

1. General

17-4PH, a martensitic stainless steel, is produced in the form of wrought, cast, and powder-metal products. It offers a good combination of high strength, toughness, corrosion resistance, and weldability. In addition, it can be fabricated in the relatively soft solution-treated condition and then precipitation hardened to a wide range of mechanical properties by an aging treatment in the range of 900F to 1150F. Strengthening is achieved by martensitic transformation (when air-cooled from its solution temperature of 1900F) and subsequent aging at 900F to 1075F, which induces the precipitation of small coherent copper-rich particles. At higher aging temperatures overaging occurs by the precipitation of incoherent larger copper-rich particles resulting in lower strength and hardness. The alloy retains useful strength at temperatures up to about 900F; like other martensitic steels, it undergoes a ductile-brittle transition at subzero temperatures. Some typical applications are aircraft and missile fittings, fasteners, gears, jet engine parts, valve parts, turbine blades, pump shafts, chemical process equipment, nuclear reactor components, and paper mill equipment. (Refs. 2, 4, 22, 23, 73)

1.1 Commercial Designation

17-4PH

1.2 Alternate Designations

AISI Type 630, CB-7Cu-1 (ACI designation for castings), UNS S17400 (wrought), UNS J92200 (castings), UNS S17480 (welding wire), UNS W37410 (covered welding electrodes).

1.3 Specifications

1.3.1 [Table] AMS, ASTM, and MIL specifications.

1.4 Composition

1.4.1 [Table] AMS specified compositions.

1.5 Heat Treatment

1.5.1 For optimum properties, 17-4PH should be precipitation hardened, which requires a solution treatment at 1900F plus aging at a temperature in the range 900 to 1150F. Generally, maximum strength and hardness are obtained with a 900F aging treatment (identified as Condition H900), but ductility, toughness, machinability, and resistance to stress corrosion increase as strength and hardness decrease with increasing aging temperature up to a maximum of 1150F. Wrought products are usually supplied by the manufacturer in the solution-treated condition (Condition A), and precipitation hardened (aged) to the desired properties

by the fabricator or user. Exceptions to this practice can be made for material to be cold worked, which may be supplied in the overaged condition (H1150 or H1150-M) for ease of forming; for such products as well as for those that are hot worked, welded, or brazed, it is necessary to fully solution treat and age harden in order to obtain optimum properties in the final product. Although the solution-treated (Condition A) alloy has performed satisfactorily in a number of applications, precipitation hardening is recommended for critical applications because it provides optimum combinations of strength, toughness, and resistance to stress corrosion cracking. For castings, a homogenization treatment at 2100F and air cool to below 90F prior to the solution treatment can significantly benefit mechanical properties, particularly ductility and toughness, and can help to ensure compliance with minimum specification requirements. (Refs. 2-4, 49, 51, 52, 70)

1.5.1.1 [Table] Heat treatments for 17-4PH.

1.5.2 During the aging treatment a predictable dimensional change occurs, ranging from contractions of 0.0004-0.0006 in./in. for the H900 treatment to 0.0008-0.0010 in./in. for the H1150 treatment. (Refs. 20, 21, 23)

1.5.3 Electric furnaces or gas-fired radiant-tube furnaces are generally used for heat treating 17-4PH. Air has proved to be a satisfactory furnace atmosphere for solution treating and age hardening. Controlled reducing atmospheres such as dissociated ammonia or bright annealing gas introduce the hazard of nitriding and carburizing or decarburizing. Bright solution treating may be accomplished in hydrogen, argon, or helium atmosphere (dew-point approximately -65F), but these atmospheres, generally, are not useful at the aging temperatures because of the extremely low dew-point required. Heat treating in a vacuum can provide freedom from scale and heat discoloration. Solution treatment in molten salts is not recommended because of the danger of carburization and intergranular penetration. However, age hardening (900 to 1150F) has been successfully accomplished in a few of the hydride or nitrate salts. (Ref. 23)

1.5.4 Thorough cleaning prior to heat treatment facilitates scale removal and prevents carburization from surface contamination such as oils or other lubricants. The following procedure has proved to be effective: first, vapor degrease or solvent clean to remove oil, grease, and drawing lubricants; second, mechanically scrub with mild abrasive cleaners to remove dirt and other insoluble materials; finally, warm-water rinse to remove the remains of the cleaners. (Ref. 23)

	Fe
17.	Cr
4.0	Ni
4.0	Cu

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17-4PH

1.6 Hardness

(See also Table 1.7.3.1)

- 1.6.1 [Table] Hardness of wrought products and castings in various heat-treated conditions.
- 1.6.2 [Figure] Effects of long-time exposures at 700F and 900F on room-temperature hardness of bar in three heat-treated conditions.

1.7 Forms and Conditions Available

- 1.7.1 Wrought Products. The alloy is available in the form of sheet, strip, plate, billets, bars, wire, forgings, tube, and welding wires and electrodes. Wrought forms are normally supplied by the mills in the solution-treated condition (Condition A), ready for fabrication and subsequent hardening by the user. For other conditions, special arrangements may be made with the mills. (Refs. 49, 50, 55)
- 1.7.2 Castings. Available as sand castings, investment castings, and centrifugal castings, which can be supplied in Condition A or in one of the hardened or overaged conditions as specified by the user. (Ref. 51)
- 1.7.3 Powder-Metal Products. Powder-metal products of 17-4PH are produced by both the conventional press-and-sinter method and the more recently developed metal-injection-molding process. These processes are attractive for certain types of parts (normally relatively small and intricate), which can be made to final or nearly final shapes, thus eliminating or reducing scrap metal and secondary machining and assembly operations. On the other hand, they normally retain a certain amount of porosity, which results in somewhat lower density and mechanical properties than wrought and cast products. (See Table 1.7.3.1)

In the conventional process, suitable powder is mixed or blended along with a lubricant such as zinc stearate or stearic acid. The mixture is then compacted in a steel die under controlled pressure into the desired shape with sufficient "green" strength to avoid damage during ejection from the die and during normal handling between compacting and sintering. Prior to sintering, the lubricant is burned off at about 800-1000F, after which the compact is sintered in a protective atmosphere, normally at a temperature in the range of 2100 to 2300F. After the sintering operation, the desired heat treatment is applied. The mechanical properties of the product tend to increase with increasing sintered (final) density; the density increases with increasing compacting pressure and increasing sintering temperature. (Refs. 56, 57, 59)

With injection molding much finer powders are used; particle size is about 10 microns rather than 100 microns as in the conventional process. Large quantities of thermoplastic binders are used to permit injection molding into dies by means of conventional plastic molding equipment, which molds the feedstock mate-

rial into the desired shape. Before sintering, the binder is removed by one of two methods: one consists of two stages in which the part is first processed in a solvent extraction unit, which removes a portion of the binder; subsequently, the remainder of the binder is burned out in an oven; the second method employs an evaporative technique in which the binder is designed to provide reasonable rheology and stability in molding yet can be rapidly evaporated from the green body under proper thermal conditions. Sintering is carried out at temperatures and controlled atmospheres similar to those used for conventional powder-metal parts, after which the desired heat treatment is applied. Injection molding permits production of denser, stronger, more uniform, and more complex powder-metal parts than conventional press and sinter. (Refs. 54, 58)

In both powder-metal processes, the parts shrink in proportion to the increase in density that occurs during sintering. The molds are sized to compensate for this shrinkage. If necessary and practical, the density and mechanical properties of powder-metal parts, in general, can be increased by a hot isostatic pressure (HIP) treatment applied to the as-sintered parts, that is prior to heat treatment. (See Fig. 3.5.1.9) (Refs. 58, 60)

- 1.7.3.1 [Table] Comparison of properties of wrought, cast, and powder-metal (P/M) products.

1.8 Melting and Casting Practice

Although 17-4PH is generally air-melted in electric-arc furnaces, consumable-electrode vacuum arc remelted (VAC CE) material is also available for aerospace and other applications requiring optimum mechanical properties. Induction melting in air or vacuum is also used, primarily in the production of castings. (Ref. 21)

1.9 Special Considerations

- 1.9.1 In common with most high-strength steels, the ductility of wrought products in the transverse and short-transverse orientations is significantly inferior to that in the longitudinal orientation, the differences being more pronounced in conjunction with the lower aging temperatures. (See Table 3.1.1 and 3.2.1.8) (Refs. 23, 35)
- 1.9.2 The transverse orientation of bar and the short-transverse orientation of plate are lower in fatigue strength than the longitudinal orientation. (Ref. 24)
- 1.9.3 In all age-hardened conditions, long-time exposure at temperatures of 700 to 900F cause sharp decreases in room-temperature impact strength. (See Table 3.2.3.2) (Ref. 23)
- 1.9.4 Material in the solution-treated condition (Condition A) is generally not recommended for critical applications since the microstructure consists of untempered martensite, which is relatively low in ductility and in resistance to stress corrosion and hydrogen embrittle-

ment. Heat treating to any of the age-hardened conditions (H conditions) has a dual effect: the martensite is tempered at the same time that precipitation hardening occurs. Thus, the combination of strength, ductility, toughness, hardness, and resistance to stress corrosion and hydrogen embrittlement is improved. (Refs. 24, 55)

- 1.9.5 Whereas the mechanical properties of the cast and powder-metal products are generally inferior to wrought material, they can be improved by hot isostatic pressing. (See Figures 3.5.1.7 and 3.5.1.9) (Refs. 60, 61)
- 1.9.6 17-4PH is susceptible to hydrogen embrittlement by galvanically introduced hydrogen or by exposure to pressurized hydrogen gas. (See Section 2.3.3)
- 1.9.7 Close control of temperature is important in solution treatment. Below 1900F, copper (the hardening element) is not completely dissolved, which results in less-than-optimum strength after the age-hardening treatment. Solution treatment at temperatures appreciably above 1900F causes excessive grain growth, resulting in deficiencies in ductility and toughness in the aged condition. (Ref. 23)
- 1.9.8 The AMS specifications on castings require that "castings shall not be peened, plugged, welded, or repaired by other methods without written permission from purchaser." (Refs. 27-31)

2. Physical Properties and Environmental Effects

2.1 Thermal Properties

- 2.1.1 Melting Range, 2550 to 2625F. (Ref. 5)
- 2.1.2 Phase Changes.
- 2.1.2.1 Time-temperature-transformation diagrams
- 2.1.2.2 When 17-4PH is heated, the martensite microstructure, which is stable at low temperatures, begins to transform to austenite at about 1160F and transformation is complete at 1300F. With further increases in temperatures, the copper dispersed in the matrix goes into solution in the austenite, the solution becoming complete at 1900F. Upon cooling from 1900F, transformation from austenite to martensite starts at approximately 270F and is complete when 90F is reached. This martensite is supersaturated with copper. Aging at 900F to about 1075F precipitates an extremely fine coherent copper-rich phase within the martensite resulting in excellent combinations of strength and toughness. At 1100F to 1160F overaging occurs, which is characterized by the precipitation of larger incoherent copper-rich particles and decreased strength and hardness but increased ductility. (Refs. 18, 23, 73)

2.1.3 Thermal Conductivity.

2.1.3.1 [Figure] Thermal conductivity from 200F to 2500F.

2.1.4 Thermal Expansion.

2.1.4.1 [Figure] Thermal expansion from -100F to 900F.

2.1.5 Specific Heat. 0.11 Btu per (lb-F) from 32F to 212F. (Refs. 21, 49, 51)

2.1.6 Thermal Diffusivity.

2.2 Other Physical Properties

2.2.1 Density.

2.2.1.1 [Table] Density in various heat-treated conditions.

2.2.2 Electrical Properties.

2.2.2.1 [Table] Electrical properties of sheet and bar in various heat-treated conditions.

2.2.3 Magnetic Properties. The alloy is magnetic.

2.2.3.1 [Table] Magnetic permeability in various heat-treated conditions.

2.2.4 Emittance.

2.2.5 Damping Capacity.

2.3 Chemical Environments

2.3.1 General Corrosion. In rural and mild industrial atmospheres, 17-4PH in all heat-treated conditions has excellent resistance to general corrosion, equivalent to Type 304 stainless steel. When exposed to seacoast atmospheres it gradually develops over-all light rusting and pitting, its resistance under such conditions being slightly inferior to Type 304 but much better than the standard hardenable (martensitic) stainless steels. It is well suited for many dynamic marine applications such as valve parts and pump and propeller shafting. However, like other stainless steels, 17-4PH is subject to crevice attack in stagnant seawater; if equipment exposed to seawater is not operated continuously, cathodic protection is desirable to prevent such attack. (Refs. 6, 36, 37, 47, 49)

Welds are subject to heat-affected-zone corrosion unless a postweld full solution and aging treatment is carried out. (Ref. 36)

In pressurized water at temperatures from 500 to 600F, 17-4PH corrodes at a rate comparable to other martensitic and ferritic stainless steels, which is about five times faster than austenitic stainless steels but only one tenth as fast as low-carbon and low-alloy steels. (Ref. 10)

In aerospace application, Type 17-4PH has been used for tanks, thrust chambers, fins, fuel-line elements, control shafts, and other components exposed to various fuels and oxidizers. These include oxygen, hydro-

17-4PH

gen, nitrogen tetroxide, red fuming nitric acid, anhydrous ammonia, hydrogen peroxide, hydrazine, and unsymmetrical dimethyl hydrazine (UDMH). Except for long-time containment of hydrogen peroxide, the alloy is suitable for storage as well as short-time usage in conjunction with these substances. (Ref. 23)

Whereas the overall corrosion resistance of 17-4PH and Type 304 stainless steels are generally considered to be comparable, their resistances to certain specific chemical media can vary significantly depending upon concentration and temperature.

2.3.1.1 [Table] Comparison of typical corrosion rates for Types 17-4PH and 304 stainless steels in several chemical media.

2.3.2 Stress Corrosion. In salt-water and marine environments, 17-4PH in Condition H900 is susceptible to stress corrosion cracking; but when hardened at temperatures of 1025F and above, the alloy is much more resistant. For maximum resistance to chloride stress corrosion cracking, 17-4PH should be hardened at the highest aging temperature that will yield required properties, but not less than 1025F. (Refs. 2, 23, 38, 40-42, 49)

2.3.2.1 [Table] Effects of heat-treat condition and applied stress on time to stress corrosion failure of bent-beam strip specimens exposed to marine environment at Kure Beach, NC.

2.3.2.2 [Table] Comparison of tensile properties for various heat-treated conditions with critical stress intensity levels for stress corrosion cracking in salt water.

In a study of the effects of welding, bent-beam specimens consisting of 17-4PH base and weld metals were stressed at 90 percent of F_{ly} and exposed to a marine atmosphere at Kure Beach, NC. The test samples were divided into three groups, each in Conditions H900, H1025, H1075, and H1150:

- a. Not welded (solution treated + aged)
- b. Solution treated + welded + aged
- c. Welded + solution treated + aged

All specimens in Condition H900 cracked due to stress corrosion in 68 days or less, regardless of whether welded or not. None of the others failed after more than 25 years in test. (Ref. 49) In addition, welded specimens were made by fusing 2-in.-diameter 17-4PH circular weld beads onto one face of 1/4-in.-thick plate. After welding and final heat treatment, the surfaces were ground to a smooth finish. The residual stresses caused by welding can approach or exceed the yield strength of the steel. These specimens were exposed to quiet sea water. The welding and heat-treat conditions were as follows:

- a. Solution treated + aged to Conditions H1025, H1075, H1150 + welded

- b. Welded + solution treated + aged to Conditions H1025, H1075, H1150

- c. Solution treated + welded + aged to Conditions H1025, H1075, H1100

Careful examination showed no evidence of stress corrosion cracking in any of the test specimens after one year in test. (Ref. 49)

Laboratory tests in synthetic sour well solution (5 percent sodium chloride + 0.5 percent acetic acid saturated with hydrogen sulfide) in accordance with NACE Test Method TM-01-77 show that for best resistance to this aggressive medium, 17-4PH should be either in Condition H1150-M or aged at 1150F for two four-hour periods. In either of these heat-treated conditions, it is considered acceptable for use in sour (sulfide) service. (Ref. 49)

2.3.3 Hydrogen Effects. Hydrogen embrittlement is a potential threat to 17-4PH, as well as to all other high-strength martensitic steels, wherever the reduction of hydrogen ions to atomic hydrogen may occur. Common examples are acid pickling, aqueous corrosion, electroplating, and galvanic coupling with less noble metals. Table 2.3.2.2 shows the deleterious effects of galvanic coupling with less noble metals on K_{Isc} in salt water. The adverse effect of the coupling on resistance to stress-corrosion cracking is due to the galvanic formation and absorption of atomic hydrogen at the surface of the 17-4PH, which functions as the cathode while the less noble metal functions as the anode. Practical experience indicates that, for most conditions of use, 17-4PH has adequate resistance to hydrogen embrittlement. Where the problem is acute and strength requirements permit, it should be aged at temperatures of 1100F or higher to obtain optimum resistance. (Refs. 16, 36, 39, 40, 49)

In one investigation of hydrogen embrittlement (Ref. 53), tensile and impact specimens that had been machined from 17-4PH Condition A bar were aged to several hardened conditions and then cathodically charged with hydrogen for up to 24 hours in a solution of sulfuric acid and arsenic trioxide at a current density of 58 mA/sq. in. When tested immediately after charging, the specimens showed marked decreases in tensile strength and ductility (reduction of area) for the higher-strength conditions but much less significant effects for the lower-strength conditions. Except for Condition A, the notch-impact properties were not significantly affected by hydrogen charging, probably because of the very high strain rate. The adverse effect on the notch-impact properties of the Condition A material is attributed to the fact that its microstructure of untempered martensite is highly sensitive to hydrogen embrittlement.

2.3.3.1 [Figure] Impact energy of specimens machined from bar, heat treated to various con-

ditions, and tested as-heat-treated and also tested immediately after cathodic hydrogen charging for 16 hours.

2.3.3.2 [Figure] Ultimate tensile strength of specimens machined from bar, heat-treated to various conditions, and tested immediately after cathodic hydrogen charging for various lengths of time.

2.3.3.3 [Figure] Tensile ductility (percent reduction of area) of specimens machined from bar, heat treated to various conditions, and tested immediately after cathodic hydrogen charging for various lengths of time.

