Technical Datasheet CARPENTER TECHNOLOGY

CarTech® 20Mo-6® HS Stainless

Identification

UNS Number

- N08036

Type Analysis

Single figures are nominal except where noted.

Carbon (Maximum)	0.06 %	**Manganese (Maximum)**	1.00 %
Phosphorus (Maximum)	0.030 %	**Sulfur (Maximum)**	0.030 %
Silicon (Maximum)	0.50 %	**Chromium**	22.00 to 26.00 %
Nickel	33.00 to 37.00 %	**Molybdenum**	5.00 to 6.70 %
Copper	1.00 to 3.00 %	**Nitrogen**	0.17 to 0.40 %
Iron	Balance		

General Information

Description

CarTech 20Mo-6 HS stainless is a 6% Mo austenitic stainless alloy possessing a unique combination of corrosion resistance and ultra high tensile strength capability (up to 280 ksi [1930 MPa]) with good ductility.

CarTech 20Mo-6 HS stainless is the result of compositional and processing modifications made to 20Mo-6 stainless for enhanced work hardening response.

The HS grade achieves high strength through cold work, not by heat treatment. In the cold-worked condition, CarTech 20Mo-6 HS stainless retains excellent resistance to environmental cracking and chloride-induced pitting and crevice corrosion while remaining nonmagnetic.

Applications

Because of its combination of mechanical, physical and corrosion resistance properties, CarTech 20Mo-6 HS stainless is suited for aggressive environmental conditions where high strength is required.

The alloy has been used for cold-drawn rod and wire applications including single strand wireline (slickline) and armoring wire for oil and gas wells, springs, yacht rigging and non-magnetic cables.

CarTech 20Mo-6 HS stainless is not intended to replace 20Mo-6 stainless, particularly for sheet, plate, pipe or tubing applications since CarTech 20Mo-6 stainless does not require post-weld annealing.

Corrosion Resistance

Annealed and cold-drawn 20Mo-6 HS stainless has shown excellent resistance to pitting and crevice corrosion under low-pH chloride conditions and stress corrosion cracking in hot chloride/sulfide environments sometimes encountered in oil and gas exploration.

Stress Corrosion Cracking:
Examples of laboratory and simulated field environments in which U-bend type test specimens of 20Mo-6 HS stainless have been evaluated and are shown in the hyperlinks entitled "Boiling Simulated Drilling Fluids, Room-Temperature NACE TM-01-77 Solution and Simulated Service Test."

Pitting and Crevice Corrosion Resistance:
Cold-drawn wire products representing several heats of 20Mo-6 HS stainless have been evaluated for resistance to chloride pitting and crevice corrosion. Typical results are shown in the text sections entitled "Critical Pitting Temperature and Crevice Corrosion Resistance" below.

Critical Pitting Temperature:
6 w/o $FeCl_3$ + 1w/o HCl, 72-hr exposure. Temperature at which first attack may occur: 176°F (80°C)

No attack at 167°F (75°C) and below.

Crevice Corrosion Resistance:
6 w/o FeCl3, 72 hours at 77°F (25°C) with crevice sites formed by making 20 wraps with a No. 12 rubber band.

Weight Loss Rate: <3 mg/cm2, typically < 1mg/cm2. Similar results are obtained for annealed products.

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	Good
Phosphoric Acid	Good	Acetic Acid	Good
Sodium Hydroxide	Good	Salt Spray (NaCl)	Excellent
Sea Water	Good	Sour Oil/Gas	Good
Humidity	Excellent		

Boiling Simulated Drilling Fluids

Wire Dia.		Condition	Ultimate Tensile		Saturated NaCl (~26 w/o) +2.5 w/o NH_4HSO_3 [228°F (109°C)]	23.5 w/o $MgCl_2$ + 6w/o KCl+0.3 w/o CaO [235°F (113°C)]
in.	mm		ksi	MPa		
0.092	2.34	77% Cold Drawn	275	1896	No cracking after 1008 hrs.	No cracking after 1008 hrs.
0.031	0.79	"	276	1903	"	"

Room-Temperature NACE TM-01-77 Solution
5 w/o NaCl + 0.5 w/o CH_3COOH, purged with H_2S.

