FERROUS ALLOYS

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

1 GENERAL

E 9310 is a carburizing high hardenability steel. It is normally carburized to a depth of 0.02 to 0.04 inch, followed by austenitizing, quenching, and tempering to produce a high strength core with a hard case. The alloy is widely used as an aircraft alloy because of its ease of processing and excellent core and case properties. It retains good tensile ductility and absence of notch sensitivity down to liquid hydrogen temperature. A major application for this alloy is high performance gears, such as in helicopter power train transmissions. Maximum service temperature in this application is 300 F; above this temperature the alloy softens and gears exhibit scoring, scuffing, and tooth bending fatigue (8–11).

The "H" designated steel (9310 H) is guaranteed by the supplier to meet established AISI-SAE hardenability limits; otherwise its properties and nominal compositions are identical to E 9310 (5).

1.01 **Commercial Designation**
E 9310.

1.02 **Alternate Designations**
SAE 9310, AISI E 9310 H, AMS 6260 E, and UNS G93106.

1.03 **Specifications**
1.031 Specification, Table 1.031.

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

1.05 **Heat Treatment**
1.051 Anneal, 1475 to 1575 F, furnace cool (1).
1.052 Normalize, 1600 to 1700 F, air cool (1). AMS specifies 1690 to 1710 F (4, 6, 7).
1.053 Austenitize, 1450 to 1550 F, oil quench (1, 5). AMS specifies 1490 to 1510 F (4, 6, 7).
1.054 Temper, 275 to 450 F for case hardened parts (1).
1.055 Spheroidize, temper, 1175 F maximum, 8 to 10 hr or austenitize at 1400 F and transform isothermally at 1100 F, 12 hr (1).
1.056 Typical case hardening procedures.
1.0561 Direct quench from pot. Carburize at 1700 F, 8 hr, circulating oil quench and temper (1).
1.0562 Single quench and temper. Carburize at 1700 F, 8 hr, pot cool, austenitize, circulating oil quench and temper (1).
1.0563 Double quench and temper. Carburize at 1700 F, 8 hr, pot cool, austenitize, circulating oil quench, repeat previous austenitizing treatment and temper. This treatment yields higher grain refinement in both case and core (1).
1.0564 For maximum core toughness temper at 450 F (see Figure 3.0231).
1.0565 Refrigeration is sometimes employed after austenitizing and quenching but before tempering. This treatment increases hardness and decreases the amount of retained austenite by promoting transformation to martensite (12).

1.06 **Hardness**
1.061 Effect of carbon content on hardness of bar, Figure 1.061.
1.062 Effect of thickness on as-quenched hardness of bar, Figure 1.062.
1.063 Effect of bar diameter on quenched and tempered hardness of bar, given simulated carburizing cycle, Figure 1.063.
1.064 Short-term hot hardness, Figure 1.064.
1.065 Hardness traverse across thickness of carburized and quenched E 9310, Figure 1.065.
1.066 Hardenability.
1.0661 AMS Specifications 6260J, 6265F, and 6267B all require that the hardenability be J41 = 1 maximum and J32 = 6 minimum for material in the normalized (1700 F) plus austenitized (1500 F) condition. The original AMS documents should be consulted for complete specification details, which also include microstructural requirements (4, 6, 7).
1.0662 End quench hardenability for 9310 H, Figure 1.0662.

1.07 **Forms and Conditions Available**
1.071 This steel is available as billets, bars, forgings, and annealed hot and cold finished rounds (1, 2), and as centerless ground bars, hot and cold drawn wire, and hot and cold rolled strip (1).

1.08 **Melting and Casting Practice**
1.081 Open hearth, electric furnace, air, and vacuum melt (3).
1.082 Vacuum melting produces improved impact properties (3) and fatigue properties (see Figure 3.056).

1.09 **Special Considerations**
1.091 E 9310 is not suitable for use in high load gear applications at temperatures above 300 F. Scuffing, scoring, and tooth fatigue can occur above this temperature (10, 11).

2 PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS

2.01 **Thermal Properties**
2.011 Melting range.
2.012 Phase changes.
2.0121 Critical temperatures are:

A_{c1} = 1315 F A_{r3} = 1305 F
A_{c3} = 1490 F A_{e1} = 1240 F
A_{r1} = 830 F A_{e3} = 1480 F (1).

2.013 Thermal conductivity.
2.014 Thermal expansion, Figure 2.014.
2.015 Specific heat.
2.016 Thermal diffusivity.

2.02 **Other Physical Properties**
2.021 Density.
2.022 Electrical properties.
2.023 Magnetic properties.
2.024 Emittance.
2.025 Damping capacity.

2.03 **Chemical Environments**

2.04 **Nuclear Environments**

3 MECHANICAL PROPERTIES

3.01 **Specified Mechanical Properties**

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

3.011 AMS specifies no mechanical property requirements for E 9310 but does specify hardenability limits. These are given in Section 1.0661.

3.02 **Mechanical Properties at Room Temperature**

3.021 Tension – stress-strain diagrams – tension properties.

3.0211 Typical properties of bar stock, Table 3.0211.

3.0212 Effect of carbon content on tensile properties of bar, Figure 3.0212.

3.0213 Effect of bar diameter on room temperature tensile properties of bar, given simulated carburizing cycle, Figure 3.0213.

3.0214 Cyclic and monotonic stress-strain curves in tension, Figure 3.0214.

3.022 Compression – stress-strain diagrams – compression properties.

3.023 Impact.

3.0231 Effect of bar diameter and tempering temperature on room temperature impact strength of bar, given simulated carburizing cycle, Figure 3.0231.

3.024 Bending.

3.025 Torsion and shear.

3.026 Bearing.

3.027 Stress concentration.

3.0271 Notch properties.

3.0272 Fracture toughness.

3.02721 Fracture toughness gradient in carburized case, Figure 3.02721.

3.028 Combined properties.

3.03 **Mechanical Properties at Various Temperatures**

3.031 Tension – stress-strain diagrams – tension properties (see Figure 3.03712).

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.

3.03711 The alloy exhibits excellent resistance to notch sensitivity at cryogenic temperatures, as indicated by tensile data in Figure 3.03712.

