COLIBRIUM ADDITIVE
a GE Aerospace company

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

L-PBF Nickel 718

Parameters for Colibrium Additive’s M2 Series 5

Nickel 718

Nickel chromium superalloys like Nickel 718 are often used in high-stress and high-temperature environments. The excellent high temperature strength and creep resistance derive from precipitation hardening of finely dispersed precipitates. Next to that Nickel 718 is a metal that is also highly resistant to the corrosive effects of hydrochloric acid and sulfuric acid. The favorable weldability of Nickel 718 makes this alloy suitable for additive manufacturing as well. Typical applications are high-quality components designed for thermally challenging environments such as rocket engines, gas-turbine hot sections, and heat exchangers.

M2 Series 5 Nickel 718

The Nickel 718 parameters for the Colibrium Additive M2 Series 5 are developed leveraging the performance of the previous M2 generations. The base parameters deliver good surface quality while maintaining a very good density and productivity. For highest all-around surface quality, the surface parameter has been developed. The hybrid parameter can significantly increase the productivity of parts having a high volume/surface ratio and still meeting highest surface quality requirements. Parameter 316 is optimized for steel recoater and highest productivity. All parameters succeed the minimum tensile properties specified in ASTM F3055 for additive manufactured parts in the heat treated state.

M2 Series 5 Nickel 718

Machine Configuration

M2 Series 5

Single- or dual-laser architecture

Nitrogen gas

Powder Chemistry

Nickel 718 powder chemical composition according to ASTM B637 UNS N07718

Particle size: 15 - 53 µm

For additional information on Nickel 718 powder, visit: www.advancedpowders.com

Thermal States

As-Built (AB)

Solution Annealed + Age (SOLN + AGE)

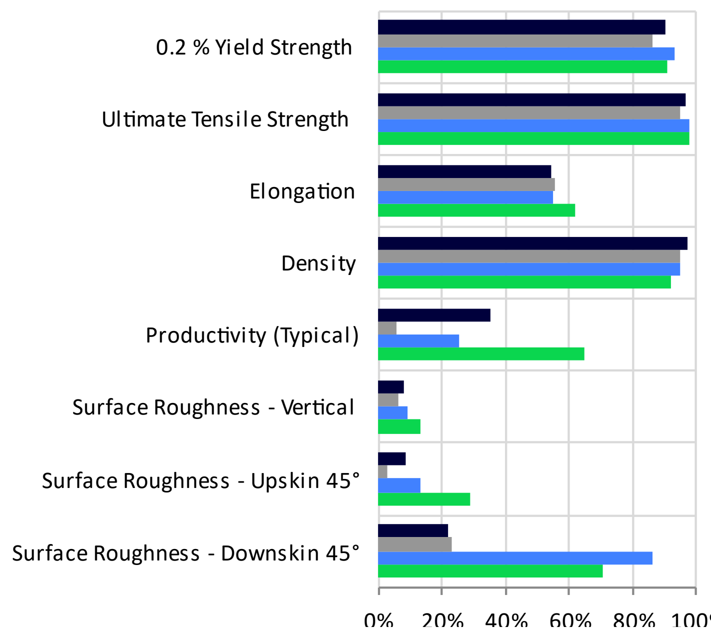
SOLN: 980 °C for 1 hour in argon; AGE: 720 °C for 8 hours furnace cooling down to 620 °C for 8 hours, cooling in air

Stress Relief + HIP + Solution +AGE (SR + HIP + SOLN + AGE)

SR: 950 °C for 2 hours in argon; HIP: 1160 °C for 4 hours, 100 MPa,
SOLN: 980 °C for 1 hour in argon; AGE: 720 °C for 8 hours furnace cooling down to 620 °C for 8 hours, cooling in air

Parameter Availability and Thermal State Comparison

- Balanced Parameter 285 SOLN + AGE
  400 W, 50µm layer thickness, rubber recoater
- Surface Parameter 286 SOLN + AGE
  400 W, 25µm layer thickness, rubber recoater
- Balanced Parameter 287 SOLN + AGE
  400 W, 50 µm layer thickness, steel recoater
- Productivity Parameter 316/401 SOLN + AGE
  400 W, 100 µm layer thickness,
  steel / rubber 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 Nickel 718-based alloys, the ranges are as follows: 0.2%YS: 0-1400 MPa UTS: 0-1500 MPa, Elongation: 0-30%, Density: 99-100% (as-built), Productivity: 5-60 cm³/h, Surface Quality (all): 5-55 µm. 0% in the bar plot indicates the lower range value, 100% indicates the upper range value

