Custom 455® Stainless

Identification

UNS Number
- S45500

Type Analysis

Single figures are nominal except where noted.

Carbon (Maximum)	0.05 %	**Manganese (Maximum)**	0.50 %
Phosphorus (Maximum)	0.040 %	**Sulfur (Maximum)**	0.030 %
Silicon (Maximum)	0.50 %	**Chromium**	11.00 to 12.50 %
Nickel	7.50 to 9.50 %	**Molybdenum (Maximum)**	0.50 %
Copper	1.50 to 2.50 %	**Titanium**	0.80 to 1.40 %
Columbium + Tantalum	0.10 to 0.50 %	**Iron**	Balance

General Information

Description

Recognizing the need for high-strength alloys with good corrosion resistance to atmospheric environments, the Carpenter Research Laboratory developed Custom 455® stainless, a martensitic age-hardenable stainless steel. This alloy is relatively soft and formable in the annealed condition. A single-step aging treatment develops exceptionally high yield strength with good ductility and toughness.

This stainless can be machined in the annealed condition, and welded in much the same manner as other precipitation hardenable stainless steels. Because of its low work-hardening rate, it can be extensively cold formed. The dimensional change during hardening is only about -0.001 in/in, which permits close-tolerance finish machining in the annealed state.

Custom 455 stainless represents a significant advancement in the area of precipitation hardening stainless steels. It should be considered where simplicity of heat treatment, ease of fabrication, high strength and corrosion resistance are required in combination.

Selection

Because of the unique combination of high strength and corrosion resistance of Custom 455 stainless there are a few other alloys available for consideration. Carpenter 13-8 stainless can be considered where good transverse toughness and ductility are necessary in large sections.

Elevated Temperature Use

Custom 455 stainless has displayed excellent resistance to oxidation up to approximately 1100°F (593°C).

Long-term exposure to elevated temperatures can result in reduced toughness in precipitation hardenable stainless steels. The reduction in toughness can be minimized in some cases by using higher aging temperatures. Short exposures to elevated temperatures can be considered, provided the maximum temperature is at least 50°F (28°C) less than the aging temperature.

Corrosion Resistance

Custom 455 stainless resists staining in normal air atmospheres, and shows no corrosion in fresh water. Tests in 5% salt spray at 95°F (35°C) and in 5% ferric chloride at room temperature have demonstrated good resistance to pitting and rusting. Laboratory tests in a variety of mild chemical environments have shown that the level of general corrosion resistance is superior to that of the 12% chromium steels (Type 410) and approaches that of the 17% chromium steels (Type 430). In most tests there was no significant effect of aging temperature on corrosion resistance.

Hydrogen embrittlement tests in 5% acetic acid saturated with H2S at room temperature show the same degree of susceptibility as other high-strength martensitic stainless steels.

All high-strength steels are subject to stress corrosion under certain stress conditions and in certain environments. Numerous severe tests have been conducted to evaluate the behavior of Custom 455 stainless in different environments and to determine the effect of aging temperature on resistance to stress-corrosion cracking. These tests include U-bend specimens, direct tension specimens, C-rings and precracked cantilever beam specimens. Environments have included marine atmospheres, 20% salt spray, and 3-1/2% sodium chloride solutions. All tests have shown that Custom 455 stainless has inherently good resistance to stress-corrosion cracking, and that this resistance improves markedly as aging temperature is increased.

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	Moderate	Sulfuric Acid	Restricted
Phosphoric Acid	Restricted	Acetic Acid	Restricted
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Good
Sea Water	Restricted	Humidity	Excellent

Properties

Physical Properties

Specific Gravity

Annealed	7.76
Condition H 1000	7.80
Condition H 1050	7.80
Condition H 1100	7.82
Condition H 900	7.78
Condition H 950	7.79

Density

Annealed	0.2800 lb/in³
Condition H 900	0.2810 lb/in³
Condition H 950	0.2810 lb/in³
Condition H 1000	0.2820 lb/in³
Condition H 1050	0.2820 lb/in³
Condition H 1100	0.2830 lb/in³

Density–Custom 455® Stainless

Condition	lb/in³	g/cm³
Annealed	0.280	7.76
H 900	0.281	7.78
H 950	0.281	7.79
H 1000	0.282	7.80
H 1050	0.282	7.80
H 1100	0.283	7.82

Mean CTE

72 to 200°F	5.90 x 10^{-6} in/in/°F
72 to 300°F	6.03 x 10^{-6} in/in/°F
72 to 500°F	6.20 x 10^{-6} in/in/°F
72 to 700°F	6.45 x 10^{-6} in/in/°F
72 to 900°F	6.68 x 10^{-6} in/in/°F