In order to evaluate the reversibility of hydrogen charging, additional charged tensile specimens were tested after they had been held for various periods of time rather than tested immediately after charging. In these tests a 40-hour holding period at room temperature resulted in recovery of about 50 percent from the embrittling effects of a 16-hour charging time; the effects of longer holding periods were not reported. However, baking at 400F for four hours produced full recovery. These test results suggest that the damaging effects of hydrogen absorbed into 17-4PH during production operations, such as pickling and electroplating, may be ameliorated naturally during the time period prior to service installation or may be completely eliminated by a mild baking treatment. However, hydrogen absorbed during service, for example due to aqueous corrosion, galvanic coupling to a less noble metal, or simply exposure to pressurized hydrogen may create more serious problems; under these conditions hydrogen damage tends to decrease as the aging temperature, applied during prior heat treatment, increases within the normal range. (Refs. 53, 64)

Solution treatment at 1900F in air creates a tight oxide surface skin about 0.0001-in. thick plus a loose flaky outer scale. If the outer scale is removed, for example by a mild abrasive, the intact inner skin provides effective mitigation of hydrogen absorption and resulting embrittlement. Of course, this benefit of an oxide skin is obviated if non-oxidizing solution atmospheres are used or if the skin is removed by full surface cleaning (Section 4.4.1) or by machining. The much lighter oxide skin developed during aging treatments has little or no effect on hydrogen absorption. Sputtered surface films of aluminum oxide, less than 0.00001-in. thick, also provide effective protection against hydrogen absorption and embrittlement. (Ref. 74)

2.4 Nuclear Environments

Nuclear irradiation described as "water loop at 450F, 3 months at 4×10^{19} and 3×10^{19} NVT (thermal)" produced no changes in the density or dimensions of 17-4PH in Conditions A and H900; it produced a 4

percent increase in the magnetic permeability of the material in Condition H900. The 4×10^{19} NVT exposure increased the hardness from 34 to 50 R_C for Condition A and from 43 to 46 for Condition H900. (Ref. 44)

3. Mechanical Properties

3.1 Specified Mechanical Properties

3.1.1 [Table] AMS specified mechanical properties for wrought products.

3.1.2 [Table] AMS specified mechanical properties for investment, sand, and centrifugal castings.

3.2 Mechanical Properties at Room Temperature

3.2.1 Tension Stress-Strain Diagrams and Tensile Properties.

3.2.1.1 [Figure] Stress-strain curves for bar in three heat-treated conditions.

3.2.1.2 [Figure] Effect of aging treatment on tensile properties of wrought products at room temperature.

3.2.1.3 [Figure] Effect of aging treatment on tensile properties of castings at room temperature.

3.2.1.4 [Figure] Effects of long-time exposure at 700F on room-temperature tensile properties of bar in three heat-treated conditions.

3.2.1.5 [Figure] Effects of long-time exposure at 900F on room-temperature properties of bar in three heat-treated conditions.

3.2.1.6 [Figure] Effects of short exposure times at high temperatures on room-temperature tensile properties of sheet in Condition H900.

3.2.1.7 [Figure] Effects of 30-second exposures at temperatures from 1000F to 2000F on room-temperature properties of sheet in Condition H1150.

3.2.1.8 [Table] Comparison of longitudinal and transverse tensile properties of plate and bar.

3.2.1.9 Tensile properties of powder-metal products. (See Table 1.7.3.1 and Figures 3.5.1.8 and 3.5.1.9)

3.2.2 Compression Stress-Strain Diagrams and Compression Properties. (See Figures 3.3.2.1 and 3.3.2.2)

3.2.3 Impact.

3.2.3.1 [Figure] Effects of aging temperature on room-temperature Charpy V-notch impact properties of wrought bar and castings.

3.2.3.2 [Table] Effects of exposures of 1000 and 2000 hours at 700F, 800F, and 900F on room-temperature Izod impact properties.

3.2.4 Bending

3.2.5 Torsion and Shear.

3.2.5.1 [Figure] Effects of aging temperature on room-temperature shear strength determined on pin-type double-shear specimens.

3.2.5.2 [Table] Torsional strength of bar in various heat-treated conditions.

3.2.6 Bearing.

3.2.6.1 [Figure] Effects of aging treatment on bearing properties at room temperature.

3.2.7 Stress Concentration.

3.2.7.1 Notch Properties.

3.2.7.1.1 [Table] Comparison of smooth and notched tensile properties.

3.2.7.2 Fracture toughness.

3.2.7.2.1 [Table] Fracture toughness of bar in several heat-treated conditions.

3.2.8 Combined Loading.

3.3 Mechanical Properties at Various Temperatures

3.3.1 Tension Stress-Strain Diagrams and Tensile Properties.

3.3.1.1 [Figure] Tensile stress-strain curves for bar at room and elevated temperatures.

3.3.1.2 [Figure] Complete tensile stress-strain curves for bar at room and cryogenic temperatures.

3.3.1.3 [Figure] Effects of elevated temperatures on tensile properties of bar in five heat-treated conditions.

3.3.1.4 [Figure] Effects of elevated temperatures on tensile properties of bar in Condition H900.

3.3.1.5 [Figure] Effects of elevated temperatures on tensile properties of plate.

3.3.1.6 [Figure] Effects of long-time exposures at 700F on tensile properties at 700F of bar in three heat-treated conditions.

3.3.1.7 [Figure] Effects of long-time exposures at 900F on tensile properties at 900F of bar in three heat-treated conditions.

3.3.1.8 [Figure] Tensile properties at room and elevated temperatures after exposures up to 7000 hours at 600F and 750F of sheet initially in Condition H1150.

3.3.1.9 [Figure] Tensile properties of sheet at temperatures from 1000F to 2000F after exposures of 30 seconds at test temperature.

3.3.1.10 [Figure] Low-temperature tensile properties of bar in various heat-treated conditions.

3.3.1.11 [Figure] Low-temperature tensile properties of investment castings in Condition H1150-M.

3.3.2 Compression Stress-Strain Diagrams - Compression Properties.

3.3.2.1 [Figure] Compressive stress-strain curves for bar at room temperature and elevated temperatures.

3.3.2.2 [Figure] Effect of elevated temperatures on compressive strength of bar.

3.3.3 Impact.

3.3.3.1 [Figure] Low-temperature impact properties of bar and forgings in several overaged conditions.

3.3.3.2 [Figure] Low-temperature impact properties of bar in various heat-treated conditions.

3.3.3.3 [Figure] Low-temperature impact properties of castings in an overaged condition.

3.3.3.4 Injection-molded powder products. (See Figure 3.5.1.9)

3.3.4 Bending.

3.3.5 Torsion and Shear.

3.3.6 Bearing.

3.3.6.1 [Figure] Effect of elevated temperatures on bearing properties.

3.3.7 Stress Concentration.

3.3.7.1 Notch properties.

3.3.7.1.1 [Figure] Comparison of low-temperature notch tensile strength with ultimate tensile strength of bar in two overaged conditions.

3.3.7.1.2 [Figure] Comparison of low-temperature notch tensile strength with ultimate tensile strength of investment casting in Condition H1150-M.

3.3.7.2 Fracture toughness.

3.3.7.2.1 [Figure] Comparison of low-temperature tensile and fracture-toughness properties of plate in Condition H900.

3.3.8 Combined Properties.

3.4 Creep and Creep Rupture

3.4.1 [Figure] Creep and rupture curves for bar at 700F, 900F, and 1100F.

3.4.2 [Figure] Effects of temperature on stress to cause creep rupture in 100 and 1000 hours for bar in various heat-treated conditions.

3.4.3 [Figure] Creep-rupture curves at 600 to 800F for smooth and notched bars in Condition H1000.

3.4.4 [Figure] Creep-rupture curves at 300 to 800F for smooth and notched bars in Condition H1100.

3.5 Fatigue Properties

3.5.1 Conventional High-Cycle Fatigue.

- 3.5.1.1 [Figure] Fatigue properties of smooth and notched bars at room temperature and elevated temperatures.
- 3.5.1.2 [Figure] Fatigue properties of bar in Conditions H900 and H1050 at room temperature.
- 3.5.1.3 [Figure] Effects of stress ratio (R) on fatigue properties of forged bar in longitudinal and transverse orientations at room temperature.
- 3.5.1.4 [Table] Rotating beam fatigue strength at 10^7 and 10^8 cycles of bar in various heat-treated conditions.
- 3.5.1.5 [Figure] Fatigue properties of smooth and notched specimens in air and brackish water at room temperature.
- 3.5.1.6 [Figure] Effects of chloride environment and shot peening on the fatigue properties of bar.
- 3.5.1.7 [Figure] Effect of hot isostatic pressing (HIP), 4-hr. at 2050F in 15,000 psi argon, on fatigue and tensile properties of investment castings.
- 3.5.1.8 [Figure] Bending fatigue and other properties of powder-metal products made by injection-molding process.
- 3.5.1.9 [Figure] Effect of hot isostatic pressing (HIP), 2-hr. at 2125F in 15,000 psi argon, on fatigue and other properties of powder products made by injection molding.

3.5.2 Low-Cycle Fatigue.

3.5.3 Fatigue Crack Propagation.

- 3.5.3.1 [Figure] Fatigue-crack growth rate as a function of stress-intensity-factor range in atmospheres of dry argon and humid argon.
- 3.5.3.2 [Figure] Fatigue-crack growth rate as a function of stress-intensity-factor range with variations in melting practice, heat-treatment, and stress ratio (R).
- 3.5.3.3 [Figure] Fatigue-crack growth rate as a function of stress-intensity-factor range in air and in flowing sea water with different applied negative electrochemical potentials and with variations in melting practice and heat treatment.
- 3.5.3.4 [Figure] Effects of stress ratio (R) on fatigue-crack growth rate at low (near threshold) stress-intensity levels.

3.6 Elastic Properties

3.6.1 Poisson's Ratio, 0.291 at room temperature for all heat-treated conditions. (Ref. 45)

3.6.1.1 [Figure] Poisson's Ratio of overaged casting determined by ultrasonic technique at temperatures from -45 to 1465F.

3.6.2 Modulus of Elasticity.

- 3.6.2.1 [Figure] Effects of elevated temperatures on static modulus of elasticity in both tension and compression.
- 3.6.2.2 [Figure] Dynamic modulus of elasticity of overaged casting at temperatures from -45 to 1465F.

3.6.3 Modulus of Rigidity.

- 3.6.3.1 [Table] Modulus of rigidity for various heat-treated conditions.
- 3.6.3.2 [Figure] Dynamic modulus of rigidity of overaged casting at temperatures from -45 to 1465F.

3.6.4 Tangent Modulus.

- 3.6.4.1 [Figure] Tangent modulus curves in compression at room and elevated temperatures.

3.6.5 Secant Modulus.

4. Fabrication

4.1 Forming

- 4.1.1 Cold Forming. Because of its relatively high yield strength, cold forming of 17-4PH is normally limited to mild operations. Test results indicate that for stretch forming and similar uniaxial methods an overaged condition such as H1150 or H1150-M is preferable. In biaxial operations such as drawing, however, Condition A may be just as satisfactory as an overaged condition. After cold forming, full solution-and-aging heat treatment is recommended to develop the higher strength levels. However, if an overaged condition (H1150 or H1150-M) is desired in the final product and the forming stock is initially in that condition, the formed part may simply be re-aged to relieve residual stresses and restore toughness. (Ref. 49)
 - 4.1.1.1 [Table] Minimum radius to make indicated cold bend with no fissuring when viewed under 10x magnification.
- 4.1.2 Warm Forming. Type 17-4PH sheet and strip can be warm formed by first solution treating at 1900F and then forming during cooling from this temperature while it is still austenitic. The preferred temperature range for such forming is 650 to 900F. After subsequent aging (hardening), the mechanical properties are comparable to those obtained by standard heat treatments. (Ref. 20, 49)
 - 4.1.2.1 [Table] Tensile properties of sheet and strip warm stretch formed during cooling from solution-treatment temperature (1900F) and subsequently aged.

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4.1.3 Hot Forming. The alloy can be readily hot forged, headed, and upset within the temperature range 2200 to 1850F. For optimum grain size and mechanical properties, hot-worked material should be cooled in air to below 90F before further processing. For proper hardening it must then be solution treated prior to the aging treatment. (Refs. 2, 21-23, 50)

4.2 Machining and Grinding

Type 17-4PH can be machined in both the solution-treated and age-hardened conditions. In the solution-treated condition (Condition A), it machines similarly to Type 302 and 304 stainless steels. After machining to final dimensions in this condition, one of the standard aging treatments can be applied, for which temperatures are low enough to obviate scaling and distortion. However, on large sections, allowance should be made for the predictable contraction on hardening (See Section 1.5.2). Generally, cutting rates vary inversely with hardness, Condition H1150-M providing optimum machinability. If material in this condition is used for best machinability, subsequent full solution and aging heat treatment is required to obtain higher mechanical properties. (Refs. 21, 50)

4.2.1 [Table] Relative machinability of 17-4PH bar in various heat-treated conditions.

4.3 Joining

4.3.1 Type 17-4PH has excellent weldability. It can be welded with any of the usual electric-arc, resistance-welding, and electron-beam processes. For optimum strength, 17-4PH filler metal is recommended in conjunction with the electric-arc processes; when high weld strength is not needed, a standard austenitic filler such as 308L can be used. No preheat is required for thicknesses up to about 4-in.; for thicker sections, preheat and interpass temperatures of 200 to 500F are recommended. Condition A is a satisfactory condition prior to welding, but for heavy sections and highly restrained joints an overaged condition (H1100 or H1150) is preferred. After welding, a full solution and aging treatment is required to obtain optimum mechanical properties. When material in Condition A is welded, however, postweld aging at 900 to 1150F without solution treatment produces properties approaching those obtained by full postweld heat treatment in sections less than 1/2-in. thick but not in heavier sections. When postweld solution treatment is not feasible in weldments 1/2-in. and greater in thickness, precipitation hardening at 1025F or less is suggested. The use of 17-4PH weldments in the as-welded condition is not recommended. Oxyacetylene welding is not advisable because of possible impairment of both corrosion resistance and mechanical properties caused by carbon pickup. For castings that are intended to be welded, copper content below 3.0 percent

is desirable since higher copper levels have been associated with under-bead cracking. (Refs. 22, 23, 50, 51, 55, 65, 66, 75)

4.3.1.1 [Table] Variations in tensile properties with section size and postweld treatment for butt welds made by the manual-shielded-metal-arc technique with 17-4PH electrodes.

4.3.1.2 [Table] Comparison of tensile properties of sheet with those of sheet containing a transverse butt weld made by automatic GTA technique with 17-4PH weld wire.

4.3.1.3 [Table] Tensile properties of sheet containing a transverse butt weld made by the GMA technique with 17-4PH weld wire.

4.3.1.4 [Figure] Comparison of fatigue properties of base metal and shielded-metal-arc weldments fully heat treated after welding.

4.3.1.5 [Table] Tensile properties of flash-butt welds in bars.

4.3.2 Satisfactory furnace-brazed joints in 17-4PH parts can be made with nickel-base, copper-base, and silver-base brazing alloys. Where feasible, a brazing alloy should be selected that permits the use of a procedure that fits into the heat-treating cycle. (Ref. 23)

4.4 Surface Treating

4.4.1 Cleaning. Scale from hot-working or solution-treating operations can be removed by wet grit blasting or by a duplex pickling procedure. One effective pickling method requires 60 minutes in a caustic permanganate bath at 160 to 180F, water rinse, and then 2 to 3 minutes in 10 percent nitric-2 percent hydrofluoric acid solution at 110 to 140F, followed by hot-water rinse with high pressure or brush scrub. Light discoloration or heat tint produced by aging treatments can be removed by mechanical means such as wet grit blasting or with a short pickle in 10 percent nitric-2 percent hydrofluoric acid (by volume) at 110-140F followed by water rinse. Alternatively, heat tint may be removed by a light electropolishing operation. Both the short pickling and the electropolishing treatments also passivate the surfaces for maximum corrosion resistance. (Refs. 23, 49, 50)

4.4.2 Nitriding. Whereas nitriding decreases the corrosion resistance of any stainless steel, it can be used when increased resistance to galling and wear is required. For example, nitriding has been used to case harden 17-4PH jet engine fuel pump shafts. Using the gas-phase method, case hardness of approximately R_C67 can be obtained to a depth of about 0.005 in. This method of nitriding utilizes a temperature of about 1050F which, when applied to material initially in Condition A, results in a strong core with good toughness. (Refs. 21, 23)

Table 1.3.1 AMS, ASTM, and MIL specifications (Refs. 26-35, 49, 51, 55)

Alloy	17-4PH
Specification	Form
AMS 5643N	Bars, Wire, Forgings, Tubing, and Rings
AMS 5604C	Plate, Sheet, and Strip
AMS 5622B	Wrought, Consumable Electrode Melted
AMS 5398D	Sand and Centrifugal Castings
AMS 5355E	Investment Castings
AMS 5342D	Investment Castings, 130 ksi
AMS 5343D	Investment Castings, 150 ksi
AMS 5344D	Investment Castings, 180 ksi
AMS 5825E	Welding Wire
AMS 5827D	Covered Welding Electrodes
ASTM A 564	Bars and Shapes
ASTM A 693	Plate, Sheet, and Strip
ASTM A 705	Forgings
ASTM A 747	Castings
MIL-C-24111	Bars, Rod, and Forgings
MIL-S-81591	Castings

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Table 1.4.1 AMS specified compositions (Refs. 26-35)

Alloy	17-4PH					
	5344D, 5342D, 5343D, 5355E		5604C, 5643N, 5622B ^a		5827D ^a , 5825E	
Form	Investment Cast ^b		Wrought		Weld Filler Metal	
Percent	Min.	Max.	Min.	Max.	Min.	Max.
Carbon	–	0.06	–	0.07	–	0.05
Manganese	–	0.70	–	1.00	0.25	0.75
Silicon	0.50	1.00	–	1.00	–	0.75
Phosphorus	–	0.025	–	0.040	–	0.04
Sulfur	–	0.025	–	0.030	–	0.03
Chromium	15.50	16.70	15.00	17.50	16.00	16.75
Nickel	3.60	4.60	3.00	5.00	4.50	5.00
Columbium	0.15	0.40	5XC	0.45 ^c	0.15	0.30
Copper	2.80	3.50	3.00	5.00	3.25	4.00
Tantalum	–	0.05	–	–	–	–
Aluminum	–	0.05	–	–	–	–
Tin	–	0.02	–	–	–	–
Nitrogen	–	0.05	–	–	–	–
Molybdenum	–	–	–	0.05	–	0.75
Iron	Remainder		Remainder		Remainder	

^a AMS 5622B and 5827D specify 0.025 percent maximum sulfur and phosphorus.

^b AMS 5398D (Sand and Centrifugal Castings) is similar with the following minor exceptions: 0.04 maximum phosphorus, 0.03 maximum sulfur, 2.50 to 3.20 copper, and 0.10 to 0.35 columbium plus tantalum.

^c Columbium plus tantalum.

