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Pyromet® Alloy 350

Identification

UNS Number

- S35000

AISI Number

- 633

Type Analysis

Carbon	0.07 to 0.11 %	**Manganese**	0.50 to 1.25 %
Phosphorus	0.040 %	**Sulfur**	0.030 %
Silicon	0.50 %	**Chromium**	16.00 to 17.00 %
Nickel	4.00 to 5.00 %	**Molybdenum**	2.50 to 3.25 %
Nitrogen	0.07 to 0.13 %	**Iron**	72.69 to 76.29 %

General Information

Description

Pyromet® alloy 350 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 350 may have an austenitic structure for best formability, or a martensitic structure with strengths comparable to those of martensitic steels. The alloy normally contains about 5 to 10% delta ferrite. The corrosion resistance of Pyromet alloy 350 approaches that of the chromium-nickel austenitic stainless steels.

Applications

Pyromet Alloy 350 has been used for gas turbine compressor components such as blades, discs, rotors and shafts, and similar parts where high strength was required at room and intermediate temperatures.

Corrosion Resistance

Pyromet alloy 350 has corrosion resistance superior to that of other quench-hardenable martensitic stainless steels. It has shown good corrosion resistance in ordinary atmospheres and numerous other mild chemical environments. Material in the double-aged or equalized condition is susceptible to intergranular corrosion because of the precipitation of chromium carbides. When the alloy is hardened by treatments employing sub-zero cooling as in the following paragraph, it is not subject to intergranular attack.

The treatment for optimum stress-corrosion resistance of Pyromet alloy 350 is as follows: Heat to 1850/1950°F (1010/1066°C), cool rapidly to room temperature, sub-zero cool 3 hours at -100°F (-73°C); reheat to 1700/1750°F (927/954°C) about 90 minutes per inch (25.4 mm) of thickness, cool rapidly to room temperature, sub-zero cool 3 hours at -100°F (-73°C), then temper 3 hours at 1000°F (538°C).

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	0.2820 lb/in³
Mean Coefficient of Thermal Expansion	
68°F, 212°F, Sub-zero Cooled, Tempered 850°F (454°C)	6.30 $\times 10^{-6}$ in/in/°F

68°F, 572°F, Sub-zero Cooled, Tempered 850°F (454°C)	6.80 $\times 10^{-6}$ in/in/°F
68°F, 752°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.00 $\times 10^{-6}$ in/in/°F
68°F, 932°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.20 $\times 10^{-6}$ in/in/°F
68°F, 1150°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.20 $\times 10^{-6}$ in/in/°F
68°F, 1350°F, Sub-zero Cooled, Tempered 850°F (454°C)	6.70 $\times 10^{-6}$ in/in/°F
68°F, 1500°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.00 $\times 10^{-6}$ in/in/°F
68°F, 1700°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.50 $\times 10^{-6}$ in/in/°F

- Mean Coefficient of Thermal Expansion

Thermal Conductivity

100°F, Sub-zero Cooled, Tempered 850°F (454°C)	101.0 BTU-in/hr/ft²/°F
200°F, Sub-zero Cooled, Tempered 850°F (454°C)	106.0 BTU-in/hr/ft²/°F
300°F, Sub-zero Cooled, Tempered 850°F (454°C)	112.0 BTU-in/hr/ft²/°F
400°F, Sub-zero Cooled, Tempered 850°F (454°C)	118.0 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)	130.0 BTU-in/hr/ft²/°F
700°F, Sub-zero Cooled, Tempered 850°F (454°C)	136.0 BTU-in/hr/ft²/°F
800°F, Sub-zero Cooled, Tempered 850°F (454°C)	140.0 BTU-in/hr/ft²/°F
900°F, Sub-zero Cooled, Tempered 850°F (454°C)	146.0 BTU-in/hr/ft²/°F

- Thermal Conductivity

Modulus of Elasticity (E)

80°F, Sub-zero Cooled, Tempered 850°F (454°C)	29.4 $\times 10^{3}$ ksi
400°F, Sub-zero Cooled, Tempered 850°F (454°C)	27.3 $\times 10^{3}$ ksi
600°F, Sub-zero Cooled, Tempered 850°F (454°C)	25.9 $\times 10^{3}$ ksi
700°F, Sub-zero Cooled, Tempered 850°F (454°C)	25.2 $\times 10^{3}$ ksi
800°F, Sub-zero Cooled, Tempered 850°F (454°C)	24.3 $\times 10^{3}$ ksi

Modulus of Rigidity (G)

80.0°F, Sub-zero Cooled, Tempered 850°F (454°C)	11.3 $\times 10^{3}$ ksi
400°F, Sub-zero Cooled, Tempered 850°F (454°C)	10.4 $\times 10^{3}$ ksi
600°F, Sub-zero Cooled, Tempered 850°F (454°C)	9.80 $\times 10^{3}$ ksi
700°F, Sub-zero Cooled, Tempered 850°F (454°C)	9.60 $\times 10^{3}$ ksi
800°F, Sub-zero Cooled, Tempered 850°F (454°C)	9.30 $\times 10^{3}$ ksi

