INCONEL® alloy 22 (UNS N06022; W. Nr. 2.4602; NiCr21Mo14W) is a fully austenitic advanced corrosion-resistant alloy that offers resistance to both aqueous corrosion and attack at elevated temperatures. This alloy provides exceptional resistance to general corrosion, pitting, crevice corrosion, intergranular attack, and stress corrosion cracking. Alloy 22 has found numerous applications in the chemical/petrochemical processing, pollution control (flue gas desulfurization), power, marine, pulp and paper processing, and waste disposal industries.

Alloy 22 is nickel-base and typically contains 22% chromium, 14% molybdenum, and 3% tungsten. Iron is normally limited to less than 3%. The alloy’s high content of chromium gives it good resistance to wet corrosion by oxidizing media (e.g., nitric acid and ferric and cupric salts). Its contents of molybdenum and tungsten give the alloy resistance to wet reducing media (e.g., sulfuric and hydrochloric acids). Alloy 22 exhibits excellent resistance to corrosive attack by seawater under stagnant and flowing conditions.

At elevated temperatures, the high chromium level of INCONEL alloy 22 helps it resist oxidation, carburization, and sulfidation. Since it is nickel-base, alloy 22 resists high temperature attack by halides (e.g., chlorides and fluorides). With these attributes, the alloy is widely used to protect steel tubes and other components in coal-fired and waste-to-energy boilers.

INCONEL alloy 22 products are covered by ASTM, ASME and ISO specifications. Alloy 22 is approved for construction of pressure vessels and components under the ASME Boiler and Pressure Vessel Code Section VIII, Division 1 for service up to 1250°F (677°C). The alloy is also approved by VdTÜV under Werkstoffblatt 479. The alloy is equivalent to and directly competes with Hastelloy® C-22® and Nicrofer® 5621hMoW alloys.

The limiting chemical composition ranges for alloy 22 are presented in Table 1. Table 2 compares the combined alloying content (Cr+Mo+W+Nb) of INCONEL alloy 22 with other similarly alloyed materials. Physical properties are presented in Table 3; mechanical properties at room temperature are found in Table 4; thermal conductivity in Table 5. Mechanical properties at elevated temperatures are seen in Figure 1.

### Table 1 - Limiting Chemical Composition, %, of INCONEL alloy 22 (ASTM B 574, B 575, etc.)

<table>
<thead>
<tr>
<th>Element</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>Balance*</td>
<td>Balance*</td>
</tr>
<tr>
<td>Chromium</td>
<td>20.0-22.5</td>
<td>20.0-22.5</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>12.5-14.5</td>
<td>12.5-14.5</td>
</tr>
<tr>
<td>Iron</td>
<td>2.0-6.0</td>
<td>2.0-6.0</td>
</tr>
<tr>
<td>Tungsten</td>
<td>2.5-3.5</td>
<td>2.5-3.5</td>
</tr>
<tr>
<td>Cobalt</td>
<td>2.5 max.</td>
<td>2.5 max.</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.35 max.</td>
<td>0.35 max.</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.015 max.</td>
<td>0.015 max.</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.50 max.</td>
<td>0.50 max.</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.02 max.</td>
<td>0.02 max.</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.08 max.</td>
<td>0.08 max.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.02 max.</td>
<td>0.02 max.</td>
</tr>
</tbody>
</table>

*Reference to the ‘balance’ of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.

### Table 2 - Typical Compositions of the Ni-Cr-Mo-W corrosion resistant alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>UNS Number</th>
<th>Werkstoff Number</th>
<th>Fe</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>W or Nb</th>
<th>PREN*</th>
</tr>
</thead>
<tbody>
<tr>
<td>686</td>
<td>N06696</td>
<td>2.4606</td>
<td>1</td>
<td>57</td>
<td>20.5</td>
<td>16.3</td>
<td>3.9</td>
<td>50.8</td>
</tr>
<tr>
<td>22</td>
<td>N06022</td>
<td>2.4602</td>
<td>2.5</td>
<td>59</td>
<td>21.5</td>
<td>14.1</td>
<td>3.1</td>
<td>47.3</td>
</tr>
<tr>
<td>C-276</td>
<td>N10276</td>
<td>2.4819</td>
<td>6</td>
<td>57</td>
<td>15.5</td>
<td>16</td>
<td>3.9</td>
<td>45.4</td>
</tr>
<tr>
<td>625</td>
<td>N06625</td>
<td>2.4856</td>
<td>3</td>
<td>62</td>
<td>22</td>
<td>9</td>
<td>3.6Nb</td>
<td>40.8</td>
</tr>
<tr>
<td>C-4</td>
<td>N06455</td>
<td>2.4611</td>
<td>2</td>
<td>66</td>
<td>16</td>
<td>16</td>
<td>-</td>
<td>40.0</td>
</tr>
</tbody>
</table>

