Applications Potential

15-5 PH® Stainless Steel offers a combination of high strength and hardness, good corrosion resistance plus excellent transverse mechanical properties. 15-5 PH Stainless Steel is the ferrite-free version of 17-4 PH® Stainless Steel. Both alloys are widely used in the aerospace, chemical, petrochemical, food processing, paper and general metalworking industries.
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15-5 PH® Stainless Steel is a martensitic precipitation-hardening stainless steel that provides an outstanding combination of high strength, good corrosion resistance, good mechanical properties at temperatures up to 600 °F (316 °C) and good toughness in both the longitudinal and transverse directions in both base metal and welds. Short-time, low-temperature heat treatments minimize distortion and scaling.

This alloy is air melted and AOD refined. For data not available on this alloy, use the 17-4 PH® Stainless Steel sheet data as a guideline when available.

**COMPOSITION (wt %)**

<table>
<thead>
<tr>
<th>Element</th>
<th>(wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (C)</td>
<td>0.07 max.</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>1.00 max.</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>0.040 max.</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.030 max.</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>1.00 max.</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>14.00 – 15.50</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>3.50 – 5.50</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>2.50 – 4.50</td>
</tr>
<tr>
<td>Niobium* (Nb)</td>
<td>0.15 – 0.45</td>
</tr>
</tbody>
</table>

*ASTM A693 requirements call for Niobium plus Tantalum (Ta) = 0.15 - 0.45. AK Steel makes no intentional Ta addition.

**AVAILABLE FORMS**

AK Steel produces 15-5 PH Stainless Steel sheet and strip in thicknesses from 0.015 – 0.125 in. (0.38 – 3.18 mm). Material is supplied in Condition A, ready for fabrication and subsequent hardening by the user. Since the material transforms to martensite on cooling to room temperature, flatness requirements should be considered and discussed as part of the order.

**SPECIFICATIONS**

The following specifications are listed without revision indications. Contact ASTM Headquarters for latest ASTM revision. For AMS revision, contact AMS Division of SAE.

AMS 5862
ASTM A693 Plate, Sheet and Strip
(Listed as Grade XM-12 - UNS S15500)

**METRIC PRACTICE**

The values shown in this bulletin were established in U.S. customary units. The metric equivalents may be approximate.
As supplied from the Mill in Condition A, 15-5 PH Stainless Steel can be heat treated at a variety of temperatures to develop a wide range of properties. Eight standard heat treatments have been developed. The following table outlines the times and temperatures required.

This alloy exhibits useful mechanical properties in Condition A. Tests conducted at an exposed marine atmosphere 82 ft. (25 m) from the waterline, show excellent stress corrosion resistance for close to 20 years. Condition A material has been used successfully in numerous applications. The hardness and tensile properties fall within the range of those for Conditions H 1100 and H 1150.

In critical applications, the alloy is used in the precipitation-hardened condition, rather than Condition A. Heat treating to the hardened condition, especially at the higher end of the temperature range, stress relieves the structure and may provide more reliable resistance to stress corrosion cracking than in Condition A.

**TABLE 1 – STANDARD HEAT TREATMENTS**

Condition A Solution Treated at 1900 °F ± 25 °F (1038 °C ± 14 °C) or Air cool below 90 °F (32 °C).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Heat To ± 15 °F (8.4 °C)</th>
<th>Time at Temperature, hrs.</th>
<th>Type of Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 900</td>
<td>900 °F (482 °C)</td>
<td>1</td>
<td>Air</td>
</tr>
<tr>
<td>H 925</td>
<td>925 °F (496 °C)</td>
<td>4</td>
<td>Air</td>
</tr>
<tr>
<td>H 1025</td>
<td>1025 °F (551 °C)</td>
<td>4</td>
<td>Air</td>
</tr>
<tr>
<td>H 1075</td>
<td>1075 °F (580 °C)</td>
<td>4</td>
<td>Air</td>
</tr>
<tr>
<td>H 1100</td>
<td>1100 °F (593 °C)</td>
<td>4</td>
<td>Air</td>
</tr>
<tr>
<td>H 1150</td>
<td>1150 °F (621 °C)</td>
<td>4</td>
<td>Air</td>
</tr>
<tr>
<td>H 1150 + 1150</td>
<td>1150 °F (621 °C)</td>
<td>4 followed by 4 Air</td>
<td>Air</td>
</tr>
<tr>
<td>H 1150-M</td>
<td>1400 °F (760 °C)</td>
<td>2</td>
<td>Air</td>
</tr>
<tr>
<td></td>
<td>1150 °F (621 °C)</td>
<td>4</td>
<td>Air</td>
</tr>
</tbody>
</table>
15-5 PH Stainless Steel provides excellent mechanical properties. For applications requiring high strength and hardness plus corrosion resistance, this alloy is an outstanding choice. In addition, it is more cost effective than many high-nickel, non-ferrous alloys.