Table 1.5.1.1 Heat treatments for 17-4PH (Refs. 5, 8, 21, 23, 49-52)

Alloy	17-4 PH		
Form	Wrought and Cast		
Solution Treatment ^a	Condition ^d	Age ^b	
		Temperature (F)	Time (Hour)
For all conditions, 1900F is the most common solution temperature, but some sources use 1925 or 1950F. A minimum of 30 minutes at solution temperature is recommended; longer times may be appropriate for large sections. Cooling to below 90F is required before aging. Air cooling is widely used, but oil quench is acceptable for simple sections less than 3 in.	A	-	-
	H900	900	1 ^c
	H925	925	4 ^c
	H1025	1025	4
	H1075	1075	
	H1100	1100	
	H1150	1150	
	H1150-M	1400 +	2
		1150	4
H1150 DBL	1150 +	4	
	1150	4	

^a For optimum properties in castings, a homogenization treatment at 2100F for 90 minutes or more followed by air cool to below 90F prior to solution treatment is sometimes applied. Also for castings, after the specified solution treatment, it is occasionally necessary to cool in dry ice to ensure complete transformation of the austenite. (Ref. 52)

^b Air cool from aging temperature.

^c For castings, 1.5 hours aging time is recommended for conditions H900 and H925. (Ref. 52)

^d Occasionally, other conditions such as H975 or H1050 are used, indicative of other aging temperatures.

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Table 1.6.1 Hardness of wrought products and castings in various heat-treated conditions (Refs. 21, 49-51, 72)

Alloy	17-4PH		
	Sheet	Bar	Castings
Condition	Hardness, R _C		
A	35	36	34
H900	45	44	
H925	43	42	44
H1025	38		
H1075	37	36	34
H1100	-	35	31
H1150	35	33	29
H1150-M	33	28	-

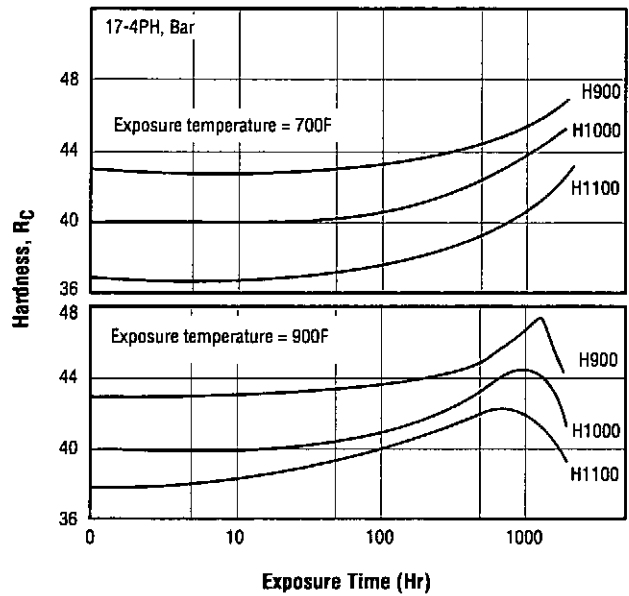


Fig. 1.6.2 Effects of long-time exposures at 700F and 900F on room-temperature hardness of bar in three heat-treated conditions (Ref. 23)

Table 1.7.3.1 Comparison of properties of wrought, cast, and powder-metal (P/M) products (Refs 49-51, 54, 57)

Alloy	17-4PH			
	Conventional P/M	MIM ^a P/M	Wrought	Castings
Condition	H900			
F _{tu} (ksi)	140.0	140.5	195.6	187.0
F _{ty} (ksi)	122.0	133.9	177.0	161.0
e, 4D (percent)	2	7	14	10
Hardness, R _C	24 ^b	34 ^b	44	44
Density, (g/cm ³)	7.15	7.48	7.81	7.76

^a Metal injection molded.

^b Apparent hardness, that is an integrated hardness representing the combination of metal and pores inherent in powder-metal products.

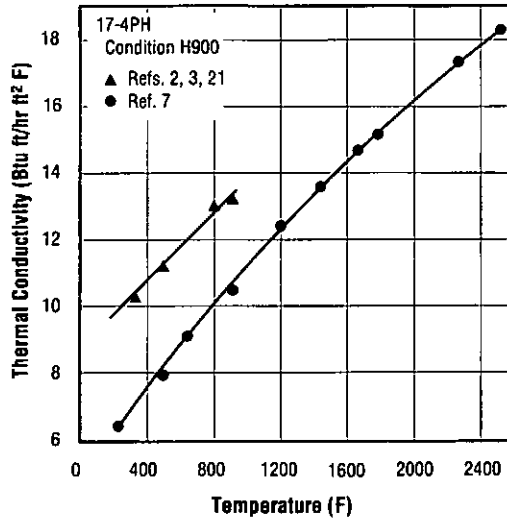


Fig. 2.1.3.1 Thermal conductivity from 200F to 2500F (Refs. 2, 3, 7, 21)

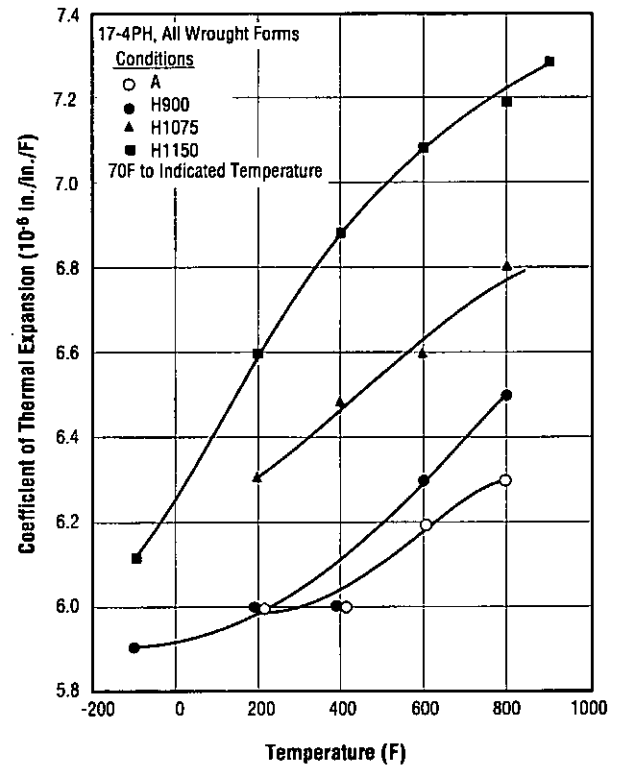


Fig. 2.1.4.1 Thermal expansion from -100F to 900F (Refs. 20, 21)

Table 2.2.1.1 Density in various heat-treated conditions (Refs. 20-22)

Alloy	17-4PH	
Form	All Wrought Forms	
	Density	
Condition	(lb./in. ³)	(g/cm ³)
A	0.280	7.75
H900	0.282	7.81
H1075	0.283	7.84
H1150	0.284	7.87

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Table 2.2.2.1 Electrical properties of sheet and bar in various heat-treated conditions (Refs. 20, 21, 49)

Alloy	17-4PH			
Form	Condition	Electrical Conductivity		Electrical Resistivity (microhm-in.)
		(percent IACS)	(megohms per cu in.)	
Sheet	A	1.76	0.0259	38.6
	H900	2.24	0.0330	30.3
Bar	A	1.73	0.0254	39.4
	H900	2.16	0.0317	31.5
	H1075			

Table 2.2.3.1 Magnetic permeability in various heat-treated conditions (Ref. 3)

Alloy	17-4PH		
Form	All Wrought Forms		
Condition	Magnetic Permeability		
	at 100 oersteds	at 200 oersteds	Maximum
A	74	48	95
H900	90	56	135
H1075	88	52	136
H1150	59	38	71

Table 2.3.1.1 Comparison of typical corrosion rates for Types 17-4PH and 304 stainless steels in several chemical media (Ref. 49)

Alloy			17-4PH				Type 304
Form			Sheet				
Condition			H925	H1025	H1075	H1150	Annealed
Medium	Concentration (percent)	Temperature (F)	Corrosion Rate ^a (mils per year)				
Sulfuric Acid	2	95	< 1				57
	5		4	7	11	9	240
	1	176	1				350
	2		8	9	13	17	480
Hydrochloric Acid	1/2	95	2		3	16	33
	1		35	174	518	650	240
Nitric Acid	25	Boiling	14	6	7	8	2
	50		70	35	47	31	4
10% Nitric + 1% Hydrofluoric Acid	–	95	1500				380
Formic Acid	10	176	2	3		5	100
Acetic Acid	33	Boiling	6	6	4	4	300
Phosphoric Acid	20		1			2	
	70		86	57	60	119	32
Sodium Hydroxide	50	176	3		4	5	1
		Boiling	480	450	560		80
Ammonium Hydroxide	10		Boiling	< 1			
Salt-Sugar-Vinegar	–	< 1					

^a Rates determined after total immersion, in most instances, for five 48-hour periods. Chemically pure reagents were used. These data should be used only as guide to comparative performance.

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Table 2.3.2.1 Effects of heat-treat condition and applied stress on time to stress corrosion failure of bent-beam strip specimens exposed to marine environment at Kure Beach, NC (Ref. 49)

Alloy	17-4PH	
Form	Strip	
Condition	Applied Stress (ksi)	Time to Failure ^a
A	124 - 100% F _{ty}	NF
	93 - 75% F _{ty}	
H900	187 - 100% F _{ty}	26 days
	140 - 75% F _{ty}	28 days
H925	173 - 100% F _{ty}	100 months + 1 NF
	130 - 75% F _{ty}	52 months + 1 NF
H975	168 - 100% F _{ty}	NF
	126- 75% F _{ty}	78 months + 2 NF
H1025	140 - 90% F _{ty}	NF
	116- 75% F _{ty}	
H1075	135 - 90% F _{ty}	
	113- 75% F _{ty}	
H1150	102 - 90% F _{ty}	
	85- 75% F _{ty}	

^a The results are based upon the average of three or five tests for each test condition. NF signifies no failure after more than 15 years of exposure.

Table 2.3.2.2 Comparison of tensile properties for various heat-treated conditions with critical stress intensity levels for stress corrosion cracking in salt water (Ref. 10)

Alloy	17-4PH				
Form	1.0 in. Plate				
	Conditions				
Properties	H900	H975	H1075	H1150	H1150-M
F_{ty} (ksi)	177.0	161.7	150.9	120.3	91.0
F_{tu} (ksi)	195.6	170.8	156.5	141.6	124.6
e , 2 in. (percent)	14	15	17	19	22
RA (percent)	50	55		61	64
K_{Isc} , (ksi $\sqrt{\text{in.}}$) ^{a,b}					
Open circuit	45	82	117	124	97
Al coupled	36	73	103	105	93
Zn coupled	30	45	59	74	88
Mg coupled	17	20	49	52	90

^a Stress corrosion tests for Condition H900 carried out in natural seawater; for all other conditions, stress-corrosion tests were done in 3.5 percent sodium chloride in distilled water.

^b K_{Isc} is the stress intensity level below which no evident crack extension will occur.

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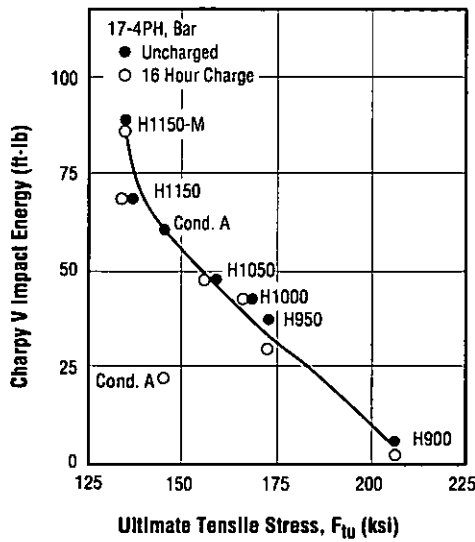


Fig. 2.3.3.1 Impact energy of specimens machined from bar, heat-treated to various conditions, and tested as-heat-treated and also tested immediately after cathodic hydrogen charging for 16 hours (Ref. 53)

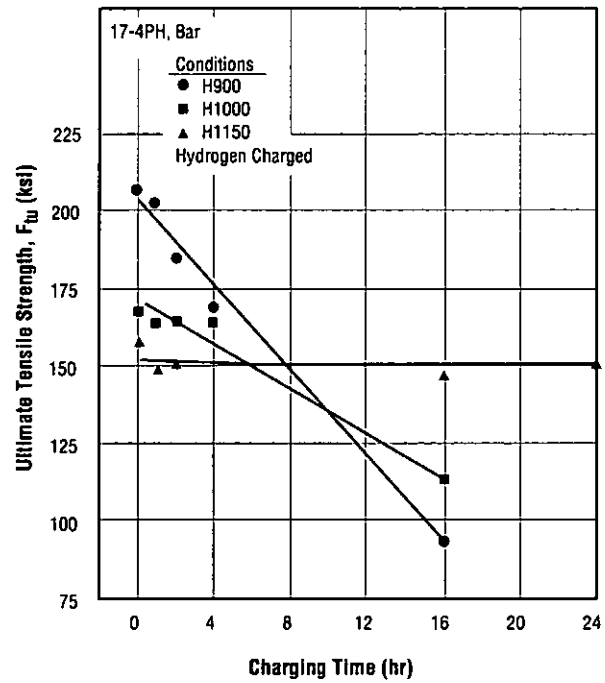


Fig. 2.3.3.2 Ultimate tensile strength of specimens machined from bar, heat-treated to various conditions, and tested immediately after cathodic hydrogen charging for various lengths of time (Ref. 53)

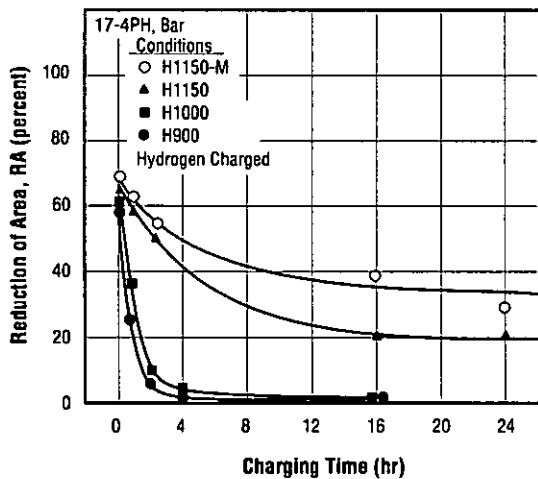


Fig. 2.3.3.3 Tensile ductility (percent reduction of area) of specimens machined from bar, heat-treated to various conditions, and tested immediately after cathodic hydrogen charging for various lengths of time (Ref. 53)

Table 3.1.1 AMS specified mechanical properties for wrought products (Refs. 26, 34, 35)

Alloy		17-4PH						
Specs.	Form	Condition	F_{ty} , min (ksi)	F_{tu} , min (ksi)	e, 4D ^a , min (percent)	RA ^a , min (percent)	Hardness	
							min	max
AMS 5604C	Sheet, Strip, Plate up to 4.0 in. thick	A	160 ^b	185 ^b	3	-	-	38 R _C
		H900	170	190	5, 8, 10	-, 30, 35	40 R _C	47 R _C
		H925	155	170	5, 8, 10	-, 30, 35	38 R _C	45 R _C
		H1025	145	155	5, 8, 12	-, 35, 40	35 R _C	42 R _C
		H1075	125	145	5, 9, 13	-, 35, 45	33 R _C	39 R _C
		H1100	115	140	5, 10, 14	-, 35, 45	32 R _C	38 R _C
		H1150	105	135	8, 10, 16	-, 40, 50	28 R _C	37 R _C
AMS 5622B	Bars, Wire, Forgings, Tubing, Rings up to 8.0 in. in diameter or thickness. (Consum- able-electrode melted.)	A	-	175 ^b	-	-	-	363 BHN
		H900	170	190	10(L), 5(T)	35(L), 15(T)	388 BHN	444 BHN
		H925	155	170	10(L), 6(T)	38(L), 20(T)	375 BHN	429 BHN
		H1025	145	155	12(L), 7(T)	45(L), 27(T)	331 BHN	401 BHN
		H1075	125	145	13(L), 8(T)	45(L), 28(T)	311 BHN	375 BHN
		H1100	115	140	14(L), 9(T)	45(L), 29(T)	302 BHN	363 BHN
		H1150	105	135	16(L), 10(T)	50(L), 30(T)	277 BHN	352 BHN
AMS 5643N	Bars, Wire, Forgings, Tubing, Rings up to 8.0 in. in diameter or thickness.	A	-	175 ^b	-	-	-	363 BHN
		H900	170	190	10	40 ^c	388 BHN	444 BHN
		H925	155	170	10	44 ^c	375 BHN	425 BHN
		H1025	145	155	12	45	331 BHN	401 BHN
		H1075	125	145	13	45	311 BHN	375 BHN
		H1100	115	140	14	45	302 BHN	363 BHN
		H1150	105	135	16	50	277 BHN	352 BHN

^a The series of e (4D) and RA numbers for AMS 5604C apply to the following thicknesses respectively: up to 0.1875 in., 0.1875 to 0.625 in., and 0.625 to 4,000 in.; the F_{ty} and F_{tu} values do not vary with thickness. For AMS 5622B, the two numbers for both e (4D) and RA refer to longitudinal (L) and transverse(T) orientations; the F_{ty} and F_{tu} values are the same for L and T.

^b This particular value is maximum rather than minimum.

^c For sizes over 3 in. these values are reduced to 35 and 38 percent respectively.

