Technical Datasheet CARPENTER TECHNOLOGY

# CarTech® 21Cr-6Ni-9Mn Stainless

## Identification

UNS Number

• S21904

## Type Analysis

*Single figures are nominal except where noted.*

| | | | |
|---|---|---|---|
| **Carbon (Maximum)** | 0.03 % | **Manganese** | 8.00 to 10.00 % |
| **Phosphorus (Maximum)** | 0.040 % | **Sulfur (Maximum)** | 0.030 % |
| **Silicon (Maximum)** | 1.00 % | **Chromium** | 19.00 to 21.50 % |
| **Nickel** | 5.50 to 7.50 % | **Nitrogen** | 0.15 to 0.40 % |
| **Iron** | Balance | | |

## General Information

Description

CarTech 21Cr-6Ni-9Mn is a high-manganese nitrogen strengthened, austenitic stainless steel that combines high strength in the annealed condition, excellent resistance to oxidation at high temperatures, good resistance to lead oxide and a high level of corrosion resistance at ambient temperatures. The alloy can be fabricated and formed much the same as CarTech 304 and CarTech 316, and is readily weldable. It remains nonmagnetic after severe cold work.

CarTech 21Cr-6Ni-9Mn has been used for chemical process and pollution-control equipment, steam and autoclave applications, and various aircraft engine components, as well as numerous other applications.

Scaling

Carpenter 21Cr-6Ni-9Mn has good resistance to high temperature oxidation in air and to corrosion by molten lead oxide.

## Corrosion Resistance

Carpenter 21Cr-6Ni-9Mn has corrosion resistance approaching that of Type 304L. Its low carbon content provides resistance to intergranular corrosion even in the welded condition.

For optimum corrosion resistance, surfaces must be free of scale, lubricants, foreign particles, and coatings applied for drawing and heading. After fabrication of parts, cleaning and/or passivation should be considered.

**Important Note:** *The following 4-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors which affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish and dissimilar metal contact.*

| | | | |
|---|---|---|---|
| Nitric Acid | Good | Sulfuric Acid | Moderate |
| Phosphoric Acid | Moderate | Acetic Acid | Moderate |
| Sodium Hydroxide | Moderate | Salt Spray (NaCl) | Good |
| Sea Water | Restricted | Humidity | Excellent |

**Typical Corrosion Properties**
Annealed condition

| Environment* | Material Condition | Average Corrosion Rate |
|---|---|---|
| 65 w/o $HNO_3$—boiling | Annealed | 7 mpy |
| 65 w/o $HNO_3$—boiling | Annealed + Sensitized 1250°F (677°C) | 9 mpy |
| 5 w/o $H_2SO_4$—R.T. | Annealed | nil |
| 10 w/o acetic acid—boiling | Annealed | nil |
| 10 w/o acetic acid—boiling | Annealed + Welded | nil |
| Oxalic acid etch test** | Annealed | pass |

*5 periods—48 hrs. each
**ASTM A262 Practice A

## Properties

### Physical Properties

| | | |
|---|---|---|
| Specific Gravity | 7.83 | |
| Density | 0.2830 | lb/in³ |
| Mean Specific Heat (32 to 212°F) | 0.1200 | Btu/lb/°F |
| Mean CTE | | |
| 80 to 200°F | 9.30 | x $10^{-6}$ in/in/°F |
| 80 to 400°F | 9.60 | x $10^{-6}$ in/in/°F |
| 80 to 600°F | 10.1 | x $10^{-6}$ in/in/°F |
| 80 to 1000°F | 10.6 | x $10^{-6}$ in/in/°F |
| 80 to 1400°F | 11.1 | x $10^{-6}$ in/in/°F |
| 80 to 1600°F | 11.2 | x $10^{-6}$ in/in/°F |
| 80 to 1800°F | 11.4 | x $10^{-6}$ in/in/°F |

