Technical Datasheet

CARPENTER TECHNOLOGY

CarTech® 20Mo-6® Stainless

Identification

UNS Number

- N08026

Type Analysis

Single figures are nominal except where noted.

Carbon (Maximum)	0.03 %	**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	2.00 to 4.00 %	**Iron**	Balance

General Information

Description

CarTech 20Mo-6 stainless is an austenitic stainless steel which is resistant to corrosion in hot chloride environments with low pH. It has good resistance to pitting, crevice corrosion and stress-corrosion cracking in chloride environments and is also resistant to oxidizing media.

CarTech 20Mo-6 stainless complements CarTech 20Cb-3® stainless rather than replacing it. The alloy is designed for applications where better pitting and crevice-corrosion resistance are required than CarTech 20Cb-3 stainless offers.

Corrosion Resistance

20Mo-6 stainless has shown excellent resistance in a number of general, pitting, intergranular and stress corrosion tests in the laboratory. It also has shown good resistance to commercial fume scrubber and wet process phosphoric acid environments.

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.

Pitting and Crevice-Corrosion Resistance:
Both laboratory and field tests have demonstrated the high level of pitting and crevice-corrosion resistance possessed by 20Mo-6 stainless. Test samples of several materials with crevices were exposed to two very severe fume scrubber environments. Very high levels of chloride plus fluoride were found in deposits from both units. Based on the results shown in they hyperlink entitled "Corrosion Resistance in a Wet Lime Scrubber System," 20Mo-6 stainless displays similar corrosion resistance to that of Hastelloy* alloy G in these wet lime scrubber system environments.

*Hastelloy is a registered trademark of Cabot Corporation

Some of the conditions in the hyperlink entitled "Corrosion Resistance in a Closed-Loop Limestone Scrubber System*" may not be typical of most flue gas desulfurization scrubber environments but they provide a severe test for comparison of alloys. 20Mo-6 stainless has shown very little or no pitting/crevice attack in similar tests with less severe scrubber environments.

20Mo-6 stainless also possesses a high level of resistance in laboratory ferric chloride tests. The hyperlink entitled "Typical Results for Pitting and Crevice Tests in 6% Ferric Chloride" shows results of pitting and crevice corrosion tests conducted according to ASTM G48.

Sulfuric Acid:
20Mo-6 stainless has excellent resistance to many sulfuric acid environments. The hyperlink entitled "Typical Iso-corrosion Chart for 20Mo-6 Stainless in Nonaerated Sulfuric Acid" shows an iso-corrosion chart for 20Mo-6 stainless. The chart is divided into zones according to the general corrosion resistance of 20Mo-6 stainless exposed to the range of temperatures and concentrations represented by each zone. These data are based on laboratory tests in reagent grade sulfuric acid with no intentional aeration or

deaeration. Charts of general corrosion data are intended for general guidance as the corrosion resistance can vary with factors such as impurities, aeration, heat transfer, velocity, deposits, material condition and fabrication. Many contaminants in commercial sulfuric acid decrease the corrosive attack. Corrosion rates in sulfuric acid can be actually much lower in the presence of iron, copper and chromium ions, usually present in pickling and plating solutions.

Thy hyperlink entitled "Typical General Corrosion Resistance in Non-aerated Sulfuric Acid at 176°F (80°C)" shows that 20Mo-6 stainless has excellent resistance to sulfuric acid at 176°F (80°C) with the exception of concentrations in the range of about 75 to 97 weight percent. The curves for 20Cb-3 stainless and Hastelloy alloy G are shown form comparison. In boiling sulfuric acid, 20Mo-6 stainless has good resistance to general corrosion only in relatively dilute concentrations. The hyperlink entitled "Typical General Corrosion Resistance in Boiling Reagent Grade Sulfuric Acid" shows that rates become excessive at about 15% boiling sulfuric acid. The curve for 20Cb-3 stainless is shown for comparison.

For resistance to uniform or general corrosion in sulfuric acid customers have selected 20Cb-3 stainless. Tests have shown in some severe sulfuric acid environments where very high chloride levels accelerated general corrosion (rather than causing pitting), that 20Cb-3 stainless was superior to 20Mo-6 stainless and Hastelloy alloy G. 20Mo-6 stainless has provided a high level of corrosion resistance in acid environments when chloride pitting or crevice attack have been predominant forms of corrosion.