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Table 3.1.2 AMS specified mechanical properties for investment, sand, and centrifugal castings (Refs. 27-31)

Alloy	17-4PH								
	Refs.	Form	Condition	F _{ty} , min (ksi)	F _{tu} , min (ksi)	e, 4D, min (percent)	RA, min (percent)	Hardness	
								min	max
	(27)	Investment castings	A	-	-	-	-	-	36 R _C
	(27)(28)	Investment castings test bar	H900	160	180	6	15	40 R _C	-
	(28)	Investment castings						40 R _C	46 R _C
	(27)	Investment castings test bar	H925	150	180	6	15	40 R _C	-
	(27)(30)	Investment castings test bar	H1000	130	150	8	20	34 R _C	-
	(30)	Investment castings						34 R _C	42 R _C
	(27)	Investment castings test bar	H1025	130	150	10	20	34 R _C	-
	(27)(29)	Investment castings test bar	H1100	120	130	10	25	30 R _C	-
	(29)	Investment castings						30 R _C	38 R _C
	(27)	Investment castings test bar	H1150	110	125	12	25	28 R _C	-
	(31)	Sand & Centrifugal castings	-	-	-	-	-	-	363 BHN
		Test bars	H925	150	180	6	12	375 BHN	-

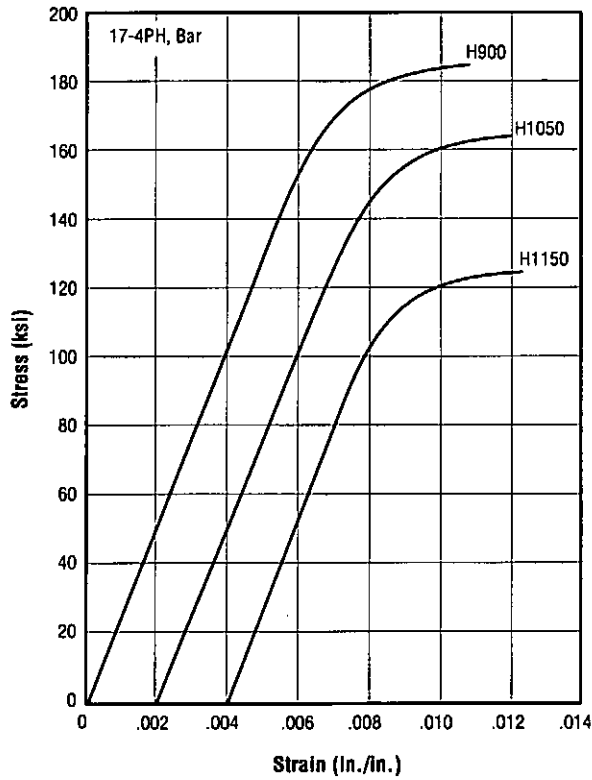


Fig. 3.2.1.1 Stress-strain curves for bar in three heat-treated conditions (Ref. 23)

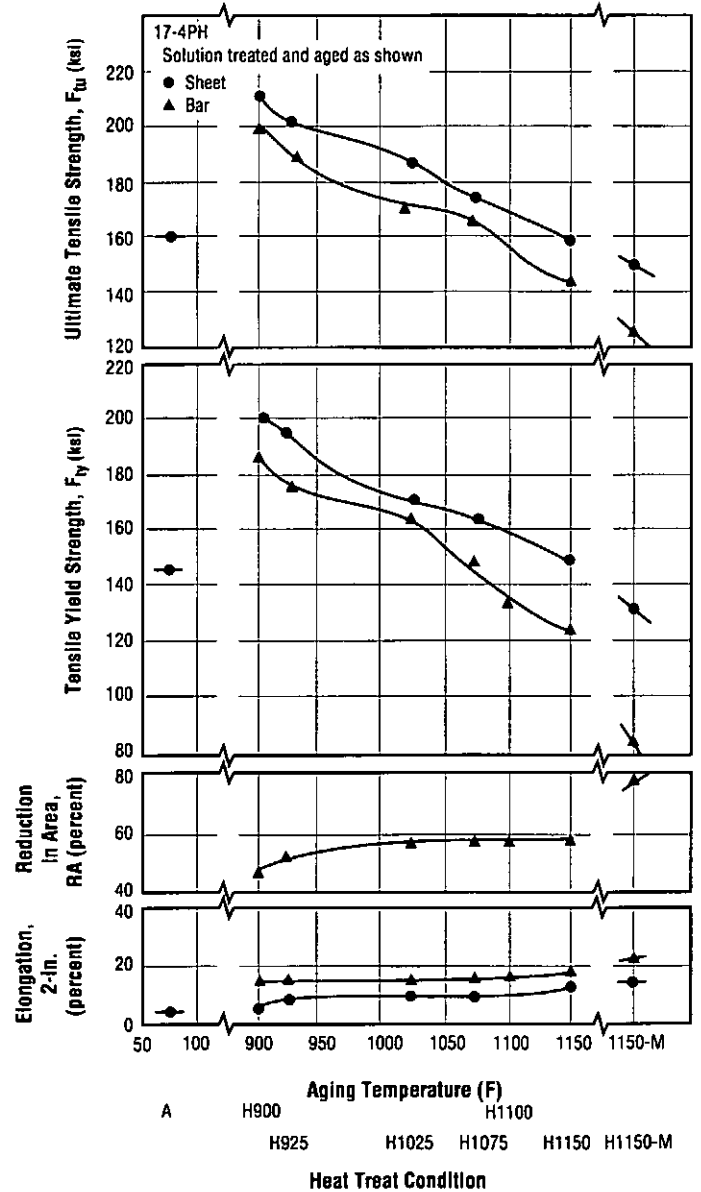


Figure 3.2.1.2 Effect of aging treatment on tensile properties of wrought products at room temperature (Ref. 20, 21)

17-4PH

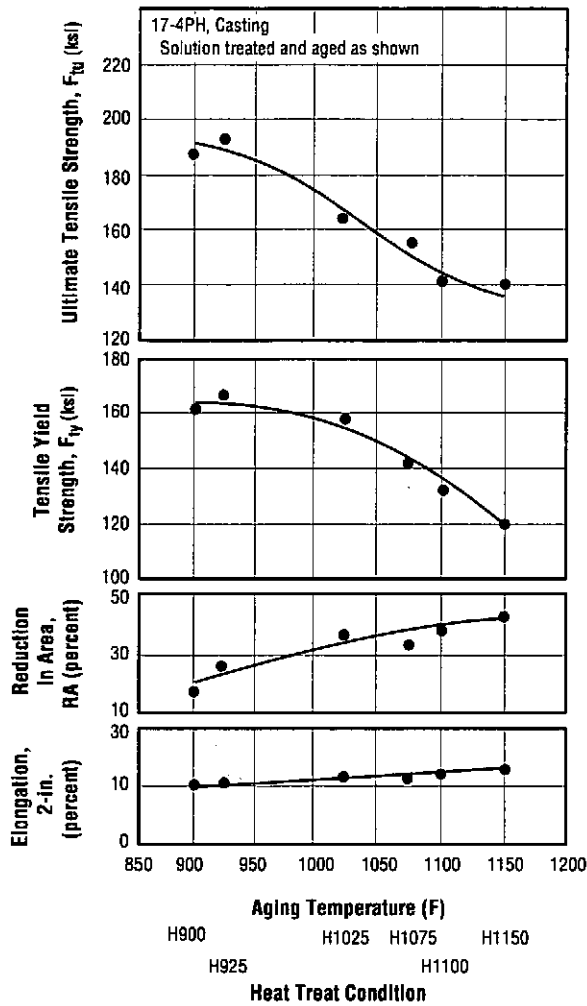


Figure 3.2.1.3 Effect of aging treatment on tensile properties of castings at room temperature (Ref. 20, 21)

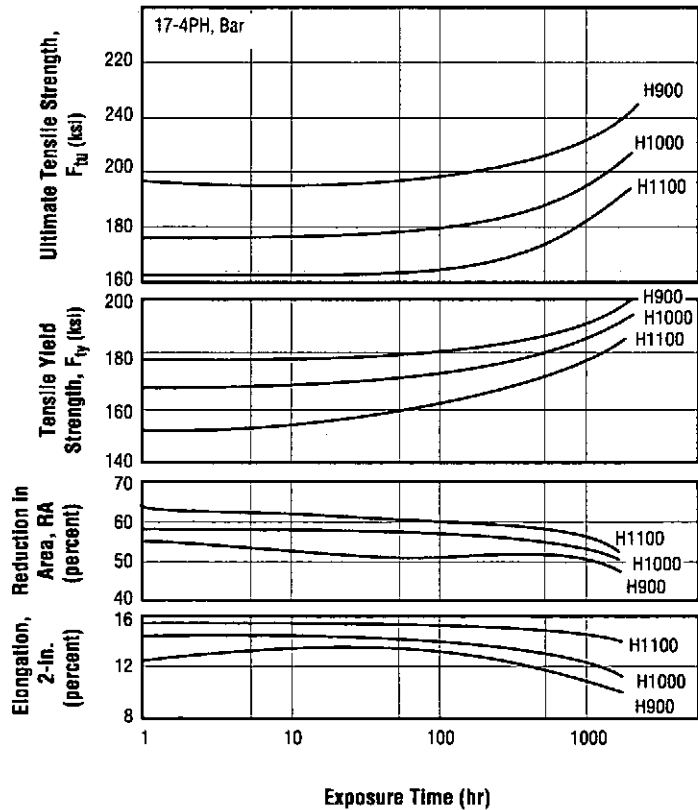


Figure 3.2.1.4 Effects of long-time exposures at 700F on room-temperature tensile properties of bar in three heat-treated conditions (Ref. 23)

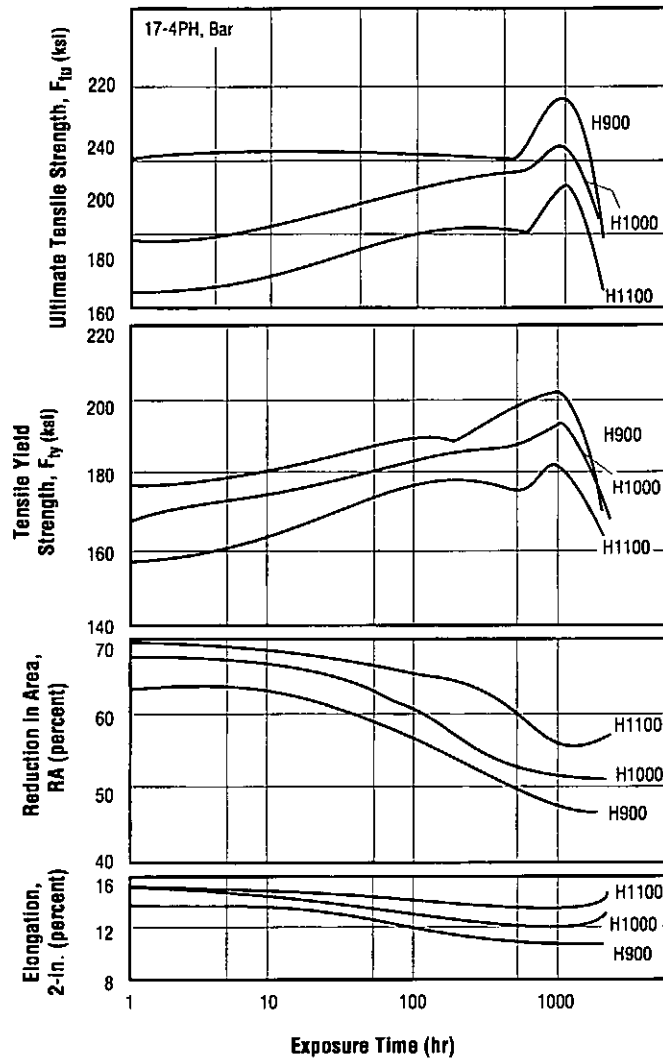


Figure 3.2.1.5 Effects of long-time exposure at 900F on room-temperature tensile properties of bar in three heat-treated conditions (Ref. 23)

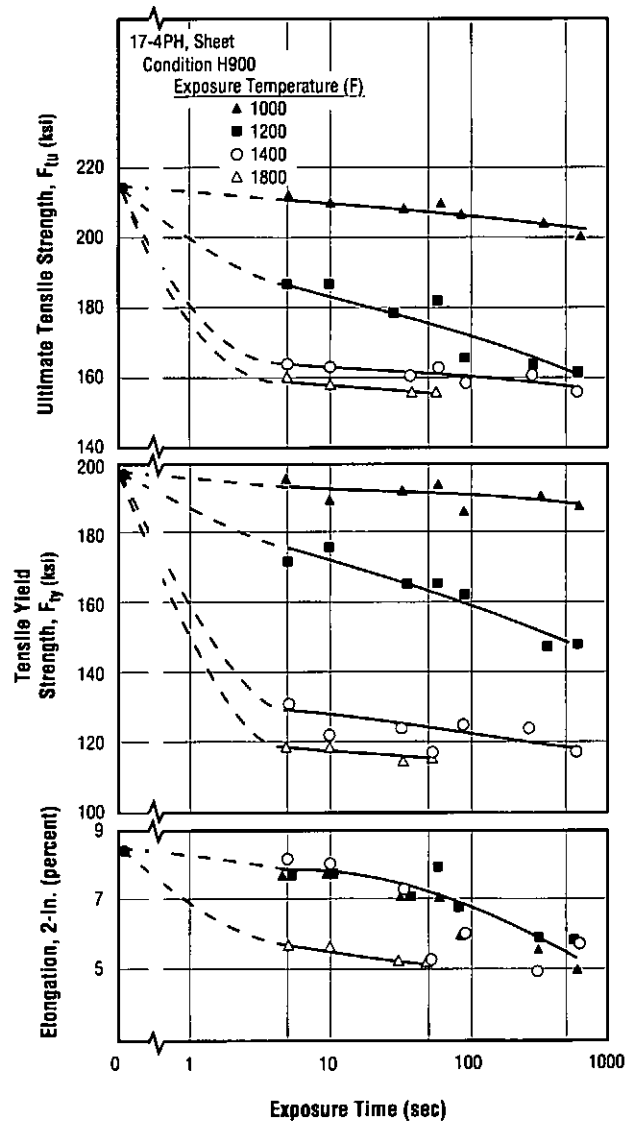


Figure 3.2.1.6 Effects of short exposure times at high temperatures on room-temperature tensile properties of sheet in condition H900 (Ref. 20)

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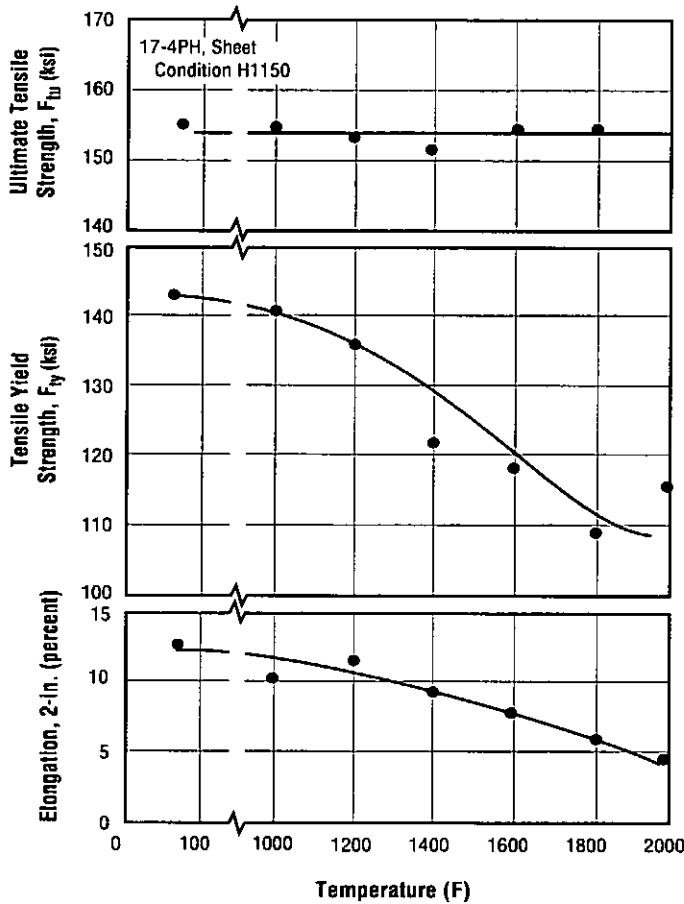


Figure 3.2.1.7 Effects of 30-second exposures at temperatures from 1000 to 2000F on room-temperature properties of sheet in Condition H1150 (Ref. 20)

Table 3.2.1.8 Comparison of longitudinal and transverse tensile properties of plate and bar (Ref. 23)

Alloy		17-4PH				
Form	Condition	Orientation ^a	F_{ty} (ksi)	F_{tu} (ksi)	e, 2 in. (percent)	RA (percent)
4-in. plate	H925	L	-	195	17.0	53.5
		ST			4.5	5.0
	H1025	L	160	163	17.0	58.0
		ST	159	162	13.0	32.0
	H1075	L	144	155	18.0	61.0
		ST	147	154	12.0	27.0
6-in. square bar	H1075	L	157	160	17.5	62.0
		T	155	158	14.0	40.0
	H1150	L	139	147	20.0	63.0
		T	136		15.0	44.0

^a L = longitudinal, ST = short transverse, T=transverse.

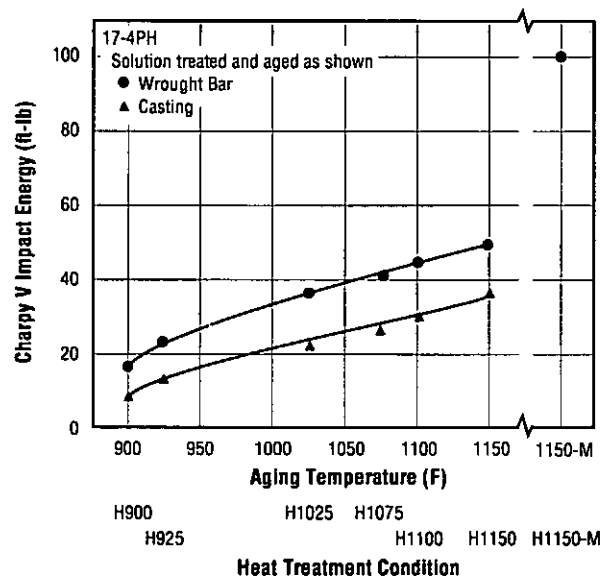


Figure 3.2.3.1 Effects of aging temperature on room-temperature Charpy V-notch impact properties of wrought bar and castings (Refs. 21, 51)

Table 3.2.3.2 Effects of exposures of 1000 and 2000 hours at 700F, 800F, and 900F on room-temperature Izod impact properties (Ref. 23)

Alloy		17-4PH		
Form		Bar		
Exposure		Izod Impact (ft-lb)		
		Condition		
Temperature (F)	Time (Hr)	H900	H1000	H1100
75	—	14	45	56
700	1000	7		
	2000	4	3	4
800	1000	2		3
	2000	2		
900	1000	3	4	6
	2000	6	8	11

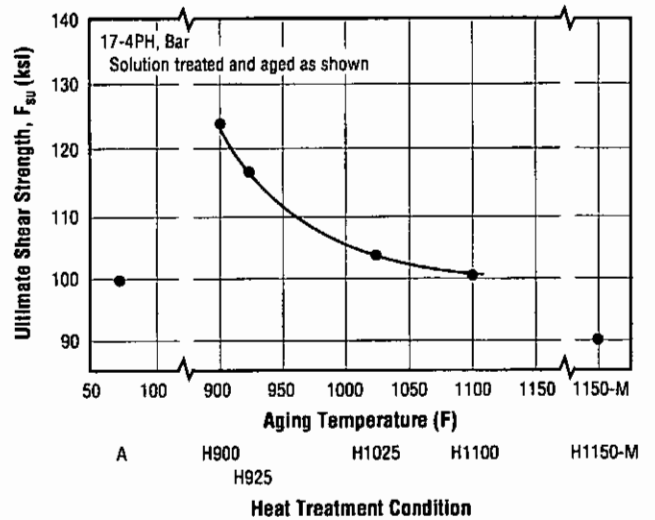


Figure 3.2.5.1 Effects of aging treatment on room-temperature shear strength determined on pin-type double-shear-specimens (Ref. 21)

