Technical Reference on Hydrogen Compatibility of Materials

High-Alloy Ferritic Steels:
Semi-Austenitic Stainless Steels (code 1700)

Prepared by:

C. San Marchi, Sandia National Laboratories, Livermore CA

Editors
C. San Marchi
B.P. Somerday
Sandia National Laboratories

This report may be updated and revised periodically in response to the needs of the technical community; up-to-date versions can be requested from the editors at the address given below or downloaded at http://www.ca.sandia.gov/matlsTechRef/. The content of this report will also be incorporated into a Sandia National Laboratory report (SAND2008-1163); the most recent version can be obtained from the link above. The success of this reference depends upon feedback from the technical community; please forward your comments, suggestions, criticisms and relevant public-domain data to:

Sandia National Laboratories
Matls Tech Ref
C. San Marchi (MS-9402)
7011 East Ave
Livermore CA 94550.

This document was prepared with financial support from the Safety, Codes and Standards program element of the Hydrogen, Fuel Cells and Infrastructure program, Office of Energy Efficiency and Renewable Energy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Sandia National Laboratories

Technical Reference on Hydrogen Compatibility of Materials

High-Alloy Ferritic Steels:

Semi-Austenitic Stainless Steels (code 1700)

1. General

The semi-austenitic stainless steels are precipitation-strengthened alloys that can be heat treated to a range of mechanical properties [1, 2]. These alloys are used for their combination of high strength, high toughness, and corrosion resistance. Alloy 17-7PH is commonly used as a spring material to temperatures as high as 590 K [3]. Semi-austenitic stainless steels, however, have low fracture toughness in high strength conditions and at low (subzero) temperature.

In general, very little data exist for these alloys in gaseous hydrogen; however, the available data indicate that the fracture resistance of semi-austenitic stainless steels is very sensitive to gaseous hydrogen [4], a characteristic that is common to high-strength alloys. The data from notched tensile tests indicate that this class of alloys has essentially no resistance to fracture in hydrogen environments [4]. Indeed, the semi-austenitic stainless steels appear to be among the families of alloys that are most susceptible to hydrogen-assisted fracture. Based on the available data, these alloys are not recommended for stress-bearing components in hydrogen gas.

1.1 Composition and microstructure

The semi-austenitic stainless steels are variants of common austenitic stainless steels (the so-called 18-8 class) with additions of alloying elements not generally associated with the austenitic alloys, such as aluminum. Table 1.1.1 lists the approximate composition specification ranges for several common semi-austenitic stainless steels. Table 1.1.2 provides the composition of a semi-austenitic stainless steel used to study hydrogen-assisted fracture.

1.2 Common designations

Tradenames are commonly used for these alloys. Common names include 17-7PH (AISI Type 631), PH15-7Mo (AISI Type 632), AM-350 (AISI Type 633), AM-355 (AISI Type 634) and PH14-8Mo. The alloy designation 17-7PH refers to the nominal chromium and nickel contents (in wt %), with the addition of “PH” to indicate its status as a precipitation-hardening composition. The designation of “Mo” indicates alloying additions of molybdenum (usually about 2.5 wt%).

2. Permeability, Diffusivity and Solubility

Hydrogen permeation and diffusion data are unavailable for this class of alloys. Based on the studies of martensitic precipitation-strengthened stainless steels [5, 6], the effective hydrogen diffusivity is expected ~10^{-12} m^2/s.

3. Mechanical Properties: Effects of Gaseous Hydrogen

3.1 Tensile properties

3.1.1 Smooth tensile properties

The data in Table 3.1.1.1 show that the ductility of 17-7PH is significantly degraded when tested in high-pressure hydrogen, i.e., hydrogen reduces the ductility by 95%. This reduction in ductility is among the most severe reported for any alloy tested in hydrogen gas. Alloy AM-350 also shows severe ductility loss in the solution annealed condition [7]; degradation is expected to be more severe in high-strength conditions.

3.1.2 Notched tensile properties

The data in Table 3.1.2.1 show that the notched tensile strength of 17-7PH is extremely degraded when tested in high-pressure hydrogen. It has also been shown that partial pressures of hydrogen less than an atmosphere can significantly reduce the notched tensile strength of 17-7PH [4].

3.2 Fracture mechanics

No known published data in hydrogen gas.

3.3 Fatigue

No known published data in hydrogen gas.

3.4 Creep

No known published data in hydrogen gas.

3.5 Impact

No known published data in hydrogen gas.

3.6 Disk rupture testing

Disk rupture tests show that the fracture resistance of semi-austenitic stainless steels (AM-355) and martensitic stainless steels (17-4PH and PH13-8Mo) is extremely sensitive to gaseous hydrogen [8].

4. Fabrication

4.1 Primary processing

Compositional control is very important with these alloys [1], thus they are often produced by premium remelting processes such as vacuum-arc remelting (VAR) and electroslag remelting (ESR).

4.2 Heat treatment

These alloys typically employ complicated precipitation-strengthening treatments; more information can be found in manufacturer's data sheets and general references.

4.3 Properties of welds

The semi-austenitic stainless steels can be welded [1], although the weld properties will typically be inferior to the base metal. See also manufacturer's specifications and data sheets.

