ALLOY 625

Alloy 625 (UNS N06625/W.Nr. 2.4856) is used for its high strength, excellent fabricability (including joining), and outstanding corrosion resistance. Service temperatures range from cryogenic to 1800°F (982°C). Composition is shown in Table 1. Strength of Alloy 625 is derived from the stiffening effect of molybdenum and niobium on its nickel-chromium matrix; thus precipitation-hardening treatments are not required. This combination of elements also is responsible for superior resistance to a wide range of corrosive environments of unusual severity as well as to high-temperature effects such as oxidation and carburization.

The properties of Alloy 625 that make it an excellent choice for sea-water applications are freedom from local attack (pitting and crevice corrosion), high corrosion-fatigue strength, high tensile strength, and resistance to chloride-ion stress-corrosion cracking. It is used as wire rope for mooring cables, propeller blades for motor patrol gunboats, submarine auxiliary propulsion motors, submarine quickdisconnect fittings, exhaust ducts for Navy utility boats, sheathing for undersea communication cables, submarine transducer controls, and steam-line bellows. Potential applications are springs, seals, bellows for submerged controls, electrical cable connectors, fasteners, flexure devices, and oceanographic instrument components.

High tensile, creep, and rupture strength; outstanding fatigue and thermal-fatigue strength; oxidation resistance; and excellent weldability and brazeability are the properties of Alloy 625 that make it interesting to the aerospace field. It is being used in such applications as aircraft ducting systems, engine exhaust systems, thrust-reverser systems, resistancewelded honeycomb structures for housing engine controls, fuel and hydraulic line tubing, spray bars, bellows, turbine shroud rings, and heat-exchanger tubing in environmental control systems. It is also suitable for combustion system transition liners, turbine seals, compressor vanes, and thrust-chamber tubing for rocket The outstanding and versatile corrosion resistance of Alloy 625 under a wide range of temperatures and pressures is a primary reason for its wide acceptance in the chemical processing field. Because of its ease of fabrication, it is made into a variety of components for plant equipment. Its high strength enables it to be used, for example, in thinner-walled vessels or tubing than possible with other materials, thus improving heat transfer and saving weight. Some applications requiring the combination of strength and corrosion resistance offered by Alloy 625 are bubble caps, tubing, reaction vessels, distillation columns, heat exchangers, transfer piping, and valves. In the nuclear field, Alloy 625 may be used for reactor-core and control-rod components in nuclear water reactors. The material can be selected because of its high strength, excellent uniform corrosion resistance, resistance to stress cracking and excellent pitting resistance in 500°-600°F (260-316°C) water. Alloy 625 is also being considered in advanced reactor concepts because of its high allowable design strength at elevated temperatures, especially between 1200°-1400°F (649-760°C). The properties given in this bulletin, results of extensive testing, are typical of the alloy but should not be used for specification purposes.

Applicable specifications appear in the last section of this publication.

Physical Constants and Thermal Properties
Some physical constants and thermal properties of Alloy 625 are shown in Tables 2 and 3. Lowtemperature thermal expansion, based on measurements made by the National Bureau of Standards, is shown in Figure 1. Elevated-temperature modulus of elasticity data are given in Table 4.
Mechanical Properties
Nominal room-temperature mechanical properties of Alloy 625 are shown in Table 5. For service at 1200°F and below, hot-finished, cold-finished, and annealed conditions (depending on requirements involved) are recommended. For service above 1200°F, either annealed or solution-treated material will give best service. The solution-treated condition is recommended for components that require optimum resistance to creep or rupture. Fine-grained (annealed) material may be advantageous at temperatures up to 1500°F with respect to fatigue strength, hardness, and tensile and yield strength. MacGregor’s two-load was used for determination of the true stress-strain curve for Alloy 625 at room temperature. The two-load test requires no strain measurement during the test, and only the maximum and fracture loads are recorded. Data for both annealed and solution-treated material are shown in Figure 2.

Tensile Properties and Hardness
Typical tensile properties of annealed and solution treated material from room to elevated temperature are shown in Figures 3, 4, and 5. The approximate relationship between the hardness and tensile and yield strength of strip is shown in Figure 6. Increased tensile properties for service at moderate temperature can be achieved by cold work. See the section, “Working Instructions” for some specific data. Upon exposure to intermediate temperatures, some hardening takes place in Alloy 625. To demonstrate this reaction, samples of annealed rod were exposed to 1200°, 1400°, and 1600°F for 2000 hours. The effect of exposure on properties both at room temperature and at exposure temperature is shown in Table 6. Measurements were made to determine dimensional stability; the samples exposed at 1200° to 1400°F for 2000 hours contracted about 0.048%.

