COLIBRIUM ADDITIVE
a GE Aerospace company

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

L-PBF Stainless Steel 17-4PH

Parameters for Colibrium Additive's M2 Series 5

Stainless Steel 17-4 PH

17-4 precipitation hardening (PH) stainless steel is used in applications for surgical or orthopedic instruments as well as chemical, oil, and aerospace industries due to high corrosion resistance and high strength and fracture toughness at moderate temperatures. Additive allows for shape freedom of complex geometries not possible with traditional manufacturing processes, in which the high strength and hardness of 17-4 PH steel is difficult to machine. Often additive parts are post-processed with blasting or polishing while traditional machining is minimized with intelligent additive design.

M2 Series 5 Stainless Steel 17-4 PH

The 17-4PH parameters for the Colibrium Additive M2 Series 5 are developed leveraging the performance of the previous M2 generations. The balanced parameters deliver 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. The hybrid parameter can significantly increase the productivity of parts having a high volume/surface ratio and still meeting highest surface quality requirements. The highest build rate without significant debit of the mechanical properties can be achieved by the productivity parameter having a layer thickness of 80 µm.

M2 Series 5 17-4PH

Machine Configuration

M2 Series 5

Single- or dual-laser architecture

Argon gas

Powder Chemistry

Steel 17-4PH powder chemical composition according to ASTM A564 / A564M – 13 UNSS17400 / SUS 630.

Particle size: 15-45 µm

Thermal States

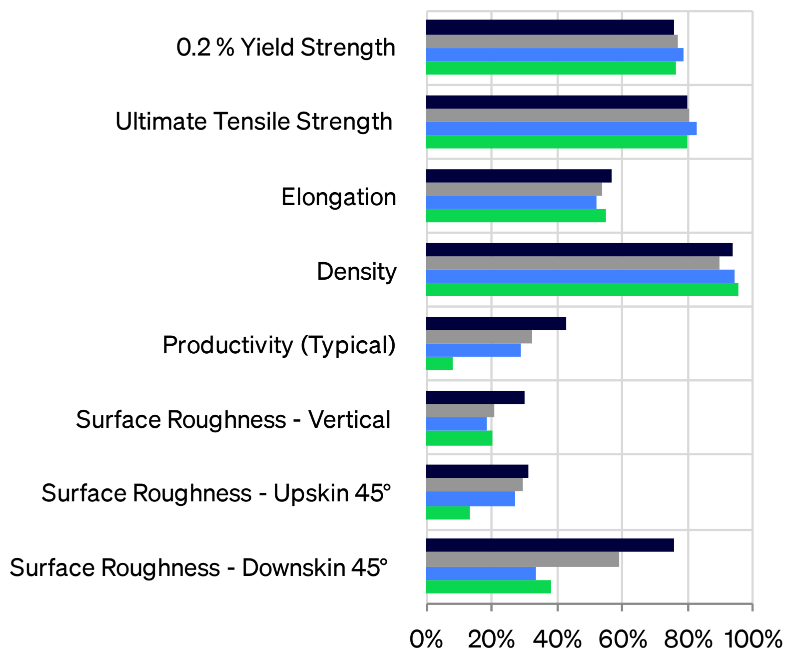
As-Built (AB)

Solution Annealed + Age (SOLN+AGE)

SOLN: 1040 °C for 1 hour, water quench; AGE: 480°C for 45 minutes, rapid cooling

Parameter Availability and Thermal State Comparison

- Productivity Parameter 302 SOLN+AGE
  400W, 80 µm layer thickness, rubber recoater
- Balanced Parameter 303 SOLN+AGE
  400W, 50 µm layer thickness, rubber recoater
- Balanced Parameter 404 SOLN+AGE
  400W, 50 µm layer thickness, steel recoater
- Surface Parameter 304 SOLN+AGE
  400 W, 25 µm layer thickness, 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 this Steel, the ranges are as follows: 0.2%YS: 0-1700 MPa UTS: 0-1800 MPa, Elongation: 0-20%, Density: 99-100% (As-Built), Productivity: 5-60 cm³/h, Surface Quality (all): 5-40 µm. 0% in the Bar plot indicates the lower range value, 100% indicates the upper range value.

