COLIBRIUM ADDITIVE
a GE Aerospace company

13 Al

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

L-PBF rematitan® CL

Parameters for Colibrium Additive's M2 Series 5

rematitan® CL

Titanium alloy in ELI quality (Grade 23) according to DIN EN ISO 22674 type 4/ DIN EN ISO 9693/ DIN EN ISO 5832-3.

Due to its proven biocompatibility and its long history in the medical industry, it is an established material used for medical/ dental applications.

rematitan® CL is particularly suitable for the manufacture of fixed and removable prosthetic restorations, appliances, and metal-ceramic frameworks.

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M2 Series 5 rematitan® CL

The parameters for the Colibrium Additive M2 Series 5 are developed leveraging the performance of other Ti6Al4V Grade 23 parameters. The surface parameter is a 30 µm parameter that produces the best surface roughness, having less than 10 µm without bead blast or shot peening. The balanced parameter has a layer thickness of 60 µm and provides nearly double the productivity of the surface parameter, but still offers very good surface quality. Both parameters have outstanding tensile properties in stress relieved state and meet the DIN EN ISO 22674 type 4/ DIN EN ISO 9693/ DIN EN ISO 5832-3 requirements.

M2 Series 5 rematitan® CL

Machine Configuration

M2 Series 5

Single- or dual-laser architecture

Argon gas

Platform heating: 200°C

Powder Chemistry

Ti6Al4V Grade 23 powder chemical composition according to DIN EN ISO 5832-3.

Produced by Dentaurum distributed by Colibrium Additive.

Thermal States

As-Built (AB)

Stress Relief (SR1)

900°C for 1 hour in argon; furnace cooling

Stress Relief (SR2) – recommended for dental restoration, following the IFU

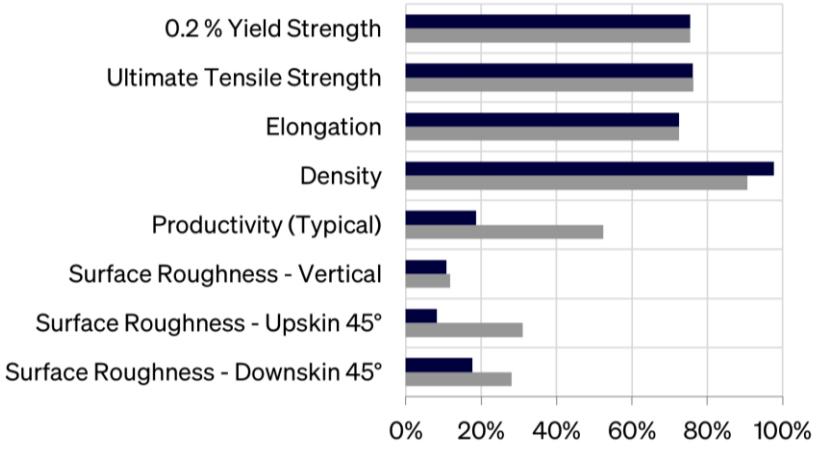
850°C for 1.5 hours in argon; furnace cooling

Stress Relief (SR3)

730°C for 2 hours in argon, furnace cooling

Parameter Availability and Thermal State Comparison

- Surface Parameter 305 SR2
  400 W, 30 µm layer thickness, rubber recoater
- Balanced Parameter 306 SR2
  400 W, 60 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 titanium-based alloys, the ranges are as follows: 0.2%YS: 0-1250 MPa UTS: 0-1350 MPa, Elongation: 0-20%, Density: 99-100%, Productivity: 5-70 cm^3/h, Surface Quality (all): 5-40 µm. 0% in the Bar plot indicates the lower range value, 100% indicates the upper range value.

