A nickel-chromium-aluminum-iron alloy with outstanding resistance to oxidation.
HAYNES® 214™ alloy is gaining rapid acceptance for use in honeycomb seals because of its outstanding oxidation resistance. The seals are made of thin gage foil and are used to prevent leakage between different stages in gas turbine engines. Such seals contribute to an engine's fuel efficiency.

Section of a 214 alloy belt which was removed after 3,000 hours at 1,800°F (980°C) in a chinaware decorating kiln. The belt showed only minimal wear and oxidation attack. Use of 214 alloy in this application has helped reduce the time of the operation from eight or twelve hours, to less than 30 minutes.

This 214 alloy flamehood remained in service for 16 months in an application where other nickel alloy hoods required replacement every three to four months. The alloy component was subjected to direct flame impingement during the entire period in an automotive products plant.

The burner assembly at left failed after 450 cycles between minus 55 and 2,000°F (minus 50 and 1,095°C) A 214 alloy burner was still in good shape after 2,000 cycles in the same test. The burners were cycled from low to high temperatures in about five minutes, held for a 15-minute burn, and then rapid-air cooled.
Nominal Chemical Composition, Weight Percent

<table>
<thead>
<tr>
<th></th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Fe</th>
<th>Mn</th>
<th>Si</th>
<th>Zr</th>
<th>C</th>
<th>B</th>
<th>Y</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>75*</td>
<td>16</td>
<td>4.5</td>
<td>3</td>
<td>0.5*</td>
<td>0.2*</td>
<td>0.1*</td>
<td>0.05</td>
<td>0.01*</td>
<td>0.01</td>
</tr>
</tbody>
</table>

* As Balance  * Maximum
Oxidation Resistance

HAYNES® 214™ alloy provides resistance to oxidation at temperatures of 1750°F (955°C) and above that is virtually unmatched by any other wrought heat-resistant alloy. It can be used for long-term continuous exposure to combustion gases or air at temperatures up to 2300°F (1260°C), and, for shorter term exposures, it can be used at even higher temperatures. Useful short-term oxidation resistance has even been demonstrated at temperatures as high as 2400°F (1315°C).

Comparative Oxidation Resistance in Flowing Air*

<table>
<thead>
<tr>
<th>Material</th>
<th>1800°F (980°C)</th>
<th>2000°F (1095°C)</th>
<th>2100°F (1150°C)</th>
<th>2200°F (1205°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mils µm</td>
<td>Mils µm</td>
<td>Mils µm</td>
<td>Mils µm</td>
</tr>
<tr>
<td>214 alloy</td>
<td>0.2 5</td>
<td>0.1 3</td>
<td>0.3 8</td>
<td>0.7 18</td>
</tr>
<tr>
<td>230® alloy</td>
<td>0.7 18</td>
<td>1.3 33</td>
<td>3.4 86</td>
<td>7.9 201</td>
</tr>
<tr>
<td>alloy 600</td>
<td>0.9 23</td>
<td>1.6 41</td>
<td>2.9 74</td>
<td>8.4 213</td>
</tr>
<tr>
<td>alloy 601</td>
<td>1.3 33</td>
<td>2.6 66</td>
<td>5.3 135</td>
<td>7.5*** 191***</td>
</tr>
<tr>
<td>RA330® alloy</td>
<td>4.3 109</td>
<td>6.7 170</td>
<td>8.7 221</td>
<td>-</td>
</tr>
<tr>
<td>alloy 800H</td>
<td>1.8 46</td>
<td>7.4 188</td>
<td>8.9 226</td>
<td>13.6 289</td>
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<tr>
<td>Type 446 SS</td>
<td>2.3 58</td>
<td>14.5 368</td>
<td>&gt;21.7 &gt;551</td>
<td>&gt;23.3 &gt;592</td>
</tr>
<tr>
<td>Type 316 SS</td>
<td>14.3 363</td>
<td>&gt;68.4 &gt;1737</td>
<td>&gt;105.0 &gt;2667</td>
<td>&gt;140.4 &gt;3566</td>
</tr>
</tbody>
</table>

* Flowing air at a velocity of 7.0 feet/minute (213.4 cm/minute) past the samples. Samples cycled to room temperature once-a-week.
** Metal Loss + Average Internal Penetration
*** 601 Sample exhibited very large internal voids.

Metallographic Technique used for Evaluating Environmental Tests

1. Metal Loss = (A - B)/2
2. Average Internal Penetration = C
3. Maximum Internal Penetration = D
4. Average Metal Affected = ((A - B)/2) + C
5. Maximum Metal Affected = ((A - B)/2) + D
Microstructures shown are for coupons exposed for 1008 hours at 2100°F (1150°C) in air flowing at 7.0 feet/minute (213.4 cm/minute) past the samples. Samples were descaled by cathodically charging the coupons while they were immersed in a molten salt solution. The black area shown at the top of each picture represents actual metal loss due to oxidation. The data clearly show HAYNES® 214™ alloy is only slightly affected by the exposure, while other nickel-chromium alloys, such as alloys 600 and 601, and iron-nickel chromium alloys, such as RA330® alloy, all exhibit significantly more oxidation damage. Of particular importance is the almost total absence of internal attack for the 214 alloy. This contrasts markedly with the very substantial amount of internal attack evidenced by the alloy 601 and RA330 alloy tests coupons. The nature of this internal attack, as illustrated by the photomicrographs, is common for alloys containing 1-2% aluminum or silicon. Such levels of these elements do promote chromium oxide scale adherence, but do not afford improved resistance to oxide penetration below the scale.