Balanced Parameter 285 - 400 W / 50 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	24.5
Theoretical melting rate bulk per laser[2]	21.6

[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	190	150	740	620	1060	970
SOLN+AGE	195	175	1305	1220	1495	1400

Thermal State	Elongation (%)	
	H	V
As-Built	29	33
SOLN+AGE	15	17.5

Physical Properties at Room Temperature

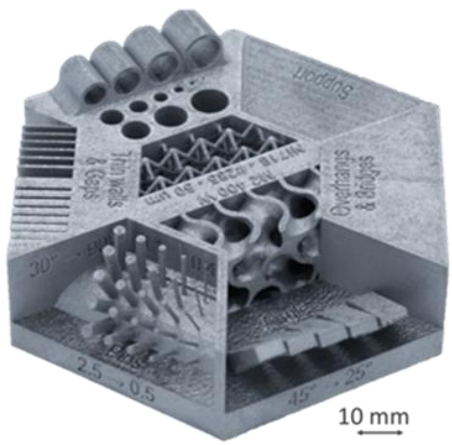
	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	8	6	5
Downskin	15	9	6

Surface Roughness, Ra (µm)	
H	18
V	8

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	282
SOLN+AGE	---	---	480

Minimum Feature Resolution

The minimum feature resolution part was designed to demonstrate parameter capability to produce specific features such as minimum wall thickness, minimum gap width, minimum pin diameter, minimum drill hole diameter (horizontal and vertical), minimum unsupported downskin angle, and maximum unsupported bridge length.



Feature	Result
Minimum Wall Thickness (mm)	0.39
Minimum Gap Width (mm)	0.07
Minimum Pin Diameter (mm)	0.35
Minimum Drill Hole Diameter, V (mm)	0.48
Minimum Drill Hole Diameter, H (mm)	0.41
Minimum Printable Angle (°)	35
Maximum Bridge Length (mm)	5

Surface Parameter 286 - 400 W / 25 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	10.2
Theoretical melting rate bulk per laser[2]	8.1

[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	170	135	810	675	1080	980
SOLN+AGE	183	173	1245	1165	1475	1365

Thermal State	Elongation (%)	
	H	V
As-Built	25.5	30
SOLN+AGE	15	18

Physical Properties at Room Temperature

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	5	4	4
Downskin	15	7	5

Surface Roughness, Ra (µm)	
H	8
V	7

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	302
SOLN+AGE	---	---	---

Surface Parameter 287 - 400 W / 50 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	19
Theoretical melting rate bulk per laser[2]	15.1

[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	185	180	755	705	1065	1040
SOLN+AGE	195	195	1315	1285	1480	1450
SR+HIP+SOLN+AGE	205	200	1100	1105	1355	1350

Thermal State	Elongation (%)		Area Reduction (%)	
	H	V	H	V
As-Built	25.5	30	---	---
SOLN+AGE	15	18	---	---
SR+HIP+SOLN+AGE	24.5	24	36.5	35.5

Physical Properties at Room Temperature

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	9	7	5
Downskin	43	12	7

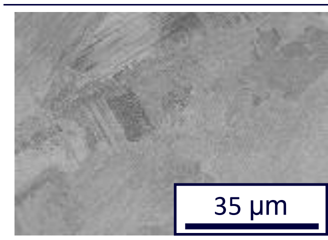
Surface Roughness, Ra (µm)	
H	7
V	7

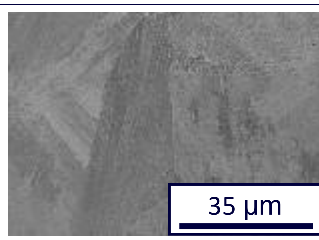
Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	289
SOLN+AGE	---	---	475

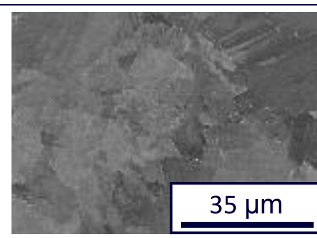
Microstructure

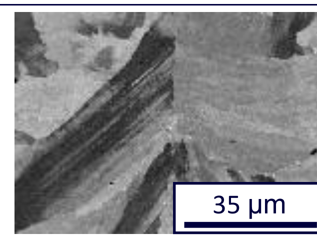
Parameter 287

As-Built		SOLN + AGE	
H	V	H	V









Scanning electron microscope images in As-Built and Solution + Aged condition as defined previously.