**TABLE 2 – TYPICAL MECHANICAL PROPERTIES**

<table>
<thead>
<tr>
<th>Transverse Property</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>UTS, ksi. (MPa)</td>
<td>160 (1103)</td>
</tr>
<tr>
<td>0.2% YS, ksi. (MPa)</td>
<td>115 (793)</td>
</tr>
<tr>
<td>Elongation, % in 2&quot; (50.8 mm)</td>
<td>5</td>
</tr>
<tr>
<td>Rockwell Hardness C</td>
<td>35</td>
</tr>
</tbody>
</table>

**TABLE 3 – PROPERTIES ACCEPTABLE FOR MATERIAL SPECIFICATION***

<table>
<thead>
<tr>
<th>Property</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>UTS, ksi. (MPa)</td>
<td>185 max. (1276)</td>
</tr>
<tr>
<td>0.2% YS, ksi. (MPa)</td>
<td>160 max. (1103)</td>
</tr>
<tr>
<td>Elongation, % in 2&quot; (50.8 mm)</td>
<td>3 min.</td>
</tr>
</tbody>
</table>

*Sheets and strip.

**TABLE 4 – SHEET CHARPY IMPACT RESISTANCE***

<table>
<thead>
<tr>
<th>Condition</th>
<th>Impact Energy, in.-lbs./in² (J/cm²)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Room Temperature</td>
</tr>
<tr>
<td>A</td>
<td>3265 (57.2)</td>
</tr>
<tr>
<td>H 900</td>
<td>2857 (50.0)</td>
</tr>
<tr>
<td>H 1025</td>
<td>3974 (69.6)</td>
</tr>
<tr>
<td>H 1150</td>
<td>4626 (81.0)</td>
</tr>
<tr>
<td>H 1150-M</td>
<td>5616 (98.4)</td>
</tr>
</tbody>
</table>

**Pressed Notch Tests**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Impact Energy, in.-lbs./in² (J/cm²)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 900</td>
<td>2184 (38.2)</td>
</tr>
<tr>
<td>H 1150</td>
<td>3406 (59.6)</td>
</tr>
</tbody>
</table>

*Average of triplicate tests for two heats.

**Samples were 0.093 in. (2.36 mm) thick with a depth beneath the notch of 0.314 in. (7.98 mm).
### TABLE 5 – MODULUS OF ELASTICITY

<table>
<thead>
<tr>
<th>Condition</th>
<th>H 900</th>
<th>H 1025</th>
<th>H 1075</th>
<th>H 1150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus in Tension, psi (MPa)</td>
<td>$28.5 \times 10^6$ ($196 \times 10^3$)</td>
<td>$11.2 \times 10^6$ ($77 \times 10^3$)</td>
<td>$11.0 \times 10^6$ ($76 \times 10^3$)</td>
<td>$10.0 \times 10^6$ ($69 \times 10^3$)</td>
</tr>
<tr>
<td>Modulus in Torsion, psi (MPa)</td>
<td>$11.0 \times 10^6$ ($76 \times 10^3$)</td>
<td>$10.0 \times 10^6$ ($69 \times 10^3$)</td>
<td>$10.0 \times 10^6$ ($69 \times 10^3$)</td>
<td></td>
</tr>
</tbody>
</table>

Data represent average of two tests from one heat.

The modulus of elasticity of 15-5 PH Stainless Steel at elevated temperatures can be expressed conveniently as % of room temperature modulus. At temperatures ranging from room to 600 °F (315 °C), this material showed the following:

### TABLE 6 – EFFECT OF TEMPERATURE ON MODULUS OF ELASTICITY

<table>
<thead>
<tr>
<th>Temperature °F (°C)</th>
<th>Modulus of Elasticity* (% of Room Temperature Modulus)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72 (22)</td>
<td>100.0</td>
</tr>
<tr>
<td>100 (38)</td>
<td>99.6</td>
</tr>
<tr>
<td>200 (93)</td>
<td>97.8</td>
</tr>
<tr>
<td>300 (149)</td>
<td>96.3</td>
</tr>
<tr>
<td>400 (204)</td>
<td>94.7</td>
</tr>
<tr>
<td>500 (260)</td>
<td>93.0</td>
</tr>
<tr>
<td>600 (315)</td>
<td>91.4</td>
</tr>
</tbody>
</table>

Poisson’s Ratio in all hardened conditions is 0.272.

