

POWDERRANGE 316L

Applicable specifications: ASTM F3184

Associated specifications: AMS5648, ASME SA479, ASTM A276, ASTM A479, QQ-S-763, MIL-S-862, AMS5653, ASTM A182, ASTM A314, DIN 1.4404, ISO 5832-1, SAE J405 (316L), UNS S31600/S31603

Type analysis

Single figures are nominal except where noted.

Iron	Balance	Chromium	16.0–18.0 %	Nickel	10.0–14.0 %
Molybdenum	2.00–3.00 %	Manganese	2.00 %	Silicon	1.00 %
Nitrogen	0.10 %	Oxygen	0.10 %	Phosphorus	0.045 %
Carbon	0.030 %	Sulfur	0.030 %		

Description

PowderRange 316L is a low carbon, non-magnetic, austenitic stainless steel that exhibits moderate to good strength, good fracture toughness, and has generally good corrosion resistance, especially intergranular corrosion. It has excellent weldability in laser and electron-beam additive manufacturing processes and can be processed in either argon or nitrogen shielding gas.

PowderRange 316L cannot be strengthened through post processing heat treatments but can be solution annealed to improve corrosion resistance. Solution annealing is application-specific, but is generally not necessary for most situations. Post processing can include traditional machining, abrasive flow machining, shot-peening, grinding, polishing, chemical milling/etching, and other methods.

Key Properties:

- High impact toughness and good ductility
- Moderate strength and creep resistance
- Good corrosion resistance

Markets:

- Aerospace
- Automotive
- Medical

Applications:

- Instrumentation devices
- Valves and fittings
- Pumps and impellers
- Manifolds
- Medical implants
- Tooling

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Powder properties

PART NUMBER	PowderRange 316L F	PowderRange 316L E
APPLICATION	L-PBF ¹	EB-PBF or DED ¹
MAXIMUM PARTICLE SIZE	Max 1 wt% > 53 μm^2	Max 10 wt% > 106 μm^2
MINIMUM PARTICLE SIZE	Max 10 vol% < 15 μm^3	Max 10 wt% < 45 μm^2
LSD PERCENTILE	D10, D50, D90 ³ , reported	
ATOMIZATION	Nitrogen Gas Atomized	
APPARENT DENSITY (G/CM³)	Measured according to ASTM B212 ⁴ and reported	
HALL FLOW (S/50G)	Measured according to ASTM B213 ⁵ and reported	

¹ ASTM/ISO 52900: Laser — Powder Bed Fusion (L-PBF), Electron-Beam Powder Bed Fusion (EB-PBF), Directed Energy Deposition (DED)

² ASTM B214 Standard Test Method for Sieve Analysis for Metal Powders

³ ASTM B822 Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering

⁴ ASTM B212 Standard Test Method for Apparent Density of Free-Flowing Metal Powders Using the Hall Flowmeter Funnel

⁵ ASTM B213 Standard Test Method for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel

Testing of powder will fulfill certification requirements to Nadcap Materials Testing and ISO/IEC 17025 Chemical, per relevant ASTM procedures

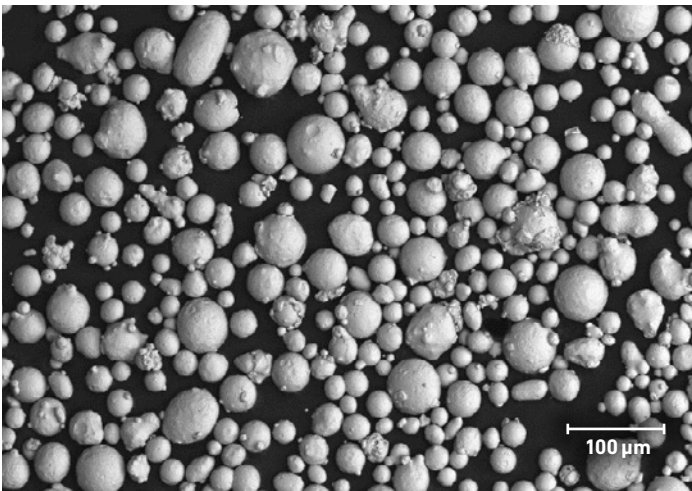


FIGURE 1—SEM IMAGE OF TYPICAL POWDERRANGE 316L POWDER

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Additive manufacturing process guidance

ASTM F3184: ADDITIVE MANUFACTURING STAINLESS STEEL ALLOY (UNS 31603) WITH POWDER BED FUSION
**Laser-Powder Bed Fusion
(L-PBF)
As-built**

PowderRange 316L for additive manufacturing is compatible with all commercially available L-PBF equipment.

To achieve mean, as-built density >99.9%, 20 to 60 µm layer thicknesses and Specific Energy $\geq 56 \text{ J/mm}^3$ is recommended.

Stress relief

Stress relief may be performed per AMS2759, i.e. 700°F (371°C) for 1 hour, or substitute Solution Anneal per below for improved corrosion resistance.

**Solution Anneal
(Sol)**

In many applications, PowderRange 316L may be used in the as-built condition or following a standard stress relief treatment on the build plate to reduce residual stress.

For greater corrosion resistance, a Solution Anneal treatment can be applied: 1900°F (1038°C) for 1 hour for every three inches of thickness, followed by a water quench.

Schedules better tailored to the AM process thermal history may be available. Please contact Carpenter Technology for information.