Productivity Parameter 316 / 401 - 400 W / 100 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	40.6
Theoretical melting rate bulk per laser[2]	32.4

[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	200	165	690	645	1035	1020
SOLN+AGE	201	195	1270	1265	1475	1455

Thermal State	Elongation (%)		Area Reduction (%)	
	H	V	H	V
As-Built	33.5	32.5	52.5	51.5
SOLN+AGE	18.5	18.5	31.5	34.5

Physical Properties at Room Temperature

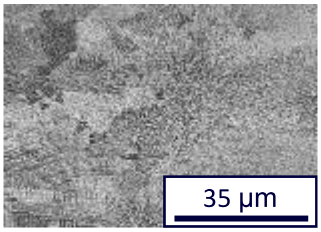
	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	18	15	10
Downskin	40	18	12

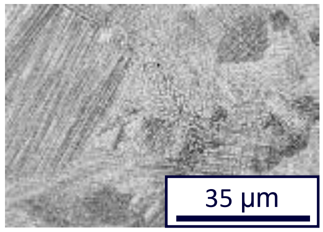
Surface Roughness, Ra (µm)	
H	9
V	7

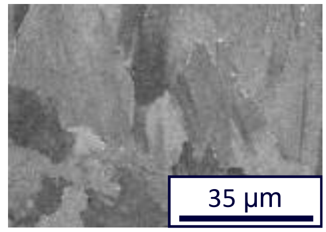
Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	289
SOLN+AGE	99.9	99.9	475

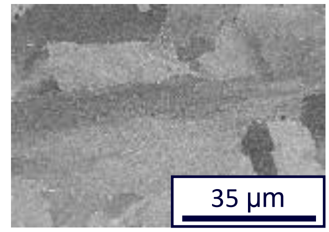
Microstructure

As-Built		SOLN + AGE	
H	V	H	V





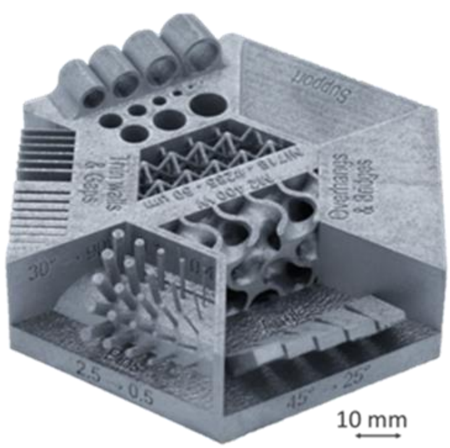




Scanning electron microscope images in As-Built and Solution + Aged condition as defined previously.

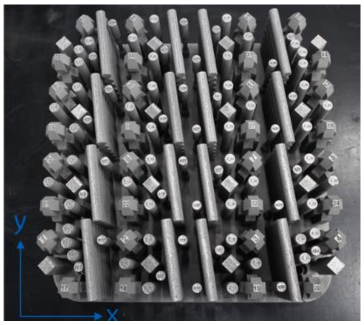
Minimum Feature Resolution

The minimum feature resolution part was designed to demonstrate parameter capability to produce specific features such as minimum wall thickness, minimum gap width, minimum pin diameter, minimum drill hole diameter (horizontal and vertical), minimum unsupported downskin angle, and maximum unsupported bridge length.



