EnduraMet™ 316LN Stainless

Identification

UNS Number

- S31653

DIN Number

- 1.4429

Type Analysis

Carbon (Maximum)	0.03 %	**Manganese (Maximum)**	2.00 %
Phosphorus (Maximum)	0.045 %	**Sulfur (Maximum)**	0.030 %
Silicon (Maximum)	1.00 %	**Chromium**	16.00 to 18.00 %
Nickel	10.00 to 14.00 %	**Molybdenum**	2.00 to 3.00 %
Nitrogen	0.10 to 0.16 %	**Iron**	Balance

General Information

Description

EnduraMet™ 316LN stainless is a nitrogen-strengthened version of Type 316L stainless. By means of solid solution strengthening, the nitrogen provides significantly higher yield and tensile strength as annealed than Type 316L without adversely affecting ductility, corrosion resistance or non-magnetic properties. In the hot rolled unannealed condition, yield strengths of 75 ksi (518 MPa)or higher can be achieved for bar diameters up to 1.375in (34.925 mm).

Applications

Rebar has been a primary application for EnduraMet 316LN 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 pilings. Because of its low magnetic permeability, EnduraMet 316LN has been used in concrete rebar applications in close proximity to sensitive electronic devices and magnetic resonance medical equipment. The higher strength capability, 75 ksi (518 MPa) minimum yield strength, of EnduraMet 316LN is an added economical advantage.

Scaling

EnduraMet 316LN stainless has excellent scale resistance up to 1600°F (871°C).

Corrosion Resistance

In general, the corrosion resistance of EnduraMet 316LN stainless is similar to Type 316L. The higher nitrogen content enhances chloride pitting and crevice corrosion resistance.

EnduraMet 316LN withstands not only ordinary rusting but also most of the organic and inorganic chemicals. It resists corrosion by nitric acid and sulfurous acid compounds.

EnduraMet 316LN has good intergranular corrosion in the as-annealed and as-welded 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, 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 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)	Good
Sea Water	Moderate	Sour Oil/Gas	Moderate
Humidity	Excellent		

Properties	
Physical Properties	
Specific Gravity	
Annealed	7.91
As Rolled	7.90
Density	
Annealed	0.2860 lb/in³
As Rolled	0.2850 lb/in³
Mean Coefficient of Thermal Expansion	
77.00 °F, 122.0 °F, Annealed	9.32 x 10^{-6} in/in/°F
77.00 °F, 212.0 °F, Annealed	9.23 x 10^{-6} in/in/°F
77.00 °F, 302.0 °F, Annealed	9.29 x 10^{-6} in/in/°F
77.00 °F, 392.0 °F, Annealed	9.46 x 10^{-6} in/in/°F
77.00 °F, 482.0 °F, Annealed	9.52 x 10^{-6} in/in/°F
77.00 °F, 572.0 °F, Annealed	9.69 x 10^{-6} in/in/°F
77.00 °F, 662.0 °F, Annealed	9.78 x 10^{-6} in/in/°F
77.00 °F, 752.0 °F, Annealed	9.87 x 10^{-6} in/in/°F
77.00 °F, 842.0 °F, Annealed	9.96 x 10^{-6} in/in/°F
77.00 °F, 932.0 °F, Annealed	10.0 x 10^{-6} in/in/°F
77.00 °F, 1012 °F, Annealed	10.1 x 10^{-6} in/in/°F
77.00 °F, 1112 °F, Annealed	10.2 x 10^{-6} in/in/°F
77.00 °F, 1202 °F, Annealed	10.3 x 10^{-6} in/in/°F
77.00 °F, 1292 °F, Annealed	10.4 x 10^{-6} in/in/°F
77.00 °F, 122.0 °F, Hot Rolled	7.90 x 10^{-6} in/in/°F
77.00 °F, 212.0 °F, Hot Rolled	8.76 x 10^{-6} in/in/°F
77.00 °F, 302.0 °F, Hot Rolled	9.11 x 10^{-6} in/in/°F
77.00 °F, 392.0 °F, Hot Rolled	9.32 x 10^{-6} in/in/°F
77.00 °F, 482.0 °F, Hot Rolled	9.48 x 10^{-6} in/in/°F
77.00 °F, 572.0 °F, Hot Rolled	9.62 x 10^{-6} in/in/°F
77.00 °F, 662.0 °F, Hot Rolled	9.72 x 10^{-6} in/in/°F
77.00 °F, 752.0 °F, Hot Rolled	9.84 x 10^{-6} in/in/°F
77.00 °F, 842.0 °F, Hot Rolled	9.96 x 10^{-6} in/in/°F
77.00 °F, 932.0 °F, Hot Rolled	10.1 x 10^{-6} in/in/°F
77.00 °F, 1012 °F, Hot Rolled	10.2 x 10^{-6} in/in/°F
77.00 °F, 1112 °F, Hot Rolled	10.3 x 10^{-6} in/in/°F
77.00 °F, 1202 °F, Hot Rolled	10.4 x 10^{-6} in/in/°F
77.00 °F, 1292 °F, Hot Rolled	10.5 x 10^{-6} in/in/°F

