	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

1 **GENERAL**
The composition of this steel, in particular the aluminum and chromium contents, is optimized for maximum case hardening by nitriding. The steel can also be strengthened by standard quench and temper procedures, allowing the production of parts with a high strength core and a hardened surface. Applications for nitrided Nitralloy 135 modified steel are widespread and its behavior has been characterized through many years of commercial use. Specific applications include weapons components, roller shafts, crankshafts, and transmission spur gears. Parts are normally final machined and heat treated before nitriding, which results in minimal dimensional change. The nitrided surface provides improved fatigue resistance, wear resistance, corrosion resistance, and resistance to softening at temperatures to 1200 F (1–4, 8–10).

1.01 **Commercial Designation**
Nitralloy 135 modified.

1.02 **Alternate Designations**
Nitralloy Type G modified, AMS 6470 Nitriding Steel, SAE 7140, UNS K24065.

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

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

1.05 **Heat Treatment**
1.051 Anneal, 1450 F, 6 hours, furnace cool (3).
1.052 Normalize, slowly heat to 1790 to 1810 F, air cool (3, 4).
1.053 Austenitize, 1700 to 1750 F (3).
1.054 Quench, less than 2 inch diameter or thickness, oil quench. Larger than 2 inch diameter or thickness, water quench (3).
1.055 Temper, 1000 to 1300 F, 1 hour minimum per inch of thickness. Temper 50 F minimum above nitriding temperatures (2).
1.056 Nitriding, 930 to 1050 F (1–3).

1.06 **Hardness**
1.061 End quench hardenability, Figure 1.061.
1.0611 AMS 6470 E specifies J50 = 8 and J45 = 12 minimum. AMS 6471B specifies J50 = 12 and J46 = 16 minimum.
1.062 Effect of tempering temperature on hardness of bar, Figure 1.062.
1.063 Hot hardness of nitrided alloy, Figure 1.063.

1.07 **Forms and Conditions Available**
1.071 This steel is available in most wrought forms such as rods, bars, plates, tubing, and forgings (1).

1.08 **Melting and Casting Practice**

1.09 **Special Considerations**
1.091 Part surfaces must be thoroughly cleaned before nitriding.
1.092 White layer is hard, brittle, and tends to crack. If greater than 0.0005 inch thick after nitriding, it should be removed to prevent flaking and surface roughening.

2 **PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS**

2.01 **Thermal Properties**
2.011 Melting range.
2.012 Phase changes. Critical temperature, A_{cl} = 1435 F (3).
2.0121 Time-temperature-transformation diagrams.
2.013 Thermal conductivity, 30.0 Btu ft/hr ft^2 F at 212 F (1).
2.014 Thermal expansion, Figure 2.014.
2.015 Specific heat, 0.11 to 0.12 Btu/lb F (1).
2.016 Thermal diffusivity.

2.02 **Other Physical Properties**
2.021 Density, 0.283 lb/in.^{3}. 7.83 gr/cm^3 (1).
2.022 Electrical properties.
2.0221 Electrical resistivity, 10.6 to 11.4 microhm-in. (1).
2.023 Magnetic properties. Steel is ferromagnetic.
2.024 Emittance.
2.025 Damping capacity.

2.03 **Chemical Environments**
2.031 The presence of the outer skin or white layer of the nitrided alloy increases its corrosion resistance compared with conventionally heat treated low alloy steels. However, the case is corroded by mineral acids (1, 2).

2.04 **Nuclear Environments**

3 **MECHANICAL PROPERTIES**

3.01 **Specified Mechanical Properties**
3.011 AMS specified mechanical properties, Table 3.011.
3.012 Typical producer's specified properties, Table 3.012.

3.02 **Mechanical Properties at Room Temperature**
3.021 Tension – stress-strain diagrams – tension properties.
3.0211 Effect of tempering temperature on room temperature tensile properties of bar, Figure 3.0211.
3.0212 Effect of tempering temperature on room temperature tensile properties of as-tempered and nitrided alloy, Figure 3.0212.
3.022 Compression – stress-strain diagrams – compression properties.
3.023 Impact.
3.0231 Effect of tempering temperature on room temperature impact properties of as-tempered and nitrided alloy, 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.
3.028 Combined properties.

	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

3.03 **Mechanical Properties at Various Temperatures**

3.031 Tension – stress-strain diagrams – tension properties.

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 Nitrided Nitralloy tested at 1000 F at 10 ksi stress creeps 0.2 percent in 4000 hour with no further extension during an additional 5000 hour (2).

