Technical Datasheet CARPENTER TECHNOLOGY

CarTech® 350 Alloy

Identification

UNS Number

- S35000

AISI Number

- 633

Type Analysis

Single figures are nominal except where noted.

Carbon	0.07 to 0.11 %	**Manganese**	0.50 to 1.25 %
Phosphorus (Maximum)	0.040 %	**Sulfur (Maximum)**	0.030 %
Silicon (Maximum)	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**	Balance

General Information

Description

CarTech 350 alloy is a chromium-nickel-molybdenum stainless steel which can be hardened by martensitic transformation and/or precipitation hardening.

Depending upon the heat treatment, CarTech 350 alloy 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 CarTech 350 approaches that of the chromium-nickel austenitic stainless steels.

Applications

CarTech 350 alloy 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/in^3
Sub-zero Cooled	0.2820	lb/in^3
Mean CTE		
68 to 212°F, Sub-zero Cooled, Tempered 850°F (454°C)	6.30	x 10^{-6} in/in/°F
68 to 572°F, Sub-zero Cooled, Tempered 850°F (454°C)	6.80	x 10^{-6} in/in/°F
68 to 752°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.00	x 10^{-6} in/in/°F
68 to 932°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.20	x 10^{-6} in/in/°F
68 to 1150°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.20	x 10^{-6} in/in/°F
68 to 1350°F, Sub-zero Cooled, Tempered 850°F (454°C)	6.70	x 10^{-6} in/in/°F
68 to 1500°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.00	x 10^{-6} in/in/°F
68 to 1700°F, Sub-zero Cooled, Tempered 850°F (454°C)	7.50	x 10^{-6} in/in/°F

Mean Coefficient of Thermal Expansion
Sub-zero cooled, tempered 850°F (454°C)

Temperature		10^{-6}/°F	10^{-6}/K
68°F to	20°C to		
212	100	6.3	11.3
572	300	6.8	12.2
752	400	7.0	12.6
932	500	7.2	13.0
1150	620	7.2	13.0
1350	735	6.7	12.1
1500	815	7.0	12.6
1700	925	7.5	13.5

Thermal Conductivity		
100°F, Sub-zero Cooled, Tempered 850°F (454°C)	101.0	BTU-in/hr/ft^2/°F
200°F, Sub-zero Cooled, Tempered 850°F (454°C)	106.0	BTU-in/hr/ft^2/°F
300°F, Sub-zero Cooled, Tempered 850°F (454°C)	112.0	BTU-in/hr/ft^2/°F
400°F, Sub-zero Cooled, Tempered 850°F (454°C)	118.0	BTU-in/hr/ft^2/°F
500°F, Sub-zero Cooled, Tempered 850°F (454°C)	124.0	BTU-in/hr/ft^2/°F
600°F, Sub-zero Cooled, Tempered 850°F (454°C)	130.0	BTU-in/hr/ft^2/°F
700°F, Sub-zero Cooled, Tempered 850°F (454°C)	136.0	BTU-in/hr/ft^2/°F
800°F, Sub-zero Cooled, Tempered 850°F (454°C)	140.0	BTU-in/hr/ft^2/°F
900°F, Sub-zero Cooled, Tempered 850°F (454°C)	146.0	BTU-in/hr/ft^2/°F

Thermal Conductivity
Sub-zero cooled, tempered 850°F (454°C)

Test Temperature		Btu•in/ft²•h•°F	W/m•K
°F	°C		
100	38	101	14.5
200	93	106	15.4
300	149	112	16.2
400	204	118	17.0
500	260	124	17.8
600	316	130	18.7
700	371	136	19.6
800	427	140	20.3
900	482	146	21.1