**Mean Coefficient of Thermal Expansion**

| Temperature | | $10^{-6}$/°F | $10^{-6}$/K |
|---|---|---|---|
| 80°F to | 27°C to | | |
| 200 | 93 | 9.3 | 16.7 |
| 400 | 204 | 9.6 | 17.3 |
| 600 | 316 | 10.1 | 18.2 |
| 1000 | 538 | 10.6 | 19.1 |
| 1400 | 760 | 11.1 | 20.0 |
| 1600 | 871 | 11.2 | 20.2 |
| 1800 | 982 | 11.4 | 20.5 |

| | | |
|---|---|---|
| Thermal Conductivity | | |
| 200°F | 96.00 | BTU-in/hr/ft²/°F |
| 400°F | 112.0 | BTU-in/hr/ft²/°F |
| 600°F | 126.0 | BTU-in/hr/ft²/°F |
| 800°F | 140.0 | BTU-in/hr/ft²/°F |
| 1000°F | 156.0 | BTU-in/hr/ft²/°F |
| 1200°F | 172.0 | BTU-in/hr/ft²/°F |
| 1400°F | 186.0 | BTU-in/hr/ft²/°F |
| 1600°F | 200.0 | BTU-in/hr/ft²/°F |

**Thermal Conductivity**

| Test Temperature | | Btu-in/ft²•h•°F | W/m•K |
|---|---|---|---|
| °F | °C | | |
| 200 | 93 | 96 | 14 |
| 400 | 204 | 112 | 16 |
| 600 | 316 | 126 | 18 |
| 800 | 427 | 140 | 20 |
| 1000 | 538 | 156 | 23 |
| 1200 | 649 | 172 | 25 |
| 1400 | 760 | 186 | 27 |
| 1600 | 871 | 200 | 29 |

| | | |
|---|---|---|
| Modulus of Elasticity (E) | 28.5 | x $10^3$ ksi |
| Electrical Resistivity (70°F) | 439.0 | ohm-cir-mil/ft |

## Magnetic Properties

| | | |
|---|---|---|
| Magnetic Permeability | | |
| 50.0 Oe, 15.000% | 1.0040 | Mu |
| 50.0 Oe, 35.000% | 1.0050 | Mu |
| 50.0 Oe, 60.000% | 1.0100 | Mu |
| Annealed, 50.0 Oe | 1.0050 | Mu |
| 100 Oe, 15.000% | 1.0040 | Mu |
| 100 Oe, 35.000% | 1.0050 | Mu |
| 100 Oe, 60.000% | 1.0100 | Mu |
| Annealed, 100 Oe | 1.0040 | Mu |
| 200 Oe, 15.000% | 1.0030 | Mu |
| 200 Oe, 35.000% | 1.0050 | Mu |
| 200 Oe, 60.000% | 1.0120 | Mu |
| Annealed, 200 Oe | 1.0040 | Mu |
| 500 Oe, 60.000% | < 1.0200 | Mu |
| Annealed, 500 Oe | 1.0020 | Mu |
| | 1.0050 | Mu |

**Magnetic Permeability**

| Condition | Test Temperature | | Field Strength (Oersteds) of | | | |
|---|---|---|---|---|---|---|
| | °F | °C | 50 | 100 | 200 | 500 |
| Annealed | 75 | 24 | 1.005 | 1.004 | 1.004 | 1.002 |
| Annealed | -350 | -212 | — | — | — | 1.005 |
| 15% cold reduced | 75 | 24 | 1.004 | 1.004 | 1.003 | — |
| 35% cold reduced | 75 | 24 | 1.005 | 1.005 | 1.005 | — |
| 60% cold reduced | 75 | 24 | 1.010 | 1.010 | 1.012 | <1.020 |

## Typical Mechanical Properties

### Effect of Annealing Temperature on Typical Room Temperature Mechanical Properties of Strip

| Annealing* Temperature | | 0.2% Yield Strength | | Ultimate Tensile Strength | | % Elongation in 2" (50.8 mm) | Rockwell B Hardness |
|---|---|---|---|---|---|---|---|
| °F | °C | ksi | MPa | ksi | MPa | | |
| 1800 | 982 | 70 | 483 | 115 | 793 | 44 | 95 |
| 1850 | 1010 | 65 | 448 | 112 | 772 | 46 | 93 |
| 1900 | 1038 | 62 | 428 | 110 | 758 | 47 | 92 |
| 1950 | 1066 | 61 | 421 | 107 | 738 | 48 | 90 |

*Annealing time was approximately 6 minutes.