3.05 **Fatigue Properties**

3.051 Endurance limits of as tempered and nitrided steel, Table 3.051.

3.052 Fatigue behavior at room temperature, Figure 3.052.

3.06 **Elastic Properties**

3.061 Poisson's ratio.

3.062 Modulus of elasticity.

3.0621 Modulus of elasticity in tension at room temperature 29-30 x 10^3 ksi (1).

3.063 Modulus of rigidity.

3.064 Tangent modulus.

3.065 Secant modulus.

4 **FABRICATION**

4.01 **Forming**

4.011 Forging, starting temperature 1950 to 2200 F, finishing temperature 1650 F, minimum (3).

4.02 **Machining and Grinding**

4.021 Rough machining prior to heat treatment is recommended particularly for large parts. If large amounts of stock must be removed, normalizing or annealing should precede machining. Residual stresses should be avoided as these may cause warping during nitriding. For this reason heat treated material must be machined with light cuts and be stress relieved after machining at a temperature not less than 100 F above the nitriding temperature. In any case sufficient material must be removed to eliminate any decarburized surface (2, 7).

4.03 **Joining**

4.031 The major problem is to avoid loss in chromium and aluminum in the weld area which would prevent subsequent nitriding. The most successful method employs 2.5 percent Cr, medium carbon rods with the atomic hydrogen process. If the weld area does not require nitriding, conventional welding methods may be employed. Welded parts should be heat treated before any machining (1, 2).

4.04 **Surface Treating**

4.041 Nitriding.

4.0411 Three nitriding processes are of commercial importance. These are conventional single-stage nitriding, two-stage Floe process nitriding, and ion nitriding. The first two processes employ anhydrous ammonia as the nitrogen source. At the nitriding temperatures of 975 F for single-stage nitriding and 975 to 1050 F for two-stage nitriding, the ammonia dissociates into atomic nitrogen and hydrogen, which react at the hot surface being nitrided. Ion nitriding has become industrially important more recently. In this process, the work piece is heated by arc discharge in a low pressure (about 0.15 psi) atmosphere of $80N_2$–$20H_2$. The current density is adjusted to maintain a work piece temperature of 975 to 1050 F. Processing times vary with the case thickness desired but generally range from 20 to 80 hours (2, 3, 9). Typical hardness-depth curves for single stage nitriding at 975 F are shown in Figure 4.0412, while case depths for various treatment times using the Floe process are given in Table 4.0413.

4.0412 Depth-hardness for several nitriding times, Figure 4.0412.

4.0413 Case depth using the Floe process on Nitralloy 135 modified, Table 4.0413.

4.0414 The mechanism of nitriding involves the initial formation of a layer of Fe_4N (white layer) at the work surface. This layer provides a constant surface concentration of nitrogen. As nitriding proceeds, nitrogen diffuses into the alloy, forming a nitrogen solution with the matrix and nitride precipitates with strong nitride-forming alloying elements such as chromium and aluminum. The thickness of the white layer and of the nitride case increase parabolically with time, as shown in Figure 4.0415, reflecting the diffusion-controlled nature of the reaction. Aluminum in Nitralloy 135 modified is nitrided easily and provides a sharp front to the nitrided case layer. The chromium-nitrogen reaction is weaker and stable precipitate nuclei do not form until relatively large supersaturations are achieved (10).

4.0415 Diffusion case and white layer thickness as a function of ion nitriding time at 970 F, Figure 4.0415.

4.0416 The ion nitriding process possesses several advantages over the single-stage and two-stage (Floe) nitriding processes. These advantages include (1) shorter processing time to achieve the same case thickness, and (2) thinner residual white layer on the surface. Case thicknesses for various treatment times are shown for the three processes in Figure 4.0417 and illustrate the shorter processing time for ion nitriding. This shorter processing time is attributed to cleaning of the work piece by sputtering, which removes adsorbed gases and films which might inhibit nitriding. The rapid cleaning during ion nitriding allows earlier formation of the Fe_4N surface layer than occurs with conventional ammonia nitriding. Although the white layer forms earlier during ion nitriding, it remains thinner because of sputtering. The thinner white layer is advantageous because white layer is normally considered detrimental and must be removed by mechanical or chemical means if greater than about 0.0005 inch in thickness (9).