Fatigue Strength
Room-temperature fatigue strength of hot-rolled round in the as-rolled and annealed conditions is shown in Figure 7. Elevated-temperature fatigue strengths of solution-treated and annealed bar can be compared in Figures 8 and 9. The endurance limit (10⁸ cycles) at room temperature of cold-rolled annealed sheet tested in completely reversed bending was found to be 90,000 psi for smooth bar and 35,000 psi (notched specimen K+3.3).

Ductility and Toughness
Alloy 625 retains its excellent ductility and toughness at low temperature. Impact and tensile data to -320°F are shown in Table 7 and Figure 10.

Creep and Rupture Strength
Typical creep and rupture strength of solution-treated material is given in Figures 11 and 12. For comparison purposes, creep and rupture properties of annealed material are shown in Figures 13 and 14. Annealed material, when selected for some other consideration, will exhibit adequate creep rupture properties for many applications, although the values are not as high as those shown for solution treated material.
ASME Boiler and Pressure Vessel Code
Alloy 625 is an approved material of construction under the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME). Allowable design stresses for Grade 1 material for Section VIII, Division 1 construction up to 1200°F, for Section III, Class 2 and 3 construction up to 800 °F, and for Grade 2 material for Section VIII, Division 1 construction up to 1600°F are reported in Table 1B of ASME Section II, Part D. Design stress intensity values for Section III, Class 1 construction for Grade 1 material are found in Table 2B of ASME Section II, Part D. Allowable stresses and rules for Section 1 construction with Grade 1 material up to 1100°F are found in ASME Code Case 1935.

Microstructure
Alloy 625 is a solid-solution matrixstiffened face-centered-cubic alloy. The alloy may contain carbides, which are inherent in this type of alloy. Carbides that can be found are MC and M6C (rich in nickel, niobium, molybdenum, and carbon). In addition M23C6, a chromium-rich carbide, appears in solution-treated material exposed at lower temperatures. The hardening effect that takes place in the material on exposure in the range centered around 1200°F (See Mechanical Properties section) is due to sluggish precipitation of a nickel-niobium-rich phase, gamma prime. This phase gradually transforms to orthorhombic Ni3Nb when the alloy is heated for long times in the intermediate temperature range. Extensive investigation of the stability of Alloy 625 following exposure for extended periods in the 1000° to 1800°F temperature range has shown complete absence of embrittling intermetallic phases such as sigma.

Corrosion Resistance
Aqueous Corrosion
The high alloy content of Alloy 625 enables it to withstand a wide variety of severe corrosive environments. In mild environments such as the atmosphere, fresh and sea water, neutral salts, and alkaline media there is almost no attack. In more severe corrosive environments the combination of nickel and chromium provides resistance to oxidizing chemicals, whereas the high nickel and molybdenum contents supply resistance to non-oxidizing environments. The high molybdenum content also makes this alloy very resistant to pitting and crevice corrosion, and niobium acts to stabilize the alloy against sensitization during welding, thereby preventing subsequent intergranular cracking. Also, the high nickel content provides freedom from chloride ion stresscorrosion cracking. This combination of characteristics makes Alloy 625 useful over a broad spectrum of corrosive conditions. For instance, it has been recommended as a material of construction for a storage tank to handle chemical wastes, including hydrochloric and nitric acids – chemicals which represent directly opposite types of corrosion problems. Materials which resist either one of these acids are normally severely attacked by the other.

High-Temperature Oxidation
Alloy 625 has good resistance to oxidation and scaling at high temperature. Its performance in an extremely sever test is shown in comparison with that of other materials in Figure 15. In this test, periodic weight-loss determinations indicate the ability of the alloy to retain a protective oxide coating under drastic cyclic conditions. 1800°F is a temperature at which scaling resistance becomes a significant factor in service.
Working Instructions

Heating
Hot- or cold-formed parts are usually annealed at 1700°-1900°F for times commensurate with thickness; higher temperatures may be used to soften material for additional cold work. Alloy 625 is solution-treated at 2000°-2200°F. These temperatures are metal temperatures based on batch operations and may not apply to continuous annealing, which normally consists of short exposure in the hot zone of a furnace set at higher temperatures. The rate of cooling after heating has no significant effect on Alloy 625. Tables 8 and 9 can be used as a guide for determining the preferred temperature for reducing the stress level of the alloy. Heating cold-drawn material at 1100° to 1400°F reduces residual stress. Stress relief is virtually complete when the material is heated to 1600°F.