3.03712 Smooth and notched tensile properties at low temperatures, Figure 3.03712.

3.0372 Fracture toughness.

3.038 Combined properties.

3.04 **Creep and Creep Rupture Properties**

3.05 **Fatigue Properties**

3.051 Refrigeration after quenching has little effect on the rotating beam fatigue life in the untempered condition, as shown in Figure 3.052. However, in the quenched and tempered condition, better fatigue life is obtained with nonrefrigerated material containing a larger fraction of retained austenite, as shown in Figures 3.053 and 3.054. Tempering at 300 F effects a significant increase in fatigue strength as seen by comparison of the data for untempered material in Figure 3.052 and for tempered material in Figure 3.053.

3.052 Rotating beam fatigue life at room temperature for carburized and quenched E 9310, Figure 3.052.

3.053 Rotating beam fatigue life at room temperature for carburized and tempered E 9310, Figure 3.053.

3.054 Weibull distribution of rotating beam fatigue life at room temperature for carburized E 9310 with two levels of retained austenite, Figure 3.054.

3.055 Double vacuum processing (vacuum induction melt-vacuum arc remelt) improves the rolling contact fatigue performance over that of single vacuum processed (vacuum arc remelt) material, as shown in Figure 3.056 (10).

3.056 Weibull distribution of rolling contact fatigue life at room temperature for single (VAR) and double (VIM-VAR) vacuum melted material, Figure 3.056.

3.057 The fatigue crack-growth rate in the carburized surface layer is much greater than in the noncarburized core for surface-carburized E 9310. This is illustrated by fatigue data on noncarburized material (representing the core) and through-carburized material (representing the case) shown in Figure 3.058. Other variables such as test frequency and stress ratio have relatively small effects (overlapping data scatter ranges), although wet air promotes rusting and increases the crack-growth rate as compared to dry air (13).

3.058 Fatigue crack-growth behavior at room temperature [(a) noncarburized, f = 204 cpm, R = 0.05, dry air; (b) noncarburized, f = 204 cpm, R = 0.50, dry air; (c) noncarburized, f = 60 cpm, R = 0.05, wet air; (d) noncarburized, f = 6 cpm, R = 0.05, wet air; and (e) carburized, f = 204 cpm, R = 0.05, dry air], Figure 3.058.

3.06 **Elastic Properties**

3.061 Poisson's ratio.

3.062 Modulus of elasticity.

3.063 Modulus of rigidity.

3.064 Tangent modulus.

3.065 Secant modulus.

4 **FABRICATION**

4.01 **Forming**

4.011 Forging.

4.0111 Starting temperature 2200 F maximum, finishing temperature 1950 F minimum (1).

4.012 Powder metallurgy.

4.0121 E 9310 can be consolidated by shock compaction of rapidly solidified powder produced by centrifugal atomization. Hardness of the individual spherical particles is 344 ± 34 DPH, which compares well with the typical value of 340 DPH for wrought 9310 steel. The shock compacted powder is harder than 340 DPH, as shown in Figure 4.0122, reflecting cold work introduced during compaction. Tensile strength of the powder compacts reaches a maximum of 190 ksi at a compaction pressure of 4500 ksi. The maximum pressure is maintained only for 2–3 microseconds due to the dynamic nature of the shock compaction process. The density of the powder compacts is essentially 100 percent for compaction pressures of 1000 ksi and greater (14).

4.0122 Hardness and strength of shock compacted rapidly solidified E 9310 powder, Figure 4.0122.

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

4.02 Machining and Grinding

4.021 Generally similar to other grades of low carbon low alloy steels. Cold drawn bars have better machinability than annealed stock. General practice for machining gears is to normalize and temper or quench and temper (1200 F, 8 to 10 hr) for best machinability (1). High speed steel tools and sulphurized cutting fluids are recommended (1).

4.022 Cutting rates in E 9310 can be increased by a factor of 2 to 3 by using ultrasonically assisted machining (15).

4.03 Joining

4.031 The steel can be readily welded by oxyacetylene or metallic arc methods. The use of bare type electrodes results in low strength and low ductility welds (1).

4.032 Stress relief after welding, 1150 to 1200 F, is recommended to increase impact properties (1).

4.04 Surface Treating

4.041 Generally, this steel is especially suited for case hardening by carburizing. See Section 1.056. It is recommended that the maximum carbon in the case be limited to 0.90 percent and some specifications limit the carbon to 0.80 percent (1).

4.042 Shot peening is frequently employed in addition to carburizing to provide a desirable residual compressive stress on the surface for gear applications. Shot peening improves the pitting fatigue life of case carburized and hardened spur gears by 50 to 60 percent (11, 16).

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	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

Alloy	E 9310
AMS Specification	Product Form
6260J	Bars, Forgings, Tubing
6265F	Bars, Forgings, Tubing
6267B	Bars, Forgings, Tubing

TABLE 1.031. SPECIFICATIONS (4, 6, 7)

Alloy	E 9310					
AMS Specification	6260J		6265F		6267B	
	Percent		Percent		Percent	
Element	Min	Max	Min	Max	Min	Max
Carbon	0.07	0.13	0.07	0.13	0.07	0.13
Nickel	3.00	3.50	3.00	3.50	3.00	3.50
Chromium	1.00	1.40	1.00	1.40	1.00	1.40
Molybdenum	0.08	0.15	0.08	0.15	0.08	0.15
Manganese	0.40	0.70	0.40	0.70	0.40	0.70
Silicon	0.15	0.35	0.15	0.35	0.20	0.35
Copper	–	0.35	–	0.35	–	0.35
Phosphorus	–	0.025	–	0.015	–	0.015
Sulfur	–	0.025	–	0.015	–	0.015

TABLE 1.041. COMPOSITION (4, 6, 7)

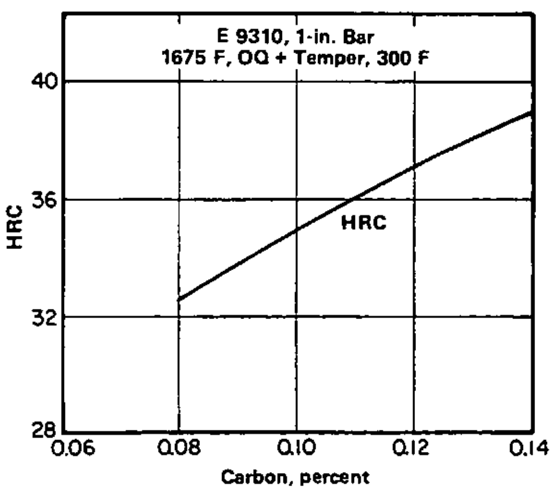


FIGURE 1.061. EFFECT OF CARBON CONTENT ON HARDNESS OF BAR (1)