Phosphoric Acid:
20Mo-6 stainless is highly resistant to phosphoric acid. Laboratory tests were conducted in both wet process plant acid and reagent grade concentrated phosphoric acid. Field samples were exposed to wet process superphosphoric acid in a two-stage evaporator. In these tests, 20Mo-6 stainless compared favorably with other materials.

Intergranular-Corrosion Resistance:
20Mo-6 stainless is melted with low carbon to provide a high level of resistance to intergranular corrosion. In the annealed and annealed plus sensitized (1250°F (677°C), one hour) conditions, 20Mo-6 stainless has passed the nitric acid test (240 hours in boiling 65% nitric acid) and the ferric sulfate-sulfuric acid test (120 hours in a 50% sulfuric acid solution containing ferric sulfate) with a rate of 24 mpy (0.002 ipm) or less. The nitric acid test is described in ASTM A-262, Practice C, and the ferric sulfate-sulfuric acid test in ASTM A-262, Practice B. The 24-hour copper accelerated acidified copper sulfate test in A-262, Practice E, is also applicable to 20Mo-6 stainless in the annealed and annealed plus sensitized (1250°F (677°C), one hour) conditions.

Stress-Corrosion-Cracking Resistance:
20Mo-6 stainless possesses excellent resistance to chloride-stress-corrosion cracking. Ten U-bend samples were exposed to magnesium chloride ($MgCl_2$) boiling at 311°F (155°C), a standard test for susceptibility to chloride-stress-corrosion cracking as described in ASTM G-36. This test is considerably more severe than virtually all field environments. In this magnesium chloride environment, 20Mo-6 stainless was more resistant to stress-corrosion than other tested materials, including 20Cb-3 stainless. This is significant because no documented field failure by chloride-stress-corrosion cracking in 20Cb-3 stainless has been reported.

Characterization of the stress-corrosion cracking behavior of 20Mo-6 stainless in sulfuric acid is not complete. Contact Carpenter for current information before applying the material for a stress-corrosion cracking application in sulfuric acid. For applications involving high temperature sulfuric acid without appreciable chloride content, consider 20Cb-3 stainless, since it has superior resistance to most sulfuric acid media.

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	Humidity	Excellent

Table 2
Corrosion resistance in a closed-loop limestone scrubber system*
Average temperature at stack entrance was 219°F (104°C).
Sludge deposit on stack breeching contained 108,000 ppm fluorides and 8300 ppm chlorides.
197-day exposure

Alloy	Maximum Pitting/Crevice Attack—mils				
	Absorber Inlet	Absorber	Absorber Outlet	Bypass Duct	Stack Entrance
20Mo-6 stainless	<1	nil	10	nil	13
Hastelloy alloy G	5	3	2	<1	21
Uddeholm alloy 904L	1	nil	13	<1	6
Type 316	6	11	36(p)	<1	(+)

(p)- perforated
(+)- General corrosion
*- Part of data extracted from "FGD Corrosion at the R.D. Morrow, Sr., Generating Plant," by E.R. Dille, P.E., et.al., Preprint No. 15 presented at a seminar entitled "Solving Corrosion Problems in Air Pollution Control Equipment," sponsored by the National Association of Corrosion Engineers, Industrial Gas Cleaning Institute and Air Pollution Control Association, August 11-13, 1981.

Table 1
Corrosion resistance in a wet lime scrubber system
1500 ppm chlorides (estimate), fluorides—see below.
pH 1-3 in outlet ducting condensate
Flue gas velocity about 70-90 ft/sec.
85-day exposure

Alloy	Absorber Outlet* 120/130°F (49/54°C)		Stack Entrance 150/160°F (66/71°C)	
	Max Pitting/ Crevice Attack (mils)	Corrosion Rate (mg/cm²)	Max Pitting/ Crevice Attack (mils)	Corrosion Rate (mg/cm²)
20Mo-6 stainless	22	7	14	1
Hastelloy alloy G	66 (p)	8	4	1
Uddeholm alloy 904L	36 (+)	29	36 (+)	5
Type 316L	35 (+)	83	36 (+)	23

* Fly ash covered spool at test completion. The fly ash contained 25% sulfates, 11,500 ppm fluorides and 2700 ppm chlorides.
(p) perforated
(+) Significant general corrosion along with pitting and crevice attack.