Balanced Parameter 303 - 400 W / 50 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	22.7
Theoretical melting rate bulk per laser[2]	18.7

[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	189	183	895	855	1000	915
SOLN+AGE	201	199	1300	1310	1440	1440

Thermal State	Elongation (%)	
	H	V
As-Built	18.0	15.0
SOLN+AGE	11.0	10.0

Physical Properties at Room Temperature

Parameter 303

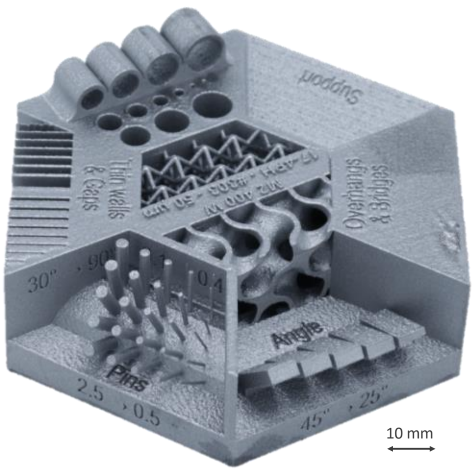
	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	12	9	6
Downskin	24	13	7

Surface Roughness, Ra (µm)	
H	13
V	9

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	288
SOLN+AGE	---	---	452

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)	0.15
Minimum Gap Width (mm)	0.13
Minimum Pin Diameter (mm)	0.19
Minimum Drill Hole Diameter, V (mm)	0.49
Minimum Drill Hole Diameter, H (mm)	0.80
Minimum Printable Angle (°)	30
Maximum Bridge Length (mm)	4

Balanced Parameter 404 - 400 W / 50 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	20.9
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	172	174	670	700	1115	1115
SOLN+AGE	191	193	1330	1330	1490	1490

Thermal State	Elongation (%)		Area Reduction (%)	
	H	V	H	V
As Built	16.0	16.0	66	67
SOLN+AGE	10.5	9.5	39	29

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	11	8	6
Downskin	14	10	7

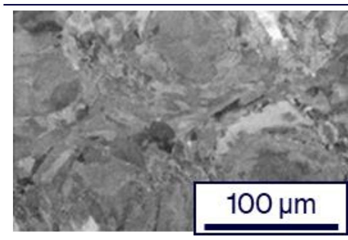
Surface Roughness, Ra (µm)	
H	11
V	8

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	354
SOLN+AGE	---	---	467

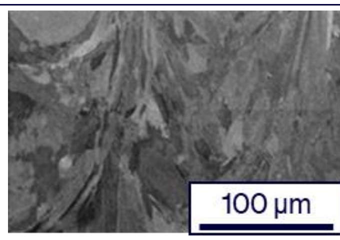
Microstructure

As-Built

H

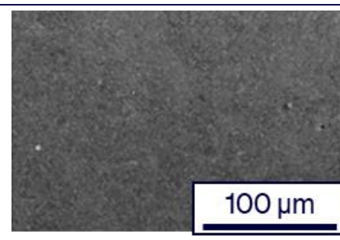


V

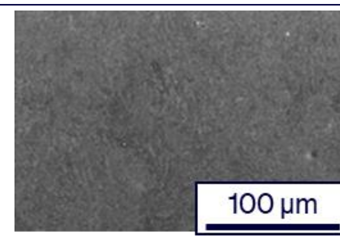


SOLN+AGE

H



V



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

Surface Parameter 304 - 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]	9.0

[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	175	161	780	765	855	805
SOLN+AGE	192	194	1280	1315	1420	1450

Thermal State	Elongation (%)	
	H	V
As Built	22.0	22.0
SOLN+AGE	12.5	8.0

Physical Properties at Room Temperature

	Overhang Surface Roughness, Ra (μm)		
	45°	60°	75°
Upskin	6	5	5
Downskin	16	6	5

Surface Roughness, Ra (μm)	
H	11
V	8

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	275

Productivity Parameter 302 - 400 W / 80 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	28.4
Theoretical melting rate bulk per laser[2]	23.5

[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	186	175	855	855	1010	985
SOLN+AGE	196	200	1285	1290	1430	1430