### Effect of Cold Reduction and Stress Relief Temperature on Typical Mechanical Properties of Strip*

| Test Temperature | | % Cold Reduction | Stress Relief Treatment (1 Hour) | | 0.2% Yield Strength | | Ultimate Tensile Strength | | % Elongation in 2"(50.8mm) | Rockwell Hardness |
|---|---|---|---|---|---|---|---|---|---|---|
| °F | °C | | °F | °C | ksi | MPa | ksi | MPa | | |
| 75 | 24 | 0 | — | — | 65 | 448 | 113 | 779 | 43 | B 95 |
| 75 | 24 | 15 | — | — | 116 | 800 | 137 | 944 | 22 | C 31 |
| 75 | 24 | 30 | — | — | 159 | 1096 | 177 | 1220 | 12 | C 37 |
| 75 | 24 | 0 | 900 | 482 | 70 | 483 | 114 | 786 | 43 | B 95 |
| 75 | 24 | 15 | 900 | 482 | 117 | 806 | 138 | 952 | 22 | C 32 |
| 75 | 24 | 30 | 900 | 482 | 175 | 1207 | 180 | 1241 | 11 | C 40 |
| 75 | 24 | 0 | 1250 | 677 | 70 | 483 | 114 | 786 | 43 | B 94 |
| 75 | 24 | 15 | 1250 | 677 | 105 | 724 | 137 | 944 | 26 | C 30 |
| 75 | 24 | 30 | 1250 | 677 | 149 | 1027 | 165 | 1138 | 19 | C 37 |
| 900 | 482 | 0 | — | — | 33 | 228 | 77 | 531 | 41 | — |
| 900 | 482 | 15 | — | — | 76 | 524 | 94 | 648 | 18 | — |
| 900 | 482 | 30 | — | — | 104 | 717 | 121 | 834 | 7 | — |
| 900 | 482 | 0 | 1250 | 677 | 34 | 234 | 77 | 531 | 42 | — |
| 900 | 482 | 15 | 1250 | 677 | 71 | 490 | 91 | 627 | 21 | — |
| 900 | 482 | 30 | 1250 | 677 | 97 | 668 | 112 | 772 | 13 | — |

*Bar properties are similar to strip properties for sizes up to approximately 2" (50.8 mm) rd. Larger bar sizes will have slightly lower strengths because hot/cold working becomes less effective in strengthening as the bar diameter increases.

### Typical Creep Strength of Annealed Bar

| Test Temperature | | Stress for Creep of | | | |
|---|---|---|---|---|---|
| °F | °C | 0.1% in 1000 Hrs. | | 0.01% in 1000 Hrs. | |
| | | ksi | MPa | ksi | MPa |
| 1200 | 649 | 14 | 47 | 10 | 64 |
| 1350 | 732 | 6 | 91 | 4 | 28 |

### Typical Cryogenic Mechanical Properties of Annealed Bar

| Test Temperature | | 0.2% Yield Strength | | Ultimate Tensile Strength | | % Elongation | % Reduction of Area | Charpy V-Notch Impact Strength | |
|---|---|---|---|---|---|---|---|---|---|
| °F | °C | ksi | MPa | ksi | MPa | | | ft-lb | J |
| 75 | 24 | 52 | 359 | 101 | 696 | 53 | 73 | 240 | 325 |
| -110 | -79 | 88 | 607 | 146 | 1007 | 52 | 72 | 213 | 289 |
| -321 | -196 | 141 | 972 | 219 | 1510 | 35 | 34 | 95 | 129 |