Pickling
When heated, Alloy 625, like other nickel-chromium and nickel-chromium-iron alloys, forms a tightly adherent oxide or scale unless it has been bright-annealed in very dry hydrogen or in a vacuum. To remove the oxide which results from heating, treatment in a fused-salt bath prior to pickling is usually recommended.

Hot and cold forming
Because Alloy 625 was especially developed to retain high strength at elevated temperature, it resists deformation at hot-working temperatures. It is readily fabricated by hot forming, however, provided adequately powerful equipment is used. When Alloy 625 is hot-formed, it should be heated in a furnace whose temperature is held at (but not above) 2150°F. The work should be brought up to as close to 2150°F as conditions permit. Heavy forging can be carried out from 2150°F down to 1850°F. Lighter reductions can be taken down to 1700°F. To guard against duplex grain structure, the work should be given uniform reductions. Final minimum reductions of 15 to 20% for open-die work are recommended. Alloy 625 can be cold-formed by standard processes. The force required to shear the alloy in the annealed condition is shown in Figure 17. More indications of its resistance to deformation can be derived from the true stress-true strain curves (see the “Mechanical Properties” section of this bulletin) and the effect of cold work on hardness (Figure 18). Increased tensile properties can be achieved by cold work for moderate-temperature applications. Tensile strengths of more than 300,000 psi accompanied by good ductility have been developed in 0.010-0.020-in.diameter wire after 75-90% cold reduction (See Table 10). Effects of cold work on plate are shown in Table 11.

Welding
Alloy 625 is readily joined by conventional welding processes and procedures. Like Alloy 625, deposited weld metals are highly resistant to corrosion and oxidation and have high strength and toughness from the cryogenic range to 1800°F. They require no postweld heat treatments to maintain their high strength and ductility. When used to weld Alloy 625 to dissimilar metals, both products tolerate a high degree of dilution yet maintain characteristic properties.

All-Weld-Metal Properties
High-temperature properties of weld metals are shown in Figures 19, 20, and 21. These welds were made by the gas-tungsten-arc process and the shielded-metal-arc process. Low-temperature toughness of weld metals is shown by the impact-strength data in Table 14.
Room-temperature fatigue strength (106 cycles; rotating-beam tests at 10,000 rpm) of polished all-weld-metal specimens was found to be 68,000 psi (Filler Metal 625) and 58,000 psi (Electrode 112).
The results of stress-rupture tests performed on all-weld-metal specimens of Electrode 112 are reported in Figure 22.

Transverse Properties
Properties of Alloy 625 welds made with the recommended welding products are shown in Figures 19 and 21.
As another example of weld quality, the gas-tungsten-arc process with 1/8-in. Filler Metal 625 was used to join 1/2-in. annealed plate. Transverse bends with a radius equal to two thicknesses (2T) had no fissuring or cracking.
Rupture strength of Alloy 625 welds made by the gas-tungsten-arc process and Filler Metal 625 is shown in Figure 23.
Both Filler Metal 625 and Welding Electrode 112 have been used to join Alloy 625 to a variety of dissimilar metals. The results of tests made on welds of Alloy 625 joined to a nickel-iron-chromium-molybdenum alloy (Alloy X), a precipitation-hardenable nickel-chromium alloy (Alloy 718), a cast chromium-nickel-iron-tungsten alloy and Types 304 and 410 stainless steel are shown in Table 15. All the joints passed dye-penetrant and radiographic inspection and guided-bend tests
### Table 1 – Limiting Chemical Composition, %

<table>
<thead>
<tr>
<th>Element</th>
<th>Limiting Composition, %</th>
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<tbody>
<tr>
<td>Nickel</td>
<td>58.0 min.</td>
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<tr>
<td>Chromium</td>
<td>20.0-23.0</td>
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<tr>
<td>Iron</td>
<td>5.0 max.</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>8.0-10.0</td>
</tr>
<tr>
<td>Niobium (plus Tantalum)</td>
<td>3.15-4.15</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.10 max.</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.50 max.</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.50 max.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.015 max.</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.015 max.</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.40 max.</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.40 max.</td>
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<tr>
<td>Cobalt</td>
<td>1.0 max.</td>
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*If determined