Mean Coefficient of Thermal Expansion

Temperature		10^{-6}/°F	10^{-6}/K
72°F to	22°C to		
200	93	5.90	10.6
300	149	6.03	10.9
500	260	6.20	11.2
700	371	6.45	11.6
900	482	6.68	12.0

Thermal Conductivity

212°F	125.0 BTU-in/hr/ft²/°F
392°F	137.0 BTU-in/hr/ft²/°F
572°F	148.0 BTU-in/hr/ft²/°F
752°F	162.0 BTU-in/hr/ft²/°F
932°F	172.0 BTU-in/hr/ft²/°F

Thermal Conductivity

Test Temperature		Btu·in/ft²·h·°F	W/m·K
°F	°C		
212	100	125	18.0
392	200	137	19.7
572	300	148	21.3
752	400	162	23.4
932	500	172	24.7

Poisson's Ratio

--	0.300

Modulus of Elasticity (E)

--	29.0 x 10^3 ksi

Modulus of Rigidity (G)

--	11.0 x 10^3 ksi

Electrical Resistivity

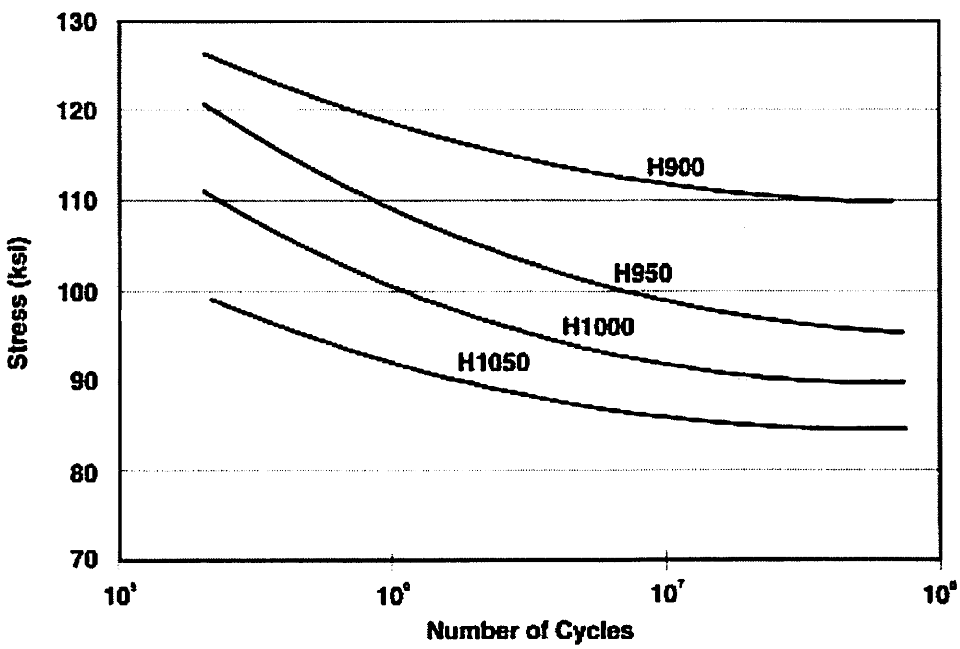
70°F, Condition A	545.0 ohm-cir-mil/ft
70°F, Condition H 950	456.0 ohm-cir-mil/ft