Table 3.2.5.2 Torsional strength of bar in various heat-treated conditions (Ref. 25)

Alloy		17-4PH	
Form		Bar	
Condition	Yield Strength, F_{sty} (ksi)	Modulus of Rupture, F_{st} (ksi)	
A	83.5	125.0	
H900	119.8	171.4	
H925	119.3	161.8	
H1025	109.8	141.1	
H1100	103.4	134.3	
H1150	91.4	130.2	
H1150-M	62.9	116.8	

17-4PH

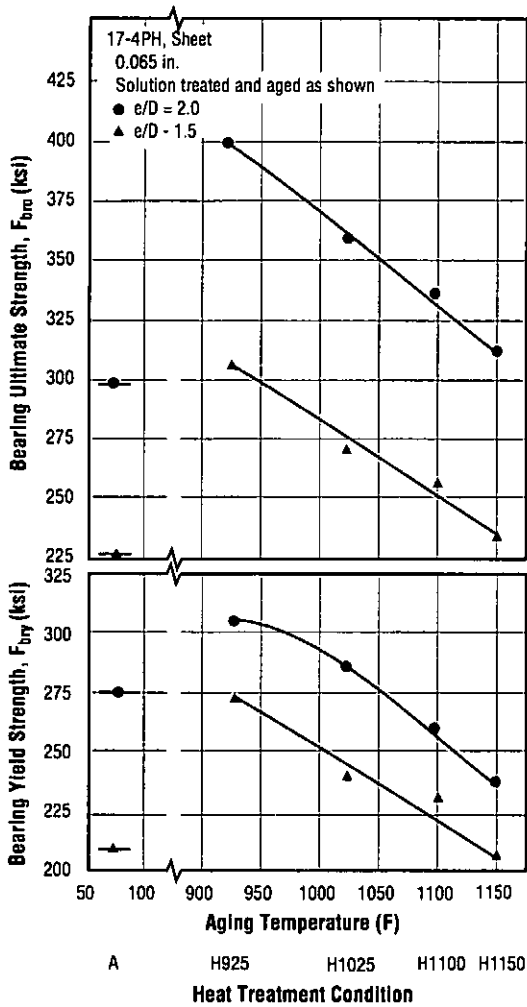


Figure 3.2.6.1 Effects of aging treatment on bearing properties at room-temperature (Ref. 24)

Table 3.2.7.1.1 Comparison of smooth and notched tensile properties (Ref. 9)

Alloy		17-4PH			
Form		Bar			
Condition		H900			
Smooth ^a			Notched		
F_{ty} (ksi)	F_{tu} (ksi)	e, 2 in. (percent)	K_t	NTS ^b (ksi)	NTS ^c (ksi)
195	201	15.4	3	318	324

^a Average of 9 tests.
^b Average of 3 tests.

^c Average of 3 tests.

Table 3.2.7.2.1 Fracture toughness of bar in several heat-treated conditions (Ref. 24)

Alloy	17-4PH
Form	Bar
Condition	K_{Ic} (ksi $\sqrt{in.}$)
A	62.4
H900	54.8
H925	100.8
H975	84.6

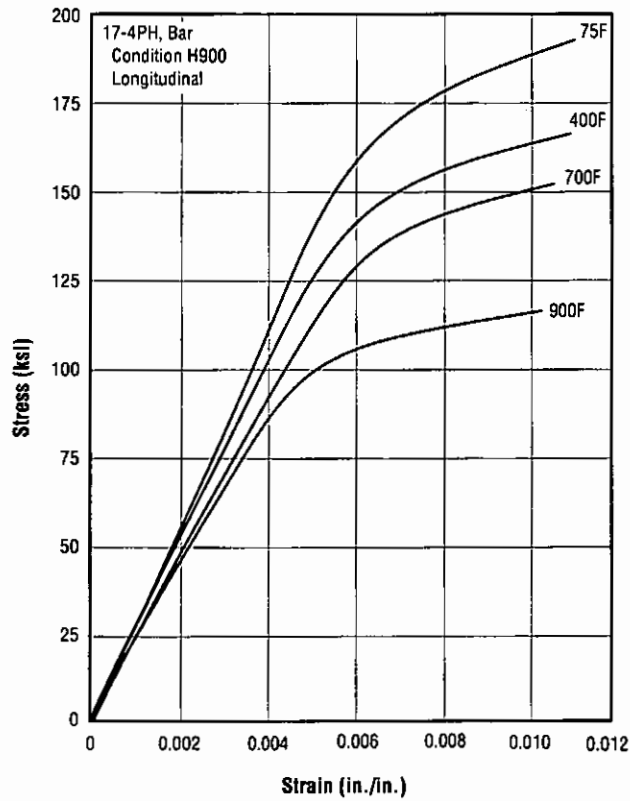


Figure 3.3.1.1 Tensile stress-strain curves for bar at room and elevated temperatures (Ref. 11)

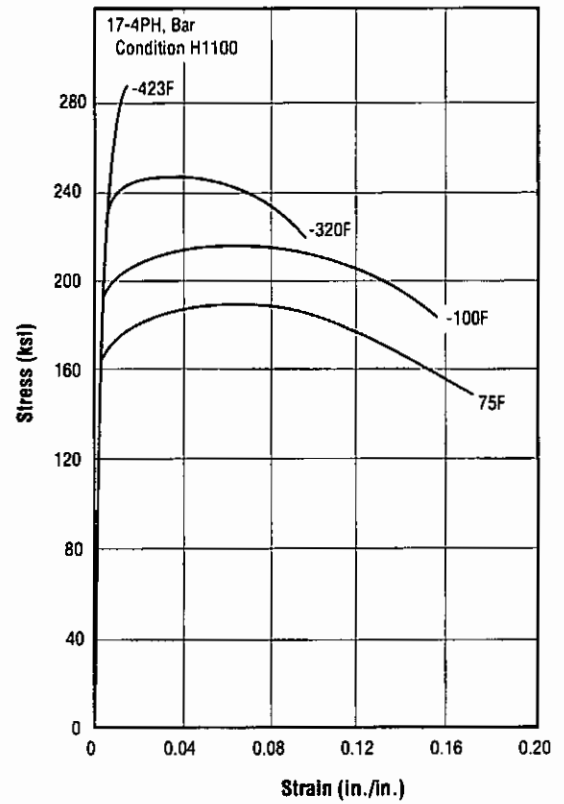


Figure 3.3.1.2 Complete tensile stress-strain curves for bar at room and cryogenic temperatures (Ref. 17)

17-4PH

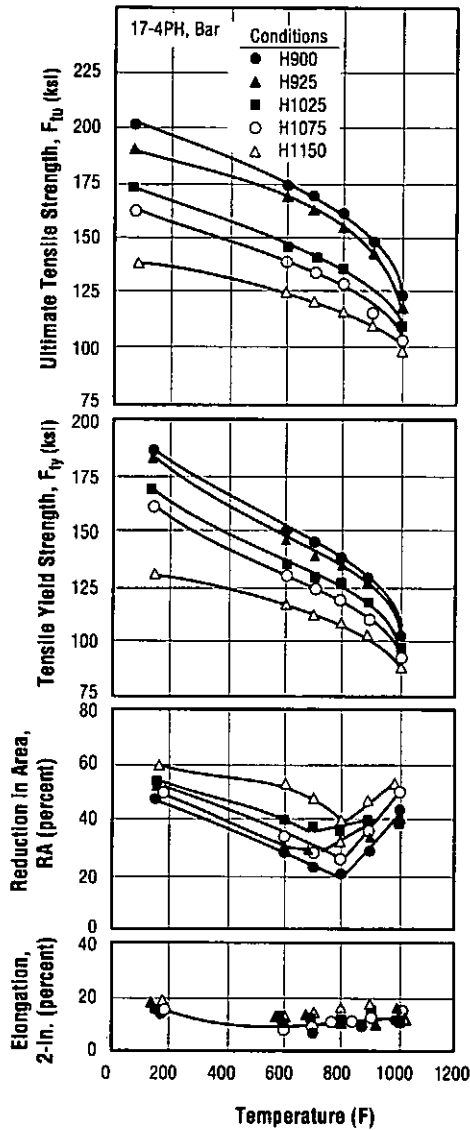


Figure 3.3.1.3 Effects of elevated temperatures on tensile properties of bar in five heat-treated conditions (Ref. 21)

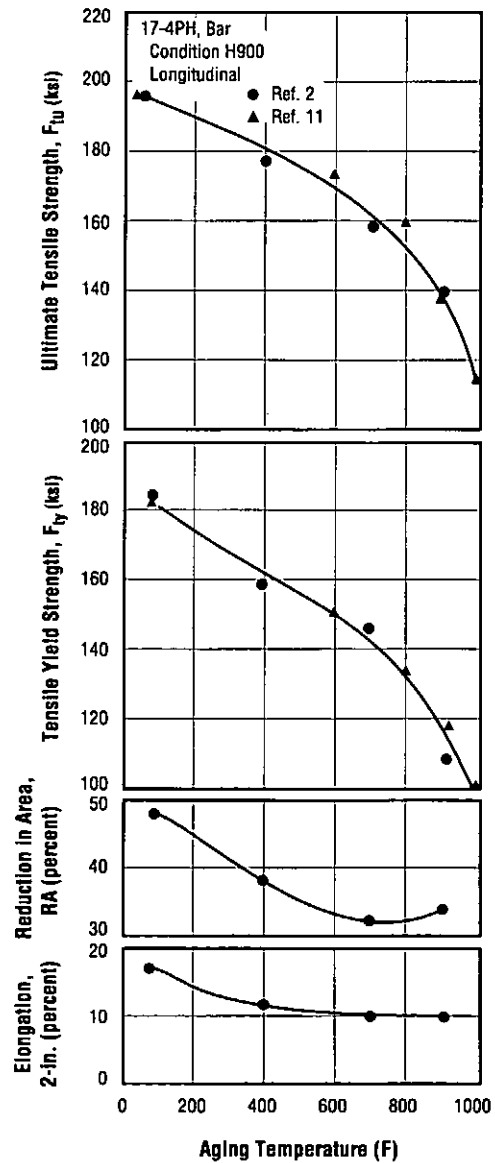


Figure 3.3.1.4 Effect of elevated temperatures on tensile properties of bar in Condition H900 (Ref. 2, 11)

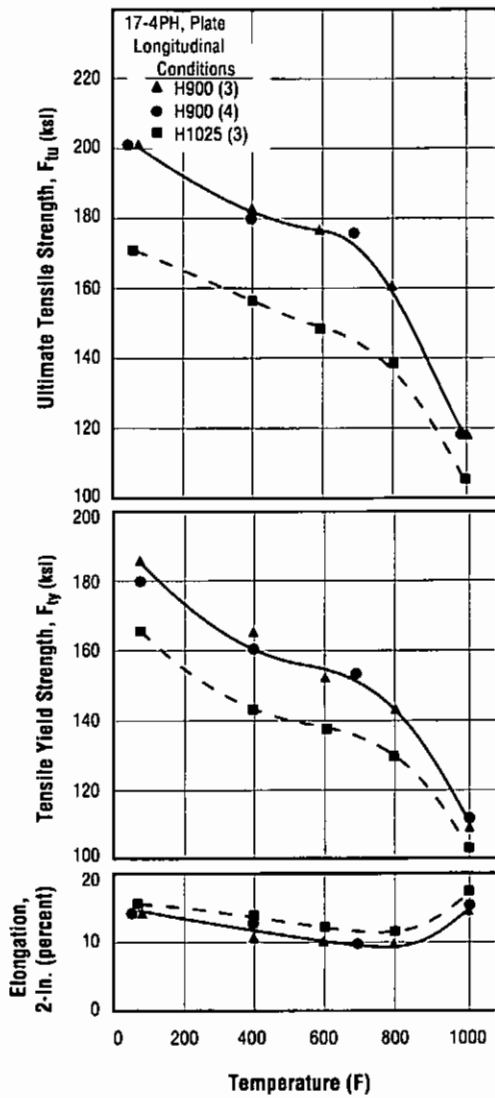


Figure 3.3.1.5 Effects of elevated temperatures on tensile properties of plate (Refs. 3, 4)

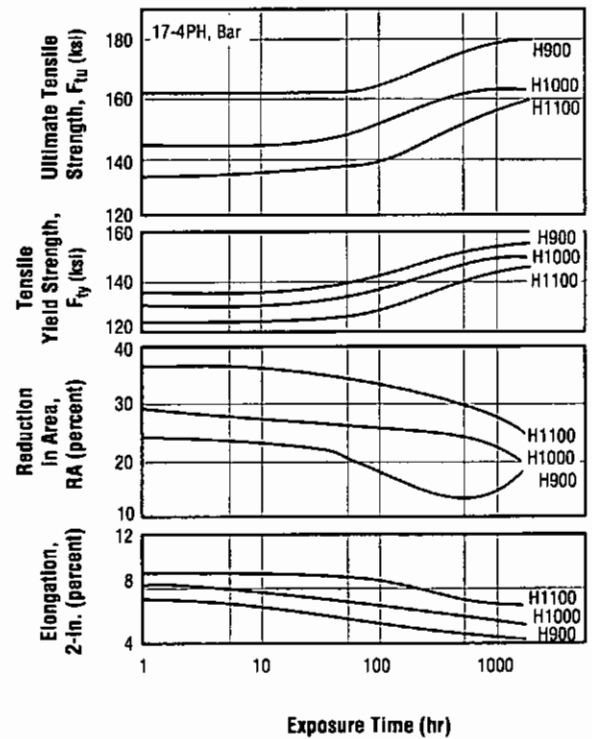


Figure 3.3.1.6 Effects of long-time exposures at 700F on tensile properties at 700F of bar in three heat-treated conditions (Ref. 23)

17-4PH

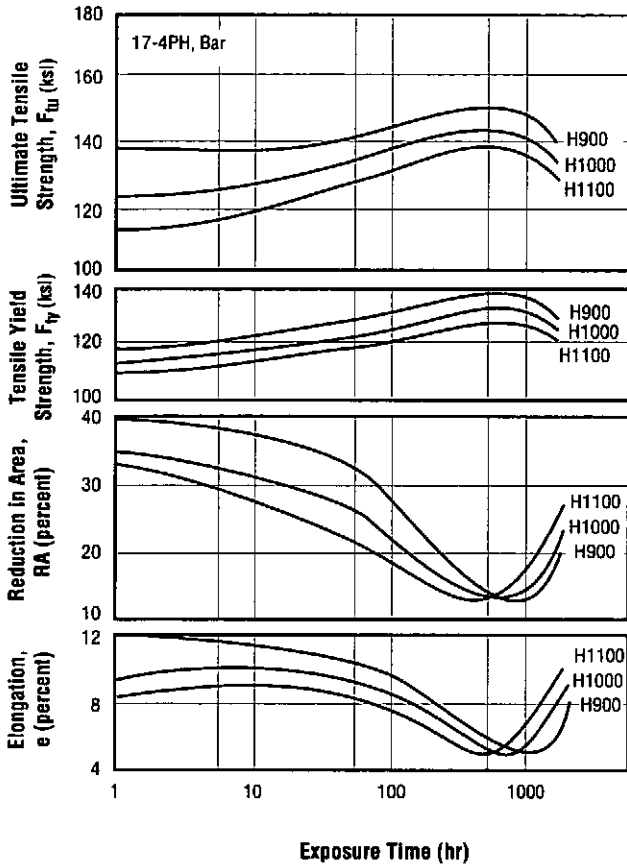


Figure 3.3.1.7 Effects of long-time exposures at 900F on tensile properties at 900F of bar in three heat-treated conditions (Ref. 23)

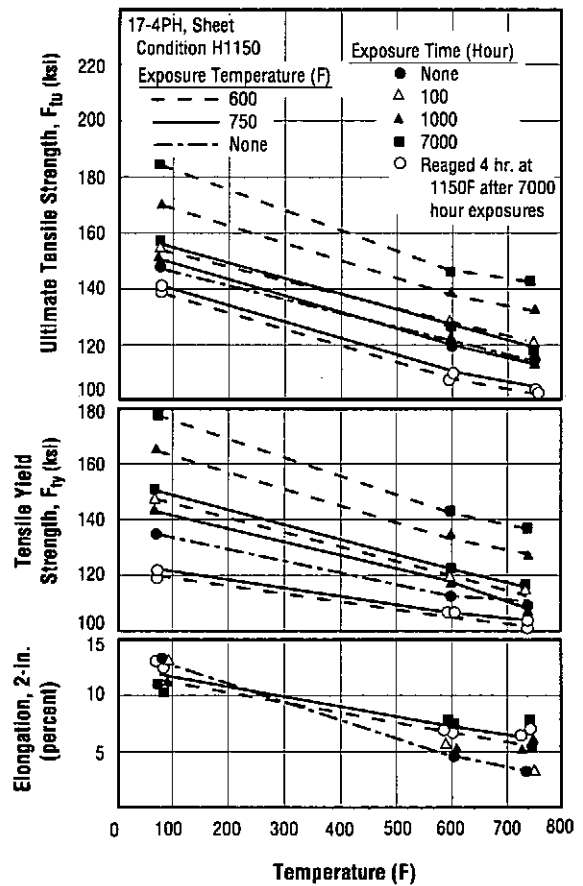


Figure 3.3.1.8 Tensile properties at room and elevated temperatures after exposures up to 7000 hours at 600F and 750F of sheet initially in Condition H1150 (Ref. 20)

