Carpenter 2205 Stainless

Identification

UNS Number

- S31803

DIN Number

- 1.4462

Type Analysis

Carbon (Maximum)	0.03 %	**Manganese (Maximum)**	2.00 %
Phosphorus (Maximum)	0.030 %	**Sulfur (Maximum)**	0.020 %
Silicon (Maximum)	1.00 %	**Chromium**	21.00 to 23.00 %
Nickel	4.50 to 6.50 %	**Molybdenum**	2.50 to 3.50 %
Nitrogen	0.08 to 0.20 %	**Iron**	Balance

General Information

Description

Carpenter 2205 stainless is a duplex stainless steel that has a microstructure consisting of austenite and ferrite phases. This duplex microstructure and the chemical composition of Carpenter 2205 stainless results in an excellent combination of strength and corrosion resistance.

Carpenter 2205 stainless has twice the annealed yield strength of typical austenitic stainless steels, like Type 304 and 316. In the hot rolled unannealed condition, yield strength of 75 ksi (518 MPa) or higher can be achieved for bar diameters up to 1.375 in. (34.925mm).

Carpenter 2205 stainless possesses good resistance to general corrosion in many acid environments and, has excellent resistance to chloride stress corrosion cracking, pitting and crevice corrosion.

Applications

Rebar has been a primary application for Carpenter 2205 stainless. Specific rebar applications have included bridge decks, barrier and retaining walls, anchoring systems, chemical plant infrastructure, coastal piers and wharves, bridge parapets, sidewalks and bridge piling. The higher strength capability, 75 ksi (518 MPa) minimum yield strength, of Carpenter 2205 stainless rebar is an added economical advantage.

Other applications for Carpenter 2205 stainless have included bridge tie wire and dowels; oil and gas production equipment, such as valves, fittings, shafts, and pump parts; heat exchangers in chemical and pulp and paper plants; and brewery tanks.

Elevated Temperature Use

Carpenter 2205 stainless is subject to 885 embrittlement when exposed for extended times between about 700 and 1000°F (371 and 538°C).

The alloy is also subject to precipitation of sigma phase when exposed between about 1250 and 1550°F (677 and 843°C) for extended time. Sigma phase increases strength and hardness, but decreases ductility and corrosion resistance.

Corrosion Resistance

Compared to conventional austenitic stainless steels, like Type 304 and 316, Carpenter 2205 stainless has superior resistance in most oxidizing and reducing acids; superior chloride pitting and crevice corrosion resistance, due to higher chromium, molybdenum and nitrogen content and superior resistance to chloride stress corrosion cracking due to its duplex microstructure.

Carpenter 2205 stainless has good intergranular corrosion in the as-annealed and as-weld conditions due to its low carbon content. Some intergranular attack may occur in the hot rolled unannealed condition.

For optimum corrosion resistance, surfaces must be free of scale and foreign particles and finished parts should be passivated.

Important Note: *The following 5-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	Moderate
Phosphoric Acid	Moderate	Acetic Acid	Good
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Excellent
Sea Water	Moderate	Sour Oil/Gas	Moderate
Humidity	Excellent		