Electrical Resistivity

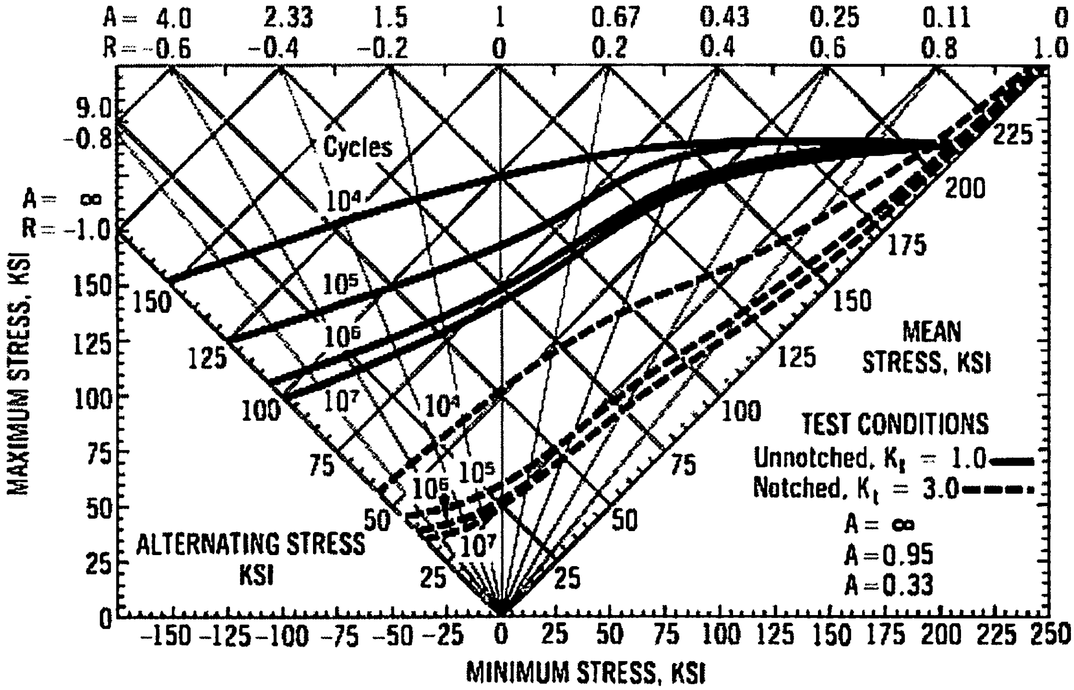
Condition	Ohm·cir mil/ft	Microhm/mm
A	545	906
H 950	456	758

Typical Mechanical Properties

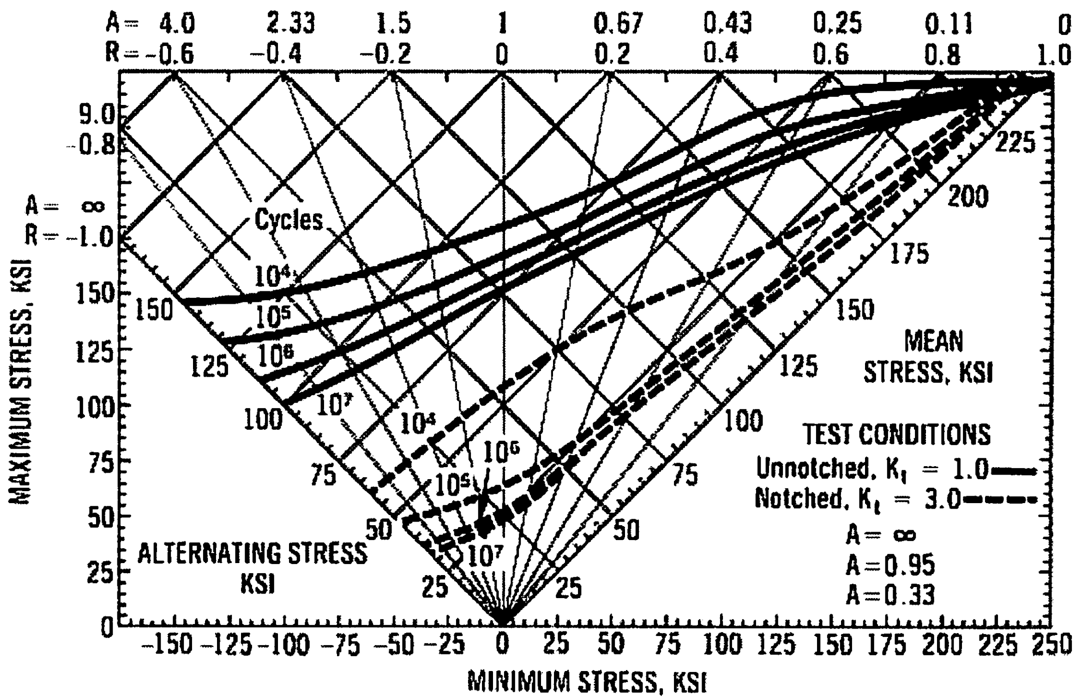
R. R. Moore Smooth Rotating Beam Fatigue Behavior—Custom 455 Stainless



Typical Constant Life Fatigue Diagram for Custom 455 Stainless Bar in the H 1000 Condition at Room Temperature
(Axial tests using longitudinal specimens)



Typical Constant Life Fatigue Diagram for Custom 455 Stainless Bar in the H 950 Condition at Room Temperature
(Axial tests using longitudinal specimens)