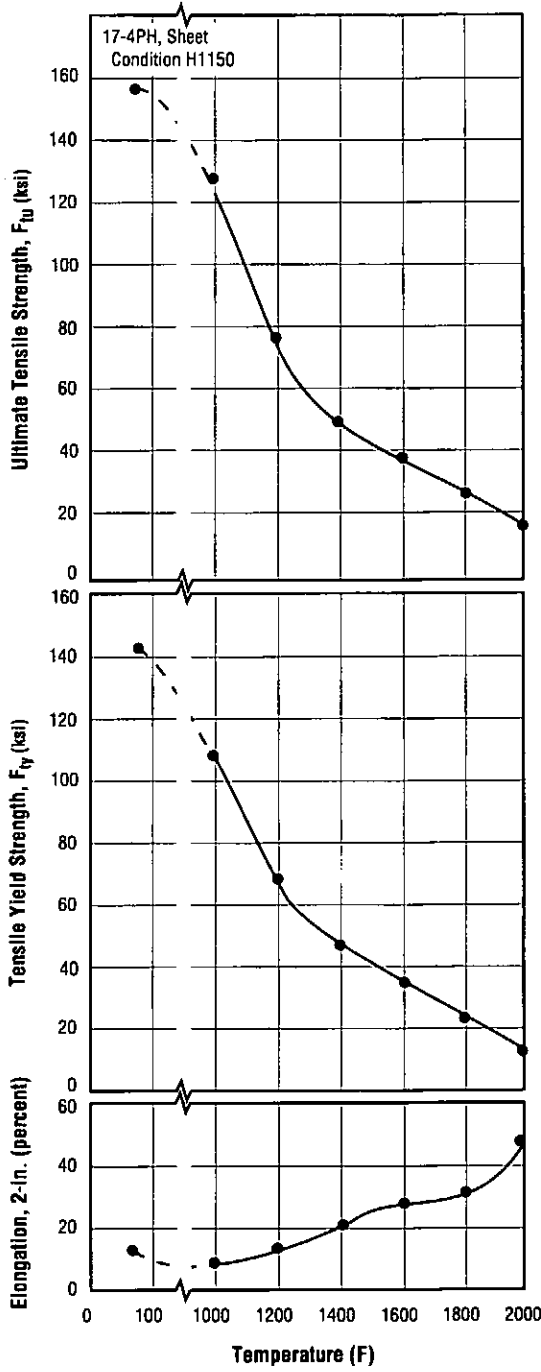


Figure 3.3.1.9 Tensile properties of sheet at temperatures from 100F and 2000F after exposures of 30 seconds at test temperature (Ref. 20)

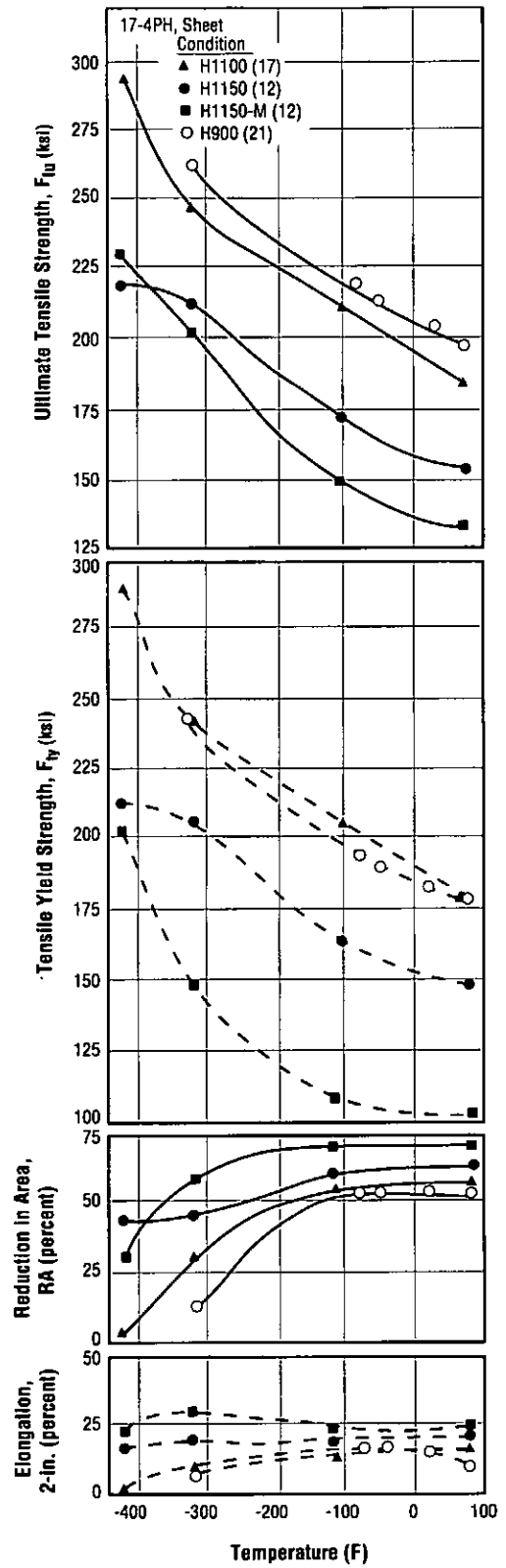


Figure 3.3.1.10 Low-temperature tensile properties of bar in various heat-treated conditions (Refs. 12, 17, 21)

17-4PH

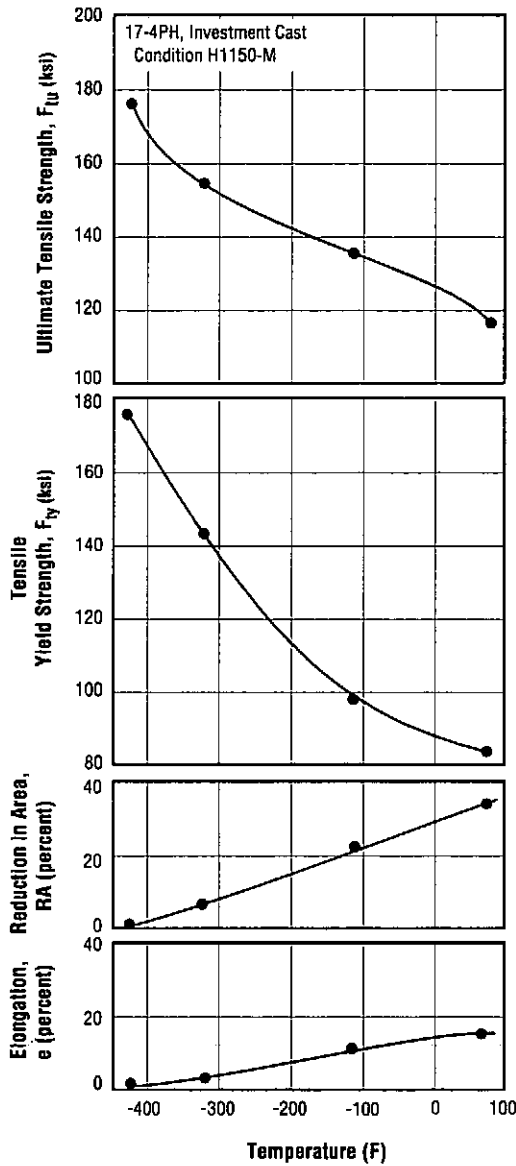


Figure 3.3.1.11 Low-temperature tensile properties of investment castings in Condition H1150-M (Ref. 13)

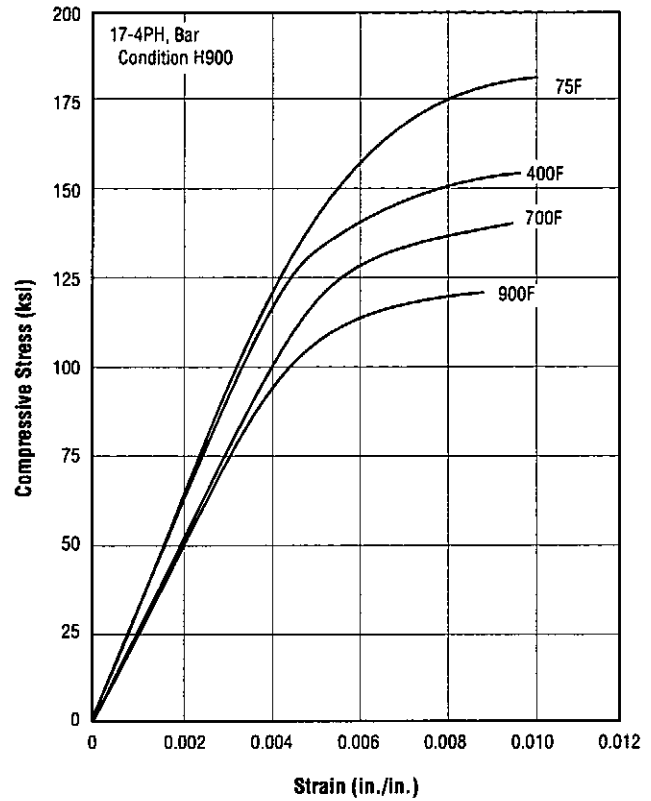


Fig. 3.3.2.1 Compressive stress-strain curves for bar at room and elevated temperatures (Ref. 11)

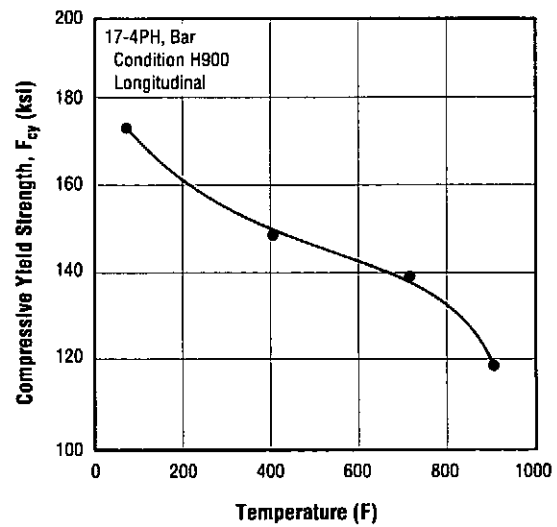


Fig. 3.3.2.2 Effect of elevated temperatures on compressive strength of bar (Ref. 11)

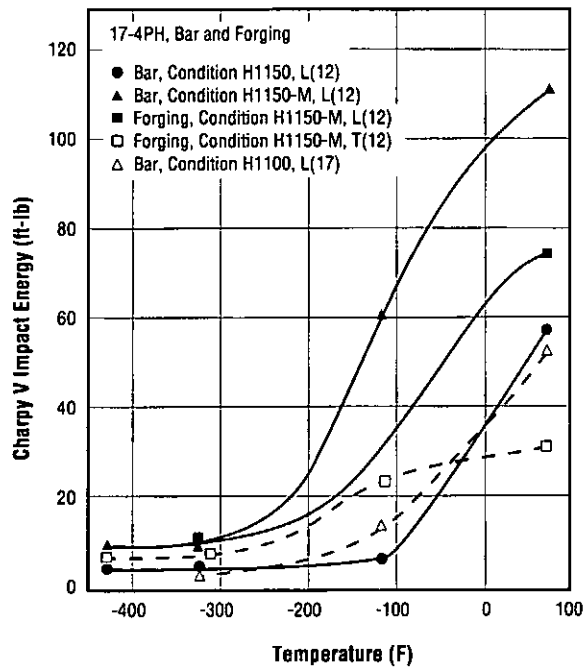


Fig. 3.3.3.1 Low-temperature impact properties of bar and forgings in several overaged conditions (Refs. 12, 17)

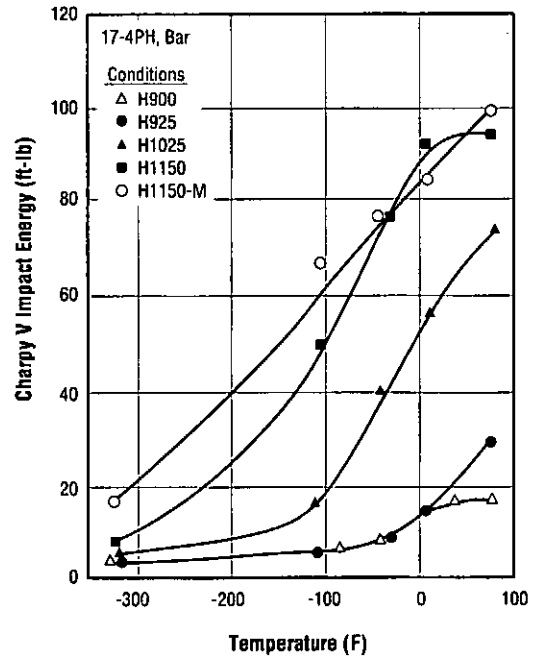


Fig. 3.3.3.2 Low-temperature impact properties of bar in various heat-treated conditions (Ref. 21)

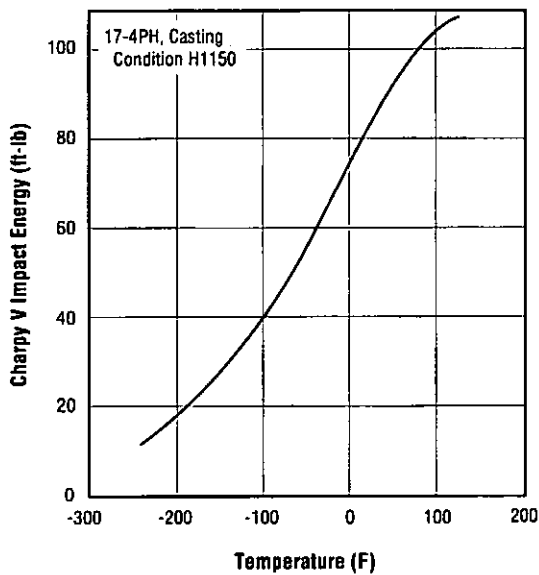


Fig. 3.3.3.3 Low-temperature impact properties of castings in an overaged condition (Ref. 71)

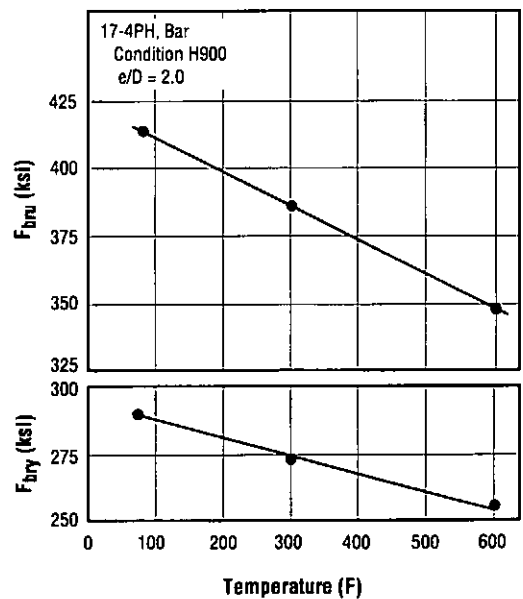


Fig. 3.3.6.1 Effect of elevated temperatures on bearing properties (Ref. 1)

17-4PH

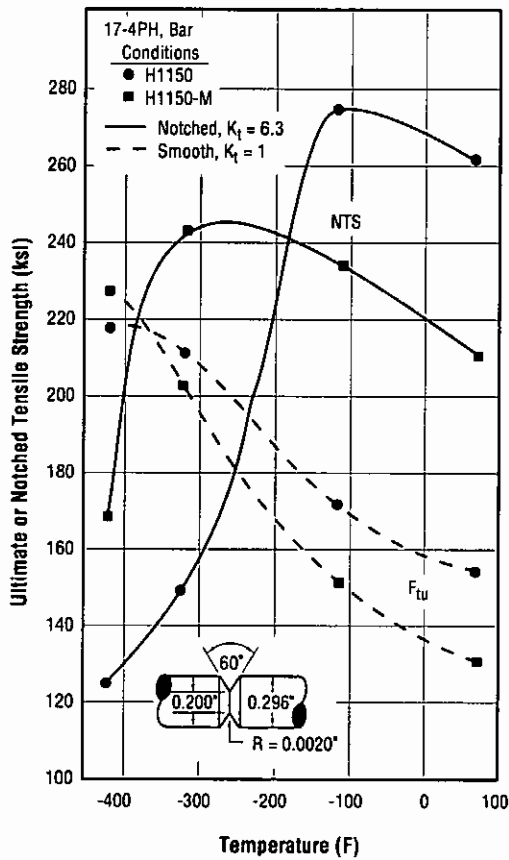


Fig. 3.3.7.1.1 Comparison of low-temperature notch tensile strength with ultimate tensile strength of bar in two overaged conditions (Ref. 12)

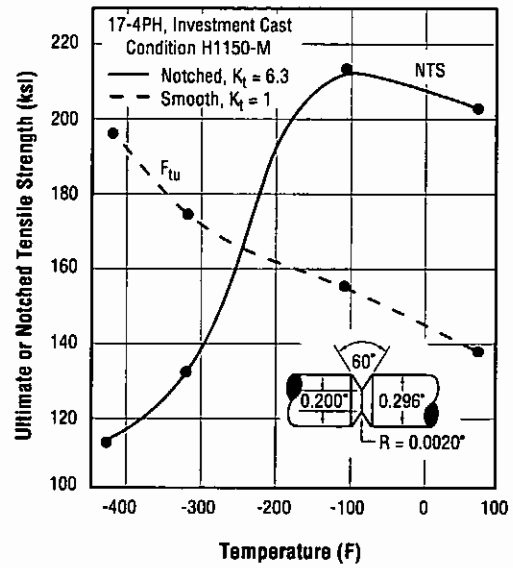


Fig. 3.3.7.1.2 Comparison of low-temperature notch tensile strength with ultimate tensile strength of investment casting in Condition H1150-M (Ref. 13)

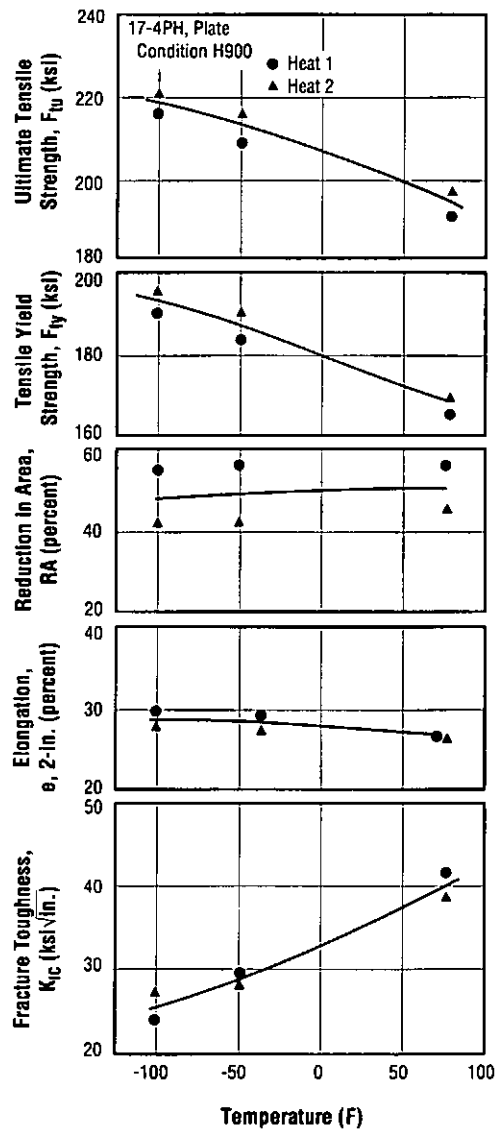


Fig. 3.3.7.2.1 Comparison of low-temperature tensile and fracture-toughness properties of plate in Condition H900 (Ref. 19)