Properties

Physical Properties		
Specific Gravity		
Annealed	7.80	
As Rolled	7.82	
Density		
Annealed	0.2820	lb/in³
As Rolled	0.2830	lb/in³
Mean Coefficient of Thermal Expansion		
77.00 °F, 122.0 °F, Annealed	6.22 x 10^{-6}	in/in/°F
77.00 °F, 122.0 °F, Hot Rolled	7.02 x 10^{-6}	in/in/°F
77.00 °F, 212.0 °F, Annealed	7.11 x 10^{-6}	in/in/°F
77.00 °F, 302.0 °F, Annealed	7.29 x 10^{-6}	in/in/°F
77.00 °F, 212.0 °F, Hot Rolled	7.48 x 10^{-6}	in/in/°F
77.00 °F, 392.0 °F, Annealed	7.53 x 10^{-6}	in/in/°F
77.00 °F, 302.0 °F, Hot Rolled	7.70 x 10^{-6}	in/in/°F
77.00 °F, 482.0 °F, Annealed	7.72 x 10^{-6}	in/in/°F
77.00 °F, 392.0 °F, Hot Rolled	7.82 x 10^{-6}	in/in/°F
77.00 °F, 572.0 °F, Annealed	7.86 x 10^{-6}	in/in/°F
77.00 °F, 662.0 °F, Annealed	7.97 x 10^{-6}	in/in/°F
77.00 °F, 752.0 °F, Annealed	7.99 x 10^{-6}	in/in/°F
77.00 °F, 482.0 °F, Hot Rolled	8.04 x 10^{-6}	in/in/°F
77.00 °F, 842.0 °F, Annealed	8.12 x 10^{-6}	in/in/°F
77.00 °F, 572.0 °F, Hot Rolled	8.17 x 10^{-6}	in/in/°F
77.00 °F, 932.0 °F, Annealed	8.23 x 10^{-6}	in/in/°F
77.00 °F, 662.0 °F, Hot Rolled	8.26 x 10^{-6}	in/in/°F
77.00 °F, 1012 °F, Annealed	8.30 x 10^{-6}	in/in/°F
77.00 °F, 752.0 °F, Hot Rolled	8.34 x 10^{-6}	in/in/°F
77.00 °F, 842.0 °F, Hot Rolled	8.44 x 10^{-6}	in/in/°F
77.00 °F, 1112 °F, Annealed	8.44 x 10^{-6}	in/in/°F
77.00 °F, 932.0 °F, Hot Rolled	8.53 x 10^{-6}	in/in/°F
77.00 °F, 1012 °F, Hot Rolled	8.57 x 10^{-6}	in/in/°F
77.00 °F, 1202 °F, Annealed	8.57 x 10^{-6}	in/in/°F
77.00 °F, 1112 °F, Hot Rolled	8.68 x 10^{-6}	in/in/°F
77.00 °F, 1292 °F, Annealed	8.77 x 10^{-6}	in/in/°F
77.00 °F, 1202 °F, Hot Rolled	8.78 x 10^{-6}	in/in/°F
77.00 °F, 1292 °F, Hot Rolled	8.92 x 10^{-6}	in/in/°F

Mean Coefficient of Thermal Expansion – Carpenter 2205 Stainless
0.5" (12.5 mm) diameter rebar

Test Temperature		Hot Rolled Condition		Annealed Condition	
77°F to	25°C to	10^{-6}/°F	10^{-6}/°C	10^{-6}/°F	10^{-6}/°C
122	50	7.02	12.64	6.22	11.20
212	100	7.48	13.47	7.11	12.48
302	150	7.70	13.86	7.29	13.12
392	200	7.82	14.07	7.53	13.56
482	250	8.04	14.47	7.72	13.89
572	300	8.17	14.71	7.86	14.14
662	350	8.26	14.87	7.97	14.34
752	400	8.34	15.01	7.99	14.39
842	450	8.44	15.20	8.12	14.62
932	500	8.53	15.36	8.23	14.82
1012	550	8.57	15.42	8.30	14.94
1112	600	8.68	15.63	8.44	15.19
1202	650	8.78	15.81	8.57	15.42
1292	700	8.92	16.11	8.77	15.79

Annealed 1950°F (1066°C) for 1 hour and water quenched. Dilatometer specimens were .250" (6.4 mm) sq. x 2" (50.8 mm) long.

Magnetic Properties

In the annealed and hot rolled conditions, Carpenter 2205 stainless is ferromagnetic.

Typical Mechanical Properties

CVN Impact Data at Various Test Temperatures – Carpenter 2205 Stainless
0.5" (12.5 mm) diameter rebar

Condition	Test Temperature		Charpy V-Notch Impact Strength	
	°F	°C	ft-lbs	Joules
As-Rolled	70	21	92	125
Annealed	70	21	120	163
As-Rolled	32	0	90	122
Annealed	32	0	104	141
As-Rolled	-100	-73	89	121
Annealed	-100	-73	96	131

Annealed 1950°F (1066°C) for 1 hour and water quenched.
Sub-size specimens 0.197" x 0.394" (5 mm x 10 mm) per ASTM E23.