### Table 2 – Physical Constants

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<tr>
<th>Property</th>
<th>Value</th>
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<tr>
<td>Density, lb/ cu ft</td>
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<td>Melting Range, °F</td>
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<td>Density, g/cm³</td>
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<tr>
<td>Melting Range, °C</td>
<td>1290-1350</td>
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<tr>
<td>Specific Heat, Btu/lb°F (°K°C)</td>
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<tr>
<td>0°F (−18°C)</td>
<td>0.098 (410)</td>
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<tr>
<td>70°F (21°C)</td>
<td>0.102 (427)</td>
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<tr>
<td>200°F (93°C)</td>
<td>0.149 (565)</td>
</tr>
<tr>
<td>400°F (204°C)</td>
<td>0.153 (575)</td>
</tr>
<tr>
<td>600°F (316°C)</td>
<td>0.153 (575)</td>
</tr>
<tr>
<td>800°F (427°C)</td>
<td>0.141 (509)</td>
</tr>
<tr>
<td>1000°F (538°C)</td>
<td>0.128 (536)</td>
</tr>
<tr>
<td>1200°F (649°C)</td>
<td>0.135 (555)</td>
</tr>
<tr>
<td>1400°F (760°C)</td>
<td>0.154 (645)</td>
</tr>
<tr>
<td>1600°F (871°C)</td>
<td>0.148 (629)</td>
</tr>
<tr>
<td>1800°F (992°C)</td>
<td>0.154 (645)</td>
</tr>
<tr>
<td>2000°F (1093°C)</td>
<td>0.160 (670)</td>
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<tr>
<td>Permeability at 200 Oersted (15.9 kA/m)</td>
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<tr>
<td>Curie Temperature, °F</td>
<td>-520</td>
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<tr>
<td>Curie Temperature, °C</td>
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*Calculated

### Table 3 – Thermal and Electrical Properties

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<th>Temp. °F</th>
<th>Meal Linear Expansion*</th>
<th>Thermal Conductivity*</th>
<th>Electrical Resistivity*</th>
<th>Temp. °C</th>
<th>Mean Linear Expansion*</th>
<th>Thermal Conductivity*</th>
<th>Electrical Resistivity*</th>
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<td>-250</td>
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<td>600</td>
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<td>824</td>
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<td>134</td>
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*From 70°F to temperature shown  
*Measurements made at Battelle Memorial Institute  
*Material annealed 2100°F/1 hr

### Table 4 – Modulus at Elevated Temperatures

<table>
<thead>
<tr>
<th>Temp. °F</th>
<th>Modulus of Elasticity, 10^3 ksi</th>
<th>Poisson’s Ratio</th>
<th>Tension</th>
<th>Shear</th>
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<tr>
<td></td>
<td>Annealed</td>
<td>Solution-Treated</td>
<td>Annealed</td>
<td>Solution-Treated</td>
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<tr>
<td>70</td>
<td>30.1</td>
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<td>29.6</td>
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<td>11.1</td>
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<td>26.9</td>
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<td>1200</td>
<td>24.7</td>
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<td>8.0</td>
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### Table 5 – Nominal Room-Temperature Mechanical Properties

<table>
<thead>
<tr>
<th>Form And Condition</th>
<th>Tensile Strength (ksi)</th>
<th>Yield Strength (ksi)</th>
<th>Elongation (%)</th>
<th>Reduction Of Area (%)</th>
<th>Hardness, Brinell</th>
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<tbody>
<tr>
<td>Rod, Bar, Plate</td>
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<tr>
<td>As-Rolled</td>
<td>120-160</td>
<td>827-1103</td>
<td>60-110</td>
<td>414-758</td>
<td>60-40</td>
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<tr>
<td>Annealed</td>
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<td>827-1034</td>
<td>60-95</td>
<td>414-655</td>
<td>60-40</td>
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<tr>
<td>Solution-Treated</td>
<td>105-130</td>
<td>724-896</td>
<td>60-60</td>
<td>290-414</td>
<td>65-40</td>
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<td>Sheet and Strip</td>
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<td>827-1034</td>
<td>60-90</td>
<td>414-621</td>
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<td>Tube and Pipe, Cold-Drawn</td>
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<td>Annealed</td>
<td>120-140</td>
<td>827-965</td>
<td>60-75</td>
<td>414-517</td>
<td>55-30</td>
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<td>Solution-Treated</td>
<td>100-120</td>
<td>689-827</td>
<td>60-60</td>
<td>276-414</td>
<td>60-40</td>
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*Values shown are composites for various product sizes up to 4 in. They are not suitable for specification purposes. For properties of larger-sized products, consult Special Metals Corporation.