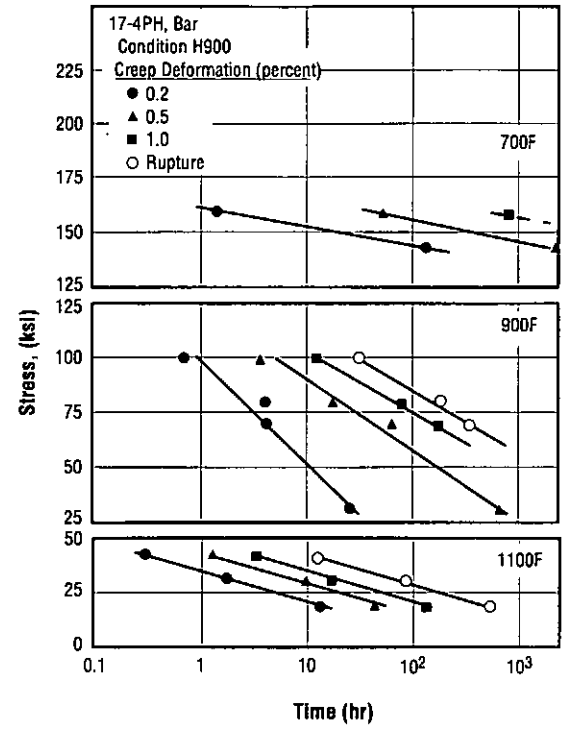


Fig. 3.4.1 Creep and rupture curves for bar at 700F, 900F, and 1100F (Ref. 11)

17-4PH

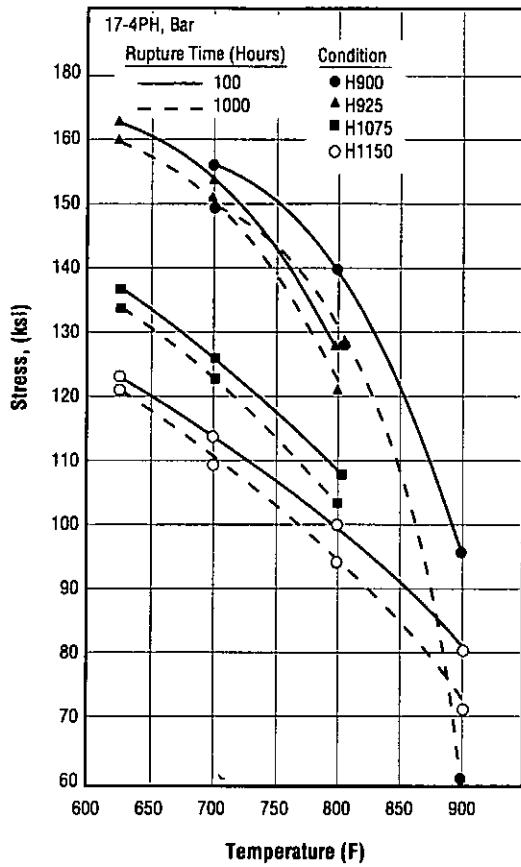


Fig. 3.4.2 Effects of temperature on stress to cause creep rupture in 100 and 1000 hours for bar in various heat-treated conditions (Ref. 21)

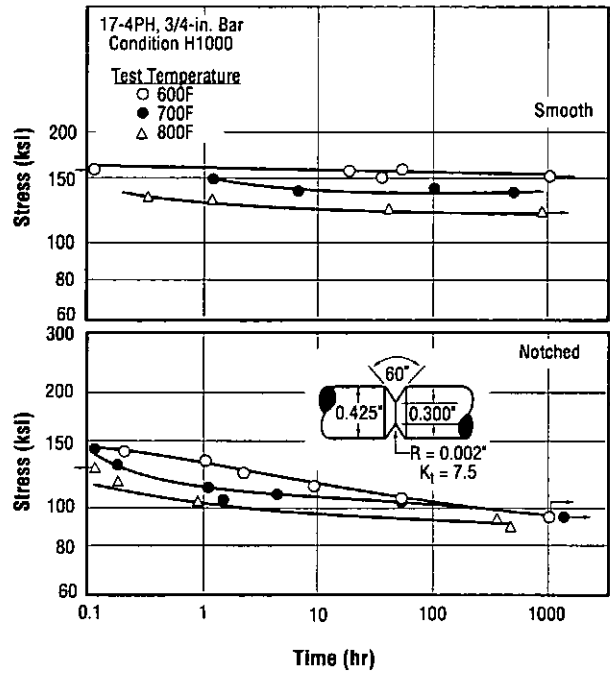


Fig. 3.4.3 Creep-rupture curves at 600 to 800F for smooth and notched bars in Condition H1000 (Ref. 43)

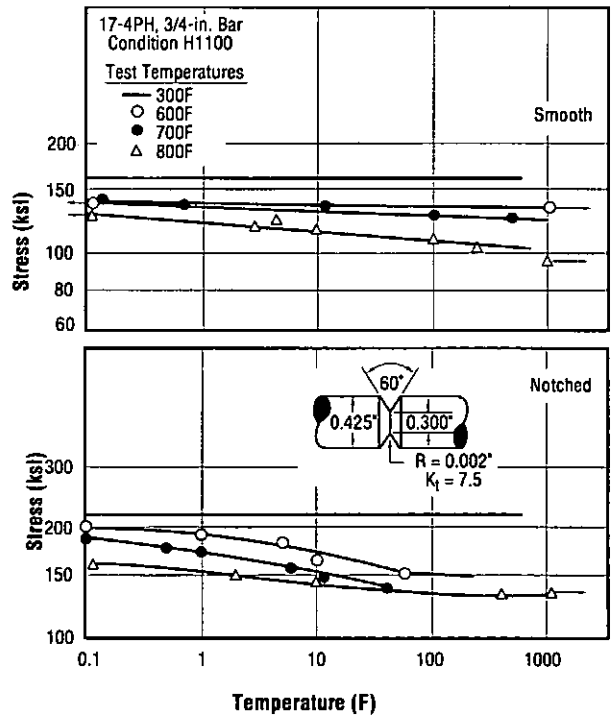


Fig. 3.4.4 Creep-rupture curves at 300 to 800F for smooth and notched bars in Condition H1100 (Ref. 43)

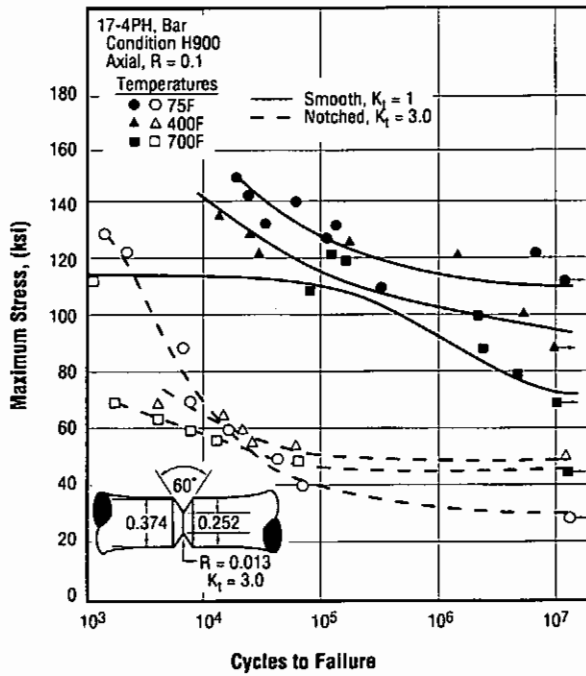


Fig. 3.5.1.1 Fatigue properties of smooth and notched bars at room and elevated temperatures (Ref. 11)

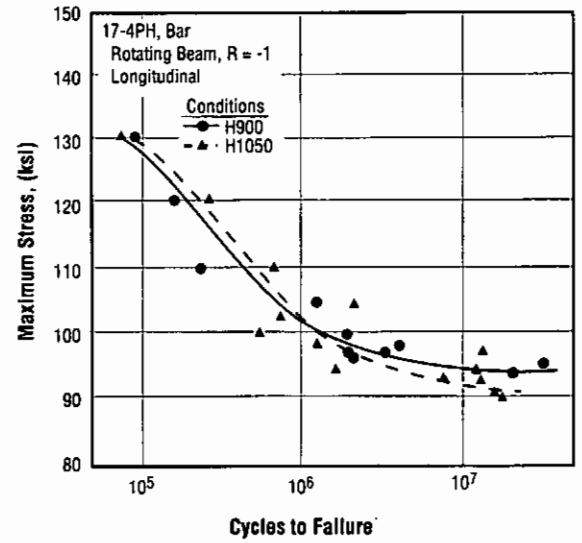


Fig. 3.5.1.2 Fatigue properties of bar in Conditions H900 and H1050 at room temperature (Ref. 14)

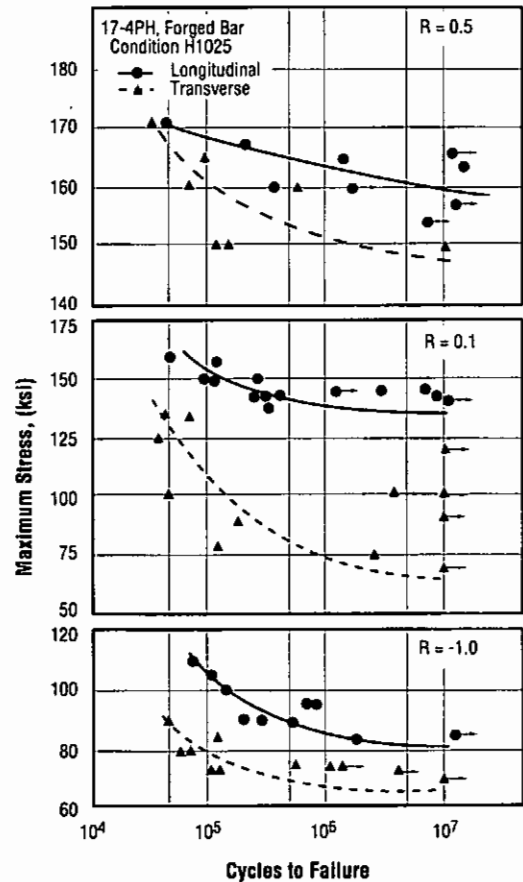


Fig. 3.5.1.3 Effects of stress ratio (R) on fatigue properties of forged bar in longitudinal and transverse orientations at room temperature (Ref. 24)

17-4PH

Table 3.5.1.4 Rotating beam fatigue strength at 10^7 and 10^8 cycles of bar in various heat-treated conditions (Ref. 21)

Alloy		17-4PH	
Form		Bar	
Condition	Temperature (F)	Fatigue Strength ^a (ksi) at	
		10^7 cycles	10^8 cycles
H900	75	90	73
H925		88	74
H1025		83	78
H1150		90	
H900	600	77	62
H1025		75	65

^a Rotating Beam, R = -1.

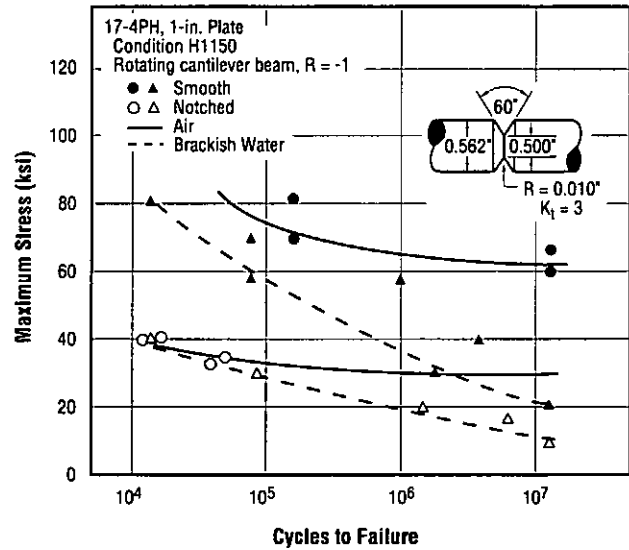


Fig. 3.5.1.5 Fatigue properties of smooth and notched specimens in air and brackish water at room temperature (Ref. 15)

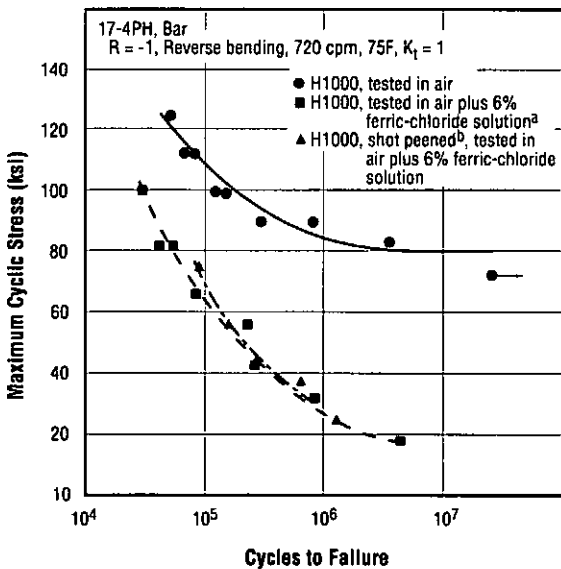


Fig. 3.5.1.6 Effects of chloride environment and shot peening on the fatigue properties of bar (Ref. 24)

Notes:

- ^a 6% water solution of ferric chloride dripped onto specimens at a controlled rate during testing.
- ^b Peened with steel shot, size S230 to a Almen intensity of 0.004 to 0.008 inch.

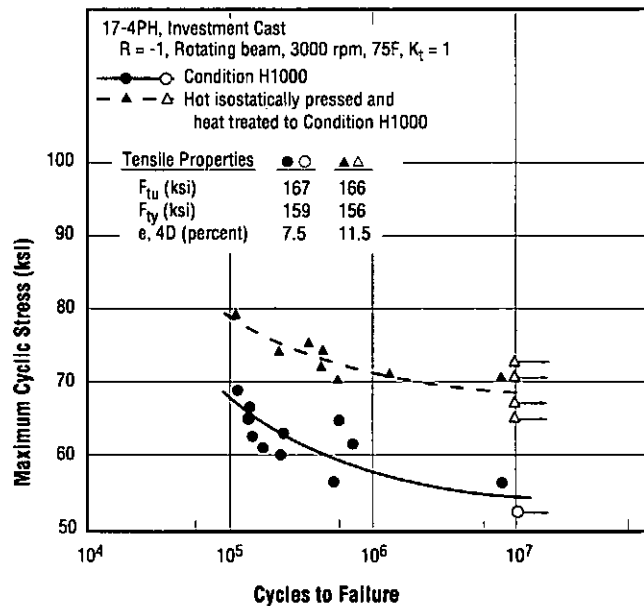


Fig. 3.5.1.7 Effects of hot isostatic pressing (HIP), 4 hr. at 2050F in 15,000 psi argon, on fatigue and tensile properties of investment castings (Ref. 61)

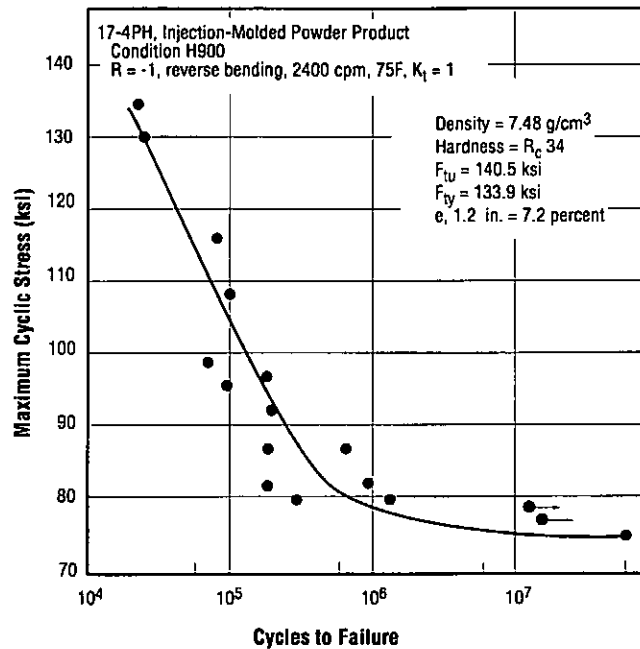


Fig. 3.5.1.8 Bending fatigue and other properties of powder-metal products made by injection-molding process (Ref. 54)

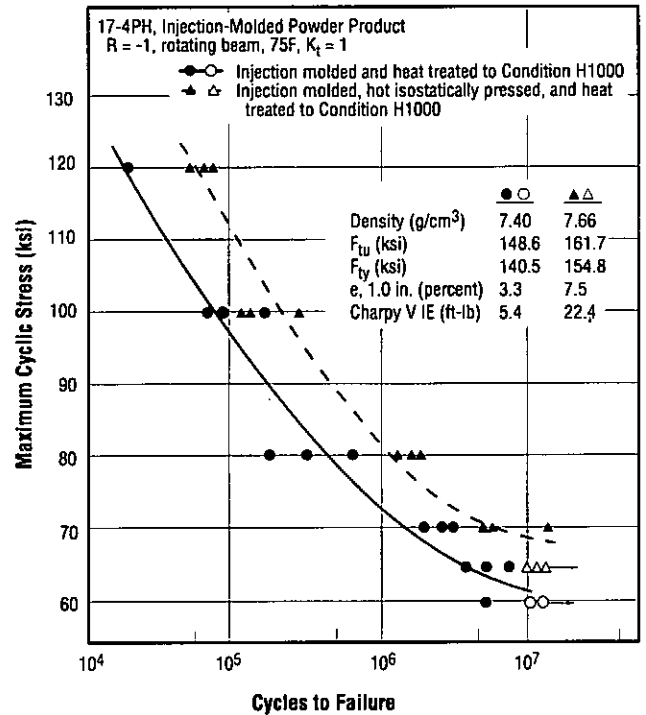


Fig. 3.5.1.9 Effect of hot isostatic pressing (HIP), 2 hours at 2125F in 15,000 psi argon, on fatigue and other properties of powder products made by injection molding (Ref. 60)

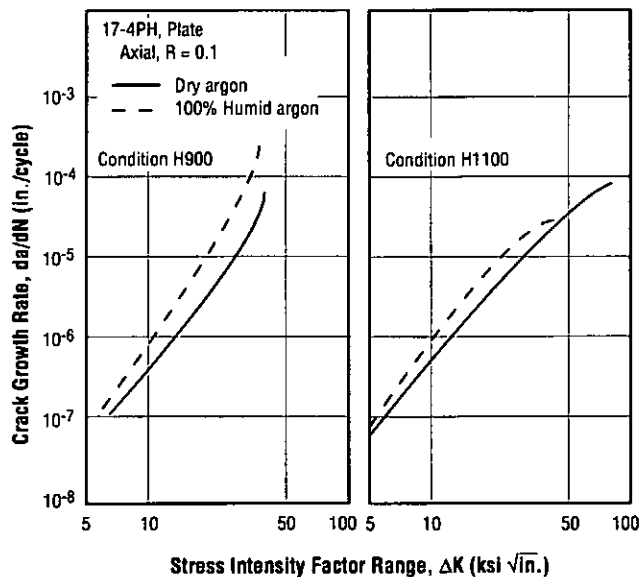


Fig. 3.5.3.1 Fatigue-crack growth rate as a function of stress-intensity-factor range in atmospheres of dry argon and humid argon (Ref. 18)