Wire Dia.		Condition	Ultimate Tensile		Without Coupling to Carbon Steel	Galvanically Coupled to Carbon Steel
in.	mm		ksi	MPa		
0.092	2.34	77% Cold Drawn	275	1896	No cracking after 1008 hrs.	No cracking after 1008 hrs.
0.031	0.79	"	276	1903	"	"

Simulated Service Test

Wire Dia.		Condition	Ultimate Tensile		Saturated NaCl (~26 w/o) + 5 w/o $MgCl_2$ + 5% H_2S at 350°F (177°C) and 5000 psi (34.5 MPa)
in.	mm		ksi	MPa	
0.031	0.79	72% Cold Drawn	274	1889	No cracking after 14 days

Properties

Physical Properties

Specific Gravity	8.08	
Density	0.2920	lb/in³
Mean CTE		
77 to 212°F	7.77	x 10^{-6} in/in/°F
77 to 392°F	8.17	x 10^{-6} in/in/°F
77 to 572°F	8.36	x 10^{-6} in/in/°F
77 to 752°F	8.54	x 10^{-6} in/in/°F
77 to 932°F	8.71	x 10^{-6} in/in/°F
77 to 1112°F	8.92	x 10^{-6} in/in/°F
77 to 1292°F	9.20	x 10^{-6} in/in/°F
77 to 1472°F	9.37	x 10^{-6} in/in/°F

Mean coefficient of thermal expansion

Temperature		Coefficient	
77°F to	25°C to	10^{-6}/°F	10^{-6}/K
212	100	7.77	13.98
392	200	8.17	14.70
572	300	8.36	15.04
752	400	8.54	15.38
932	500	8.71	15.67
1112	600	8.92	16.05
1292	700	9.20	16.56
1472	800	9.37	16.87

Modulus of Elasticity (E)	27.5	x 10^{3} ksi
Electrical Resistivity (70°F)	652.0	ohm-cir-mil/ft

Magnetic Properties

Magnetic Permeability		
Cold Reduced up to 80%	1.0048	Mu
Annealed, 200 Oe	1.0028	Mu

Typical Mechanical Properties

Ductility:

For applications involving small diameter cold-drawn wire products, often the best measure of ductility is the degree to which the wore can be bent, wrapped or ties without cracking or fracturing.

20Mo-6 HS stainless wire [e.g., 0.092" (2.34 mm) diameter] and armoring wire [e.g., 0.0355" (0.90 mm) to 0.031" (0.79 mm) diameter] products cold drawn up to 80% have shown sufficient ductility to survive such treatment as wrap testing. In this test, a single loop of the subject wire is made around a 3/8" (9.35 mm) diameter rod or spool, then the wire is wrapped around its own diameter several times.

Effect of "Well Aging" on Ductility

Wireline and armored cables utilized for oil and gas well applications often encounter repeated exposures to elevated temperatures within the range of about 250 to 500°F (121 to 260°C) as excursions are made down-hole.

Such thermal treatments can trigger a strengthening/embrittling phenomenon known as strain aging in some heavily cold-worked alloys.

To demonstrate the resistance of 20Mo-6 HS stainless to significant ductility loss as a result of strain aging, cold-drawn armoring wire products were given simulated "well-age" treatments, then subsequently wrap tested.

Results are summarized as shown on the following:

Wire Dia.		Initial Condition	Initial Ultimate Tensile		Thermal Treatments Applied to Straight Wire Sections	Wrap Test Results
in.	mm		ksi	MPa		
0.0355	0.90	69% Cold Drawn	264	1820	Temperatures ranging from 250 to 500°F (121 to 260°C) for time periods of up to 336 hours (2 weeks)	No cracking
0.031	0.79	77% Cold Drawn	276	1903	"	"

Another suitable means of evaluating bend ductility, especially for cold-drawn wireline, is with a bend test in which 0.092" (2.34 mm) diameter wire is formed 180° around a 3/8" (9.53 mm) diameter mandrel through a 5/8" (15.9 mm) roller gap.

Wire Dia.		Initial Condition	Initial Ultimate Tensile		Thermal Treatments Applied to Straight Wire Sections	Bend Test Results
in.	mm		ksi	MPa		
0.092	2.34	46% Cold Drawn	225	1551	Temperatures ranging from 250 to 500°F (121 to 260°C) for time periods of up to 336 hours (2 weeks)	No cracking
"	"	69% Cold Drawn	260	1792	"	"

Strength levels and wire diameters greater than those described and microstructure can influence "well age" embrittlement susceptibility. Such factors should be evaluated prior to application at elevated temperature.

Typical Room-Temperature Mechanical Properties - 20Mo-6 HS Stainless

Material in the annealed condition

0.2% Yield Strength		Ultimate Tensile Strength		% Elongation (in 4D)	% Reduction of Area	Hardness Rockwell B
ksi	MPa	ksi	MPa			
4-1/2" (114.3 mm) Dia. Billet - Transverse (Midradius)						
64	441	123	848	60	64	95
0.190" (4.8 mm) Dia Wire - Longitudinal						
56	386	119	820	49	77	93

Heat Treatment

Annealing

Heat uniformly to 2100/2200°F (1150/1200°C) for 1/2 hour per 1" (25.4 mm) of thickness and cool rapidly, preferably by water quenching.

Hardening

20Mo-6 HS stainless is hardened only by cold working.