*Data represent average of two tests from one heat.

### TABLE 7 – PHYSICAL PROPERTIES

<table>
<thead>
<tr>
<th>Condition</th>
<th>A</th>
<th>H 900</th>
<th>H 1075</th>
<th>H 1150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, lbs./in$^3$ (g/cm$^3$)</td>
<td>0.28 (7.78)</td>
<td>0.282 (7.80)</td>
<td>0.283 (7.81)</td>
<td>0.284 (7.82)</td>
</tr>
<tr>
<td>Electrical Resistivity, µΩ•cm</td>
<td>98</td>
<td>77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific Heat, BTU/lbs./°F (kJ/kg/°C)</td>
<td>0.11 (0.46)</td>
<td>0.10 (0.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity, BTU/hr./ft$^2$/°F (W/m/K)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 °F (149 °C)</td>
<td>124 (17.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 °F (260 °C)</td>
<td>135 (19.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 °F (460 °C)</td>
<td>156 (22.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>900 °F (482 °C)</td>
<td>157 (22.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Coefficient of Thermal Expansion, in./in./°F (μm/m/K)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-100 – 70 °F (-73 – 21 °C)</td>
<td>–</td>
<td>5.8 x 10$^{-6}$ (10.4)</td>
<td>–</td>
<td>6.1 x 10$^{-6}$ (11.0)</td>
</tr>
<tr>
<td>70 – 200 °F (21 – 93 °C)</td>
<td>6.0 x 10$^{-6}$ (10.8)</td>
<td>6.0 x 10$^{-6}$ (10.8)</td>
<td>6.3 x 10$^{-6}$ (11.3)</td>
<td>6.6 x 10$^{-6}$ (11.9)</td>
</tr>
<tr>
<td>70 – 400 °F (21 – 204 °C)</td>
<td>6.0 x 10$^{-6}$ (10.8)</td>
<td>6.3 x 10$^{-6}$ (11.3)</td>
<td>6.5 x 10$^{-6}$ (11.7)</td>
<td>6.8 x 10$^{-6}$ (12.2)</td>
</tr>
<tr>
<td>70 – 600 °F (21 – 316 °C)</td>
<td>6.2 x 10$^{-6}$ (11.2)</td>
<td>6.3 x 10$^{-6}$ (11.3)</td>
<td>6.6 x 10$^{-6}$ (11.9)</td>
<td>7.1 x 10$^{-6}$ (12.8)</td>
</tr>
<tr>
<td>70 – 800 °F (21 – 427 °C)</td>
<td>6.3 x 10$^{-6}$ (11.3)</td>
<td>6.5 x 10$^{-6}$ (11.7)</td>
<td>6.8 x 10$^{-6}$ (12.2)</td>
<td>7.2 x 10$^{-6}$ (13.0)</td>
</tr>
<tr>
<td>70 – 900 °F (21 – 482 °C)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>7.3 x 10$^{-6}$ (13.1)</td>
</tr>
</tbody>
</table>
DIMENSIONAL CHANGE

DIMENSIONAL CHANGE IN HARDENING

On hardening 15-5 PH Stainless Steel, a dimensional change will take place. Typical dimensional changes are shown in Table 8. They can vary from heat to heat.

TABLE 8 – CONTRACTION FROM HEAT TREATMENT

<table>
<thead>
<tr>
<th>Condition</th>
<th>Contraction in./in. (mm/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 900</td>
<td>0.00045</td>
</tr>
<tr>
<td>H 925</td>
<td>0.00051</td>
</tr>
<tr>
<td>H 1025</td>
<td>0.00053</td>
</tr>
<tr>
<td>H 1100</td>
<td>0.0009</td>
</tr>
<tr>
<td>H 1150</td>
<td>0.0022</td>
</tr>
<tr>
<td>H 1150-M</td>
<td>1400 —–&gt; 0.000037</td>
</tr>
<tr>
<td></td>
<td>1150 —–&gt; 0.00206</td>
</tr>
<tr>
<td>.. 1400 + 1150 —–&gt; 0.00243</td>
<td></td>
</tr>
</tbody>
</table>

Data represent single tests from one heat.