5. References

1. D Peckner and IM Bernstein. Handbook of Stainless Steels. New York: McGraw-Hill (1977).
2. RA Lula. Stainless Steel (revised from "An Introduction to Stainless Steel" by JG Parr and A Hanson). Metals Park OH: American Society for Metals (1986).
3. JR Kattus. Age Hardening Steels: Fe-17Cr-7Ni-1Al (code 1502). in: WF Brown, H Mindlin and CY Ho, editors. Aerospace Structural Metals Handbook. 2. CINDAS/UASF CRDA Handbooks Operation, Purdue University (1992).
4. RJ Walter and WT Chandler. Effects of High-Pressure Hydrogen on Metals at Ambient Temperature: Final Report. Rocketdyne (report no. R-7780-1) for the National Aeronautics and Space Administration, Canoga Park CA (February 1969).
5. LW Tsay, WC Lee, RK Shiue and JK Wu. Notch tensile properties of laser-surface-annealed 17-4 PH stainless steel in hydrogen-related environments. Corros Sci 44 (2002) 2101-2118.
6. WC Chiang, CC Pu, BL Yu and JK Wu. Hydrogen susceptibility of 17-4 PH stainless steel. Mater Lett 57 (2003) 2485-2488.
7. GR Caskey. Hydrogen Compatibility Handbook for Stainless Steels (DP-1643). EI du Pont Nemours, Savannah River Laboratory, Aiken SC (June 1983).
8. J-P Fidelle. Present status of the disk pressure test for hydrogen embrittlement. in: L Raymond, editor. Test Methods for Hydrogen Embrittlement: Prevention and Control, ASTM STP 962, American Society for Testing and Materials. (1988) p. 153-172.
9. ASTM DS-56H, Metals and Alloys in the UNIFIED NUMBERING SYSTEM (SAE HS-1086 OCT01). American Society for Testing and Materials (Society of Automotive Engineers) (2001).

Table 1.1.1. Compositions (wt%) of several common semi-austenitic (precipitation-strengthened) stainless steels [9].

UNS No	Common Name (AISI No)	Fe	Cr	Ni	Mo	Al	Mn	Si	C	other
S17700	17-7PH (Type 631)	Bal	16.00 18.00	6.50 7.75	—	0.75 1.50	1.00 max	1.00 max	0.09 max	0.040 max P; 0.040 max S
S15700	PH15-7Mo (Type 632)	Bal	14.00 16.00	6.50 7.75	2.00 3.00	0.75 1.50	1.00 max	1.00 max	0.09 max	0.04 max P; 0.03 max S
S14800	PH14-8Mo	Bal	13.75 15.00	7.75 8.75	2.00 3.00	0.75 1.50	1.00 max	1.00 max	0.05 max	0.015 max P; 0.010 max S
S35000	AM-350 (Type 633)	Bal	16.00 17.00	4.00 5.00	2.50 3.25	—	0.50 1.25	0.50 max	0.07 0.11	0.07-0.13 N; 0.040 max P; 0.030 max S
S35500	AM-355 (Type 634)	Bal	15.00 16.00	4.00 5.00	2.50 3.25	—	0.50 1.25	0.50 max	0.10 0.15	0.07-0.13 N; 0.040 max P; 0.030 max S

Table 1.1.2. Compositions (wt%) of semi-austenitic stainless steel used to study the effects of hydrogen on mechanical properties.

Heat	Alloy	Fe	Cr	Ni	Mo	Al	Mn	Si	C	Other	Ref.
W69	17-7PH	Bal	17.29	7.10	nr	0.9	0.68	0.64	0.072	0.028 P; 0.005 S	[4]

nr = not reported

Table 3.1.1.1. Smooth tensile properties of semi-austenitic stainless steel at room temperature; measured in external hydrogen gas or with internal gas.

Material	Thermal precharging	Test environment	Strain rate (s^{-1})	S_y (MPa)	S_u (MPa)	El_u (%)	El_t (%)	RA (%)	Ref.
17-7PH ‡ (heat W69)	None	air	0.67 x10^{-3}	1124	1200	—	17	45	[4]
	None	69 MPa H_2		—	1041	—	1.7	2.5	
AM-350, SA	None	air	—	420	1160	—	70	—	[7]
	None	69 MPa He		420	1240	—	55	—	
	None	0.69 MPa D_2		410	455	—	3	—	
	None	6.9 MPa D_2		345	430	—	4	—	
	None	69 MPa D_2		430	520	—	2.6	—	
	(1)	air		455	580	—	3/4	—	

SA = solution annealed (1330K)
‡ condition TH1050
(1) 69 MPa deuterium gas, 570 K, 625 h

Table 3.1.2.1. Notched tensile properties of semi-austenitic stainless steel at room temperature; measured in external hydrogen gas.

Material	Specimen	Thermal precharging	Test environment	Displ. rate (mm/s)	S_y † (MPa)	σ_s (MPa)	RA (%)	Ref.
17-7PH ‡ (heat W69)	(a)	None	Air	~0.35 x10^{-3}	1124	2151	0.6	[4]
		None	69 MPa H_2		—	483	0.4	

† yield strength of smooth tensile specimen
‡ condition TH1050
(a) V-notched specimen: 60˚ included angle; minimum diameter = 3.81 mm; maximum diameter = 7.77 mm; notch root radius = 0.024 mm. Stress concentration factor (K_t) = 8.4.