						13 Al
22 Ti	24 Cr	26 Fe	27 Co	28 Ni	29 Cu	

L-PBF Stainless Steel 316L

Parameters for Colibrium Additive's M2 Series 5

Stainless Steel 316L

316L is a chromium-nickel-molybdenum austenitic stainless steel having a higher corrosion resistance compared to the most common stainless steel 304 without any significant disadvantages in costs. By the addition of molybdenum this steel is particularly suitable for components within harsh chemical environments containing chlorides and other halides. Typical applications can be found across a wide range of industries like plant engineering, oil & gas industry, automotive, medical technology, and jewelry and components for molds. 316L is easily weldable and offers excellent ductility and high creep strength at elevated temperatures.

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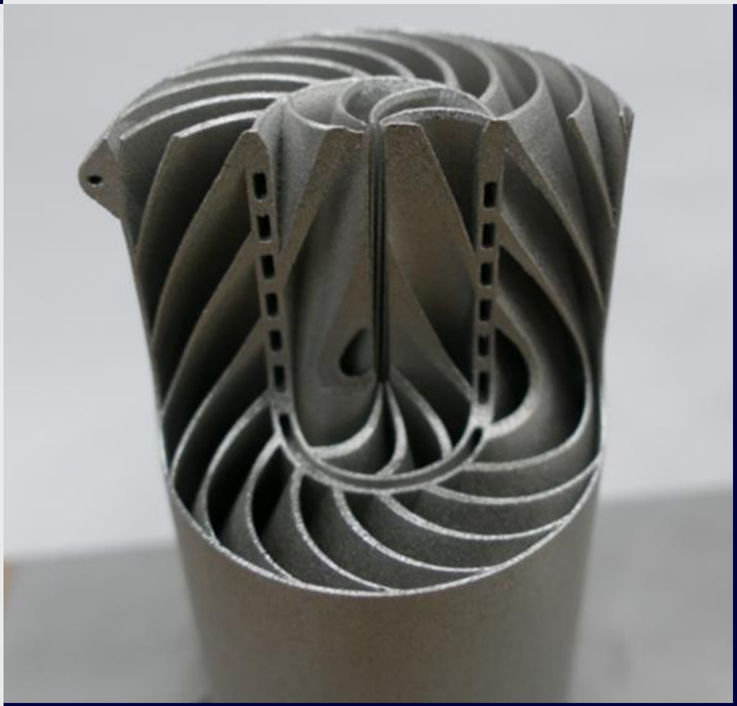
M2 Series 5 Stainless Steel 316L

The 316L parameters for the Colibrium Additive M2 Series 5 are developed leveraging the performance of the previous M2. The balanced parameter delivers good surface quality while maintaining a very good density, mechanical strength and productivity. For highest all-around surface quality, particularly within overhang downskin and upskin regions, the surface parameter has been developed.

All parameters succeed the minimum tensile properties specified in ASTM F3184 for additive manufactured parts in the stress relieved state.



M2 Series 5 Stainless Steel 316L

Machine Configuration

M2 Series 5

Single- or dual-laser architecture

Nitrogen gas

Powder Chemistry

316L powder chemical composition according to ASTM F3184 UNS S31603 / ASTM A276

Particle size: 15-45 µm

Thermal States

As-Built (AB)

Stress Relief according to AMS2759/11A (SR)

899 °C for 1 hour in argon; cooling in air

Solution Annealed according to AMS2659/4D (SOLN1)