4.0417 Case thickness as a function of treatment time for ion nitrided, conventional nitrided, and Floe process nitrided alloy, Figure 4.0417.

4.0418 Parts to be nitrided must be cleaned of surface contaminants such as oil, grease, machining lubricants, oxides, copper, lead, and so forth. Vapor degreasing will remove organic compounds, but the remaining contaminants must be removed by buffing, glass shot blasting, or chemical stripping. Mechanical masking is the preferred method of preventing ion nitriding of selected areas. The mechanical mask is fabricated from low carbon steel and fits the workpiece with a clearance of 0.010 to 0.025 inch. Copper or nickel electroplates are unacceptable for masking during ion nitriding because of sputtering and redeposition elsewhere (copper) or diffusional contamination of the substrate (nickel) (9). During conventional nitriding with ammonia, areas of parts that do not require nitriding may be protected by tin, bronze or copper plating (2).

4.0419 Size increase due to nitriding is approximately 0.001 to 0.002 inch depending on the time and temperature of nitriding. Dimensions may be restored by careful grinding or lapping (3).

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	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

Nitralloy 135 Modified	
AMS Specification	Product Form
6470H	Bars, Forgings, Tubing
6471B	Bars, Forgings, Tubing
6472B	Bars, Forgings

TABLE 1.031. SPECIFICATIONS (4, 6, 7)

Nitralloy 135 Modified				
AMS Specifications	6470H, 6472B		6471B	
	Percent		Percent	
Element	Min	Max	Min	Max
Carbon	0.38	0.43	0.38	0.43
Chromium	1.40	1.80	1.40	1.80
Aluminum	0.95	1.30	0.95	1.30
Manganese	0.50	0.80	0.50	0.80
Molybdenum	0.30	0.40	0.30	0.40
Silicon	0.20	0.40	0.15	0.40
Copper	–	0.35	–	0.35
Nickel	–	0.25	–	0.25
Phosphorus	–	0.025	–	0.015
Sulfur	–	0.025	–	0.015

TABLE 1.041. COMPOSITION (4, 6, 7)

	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

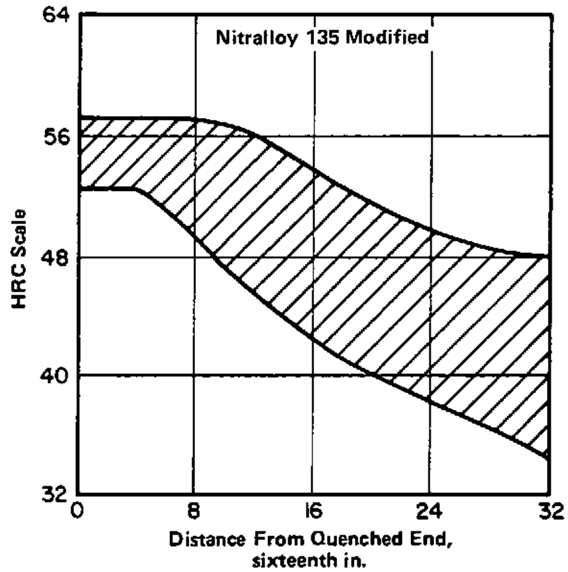

FIGURE 1.061. END QUENCH HARDENABILITY (2)

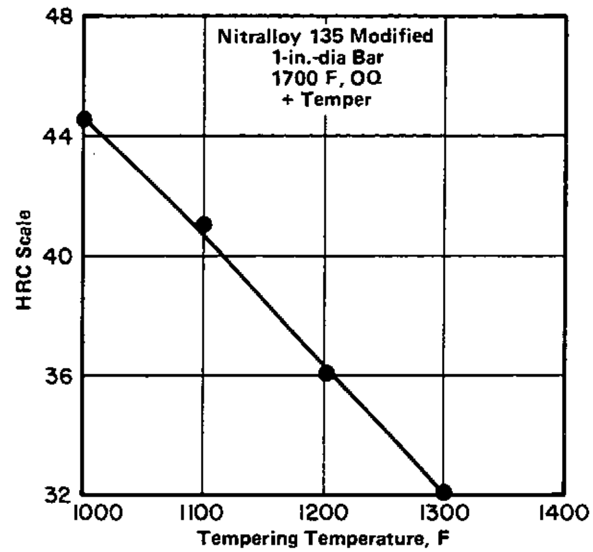

FIGURE 1.062. EFFECT OF TEMPERING TEMPERATURE ON HARDNESS OF BAR (1)