**Average Metal Affected**

- **HAYNES 214 alloy**
  - Average Metal Affected = 0.3 Mils (8 µm)

- **Alloy 600**
  - Average Metal Affected = 2.9 Mils (74 µm)

- **Alloy 601**
  - Average Metal Affected = 5.3 Mils (135 µm)

- **RA330 alloy**
  - Average Metal Affected = 8.7 Mils (221 µm)
Comparative Burner Rig Oxidation Resistance

<table>
<thead>
<tr>
<th>Material</th>
<th>1800°F (980°C)/1000 Hours</th>
<th>2000°F (1095°C)/500 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metal Loss</td>
<td>Av. Metal Affected*</td>
</tr>
<tr>
<td></td>
<td>Mils μm</td>
<td>Mils μm</td>
</tr>
<tr>
<td>214 alloy</td>
<td>0.4 10</td>
<td>1.0 25</td>
</tr>
<tr>
<td>230® alloy</td>
<td>0.8 20</td>
<td>2.8 71</td>
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<tr>
<td>X alloy</td>
<td>2.7 69</td>
<td>5.6 142</td>
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<tr>
<td>RA330® alloy</td>
<td>7.8 198</td>
<td>11.8 300</td>
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<td>alloy 600</td>
<td>12.3a 312a</td>
<td>14.4a 366a</td>
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<tr>
<td>alloy 800H</td>
<td>12.3 312</td>
<td>14.5 368</td>
</tr>
<tr>
<td>Type 310 Stainless</td>
<td>13.7 348</td>
<td>16.2 411</td>
</tr>
<tr>
<td>alloy 601</td>
<td>3.0 76</td>
<td>18.8 478</td>
</tr>
</tbody>
</table>

* Metal Loss + Average Internal Penetration ** Extrapolated from 917 hours  
* Extrapolated from 400 hours  
* Internal penetration through entire thickness

Oxidation Test Parameters
Burner rig oxidation tests were conducted by exposing, in a rotating holder, samples 0.375 inch x 2.5 inches x thickness (9.5mm x 64mm x thickness) to the products of combustion of fuel oil (2 parts No. 1 and 1 part No. 2) burned at a ratio of air to fuel of about 50:1. (Gas velocity was about 0.3 mach). Samples were automatically removed from the gas stream every 30 minutes and fan cooled to less than 500°F (260°C) and then reinserted into the flame tunnel.

(Black areas of micros indicates actual metal loss)
CARBURATION RESISTANCE

HAYNES® 214™ alloy has very good resistance to carburization, as measured in both packed graphite exposure tests and mixed gas exposure tests. Results for these tests are presented in the following pages. All results are presented in terms of the mass of carbon absorption per unit area, which was obtained from the equation \( M = C(W/A) \) where \( M \) = the mass of carbon absorption per unit area (mg/cm²) \( C \) = difference in carbon (weight fraction) before and after exposure \( W \) = weight of the unexposed specimen (mg) and \( A \) = surface area of the specimen exposed to the test environment (cm²).

Packed Carburization Resistance

Carbon absorption observed for 214 alloy following 500 hour exposure in packed graphite at 1800°F (980°C) was very low, as shown below. While superior resistance was exhibited by HAYNES HR-120™ and 556™ alloys, other alloys tested exhibited significantly greater carbon absorption. In particular, the resistance to carburization of 214 alloy was far better than that for the stainless steel type materials.

Mixed Gas Carburization Tests

Carbon absorption observed for 214 alloy following exposure at both 1700°F (925°C) and 1800°F (980°C) to a carburizing gas mixture was significantly lower than that for all other materials tested. This is shown in the graphs on the following pages. For these tests, the exposure was performed in a gas environment consisting of (by volume %) 5.0% \( H_2 \), 5.0% \( CO \), 5.0% \( CH_4 \) and the balance argon. The calculated equilibrium composition (volume %) at 1800°F (980°C) and one atm was 14.2% \( H_2 \), 4.8%\( CO \), 0.003% \( CO_2 \), 0.026% \( CH_4 \), 0.011% \( H_2O \) and the balance argon. The activity of carbon was 1.0 and the partial pressure of oxygen was 9 x 10⁻²² atm at 1800°F (980°C).
Comparative 1700°F (925°C) Mix Gas Carburization Tests

1700°F (925°C) for 217 Hours

Carbon Absorption Per Unit Area (mg/cm²)

- HAYNES® 214™ alloy
- HAYNES 556™ alloy
- Alloy 800H
- Alloy 600
- HASTELLOY X alloy
- INCONEL alloy 601
- INCONEL alloy 617
- Type 301 stainless steel

Typical Carburized Microstructures (Unetched) After Exposure For 215 Hours At 1700°F (925°C)