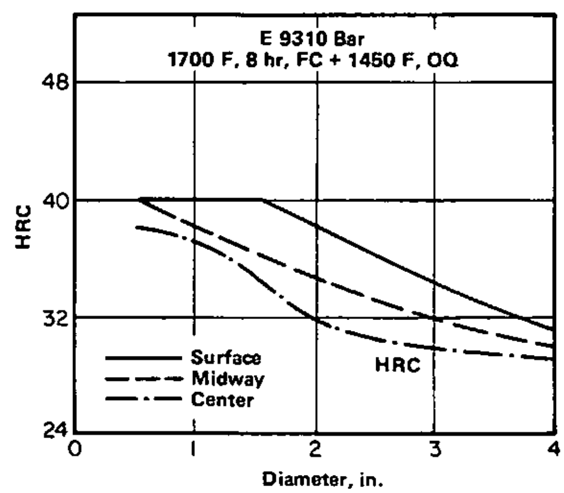


FIGURE 1.062. EFFECT OF THICKNESS ON AS-QUENCHED HARDNESS OF BAR (1)

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

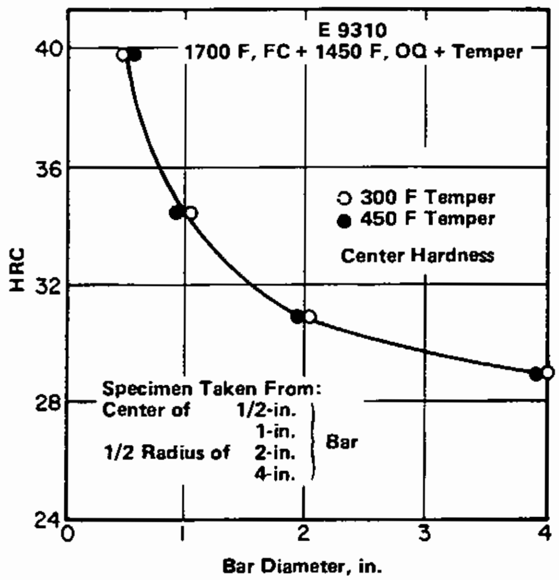


FIGURE 1.063. EFFECT OF BAR DIAMETER ON QUENCHED AND TEMPERED HARDNESS OF BAR, GIVEN SIMULATED CARBURIZING CYCLE (1)

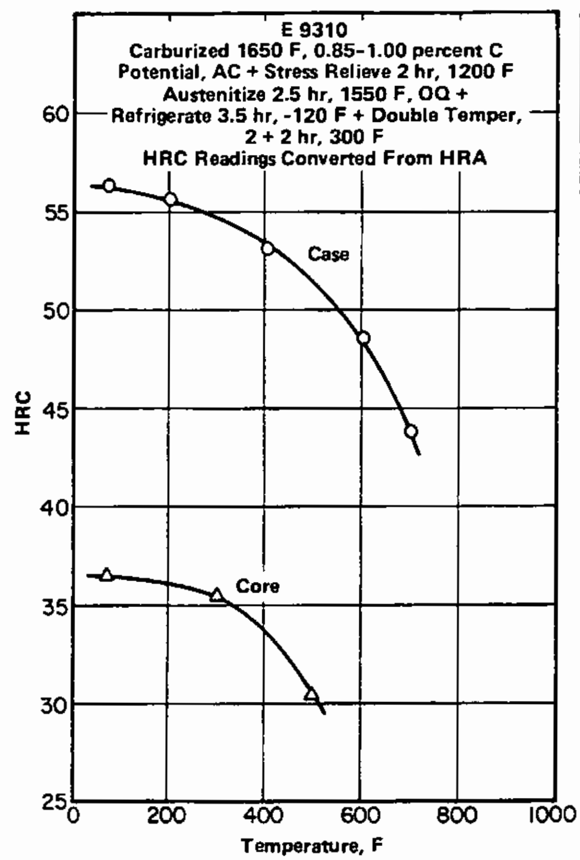


FIGURE 1.064. SHORT-TERM HOT HARDNESS (17)

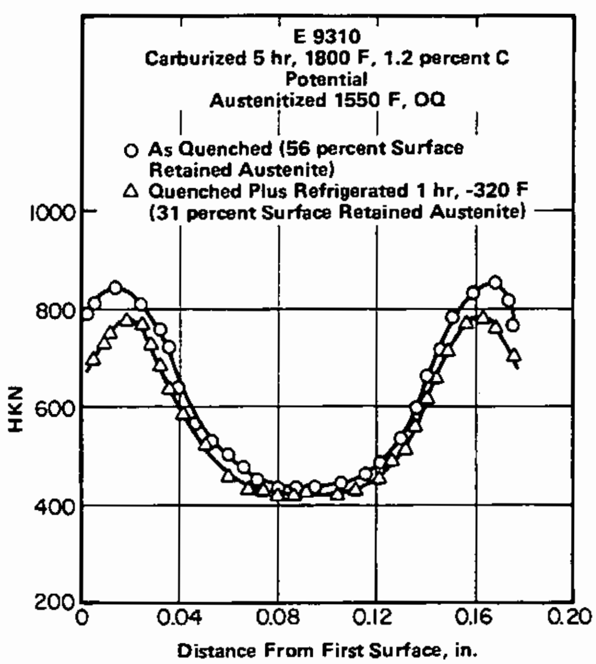


FIGURE 1.065. HARDNESS TRAVERSE ACROSS THICKNESS OF CARBURIZED AND QUENCHED E 9310 (12)