Table 4
Corrosion resistance in a wet process superphosphoric acid evaporator
70% phosphoric acid with 3% sulfates 6000 ppm fluorides
87-day test

Alloy	Weight Loss in mg/cm²	
	First-Stage Evaporator 320°F (160°C)	Second-Stage Evaporator† 370°F (188°C)
20Mo-6 stainless	34	100
Hastelloy alloy G	35	83
Uddeholm alloy 904L	55	158
Incoloy* alloy 825	55	141

†Residue formed on surface of samples during exposure.
The residue contained 81,000 ppm chlorides and 1500 ppm fluorides.
*Incoloy is a registered trademark of INCO family of companies.

Table 5
Typical corrosion resistance in laboratory tests in phosphoric acid
144-hour test

Alloy	Corrosion Rate in MPY	
	Reagent Grade Concentrated 85% - Boiling	Wet Process Acid* 212°F (100°C)
20Mo-6 stainless	26	3
Hastelloy alloy G	26	3
Uddeholm alloy 904L	Not Tested	7

*68.9% phosphoric acid, 4.15% sulfuric acid, 1.85% iron, 5400 ppm fluorides, 2000 ppm chlorides. Samples activated immediately prior to test.

Figure 3
Typical general corrosion resistance in boiling reagent grade sulfuric acid

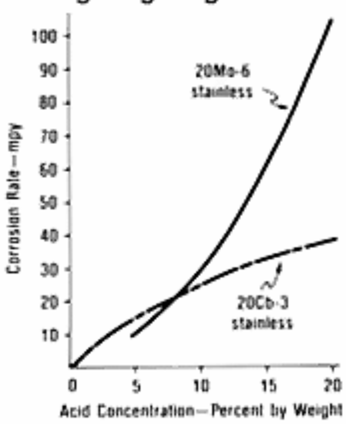

Figure 2
Typical general corrosion resistance in non-aerated sulfuric acid at 176°F (80°C)

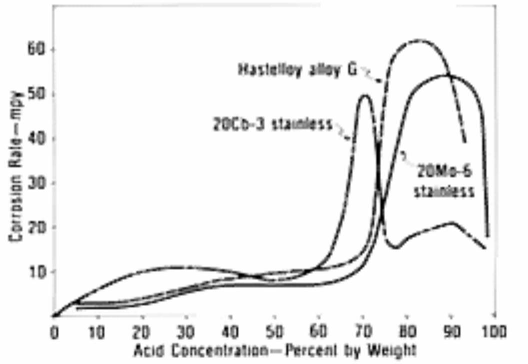

Figure 1
Typical iso-corrosion chart for 20Mo-6 stainless in nonaerated sulfuric acid

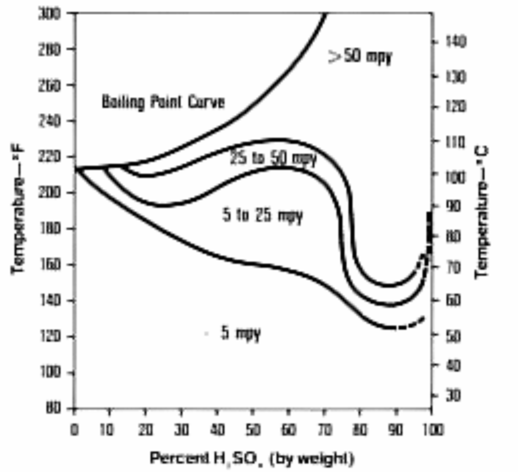

Table 3
Typical results for pitting and crevice tests in 6% ferric chloride
($10\%\ FeCl_3 \cdot 6H_2O$)

Alloy	Weight Loss in mg/cm²		
	Pitting 122°F (50°C)	Pitting Room Temperature	Crevice Room Temperature
20Mo-6 stainless	1.1	< 0.01	0.5
Hastelloy alloy G	< 0.01	< 0.01	0.1
Uddeholm alloy 904L	46.3	0.01	4.7

Each value represents the average of 2 to 4 samples.