### Typical Elevated Temperature Tensile Properties of Annealed Strip

| Test Temperature °F | Test Temperature °C | 0.2% Yield Strength ksi | 0.2% Yield Strength MPa | Ultimate Tensile Strength ksi | Ultimate Tensile Strength MPa | % Elongation In 2" (50.8 mm) | Rockwell B Hardness |
|---|---|---|---|---|---|---|---|
| 75 | 24 | 65 | 448 | 112 | 772 | 42 | 95 |
| 200 | 93 | 52 | 359 | 100 | 690 | 41 | - |
| 400 | 204 | 41 | 283 | 89 | 614 | 40 | - |
| 600 | 316 | 38 | 262 | 86 | 593 | 33 | - |
| 800 | 427 | 32 | 221 | 79 | 545 | 33 | - |
| 900 | 482 | 29 | 200 | 75 | 517 | 41 | - |
| 1000 | 538 | 29 | 200 | 71 | 490 | 35 | - |
| 1100 | 593 | 28 | 193 | 68 | 469 | 35 | - |
| 1200 | 649 | 26 | 179 | 60 | 414 | 26 | - |
| 1300 | 704 | 26 | 179 | 51 | 352 | 24 | - |

### Typical Room Temperature Mechanical Properties of Annealed Bar

| Cross Section Size | Test Direction | 0.2% Yield Strength ksi | 0.2% Yield Strength MPa | Ultimate Tensile Strength ksi | Ultimate Tensile Strength MPa | % Elongation in 4D | % Reduction of Area | Rockwell B Hardness |
|---|---|---|---|---|---|---|---|---|
| 6"(152mm) sq. | Longitudinal | 62 | 428 | 95 | 655 | 46 | 69 | — |
| 6"(152mm) sq. | Transverse | 52 | 358 | 93 | 641 | 30 | 45 | — |
| 4"(102mm) sq. | Longitudinal | 56 | 386 | 97 | 668 | 53 | 73 | — |
| 1"(25.4mm) rd. | Longitudinal | 52 | 358 | 101 | 696 | 53 | 73 | 90 |

### Typical Room Temperature Mechanical Properties of Cold-Drawn Wire

| % Cold Reduction | Stress Relief Treatment (2 Hours) °F | Stress Relief Treatment (2 Hours) °C | 0.2% Yield Strength ksi | 0.2% Yield Strength MPa | Ultimate Tensile Strength ksi | Ultimate Tensile Strength MPa | % Elongation in 4D | % Reduction of Area | Rockwell C Hardness |
|---|---|---|---|---|---|---|---|---|---|
| 15 | none | none | 106 | 731 | 127 | 876 | 55 | 70 | — |
| 15 | 1000 | 538 | 101 | 696 | 127 | 876 | 55 | 65 | 20 |
| 15 | 1150 | 621 | 91 | 627 | 124 | 855 | 44 | 65 | 20 |
| 15 | 1300 | 704 | 90 | 620 | 121 | 834 | 59 | 63 | 20 |
| 30 | none | none | 152 | 1048 | 172 | 1186 | 24 | 54 | 37 |
| 30 | 1000 | 538 | 154 | 1062 | 172 | 1186 | 24 | 53 | 37 |
| 30 | 1150 | 621 | 140 | 965 | 153 | 1054 | 26 | 53 | 31 |
| 30 | 1300 | 704 | 127 | 876 | 147 | 1014 | 39 | 53 | 28 |

### Typical Stress Rupture Strength of Annealed Bar

| Test Temperature °F | Test Temperature °C | Stress for Rupture in 100 Hours ksi | Stress for Rupture in 100 Hours MPa | Stress for Rupture in 1000 Hours ksi | Stress for Rupture in 1000 Hours MPa |
|---|---|---|---|---|---|
| 1200 | 649 | 34 | 234 | 28 | 193 |
| 1350 | 732 | 21 | 145 | 14 | 97 |
| 1500 | 816 | 10 | 69 | 6 | 41 |

### Typical Stress Rupture Strength of Annealed Strip

| Test Temperature °F | Test Temperature °C | Stress for Rupture in 100 Hours ksi | Stress for Rupture in 100 Hours MPa | Stress for Rupture in 1000 Hours ksi | Stress for Rupture in 1000 Hours MPa |
|---|---|---|---|---|---|
| 1200 | 649 | 32 | 221 | 32 | 152 |
| 1500 | 816 | 6 | 40 | 3 | 21 |

## Heat Treatment

### Annealing

Annealing is used for best stress rupture life and for operating temperatures between 1300 and 1600ºF (704 and 871ºC). The alloy is not recommended for service above 1600ºF (871ºC). Also, annealing softens the alloy for maximum formability. After annealing the strength of the material can be increased only by hot/cold working or cold working.