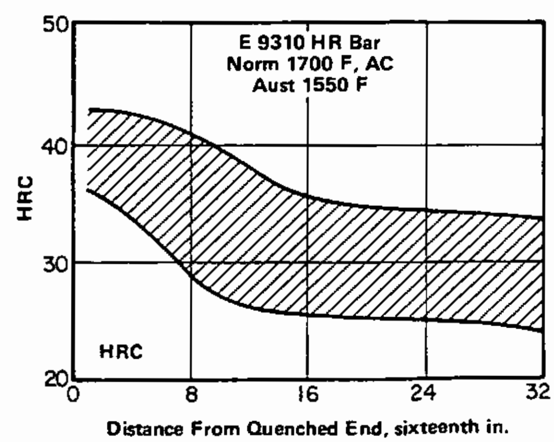


FIGURE 1.0662. END QUENCH HARDENABILITY FOR 9310 H (5)

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

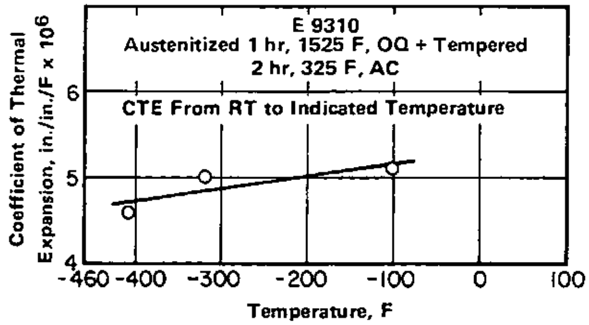


FIGURE 2.014. THERMAL EXPANSION (8)

Alloy	E 9310				
Form	Bar(a)				
Condition	As Rolled		Ann	Norm	
Diameter, in.	1	4	4	1	4
F_{tu}, typ, ksi	131	117.5	100	131.5	125.25
F_{ty}, typ, ksi	88	84	80	82.75	81.75
e (2 in.), percent	19	18.8	25	18.8	19.5
RA, percent	61.5	59.2	60	58.1	61.7
Hardness, BHN	269	241	200	269	255

(a) Tests were taken from center of 1-in. rounds and from 1/2 radius of 4-in. rounds.

TABLE 3.0211. TYPICAL PROPERTIES OF BAR STOCK (1)

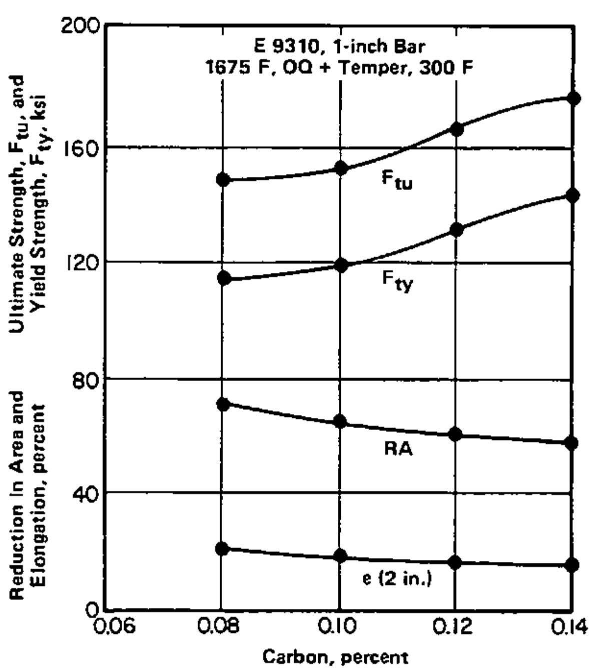


FIGURE 3.0212. EFFECT OF CARBON CONTENT ON TENSILE PROPERTIES OF BAR (1)

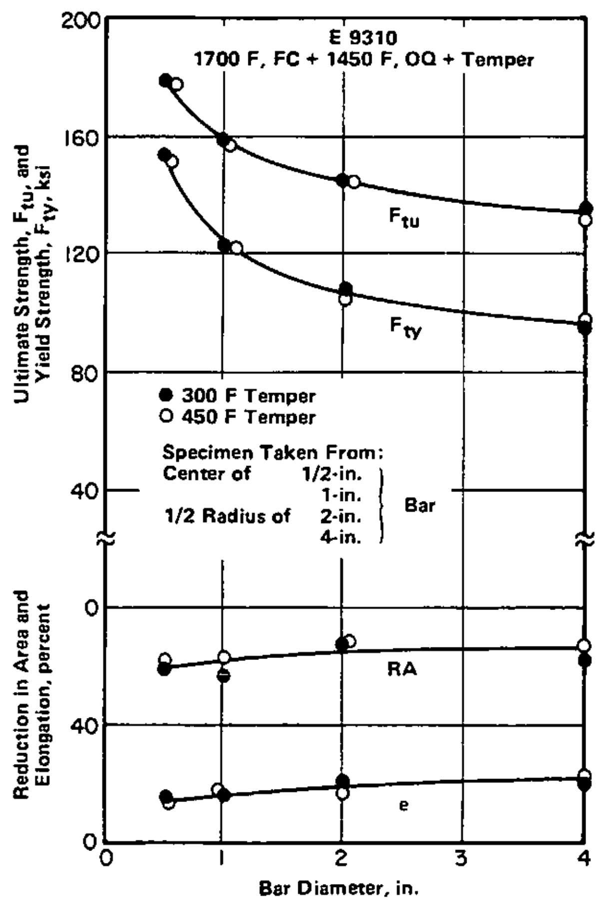


FIGURE 3.0213. EFFECT OF BAR DIAMETER ON ROOM TEMPERATURE TENSILE PROPERTIES OF BAR, GIVEN SIMULATED CARBURIZING CYCLE (1)

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

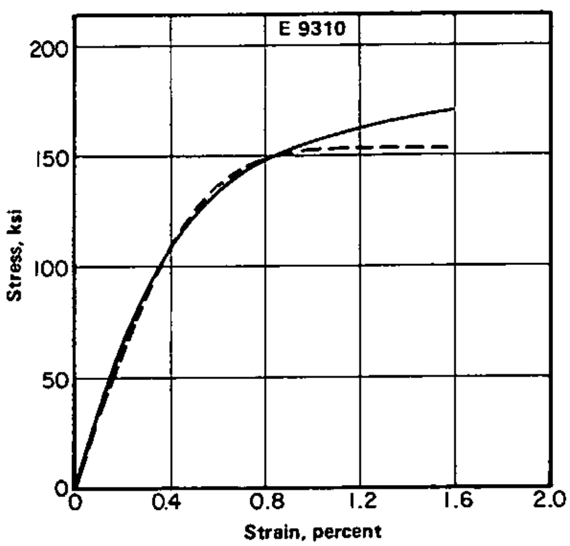


FIGURE 3.0214. CYCLIC AND MONOTONIC STRESS-STRAIN CURVES IN TENSION (18)