Surface Parameter 305 - 400 W / 30 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	17.1
Theoretical melting rate bulk per laser[2]	16.8

[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	111	110	1145	1140	1295	1270
SR1	116	118	920	915	1010	1005
SR2	114	116	940	945	1030	1025

Thermal State	Elongation (%)	
	H	V
As-Built	8.0	8.5
SR1	15.5	15.0
SR2	14.5	14.5

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	8	8	7
Downskin	12	8	6

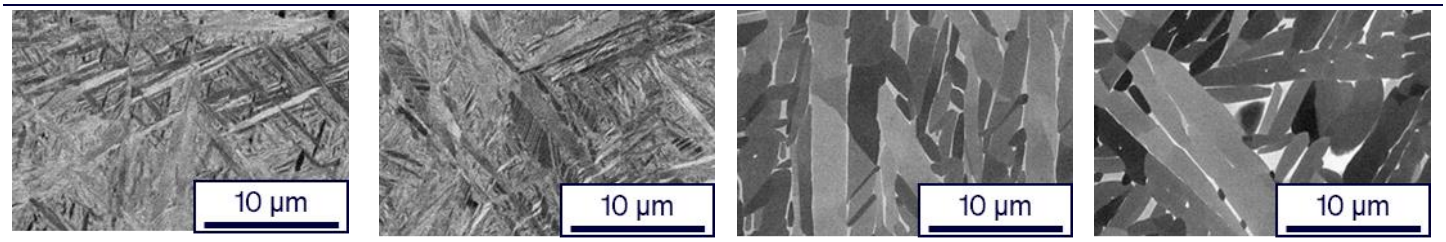
Surface Roughness, Ra (µm)	
H	12
V	9

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	353
SR1	99.9	99.9	334
SR2	99.9	99.9	343

Thermal State	Melting range (°C)	Coefficient of Thermal Expansion CTE 25-500°C (10^{-6}/K)
As-Built	1605-1650	11.1
SR2	---	10.1

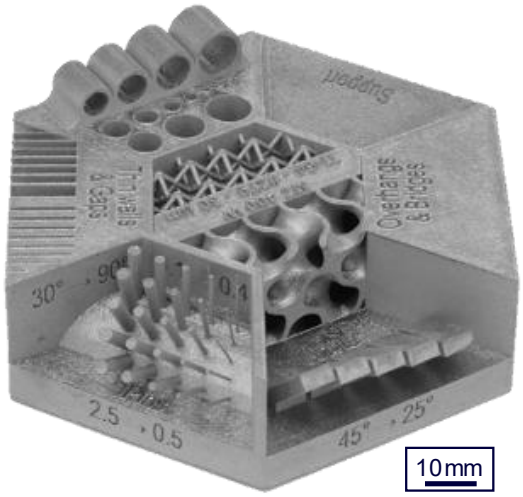
Microstructure

As-Built		SR1	
H	V	H	V



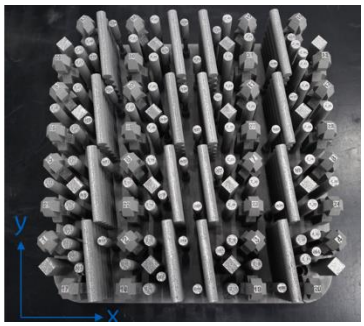
Scanning electron microscope images in As-Built and Stress Relief (SR1) condition as defined previously.

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.



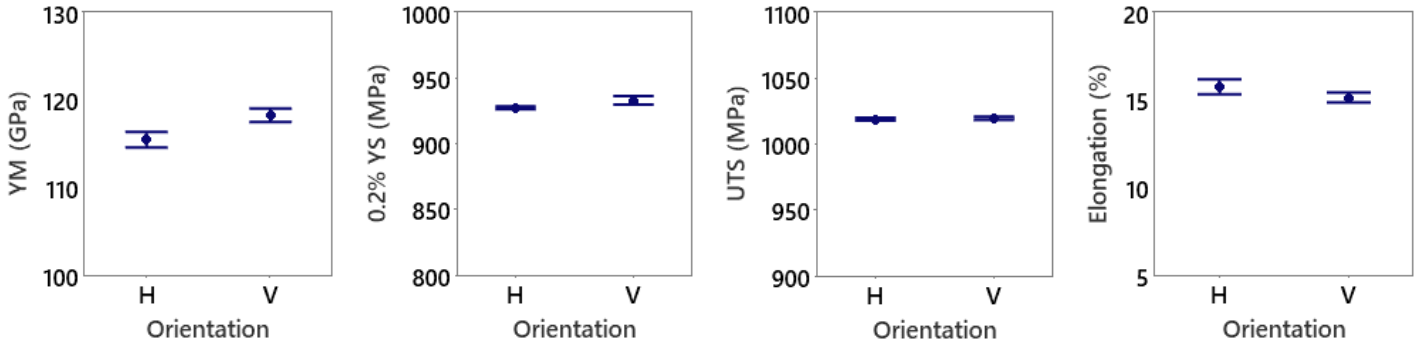
Feature	Result
Minimum Wall Thickness (mm)	0.13
Minimum Gap Width (mm)	0.20
Minimum Pin Diameter (mm)	0.22
Minimum Drill Hole Diameter, V (mm)	0.46
Minimum Drill Hole Diameter, H (mm)	0.47
Minimum Printable Angle (°)	35
Maximum Bridge Length (mm)	5