HAYNES 214 alloy

Type 301 Stainless Steel
Comparative 1800°F (980°C) Mixed Gas Carburization Tests

1800°F (980°C) for 55 hours

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Carbon Absorption Per Unit Area (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAYNES® 214™ alloy</td>
<td>1</td>
</tr>
<tr>
<td>Alloy 800H</td>
<td>2</td>
</tr>
<tr>
<td>HAYNES 556™ alloy</td>
<td>3</td>
</tr>
<tr>
<td>HASTELLOY X alloy</td>
<td>4</td>
</tr>
<tr>
<td>Alloy 600</td>
<td>5</td>
</tr>
<tr>
<td>INCONEL alloy 601</td>
<td>1</td>
</tr>
<tr>
<td>INCONEL alloy 617</td>
<td>7</td>
</tr>
</tbody>
</table>

Carbon Absorption Per Unit Area (mg/cm²)

Typical Carburized Microstructures (Unetched) After Exposure For 55 Hours At 1800°F (980°C)

HAYNES 214 alloy

INCONEL alloy 617

Note: Alloy 617 is carburized to the center of the sample.
HAYNES® 214™ alloy provides outstanding resistance to corrosion in high-temperature, chlorine-contaminated oxidizing environments. This is particularly evident for exposures at temperatures at or above 1800°F (980°C), where the formation of the Al₂O₃-rich protective oxide scale is favored. Test results are shown for 400 hour exposures in a flowing gas mixture of Ar + 20% O₂ + 0.25% Cl₂. Note that the metal loss exhibited by 214 alloy is very low compared to other alloys tested.
HAYNES® 214™ alloy has also been tested in environments with higher levels of chlorine contamination. The photomicrographs to the right are for samples exposed to a mixture of air and 2% chlorine for 50 hours at 1830°F (1000°C). Once again, the black area at the top of each photograph represents actual metal loss experience. Alloy 601 exhibited 2.0 Mils (51 µm) of metal loss, and an average internal penetration of 6.0 Mils (152 µm), for a total average metal affected of 8.0 Mils (203 µm). Results for 214 alloy, by contrast, were 1.0 Mils (25 µm) of metal loss, 1.0 Mils (25 µm) of average internal penetration, for a total average metal affected of only 2.0 Mils (51 µm). These results are consistent with the results for lower chlorine level, longer-term tests given on the previous page.

NITRIDING RESISTANCE

While not the most resistant alloy for nitriding environments at traditional 1000°F to 1200°F (540°C to 650°C) temperatures, 214 alloy exhibits outstanding resistance at the higher temperatures where its protective Al2O3 scale can form, even in extremely low oxygen environments. Tests were performed in flowing ammonia at 1200, 1800 and 2000°F (650, 980 and 1095°C) for 168 hours. Nitrogen absorption was determined by technical analysis of samples before and after exposure, and knowledge of the exposed specimen area.

<table>
<thead>
<tr>
<th>Material</th>
<th>1200°F (650°C)</th>
<th>1800°F (980°C)</th>
<th>2000°F (1095°C)</th>
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</thead>
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<tr>
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<td>1.5</td>
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<td>0.2</td>
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<tr>
<td>Alloy 600</td>
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<td>0.3</td>
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<td>Alloy 601</td>
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<td>230® alloy</td>
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<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Alloy 625</td>
<td>0.8</td>
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<td>3.3</td>
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<td>X alloy</td>
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<td>3.2</td>
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</tr>
<tr>
<td>Alloy 800 H</td>
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<td>4.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Type 310 Stainless</td>
<td>7.4</td>
<td>7.7</td>
<td>9.5</td>
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### TYPICAL PHYSICAL PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Room</th>
<th>Temp., °F</th>
<th>Density, British Units</th>
<th>Room</th>
<th>Temp., °C</th>
<th>Metric Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.291 lb/in.³</td>
<td>Room</td>
<td>135.9 microhm-cm</td>
<td>8.05 g/cm.³</td>
<td>Room</td>
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<tr>
<td>Melting Temperature</td>
<td>2475-2550</td>
<td></td>
<td>1355-1400</td>
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<td></td>
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<tr>
<td>Electrical Resistivity</td>
<td>Room 53.5</td>
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<td>136.9 microhm-cm</td>
<td>200</td>
<td>136.9</td>
<td>microhm-cm</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>100</td>
<td>136.9 microhm-cm</td>
<td>300</td>
<td>136.9</td>
<td>microhm-cm</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>400</td>
<td>137.7 microhm-cm</td>
<td>400</td>
<td>137.9</td>
<td>microhm-cm</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>500</td>
<td>137.9 microhm-cm</td>
<td>500</td>
<td>137.9</td>
<td>microhm-cm</td>
</tr>
<tr>
<td></td>
<td>1200</td>
<td>600</td>
<td>136.8 microhm-cm</td>
<td>600</td>
<td>136.8</td>
<td>microhm-cm</td>
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<tr>
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<td>133.7 microhm-cm</td>
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<td>121.6 microhm-cm</td>
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<td>121.0</td>
<td>microhm-cm</td>
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<td>1150</td>
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<td>microhm-cm</td>
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<td>122.9</td>
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<table>
<thead>
<tr>
<th>Temperature Conductivity</th>
<th>Room 83 Btu-in./ft.² hr.-°F</th>
<th>Room 12.0 W/m-K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200 88 Btu-in./ft.² hr.-°F</td>
<td>100 12.8 W/m-K</td>
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<td></td>
<td>400 99 Btu-in./ft.² hr.-°F</td>
<td>200 14.2 W/m-K</td>
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<td>600 112 Btu-in./ft.² hr.-°F</td>
<td>300 15.9 W/m-K</td>
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<td></td>
<td>800 132 Btu-in./ft.² hr.-°F</td>
<td>400 18.4 W/m-K</td>
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<td></td>
<td>1000 153 Btu-in./ft.² hr.-°F</td>
<td>500 21.1 W/m-K</td>
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<td></td>
<td>1200 175 Btu-in./ft.² hr.-°F</td>
<td>600 23.9 W/m-K</td>
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<td></td>
<td>1400 200 Btu-in./ft.² hr.-°F</td>
<td>700 26.9 W/m-K</td>
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<td></td>
<td>1600 215 Btu-in./ft.² hr.-°F</td>
<td>800 29.7 W/m-K</td>
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<td></td>
<td>1800 225 Btu-in./ft.² hr.-°F</td>
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<td></td>
<td>2000 234 Btu-in./ft.² hr.-°F</td>
<td>1000 32.7 W/m-K</td>
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<tr>
<td></td>
<td>2200 255 Btu-in./ft.² hr.-°F</td>
<td>1100 34.0 W/m-K</td>
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<td>1200 36.7 W/m-K</td>
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### Typical Physical Properties (continued)