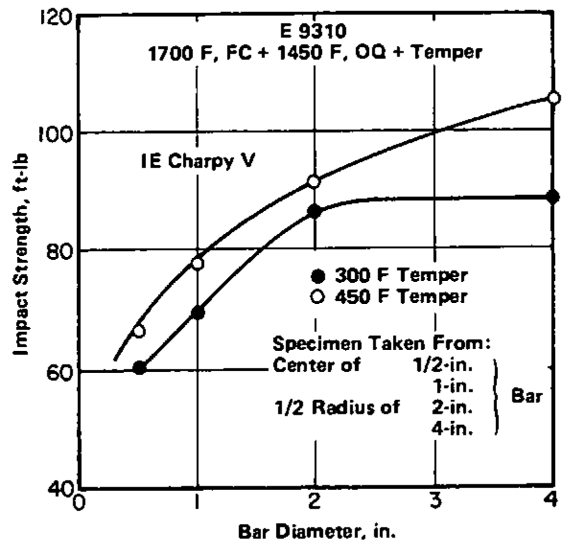


FIGURE 3.0231. EFFECT OF BAR DIAMETER AND TEMPERING TEMPERATURE ON ROOM TEMPERATURE IMPACT STRENGTH OF BAR, GIVEN SIMULATED CARBURIZING CYCLE (1)

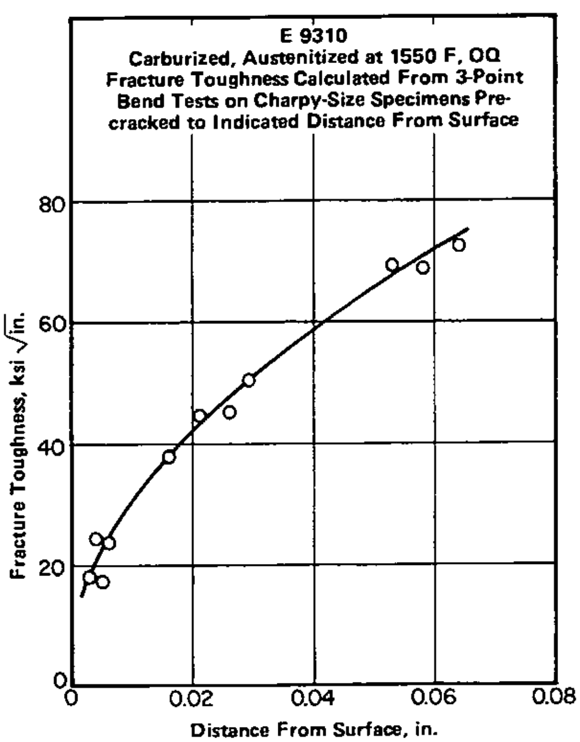


FIGURE 3.02721. FRACTURE TOUGHNESS GRADIENT IN CARBURIZED CASE (19)

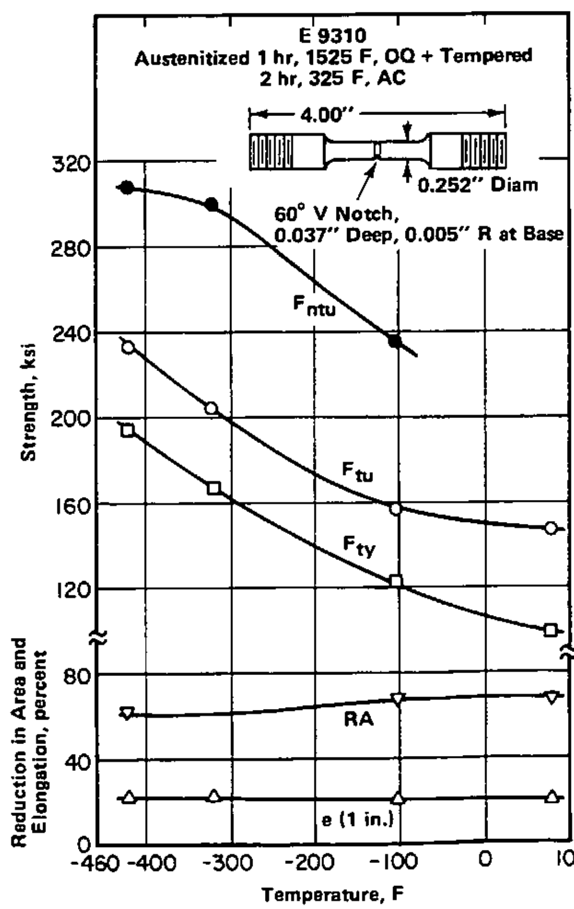


FIGURE 3.03712. SMOOTH AND NOTCHED TENSILE PROPERTIES AT LOW TEMPERATURES (8)

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

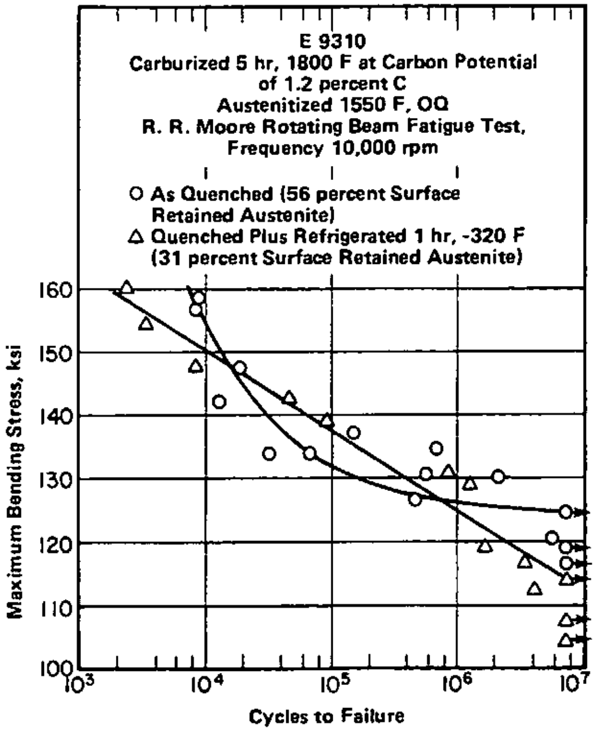


FIGURE 3.052. ROTATING BEAM FATIGUE LIFE AT ROOM TEMPERATURE FOR CARBURIZED AND QUENCHED E 9310 (12)