Modulus of Elasticity (E)		
80°F, Sub-zero Cooled, Tempered 850°F (454°C)	29.4	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)	25.9	x 10^3 ksi
700°F, Sub-zero Cooled, Tempered 850°F (454°C)	25.2	x 10^3 ksi
800°F, Sub-zero Cooled, Tempered 850°F (454°C)	24.3	x 10^3 ksi
Modulus of Rigidity (G)		
80°F, Sub-zero Cooled, Tempered 850°F (454°C)	11.3	x 10^3 ksi
400°F, Sub-zero Cooled, Tempered 850°F (454°C)	10.4	x 10^3 ksi
600°F, Sub-zero Cooled, Tempered 850°F (454°C)	9.80	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)	9.30	x 10^3 ksi
Electrical Resistivity		
80°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
1162°F, Sub-zero Cooled, Tempered 850°F (454°C)	678.0	ohm-cir-mil/ft
1349°F, Sub-zero Cooled, Tempered 850°F (454°C)	693.0	ohm-cir-mil/ft

Electrical resistivity
Sub-zero cooled, tempered 850°F (454°C)

Test Temperature		Ohm—cir mil/ft	Microhm-mm
°F	°C		
80	27	474	788
134	57	485	806
199	93	497	826
370	188	532	884
461	238	549	912
541	282	566	941
729	388	601	999
835	446	618	1027
981	527	647	1075
1162	627	678	1128
1349	732	693	1152

Melting Range	2500 to 2550	°F

Moduli of elasticity (E) and rigidity (G)

Test Temperature		E		G	
°F	°C	ksi x 10^3	MPa x 10^3	ksi x 10^3	MPa x 10^3
80	27	29.4	203	11.3	78
400	204	27.3	188	10.4	72
600	316	25.9	179	9.8	68
700	371	25.2	174	9.6	66
800	427	24.3	168	9.3	64

Typical Mechanical Properties

Effect of Temperature on Typical Charpy V-Notch Impact Strength
Sub-zero cooled, tempered

Test Temperature		Tempering Temperature		Impact Strength	
°F	°C	°F	°C	ft-lb	J
-320	-196	850	454	4	5
		1000	538	6	8
-100	-79	850	454	8	11
70	21	850	454	14	19
		1000	538	25	34
212	100	850	454	24	33

Typical Elevated Temperature Tensile Properties
Sub-zero cooled, tempered 850°F (454°C)

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 2" (50.8 mm)
°F	°C	ksi	MPa	ksi	MPa	
80	27	170	1172	203	1400	13
400	204	141	972	188	1296	9
600	316	136	938	189	1303	7
700	371	128	883	190	1310	8
800	427	125	862	186	1282	10
900	482	111	765	166	1145	9
1000	538	85	586	106	731	16

Typical Room Temperature Mechanical Properties

Treatment	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 2" (50.8 mm)	% Reduction of Area	Rockwell Hardness
	ksi	MPa	ksi	MPa			
SCT 850°F (454°C)	162	1117	198	1365	15	49	C 48
SCT 1000°F (538°C)	150	1034	163	1124	22	53	C 38
Double Aged	142	979	171	1179	12	—	C 40
Annealed	60	414	160	1103	30	—	B 95

Typical Room Temperature Tensile Properties After Exposure to Elevated Temperatures Under Stress
Sub-zero cooled, tempered 850°F (454°C)

Exposure					0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 2" (50.8mm)
Temperature		Stress		Time					
°F	°C	ksi	MPa	hours	ksi	MPa	ksi	MPa	
Room		—	—	—	158	1089	201	1386	12
600	316	60	414	1000	162	1117	198	1365	14
		90	621	1000	177	1220	202	1393	13
		140	965	1000	201	1386	204	1407	12
700	371	60	414	1000	169	1165	204	1407	11
		90	621	1000	180	1241	206	1420	11
		150	1034	1000	227	1565	228	1572	5
800	427	60	414	1000	190	1310	220	1517	7
		90	621	1000	192	1324	214	1476	8
		130	896	1000	212	1462	220	1517	5*

*Broke outside gage marks

Typical Stress Rupture Strength
Sub-zero cooled, tempered

Test Temperature		Tempering Temperature		Stress for Rupture in					
				10 hours		100 hours		1000 hours	
°F	°C	°F	°C	ksi	MPa	ksi	MPa	ksi	MPa
800	427	850	454	188	1296	186	1282	183	1262
		1000	538	132	910	130	896	127	876
900	482	850	454	140	965	118	814	95	655
		1000	538	110	758	103	710	98	676

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

From Annealed Condition to	Growth in/in (m/m)	
	Longitudinal	Transverse
Double Aged	0.0042	0.0044
1710°F (932°C), to Double Aged	0.0048	0.0050
1710°F (932°C), to SCT	0.0047	0.0047

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.