FIGURE 1 – DIMENSIONAL CHANGE IN HARDENING

AC3 = 1300 °F (704 °C)
Ms = 270 °F (132 °C)

INITIAL CONDITION – ANNEALED
HELD AT 900 °F (482 °C) FOR 1 HOUR
AC1 = 1160 °F (627 °C)
Mf Temperature, (°C)

Mf = 270 °F (132 °C)

Temperature, (°F)

Temperature, (°C)
15-5 PH® STAINLESS STEEL

CORROSION RESISTANCE

The general level of corrosion resistance of 15-5 PH Stainless Steel exceeds that of Types 410 and 431, and is approximately equal to that of 17-4 PH Stainless Steel. This is indicated by laboratory tests in both strongly oxidizing and reducing media, as well as by atmospheric exposures. In all heat-treated conditions, this alloy exhibits very little rusting after 500 hours exposure to 5% salt fog at 95 °F (35 °C).

When exposed to seacoast atmospheres for long periods of time, the material gradually develops a superficial layer of rust like other precipitation-hardening stainless steels. The general level of corrosion resistance is best in the fully hardened condition, and decreases slightly as the aging temperature is increased.

TABLE 9 – CORROSION RATES IN VARIOUS MEDIA

<table>
<thead>
<tr>
<th>Corrosive Media</th>
<th>Time</th>
<th>Condition</th>
<th>Corrosion Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>65% HNO₃</td>
<td>Average 5 – 48 hour periods</td>
<td>H 900</td>
<td>0.0083 IPM*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H1025</td>
<td>0.0106 IPM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H1150</td>
<td>0.0083 IPM</td>
</tr>
<tr>
<td>1% HCl, 95 °F (35 °C)</td>
<td>Average 5 – 48 hour periods</td>
<td>H 900</td>
<td>0.025 IPY**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H1025</td>
<td>0.085 IPY</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H1150</td>
<td>0.730 IPY</td>
</tr>
<tr>
<td>Commercial bleach</td>
<td>7 days</td>
<td>H 900</td>
<td>0.0016 IPY**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H1025</td>
<td>0.013 IPY</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H1150</td>
<td>0.0083 IPY</td>
</tr>
</tbody>
</table>

*Inches per month

**Inches per year

TABLE 10 – STRESS CORROSION CRACKING TEST RESULTS OF AK STEEL 15-5 PH*

<table>
<thead>
<tr>
<th>Heat</th>
<th>Heat Treatment</th>
<th>0.2% YS, ksi. (MPa)</th>
<th>0.2% YS, ksi. (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>100% YS</td>
</tr>
<tr>
<td>F</td>
<td>Condition A</td>
<td>133 (917)</td>
<td>NF, NF, NF</td>
</tr>
<tr>
<td>E</td>
<td>H 900</td>
<td>180 (1241)</td>
<td>22, 22, 22</td>
</tr>
<tr>
<td></td>
<td>173 (1193)</td>
<td>21, 21, 21</td>
<td>21, 21, 28</td>
</tr>
<tr>
<td>E</td>
<td>H 925</td>
<td>172 (1186)</td>
<td>22(1), 22(1), 266(1)</td>
</tr>
<tr>
<td></td>
<td>166 (1145)</td>
<td>23(1), 23(1), 23(1)</td>
<td>23(1), 23(1), 23(1)</td>
</tr>
<tr>
<td>E</td>
<td>H 975</td>
<td>163 (1124)</td>
<td>NF, NF, NF</td>
</tr>
<tr>
<td></td>
<td>159 (1096)</td>
<td>NF, NF, NF</td>
<td>NF, NF, NF</td>
</tr>
<tr>
<td>E</td>
<td>H 1025</td>
<td>159 (1096)</td>
<td>NF, NF, NF</td>
</tr>
</tbody>
</table>

*NF indicates no failure.

(1)Cracked at code numbers that were stamped near the ends of specimens. Materials Performance Vol.26, No. 2 (1987).

TABLE 11 – 5% SALT FOG EXPOSURE FOR 10 DAYS

<table>
<thead>
<tr>
<th>Condition</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 900</td>
<td>A+ (0% rust and stain covered)</td>
</tr>
<tr>
<td>H 1025</td>
<td>A (0 – 5% rust and stain covered)</td>
</tr>
<tr>
<td>H 1150</td>
<td>A (0 – 5% rust and stain covered)</td>
</tr>
</tbody>
</table>
FORMABILITY

Because 15-5 PH Stainless Steel in Condition A is strong, forming normally should be limited to mild operations. However, fabrication can be improved greatly by heat treating before cold working. Table 12 indicates minimum bend radii for forming this material.