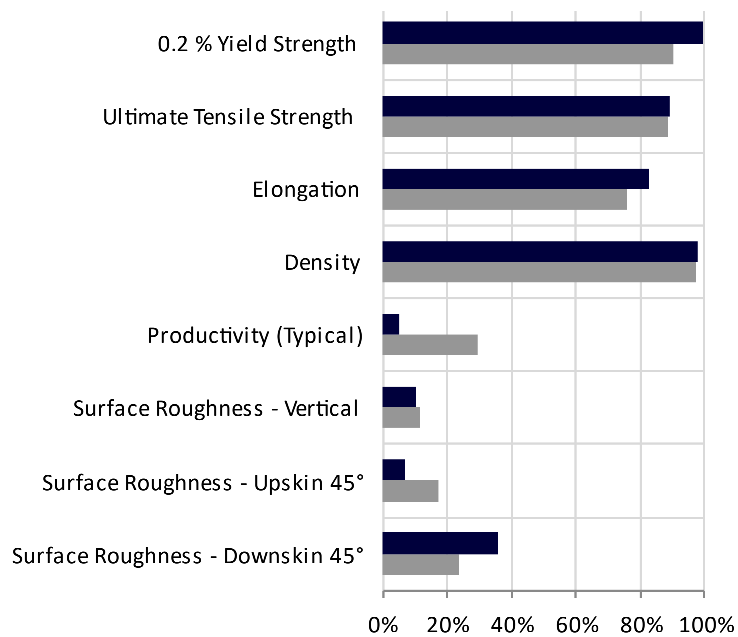
1066 °C for 1 hour in argon, cooling in air

Solution Annealed (SOLN2)

1100 °C for 4 hours in argon; water quench

Parameter Availability and Thermal State Comparison

- Surface Parameter 293 SR
  400 W, 25 µm layer thickness, rubber recoater
- Balanced Parameter 360 / 365 SR
  400 W, 50 µm layer thickness, rubber /steel recoater



Bar plot is generated by normalizing typical material data (containing both horizontal and vertical data) against a range defined for each material family. For 316L, the ranges are as follows: 0.2%YS: 0-600 MPa UTS: 0-750 MPa, Elongation: 0-60%, Density: 99-100%, Productivity: 5-60 cm³/h, Surface Quality (all): 3-40 µm. 0% in the bar plot indicates the lower range value, 100% indicates the upper range value

Surface Parameter 293 - 400 W / 25 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	9.3
Theoretical melting rate bulk per laser[2]	7.2

[1] Using standard Factory Acceptance Test layout and 2 lasers
[2] Calculated (layer thickness × scan velocity × hatch distance)

Tensile Performance at Room Temperature

Thermal State	Modulus of Elasticity (GPa)		0.2% Yield Strength (MPa)		Ultimate Tensile Strength (MPa)	
	H	V	H	V	H	V
As-Built	208	172	645	550	740	600

Thermal State	Elongation (%)	
	H	V
As-Built	34.5	65.0

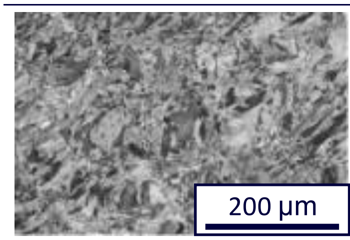
	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	6	5	5
Downskin	17	7	6

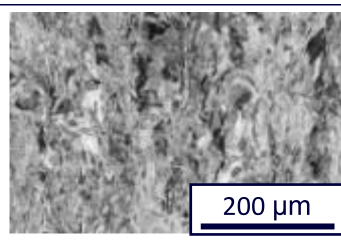
Surface Roughness, Ra (µm)	
H	9
V	7

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	220

Microstructure

As-Built	
H	V





Scanning electron microscope images in As-Built condition as defined previously

Balanced Parameter 360 / 365 - 400 W / 50 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	21.1
Theoretical melting rate bulk per laser[2]	17.8

[1] Using standard Factory Acceptance Test layout and 2 lasers
[2] Calculated (layer thickness × scan velocity × hatch distance)

Tensile Performance at Room Temperature

Thermal State	Modulus of Elasticity (GPa)		0.2% Yield Strength (MPa)		Ultimate Tensile Strength (MPa)	
	H	V	H	V	H	V
As-Built	188	161	565	520	695	635
SR	197	197	405	385	650	600
SOLN1	200	198	370	360	650	600
SOLN2	190	182	250	245	600	575

