Technical Datasheet

CARPENTER

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# Pyromet® Alloy 355

## Identification

**UNS Number**

- S35500

**AISI Number**

- 634

## Type Analysis

| | | | |
|---|---|---|---|
| **Carbon** | 0.10 to 0.15 % | **Manganese** | 0.50 to 1.25 % |
| **Phosphorus** | 0.040 % | **Sulfur** | 0.030 % |
| **Silicon** | 0.50 % | **Chromium** | 15.00 to 16.00 % |
| **Nickel** | 4.00 to 5.00 % | **Molybdenum** | 2.50 to 3.25 % |
| **Nitrogen** | 0.07 to 0.13 % | **Iron** | 73.65 to 77.26 % |

## General Information

**Description**

Pyromet® alloy 355 is a chromium-nickel-molybdenum stainless steel which can be hardened by martensitic transformation and/or precipitation hardening.

Depending upon the heat treatment, Pyromet alloy 355 may have an austenitic structure and formability similar to other austenitic stainless steels or a martensitic structure and high strength comparable to other martensitic stainless steels. High strengths may also be attained by cold working, and are maintained (whether produced by heat treatment or by cold work) at temperatures up to 1000°F (538°C). Corrosion resistance of the alloy is superior to that of other quench-hardenable martensitic stainless steels and approaches that of the chromium-nickel austenitic stainless steels.

The alloy is usually supplied in either the annealed or in the equalized and over-tempered condition.

**Applications**

It has been used for gas turbine compressor components such as blades, discs, rotors and shafts and similar parts where high strength is required at intermediate elevated temperatures.

## Corrosion Resistance

Pyromet alloy 355 has corrosion resistance superior to that of other quench-hardenable martensitic stainless steels. It offers good resistance to atmospheric corrosion and to a number of other mild chemical environments. Material in the double-aged or equalized and overtempered condition is susceptible to intergranular corrosion because of grain boundary precipitation of carbides. When this alloy is hardened by sub-zero cooling, it is not subject to intergranular attack.

The treatment for optimum stress-corrosion resistance is as follows: Heat to 1875/1900°F (1024/1038°C), water quench, sub-zero cool 3 hours at -100°F (-73°C); reheat to 1700°F (927°C), air cool, sub-zero cool to -100°F (-73°C) for 3 hours, and then temper at 1000°F (538°C) for 3 hours.

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

## Properties

**Physical Properties**

**Specific Gravity**

| | |
|---|---|
| Annealed | 7.92 |
| Sub-zero Cooled, Tempered 850°F | 7.81 |

**Density**

| | |
|---|---|
| Annealed | 0.2860 lb/in³ |
| Sub-zero Cooled, Tempered 850°F (454°C) | 0.2820 lb/in³ |

| | |
|---|---|
| **Mean Specific Heat** | |
| 32°F, 212°F | 0.1200 Btu/lb/°F |
| **Mean Coefficient of Thermal Expansion** | |
| 68°F, 212°F, Annealed | 8.30 x $10^{-6}$ in/in/°F |
| 68°F, 572°F, Annealed | 7.90 x $10^{-6}$ in/in/°F |
| 68°F, 752°F, Annealed | 8.30 x $10^{-6}$ in/in/°F |
| 68°F, 932°F, Annealed | 9.40 x $10^{-6}$ in/in/°F |
| 68°F, 1150°F, Annealed | 9.20 x $10^{-6}$ in/in/°F |
| 68°F, 1350°F, Annealed | 9.70 x $10^{-6}$ in/in/°F |
| 68°F, 1500°F, Annealed | 10.2 x $10^{-6}$ in/in/°F |
| 68°F, 1700°F, Annealed | 10.6 x $10^{-6}$ in/in/°F |
| 68°F, 212°F, Sub-zero Cooled, Tempered 850°F (454°C) | 6.40 x $10^{-6}$ in/in/°F |
| 68°F, 572°F, Sub-zero Cooled, Tempered 850°F (454°C) | 6.80 x $10^{-6}$ in/in/°F |
| 68°F, 752°F, Sub-zero Cooled, Tempered 850°F (454°C) | 7.00 x $10^{-6}$ in/in/°F |
| 68°F, 932°F, Sub-zero Cooled, Tempered 850°F (454°C) | 7.20 x $10^{-6}$ in/in/°F |
| 68°F, 1150°F, Sub-zero Cooled, Tempered 850°F (454°C) | 7.20 x $10^{-6}$ in/in/°F |
| 68°F, 1350°F, Sub-zero Cooled, Tempered 850°F (454°C) | 6.50 x $10^{-6}$ in/in/°F |
| 68°F, 1500°F, Sub-zero Cooled, Tempered 850°F (454°C) | 6.70 x $10^{-6}$ in/in/°F |
| 68°F, 1700°F, Sub-zero Cooled, Tempered 850°F (454°C) | 7.10 x $10^{-6}$ in/in/°F |