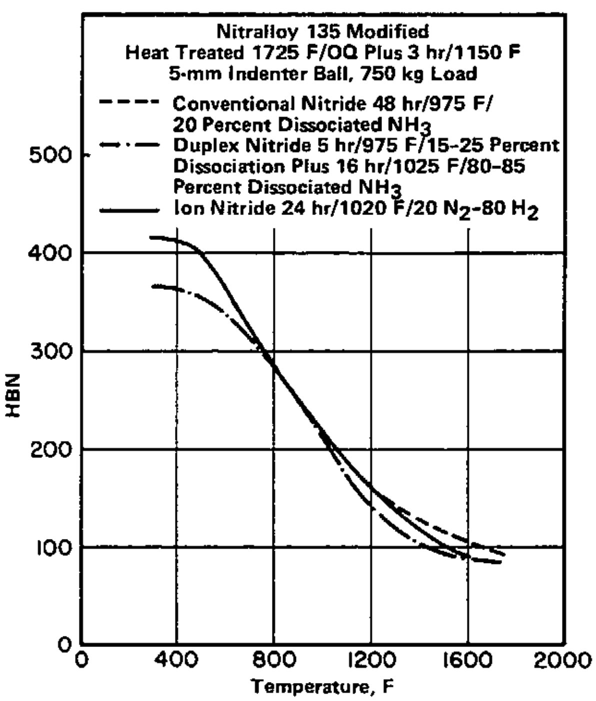

FIGURE 1.063. HOT HARDNESS OF NITRIDED ALLOY (11)

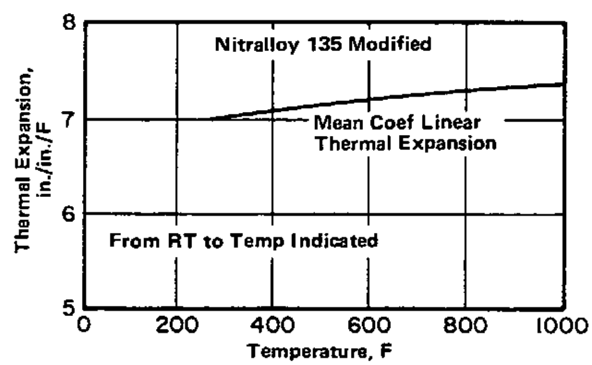

FIGURE 2.014. THERMAL EXPANSION (3)

	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

Nitralloy 135 Modified										
AMS Spec	Product Form	Condition	Thickness, in.	F_{tu}, ksi Min	F_{tu}, ksi Max	F_{ty}, ksi, Min	Elongation, %, Min	RA, pct, Min	Hardness Min	Hardness Max
6470H,	Bar	Cold Finished	≤0.500	–	135	–	–	–	–	–
6471B	Bar	Cold Finished	>0.500	–	–	–	–	–	–	269 HB
	Bar	Hot Finished	>0.500	–	–	–	–	–	–	229 HB
	Tubing	Cold Finished	–	–	–	–	–	–	–	25 HRC
	Tubing	Hot Finished Plus Annealed	–	–	–	–	–	–	–	99 HRB
6472B	Bars, Forgings	Quenched, Tempered(a)	–	112	–	90	16	50	–	–
	Bars, Forgings	Quenched, Tempered(a)	≤3.125	–	–	–	–	–	241 HB	285 HB
	Bars, Forgings	Quenched, Tempered(a)	>3.125; ≤6.000	–	–	–	–	–	229 HB	285 HB

Note: The original AMS documents should be consulted for complete specification details.
(a) Quenched from 1700 F and hardened to meet tensile property requirements of AMS 6472B.

TABLE 3.011. AMS SPECIFIED MECHANICAL PROPERTIES (4, 6, 7)

Alloy	Nitralloy 135 Modified		
Form	Bar(a)		
Condition	1725 F, OQ < 3 in WQ > 3 in Temper 1200 F (Min) 5 hr		
Size, dia	<1-1/2	>1-1/2 to 3	>3 to 5
F_{tu}, Min, ksi	135	125	110
F_{ty}, Min, ksi	100	90	85
e (2 in.) Min, percent	16	15	15
RA, Min, percent	50	40	40
BHN			
Min	280	269	240
Max	340	321	300

(a) Specimen taken at 1/2 radius.