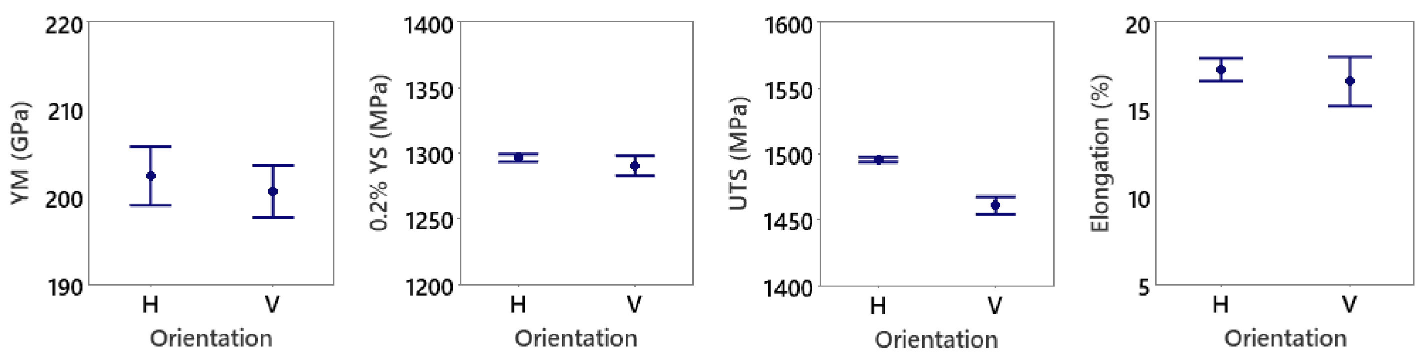
Feature	Result
Minimum Wall Thickness (mm)	0.31
Minimum Gap Width (mm)	0.07
Minimum Pin Diameter (mm)	0.34
Minimum Drill Hole Diameter, V (mm)	0.49
Minimum Drill Hole Diameter, H (mm)	0.77
Minimum Printable Angle (°)	25
Maximum Bridge Length (mm)	5

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.

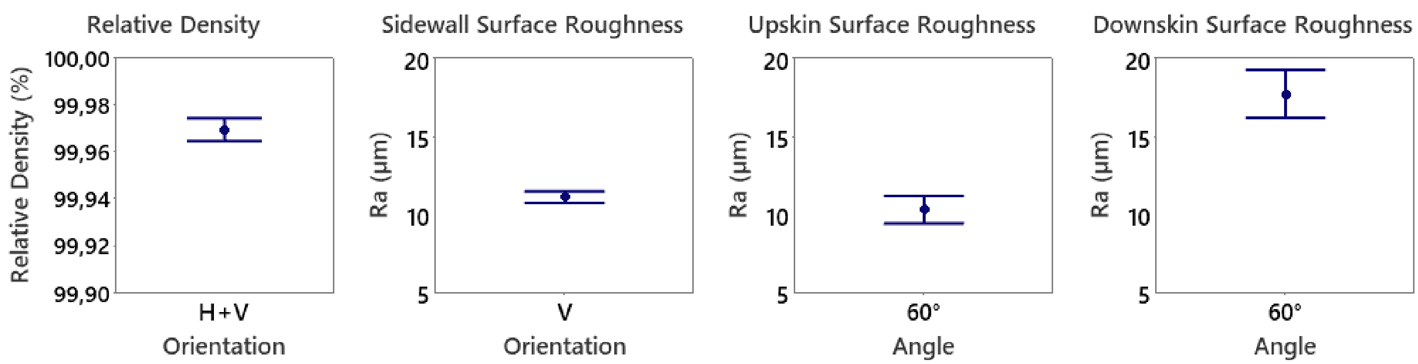


	Sample Size	Mean	Std. Dev.		Sample Size	Mean	Std. Dev.
YM (GPa) H/V - SR1	16/16	202/201	2/1	Rel. Density (%)	32	99.99	0.01
0.2% YS (MPa) H/V - SR1	16/16	1296/1291	1/4	Sidewall Roughness Ra (µm)	64	11.1	1.5
UTS (MPa) H/V - SR1	16/16	1496/1461	1/3	60° Upskin Roughness Ra (µm)	64	10.3	3.6
Elongation (%) H/V - SR1	16/16	17.3/16.6	1.2/2.6	60° Downskin Roughness Ra (µm)	64	17.7	6.2

Results Platform Stability: Mechanical properties in SR1 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.