*PREN*= %Cr + 1.5(%Mo + %W + %Nb)

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INCONEL® alloy 22

Table 3 - Physical Properties of INCONEL alloy 22

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (lb/in³)</td>
<td>0.311</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>8.61</td>
</tr>
<tr>
<td>Melting Range (°F, °C)</td>
<td>2464-2529 (1351-1387)</td>
</tr>
<tr>
<td>Specific Heat (Btu/lb °F)</td>
<td>0.091</td>
</tr>
<tr>
<td>Specific Heat (J/kg °C)</td>
<td>381</td>
</tr>
<tr>
<td>Permeability</td>
<td>≤1.001</td>
</tr>
<tr>
<td>Electrical Resistivity (ohm•cm)</td>
<td>730.7</td>
</tr>
<tr>
<td>Electrical Resistivity (μm)</td>
<td>1.215</td>
</tr>
<tr>
<td>Young’s Modulus (Dynamic)</td>
<td>30.3 GPa</td>
</tr>
<tr>
<td>Coefficient of Expansion</td>
<td>6.90 (21-193°C, μm/m•°C)</td>
</tr>
<tr>
<td>Coefficient of Expansion (20-80°F)</td>
<td>12.42</td>
</tr>
</tbody>
</table>

Table 4 - Typical Room-Temperature Mechanical Properties of INCONEL alloy 22

<table>
<thead>
<tr>
<th>Form</th>
<th>Material Thickness or Diameter</th>
<th>Tensile Strength</th>
<th>Yield Strength (0.2% Offset)</th>
<th>Elongation</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in</td>
<td>mm</td>
<td>ksi</td>
<td>MPa</td>
<td>ksi</td>
</tr>
<tr>
<td>Plate</td>
<td>0.25-1.75</td>
<td>6.35-44.45</td>
<td>112</td>
<td>772</td>
<td>53</td>
</tr>
<tr>
<td>Sheet</td>
<td>0.038-0.15</td>
<td>0.97-3.81</td>
<td>122</td>
<td>841</td>
<td>63</td>
</tr>
<tr>
<td>Bar</td>
<td>0.50-5.50</td>
<td>12.7-139.7</td>
<td>115</td>
<td>793</td>
<td>55</td>
</tr>
</tbody>
</table>

ASTM Limiting Mechanical Properties of INCONEL alloy 22

<table>
<thead>
<tr>
<th>Form</th>
<th>Material Thickness or Diameter</th>
<th>Tensile Strength</th>
<th>Yield Strength (0.2% Offset)</th>
<th>Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in</td>
<td>mm</td>
<td>ksi</td>
<td>MPa</td>
</tr>
<tr>
<td>Plate</td>
<td>0.25-1.75</td>
<td>6.35-44.45</td>
<td>112</td>
<td>772</td>
</tr>
<tr>
<td>Sheet</td>
<td>0.038-0.15</td>
<td>0.97-3.81</td>
<td>122</td>
<td>841</td>
</tr>
<tr>
<td>Bar</td>
<td>0.50-5.50</td>
<td>12.7-139.7</td>
<td>115</td>
<td>793</td>
</tr>
</tbody>
</table>

Table 5 - Thermal Conductivity of INCONEL alloy 22

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Conductivity W/cm K</th>
<th>Temperature °F</th>
<th>Conductivity BTU in/ft² h °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>0.07995</td>
<td>73</td>
<td>55.47</td>
</tr>
<tr>
<td>50</td>
<td>0.08911</td>
<td>122</td>
<td>61.83</td>
</tr>
<tr>
<td>100</td>
<td>0.10148</td>
<td>212</td>
<td>70.41</td>
</tr>
<tr>
<td>200</td>
<td>0.12328</td>
<td>392</td>
<td>85.54</td>
</tr>
<tr>
<td>300</td>
<td>0.14089</td>
<td>572</td>
<td>97.75</td>
</tr>
<tr>
<td>400</td>
<td>0.15274</td>
<td>752</td>
<td>105.97</td>
</tr>
<tr>
<td>500</td>
<td>0.16400</td>
<td>932</td>
<td>113.78</td>
</tr>
</tbody>
</table>

Figure 1 - Typical mechanical properties of INCONEL alloy 22 at elevated temperatures.
The major attribute of INCONEL alloy 22 is outstanding resistance to a broad range of corrosive media. It resists oxidizing acids as well as reducing acids such as sulfuric and hydrochloric. Some other corrosive chemicals to which the alloy has high resistance are oxidizing acid chlorides, wet chlorine, formic and acetic acids, ferric and cupric chlorides, sea water, brines and many mixed or contaminated chemical solutions, both organic and inorganic.

