F, AC+1300F 1 hr, AC	65	90	-	3	-	-

TABLE 3.01 SPECIFIED MECHANICAL PROPERTIES

Fe	
13	Cr
3	W
2	Ni

GREEK ASCOLOY

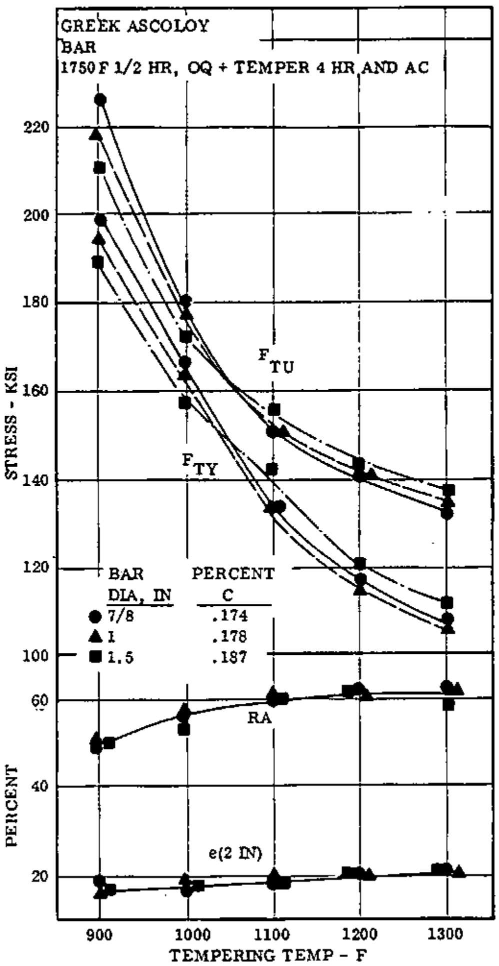

FIG. 3.0212 EFFECTS OF TEMPERING TEMPERATURE ON TENSILE PROPERTIES OF BARS OF VARIOUS DIAMETERS AND CARBON CONTENTS. (9)

Alloy	Greek Ascoloy
Condition	Annealed
Source	(7)
F_{ty} (ksi)	85 to 120
F_{tu} (ksi)	115 to 150
e (2 in) (percent)	18 to 22

TABLE 3.0214 RANGES OF TENSILE PROPERTIES FOR ANNEALED BILLETS AND BARS

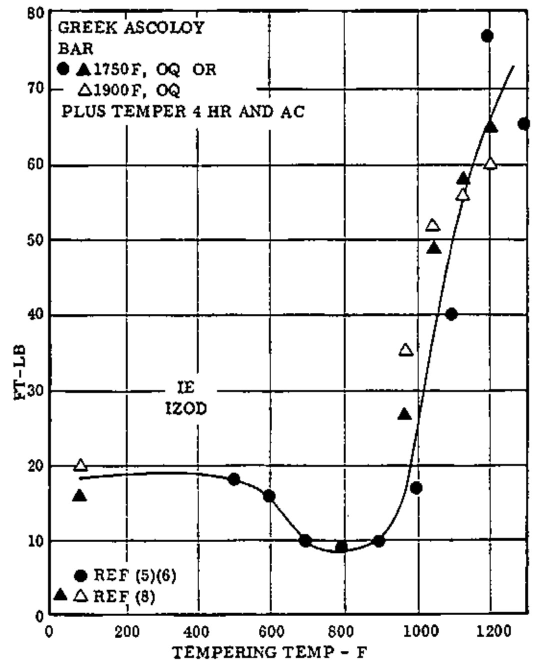

FIG. 3.0231 EFFECTS OF TEMPERING TEMPERATURE, AFTER TWO DIFFERENT AUSTENITIZING TREATMENTS, ON ROOM TEMPERATURE IMPACT PROPERTIES. (5)(6)(8)

Alloy	Greek Ascoloy					
Form	0.75 in. x 3-1/8 in extruded flat					
Source	(10)					
Condition	Orientation	ASTM Grain size	F_{ty} (ksi)	F_{tu} (ksi)	e (4D) (percent)	RA (percent)
Ann. 1450F 2 hr.	L	6-7	120	147	18	56
	T	6-7	122	147	18	44
Ann. 1600F, FC to 1100F	L	7-8	120	146	18	68
	T	7-8	120	145	11	59
1800F, AC + temper 700F	L	7-8	178	206	20	46
	T	7-8	169	203	13	31
1750F, OQ + temper 1050F 2 hr	L	7-8	128	147	21	71
	T	7-8	129	146	17	60