Mechanical Properties at Various Test Temperatures – Carpenter 2205 Stainless
0.5" (12.5 mm) diameter rebar

	Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elonga-tion in 4D	% Reduction of Area
	°F	°C	ksi	MPa	ksi	MPa		
As-Rolled	-100	-73	127	875	159	1100	63.0	80.5
Annealed	-100	-73	90	621	144	994	70.5	81.0
As-Rolled	70	21	97	670	131	903	42.3	84.3
Annealed	70	21	70	480	113	777	50.1	85.3
As-Rolled	400	204	75	519	106	728	35.6	81.6
Annealed	400	204	51	350	93	640	40.6	80.4

Annealed 1950°F (1066°C) for 1 hour and water quenched.
Standard 0.250" (6.4 mm) gage diameter tensile specimens.

RR Moore Rotating Beam Fatigue Tests – Carpenter 2205 Stainless

0.5" (12.5 mm) diameter rebar

Hot Rolled Condition			Annealed Condition		
Test Stress		Cycles to Fracture	Test Stress		Cycles to Fracture
ksi	MPa		ksi	MPa	
40	276	1.5×10^7 (NF)	35	242	2.1×10^7 NF
50	345	1.3×10^7 (NF)	50	345	1.3×10^7 NF
60	414	1.4×10^7 (NF)	60	414	1.4×10^7 NF
70	483	1.4×10^7 (NF)	65	449	1.2×10^7 NF
80	552	2.6×10^7 (NF)	67.5	466	1.3×10^5
90	621	3.7×10^4	70	483	1.2×10^5

Annealed 1950°F (1066°C) for 1 hour and water quenched. NF indicates test was terminated without specimen fracturing. Standard 0.250" (6.4 mm) gage diameter fatigue specimens.

Endurance Limit at 10^7 cycles: 80 ksi (552 MPa) hot rolled condition.
65 ksi (449 MPa) annealed condition.

Typical Room Temperature Hot Rolled Mechanical Properties – Carpenter 2205 Stainless

Samples were full-section rebar

Bar Size		Rebar #	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 8" (203 mm)
in	mm		ksi	MPa	ksi	MPa	
0.5	12.7	4	92.5	638	126	869	26.8
0.625	15.9	5	90.5	624	126.5	873	29.7
0.750	19.1	6	90.0	621	120.5	831	29.0
1.250	31.8	10	86.0	593	120.0	828	28.3
1.375	34.9	11	86.0	593	119.0	814	31.8

Heat Treatment

Annealing

Heat to 1850/2050°F (1010/1121°C) and rapidly quench in water or air. Typical hardness as-annealed is HRC 20.

Hardening

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

Workability

Hot rolling and controlling the finishing temperature can strengthen Carpenter 2205 stainless bar. After hot rolling, bars are not annealed.

Hot Working

Heat uniformly to 2000/2100°F (1093/1149°C). Reheat as often as necessary. Cool forgings in air.

Cold Working

Cold working increases strength and hardness. Work hardening rate is lower than Type 304; however, the annealed strength is significantly higher.

Machinability

The machinability of Carpenter 2205 stainless generally has been between that of conventional Type 316 stainless and Carpenter 22Cr-13Ni-5Mn stainless.

The following chart includes typical machining parameters used to machine Carpenter 2205 stainless. The data listed should be used as a guide for initial machine setup only.

Typical Machining Speeds and Feeds – Carpenter 2205 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	T15	85	.015	C2	350	450	.015
.025	M42	100	.007	C3	400	525	.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	1½	2
M2		75	.001	.0015	.002	.0015	.001	.001	.001
	C2	275	.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	1½	2
M7	70	C2	90	.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
M7, M10	50-60	.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
M1, M2, M7, M10	8-15	10-20	15-25	25-30

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	75	.001	.002	.003	.004	C2	270	.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	15	.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.

Weldability

Carpenter 2205 stainless has been welded using many of the standard electric arc welding processes. Autogeneous welding will increase the amount of ferrite present in the weldement and heat affected zone. When a filler metal is required, consider AWS E/ER 209.

Oxyacetylene welding is not recommended, because carbon pickup in the weld may occur.

Postweld annealing is not required for most applications, but will provide optimum properties for severe service.

Other Information

Applicable Specifications

- ASME SA479
- ASTM A240
- ASTM A276
- ASTM A479
- ASTM A955M
- BS 6744: 2001

- NACE MR0175

Forms Manufactured	
• Bar-Rounds	• Billet
• Rebar or (Bar-Reinforcing)	• Strip
• Wire	• Wire-Rod

Technical Articles

- Stainless Steel Rebar For Concrete Reinforcement: An Update And Selection Guide

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