### General Corrosion Resistance

Table 6 - General Corrosion Resistance in acid solutions (mpy)

<table>
<thead>
<tr>
<th>Test Medium</th>
<th>Temp °C</th>
<th>C-4</th>
<th>C-276</th>
<th>22</th>
<th>686</th>
</tr>
</thead>
<tbody>
<tr>
<td>1% HCl</td>
<td>Boiling</td>
<td>36</td>
<td>10</td>
<td>3</td>
<td>0.4</td>
</tr>
<tr>
<td>2% HCl</td>
<td>Boiling</td>
<td>85</td>
<td>43</td>
<td>52</td>
<td>6</td>
</tr>
<tr>
<td>5% HCl</td>
<td>70</td>
<td>–</td>
<td>13</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>10% H₂SO₄</td>
<td>Boiling</td>
<td>25</td>
<td>23</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>80% H₂SO₄</td>
<td>93</td>
<td>–</td>
<td>24</td>
<td>68</td>
<td>29</td>
</tr>
<tr>
<td>90% H₂SO₄</td>
<td>93</td>
<td>–</td>
<td>18</td>
<td>–</td>
<td>8</td>
</tr>
<tr>
<td>85% H₃PO₄</td>
<td>Boiling</td>
<td>61</td>
<td>10</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>65% HNO₃</td>
<td>Boiling</td>
<td>217</td>
<td>888</td>
<td>76</td>
<td>231</td>
</tr>
<tr>
<td>10% H₂SO₄</td>
<td>Boiling</td>
<td>–</td>
<td>138</td>
<td>279</td>
<td>321</td>
</tr>
<tr>
<td>10% H₂SO₄ +2% HCl</td>
<td>80</td>
<td>–</td>
<td>–</td>
<td>82</td>
<td>34</td>
</tr>
<tr>
<td>10% H₂SO₄ +5% HCl</td>
<td>80</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>17</td>
</tr>
<tr>
<td>10% HF</td>
<td>80</td>
<td>–</td>
<td>28</td>
<td>–</td>
<td>26</td>
</tr>
<tr>
<td>40% HF +10% H₂SO₄</td>
<td>80</td>
<td>–</td>
<td>23</td>
<td>18</td>
<td>22</td>
</tr>
</tbody>
</table>

- No data available

Note: To convert mpy to mm/a, multiply by 0.0254

### Figure 2 - A summary iso-corrosion chart for 20 mpy (0.51 mm/a) data in hydrofluoric acid.

### Figure 3 - Iso-corrosion chart for INCONEL alloy 22 in sulfuric acid.

### Figure 4 - Iso-corrosion chart for INCONEL alloy 22 in hydrochloric acid.
Pitting and crevice corrosion are often evaluated by measurement of the minimum, or critical, temperature at which attack will occur. Critical pitting temperatures (CPT) and critical crevice temperatures (CCT) were determined in 6 wt. % ferric chloride + 1 wt. % hydrochloric acid at a maximum test temperature 85°C (185°F), Table 7. The relatively high molybdenum and tungsten and low iron content of INCONEL alloy 22 provide superior pitting resistance in this acid chloride environment.

**Table 7** - Critical crevice (CCT) and critical pitting (CPT) temperatures following testing in the ASTM G48 C and D environments of 6% FeCl₃ + 1% HCl for 72 hours.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Critical Crevice Temperature</th>
<th>Critical Pitting Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>°F</td>
</tr>
<tr>
<td>INCONEL alloy 686</td>
<td>&gt;85</td>
<td>&gt;185</td>
</tr>
<tr>
<td>INCONEL alloy 22</td>
<td>75</td>
<td>167</td>
</tr>
<tr>
<td>UNS N06022</td>
<td>58</td>
<td>136</td>
</tr>
<tr>
<td>UNS N10276</td>
<td>50</td>
<td>122</td>
</tr>
<tr>
<td>INCOLOY alloy 27-7MO</td>
<td>50</td>
<td>122</td>
</tr>
<tr>
<td>INCOLOY alloy 25-6MO</td>
<td>30</td>
<td>86</td>
</tr>
<tr>
<td>Type 316 stainless steel</td>
<td>20</td>
<td>68</td>
</tr>
</tbody>
</table>

**Figure 5** - Relative resistance of nickel-base alloys to crevice corrosion as a function of temperature in 11.9% H₂SO₄ + 1.3% HCl + 1% FeCl₃ + 1% CuCl₂ at 125 °C.