Thermal State	Elongation (%)		Area Reduction (%)	
	H	V	H	V
As-Built	41.0	50.0	69	73
SR	48.0	59.5	67	72
SOLN1	49.5	61.0	65	72
SOLN2	59.5	66.5	64	69

Physical Properties at Room Temperature

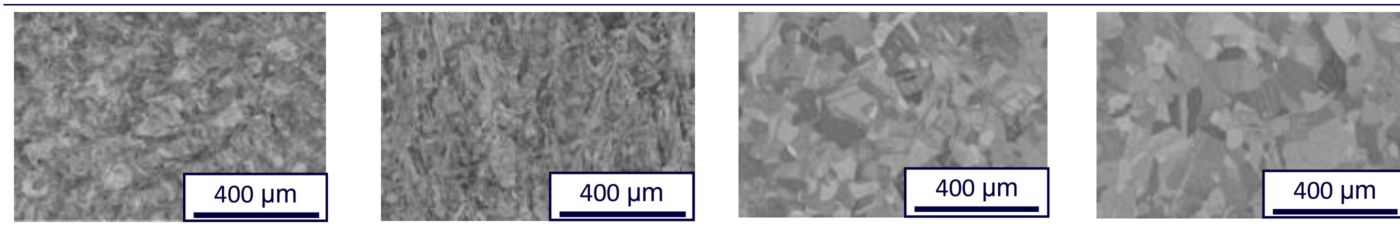
	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	10	7	6
Downskin	12	10	7

Surface Roughness, Ra (µm)	
H	9
V	8

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	220
SR	---	---	187
SOLN1	---	---	180
SOLN2	---	---	144

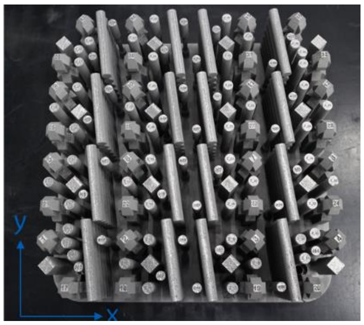
Microstructure

As-Built		SOLN1	
H	V	H	V



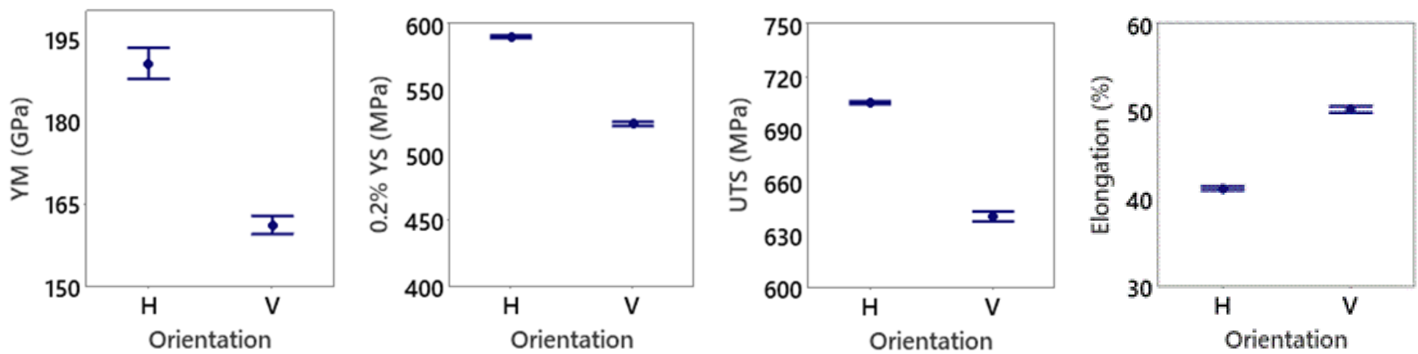
Scanning electron microscope images in As-Built and SOLN1 condition as defined previously

The platform stability build evaluates relative density, roughness and tensile properties across different positions and orientations. To illustrate the position dependency of the M2 Series 5, the samples were homogenously distributed across the platform on 16 different positions. Regarding surface quality all sides of the specimen, so all orientations with respect to gas flow and optical system, are included in the analysis. Data shown below are dependent on part & print layout as well as batch chemistry variations and thus might deviate from "typical values" given on previous pages.