<table>
<thead>
<tr>
<th>Temp., °F</th>
<th>British Units</th>
<th>Temp., °C</th>
<th>Metric Units</th>
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<tr>
<td>Specific Heat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room</td>
<td>0.108 Btu/lb.-°F</td>
<td>Room</td>
<td>452 J/Kg-K</td>
</tr>
<tr>
<td>200</td>
<td>0.112 Btu/lb.-°F</td>
<td>100</td>
<td>470 J/Kg-K</td>
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<tr>
<td>400</td>
<td>0.118 Btu/lb.-°F</td>
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<td>493 J/Kg-K</td>
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<td>0.124 Btu/lb.-°F</td>
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<td>515 J/Kg-K</td>
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<td>0.130 Btu/lb.-°F</td>
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<td>535 J/Kg-K</td>
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<td>1000</td>
<td>0.136 Btu/lb.-°F</td>
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<td>561 J/Kg-K</td>
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<td>0.179 Btu/lb.-°F</td>
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<td>2200</td>
<td>0.180 Btu/lb.-°F</td>
<td>1200</td>
<td>753 J/Kg-K</td>
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<tr>
<td>Mean Coefficient of Thermal Expansion</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>70-400</td>
<td>7.4 microinches/in.-°F</td>
<td>25-200</td>
<td>13.3 10^-6 m/m-°C</td>
</tr>
<tr>
<td>70-600</td>
<td>7.6 microinches/in.-°F</td>
<td>25-300</td>
<td>13.6 10^-6 m/m-°C</td>
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<tr>
<td>70-800</td>
<td>7.9 microinches/in.-°F</td>
<td>25-400</td>
<td>14.1 10^-6 m/m-°C</td>
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<tr>
<td>70-1000</td>
<td>8.2 microinches/in.-°F</td>
<td>25-500</td>
<td>14.6 10^-6 m/m-°C</td>
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<tr>
<td>70-1200</td>
<td>8.6 microinches/in.-°F</td>
<td>25-600</td>
<td>15.2 10^-6 m/m-°C</td>
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<tr>
<td>70-1400</td>
<td>9.0 microinches/in.-°F</td>
<td>25-700</td>
<td>15.8 10^-6 m/m-°C</td>
</tr>
<tr>
<td>70-1600</td>
<td>9.6 microinches/in.-°F</td>
<td>25-800</td>
<td>16.6 10^-6 m/m-°C</td>
</tr>
<tr>
<td>70-1800</td>
<td>10.2 microinches/in.-°F</td>
<td>25-900</td>
<td>17.6 10^-6 m/m-°C</td>
</tr>
<tr>
<td>70-2000</td>
<td>11.1 microinches/in.-°F</td>
<td>25-1000</td>
<td>18.6 10^-6 m/m-°C</td>
</tr>
<tr>
<td>70-2200</td>
<td>11.5 microinches/in.-°F</td>
<td>25-1100</td>
<td>20.2 10^-6 m/m-°C</td>
</tr>
</tbody>
</table>