Typical Cryogenic Mechanical Properties

Condition H 1000

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Notch Tensile Strength		% Elongation	% Reduction of Area	Charpy V-Notch Impact Strength	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa			ft-lb	J
Room		195	1345	205	1413	290	2000	14	55	22	30
-100	-73	-	-	220	1517	300	2068	13	50	16	22
-300	-184	-	-	255	1758	220	1517	13	45	5	7

Typical Cryogenic Mechanical Properties

Condition H 950

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Notch Tensile Strength		% Elongation	% Reduction of Area	Charpy V-Notch Impact Strength	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa			ft-lb	J
Room		220	1517	230	1586	300	2068	12	50	15	20
-100	-73	-	-	245	1689	280	1931	11	45	10	14
-300	-184	-	-	280	1931	115	793	5	20	3	4

Typical Double Restrained Shear Strength

1-1/16" (27mm) Rd. to 6" (152mm) sq. sections, longitudinal

Test Temperature		Condition			
		H 950		H 1000	
°F	°C	ksi	MPa	ksi	MPa
-100	-73	161	1110	143	986
RT		147	1014	129	889
400	204	126	869	114	786
600	316	114	786	104	717
800	427	103	710	88	607

Typical Elevated Temperature

Tensile properties, condition H 1000

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elong. in 4D	% Reduction of Area	Room Temp. Rockwell C Hardness after test
°F	°C	ksi	MPa	ksi	MPa			
Room		195	1345	205	1413	14	55	44
600	316	165	1138	174	1200	14	60	44
800	427	148	1020	154	1062	15	65	44
1000	538	110	758	118	814	20	75	44

Typical Elevated Temperature

Tensile Properties, condition H 900

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elong. in 4D	% Reduction of Area	Room Temp. Rockwell C Hardness after test
°F	°C	ksi	MPa	ksi	MPa			
Room		237	1634	245	1689	11	48	49
500	260	199	1372	214	1476	10	49	49
600	316	188	1296	204	1407	11	50	49
700	371	180	1241	195	1345	12	52	49
800	427	166	1145	180	1241	14	56	49

Typical Elevated Temperature
Tensile properties, condition H 950

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elong. in 4D	% Reduction of Area	Room Temp. Rockwell C Hardness after test
°F	°C	ksi	MPa	ksi	MPa			
Room		220	1517	230	1586	12	50	48
600	316	185	1276	195	1345	12	50	48
800	427	163	1124	175	1207	14	60	48
1000	538	110	758	130	896	18	70	48

Typical Room Temperature Mechanical Properties
Bar, 1" (25.4 mm) section

Condition	0.2% Yield Strength		Ultimate Tensile Strength		Notch Tensile Strength $K_t = 10$		% Elong. in 4D	% Reduction of Area	Rockwell C Hardness	Charpy V-Notch Impact Strength	
	ksi	MPa	ksi	MPa	ksi	MPa				ft-lb	J
A	115	793	145	1000	230	1585	14	60	31	70	95
H 900	245	1689	250	1724	250	1792	10	45	49	9	12
H 950	225	1551	235	1620	300	2068	12	50	48	14	19
H 1000	200	1379	210	1448	290	2000	14	55	45	20	27
H 1050	175	1207	190	1310	260	1793	15	55	40	35	48

Typical Room Temperature Mechanical Properties
Bar, 4" (102 mm) section

Condition	0.2% Yield Strength		Ultimate Tensile Strength		Notch Tensile Strength $K_t = 10$		% Elong. in 4D	% Reduction of Area	Rockwell C Hardness	Charpy V-Notch Impact Strength	
	ksi	MPa	ksi	MPa	ksi	MPa				ft-lb	J
A	115	793	140	965	-	-	12	50	31	-	-
H 950	220	1516	230	1585	250	1723	10	45	48	8	11
H 1000	195	1344	205	1413	250	1723	12	45	45	12	16
H 1050	175	1206	190	1309	250	1723	14	50	40	25	34

Typical Room Temperature Mechanical Properties
Strip, .050" (1.27 mm) thick

Condition	0.2% Yield Strength		Ultimate Tensile Strength		% Elong. in 1 inch (25.4 mm)	% Elong. in 2 inches (50.8 mm)	% Reduction of Area	Rockwell C Hardness
	ksi	MPa	ksi	MPa				
A	150	1034	160	1103	10	6	-	34
H 900	250	1724	260	1793	6	3	-	51
H 950	240	1655	250	1724	8	4	-	47
H 1000	210	1448	220	1517	12	5	-	44