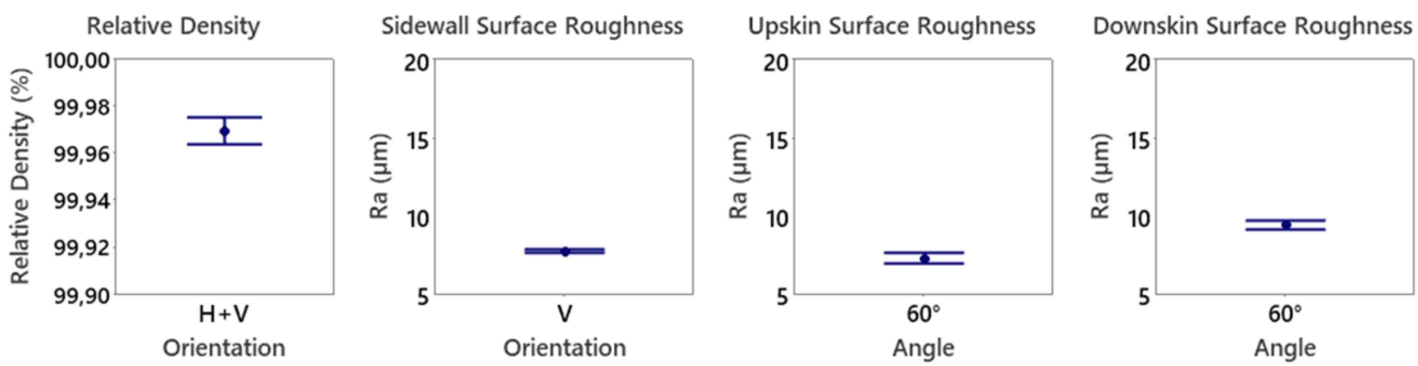


	Sample Size	Mean	Std. Dev.		Sample Size	Mean	Std. Dev.
YM (GPa) H/V - AB	16/16	190/161	6/4	Rel. Density (%)	32	99.97	0.02
0.2% YS (MPa) H/V - AB	16/16	590/523	3/3	Sidewall Roughness Ra (µm)	64	8	1
UTS (MPa) H/V - AB	16/16	705/640	2/6	60° Upskin Roughness Ra (µm)	64	8	1
Elongation (%) H/V - AB	16/16	41.1/50.1	0.5/0.7	60° Downskin Roughness Ra (µm)	64	8	1

Results Platform Stability: Mechanical properties in AB condition



Results Platform Stability: Relative Density and Surface Quality



Data Sheet Nomenclature and Notation

H: Horizontal, perpendicular to build direction.
V: Vertical, parallel to build direction.
Other angles are measured from horizontal.

Roughness measurements have been performed according to DIN EN ISO 4287 and DIN EN ISO 4288. In general analysis of the surface quality is strongly dependent on the methodology used and therefore deviations might be observed depending on methodology used. Vertical and horizontal sidewalls have been characterized using a tactile system, overhangs using an optical system.

Tensile evaluations were performed according to ASTM E8 or E21, depending on test temperature.

Minimum features have been characterized using a coordinate measuring machine (CMM) and an optical microscope.

All figures and data contained herein are approximate and/or typical only and are dependent on several factors including but not limited to process and machine parameters. The information provided on this material data sheet is illustrative only and cannot be considered binding.