TABLE 3.0213 TENSILE PROPERTIES OF EXTRUSIONS IN THE ANNEALED AND THE HARDENED-AND-TEMPERED CONDITIONS

	Fe
13	Cr
3	W
2	Ni

GREEK ASCOLOY

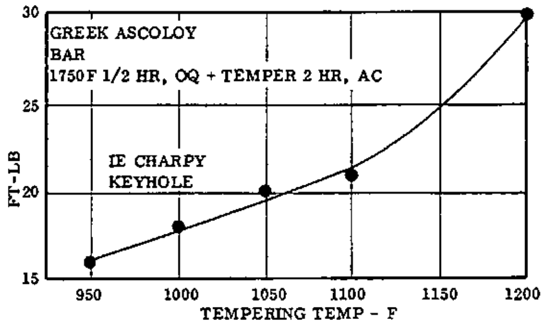

FIG. 3.0232 EFFECT OF TEMPERING TEMPERATURE ON CHARPY KEYHOLE IMPACT PROPERTIES. (5)

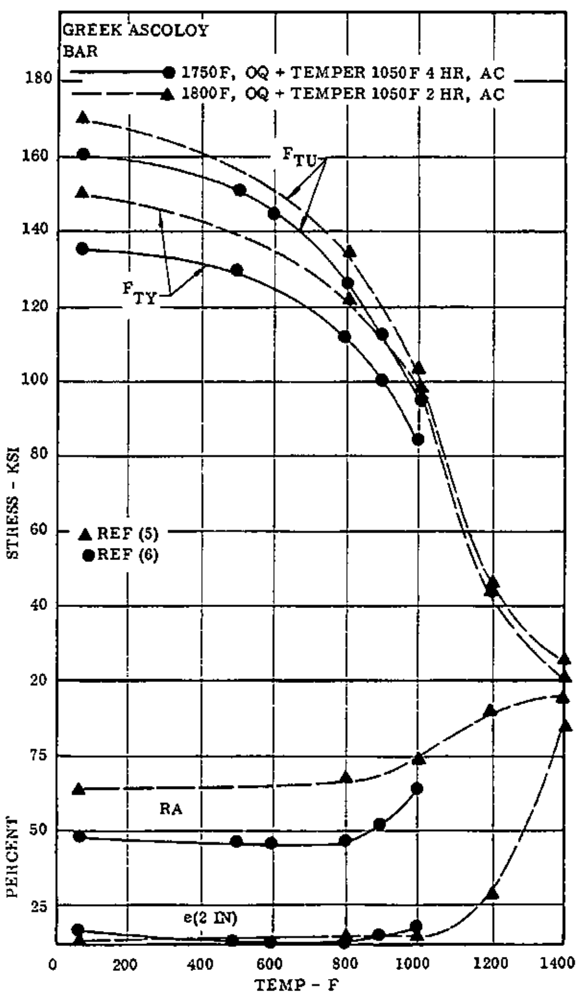

FIG. 3.0311 EFFECTS OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF BAR AUSTENITIZED AT TWO TEMPERATURES AND TEMPERED AT 1050F. (5)(6)