Typical Room Temperature Mechanical Properties
Strip, 0.160" (4.1 mm) thick

Condition	0.2% Yield Strength		Ultimate Tensile Strength		% Elong. in 1 inch (25.4 mm)	% Elong. in 2 inches (50.8 mm)	% Reduction in Area	Rockwell C Hardness
	ksi	MPa	ksi	MPa				
A	135	930	160	1103	18	8	54	33
H 900	250	1724	260	1792	8	3	25	51
H 950	240	1655	250	1724	10	4	40	48
H 1000	210	1448	220	1517	14	6	45	46

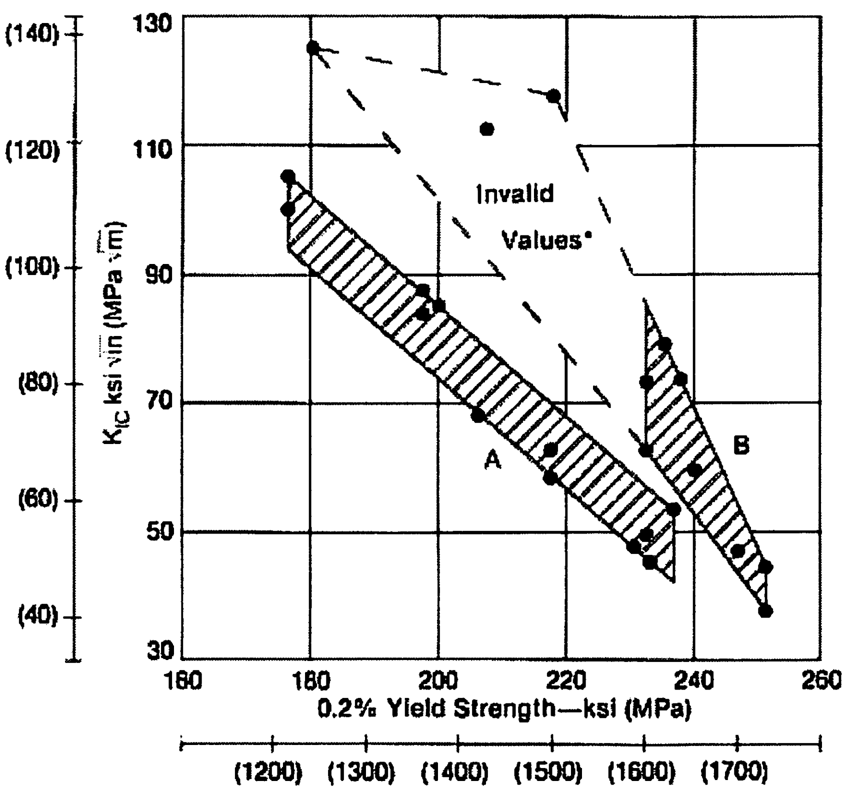
Typical Stress Rupture Strength

Test Temperature		Condition	Stress for rupture in					
			10 Hrs.		100 Hrs.		1000 Hrs.	
°F	°C		ksi	MPa	ksi	MPa	ksi	MPa
800	427	H 900	150	1034	120	827	93	641
800	427	H 950	142	979	117	807	91	627
900	482	H 950	109	752	82	565	54	372

Toughness

Fracture toughness is the resistance of a material to abrupt, brittle failure at stresses below its yield strength when various stress concentrators are present. It is described by a stress intensity parameter K. Custom 455 stainless has good fracture toughness after various aging treatments.

Relation Between Yield Strength and Fracture Toughness
A: 3.5 or 4" Sq., Longitudinal or Transverse
B: 1" Rd., 1.1875" Rd., or 0.5" x 1.25" Flat, Longitudinal



Each data point represents an average of two or more values
*Inadequate specimen thickness due to small section size.

Heat Treatment

Solution Treatment

Condition A (Solution Treated or Annealed):
Heat to 1500/1550 (816/843°C), and cool rapidly. Water quenching is preferred for small sections.

Custom 455 stainless will normally be supplied from the mill in the annealed condition, ready for the one-step hardening treatment.

Age

Condition H 900, H 950, H 1000, H 1050 (Precipitation or Age Hardened):

The high strength levels of Carpenter Custom 455 stainless are derived from a simple precipitation-hardening treatment consisting of heating to a selected temperature between 900/1050°F (482/566°C), holding for four hours and air cooling.

Average Longitudinal Size Change (Contraction)
Solution-treated to aged condition

Condition	Contraction in./in.(m/m)
H 900	0.0007
H 950	0.0009
H 1000	0.0012

Workability

Hot Working

Custom 455 stainless is easily forged within the temperature range of 1650/2300°F (899/1260°C). For optimum mechanical properties, material to be forged should be heated uniformly to 1900/2100°F (1038/1149°C) and soaked at heat; finishing temperature should be within the range of 1500/1700°F (816/927°C) to obtain an optimum grain size and properties after heat treating. Cool forgings in air to room temperature and anneal.