TABLE 3.012. TYPICAL PRODUCER'S SPECIFIED PROPERTIES (2)

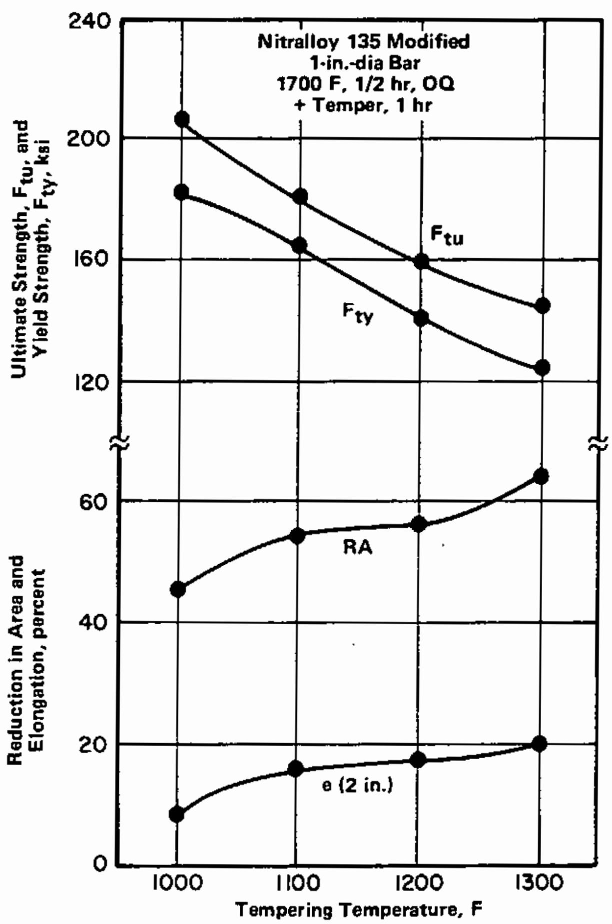

FIGURE 3.0211. EFFECT OF TEMPERING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF BAR (1, 2)

	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

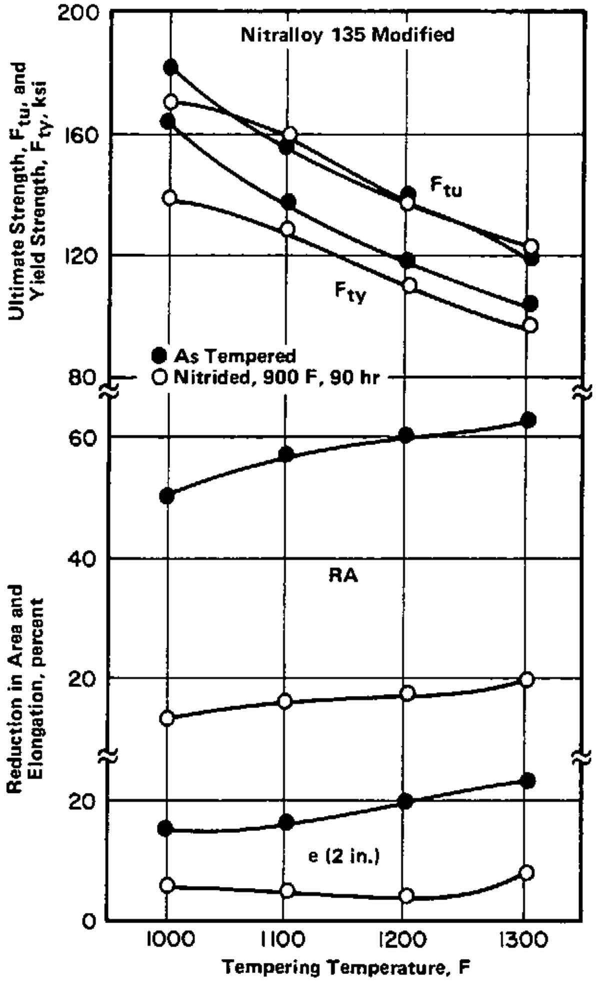

FIGURE 3.0212. EFFECT OF TEMPERING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF AS-TEMPERED AND NITRIDED ALLOY (1)