### Table 6 – Effect of Intermediate-Temperature Exposure (2000 hrs) on Properties of Hot-Rolled Annealed Bar

<table>
<thead>
<tr>
<th>Exposure Temperature, °F (°C)</th>
<th>Properties at Room Temperature</th>
<th>Properties at Exposure Temperature</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Tensile Strength, ksi</td>
<td>Yield Strength (0.2% offset), ksi</td>
</tr>
<tr>
<td></td>
<td>kpsi</td>
<td>MPa</td>
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<tr>
<td>No Exposure</td>
<td>140.0</td>
<td>965.3</td>
</tr>
<tr>
<td>1200 (649)</td>
<td>176.0</td>
<td>1213.5</td>
</tr>
<tr>
<td>1400 (760)</td>
<td>163.0</td>
<td>1123.8</td>
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</table>

*Values shown are composites for various product sizes up to 4 in. They are not suitable for specification purposes. For properties of larger-sized products, consult Special Metals Corporation.

### Table 7 – Low-Temperature Impact Strength* of Hot-Rolled, As-Rolled Plate (1/2-in. thickness)

<table>
<thead>
<tr>
<th>Test Temperature, °F</th>
<th>Orientation</th>
<th>Impact Strength, ft-lb</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Longitudinal</td>
<td>Transverse</td>
</tr>
<tr>
<td>-29°F (-33°C)</td>
<td>48.59</td>
<td>65.66</td>
</tr>
<tr>
<td>-79°F (-53°C)</td>
<td>46.49</td>
<td>62.70</td>
</tr>
<tr>
<td>-196°F (-80°C)</td>
<td>35.35</td>
<td>47.48</td>
</tr>
</tbody>
</table>

*Chassy keyhole specimens in triplicate.

### Table 8 – Effect of Annealing (1 hour) on Room-Temperature Properties of Hot-Rolled Rod

<table>
<thead>
<tr>
<th>Annealing Temperature, °F</th>
<th>Tensile Strength, ksi</th>
<th>Yield Strength (0.2% Offset), ksi</th>
<th>Elongation, %</th>
<th>Reduction Of Area, %</th>
<th>Hardness, Rockwell</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-Rolled</td>
<td>147.5</td>
<td>92.0</td>
<td>46.0</td>
<td>55.3</td>
<td>98</td>
</tr>
<tr>
<td>1500</td>
<td>145.5</td>
<td>90.8</td>
<td>43.0</td>
<td>49.5</td>
<td>101</td>
</tr>
<tr>
<td>1600</td>
<td>143.5</td>
<td>85.0</td>
<td>42.0</td>
<td>45.7</td>
<td>101</td>
</tr>
<tr>
<td>1700</td>
<td>145.5</td>
<td>87.2</td>
<td>39.0</td>
<td>41.5</td>
<td>101</td>
</tr>
<tr>
<td>1800</td>
<td>147.0</td>
<td>86.0</td>
<td>40.0</td>
<td>48.0</td>
<td>103</td>
</tr>
<tr>
<td>1850</td>
<td>143.5</td>
<td>82.6</td>
<td>44.0</td>
<td>48.0</td>
<td>101</td>
</tr>
<tr>
<td>1900</td>
<td>142.5</td>
<td>78.6</td>
<td>46.0</td>
<td>53.0</td>
<td>99</td>
</tr>
<tr>
<td>1950</td>
<td>142.5</td>
<td>76.3</td>
<td>49.0</td>
<td>51.5</td>
<td>95</td>
</tr>
<tr>
<td>2000</td>
<td>142.0</td>
<td>72.5</td>
<td>54.0</td>
<td>62.5</td>
<td>93</td>
</tr>
<tr>
<td>2100</td>
<td>116.0</td>
<td>60.0</td>
<td>62.0</td>
<td>61.0</td>
<td>89</td>
</tr>
<tr>
<td>2200</td>
<td>116.5</td>
<td>48.0</td>
<td>72.0</td>
<td>61.3</td>
<td>88</td>
</tr>
</tbody>
</table>