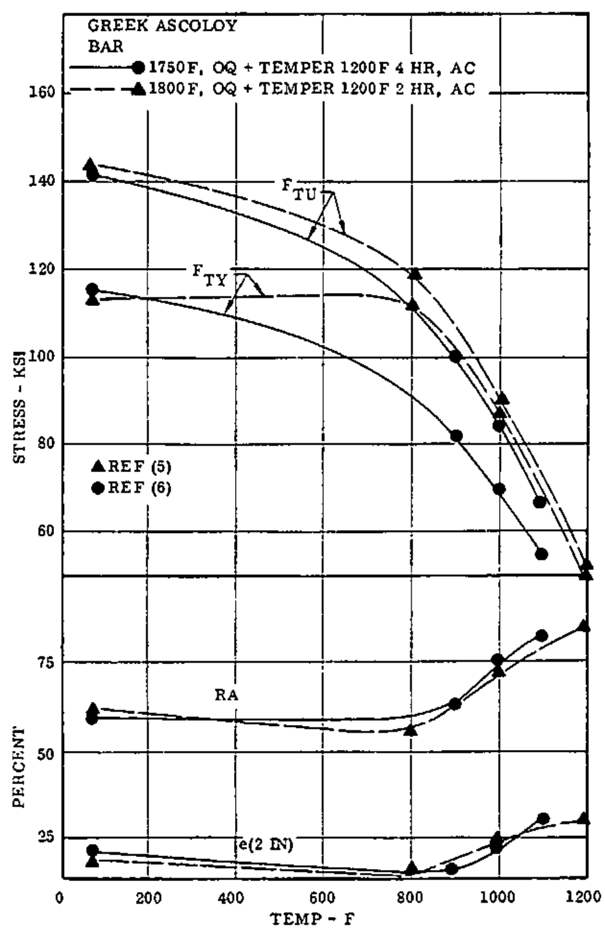

FIG. 3.0312 EFFECTS OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF BAR AUSTENITIZED AT TWO TEMPERATURES AND TEMPERED AT 1200F. (5)(6)

	Fe
13	Cr
3	W
2	Ni

GREEK ASCOLOY

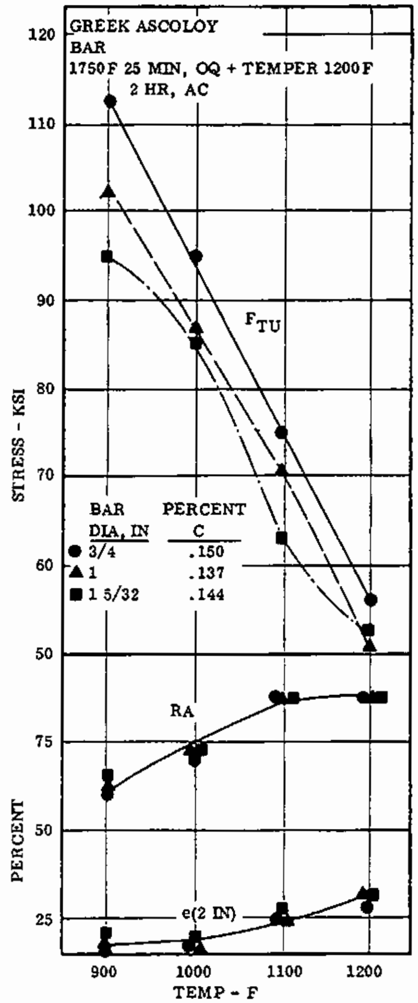

FIG. 3.0313 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES OF BAR OF VARIOUS DIAMETERS AND CARBON CONTENTS. (8)