Properties

Physical Properties

Specific Gravity	8.13	
Density	0.2940	lb/in³
Mean Specific Heat (32 to 212°F)	0.1100	Btu/lb/°F

Mean CTE		
77 to 212°F	8.22	x 10^{-6} in/in/°F
77 to 392°F	8.29	x 10^{-6} in/in/°F
77 to 572°F	8.52	x 10^{-6} in/in/°F
77 to 752°F	8.73	x 10^{-6} in/in/°F
77 to 932°F	8.89	x 10^{-6} in/in/°F
77 to 1112°F	9.29	x 10^{-6} in/in/°F
77 to 1292°F	9.55	x 10^{-6} in/in/°F
77 to 1472°F	9.76	x 10^{-6} in/in/°F
77 to 1652°F	9.86	x 10^{-6} in/in/°F

Mean coefficient of thermal expansion

Temperature		10^{-6}/°F	10^{-6}/K
77°F to	25°C to		
212	100	8.22	14.80
392	200	8.29	14.92
572	300	8.52	15.34
752	400	8.73	15.71
932	500	8.89	16.01
1112	600	9.29	16.72
1292	700	9.55	17.19
1472	800	9.76	17.57
1652	900	9.86	17.74

Thermal Conductivity		
122°F	83.90	BTU-in/hr/ft²/°F
212°F	90.10	BTU-in/hr/ft²/°F
392°F	102.6	BTU-in/hr/ft²/°F
572°F	114.4	BTU-in/hr/ft²/°F
752°F	126.2	BTU-in/hr/ft²/°F

Thermal Conductivity

Test Temperature		Thermal Conductivity		
°F	°C	Btu/ft • hr • °F	Btu • in/ft² • hr • °F	Watts/m • K
122	50	6.99	83.9	12.1
212	100	7.51	90.1	13.0
392	200	8.55	102.6	14.8
572	300	9.53	114.4	16.5
752	400	10.52	126.2	18.2

Magnetic permeability μ
-76°F to 122°F
(-60°C to 50°C) 1.0056

Mean specific heat
Btu/lb • °F (32/212°F) 0.11
j/kg • K (0/100°C) 450

Modulus of elasticity in tension (E)
psi . . . . 27.0 x 10^6
MPa . . . . 186 x 10^3
Poisson's Ratio 0.29

Poisson's Ratio	0.290	
Modulus of Elasticity (E) (In Tension (E))	27.0	x 10^3 ksi
Electrical Resistivity (70°F)	651.0	ohm-cir-mil/ft

Magnetic Properties

Magnetic Permeability (-76 to 122°F)	1.0056	Mu

Typical Mechanical Properties

Typical elevated temperature tensile properties

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 1" (25.4mm)	% Reduction of Area
°F	°C	ksi	MPa	ksi	MPa		
200	93	41	283	87	600	55	74
300	149	38	262	83	572	56	72
400	204	37	255	79	545	56	70
500	260	34	234	77	531	53	65
600	316	31	214	75	517	53	59
700	371	29	200	74	510	52	58
800	427	29	200	72	496	50	53
900	482	28	193	71	490	54	53
1000	538	27	186	67	462	53	51
1100	593	27	186	65	448	56	55

Typical room temperature mechanical properties annealed 2050°F (1121°C), water quench

Product Form	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 2" (50.8mm)	% Reduction of Area	Rockwell B Hardness
	ksi	MPa	ksi	MPa			
Plate	45	310	93	641	50	80	85
Strip	40	276	88	607	48	73	—

Heat Treatment

Annealing

To anneal 20Mo-6 stainless, heat to 2050/2200°F (1121/1204°C) for 1/2 hour per 1" (25.4mm) of thickness and water quench.

Hardening

Cannot be hardened by heat treatment. Can be hardened only by cold working.