Thermal State	Elongation (%)	
	H	V
As Built	16.0	15.5
SOLN+AGE	11.5	11.0

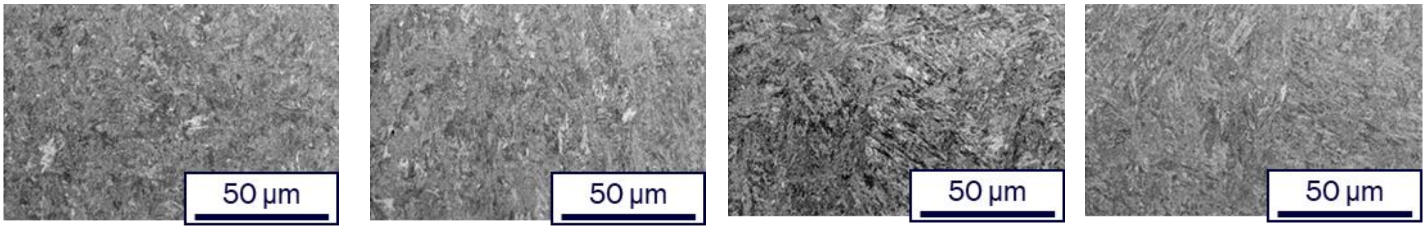
Physical Properties at Room Temperature

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	13	10	8
Downskin	31	21	11

Surface Roughness, Ra (µm)	
H	13
V	13

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	323
SOLN+AGE	---	---	451

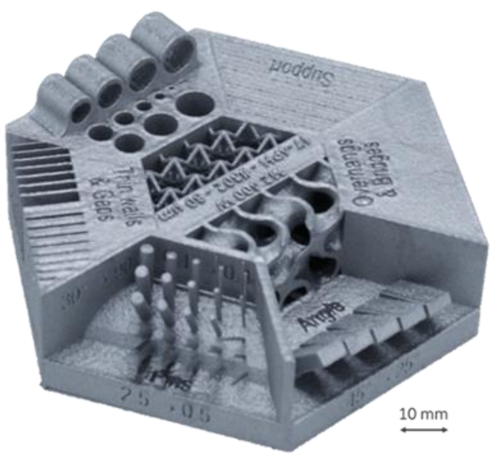
As-Built		SOLN+AGE	
H	V	H	V



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

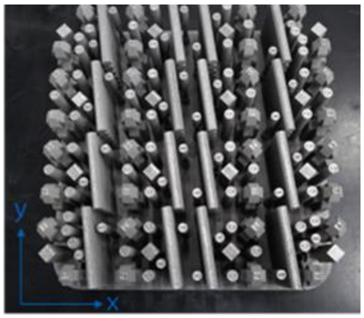
Minimum Feature Resolution

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.

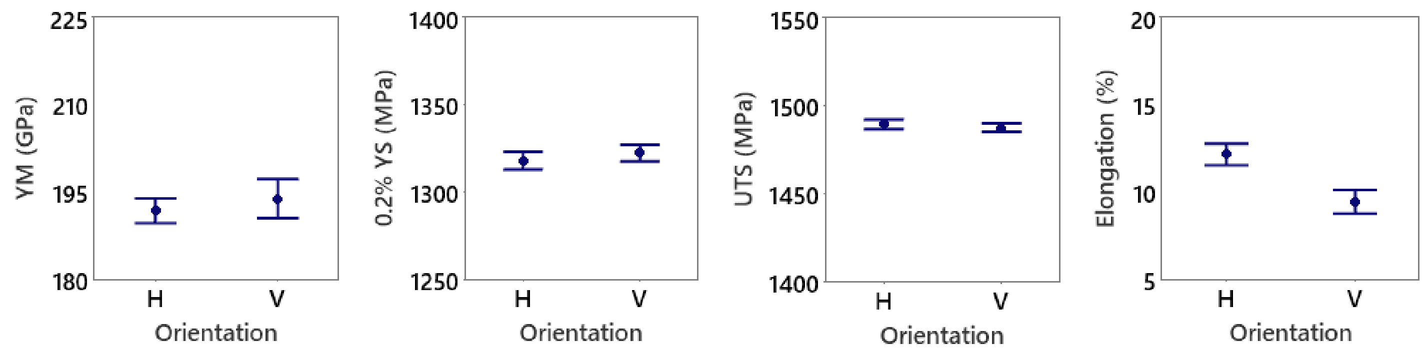


Feature	Result
Minimum Wall Thickness (mm)	0.26
Minimum Gap Width (mm)	0.37
Minimum Pin Diameter (mm)	0.32
Minimum Drill Hole Diameter, V (mm)	0.43
Minimum Drill Hole Diameter, H (mm)	0.75
Minimum Printable Angle (°)	25
Maximum Bridge Length (mm)	5