**Hot Isostatic Press
(HIP/Sol)**

We recommend HIP as standard practice for microstructure homogenization; removal of residual spatter-induced voids, trapped gas porosity in powder and keyhole porosities; as well as to heal any shrinkage-induced micro-cracks in the material.

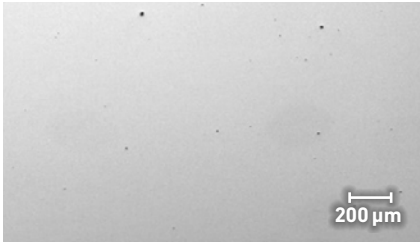
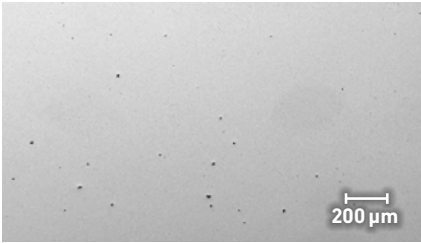


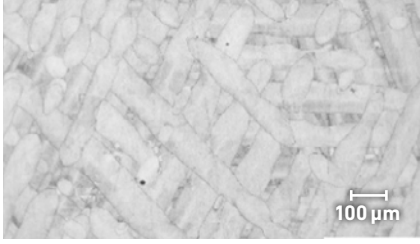

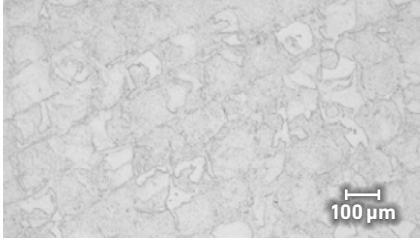



To achieve up to full density (100%): Process components per ASTM F3184 section 13: minimum pressure of 14.5 ksi (100 MPa) at a temperature of approximately 2087°F (1141°C) for 240 minutes in argon.

Follow with Solution Anneal treatment as described above to reduce sensitization and improve corrosion response.

Machinability

Stainless Type 316L machines with chip characteristics that are tough and stringy. The use of chip curlers and breakers is advised. To minimize work hardening, a strong positive heavy feed should be maintained; thus, the machines should have a minimum of backlash and the tool and workpiece must be rigidly supported. If possible, avoid very small cuts and feeds.

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TYPICAL MICROSTRUCTURES			
CONDITION	TRANSVERSE (X-Y PLANE)	LONGITUDINAL (Y-Z PLANE)	NOTES
As-built			Mean densities greater than 99.9%
HIP/Sol			Up to 100% density
As-built, etched⁶			Clean weld tracks visible Minimal spatter porosity
Sol, etched⁶			Minimal grain growth Weld tracks may still be visible Grain size ASTM 4-5 ⁷
HIP/Sol, etched⁶			Homogenized microstructure Grain size ASTM 4-5 ⁷

⁶ Etched with Ralph's etchant

⁷ ASTM E112-13 Standard Test Method for Determining Average Grain Size

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Typical achievable mechanical properties

ROOM TEMPERATURE MECHANICAL PROPERTIES ⁸										
FORM	ORIENTATION	0.2% YIELD STRENGTH $\sigma_{0.2\%}$		ULTIMATE TENSILE STRENGTH σ_{UTS}		ELONGATION IN 4D	REDUCTION OF AREA	IMPACT ENERGY		HARDNESS
		ksi	MPa	ksi	MPa	%	%	FT-LBS	J	HRB
As-built	X and Y	80	552	102	703	57	77	111	150	93
	Z	71	490	95	655	67	81	122	165	94
Sol	X and Y	55	379	95	655	68	73	92	125	89
	Z	52	358	89	614	78	77	117	159	88
HIP/Sol	X and Y	41	283	93	641	70	63	58	79	84
	Z	41	283	88	607	80	71	66	89	80
ASTM Spec. ⁹	X and Y	30	205	75	515	30	40	—	—	—
	Z	30	205	75	515	30	40	—	—	—

⁸ Average of a minimum of 5 samples taken from across the extents of a build plate in each orientation and for each heat treatment. Testing performed in accordance with ASTM E8/E8M-16a (tensile), ASTM E23-18 (impact energy) and ASTM E18-19 (hardness). Additional data may be available through a wide range of consortia and other collaborations. Please contact Carpenter Additive for additional information.

⁹ ASTM F3184-16 Condition "A—Stress Relieved" Minimum Tensile Requirements

Corrosion resistance

IMPORTANT NOTE:

The following 4-level rating scale (Excellent, Good, Moderate, Restricted) is intended for comparative purposes only and is derived from experiences with wrought product. Additive manufactured material may perform differently; corrosion testing is recommended. Factors that 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
Sea Water	Moderate	Salt Spray (NaCl)	Good
Humidity	Excellent	Sour Oil/Gas	Moderate
Sodium Hydroxide	Moderate		

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Similar materials

COMPANY	ALTERNATIVE TITLE
Other Generic Names	1.4404, 316L
3D Systems	LaserForm 316L
GE (Concept Laser)	316L
EOS	316L
DMG Mori (Realizer)	—
Renishaw	SS 316L-0407
SLM Solutions	1.4404 (316L)

**For additional information, please
contact your nearest sales office:**

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The mechanical and physical properties of any additively-manufactured material are strongly dependent on the processing conditions used to produce the final part. Significantly differing properties can be obtained by utilizing different equipment, different process parameters, different build rates and different geometries. The properties listed are intended as a guide only and should not be used as design data.

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