2.6.6 PH13-8Mo

2.6.6.0 *Comments and Properties* — PH13-8Mo is a martensitic precipitation-hardening stainless steel used for parts requiring corrosion resistance, high strength, high fracture toughness, and oxidation resistance up to 800°F. When used at temperatures between 600°F and 800°F, some loss in notch toughness will occur. The loss is time-temperature dependent and will occur gradually over thousands of hours at 600°F and hundreds of hours at 800°F. Depending upon the application, this loss in notch toughness may not be important and useful engineering properties may still be available. Good transverse mechanical properties are one of the major advantages of PH13-8Mo. PH13-8Mo is produced by double vacuum melting and is available in the form of forgings, plate, bar, and wire, normally furnished in the solution-treated (A) condition.

Manufacturing Considerations — Forming, joining, and machining operations are usually performed on material in Condition A, using similar procedures and equipment to those employed for other precipitation-hardening stainless steels. Best machinability is exhibited by Conditions H1150 and H1150M. A dimensional contraction of 0.0004 to 0.0006 and 0.0008 to 0.0012 in./in. occurs upon hardening to the H1000 and H1100 conditions, respectively.

Heat Treatment — PH13-8Mo must be used in the heat-treated condition and should not be placed in service in Condition A. The alloy can be heat treated to various strength levels having a wide range of properties. Consult the applicable material specification or MIL-H-6875 for specific heat treatment procedures.

Environmental Considerations — PH13-8Mo is nearly equal to 17-4PH in general corrosion resistance and surpasses the other hardenable stainless steels in stress-corrosion resistance. However, for tensile application where stress corrosion is a possibility, PH13-8Mo should be aged at the highest temperature compatible with strength requirements and at a temperature not lower than 1000°F for 4 hours minimum aging time.

Specification and Properties — A material specification for PH13-8Mo is presented in Table 2.6.6.0(a). The room-temperature mechanical and physical properties for PH13-8Mo are presented in Table 2.6.6.0(b) and (c). The physical properties of this alloy at elevated temperatures are presented in Figure 2.6.6.0.

Table 2.6.6.0(a). Material Specification for PH13-8Mo Stainless Steel

Specification	Form
AMS 5629	Bar, forging, ring, and extrusion (VIM plus CEVM)

2.6.6.1 *H950 and H1000 Conditions* — Elevated temperature curves for tensile yield and ultimate strengths are presented in Figure 2.6.6.1.1. Typical tensile and compressive stress-strain and tangent-modulus curves for the H1000 condition at room temperature are depicted in Figures 2.6.6.1.6(a) and (b). Figure 2.6.6.1.6(c) contains typical full-range stress-strain curves at room temperature for various heat-treated conditions. Unnotched and notched fatigue information for H1000 condition at room temperature is presented in Figures 2.6.6.1.8(a) through (c).

2.6.5 CUSTOM 465

2.6.5.0 *Comments and Properties* — Custom 465® stainless is a double-vacuum melted, martensitic, age-hardenable alloy. This alloy was designed to have excellent notch tensile strength and fracture toughness over a wide range of section sizes. In the H950 condition, the alloy achieves a minimum ultimate tensile strength of 240 ksi while retaining good toughness and resistance to stress-corrosion cracking. Overaging to the H1000 condition provides a greater level of toughness at a minimum ultimate tensile strength of 220 ksi. Custom 465 stainless provides a superior combination of strength, toughness and stress corrosion cracking resistance compared with other high-strength PH stainless alloys such as Custom 455® stainless or PH13-8Mo® stainless. Other combinations of strength and toughness are possible employing age-hardening temperatures between 900°F and 1150°F. Custom 465 stainless is available in the form of forgings, billet, bar, wire and strip.

Manufacturing Considerations —Custom 465 stainless normally is supplied and fabricated in the solution-annealed condition. Billet products will be provided in the hot finished condition. Forming, machining, and joining operations are similar to those employed for other precipitation-hardening stainless steels. Optimum weld strength and ductility are obtained by postweld solution annealing and subzero cooling prior to aging. Pyromet®X23 stainless filler metal should be considered under multi-bead GMA welding conditions.