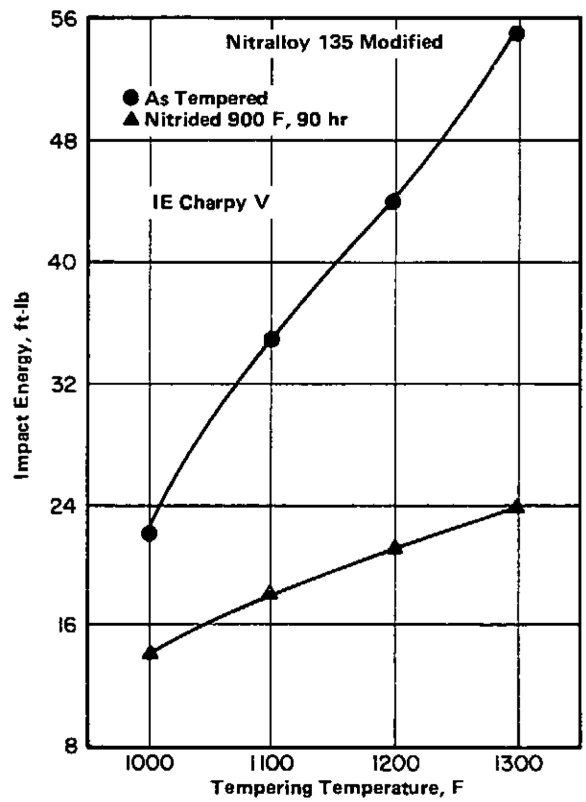

FIGURE 3.0231. EFFECT OF TEMPERING TEMPERATURE ON ROOM TEMPERATURE IMPACT PROPERTIES OF AS-TEMPERED AND NITRIDED ALLOY (1)

Alloy		Nitralloy 135 Modified	
Form		Bar	
Condition		HT and Nitrided 975 F, 40 hr	
		Endurance Limit, ksi	
Reverse Bending (Rayflex)		As Tempered to BHN 269	Nitrided
Smooth	K = 1.0	45	90
Notched	K = 3.3	24	80

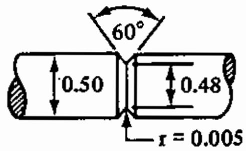

TABLE 3.051. ENDURANCE LIMITS OF AS-TEMPERED AND NITRIDED STEEL (2)

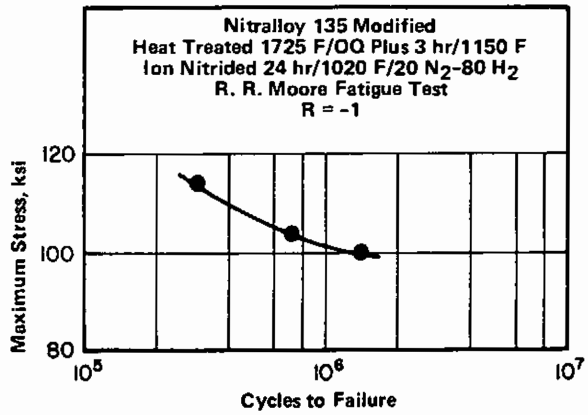

FIGURE 3.052. FATIGUE BEHAVIOR AT ROOM TEMPERATURE (11)

	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

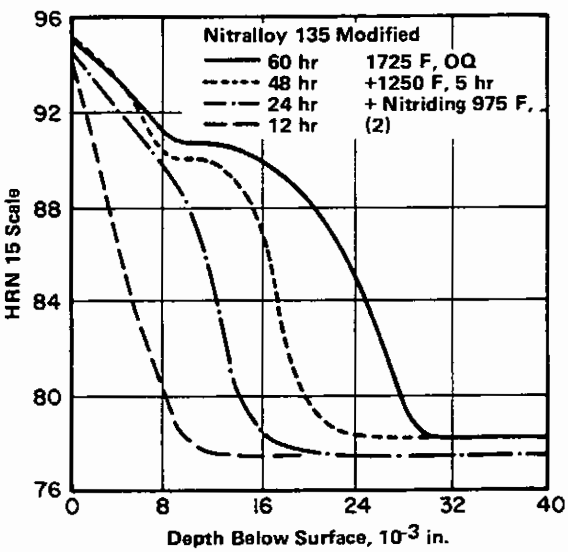

FIGURE 4.0412. DEPTH-HARDNESS FOR SEVERAL NITRIDING TIMES (2)

Alloy	Nitralloy 135 Modified	
Stage	First	Second
Temperature	975 F	1050 F
Percent Ammonia Dissociation	15–25	83–86
Case Depth, in.	Time, hr	Time, hr
0.005–0.008	5	0
0.008–0.012	5	5
0.011–0.015	5	20
0.013–0.018	6	26
0.017–0.022	8	42

TABLE 4.0413. CASE DEPTH USING THE FLOE PROCESS ON NITRALLOY 135 MODIFIED (2)

	Fe
0.4	C
1.6	Cr
1.1	Al
0.6	Mn
0.35	Mo

Nitralloy 135 Mod.