Stress Relieving

There may be occasions when stress relieving is desired for complex welded structures involving 20Mo-6 stainless. Intergranular corrosion tests on welded samples suggest that 20Mo-6 stainless can be stress relieved at temperatures below 950°F (510°C), for treating times less than 15 hours.

Effect of cold reduction on typical hardness

% Cold Reduction	Rockwell Hardness	% Cold Reduction	Rockwell Hardness
0	B 85	42	C 30
6	B 94	49	C 32
12	B 99	55	C 33
20	C 22	61	C 34
26	C 25	68	C 35
32	C 28	—	—

Workability

Hot Working

For forging, heat uniformly to 2200 2250°F (1204/1232°C). After hot working operations, it should reheated to 2050/2200°F (1121/1204°C) for a minimum of 1/2 hour per inch (25.4mm) of thickness and water quenched.

Machinability

Carpenter 20Mo-6 machines with a tough stringy chip.

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

Typical Machining Speeds and Feeds – 20Mo-6® 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	T15	65	.015	C2	280	330	.015
.025	M42	75	.007	C3	330	380	.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		50	.001	.0015	.002	.001	.001	.001	.001
	C2	175	.004	.0055	.007	.005	.004	.0035	.0035

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			.003	.005	.008	.011	.014	.017
		C2	80	.003	.005	.008	.011	.014	.017

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	45-55	.001	.003	.006	.010	.014	.017	.021	.025

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	70	.001	.002	.003	.004	C2	250	.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 stainless can be satisfactorily welded by using standard austenitic stainless steel welding techniques. Oxyacetylene welding is not recommended, because carbon pickup in the weld may occur.

AWS ER Ni Cr Mo-3 or E Ni Cr Mo-3 welding consumables (Alloy 625) should always be used when articles are fabricated by welding. This is necessary so that the welds in the as-welded material have corrosion resistance equal to that of the base metal. Autogenous welding is not a recommended method of fabrication. If autogenous welding is deemed absolutely necessary, it is imperative that the material be properly heat treated after welding. Contact Carpenter for heat-treating parameters. Gas tungsten-arc (with filler metal) or gas metal-arc welding with argon cover gas is suggested. Annealing is not required after welding, but if performed, a water quench is suggested.

Other Information

Applicable Specifications

Code Approval:
20Mo-6 stainless is approved by the American Society of Mechanical Engineers for the Boiler and Pressure Vessel Code, Section VIII, Div. 1. (Code Case 1931).

- ASME SB463
- ASME SB464
- ASME SB468
- ASME SB474
- ASTM B463
- ASTM B464
- ASTM B468
- ASTM B474

Allowable stresses[1]

For Metal Temperatures Not Exceeding		Maximum Allowable Stress Values							
		Sheet and Strip		Plate		Welded Pipe[2]		Tube[2]	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
100	38	20.0	138	20.0	138	17.0	117	17.0	117
200	93	20.0	138	20.0	138	17.0	117	17.0	117
300	149	18.9	130	19.6[3]	135	16.1	111	16.7[3]	115
400	204	17.5	121	19.2[3]	132	14.9	103	16.3[3]	112
500	260	16.3	112	18.5[3]	128	13.8	95	15.7[3]	108
600	316	15.3	105	18.1[3]	125	13.0	90	15.4[3]	106
700	371	14.6	101	17.5[3]	121	12.4	85	14.8[3]	102
800	427	13.9	96	17.0[3]	117	11.8	81	14.5[3]	100

[1] From ASME Boiler & Pressure Vessel Code Section VIII, Division 1.

[2] For welded pipe and tube, a joint efficiency factor of 0.85 has been applied.

[3] Due to the relatively low yield strength of this material, these higher stress values were established at temperatures where the short-time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

Forms Manufactured

Sheet & Plate - Available from Authorized Distributors

- Bar-Rounds
- Billet
- Plate
- Sheet
- Strip
- Wire

Disclaimer:
The information and data presented herein are typical or average values and are not a guarantee of maximum or minimum values. Applications specifically suggested for material described herein are made solely for the purpose of illustration to enable the reader to make his/her own evaluation and are not intended as warranties, either express or implied, of fitness for these or other purposes. There is no representation that the recipient of this literature will receive updated editions as they become available.

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