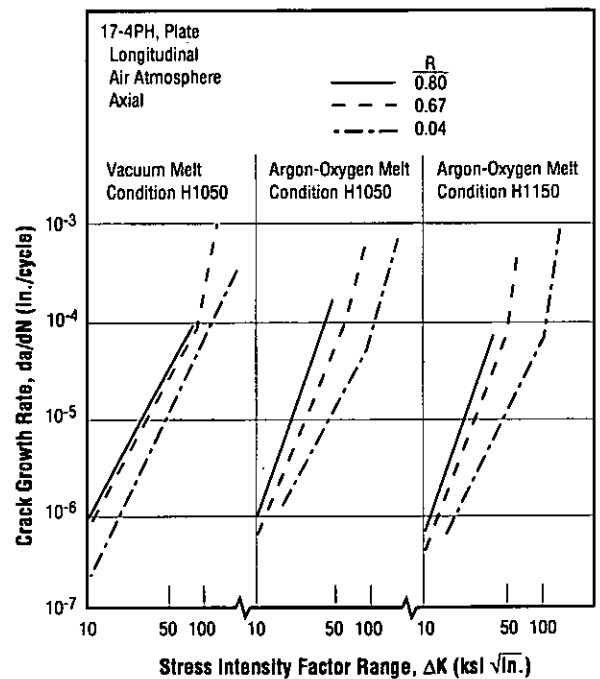


Fig. 3.5.3.2 Fatigue-crack growth rate as a function of stress-intensity-factor range with variations in melting practice, heat-treatment, and stress ratio (R) (Ref. 48)

17-4PH

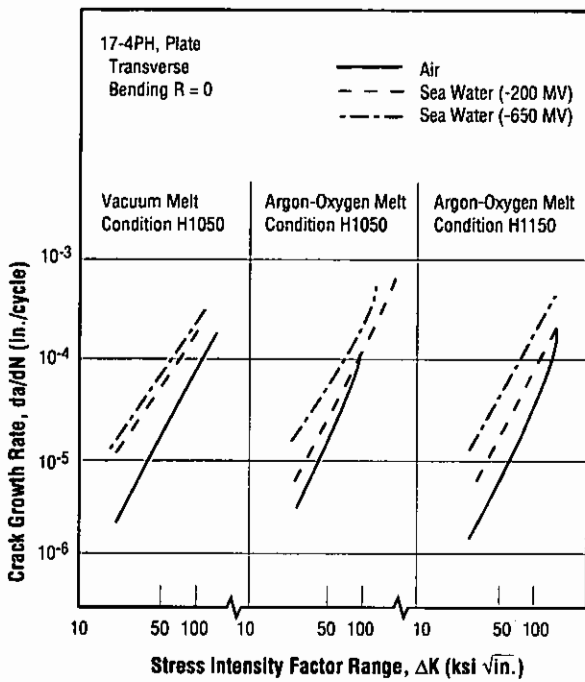


Fig. 3.5.3.3 Fatigue-crack growth rate as a function of stress-intensity-factor range in air and in flowing sea water with different applied negative electrochemical potentials and with variations in melting practice and heat-treatment (Ref. 48)

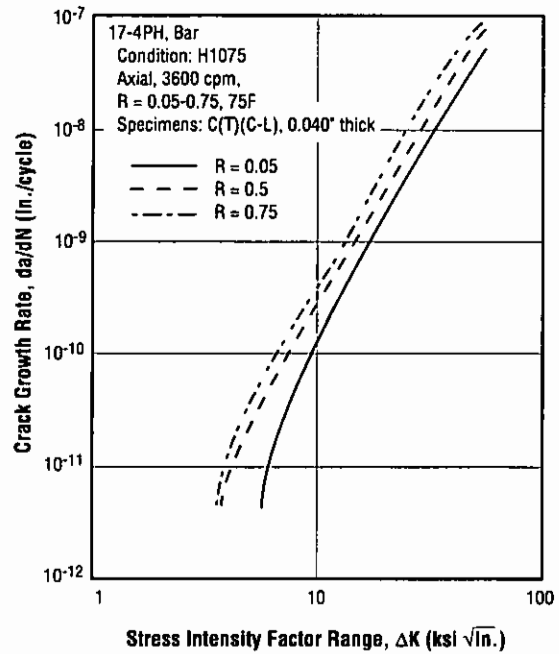


Fig. 3.5.3.4 Effects of stress ratio (R) on fatigue-crack growth rates at low (near threshold) stress-intensity levels (Ref. 62)

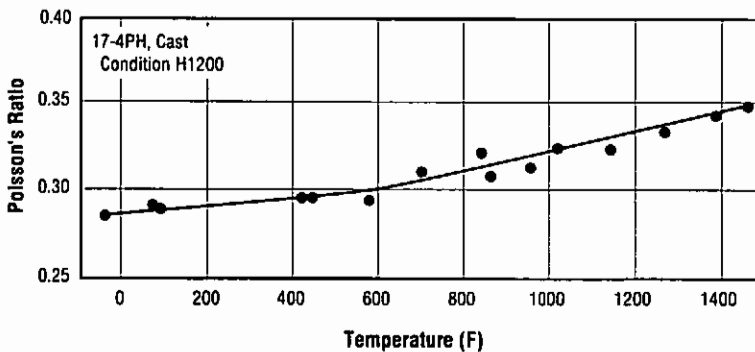


Fig. 3.6.1.1 Poisson's ratio of overaged casting determined by ultrasonic techniques at temperatures from -45 to 1465F (Refs. 67, 68)

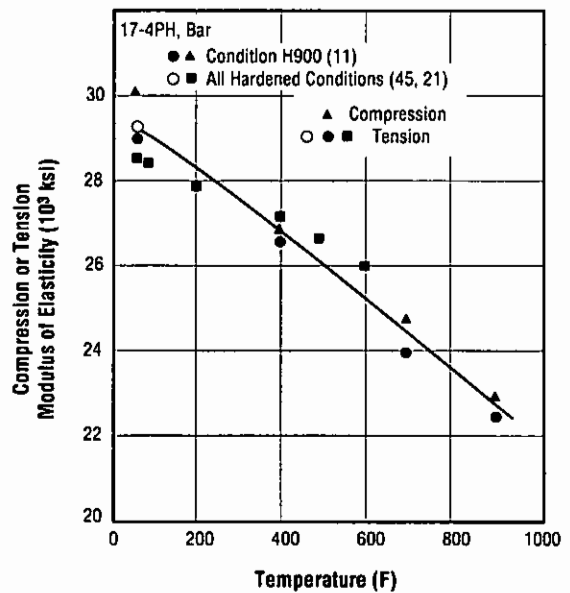


Fig. 3.6.2.1 Effects of elevated temperatures on static modulus of elasticity in both tension and compression (Refs. 11, 21, 45)

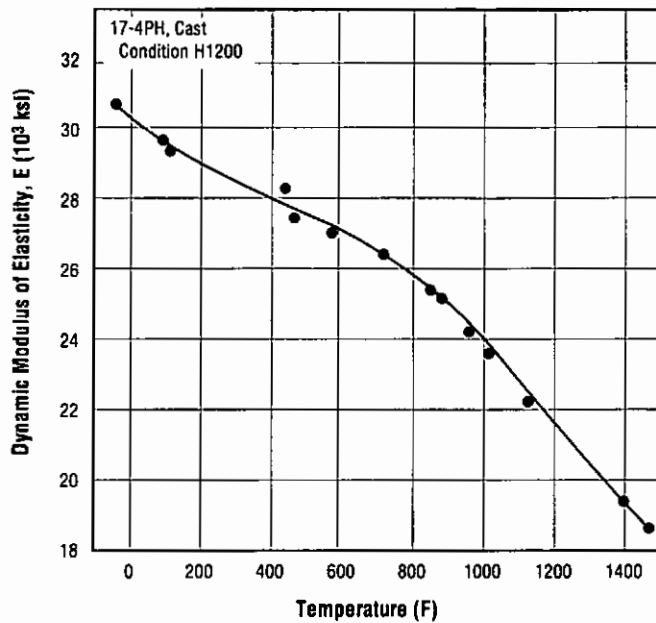


Fig. 3.6.2.2 Dynamic modulus of elasticity of overaged casting at temperatures from -45 to 1465F (Refs. 67, 68)

Table 3.6.3.1 Modulus of rigidity for various heat-treated conditions (Ref. 25)

Alloy	17-4PH
Form	Bar
Condition	G (10 ³ ksi)
A	9.68
H900	11.00
H925	10.70
H1025	10.70
H1100	10.80
H1150	10.10
H1150-M	9.50

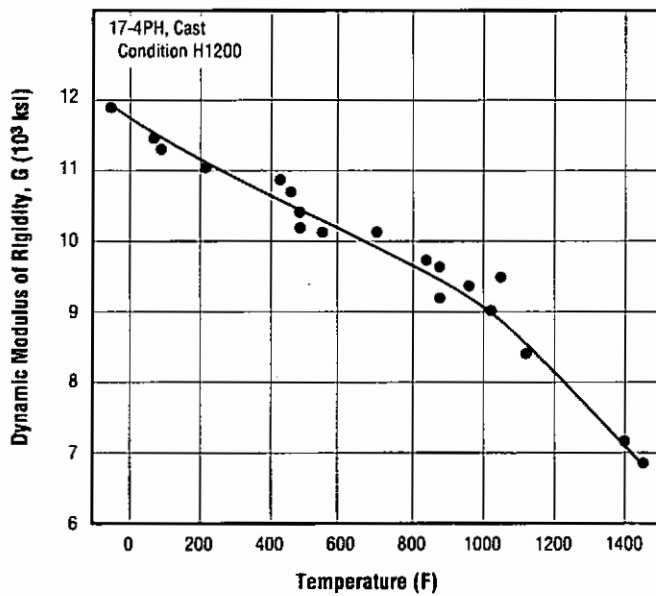


Fig. 3.6.3.2 Dynamic modulus of rigidity of overaged casting at temperatures from -45 to 1465F (Refs. 67, 68)

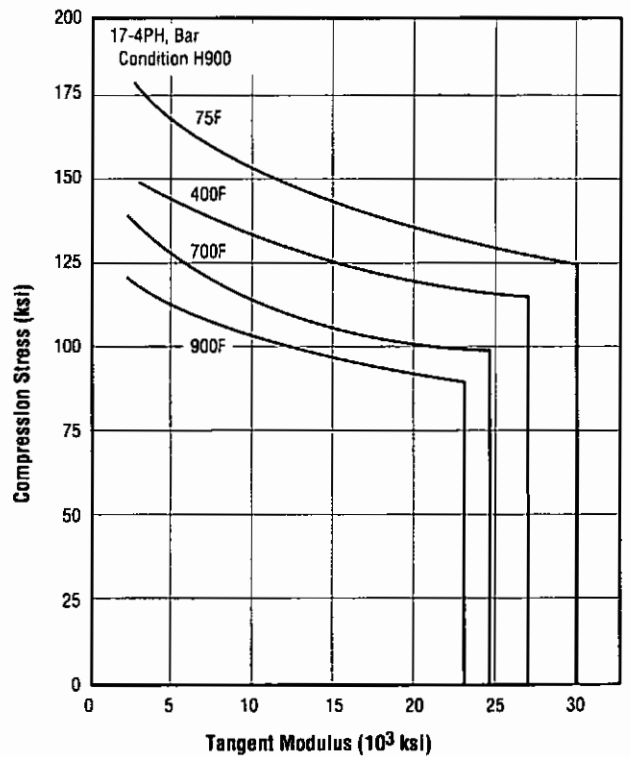


Fig. 3.6.4.1 Tangent modulus curves in compression at room and elevated temperatures (Ref. 11)

17-4PH

Table 4.1.1.1 Minimum radius to make indicated cold bend with no fissuring when viewed under 10X magnification (Refs. 23, 49)

Alloy	17-4PH					
Form	Sheet and Strip, 0.015 to 0.109 in. thick					
Condition	90° Bend		135° Bend		180° Bend	
	L	T	L	T	L	T
A	3T	4T	3T	5T	6T	9T
H900	3T	4T	3T	6T	5T	9T
H925	2T	4T	3T	6T	5T	9T
H1025	2T	4T	3T	6T	4T	7T
H1075	2T	4T	3T	4T	4T	7T
H1150	2T	2T	2T	3T	4T	6T

Table 4.1.2.1 Tensile properties of sheet and strip warm stretch formed during cooling from solution-treatment temperature (1900F) and subsequently aged (Ref. 49)

Alloy		17-4PH			
Form		Sheet and Strip			
Warm Forming Temperature (F)	% Stretch in 2 in.	Aging Temp., 4 hr. (F)	F _{ty} (ksi)	F _{TU} (ksi)	e, 2 in. (percent)
a	a	900	173.8	195.0	11.0
500	9.0		198.0	202.2	9.0
650	33.5	none	133.6	162.4	6.0
	16.0	900	168.7	190.8	
	20.0		171.8	190.5	
	35.0		181.4	194.6	
		1050	155.0	160.0	7.5
800	42.0	none	116.0	155.8	7.0
	22.0	900	166.6	178.4	11.0
	47.5		176.0	190.0	8.0

^a Standard H900, not stretch formed.

Table 4.2.1 Relative machinability of 17-4PH bar in various heat-treated conditions (Ref. 21)

Alloy	17-4PH		
Form	Bar		
Condition	Hardness, Rockwell C	Cutting Rate, SF/M ^a (Automatics)	Comments
H1150-M	27	100-130	Best cutting rate. Surface not as good as other heat-treated conditions.
H1150	33	80-100	Machinability improves as hardening temperature increases. Higher cutting rates obtained with some sacrifice in surface finish.
H1100	34	75-95	
H1075	36	70-90	
A (Solution Treated)	34	60-80	Machinability, cutting rate, and surface finish comparable to Types 302 and 304.
H1025	38	50-70	Machinability improves as hardening temperature increases.
H925	42	30-50	
H900	44	20-30	High hardness and strength limit machinability. Carbide cutters needed for maximum production.

^a SF/M = surface feet per minute.

Table 4.3.1.1 Variations in tensile properties with section size and postweld treatment for butt welds made by the manual-shielded-metal-arc technique with 17-4PH electrodes (Ref. 23)

Alloy	17-4PH					
Condition	A (Before Welding)					
Form	Postweld Treatment	F _{ty} (ksi)	F _{tu} (ksi)	e, 2 in. (percent)	RA (percent)	Fracture Location
1-in. thick flat bars ^a	900F age	118	158	8.0	21.0	Weld
	1000F age	108	155	9.5	27.0	
	1100F age	111	158	7.5	18.5	
	H900	163	186	9.5	36.0	
	H1000	146	167		39.0	
	H1100	129	158	11.0	38.0	
3/4-in. thick flat bars ^b	900F age	154	178	10.0	32.0	Base
	1000F age	136	160	11.0	29.0	Weld
	1100F age	112	159	13.5	50.0	Base
	H900	172	187	11.0	48.0	Weld
	H1000	161	170	12.0		
	H1100	134	158		54.0	

^a Standard 0.505-inch tensile specimens taken transverse to weld axis.

^b Subsize 0.200-inch tensile specimens taken transverse to weld axis.

Table 4.3.1.2 Comparison of tensile properties of sheet with those of sheet containing a transverse butt weld made by the automatic GTA technique with 17-4PH weld wire (Ref. 8)

Alloy	17-4PH			
Condition	H900			
Form	0.090-in Sheet			
Specimens	Orientation	F _{ty} (ksi)	F _{tu} (ksi)	e, 2 in. (percent)
Base Metal	L	178	199	8.4
	T	181	202	7.6
Welded ^{a,b}	L	178	201	9.5

^a Failed in base metal.

^b Fully solution treated and aged to Condition H900 after welding; no preheat.

17-4PH

4.3.1.3 Tensile properties of sheet containing a transverse butt weld made by the GMA technique with 17-4PH weld wire (Ref. 23)

Alloy	17-4PH		
Condition	A (Before Welding)		
Form	0.188-in. Sheet		
Postweld Treatment	F _{ty} (ksi)	F _{tu} (ksi)	e, 2 in. (percent)
H900	181	203	7.0
H950	174	185	7.5
H1025	163	173	

Tensile-test fractures occurred in the welds.

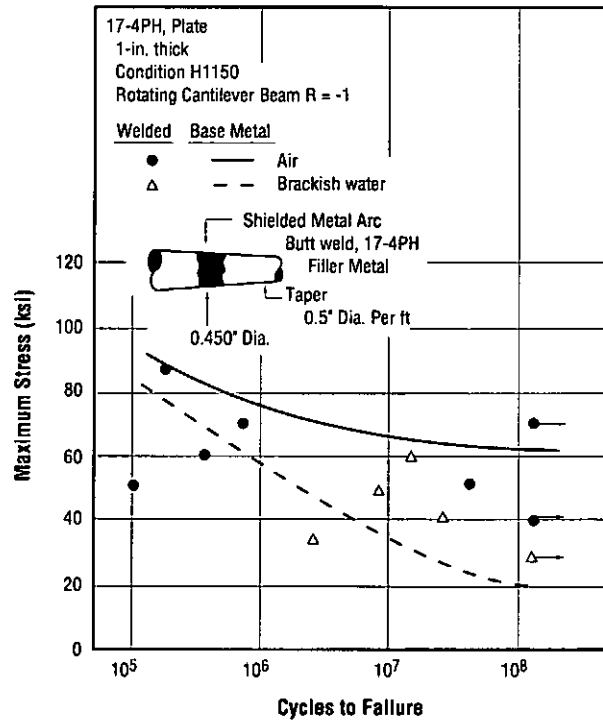


Fig. 4.3.1.4 Comparison of fatigue properties of base metal and shielded-metal-arc weldments fully heat treated after welding (Ref. 15)

4.3.1.5 Tensile properties of flash-butt welds in bars (Ref. 23)

Alloy	17-4PH				
Condition	A (Before Welding)				
Form	Bars ^a				
Postweld Treatment	F _{ty} (ksi)	F _{tu} (ksi)	e, 2 in. (percent)	RA (percent)	Fracture Location
900F age	b	182	14.2	b	Base Metal
H900	184	203	8.0	37.0	Weld

^a -Standard 0.505-in. tensile test bars used.

^b Not reported.

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