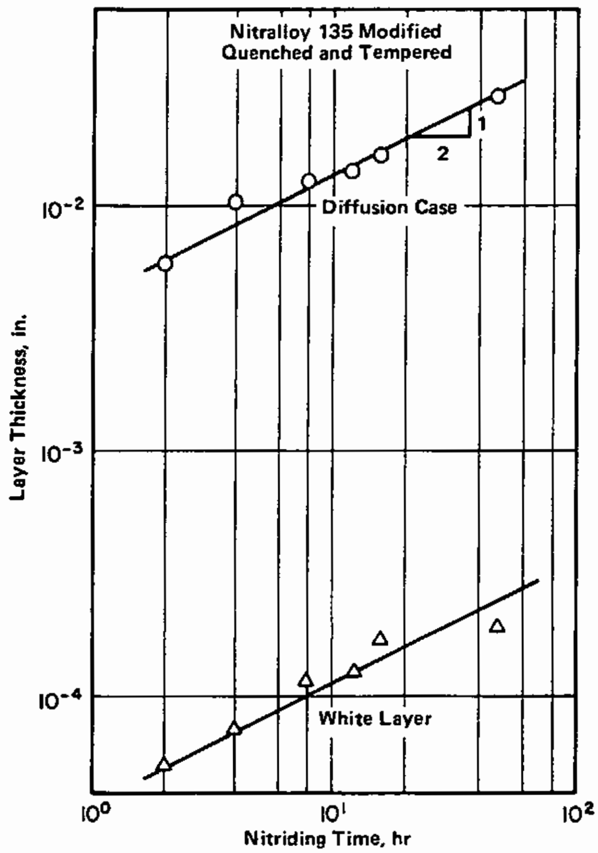

FIGURE 4.0415. DIFFUSION CASE AND WHITE LAYER THICKNESS AS A FUNCTION OF ION NITRIDING TIME AT 970 F (10)

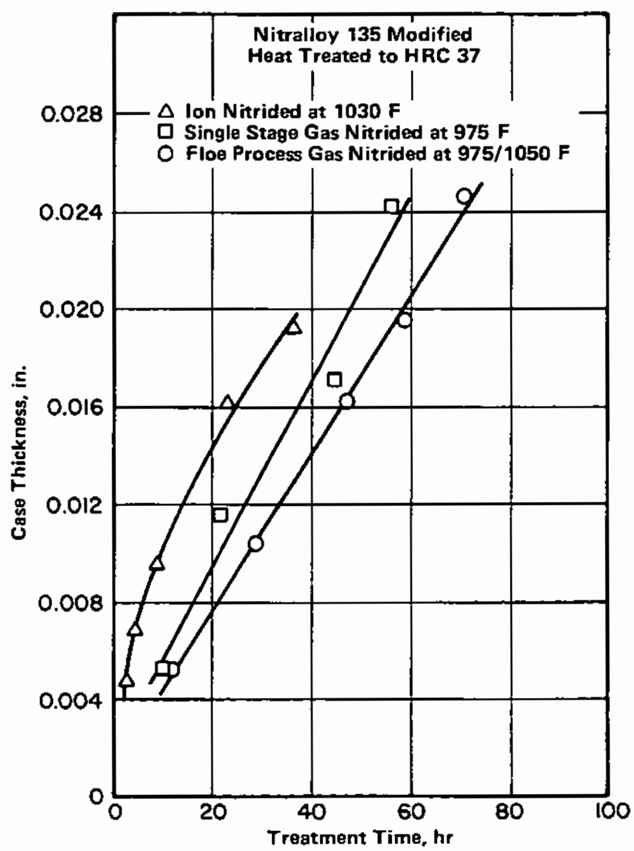

FIGURE 4.0417. CASE THICKNESS AS A FUNCTION OF TREATMENT TIME FOR ION NITRIDED, CONVENTIONAL NITRIDED, AND FLOE PROCESS NITRIDED ALLOY (9)