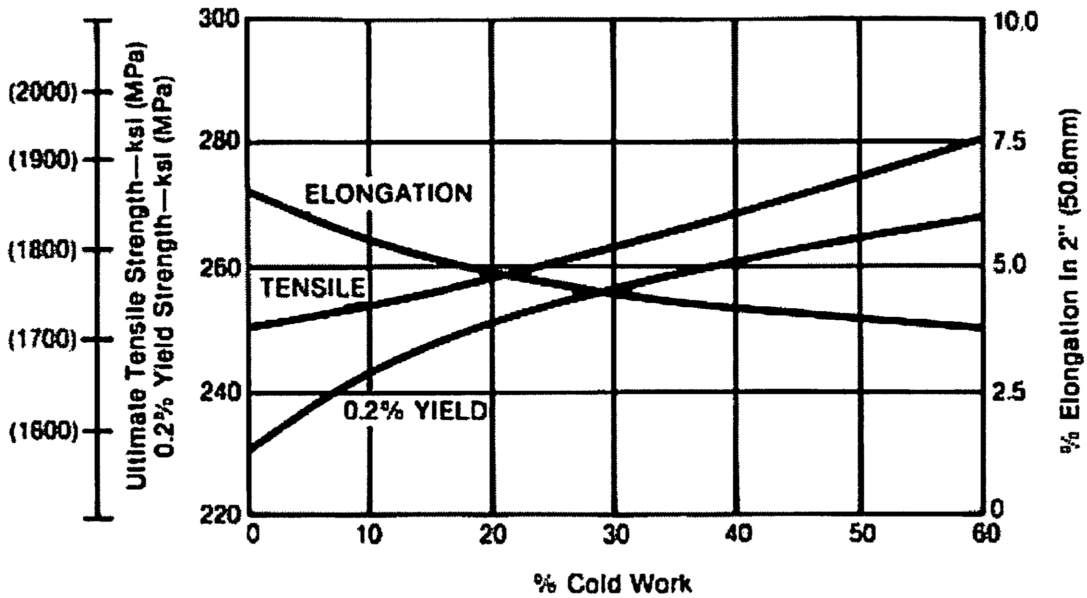
Cold Working

Cold working is readily performed despite the fact that Custom 455 stainless is martensitic in the annealed condition, and has a hardness of Rockwell C 30/35. Deep drawing or stretching operations will require intermediate anneals because the elongation tends to be localized. For other cold-forming operations such as cold drawing and cold rolling, the work-hardening rate in the annealed condition is extremely low allowing considerable cold working without intermediate annealing. Cold-heading and warm-heading operations are also easily performed. Cold working prior to aging results in even higher tensile and yield strengths in the hardened condition.

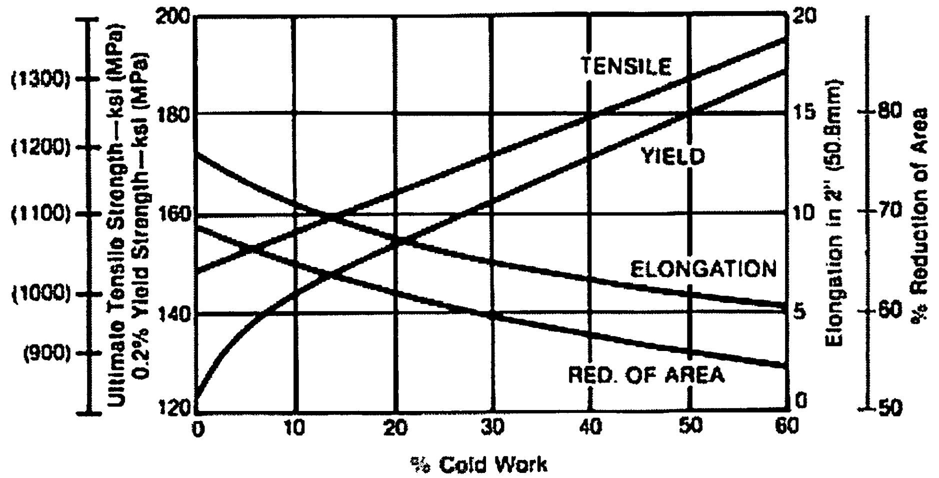
Spring Properties:
Wire in the annealed or lightly drawn condition and annealed strip can be aged for 2 to 4 hours at 900°F (482°C) to achieve a tensile strength in excess of 250 ksi (1742 MPa). As such, Custom 455 stainless can be used in relatively large diameters and thicknesses and still have good spring characteristics. This greatly expands the range of sizes of corrosion-resistant springs available to designer.