### DYNAMIC MODULUS OF ELASTICITY

<table>
<thead>
<tr>
<th>Temp., °F</th>
<th>Dynamic Modulus of Elasticity, 10^6 psi</th>
<th>Temp., °C</th>
<th>Dynamic Modulus of Elasticity, GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room</td>
<td>31.6 x 10^6 psi</td>
<td>Room</td>
<td>218 GPa</td>
</tr>
<tr>
<td>200</td>
<td>30.6 x 10^6 psi</td>
<td>100</td>
<td>210 GPa</td>
</tr>
<tr>
<td>400</td>
<td>29.6 x 10^6 psi</td>
<td>200</td>
<td>204 GPa</td>
</tr>
<tr>
<td>600</td>
<td>28.7 x 10^6 psi</td>
<td>300</td>
<td>199 GPa</td>
</tr>
<tr>
<td>800</td>
<td>27.4 x 10^6 psi</td>
<td>400</td>
<td>190 GPa</td>
</tr>
<tr>
<td>1000</td>
<td>25.3 x 10^6 psi</td>
<td>500</td>
<td>184 GPa</td>
</tr>
<tr>
<td>1200</td>
<td>23.9 x 10^6 psi</td>
<td>600</td>
<td>177 GPa</td>
</tr>
<tr>
<td>1400</td>
<td>22.3 x 10^6 psi</td>
<td>700</td>
<td>170 GPa</td>
</tr>
<tr>
<td>1600</td>
<td>20.2 x 10^6 psi</td>
<td>800</td>
<td>162 GPa</td>
</tr>
<tr>
<td>1800</td>
<td>19.0 x 10^6 psi</td>
<td>900</td>
<td>151 GPa</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td>1000</td>
<td>137 GPa</td>
</tr>
</tbody>
</table>

HAYNES 214 alloy
## TYPICAL TENSILE PROPERTIES

**Cold-Rolled and Solution Annealed Sheet, 0.078 to 0.125 Inches (2.0 to 3.2 mm) Thick**

<table>
<thead>
<tr>
<th>Test Temperature</th>
<th>Ultimate Tensile Strength</th>
<th>Yield Strength at 0.2% Offset</th>
<th>Elongation in 2 in. (50.8 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>°C</td>
<td>Ksi</td>
<td>MPa</td>
</tr>
<tr>
<td>Room</td>
<td>Room</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>540</td>
<td>144.2</td>
<td>995</td>
</tr>
<tr>
<td>1200</td>
<td>650</td>
<td>118.5</td>
<td>815</td>
</tr>
<tr>
<td>1400</td>
<td>760</td>
<td>102.0</td>
<td>705</td>
</tr>
<tr>
<td>1600</td>
<td>870</td>
<td>85.2</td>
<td>555</td>
</tr>
<tr>
<td>1800</td>
<td>980</td>
<td>75.2</td>
<td>515</td>
</tr>
<tr>
<td>2000</td>
<td>1095</td>
<td>15.2</td>
<td>105</td>
</tr>
<tr>
<td>2100</td>
<td>1150</td>
<td>8.4</td>
<td>58</td>
</tr>
<tr>
<td>2200</td>
<td>1205</td>
<td>4.6</td>
<td>32</td>
</tr>
</tbody>
</table>

* Average of six tests for each condition

**Hot-Rolled and Solution Annealed Plate, 0.500 Inches (12.7 mm) Thick**

<table>
<thead>
<tr>
<th>Test Temperature</th>
<th>Ultimate Tensile Strength</th>
<th>Yield Strength at 0.2% Offset</th>
<th>Elongation in 1.25 in. (31.8 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>°C</td>
<td>Ksi</td>
<td>MPa</td>
</tr>
<tr>
<td>Room</td>
<td>Room</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>540</td>
<td>138.9</td>
<td>960</td>
</tr>
<tr>
<td>1200</td>
<td>650</td>
<td>114.9</td>
<td>790</td>
</tr>
<tr>
<td>1400</td>
<td>760</td>
<td>97.4</td>
<td>670</td>
</tr>
<tr>
<td>1600</td>
<td>870</td>
<td>66.4</td>
<td>460</td>
</tr>
<tr>
<td>1800</td>
<td>980</td>
<td>16.7</td>
<td>115</td>
</tr>
<tr>
<td>2000</td>
<td>1095</td>
<td>9.0</td>
<td>62</td>
</tr>
<tr>
<td>2100</td>
<td>1150</td>
<td>6.6</td>
<td>46</td>
</tr>
<tr>
<td>2200</td>
<td>1205</td>
<td>5.0</td>
<td>34</td>
</tr>
</tbody>
</table>

* Average of six tests for each condition
# Typical Creep and Stress-Rupture Properties