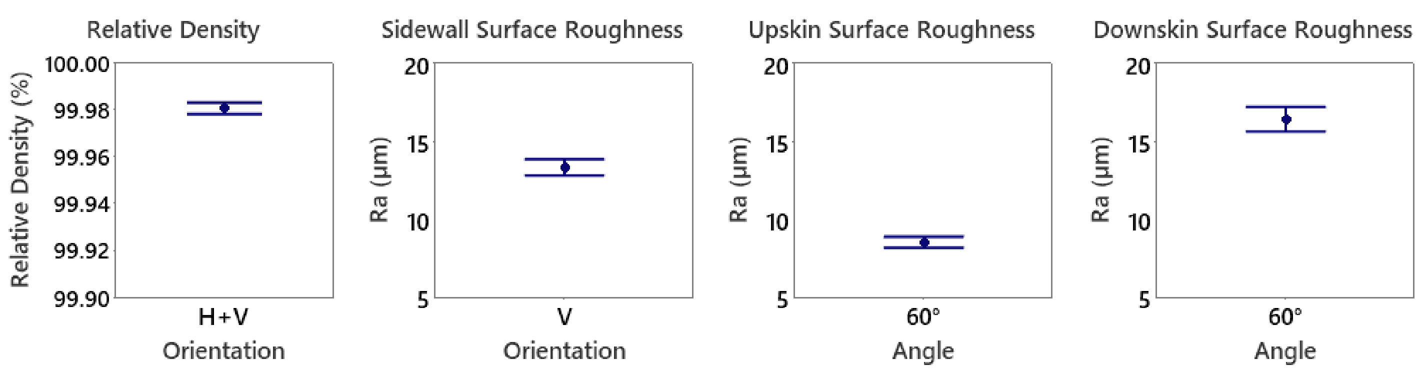
The platform stability build evaluates relative density, roughness and tensile properties across different positions and orientations. To illustrate the position dependency of the M2 Series 5, the samples were homogenously distributed across the platform on 16 different positions. Regarding surface quality 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 – SOLN+AGE	16/16	192/194	4/6	Rel. Density (%)	32	99.98	0.01
	0.2% YS (MPa) H/V – SOLN+AGE	16/16	1318/1322	10/9	Sidewall Roughness Ra (µm)	64	13	2
	UTS (MPa) H/V – SOLN+AGE	16/16	1489/1488	5/4	60° Upskin Roughness Ra (µm)	64	9	1
	Elongation (%) H/V – SOLN+AGE	16/16	12.2/9.4	1.2/1.3	60° Downskin Roughness Ra (µm)	64	16	3

Results Platform Stability: Mechanical properties in SOLN+AGE condition



Results Platform Stability: Relative Density and Surface Quality



Hybrid Parameter 192 rubber recoater - 400 W / 25/50 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	8.5 *(8-20)*[3]
Theoretical melting rate bulk per laser[2]	18.7

[1] Using standard Factory Acceptance Test layout and 2 lasers
[2] Calculated (layer thickness × scan velocity × hatch distance)
[3]The hybrid parameter build rate is strongly dependent on application design, in particular wall thickness. For this parameter, a larger increase in productivity (faster build rate) can be expected for parts having high volume/surface ratios.

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	181	168	765	775	935	935
SOLN+AGE	190	195	1290	1300	1430	1435

Thermal State	Elongation (%)	
	H	V
As Built	18.0	18.5
SOLN+AGE	13.0	10.0

Physical Properties at Room Temperature

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	6	5	5
Downskin	20	6	5

Surface Roughness, Ra (µm)	
H	10
V	8

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	287

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.