### TABLE 12 – BEND TEST DATA MINIMUM BEND RADIUS*

<table>
<thead>
<tr>
<th>Condition</th>
<th>90°</th>
<th>135°</th>
<th>189°</th>
</tr>
</thead>
<tbody>
<tr>
<td>L T</td>
<td>L T</td>
<td>L T</td>
<td>L T</td>
</tr>
<tr>
<td>A</td>
<td>3T</td>
<td>4T</td>
<td>3T</td>
</tr>
<tr>
<td>H 900</td>
<td>3T</td>
<td>4T</td>
<td>3T</td>
</tr>
<tr>
<td>H 925</td>
<td>2T</td>
<td>4T</td>
<td>3T</td>
</tr>
<tr>
<td>H 1025</td>
<td>2T</td>
<td>4T</td>
<td>3T</td>
</tr>
<tr>
<td>H 1075</td>
<td>2T</td>
<td>4T</td>
<td>3T</td>
</tr>
<tr>
<td>H 1150</td>
<td>2T</td>
<td>2T</td>
<td>3T</td>
</tr>
</tbody>
</table>

*Expressed as function of sheet thickness. Minimum radius to make indicated bend with no fissuring when viewed under 10X magnifying glass.

HEAT TREATMENT

For maximum hardness and strength, material in the solution-treated condition is heated for one hour at 900 °F ± 15 °F (482 °C ± 8.4 °C) and air cooled to room temperature. If the material is purchased in the solution-treated condition (Condition A) and not subsequently hot worked, the hardening treatment can be performed without solution treating before hardening.

Where ductility in the hardened condition is of importance, better toughness can be obtained by raising the temperature of the hardening heat treatment. Unlike regular hardenable materials that require hardening plus a tempering or stress relieving treatment, this alloy can be hardened to the final desired properties in one operation. By varying the heat-treating procedure between 900 – 1150 °F (482 – 621 °C) for one to four hours, a wide range of properties can be attained.

If the alloy is not sufficiently ductile in any given hardened condition, it can be reheated at a higher hardening temperature to increase impact strength and elongation.

This can be accomplished without a solution treatment prior to final heat treatment. However, strength will be reduced.

For hot-worked or overaged material, a solution treatment at 1875 – 1925 °F (1024 – 1052 °C) for three minutes for each 0.1 in. (2.5 mm) of thickness, followed by cooling to at least 90 °F (32 °C) must be done prior to hardening. The solution treatment refines the grain size and makes hardened material more uniform.

When fabricating 15-5 PH Stainless Steel, it is important to keep in mind the low temperatures at which the start of transformation to martensite (Ms) and the completion of the martensite transformation (Mf) occur. These temperatures are approximately 270 °F (132 °C) and 90 °F (32 °C) respectively.

Because of this characteristic, it is necessary to cool parts in process at least to 90 °F (32 °C) prior to applying subsequent heat treatments if normal final properties are to be obtained. This practice is essential to assure grain refinement and to assure good ductility.

WELDABILITY

The precipitation hardening class of stainless steels is generally considered to be weldable by the common fusion and resistance techniques. Special consideration is required to achieve optimum mechanical properties by considering the best heat-treated conditions in which to weld and which heat treatments should follow welding. This particular alloy is generally considered to have equivalent weldability to the most common alloy of this stainless class, 17-4 PH Stainless Steel. When a weld filler is needed, AWS E/ER 630 is most often specified. 15-5 PH Stainless Steel is well known in reference literature and more information can be obtained in the following ways:

1. ANSI/AWS A5.9, A5.22, and A5.4 (stainless steel filler metals, welding electrode specifications).
DESCALING

Hardening treatments produce only a light heat tint on surfaces. This tint can be removed easily by mechanical means such as wet grit blasting or with a short pickle in 10% nitric – 2% hydrofluoric acid (by volume) at 110 – 140 °F (43 – 60 °C). Where pickling is undesirable, heat tint may be removed by a light electropolishing operation. The latter two treatments also clean and passivate the surfaces for maximum corrosion resistance.

Where solution treating is performed, the following pickling method satisfactorily removes surface scale. The use of molten salts such as sodium hydride or Kolene processes to descale is limited since these methods partially harden solution-treated material.

In pickling operations, time and temperature should be controlled closely to obtain uniform scale removal without over etching. Scale softening methods may be used on material that has been solution treated (not pickled) and precipitation hardened.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Acid Bath</th>
<th>Temperature °F (°C)</th>
<th>Time at Temperature Minutes</th>
<th>Rinse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Caustic Permanganate</td>
<td>160 – 180 (71 – 82)</td>
<td>60</td>
<td>Water</td>
</tr>
<tr>
<td>Step 2</td>
<td>10% Nitric Acid + 2% Hydrofluoric Acid</td>
<td>110 – 140 (43 – 60)</td>
<td>2 – 3</td>
<td>Hot water, high pressure water or brush scrub</td>
</tr>
</tbody>
</table>
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