Workability

Hot Working

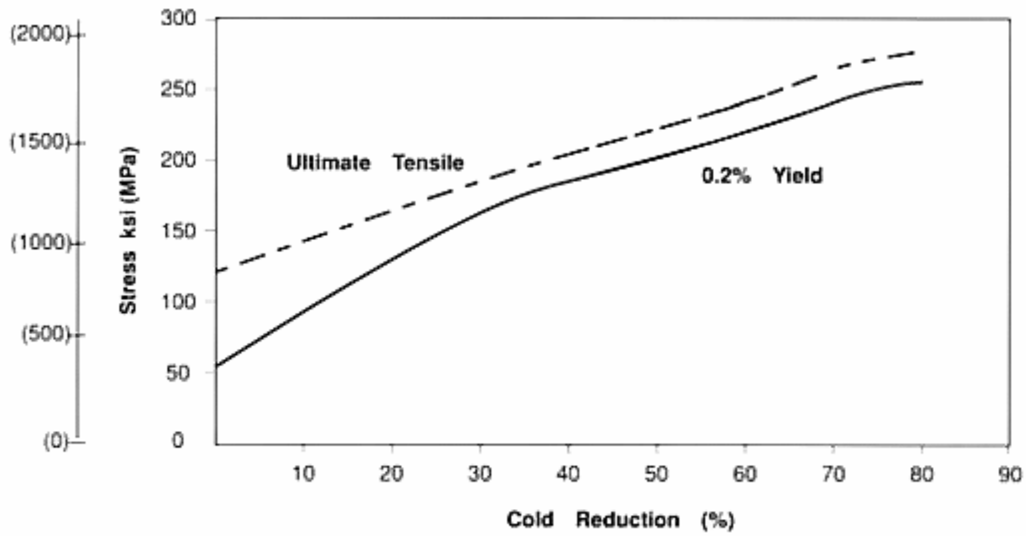
For hot working, heat uniformly to 2050/2200°F (1120/1200°C). Do not forge at temperatures below 1900°F (1040°C) because of the alloy's increased stiffness. Forgings can be air cooled or water quenched.

After hot working, the alloy should be annealed to recrystallize the grain structure and optimize corrosion resistance.

Cold Working

Strength and hardness are significantly increased by cold working as indicated by the hyperlinks entitled "Typical Room-Temperature Tensile Strength of Wire and Effect of Cold Reduction on Room Temperature Longitudinal Yield and Tensile Strengths."

Effect of Cold Reduction on Room Temperature Longitudinal Yield and Tensile Strengths - 20Mo-6 HS Stainless



Ductility

For applications involving small diameter cold-drawn wire products, often the best measure of ductility is the degree to which the wire can be bent, wrapped or tied without cracking or fracturing.

20Mo-6 HS stainless wireline [e.g., 0.092" (2.34 mm) diameter] and armoring wire [e.g., 0.0355" (0.90 mm) to 0.031" (0.79 mm) diameter] products cold drawn up to 80% have shown sufficient ductility to survive such treatment as wrap testing. In this test, a single loop of the subject wire is made around a 3/8" (9.53 mm) diameter rod or spool then the wire is wrapped around its own diameter several times.

Cold Working

Strength and hardness are significantly increased by cold working as indicated by the following data.

Typical Room-Temperature Tensile Strength of Wire - 20Mo-6 HS Stainless

% Cold Reduction	0.2% Yield Strength		Ultimate Tensile Strength	
	ksi	MPa	ksi	MPa
0*	54	372	121	834
29	170	1172	184	1269
41	185	1276	206	1420
58	215	1482	235	1620
62	224	1544	245	1689
70	242	1669	265	1827
72	245	1689	269	1855
77	254	1751	274	1889
80	255	1758	277	1910

* Starting material is batch annealed [2150°F (1177°C), WQ] coil product. Results may differ slightly if strand annealed product is employed depending upon annealing conditions.

Machinability

20Mo-6 HS stainless machines with a tough, stringy chip.

Following are typical feeds and speeds for 20Mo-6 HS stainless.

Typical Machining Speeds and Feeds – 20Mo-6® HS 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) Uncoated	Speed (fpm) Coated	Feed (ipr)
.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)						
			Cut-Off Tool Width (Inches)				Form Tool Width (inches)		
High Speed Tools	Carbide Tools		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

High Speed Tools									
Tool Material	Speed (fpm)	Feed (inches per revolution) Nominal Hole Diameter (inches)							
		1/16	1/8	1/4	1/2	3/4	1	1 ½	2
T15 M42	45-50	.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

20Mo-6 HS stainless can be readily joined by the standard electric-arc welding methods. AWS ER Ni Cr Mo-3 or E Ni Cr Mo-3 consumables (Alloy 625) are suggested for welding.

Material should be annealed after welding for optimum corrosion resistance.

Other Information

Forms Manufactured

• Wire

Technical Articles

• Testing of Carpenter 20Mo-6 HS® Stainless to High Pressure and High Temperature Simulated Oil/Gas Well Environment

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