Technical Reference on Hydrogen Compatibility of Materials

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

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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 \( \approx 10^{-14} \text{ m}^2/\text{s} \).
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

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

<table>
<thead>
<tr>
<th>UNS No</th>
<th>Common Name (AISI No)</th>
<th>Fe</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Al</th>
<th>Mn</th>
<th>Si</th>
<th>C</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>S17700</td>
<td>17-7PH (Type 631)</td>
<td>Bal</td>
<td>16.00</td>
<td>7.75</td>
<td>—</td>
<td>0.75</td>
<td>1.00</td>
<td>1.00</td>
<td>0.09</td>
<td>0.040 max P; 0.040 max S</td>
</tr>
<tr>
<td>S15700</td>
<td>PH15-7Mo (Type 632)</td>
<td>Bal</td>
<td>14.00</td>
<td>7.75</td>
<td>6.50</td>
<td>2.00</td>
<td>0.75</td>
<td>1.50</td>
<td>1.00</td>
<td>0.9 max</td>
</tr>
<tr>
<td>S14800</td>
<td>PH14-8Mo</td>
<td>Bal</td>
<td>13.75</td>
<td>8.75</td>
<td>7.75</td>
<td>2.00</td>
<td>0.75</td>
<td>1.50</td>
<td>1.00</td>
<td>0.9 max</td>
</tr>
<tr>
<td>S35000</td>
<td>AM-350 (Type 633)</td>
<td>Bal</td>
<td>16.00</td>
<td>5.00</td>
<td>4.00</td>
<td>2.50</td>
<td>—</td>
<td>0.50</td>
<td>0.75</td>
<td>0.07-0.13 N; 0.040 max P;</td>
</tr>
<tr>
<td>S35500</td>
<td>AM-355 (Type 634)</td>
<td>Bal</td>
<td>15.00</td>
<td>5.00</td>
<td>4.00</td>
<td>2.50</td>
<td>—</td>
<td>0.50</td>
<td>0.75</td>
<td>0.030 max S</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Heat</th>
<th>Alloy</th>
<th>Fe</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Al</th>
<th>Mn</th>
<th>Si</th>
<th>C</th>
<th>Other</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>W69</td>
<td>17-7PH</td>
<td>Bal</td>
<td>17.29</td>
<td>7.10</td>
<td>nr</td>
<td>0.9</td>
<td>0.68</td>
<td>0.64</td>
<td>0.072</td>
<td>0.028 P; 0.005 S</td>
<td>[4]</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal precharging</th>
<th>Test environment</th>
<th>Strain rate ( (s^{-1}) )</th>
<th>( S_y ) (MPa)</th>
<th>( S_u ) (MPa)</th>
<th>( \varepsilon_{ul} ) (%)</th>
<th>( \varepsilon_{lt} ) (%)</th>
<th>RA (%)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-7PH ( \dagger ) (heat W69)</td>
<td>None</td>
<td>air</td>
<td>0.67 \times 10^{-3}</td>
<td>1124</td>
<td>1200</td>
<td>—</td>
<td>—</td>
<td>17</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>69 MPa H(_2)</td>
<td></td>
<td>420</td>
<td>1160</td>
<td>—</td>
<td>—</td>
<td>70</td>
<td>—</td>
</tr>
<tr>
<td>AM-350, SA</td>
<td>None</td>
<td>air</td>
<td></td>
<td>410</td>
<td>455</td>
<td>—</td>
<td>—</td>
<td>55</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>69 MPa He</td>
<td></td>
<td>345</td>
<td>430</td>
<td>—</td>
<td>—</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>0.69 MPa D(_2)</td>
<td></td>
<td>430</td>
<td>520</td>
<td>—</td>
<td>—</td>
<td>2.6</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>6.9 MPa D(_2)</td>
<td></td>
<td>455</td>
<td>580</td>
<td>—</td>
<td>—</td>
<td>3/4</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SA = solution annealed (1330K)

\( \dagger \) 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.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specimen</th>
<th>Thermal precharging</th>
<th>Test environment</th>
<th>Displ. rate (mm/s)</th>
<th>( S_y ) ( \dagger ) (MPa)</th>
<th>( \sigma_s ) (MPa)</th>
<th>RA (%)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-7PH ( \dagger ) (heat W69)</td>
<td>(a)</td>
<td>None</td>
<td>Air</td>
<td>(~0.35) \times 10^{-3}</td>
<td>1124</td>
<td>2151</td>
<td>0.6</td>
<td>[4]</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>None</td>
<td>69 MPa H(_2)</td>
<td></td>
<td></td>
<td>483</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

\( \dagger \) yield strength of smooth tensile specimen

\( \dagger \) 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 \((K_t) = 8.4.\)