### Table 9 – Room-Temperature Tensile Properties of As-Drawn Wire

<table>
<thead>
<tr>
<th>Wire Diameter, MN</th>
<th>Cold Reduction, %</th>
<th>Tensile Strength, ksi</th>
<th>Yield Strength (0.2% offset), ksi</th>
<th>Elongation In 10,inches, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0308</td>
<td>1.008</td>
<td>0</td>
<td>138</td>
<td>61.5</td>
</tr>
<tr>
<td>0.036</td>
<td>0.914</td>
<td>19</td>
<td>174.5</td>
<td>51.3</td>
</tr>
<tr>
<td>0.0311</td>
<td>0.828</td>
<td>37</td>
<td>220</td>
<td>54</td>
</tr>
<tr>
<td>0.0264</td>
<td>0.724</td>
<td>49</td>
<td>246</td>
<td>55</td>
</tr>
<tr>
<td>0.0255</td>
<td>0.643</td>
<td>60</td>
<td>269</td>
<td>55</td>
</tr>
<tr>
<td>0.0226</td>
<td>0.574</td>
<td>68</td>
<td>283</td>
<td>55</td>
</tr>
<tr>
<td>0.0206</td>
<td>0.508</td>
<td>75</td>
<td>295</td>
<td>55</td>
</tr>
<tr>
<td>0.0179</td>
<td>0.455</td>
<td>80</td>
<td>295</td>
<td>55</td>
</tr>
<tr>
<td>0.0189</td>
<td>0.424</td>
<td>84</td>
<td>300</td>
<td>55</td>
</tr>
<tr>
<td>0.0142</td>
<td>0.381</td>
<td>97</td>
<td>306</td>
<td>55</td>
</tr>
<tr>
<td>0.0125</td>
<td>0.320</td>
<td>99</td>
<td>310</td>
<td>55</td>
</tr>
<tr>
<td>0.0111</td>
<td>0.282</td>
<td>92</td>
<td>310</td>
<td>55</td>
</tr>
<tr>
<td>0.0099</td>
<td>0.251</td>
<td>94</td>
<td>322</td>
<td>55</td>
</tr>
</tbody>
</table>

*Average of 2 tests unless otherwise shown.

Crosshead speed, 0.1 in./min.

Strain-rate-affected at 219°F, 29 ft/min, in 10-ft furnace with 6-7 ft hot zone

One test.
### Table 9 – Effect of Annealing (1 Hour) on Room-Temperature Properties of Cold-Drawn Rod