Typical Machining Speeds and Feeds – Pyromet® Alloy 350

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				
	Tool Material	Speed (fpm)	Feed (ipr)	Tool Material	Speed (fpm) Brazed	Speed (fpm) Throw Away	Speed (fpm) Coated	Feed (ipr)
Equalized and Overtempered								
.150	T15, M33,	70	.015	C6	250	280	400	.015
.025	M41/M47	75	.007	C7	300	350	475	.007
Aged HRC 38 - 40								
.150	T15, M41,	60	.015	C6	240	270	350	.010
.025	M42, M43,	70	.007	C7	290	325	400	.005
	M44							
Aged over HRC 40								
.150	T15, M41,	40	.010	C6	150	190	250	.010
.025	M42, M43, M44	45	.005	C7	190	225	280	.005

Turning—Cut-Off and Form Tools

Tool Material		Speed (fpm)	Feed (ipr)						
			Cut-Off Tool Width (Inches)				Form Tool Width (Inches)		
High Speed Tools	Car-bide Tools		1/16	1/8	1/4	1/2	1	1 ½	2
Equalized and Overtempered									
M2 T15		45	.001	.001	.0015	.0015	.001	.001	.0005
	C6	175	.0025	.0025	.003	.003	.0025	.0025	.0015
Aged HRC 38 - 40									
M2 T15		40	.001	.001	.001	.0015	.001	.001	.0005
	C6	170	.0025	.0025	.003	.003	.002	.002	.002
Aged over HRC 40									
M2 T42		25	.001	.001	.0015	.0015	.001	.0005	.0005
	C6	110	.0025	.0025	.0035	.0025	.0015	.0015	.0015

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
Equalized and Overtempered									
M7	60	C2	190	.003	.005	.008	.011	.015	.018
Aged HRC 38 - 40									
T15	30	C2	100	.001	.001	.001	.001	.001	.001
Aged over HRC 40									
T15	-	C2	-	-	-	-	-	-	-

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
Equalized and Overtempered									
M1, M10	50	.001	.002	.004	.007	.008	.010	.012	.015
Aged HRC 38 - 40									
T15, M42	35	-	.002	.004	.006	.008	.009	.011	.012
Aged over HRC 40									
T15, M42	20	-	.001	.002	.003	.004	.004	.004	.004

Die Threading

Tool Material	FPM for High Speed Tools: 7 or less, tpi	8 to 15, tpi	16 to 24, tpi	25 and up, tpi
Equalized and Overtempered				
M1, M2, M7, M10	5 – 12	8 – 15	10 – 20	15 – 25
Aged				
T15, M42	4 – 8	6 – 10	8 – 12	10 – 15

Milling, End-Peripheral

Depth of Cut (inches)	High Speed Tools: Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in)				Carbide Tools: 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
Equalized and Overtempered												
.050	M2, M7	85	.001	.002	.003	.004	C2	230	.001	.002	.004	.006
Aged HRC 38 - 40												
.050	M2, M7	65	.0005	.001	.002	.003	C2	190	.001	.002	.003	.004
Aged over HRC 40												
.050	T15	60	.0005	.001	.002	.003	C2	90	.001	.002	.003	.004

Tapping

Tool Material	High Speed Tools: Speed (fpm)
Equalized and Overtempered	
M1, M7, M10	12 – 25
Aged HRC 38 - 40	
M1, M7, M10	10 - 20
Aged over HRC 40	
M1, M7, M10 Nitrided	5 – 15

Broaching

Tool Material	High Speed Tools: Speed (fpm)	Chip Load (ipt)
Equalized and Overtempered		
T15, M42	10	.002
Aged HRC 38 - 40		
T15, M42	8	.002
Aged over HRC 40		
-	-	-

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

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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