Mean Coefficient of Thermal Expansion – EnduraMet 316LN 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	7.90	14.22	9.32	16.77
212	100	8.76	15.76	9.23	16.62
302	150	9.11	16.39	9.29	16.73
392	200	9.32	16.78	9.46	17.03
482	250	9.48	17.06	9.52	17.24
572	300	9.62	17.31	9.69	17.44
662	350	9.72	17.50	9.78	17.61
752	400	9.84	17.72	9.87	17.77
842	450	9.96	17.92	9.96	17.93
932	500	10.06	18.11	10.04	18.07
1012	550	10.15	18.27	10.11	18.19
1112	600	10.31	18.55	10.19	18.34
1202	650	10.42	18.75	10.30	18.54
1292	700	10.53	18.96	10.38	18.68

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.

Typical Mechanical Properties

CVN Impact Data at Various Test Temperatures – EnduraMet 316LN 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	94	128
Annealed	70	21	100	136
As-Rolled	32	0	109	148
Annealed	32	0	90	122
As-Rolled	-100	-73	104	141
Annealed	-100	-73	83	113

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 – EnduraMet 316LN 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	110	756	150	1032	61.5	80.5
Annealed	-100	-73	64	444	130	894	81.0	84.0
As-Rolled	70	21	88	607	118	812	48.4	79.7
Annealed	70	21	46	318	95	657	67.6	81.3
As-Rolled	400	204	63	436	91	629	41.4	74.8
Annealed	400	204	28	195	74	513	50.6	80.9

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 – EnduraMet 316LN 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	2.8×10^7 NF	50	276	1.4×10^7 NF
60	414	1.3×10^7 NF	43	297	1.5×10^7 NF
65	449	2.8×10^7 NF	45	311	1.4×10^7 NF
67.5	466	2.1×10^7 NF	50	345	7×10^3 (bent)
70	483	3.7×10^6	60	466	2×10^3 (bent)

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: 67.5 ksi (446 MPa) hot rolled condition.
45 ksi (311 MPa) annealed condition.

Typical Room Temperature Hot Rolled Mechanical Properties – EnduraMet 316LN 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	93	642	115	794	27.5
0.75	19.1	6	84	580	113	780	29.0

Heat Treatment

Annealing

Heat to 1850/2050°F (1010/1121°C) and rapidly quench in water or air. Typical hardness is Rockwell B 90/95.

Hardening

Cannot be hardened by heat treatment.

Workability

Hot rolling and controlling the finishing temperature can strengthen EnduraMet 316LN bar. After hot rolling, bars are not annealed.

Hot Working

EnduraMet 316LN stainless hot works similar to Type 316L, except more power is required to produce the same reduction.

Heat uniformly to 2100/2300°F (1149/1260°C). Reheat as often as necessary. Cool forgings in air. For optimum corrosion resistance, forgings must be annealed.

Cold Working

EnduraMet 316LN stainless can be heavily cold worked without intermediate annealing. Because of its higher initial strength, more power is required than Type 316L. Cold working can significantly increase strength and hardness.

Machinability

The machinability of EnduraMet 316LN is similar to other nitrogen-strengthened stainless steels, like EnduraMet 18Cr-3Ni-12Mn. Slow to moderate speeds, moderate feeds and rigid tools should be considered. Chips lend to be tough and stringy. Chip curlers or breakers are helpful. Use a sulfurized cutting fluid, preferably of the chlorinated type.

Following are typical feeds and speeds for EnduraMet 316LN stainless.

Typical Machining Speeds and Feeds – EnduraMet 316LN 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	60	.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	1½	2
T15		45	.001	.001	.0015	.0015	.001	.0007	.0007
	C6	160	.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	1½	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	1½	2
T15, M42	45-55	.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

Weldability

EnduraMet 316LN stainless can be satisfactorily welded by the shielded and resistance welding processes. Oxyacetylene welding is not recommended, since carbon pickup in the weld may occur. Since austenitic welds do not harden on air cooling, the welds should have good toughness.

When a filler metal is required, consider using a welding consumable with a matching analysis to Type 316LN or AWS E/ER 209. Both should provide welds with strength approaching that of the base metal. If high weld strength is not necessary, then consider AWS E/ER 316L.

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

Other Information

Applicable Specifications

- ASTM A240
- ASTM A276
- ASTM A479
- ASTM A955
- BS 6744: 2001

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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