## Solution Annealed Sheet, Plate and Bar

<table>
<thead>
<tr>
<th>Temperature °F</th>
<th>Creep, Percent</th>
<th>Average Initial Stress, Ksi (MPa) to Produce Specified Creep and Rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>10 Hours</td>
</tr>
<tr>
<td>1400</td>
<td>37.2 (255)</td>
<td>27.5 (190)</td>
</tr>
<tr>
<td></td>
<td>39.8 (275)</td>
<td>29.5 (205)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>47.9 (330)</td>
</tr>
<tr>
<td>1500</td>
<td>23.4 (160)</td>
<td>17.4 (120)</td>
</tr>
<tr>
<td></td>
<td>26.3 (180)</td>
<td>18.6 (130)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>30.2 (210)</td>
</tr>
<tr>
<td>1600</td>
<td>13.8 (95)</td>
<td>9.6 (66)</td>
</tr>
<tr>
<td></td>
<td>15.9 (110)</td>
<td>10.5 (72)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>22.4 (155)</td>
</tr>
<tr>
<td>1700</td>
<td>7.6 (52)</td>
<td>4.7 (32)</td>
</tr>
<tr>
<td></td>
<td>8.3 (57)</td>
<td>5.1 (35)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>11.0 (76)</td>
</tr>
<tr>
<td>1800</td>
<td>2.1 (14)</td>
<td>1.3 (9.0)</td>
</tr>
<tr>
<td></td>
<td>2.3 (16)</td>
<td>1.5 (10)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>3.7 (26)</td>
</tr>
<tr>
<td>1900</td>
<td>1.2 (8.3)</td>
<td>0.69 (4.8)</td>
</tr>
<tr>
<td></td>
<td>1.4 (9.7)</td>
<td>0.84 (5.8)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>3.2 (22)</td>
</tr>
<tr>
<td>2000</td>
<td>0.72 (5.0)</td>
<td>0.41 (2.8)</td>
</tr>
<tr>
<td></td>
<td>0.90 (6.2)</td>
<td>0.53 (3.7)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>2.2 (15)</td>
</tr>
</tbody>
</table>

* Significant extrapolation for 0.5% and 1.0% creep values

## Comparative Stress-Rupture Strengths, 1800°F (980°C)/10,000 Hours

![Graph showing comparative stress-rupture strengths](image-url)
THERMAL STABILITY

HAYNES® 214™ alloy exhibits reasonable room temperature ductility after long-term thermal exposure at intermediate temperatures. Precipitation of gamma prime phase occurs for exposures below 1750°F (955°C), along with minor chromium-rich carbides. Exposure at temperatures above about 1700°F (925°C) have little effect upon the properties of 214 alloy, but significant grain growth can occur above about 2000°F (1095°C).

<table>
<thead>
<tr>
<th>Exposure Temperature</th>
<th>Ultimate Tensile Strength</th>
<th>Yield Strength at 0.2% Offset</th>
<th>Elongation in 2 in. (50.8 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>°C</td>
<td>Hours</td>
<td>Ksi</td>
</tr>
<tr>
<td>1400</td>
<td>760</td>
<td>0</td>
<td>141.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32</td>
<td>157.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>157.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000</td>
<td>156.4</td>
</tr>
<tr>
<td>1600</td>
<td>870</td>
<td>0</td>
<td>141.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32</td>
<td>139.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>135.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000</td>
<td>132.5</td>
</tr>
<tr>
<td>1800</td>
<td>980</td>
<td>0</td>
<td>141.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32</td>
<td>137.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>137.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000</td>
<td>139.6</td>
</tr>
</tbody>
</table>

FABRICATION CHARACTERISTICS

Heat Treatment

HAYNES 214 alloy is normally final solution heat-treated at 2000°F (1095°C) for a time commensurate with section thickness. Solution heat-treating can be performed at temperatures as low as about 1950°F (1065°C), but resulting material properties will be altered accordingly. Annealing during fabrication can be performed at even lower temperatures, but a final, subsequent solution heat treatment is needed to produce optimum structure and properties.

Typical Hardness Properties for Sheet

<table>
<thead>
<tr>
<th>Condition</th>
<th>Rockwell C Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Annealed</td>
<td>24.3</td>
</tr>
<tr>
<td>10% Cold Reduced</td>
<td>33.8</td>
</tr>
<tr>
<td>20% Cold Reduced</td>
<td>37.6</td>
</tr>
<tr>
<td>30% Cold Reduced</td>
<td>40.6</td>
</tr>
<tr>
<td>40% Cold Reduced</td>
<td>42.4</td>
</tr>
<tr>
<td>50% Cold Reduced</td>
<td>43.0</td>
</tr>
</tbody>
</table>
Fabrication Characteristics (continued)