<table>
<thead>
<tr>
<th>Annealing Temperature, °F</th>
<th>Tensile Strength, ksi</th>
<th>Yield Strength, ksi</th>
<th>Elongation %</th>
<th>Reduction Of Area, %</th>
<th>Hardness, Rb</th>
<th>Impact Strength (Charpy V), ft-lb</th>
<th>Grain Size, in.</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-Drawn</td>
<td>163.0</td>
<td>1123.8</td>
<td>145.5</td>
<td>1003.2</td>
<td>21.0</td>
<td>50.5</td>
<td>106</td>
<td>64.5</td>
</tr>
<tr>
<td>1100</td>
<td>593.0</td>
<td>1016.0</td>
<td>134.3</td>
<td>926.0</td>
<td>28.0</td>
<td>48.3</td>
<td>106</td>
<td>75.0</td>
</tr>
<tr>
<td>1200</td>
<td>649.0</td>
<td>1099.7</td>
<td>133.5</td>
<td>920.5</td>
<td>28.5</td>
<td>47.2</td>
<td>106</td>
<td>71.5</td>
</tr>
<tr>
<td>1300</td>
<td>704.0</td>
<td>1130.7</td>
<td>135.0</td>
<td>938.8</td>
<td>26.0</td>
<td>38.8</td>
<td>106</td>
<td>57.0</td>
</tr>
<tr>
<td>1400</td>
<td>760.0</td>
<td>1120.4</td>
<td>135.5</td>
<td>934.2</td>
<td>27.0</td>
<td>39.0</td>
<td>106</td>
<td>53.0</td>
</tr>
<tr>
<td>1500</td>
<td>816.0</td>
<td>1048.0</td>
<td>120.0</td>
<td>827.4</td>
<td>29.0</td>
<td>41.5</td>
<td>105</td>
<td>55.0</td>
</tr>
<tr>
<td>1600</td>
<td>871.0</td>
<td>1010.1</td>
<td>102.5</td>
<td>706.7</td>
<td>35.0</td>
<td>45.2</td>
<td>103</td>
<td>62.0</td>
</tr>
<tr>
<td>1700</td>
<td>927.0</td>
<td>920.5</td>
<td>62.3</td>
<td>429.5</td>
<td>48.5</td>
<td>44.0</td>
<td>97</td>
<td>82.5</td>
</tr>
<tr>
<td>1800</td>
<td>982.0</td>
<td>879.1</td>
<td>62.3</td>
<td>429.5</td>
<td>52.0</td>
<td>55.3</td>
<td>95</td>
<td>84.5</td>
</tr>
<tr>
<td>1900</td>
<td>1038.0</td>
<td>899.8</td>
<td>60.8</td>
<td>419.2</td>
<td>50.0</td>
<td>55.7</td>
<td>95</td>
<td>91.0</td>
</tr>
<tr>
<td>2000</td>
<td>1093.0</td>
<td>872.2</td>
<td>56.5</td>
<td>389.6</td>
<td>57.0</td>
<td>61.0</td>
<td>93</td>
<td>115.5</td>
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<tr>
<td>2100</td>
<td>1149.0</td>
<td>813.6</td>
<td>48.3</td>
<td>333.0</td>
<td>63.0</td>
<td>60.4</td>
<td>89</td>
<td>138.0</td>
</tr>
<tr>
<td>2200</td>
<td>1204.0</td>
<td>779.1</td>
<td>44.6</td>
<td>307.5</td>
<td>62.3</td>
<td>58.4</td>
<td>86</td>
<td>141.0</td>
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</table>

### Table 11 – Effect of Cold Work on Mechanical Properties of Strips Cut From Hot-Rolled Plate (0.372-in.), Solution-Treated 2150°F/1 hr and Cold Worked

<table>
<thead>
<tr>
<th>Cold Reduction, %</th>
<th>Tensile Strength, ksi</th>
<th>Yield Strength (0.2% offset), ksi</th>
<th>Elongation %</th>
<th>Reduction Of Area, %</th>
<th>Hardness, Rockwell C</th>
<th>Vickers</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>115.5</td>
<td>796.3</td>
<td>49.5</td>
<td>341.3</td>
<td>67.0</td>
<td>60.4</td>
</tr>
<tr>
<td>5</td>
<td>121.0</td>
<td>834.3</td>
<td>77.5</td>
<td>534.3</td>
<td>58.0</td>
<td>58.1</td>
</tr>
<tr>
<td>10</td>
<td>130.0</td>
<td>896.3</td>
<td>102.5</td>
<td>706.7</td>
<td>47.5</td>
<td>54.6</td>
</tr>
<tr>
<td>15</td>
<td>137.0</td>
<td>944.6</td>
<td>112.5</td>
<td>775.7</td>
<td>39.0</td>
<td>51.9</td>
</tr>
<tr>
<td>20</td>
<td>143.0</td>
<td>986.0</td>
<td>125.0</td>
<td>861.8</td>
<td>31.5</td>
<td>50.0</td>
</tr>
<tr>
<td>30</td>
<td>165.0</td>
<td>1136.6</td>
<td>152.0</td>
<td>1048.0</td>
<td>17.0</td>
<td>49.3</td>
</tr>
<tr>
<td>40</td>
<td>179.5</td>
<td>1237.6</td>
<td>167.0</td>
<td>1151.4</td>
<td>12.5</td>
<td>41.9</td>
</tr>
<tr>
<td>50</td>
<td>189.5</td>
<td>1306.6</td>
<td>177.0</td>
<td>1220.4</td>
<td>8.5</td>
<td>38.9</td>
</tr>
<tr>
<td>60</td>
<td>205.0</td>
<td>1413.4</td>
<td>180.5</td>
<td>1244.5</td>
<td>6.5</td>
<td>32.7</td>
</tr>
<tr>
<td>70</td>
<td>219.0</td>
<td>1510.0</td>
<td>201.0</td>
<td>1385.8</td>
<td>5.0</td>
<td>25.4</td>
</tr>
</tbody>
</table>