**Figure 6** - Relative resistance of nickel-base alloys to crevice corrosion in 11.9% H₂SO₄ + 1.3% HCl + 1% FeCl₃ + 1% CuCl₂ at 125 °C.
Applications at Elevated Temperatures

While INCONEL alloy 22 is widely used for its excellent resistance to aqueous corrosion, the alloy is also resistant to many process environments at elevated temperatures up to 1250°F (677°C). Alloy 22 has been found to be especially effective for protection of boiler tubes, waterwalls, and other components in coal-fired electric power generation boilers. The alloy has given superior service in low NOx boilers as well. Alloy 22 is resistant to attack at elevated temperatures by halides (especially chlorides) and sulfur, which are often present in the grades of coal used for power generation. INCONEL alloy 22 also offers excellent resistance to aggressive corrosion by metal chloride and sulfate salts found in power generation boilers fired by municipal solid waste. Alloy steel components are commonly overlaid with alloy 22 by welding. Weld deposits fabricated using the Ni-Cr-Mo-W alloy 22 do not exhibit the segregation tendencies shown by Ni-Cr-Mo-Nb alloy systems. This affords significant enhancements in corrosion resistance and excellent resistance to the corrosion-fatigue cracking which is commonly observed in low NOx boiler waterwall overlays applied using Ni-Cr-Mo-Nb materials. In addition, solid components are used and alloy 22 clad steel tubes are also available.

To meet stringent emission limits, fossil fuel and waste-fired power generation boilers are being redesigned to add burners to limit the formation of oxides of nitrogen (NOx). Improved protection of the boiler tubes and waterwalls for service in these more aggressive environments is required. INCONEL Filler Metal 625 weld overlays have long been used for protection of such boiler components, but a recent study determined that these overlays can suffer from circumferential cracking due to stress-accelerated sulfidation of the dendrite centers of the weld overlays in as little as 18 months of service. The study also indicated that INCONEL Filler Metal 622 overlays should offer significantly better resistance to this attack and, thus, extended service life. This superior performance is attributed to the higher molybdenum content and the absence of niobium, which has been blamed for elemental segregation problems in alloy 625 weld overlays. As a result, INCONEL alloy 622 welding products are preferred over alloy 625 products for overlay of boiler components.
INCONEL® alloy 22

**Forming and Welding**

INCONEL alloy 22 is readily fabricated by standard procedures for nickel alloys. Its high ductility aids cold forming, although work hardening may require intermediate annealing. Welding can be by gas tungsten-arc, gas metal-arc, and shielded metal-arc processes. Matched composition welding products, INCONEL Welding Electrode 122 and Filler Metal 622, are available. Overmatching composition welds may be deposited with INCO-WELD® Filler Metal 686 CPT® or INCO-WELD Welding Electrode 686CPT.

INCONEL Welding Electrode 122 and INCONEL Filler Metal 622 welding products are also used to join high nitrogen super-duplex and super-austenitic stainless steels when the use of niobium-bearing welding products may result in the undesirable formation of niobium nitride particles. Alloy 622 welding products are also used for weld overlay of boiler tubes, waterwalls, and hardware in electric power generation boilers fired by high sulfur coal or oil and waste-to-energy incineration systems fired by municipal and industrial waste.

Information on fabrication, joining and machining is available in the Special Metals publications “Fabricating,” “Joining” and “Machining,” respectively, on the website, www.specialmetals.com.

**Available Products and Specifications**

INCONEL alloy 22 is designated as UNS N06022 and Werkstoff Nr. 2.4602. Standard product forms include sheet, strip, plate, round bar, flat bar, forging stock, hexagon, and wire. The products are available in a wide range of sizes.

**Rod, Bar, Wire and Forging Stock** - ASTM B 462 (Rod, Bar and Forging Stock), ASTM B 564 & ASME SB 564 (Forgings), ASTM B 574 & ASME SB 574 (Rod, Bar and Wire), ASME Code Case 2226, ASME Code Case N-621, ISO 9723, ISO 9724, DIN 17752 (Rod & Bar), DIN 17753 (Wire), DIN 17754 (Forgings)

**Plate, Sheet and Strip** - ASTM B 575/B 906 & ASME SB 575/SB 906, ASME Code Case 2226, ASME Code Case N-621, ISO 6208, DIN 17750


**Welding Products** - INCONEL Filler Metal 622 - AWS A5.14 / ERNiCrMo-10, INCONEL Welding Electrode 622 - AWS A5.11 / ENiCrMo-10

**Other Product Forms** - ASTM B 366 & ASME SB-366 (Fittings)

**Composition** - DIN 17744
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- DEPOLARIZED®
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- FERRY®
- INCOBAR®
- INCOCLAD®
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- INCOFLUX®
- INCOLOY®
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- INCOLOY®
- INCOBAR®
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- INCONEL®
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- INCOTHERM®
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- KOTHERM®
- MONEL®
- NIMO®
- NILOMAG®
- NIMONIC®
- NIOTHERM®
- NI-ROD®
- NI-SPAN-C®
- RESISTOHM®
- UDIMAR®
- UDIMET®
- 601GC®
- 625LCF®
- 718SPF™
- 725NDUR®
- 800HT®
- 956HT™
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