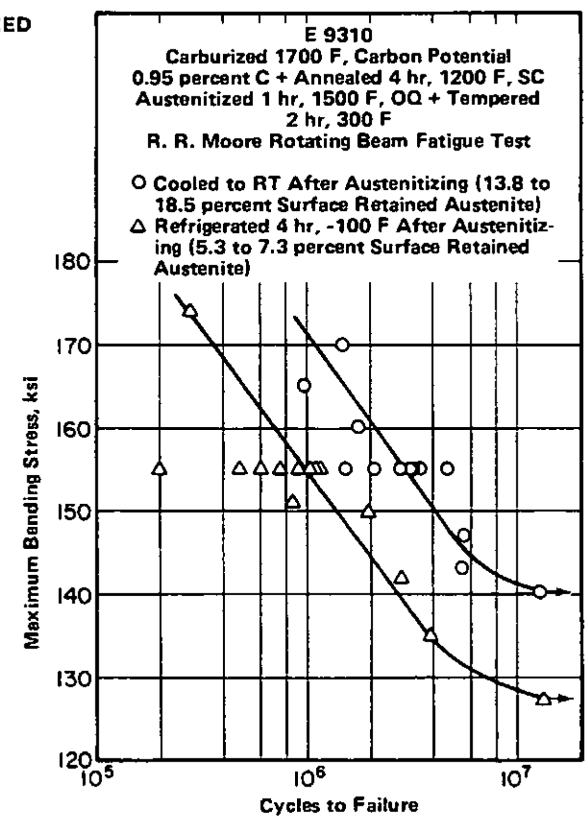


FIGURE 3.053. ROTATING BEAM FATIGUE LIFE AT ROOM TEMPERATURE FOR CARBURIZED AND TEMPERED E 9310 (20)

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310

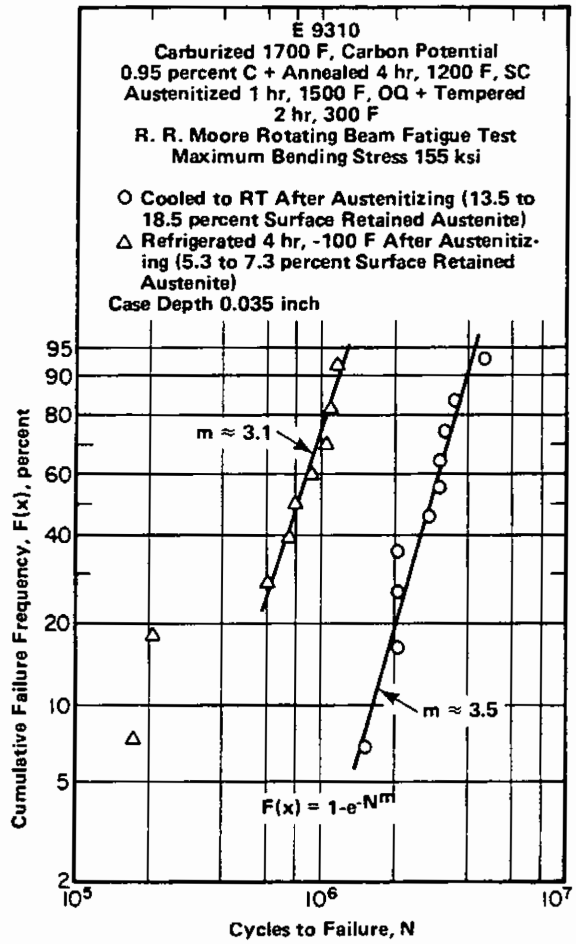


FIGURE 3.054. WEIBULL DISTRIBUTION OF ROTATING BEAM FATIGUE LIFE AT ROOM TEMPERATURE FOR CARBURIZED E 9310 WITH TWO LEVELS OF RETAINED AUSTENITE (20)