### Table 12 – Recommended Conditions for Turning with Single-Point Tools

<table>
<thead>
<tr>
<th></th>
<th>High Speed Steel</th>
<th>Coated Carbide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Speed</td>
<td>Feed</td>
<td>Surface Speed</td>
</tr>
<tr>
<td>fpm</td>
<td>m/min</td>
<td>lpr</td>
</tr>
<tr>
<td>13-35</td>
<td>4.0-10.7</td>
<td>0.005-0.020</td>
</tr>
<tr>
<td>45-110</td>
<td>14-34</td>
<td>0.005-0.020</td>
</tr>
</tbody>
</table>

### Table 14 – Low-Temperature Impact Strength

<table>
<thead>
<tr>
<th>Welding Material</th>
<th>Notch Orientation</th>
<th>Charpy V-Notch Impact Strength, ft-lb (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>To Welding Direction</td>
<td>-320°F (-196°C)</td>
</tr>
<tr>
<td>Filler Metal 625%</td>
<td>Perpendicular</td>
<td>37.0 (77.3)</td>
</tr>
<tr>
<td>Electrode 112</td>
<td>Perpendicular</td>
<td>34.8 (74.7)</td>
</tr>
<tr>
<td></td>
<td>Parallel</td>
<td>32.8 (64.5)</td>
</tr>
</tbody>
</table>
Table 15 – Strength of Dissimilar Welds

<table>
<thead>
<tr>
<th>alloy 625 Joined to</th>
<th>Gas-Metal-Arc (Spray Transfer) With Filler Metal 265</th>
<th>Gas-Tungsten-Arc With Filler Metal 625</th>
<th>Shielded-Metal-Arc With Welding Electrode 112</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tensile Strength, Ksi (MPa)</td>
<td>Fracture Location</td>
<td>Tensile Strength, Ksi (MPa)</td>
</tr>
<tr>
<td>Alloy X</td>
<td>121.2 (835.6)</td>
<td>Alloy X</td>
<td>119.7 (825.3)</td>
</tr>
<tr>
<td>Alloy 718</td>
<td>120.7 (832.2)</td>
<td>Alloy 718</td>
<td>107.5 (741.2)</td>
</tr>
<tr>
<td>Type 304 Stainless Steel</td>
<td>88.5 (610.2)</td>
<td>Type 304</td>
<td>92.0 (634.3)</td>
</tr>
<tr>
<td>Type 410 Stainless Steel</td>
<td>65.6 (452.3)</td>
<td>Type 410</td>
<td>67.6 (466.1)</td>
</tr>
</tbody>
</table>

Figure 1 – Thermal Expansion at Low Temperatures

Figure 2 – True stress-true strain of round.

Figure 3 – High-temperature tensile properties of annealed bar.

Figure 4 – High-temperature tensile properties of cold-rolled annealed sheet.

Figure 5 – High-temperature tensile properties of hot-rolled solution-treated rod.
Figure 6 – Approximate relationships between hardness and tensile properties of strip.

Figure 7 – Fatigue strength at room temperature of hot-rolled round (5/8-in. diameter).

Figure 8 – Rotating-beam fatigue strength of hot-rolled solution-treated bar (0.625-in. diameter) at elevated temperature. Average grain size, 0.004 in.

Figure 9 – Rotating-beam fatigue strength of hot-rolled annealed bar (0.625-in. diameter) at elevated temperature. Average grain size, 0.006 in.; room-temperature hardness, 24.5 Rc.
Figure 10 – Tensile properties of cold-rolled (20% reduction), as-rolled sheet (0.024 gage) from low to elevated temperatures.

Figure 11 – Creep strength of solution-treated material.
**Figure 12** – Rupture life of solution-treated material.

**Figure 13** – Creep strength of annealed material.
Figure 14 – Rupture life of annealed material.

Figure 15 – Scaling resistance at 1800°F

Figure 17 – Load required for shearing annealed material (hydraulic shear; 21-64 in./β-knife rake).
Figure 18 – Effect of cold work on hardness.

Figure 19 – High-temperature tensile properties of transverse alloy 625 welds

Figure 20 – High-temperature tensile properties of alloy 625

Figure 21 – High-temperature tensile properties of deposited weld metal from weld made in alloy 625
Figure 22 – Rupture strength of Welding Electrode 112 all-weld metal.

Figure 23 – 100-hr rupture strength of transverse specimens from joints alloy 625 made by gas-tungsten-arc process.