- Mean Coefficient of Thermal Expansion

| | |
|---|---|
| **Thermal Conductivity** | |
| 100°F, Sub-zero Cooled, Tempered 850°F (454°C) | 105.0 BTU-in/hr/ft²/°F |
| 200°F, Sub-zero Cooled, Tempered 850°F (454°C) | 110.0 BTU-in/hr/ft²/°F |
| 300°F, Sub-zero Cooled, Tempered 850°F (454°C) | 114.0 BTU-in/hr/ft²/°F |
| 400°F, Sub-zero Cooled, Tempered 850°F (454°C) | 114.0 BTU-in/hr/ft²/°F |
| 500°F, Sub-zero Cooled, Tempered 850°F (454°C) | 124.0 BTU-in/hr/ft²/°F |
| 600°F, Sub-zero Cooled, Tempered 850°F (454°C) | 128.0 BTU-in/hr/ft²/°F |
| 700°F, Sub-zero Cooled, Tempered 850°F (454°C) | 134.0 BTU-in/hr/ft²/°F |
| 800°F, Sub-zero Cooled, Tempered 850°F (454°C) | 139.0 BTU-in/hr/ft²/°F |
| 900°F, Sub-zero Cooled, Tempered 850°F (454°C) | 144.0 BTU-in/hr/ft²/°F |

- Thermal Conductivity

| | |
|---|---|
| **Modulus of Elasticity (E)** | |
| 80°F, Sub-zero Cooled, Tempered 850°F (454°C) | 29.3 x $10^{3}$ ksi |
| 400°F, Sub-zero Cooled, Tempered 850°F (454°C) | 27.3 x $10^{3}$ ksi |
| 600°F, Sub-zero Cooled, Tempered 850°F (454°C) | 26.3 x $10^{3}$ ksi |
| 700°F, Sub-zero Cooled, Tempered 850°F (454°C) | 25.3 x $10^{3}$ ksi |
| 800°F, Sub-zero Cooled, Tempered 850°F (454°C) | 24.6 x $10^{3}$ ksi |
| **Modulus of Rigidity (G)** | |
| 80.0°F, Sub-zero Cooled, Tempered 850°F (454°C) | 11.4 x $10^{3}$ ksi |
| 400°F, Sub-zero Cooled, Tempered 850°F (454°C) | 10.5 x $10^{3}$ ksi |
| 600°F, Sub-zero Cooled, Tempered 850°F (454°C) | 9.90 x $10^{3}$ ksi |
| 700°F, Sub-zero Cooled, Tempered 850°F (454°C) | 9.60 x $10^{3}$ ksi |
| 800°F, Sub-zero Cooled, Tempered 850°F (454°C) | 9.40 x $10^{3}$ ksi |
| **Electrical Resistivity** | |
| 82.0°F, Sub-zero Cooled, Tempered 850°F (454°C) | 456.0 ohm-cir-mil/ft |
| 113°F, Sub-zero Cooled, Tempered 850°F (454°C) | 461.0 ohm-cir-mil/ft |
| 211°F, Sub-zero Cooled, Tempered 850°F (454°C) | 480.0 ohm-cir-mil/ft |
| 320°F, Sub-zero Cooled, Tempered 850°F (454°C) | 498.0 ohm-cir-mil/ft |
| 470°F, Sub-zero Cooled, Tempered 850°F (454°C) | 522.0 ohm-cir-mil/ft |
| 607°F, Sub-zero Cooled, Tempered 850°F (454°C) | 549.0 ohm-cir-mil/ft |
| 734°F, Sub-zero Cooled, Tempered 850°F (454°C) | 570.0 ohm-cir-mil/ft |
| 885°F, Sub-zero Cooled, Tempered 850°F (454°C) | 597.0 ohm-cir-mil/ft |
| 1050°F, Sub-zero Cooled, Tempered 850°F (454°C) | 623.0 ohm-cir-mil/ft |
| 1210°F, Sub-zero Cooled, Tempered 850°F (454°C) | 650.0 ohm-cir-mil/ft |
| 1390°F, Sub-zero Cooled, Tempered 850°F (454°C) | 660.0 ohm-cir-mil/ft |

- Electrical Resistivity

**Melting Range**

| | |
|---|---|
| -- | 2500.000 to 2550.000 °F |

- Moduli of Elasticity (E) and Rigidity (G)

**Magnetic Properties**

- Magnetic Properties

**Typical Mechanical Properties**

- Typical Charpy V-Notch Impact Strength
- Typical Elevated Temperature Tensile Properties of Bar
- Typical Fatigue Strength
- Typical Longitudinal Charpy V-Notch Impact Strength of Bar
- Typical Room Temperature Mechanical Properties
- Typical Room Temperature Tensile Properties After Exposure to Elevated Temperatures
- Typical Room Temperature Tensile Properties After Exposure to Elevated Temperatures Under Stress
- Typical Stress Rupture Strength Bar
- Typical Tensile Ductility at Elevated Temperatures
- Typical Yield and Tensile Strengths at Elevated Temperatures

## Heat Treatment

**Annealing**

Heat to 1850/1900°F (1024/1038°C) and cool rapidly.