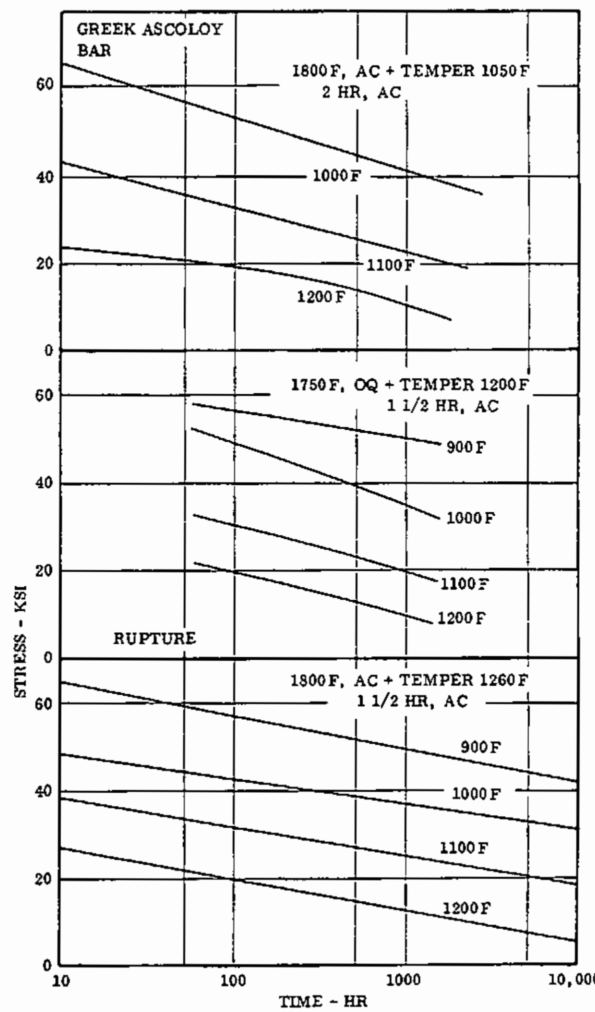

FIG. 3.041 CREEP-RUPTURE CURVES FOR BAR WITH THREE DIFFERENT HEAT TREATMENTS. (5)(6)(7)

	Fe
13	Cr
3	W
2	Ni

GREEK ASCOLOY

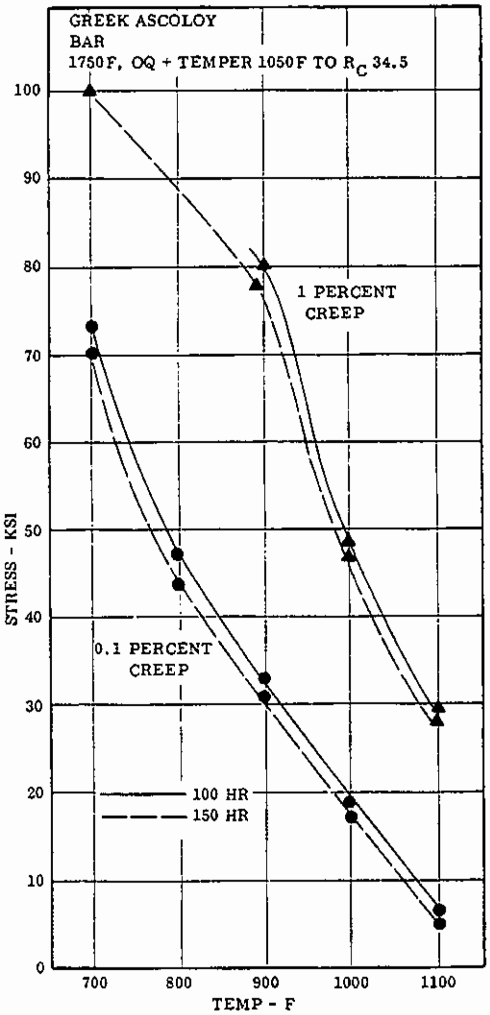

FIG. 3.042 STRESSES REQUIRED TO PRODUCE 0.1 AND 1 PERCENT CREEP DEFORMATION IN 100 AND 150 HOURS AT TEMPERATURES FROM 700 TO 1100F. (5)

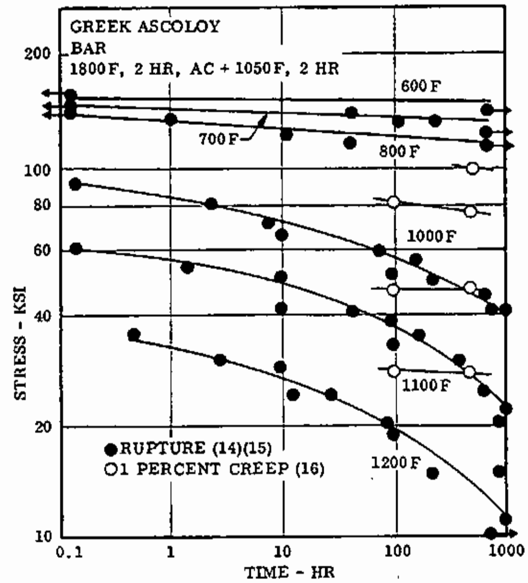

FIG. 3.043 CREEP-RUPTURE CURVES FOR BAR AT 600 TO 1200F. (14)(15)(16)