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.

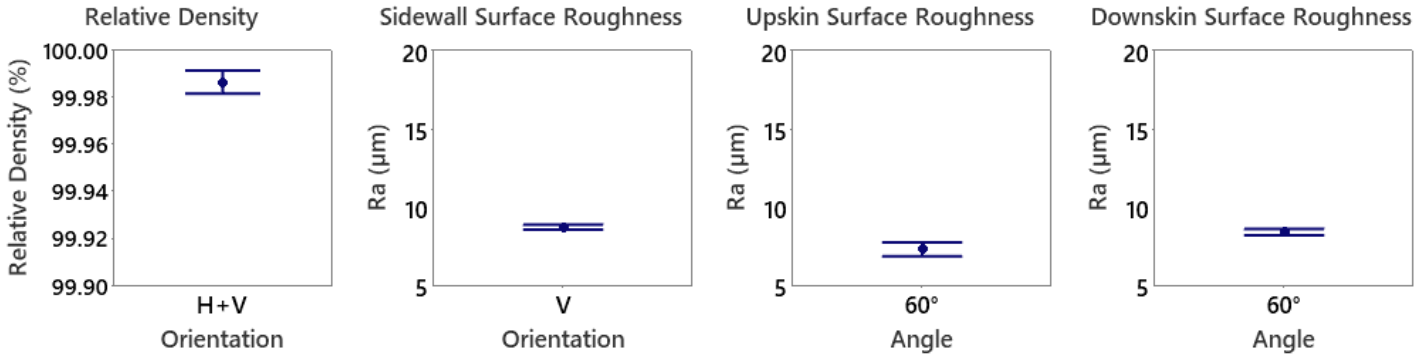


	Sample Size	Mean	Std. Dev.		Sample Size	Mean	Std. Dev.
YM (GPa) H/V - SR1	16/16	115/118	2/1	Rel. Density (%)	32	99.99	0.01
0.2% YS (MPa) H/V - SR1	16/16	927/933	2/6	Sidewall Roughness Ra (µm)	64	8.7	0.8
UTS (MPa) H/V - SR1	16/16	1019/1020	2/2	60° Upskin Roughness Ra (µm)	64	7.3	1.8
Elongation (%) H/V - SR1	16/16	15.7/15.1	0.8/0.5	60° Downskin Roughness Ra (µm)	64	8.4	0.8

Results Platform Stability: Mechanical properties in SR1 condition



Results Platform Stability: Relative Density and Surface Quality



Balanced Parameter 306 - 400 W / 60 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	39.0
Theoretical melting rate bulk per laser[2]	40.4

[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	113	112	1115	1125	1255	1275
SR1	121	118	940	940	1015	1015
SR2	118	115	945	940	1030	1030
SR3	119	120	1080	1075	1135	1130

Thermal State	Elongation (%)		Reduction of Area (%)	
	H	V	H	V
As-Built	7.0	8.0	---	---
SR1	16.0	14.5	---	---
SR2	15.0	14.0	42	40
SR3	12.0	11.5	---	---