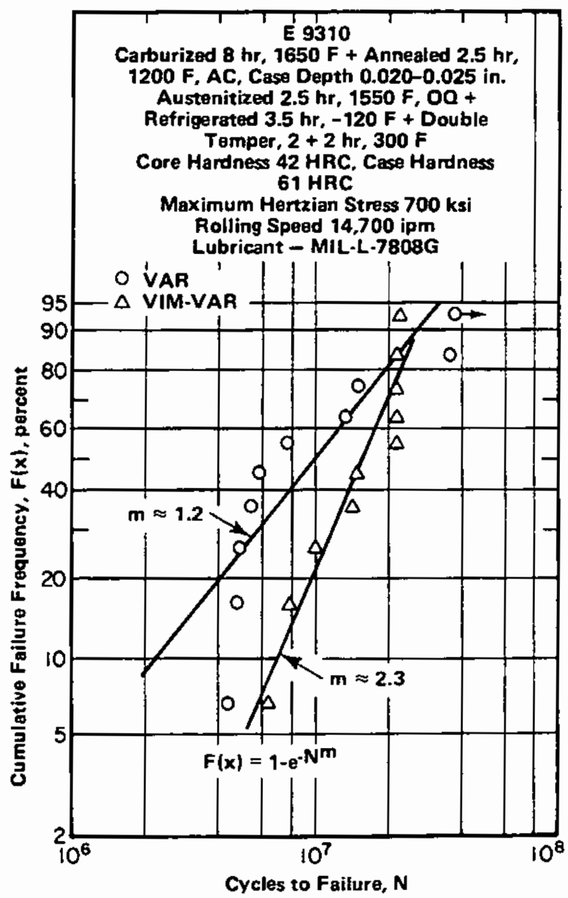
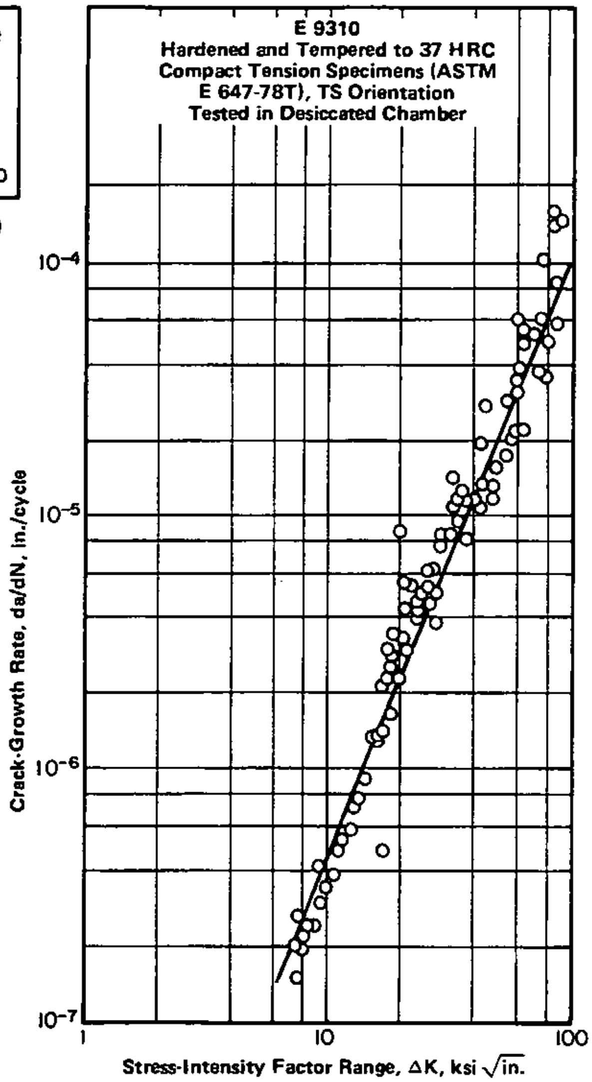


FIGURE 3.056. WEIBULL DISTRIBUTION OF ROLLING CONTACT FATIGUE LIFE AT ROOM TEMPERATURE FOR SINGLE (VAR) AND DOUBLE (VIM-VAR) VACUUM MELTED MATERIAL (10)

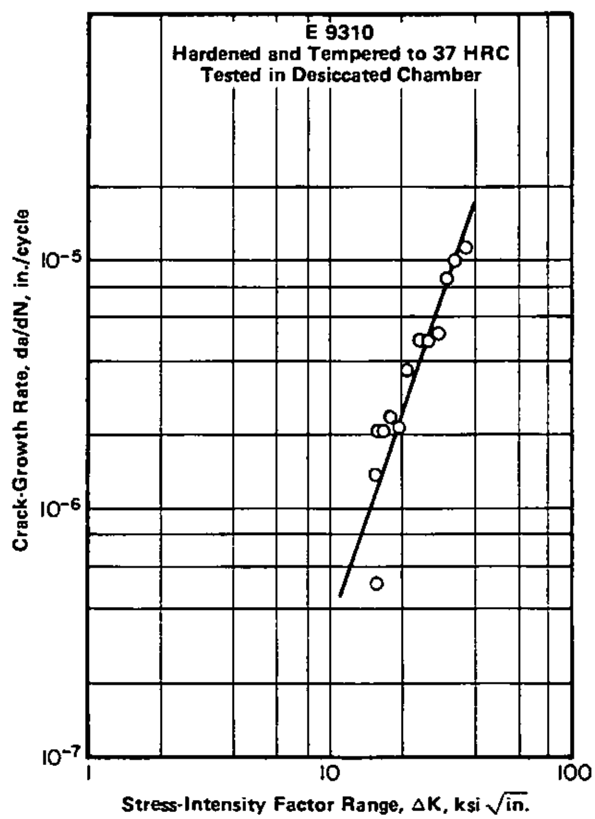
	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310



(a) Noncarburized, f = 204 cpm, R = 0.05, dry air.

FIGURE 0.058. FATIGUE CRACK-GROWTH BEHAVIOR AT ROOM TEMPERATURE (13)

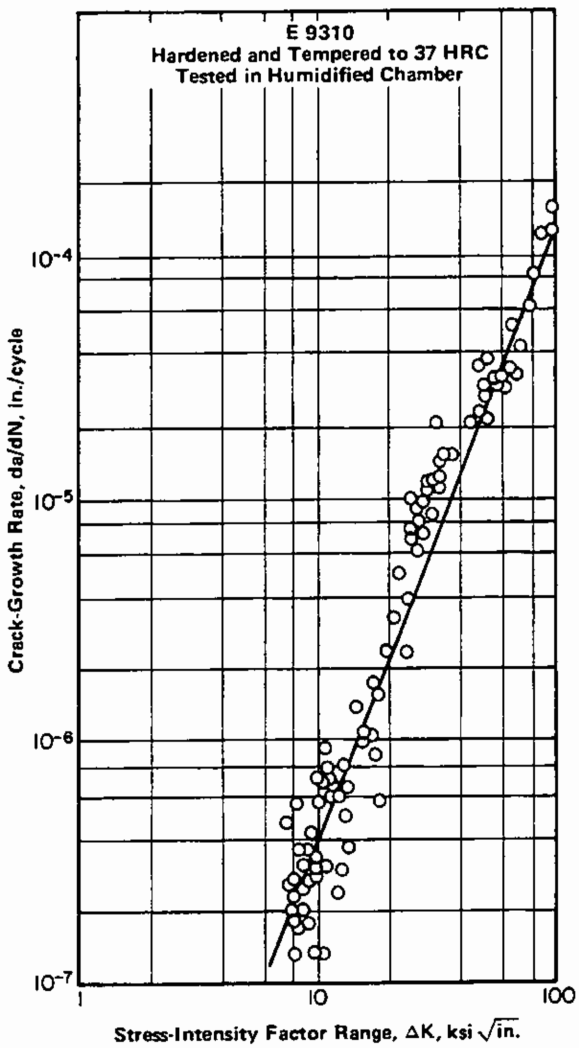


(b) Noncarburized, f = 204 cpm, R = 0.50, dry air.