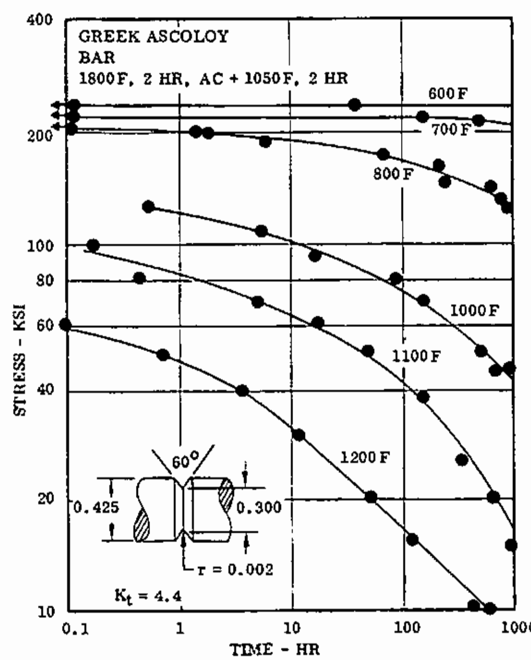

FIG. 3.044 CREEP-RUPTURE CURVES FOR NOTCHED BAR AT 600 TO 1200F. (14)(15)

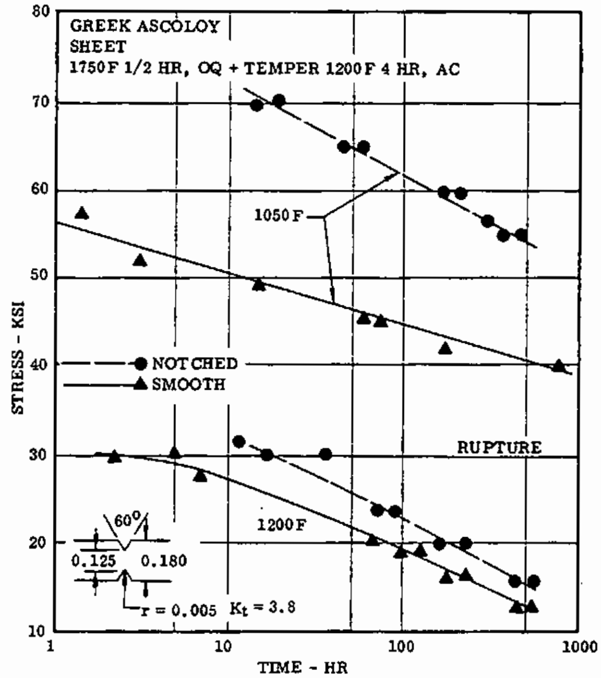

FIG. 3.045 CREEP-RUPTURE CURVES FOR SMOOTH AND NOTCHED SHEET AT 1050 AND 1200F. (17)

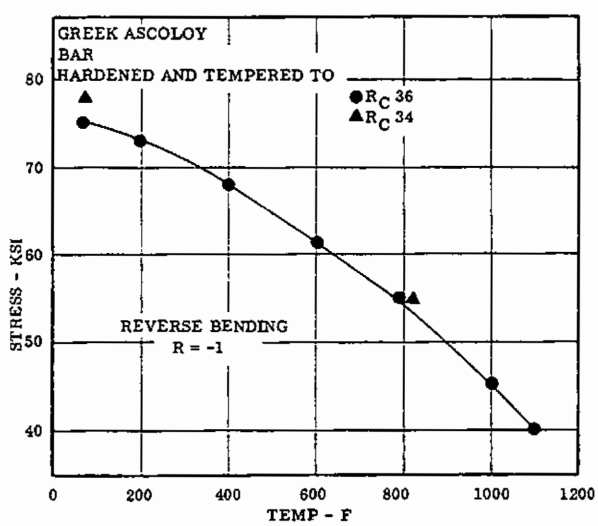

FIG. 3.051 EFFECTS OF TEMPERATURE ON THE FATIGUE ENDURANCE LIMIT AT 10^7 CYCLES FOR BAR HEAT TREATED TO TWO HARDNESS LEVELS. (5)

Alloy	Greek Ascoloy
Source	(5)
Temperature, F	E, 10^3 ksi
70	29.0
1000	21.5
1100	17.0

TABLE 3.0621 MODULUS OF ELASTICITY AT VARIOUS TEMPERATURES

	Fe
13	Cr
3	W
2	Ni

GREEK ASCOLOY

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