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	16	13	9
Downskin	15	10	7

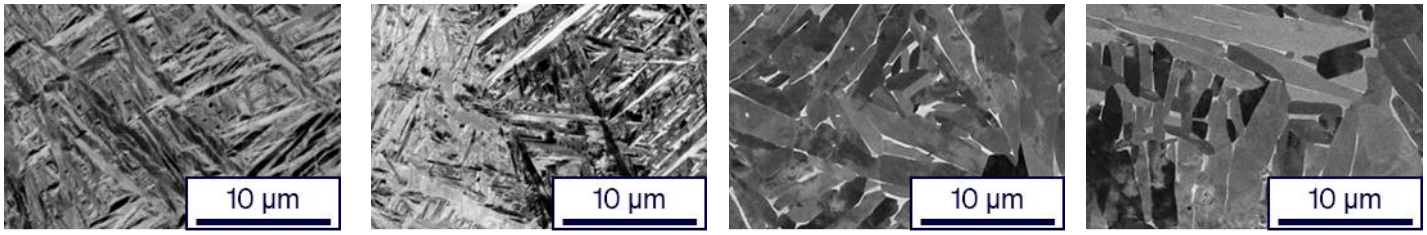
Surface Roughness, Ra (µm)	
H	18
V	10

Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	357
SR1	99.9	99.9	342
SR2	99.9	99.9	347

Thermal State	Melting range (°C)	Coefficient of Thermal Expansion CTE 25-500°C (10^{-6}/K)
As-Built	1605-1650	10.9
SR2	---	10.1

Microstructure

As-Built		SR1	
H	V	H	V



Scanning electron microscope images in As-Built and Stress Relief (SR1) condition as defined previously.

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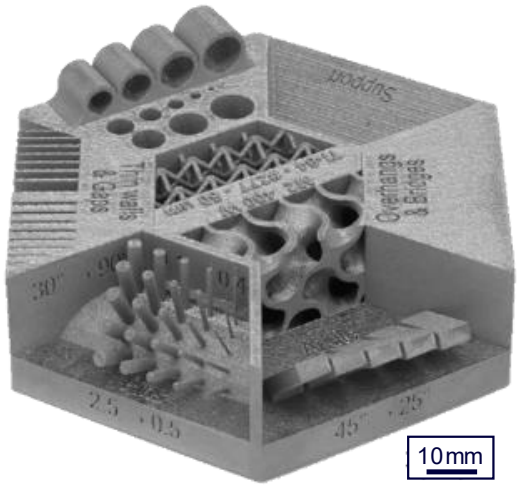
Minimum Feature Resolution

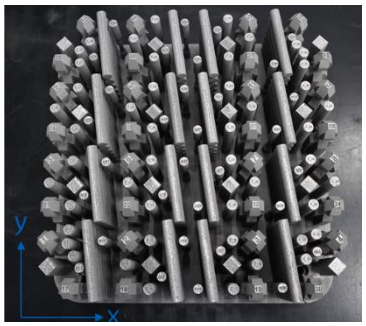
Parameter 306

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.



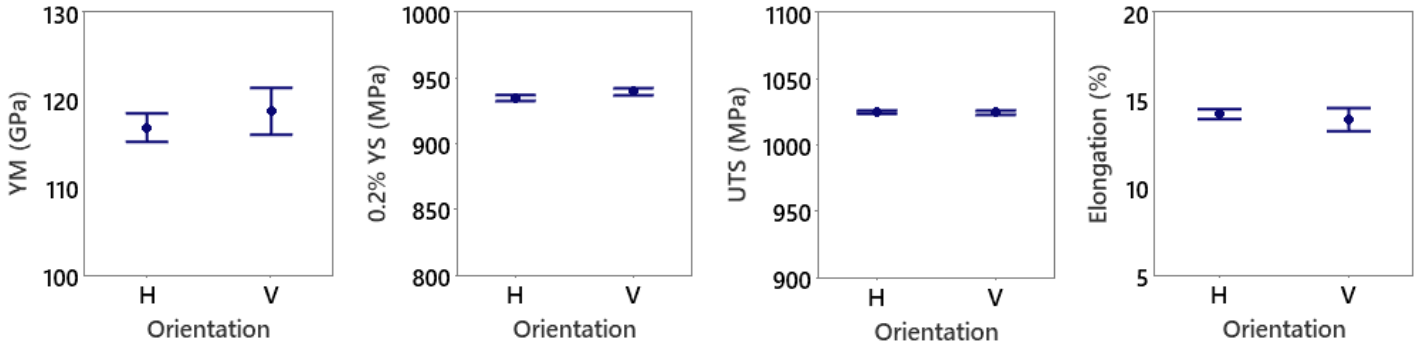
Feature	Result
Minimum Wall Thickness (mm)	0.17
Minimum Gap Width (mm)	0.16
Minimum Pin Diameter (mm)	0.30
Minimum Drill Hole Diameter, V (mm)	0.29
Minimum Drill Hole Diameter, H (mm)	0.41
Minimum Printable Angle (°)	25
Maximum Bridge Length (mm)	5

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.