**Hardening**

The alloy can be hardened by either sub-zero cooling or by a double-aging treatment. Hardening by sub-zero cooling will result in higher strength than that attained by double aging. "Conditioning" of the alloy by rapid cooling from 1710/1750°F (932/954°C) is required before either hardening treatment.

**Double Age**

1350/1400°F (732/760°C) for 3-4 hours, rapid cool; 825/875°F (440/468°C) for 2-3 hours, air cool. The 1350/1400°F (732/760°C) treatment results in carbide precipitation so that the material will completely transfer to martensite when rapidly cooled to room temperature. The treatment at 825/875°F (440/468°C) after transformation provides further increases in strength and hardness.

**Sub-Zero Cooling**

After conditioning, the alloy is held at -100°F (-73°C) for a minimum of 3 hours and then tempered at 850°F (454°C) for the best combination of strength and ductility. If, however, applications require better finish machining characteristics, higher impact strengths, or higher ductilities than are provided by an 850°F (454°C) temper, tempering temperatures up to 1000°F (538°C) may be employed. Optimum stress-corrosion-cracking resistance is provided by the 1000°F (538°C) temper.

**Equalized and Overtempered**

In this variation of double-age, treat at 1375/1475°F (732/801°C) for 3-4 hours, rapid cool, then treat at 1000/1100°F (538/593°C), air cool. This treatment imparts higher ductility and lower hardness than double aging. It is the condition in which this alloy is most readily machined.

Bars and billets are normally equalized and overtempered before being "conditioned" for hardening. Surface conditions such as nitriding, carburization, or decarburization are to be avoided as they will inhibit the response of the material to hardening.

## Workability

**Hot Working**

The hot working characteristics of Pyromet alloy 355 are similar to those of other chromium-nickel stainless steels. It is worked from a maximum temperature of 2100°F (1149°C) and finished in the range 1700/1800°F (927/982°C). The use of starting temperatures higher than 2100°F (1149°C) results in an increased amount of delta ferrite in the alloy. A relatively low finishing temperature prevents subsequent grain coarsening and promotes homogeneous precipitation of carbides. Cool forgings in air to room temperature. Then equalize and over-temper.

**Cold Working**

In the annealed condition Pyromet alloy 355 is handled in much the same manner as AISI Type 300 series stainless steels. It has, however, a high rate of work hardening, about the same as AISI Type 301. When desirable the rate of work hardening may be lowered slightly by heating the material to 600/700°F (316/371°C) before cold working.

In the hardened condition this alloy has sufficient ductility for limited forming and straightening operations.

**Machinability**

Successful machining of Pyromet alloy 355 requires the same practices used for other stainless steels; i.e., rigid tool and work supports, slower speeds, positive cuts, absence of dwelling or glazing, and adequate amounts of coolant.

In the annealed condition this alloy has a high rate of work hardening and a tendency to be gummy. Machining this alloy in the annealed condition is not, therefore, recommended.

If machining is to be done after sub-zero hardening, tempering at 1000°F (538°C), hardness Rockwell C40, is suggested. This will provide improved machinability compared to that obtained after lower tempering treatments.

Optimum machinability of this alloy is obtained when the material is in the equalized and overtempered condition.

Following are typical feeds and speeds for Pyromet alloy 355.

- Machinability Tables 1
- Machinability Tables 2

**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 Pyromet alloy 355 can be satisfactorily welded by the shielded fusion and resistance welding processes. Oxyacteylene welding is not recommended, since carbon pickup in the weld may occur. When a filler metal is required, a matching analysis should be used to provide welds with properties approximately the same as the base metal. When designing the weld joint, care should be exercised to avoid stress concentrators, such as sharp corners, threads, and partial-penetration welds. When high weld strength is not needed, a standard austenitic stainless filler, such as E/ER 308, should be considered.

Preheating is not required to prevent cracking. If possible, the weldment should be annealed after welding to provide the optimum combination of strength, ductility and corrosion resistance.

**Brazing**

All common silver- or nickel-base brazing alloys with flow points between 1600/1900°F (871/1038°C) can be used successfully on Pyromet alloy 355. If the brazing temperature is above 1710°F (932°C), the material should be cooled to 1710°F (932°C) and held for a short time before cooling to room temperature.

## Other Information

**Applicable Specifications**

Carpenter Pyromet alloy 355 meets specifications:
AMS 5743 (bars, equalized and over-tempered)
AMS 5744 (bars, sub-zero cooled and tempered)

- AMS 5743
- AMS 5744

**Forms Manufactured**

- Bar-Flats
- Bar-Rounds
- Billet
- Wire

**Technical Articles**

- How to Passivate Stainless Steel Parts
- Passivating and Electropolishing Stainless Steel Parts

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