Effect of Cold Reduction upon Room-Temperature Tensile Properties*

<table>
<thead>
<tr>
<th>Percent Cold Reduction</th>
<th>Subsequent Anneal Temperature</th>
<th>Ultimate Tensile Strength Ksi MPa</th>
<th>Yield Strength at 0.2% Offset Ksi MPa</th>
<th>Elongation in 2 in. (50.8 mm) %</th>
<th>Hardness Rc</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
<td>144.7 1000</td>
<td>86.2 595</td>
<td>36.3</td>
<td>24.3</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>159.4 1100</td>
<td>121.9 840</td>
<td>22.5</td>
<td>33.8</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>176.5 1215</td>
<td>148.8 1025</td>
<td>12.9</td>
<td>37.6</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>194.1 1340</td>
<td>169.5 1170</td>
<td>8.1</td>
<td>40.6</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>208.6 1440</td>
<td>183.2 1265</td>
<td>5.3</td>
<td>42.4</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>219.8 1515</td>
<td>193.8 1335</td>
<td>4.0</td>
<td>43.0</td>
</tr>
<tr>
<td>0</td>
<td>1800°F (980°C) for 5 min.</td>
<td>147.2 1015</td>
<td>90.8 625</td>
<td>33.1</td>
<td>27.4</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>150.3 1035</td>
<td>89.9 620</td>
<td>33.7</td>
<td>24.9</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>155.6 1075</td>
<td>94.2 650</td>
<td>33.5</td>
<td>27.1</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>154.3 1065</td>
<td>92.5 640</td>
<td>33.7</td>
<td>27.9</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>157.9 1090</td>
<td>95.1 655</td>
<td>33.7</td>
<td>29.3</td>
</tr>
<tr>
<td>50</td>
<td>1900°F (925°C) for 5 min.</td>
<td>145.5 1005</td>
<td>83.6 575</td>
<td>36.2</td>
<td>24.3</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>149.5 1030</td>
<td>88.5 610</td>
<td>34.6</td>
<td>25.1</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>151.8 1045</td>
<td>91.8 635</td>
<td>33.3</td>
<td>24.0</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>154.1 1060</td>
<td>95.2 655</td>
<td>32.9</td>
<td>24.3</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>152.0 1050</td>
<td>90.3 625</td>
<td>32.3</td>
<td>24.4</td>
</tr>
<tr>
<td>50</td>
<td>2000°F (1095°C) for 5 min.</td>
<td>143.6 990</td>
<td>84.8 585</td>
<td>36.4</td>
<td>22.9</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>145.8 1005</td>
<td>87.2 600</td>
<td>34.4</td>
<td>24.0</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>146.2 1010</td>
<td>84.5 585</td>
<td>36.5</td>
<td>24.5</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>147.4 1015</td>
<td>86.1 595</td>
<td>36.5</td>
<td>22.5</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>148.3 1020</td>
<td>86.8 600</td>
<td>34.7</td>
<td>23.3</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based upon rolling reductions taken upon 0.120-inch (3.0mm) thick sheet. Duplicate tests

WELDING

HAYNES® 214™ alloy is readily welded by gas tungsten arc (TIG), gas metal arc (MIG), and shielded metal arc (coated electrode), welding techniques. Submerged arc welding is not recommended as this process is characterized by high heat input to the base metal and slow cooling of the weld. These factors can increase weld restraint and promote cracking.

**Base Metal Preparation**

The joint surface and adjacent area should be thoroughly cleaned before welding. All grease, oil, crayon marks, sulfur compounds and other foreign matter should be removed. It is preferable that the alloy be in the solution-annealed condition when welded.
Welding (continued)

**Filler Metal Selection**
Matching composition filler metal is recommended for joining 214™ alloy. For shielded metal-arc welding, HASTELLOY® X electrodes (AMS 5799) are suggested. For dissimilar metal joining of 214 alloy to nickel- or cobalt-base materials, 230-W™ filler metal will generally be a good selection, but HASTELLOY® S alloy (AMS 5838A) or HASTELLOY® W alloy (AMS 5786B, 5787A) welding products may be used. For dissimilar welding to iron-base materials, 556 filler metal is recommended. Please see publication H-3159.

**Preheating, Interpass Temperatures and Post-Weld Heat Treatment**
Preheat is not usually required so long as base metal to be welded is above 32°F (0°C). Interpass temperatures generally should be low. Auxiliary cooling methods may be used between weld passes, as needed, providing that such methods do not introduce contaminants. Post-weld heat treatment is not normally required for 214 alloy.

**Nominal Welding Parameters**
Nominal welding parameters are provided as a guide for performing typical operations. These are based upon welding conditions used in Haynes International, Inc. laboratories. For further information, please consult Haynes International.

---

**Automatic Gas Tungsten Arc Welding**

**Square Butt Joint - No Filler Metal Added**

<table>
<thead>
<tr>
<th>Material Thickness</th>
<th>0.040&quot; (1.0mm)</th>
<th>0.062&quot; (1.6mm)</th>
<th>0.125&quot; (3.2mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (DCEN), amperes</td>
<td>50</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>Voltage</td>
<td>8</td>
<td>8.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Travel Speed, in/min. (mm/min)</td>
<td>10 (254)</td>
<td>12 (305)</td>
<td>12 (305)</td>
</tr>
<tr>
<td>Electrode Size-EWTH-2, in (mm)</td>
<td>1/16 (1.6)</td>
<td>3/32 (2.4)</td>
<td>1/8 (3.2)</td>
</tr>
<tr>
<td>Electrode Shape</td>
<td>45° inc</td>
<td>45° inc</td>
<td>45° inc</td>
</tr>
<tr>
<td>Cup Size</td>
<td>#8</td>
<td>#8</td>
<td>#8</td>
</tr>
<tr>
<td>Shielding Gas Flow, CFH (l/min.)</td>
<td>30 (14.2)</td>
<td>30 (14.2)</td>
<td>30 (14.2)</td>
</tr>
<tr>
<td>Gas Type</td>
<td>Argon</td>
<td>Argon</td>
<td>Argon</td>
</tr>
<tr>
<td>Backing Gas, CFH (l/min.)</td>
<td>10 (4.7)</td>
<td>10 (4.7)</td>
<td>10 (4.7)</td>
</tr>
<tr>
<td>Gas Type</td>
<td>Argon</td>
<td>Argon</td>
<td>Argon</td>
</tr>
</tbody>
</table>