Custom 455 stainless can also be extensively cold worked prior to aging to achieve even higher levels of strength. Extensive cold working reduces the aging time required to reach maximum mechanical properties. Therefore, cold-drawn spring wire and cold-rolled strip in Condition C need only be aged for ½ hour at 850°F (454°C).

Effect of Cold Reduction on Typical Aged Tensile Properties of Custom 455 Stainless Wire
Annealed 1500°F (816°C) 1/2 hr., water quench, cold drawn, aged 900°F (482°C) 4 hr., air cool



Effect of Cold Work on Typical Tensile Properties of Custom 455 Stainless Wire
Annealed 1500°F (816°C) 1/2 hr., water quench before cold drawing



Machinability

Custom 455 stainless has been machined successfully using the same practices required for other high-strength alloys; i.e., rigid tool and work supports, slower speeds, positive cuts and adequate amounts of coolant. The machining characteristics of Custom 455 stainless are similar to those of the nickel maraging steels.

Following are typical feeds and speeds for Custom 455 stainless.

Typical Machining Speeds and Feeds – Custom 455® Stainless

The speeds and feeds in the following charts are conservative recommendations for initia setup. Higher speeds and feeds may be attainable depending on machining environmen

Turning—Single-Point and Box Tools

Depth of Cut (Inches)	Micro-Melt® Powder High Speed Tools Tool Material	Speed (fpm)	Feed (ipr)	Carbide Tools Tool Material	Speed (fpm) Uncoated	Speed (fpm) Coated	Feed (ipr)
				Annealed			
.150	M48,T15	72	.015	C6	270	350	.010
.025	M48,T15	84	.007	C7	325	425	.005
				Aged			
.150	M48,T15	48	.010	C6	190	250	.010
.025	M48,T15	54	.005	C7	225	290	.005

Turning—Cut-Off and Form Tools

Tool Material: Micro-Melt® Powder HS Tools	Tool Material: Carbide Tools	Speed (fpm)	Feed (ipr) Cut-Off Tool Width (Inches) 1/16	1/8	1/4	Form Tool Width (Inches) 1/2	1	1-1/2	2
				Annealed					
M48,T15		72	.001	.0015	.002	.0015	.001	.0007	.0005
	C6	216	.003	.003	.007	.005	.004	.0035	.0035
				Aged					
M48, T15		36	.001	.001	.0015	.0015	.001	.0005	.0005
	C6	132	.003	.003	.0045	.003	.002	.002	.002

Rough Reaming

Micro-Melt® Powder HS Tools Tool Material	Speed (fpm)	Carbide Tools (inserts) Tool Material	Speed (fpm)	Feed (ipr) Reamer Diameter (inches) 1/8	1/4	1/2	1	1-1/2	2
				Annealed					
M48, T15	72	C2	190	.003	.005	.008	.011	.015	.018
				Aged					
M48, T15	36	C2	100	.001	.001	.001	.001	.001	.001

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	1-1/2	2
				Annealed					
M42	50	.001	.002	.004	.007	.008	.010	.012	.015
				Aged					
M42	35	-	.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
		Annealed		
M2, M7, M10	5–12	8–15	10–22	15–27
		Aged		
T15, M42	4–8	6–10	8–12	10–15

Milling, End-Peripheral

Depth of Cut (in)	High Speed Tools: Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in) 1/4	1/2	3/4	1-2	Carbide Tools: Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in) 1/4	1/2	3/4	1-2
					Annealed							
.050	M48, T15	108	.001	.002	.003	.004	C2	275	.001	.002	.004	.008
					Aged							
.050	M48, T15	72	.0005	.001	.002	.003	C2	90	.001	.002	.003	.004

Tapping

High Speed Tools: Tool Material	Speed (fpm)
Annealed	
M7, M10	12–25
Aged	
M7, M10 Nitrided	5–15

Broaching

Micro-Melt® Powder High Speed Tools: Tool Material	Speed (fpm)	Chip Load (ipt)
	Annealed	
M48, T15	9.6	.002
	Aged	
M48, T15	12	.002