Heat Treatment —Among the corrosion-resistant alloys of its type, Custom 465 stainless provides the highest minimum combinations of strength and toughness in the H950 and H1000 conditions. Usually, parts are aged directly from the mill-supplied, solution-annealed condition. However, if material has been hot worked or welded, components should be reannealed (1800°F/982°C) and subzero cooled (-100°F/-73°C, 8-hour hold) prior to age hardening. Components should be cooled rapidly from the annealing temperature. Section sizes up to 12" (305 mm) can be cooled in a suitable liquid quench medium. The subsequent subzero treatment should be applied within 24-hours of solution annealing. The refrigeration treatment after annealing is important for achieving optimum aging response by eliminating small amounts of retained austenite from the microstructure. The mill-supplied solution anneal includes the subzero treatment.

Aging treatments are performed by heating components to the specified temperature, holding for four hours, followed by cooling in air, oil or other suitable liquid quench medium. The 4-hour aging cycle is important developing optimum toughness and ductility at the specified strength levels. Increased cooling rates from the aging temperature tend to improve toughness and ductility and may be beneficial for 3" (76mm) section sizes and greater.

Environmental Considerations — The general corrosion resistance of Custom 465 stainless approaches that of Type 304 stainless. Exposure to 5% neutral salt spray at 95°F (35°C) (per ASTM B117) caused little or no corrosion after 200 hours regardless of condition (i.e., annealed or H900-H1100 conditions).

Double cantilever beam tests conducted in 3.5% NaCl (pH 6) show Custom 465 stainless to possess inherently good resistance to stress corrosion cracking which improves with increasing aging temperature. Typical results for 1/2" thick double cantilever beam specimens (T-L orientation) from 4-1/2" x 2-3/4" forged bar exposed to 3.5 wt. % NaCl (pH 6) for 1270 hours by constant immersion per NACE Standard TM0177-96 (Reference 2.6.5.0), are shown in Table 2.6.5.0(a).

Table 2.6.5.0(a). Typical Stress Corrosion Cracking Resistance[a]

Condition	TYS (T), ksi	K_{Iscc}, ksi√in.	Remarks
H950	226	68	No cracking
H1000	213	98	No cracking

a Double-cantilever-beam, wedge loaded, constant immersion in 3.5% NaCl (pH 6) per NACE Standard TM0177-96. See Reference 2.6.5.0.

Typical tensile properties following exposure to elevated temperatures for 200 and 1000 hours are shown in Table 2.6.5.0(b).

Table 2.6.5.0(b). Effect of Elevated Temperature Exposure on Typical Tensile Properties of Custom 465 Alloy[a]

Condition	Exposure Temp., °F	Exposure Time, Hours	Room-temperature properties			
			UTS, ksi	TYS, ksi	e, %	RA, %
H950	Room Temp.	Unexposed	255	238	14	62
	600	200	258	240	14	61
	700	200	266	249	13	59
	800	200	266	249	14	58
	900	200	236	223	15	64
	600	1000	259	242	16	59
	700	1000	268	250	14	56
	800	1000	272	253	13	54
	900	1000	223	211	19	67
H1000	Room Temp.	Unexposed	231	218	16	66
	600	200	234	220	14	66
	700	200	241	226	15	64
	800	200	240	226	14	66
	900	200	230	218	16	66
	600	1000	232	219	18	65
	700	1000	240	226	16	64
	800	1000	245	229	15	62
	900	1000	222	210	20	66

a Data from 1 heat, 4.5" x1.5" forged bar, duplicate tests

Specifications and Properties — Material specifications for Custom 465 are shown in Table 2.6.5.0(c). The room-temperature mechanical properties are presented in Tables 2.6.5.0(b).

Table 2.6.5.0(c). Material Specifications for Custom 465 Stainless Steel

Specification	Form
AMS 5936	Bars, Wires, and Forgings

2.6.5.1 *H950 and H1000 Condition* — Figure 2.6.5.1(a) presents the typical tensile stress-strain curves at room temperature. Figures 2.6.5.1(b) and (c) present the full-range tensile stress-strain curves at room temperature for the H950 and H1000 conditions.