Annealing is generally done in the temperature range of 1800/2150ºF (982/1177ºC). Grain coarsening will occur at the higher temperatures. Lower temperatures such as 1650ºF (899ºC) can be used; the temperature must be selected according to the degree of softening required and grain size restrictions.

### Stress Relieving

Stress relieving is used to achieve best all-around properties and for operating temperatures below 1300ºF (704ºC). The temperature range for stress relieving is 900/1400ºF (482/760ºC). Temperatures between 900 and 1250ºF (482 and 677ºC) will have little effect on the mechanical properties of cold reduced material unless the percent cold reduction is high; then slight increases or decreases in strength will occur. Above 1250ºF (677ºC), the change in mechanical properties will occur more rapidly; a temperature of 1500ºF (816ºC) begins to cause rapid softening. The proper stress relief treatment should be selected carefully in order to produce the desired strength levels.

## Workability

Carpenter 21Cr-6Ni-9Mn is a solution-strengthened alloy and cannot be strengthened by heat treatment. Hot/cold working or cold working can be employed to strengthen this alloy. Hot/cold working is normally done in the temperature range of 1200/1500ºF (649/816ºC); reductions in the order of 10 to 40% are used and the percent used is dependent on the strength level required. A stress relief of 900/1400ºF (482/760ºC) is normally applied after hot/cold working operations. Heat treatment of hot/cold worked material, as discussed in the preceding section, will aid in adjusting mechanical properties to the desired levels.

### Hot Working

Carpenter 21Cr-6Ni-9Mn can be forged, hot rolled, hot headed and upset. An initial forging temperature of 2100/2200ºF (1149/1204ºC) is normally used. Preheating to an intermediate temperature is not required. Forgings can be rapidly cooled without danger of cracking. This alloy can be hot worked as low as 1200ºF (649ºC), and is not susceptible to hot shortness in the entire working range. For best corrosion resistance, anneal after forging.

### Cold Working

Carpenter 21Cr-6Ni-9Mn is readily cold worked by conventional methods. The alloy's high work-hardening rate and higher initial yield strength dictate greater force than when forming the same part from Types 301, 302, 304, 316, etc.

### Machinability

Carpenter 21Cr-6Ni-9Mn is readily machined using the techniques applied to the austenitic stainless steels. A rigid setup and ample coolant flow should be considered.

Following are typical feeds and speeds for Carpenter 21Cr-6Ni-9Mn.

## Typical Machining Speeds and Feeds – Carpenter 21Cr-6Ni-9Mn Stainless

*The speeds and feeds in the following charts are conservative recommendations for initial setup. Higher speeds and feeds may be attainable depending on machining environment.*

### Turning—Single-Point and Box Tools

| Depth of Cut (Inches) | High Speed Tools | | | Carbide Tools (Inserts) | | | |
|---|---|---|---|---|---|---|---|
| | Tool Material | Speed (fpm) | Feed (ipr) | Tool Material | Speed (fpm) | | Feed (ipr) |
| | | | | | Uncoated | Coated | |
| .150 | M2 | 55 | .015 | C6 | 250 | 300 | .015 |
| .025 | T15 | 70 | .007 | C7 | 300 | 350 | .007 |

### Turning—Cut-Off and Form Tools

| Tool Material | | Speed (fpm) | Feed (ipr) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| High Speed Tools | Carbide Tools | | Cut-Off Tool Width (inches) | | | | Form Tool Width (inches) | | |
| | | | 1/16 | 1/8 | 1/4 | 1/2 | 1 | 1 ½ | 2 |
| T15 | | 40 | .001 | .001 | .0015 | .0015 | .001 | .0007 | .0007 |
| | C6 | 140 | .004 | .0055 | .0045 | .004 | .003 | .002 | .002 |