FIGURE 3.058. FATIGUE CRACK-GROWTH BEHAVIOR AT ROOM TEMPERATURE (13)

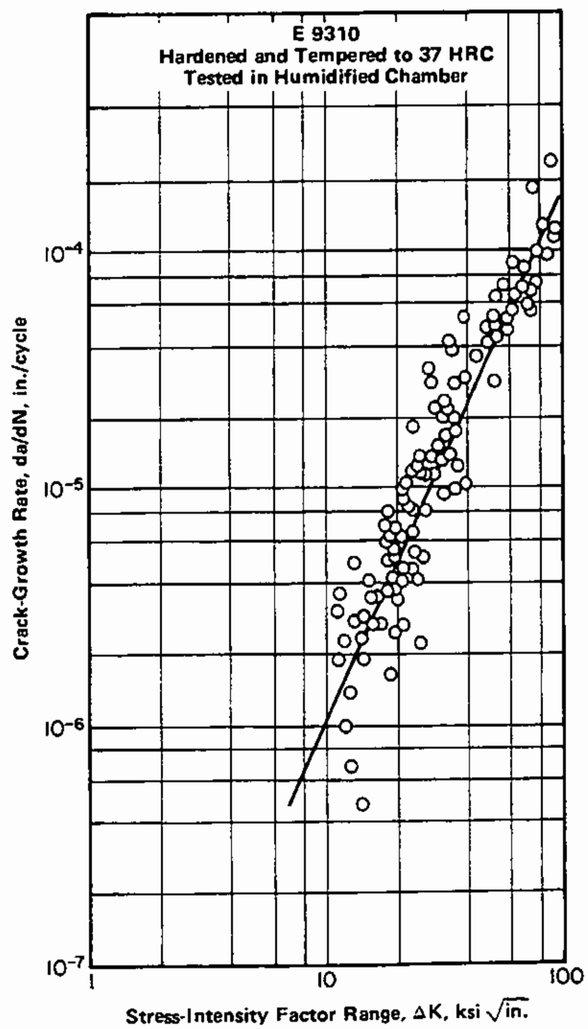
	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310



(c) Noncarburized, f = 60 cpm, R = 0.05, wet air.

FIGURE 3.058. FATIGUE CRACK-GROWTH BEHAVIOR AT ROOM TEMPERATURE (13)

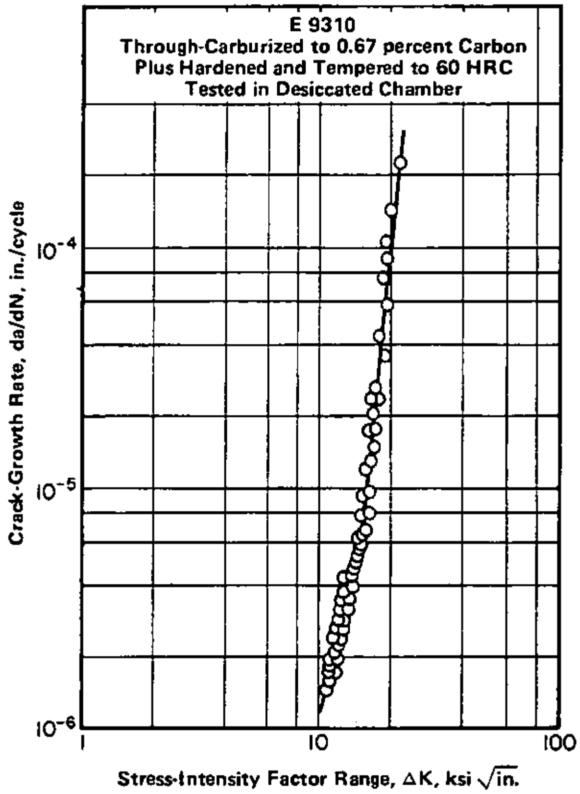


(d) Noncarburized, f = 6 cpm, R = 0.05, wet air.

FIGURE 3.058. FATIGUE CRACK-GROWTH BEHAVIOR AT ROOM TEMPERATURE (13)

	Fe
0.1	C
3.25	Ni
1.2	Cr
0.1	Mo

E 9310



(e) Carburized, f = 204 cpm, R = 0.05, dry air.

FIGURE 3.058. FATIGUE CRACK-GROWTH BEHAVIOR AT ROOM TEMPERATURE (13)

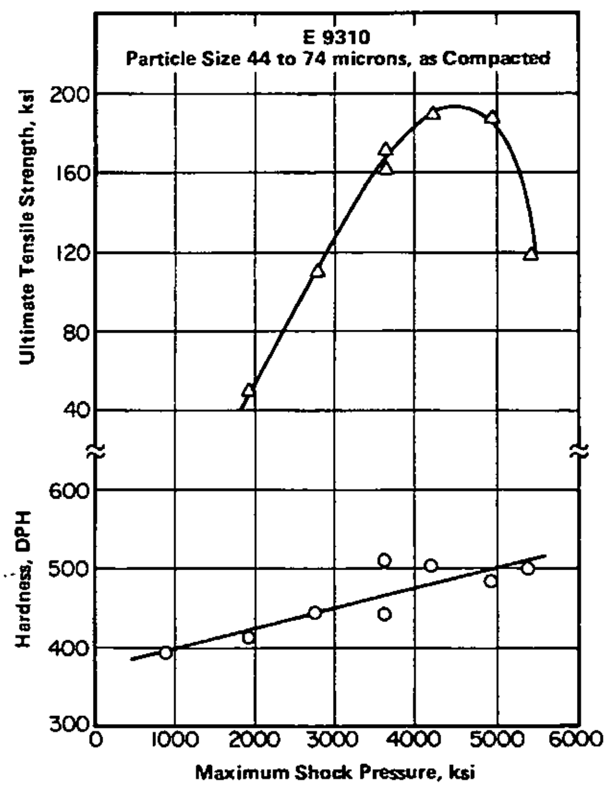


FIGURE 4.0122. HARDNESS AND STRENGTH OF SHOCK COMPACTED RAPIDLY SOLIDIFIED E 9310 POWDER (14)