Electrical Resistivity

80.0°F, Sub-zero Cooled, Tempered 850°F (454°C)	474.0 ohm-cir-mil/ft
134°F, Sub-zero Cooled, Tempered 850°F (454°C)	485.0 ohm-cir-mil/ft
199°F, Sub-zero Cooled, Tempered 850°F (454°C)	497.0 ohm-cir-mil/ft
370°F, Sub-zero Cooled, Tempered 850°F (454°C)	532.0 ohm-cir-mil/ft
461°F, Sub-zero Cooled, Tempered 850°F (454°C)	549.0 ohm-cir-mil/ft
541°F, Sub-zero Cooled, Tempered 850°F (454°C)	566.0 ohm-cir-mil/ft
729°F, Sub-zero Cooled, Tempered 850°F (454°C)	601.0 ohm-cir-mil/ft
835°F, Sub-zero Cooled, Tempered 850°F (454°C)	618.0 ohm-cir-mil/ft
981°F, Sub-zero Cooled, Tempered 850°F (454°C)	647.0 ohm-cir-mil/ft
1160°F, Sub-zero Cooled, Tempered 850°F (454°C)	678.0 ohm-cir-mil/ft
1350°F, Sub-zero Cooled, Tempered 850°F (454°C)	693.0 ohm-cir-mil/ft

- Electrical Resistivity

Melting Range

--	2500.000 to 2550.000 °F

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

Typical Mechanical Properties

- Effect of Temperature on Typical Charpy V-Notch Impact Strength
- Typical Elevated Temperature Mechanical Properties
- Typical Room Temperature Mechanical Properties
- Typical Room Temperature Tensile Properties After Exposure to Elevated Temperatures Under Stress
- Typical Stress Rupture Strength

Heat Treatment

Annealing

Heat to 1850/1950°F (1010/1066°C), cool rapidly to room temperature.

Hardening

Pyromet alloy 350 can be hardened by either sub-zero cooling and tempering (SCT) or double aging (DA). Sub-zero cooling and tempering will result in higher strength than double aging. "Conditioning" of the alloy by rapid cooling from 1710°F (932°C) ±25°F is required before the SCT treatment, and is not required but is recommended before double aging. It is further recommended that following an anneal at 1850/1950°F (1010/1066°C), Pyromet alloy 350 be cooled to -100°F (-73°C) for at least 3 hours before hardening.

Double Age

Hold for 3 hours at 1350/1400°F (732/760°C), air cool to room temperature; heat to 825/875°F (440/468°C), hold 2-3 hours, air cool.

Sub-Zero Cooling

After conditioning at 1710°F (932°C) ±25°F (rapid cool) for 90 minutes per inch (25.4 mm) of thickness, Pyromet alloy 350 is held for a minimum of 3 hours at -100°F (-73°C), then tempered at either 850°F or 1000°F (454°C or 538°C) for a minimum of 3 hours. The 850°F (454°C) temper produces the highest strengths and hardnesses, and the 1000°F (538°C) temper produces improved toughness and stress corrosion properties.

Equalized and Overtempered

Bars and billets are normally shipped in this condition unless otherwise specified. This treatment, 1375/1475°F (745/801°C), 3-4 hours, air cool to room temperature, then 1000/1100°F (538/593°C), 3 hours, air cool, produces a stable tempered martensitic structure which is most readily machinable.

- Dimensional Growth During Heat Treatment

Workability

Hot Working

Pyromet alloy 350 is readily hot worked. It is worked from a maximum temperature of 2150°F (1177°C). The use of temperatures above 2150°F (1177°C) will cause an increase in the amount of ferrite. Finishing temperature should be in the range of 1700/1800°F (927/982°C) to prevent grain coarsening on subsequent heat treatment and promote homogeneous precipitation of carbides.

Cold Working

In the annealed condition, Pyromet alloy 350 is essentially austenitic and has forming characteristics similar to those of the AISI 300 series stainless steels. It has a higher rate of work hardening and cold forming will cause martensite formation in proportion to the amount of deformation. If capacity is limited or deformation is severe, heating the material to 300°F (149°C) or above will minimize work hardening. In the hardened condition, Pyromet alloy 350 has sufficient ductility for limited forming or straightening operations.

Machinability

Successfully machining Pyromet alloy 350 requires the same practices used for other stainless steels, such as rigid tool and work supports, slower speeds, positive cuts, absence of dwelling or glazing, and adequate coolant. In the annealed condition, the alloy is soft and gummy and has a high work-hardening rate. Machining Pyromet alloy 350 in the annealed condition is consequently not recommended. Best machinability is obtained in the equalized and overtempered condition. Finishing operations may be performed in this condition if proper allowances are made for growth during subsequent hardening treatments. If extreme dimensional accuracy is necessary, finish machining should be done in the hardened condition.

Following are typical feeds and speeds for Pyromet alloy 350.

- 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

Pyromet alloy 350 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, 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/ER308, 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.

The alloy must be treated at 1710°F (932°C) before hardening by sub-zero cooling and tempering.

Brazing

Pyromet alloy 350 can be brazed successfully with the common silver- or nickel-base brazing alloys with melting or flow points between 1600/1900°F (871/1038°C). If brazing temperature is above 1710°F (932°C), the assembly should be cooled to 1710°F (932°C), and held for a short time before cooling to room temperature.

Other Information

Applicable Specifications

- AMS 5548 (Strip)
- AMS 5745 (Bar)

Forms Manufactured

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

Technical Articles

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

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