### Rough Reaming

| High Speed | | Carbide Tools | | Feed (ipr) Reamer Diameter (inches) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tool Material | Speed (fpm) | Tool Material | Speed (fpm) | 1/8 | 1/4 | 1/2 | 1 | 1 ½ | 2 |
| M7 | 60 | | | | | | | | |
| | | C2 | 80 | .003 | .005 | .008 | .012 | .015 | .018 |

### Drilling

| Tool Material | Speed (fpm) | High Speed Tools | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Feed (inches per revolution) Nominal Hole Diameter (inches) | | | | | | | |
| | | 1/16 | 1/8 | 1/4 | 1/2 | 3/4 | 1 | 1 ½ | 2 |
| T15, M42 | 50-60 | .001 | .002 | .004 | .007 | .010 | .012 | .015 | .018 |

### Die Threading

| FPM for High Speed Tools | | | | |
|---|---|---|---|---|
| Tool Material | 7 or less, tpi | 8 to 15, tpi | 16 to 24, tpi | 25 and up, tpi |
| T15, M42 | 4-8 | 6-10 | 8-12 | 10-15 |

### Milling, End-Peripheral

| Depth of Cut (inches) | High Speed Tools | | | | | | Carbide Tools | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tool Material | Speed (fpm) | Feed (ipt) Cutter Diameter (in) | | | | Tool Material | Speed (fpm) | Feed (ipt) Cutter Diameter (in) | | | |
| | | | 1/4 | 1/2 | 3/4 | 1-2 | | | 1/4 | 1/2 | 3/4 | 1-2 |
| .050 | M2, M7 | 65 | .001 | .002 | .003 | .004 | C2 | 245 | .001 | .002 | .003 | .005 |

### Tapping

| High Speed Tools | |
|---|---|
| Tool Material | Speed (fpm) |
| M1, M7, M10 | 12-25 |

### Broaching

| High Speed Tools | | |
|---|---|---|
| Tool Material | Speed (fpm) | Chip Load (ipt) |
| M2, M7 | 10 | .003 |

When using carbide tools, surface speed feet/minute (SFPM) can be increased between 2 and 3 times over the high-speed suggestions. Feeds can be increased between 50 and 100%.

Figures used for all metal removal operations covered are average. On certain work, the nature of the part may require adjustment of speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.

Additional Machinability Notes

When using carbide tools, surface speed feet/minute (SFPM) can be increased between 2 and 3 times over the high speed suggestions. Feeds can be increased between 50 and 100%.

Figures used for all metal removal operations covered are average. On certain work, the nature of the part may require adjustment of speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.

Weldability

Carpenter 21Cr-6Ni-9Mn can be satisfactorily welded by the shielded fusion and resistance welding processes. Oxyacetylene welding is not recommended, since carbon pickup in the weld may occur. When a filler metal is required, consider AWS E/ER219 welding consumables which should provide welds with strength approaching that of the base metal. If high weld strength is not necessary, then E/ER309 should be considered. Resistance to intergranular corrosion can be restored by a postweld annealing treatment.

## Other Information

### Applicable Specifications

AMS 5561 High Pressure Hydraulic Seamless or Welded Tubing

- AMS 5561
- AMS 5562 (Seamless Tubing)
- AMS 5595 (Plate, Sheet, Strip)
- AMS 5656 (Bar, Forging, Rings)
- ASTM A276 (Bars and Shapes)
- ASTM A412 (Plate, Sheet, Strip)
- ASTM A580 (Wire)
- MIL-T-9821 (Sheet, Plate, Strip, Bars, Shapes, Forgings)

### Forms Manufactured

- Bar-Rounds
- Billet
- Strip
- Wire

### Technical Articles

- A Guide to Etching Specialty Alloys for Microstructural Evaluation
- Selecting Stainless Steels for Valves

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