Spring Temper Tensile Strength Range–Custom 455® Stainless

Diameter inches	Diameter mm	Nominal Cold-Drawn Tensile Strength ksi	Nominal Cold-Drawn Tensile Strength MPa	Age-Hardened Tensile Strength ksi MIN	ksi MAX	MPa MIN	MPa MAX
0.010 to 0.040 incl	0.25 to 1.02 incl	245	1688	320	350	2205	2412
Over 0.040 to 0.050 incl	Over 1.02 to 1.27 incl	235	1620	310	340	2137	2343
Over 0.050 to 0.060 incl	Over 1.27 to 1.52 incl	225	1550	305	335	2102	2309
Over 0.060 to 0.075 incl	Over 1.52 to 1.91 incl	220	1516	295	325	2033	2240
Over 0.075 to 0.085 incl	Over 1.91 to 2.16 incl	215	1482	290	320	1999	2205
Over 0.085 to 0.095 incl	Over 2.16 to 2.41 incl	210	1447	285	315	1964	2171
Over 0.095 to 0.110 incl	Over 2.41 to 2.79 incl	200	1378	278	308	1916	2123
Over 0.110 to 0.125 incl	Over 2.79 to 3.18 incl	195	1344	272	302	1875	2081
Over 0.125 to 0.150 incl	Over 3.18 to 3.81 incl	190	1309	265	295	1826	2033
Over 0.150 to 0.500 incl	Over 3.81 to 12.70 incl	180	1240	260	290	1792	1999

Aging Treatment: 1/2 hour at 850°F (454°C)

Additional Machinability Notes

Figures used for all metal removal operations covered are starting points. 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

Custom 455 stainless 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. Preheating is not required to prevent cracking during the welding of this alloy. Normally, welding in the solution-annealed condition is satisfactory; however, where high welding stresses are anticipated, it may be advantageous to weld in the overaged [aged at 1150°F (621 °C)] condition. If welded in the solution-annealed condition, the alloy can be directly aged to the desired strength level after welding.

However, the optimum combination of strength, ductility and corrosion resistance is obtained by solution annealing the welded part before aging. If welded in the overaged condition, the part should be solution annealed before aging.

Other Information

Descaling (Cleaning)

Descaling following forging and annealing can be accomplished by acid cleaning or grit blasting. The acid treatment consists of 2 minutes in 50% by volume muriatic acid at 180°F (82°C), followed by 4 minutes in a mixture of 15% by volume nitric acid, plus 3% by volume hydrofluoric acid at room temperature. Repeat cleaning procedure as necessary but decrease the times by 50% (i.e., 1 and 2 minutes, respectively).

The heat tint from aging can be removed by polishing, vapor blasting or pickling 4 to 6 minutes in a mixture of 15% by volume nitric acid, plus 3% by volume hydrofluoric acid, followed by a water rinse. Repeat the acid cleaning procedure if necessary, but decrease the time by 2 to 3 minutes. Desmut in 20% by volume nitric acid at room temperature.

After acid cleaning, bake 1 to 3 hours at 300/350°F (149/177°C) to remove hydrogen.

Applicable Specifications

- AMS 5617
- ASME SA564
- ASTM A693 (XM-16)
- AMS 5860 (Strip)
- ASTM A564 (XM-16)

Forms Manufactured

- Bar-Flats
- Bar-Shapes
- Billet
- Wire
- Bar-Rounds
- Bar-Squares
- Strip

Technical Articles

- A Designer's Manual On Specialty Alloys For Critical Automotive Components
- A Guide to Etching Specialty Alloys for Microstructural Evaluation
- Advanced Stainless Offers High Strength, Toughness and Corrosion Resistance Wherever Needed
- Alloy Selection for Cold Forming (Part I)
- Alloy Selection for Cold Forming (Part II)
- How to Passivate Stainless Steel Parts
- How to Select the Right Stainless Steel or High Temperature Alloy for Heading
- Improved Stainless Steels for Medical Instrument Tubing
- New Ideas for Machining Austenitic Stainless Steels
- New Ph Stainless Combines High Strength, Fracture Toughness and Corrosion Resistance
- New Requirements for Ferrous-Base Aerospace Alloys
- New Stainless Steel for Instruments Combines High Strength and Toughness
- Passivating and Electropolishing Stainless Steel Parts
- Selecting New Stainless Steels for Unique Applications
- Selecting Stainless Steels for Valves
- Selection of High Strength Stainless Steels for Aerospace, Military and Other Critical Applications
- Specialty Alloys And Titanium Shapes To Consider For Latest Medical Materials Requirements
- Steels for Strength and Machinability
- Unique Properties Required of Alloys for the Medical and Dental Products Industry

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