---

**Manual Gas Tungsten Arc Welding**

**V-or U-Groove - All Thicknesses 1/8" (3.2 mm) or greater**

| Technique     | - Stringer Bead               |
| Current (DCEN), amperes | - 120 root, 140-150 Fill |
| Voltage       | - 11 to 14                    |
| Filler Metal  | - 1/8" diameter (3.2 mm) 214 alloy |
| Travel Speed, ipm (mm/min) | - 4 to 6 (102-152) |
| Electrode Size-EWTH-2, in (mm) | - 1/8" diameter (3.2 mm) |
| Electrode Shape | - 30° included                |
| Cup Size      | - #8 or larger                |
| Gas Type      | - Argon                       |
| Shielding Gas Flow, CFH (l/min.) | - 30 to 35 (14.2 to 16.5) |
| Backing Gas Flow, CFH (l/min.) | - 10 (4.7) or back-gouge to sound metal and fill from root side |
| Preheat       | - Ambient                      |
| Interpass Temperature Maximum | - 200°F (93°C) |

HAYNES 214 alloy
### Gas Metal Arc Welding

#### Short Circuiting Transfer Mode

<table>
<thead>
<tr>
<th>All Thicknesses 0.090&quot; (2.3mm) and greater</th>
<th>Spray Transfer Mode All Thicknesses 0.156&quot; (4.0mm) and greater</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wire Type</strong></td>
<td><strong>Wire Diameter, in (mm)</strong></td>
</tr>
<tr>
<td>214™ alloy</td>
<td>214 alloy</td>
</tr>
<tr>
<td><strong>Feed Speed, ipm (m/min)</strong></td>
<td><strong>Current (DCEP), amperes</strong></td>
</tr>
<tr>
<td>170 to 190 (4.3 to 4.8)</td>
<td>100 to 110</td>
</tr>
<tr>
<td><strong>Voltage</strong></td>
<td><strong>Travel Speed, ipm (mm/min)</strong></td>
</tr>
<tr>
<td>20 to 22</td>
<td>8 to 10 (203 to 254)</td>
</tr>
<tr>
<td><strong>Stickout, in (mm)</strong></td>
<td><strong>Torch Gas Flow, CFH (l/min.)</strong></td>
</tr>
<tr>
<td>1/2-3/4 (12.7 to 19.1)</td>
<td>40 (18.9)</td>
</tr>
<tr>
<td><strong>Gas Type</strong></td>
<td><strong>Gas Type</strong></td>
</tr>
<tr>
<td>A1025 (90% He, 7.5% Ar, 2.5% CO₂)</td>
<td>Argon</td>
</tr>
</tbody>
</table>

#### Shielded Metal Arc Welding

No matching chemistry SMAW electrodes are currently available for 214 alloy. HASTELLOY X electrodes (AMS 5799) have been successfully used to join 214 alloy. Typical parameters for X alloy electrodes (flat position) are given below.

<table>
<thead>
<tr>
<th>Electrode Diameter</th>
<th>Voltage</th>
<th>Current (DCEP)</th>
<th>Travel Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>in (mm)</td>
<td>amperes</td>
<td>ipm (mm/min)</td>
<td></td>
</tr>
<tr>
<td>3/32 (2.4)</td>
<td>22 - 24</td>
<td>45 - 75</td>
<td>3 - 5 (76 - 127)</td>
</tr>
<tr>
<td>1/8 (3.2)</td>
<td>22 - 24</td>
<td>70 - 110</td>
<td>4 - 6 (102 - 152)</td>
</tr>
<tr>
<td>5/32 (4.0)</td>
<td>23 - 25</td>
<td>110 - 140</td>
<td>4 - 6 (102 - 152)</td>
</tr>
</tbody>
</table>

### HEALTH AND SAFETY

Welding can be a safe occupation. Those in the welding industry, however, should be aware of the potential hazards associated with welding fumes, gases, radiation, electric shock, heat, eye injuries, burns, etc. Also, local, municipal, state, and federal regulations (such as those issued by OSHA) relative to welding and cutting processes should be considered.

Nickel-, cobalt-, and iron-base alloy products may contain, in varying concentration, the following elemental constituents: aluminum, cobalt, chromium, copper, iron, manganese, molybdenum, nickel and tungsten. For specific concentrations of these and other elements present, refer to the Material Safety Data Sheets (MSDS) available from Haynes International, Inc.

Inhalation of metal dust or fumes generated from welding, cutting, grinding, melting, or dross handling of these alloys may cause adverse health effects such as reduced lung function, nasal and mucous membrane irritation. Exposure to dust or fumes which may be generated in working with these alloys may also cause eye irritation, skin rash and effects on other organ systems.

The operation and maintenance of welding and cutting equipment should conform to the provision of American National Standard ANSI/AWS Z49.1, "Safety in Welding and Cutting". Attention is especially called to Section 4 (Protection of Personnel) and 5 (Health Protection and Ventilation) of ANSI/AWS Z49.1. Mechanical ventilation is advisable and, under certain conditions such as a very confined space, is necessary during welding or cutting operations, or both, to prevent possible exposure to hazardous fumes, gases, or dust that may occur.

Acknowledgements:

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By Brand or Alloy Designation:

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HASTELLOY Family of Heat-Resistant Alloys
S, W, and X

HAYNES® Family of Heat-Resistant Alloys

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ULTIMET®

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