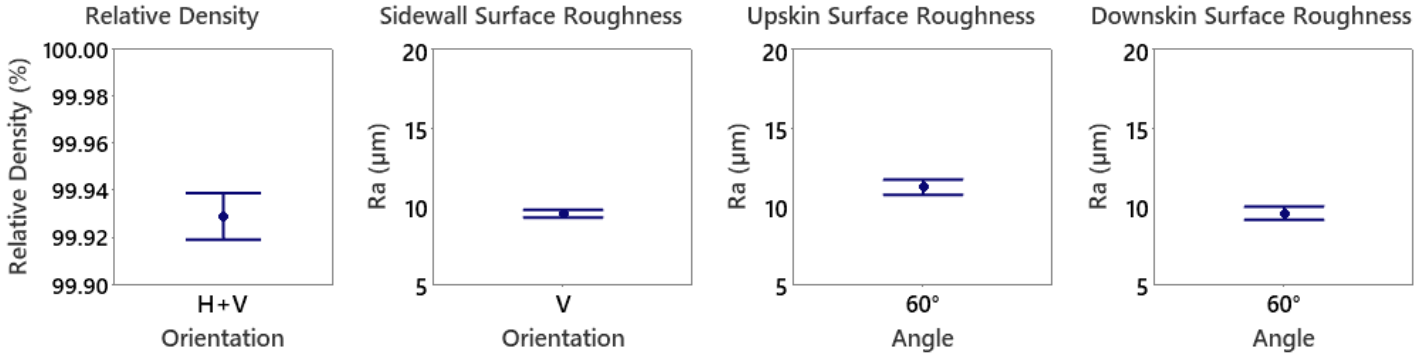


	Sample Size	Mean	Std. Dev.		Sample Size	Mean	Std. Dev.
YM (GPa) H/V - SR1	16/16	117/119	3/5	Rel. Density (%)	32	99.93	0.03
0.2% YS (MPa) H/V - SR1	16/16	935/940	4/5	Sidewall Roughness Ra (µm)	64	9.5	1.0
UTS (MPa) H/V - SR1	16/16	1025/1024	2/3	60° Upskin Roughness Ra (µm)	64	11.7	2.0
Elongation (%) H/V - SR1	16/16	14.2/13.9	0.5/1.3	60° Downskin Roughness Ra (µm)	64	9.6	1.5

Results Platform Stability: Mechanical properties in SR1 condition



Results Platform Stability: Relative Density and Surface Quality



COLIBRIUM ADDITIVE
a GE Aerospace company

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

L-PBF rematitan® CL

Mesh+ Parameters for Colibrium Additive's M2 Series 5

rematitan® CL

Titanium shows a high corrosion resistance and proven biocompatibility and has been employed successfully in human implant applications in contact with soft tissue and bone for decades.

Porous (trabecular) structures are very common for AM-manufactured medical implants. The open titanium architecture results in open structures that lead to enhanced osseointegration and allows adjusting the final device characteristics (density, stiffness).

M2 Series 5 rematitan® CL

The Mesh+ parameters enable the user to design porosity and pore size, as well as interconnectivity of trabecular structures to allow for enhanced initial fixation and bone ingrowth. The parameters further provide the user with an exceptional balance of high grade of detail and high productivity.

The Mesh+ parameters can be used in conjunction with the Colibrium Additive M2 Series 5 rematitan® CL parameters to create parts with both solid and mesh volumes to create hybrid components.

M2 Series rematitan® CL

Machine Configuration

M2 Series 5

Single- or dual-laser architecture

Argon gas

Platform heating: 200°C

Powder Chemistry

Ti6Al4V Grade 23 powder chemical composition according to ASTM F3001

Produced by Dentaurum distributed by Colibrium Additive.

Thermal States

As-Built

Stress Relief (SR1)

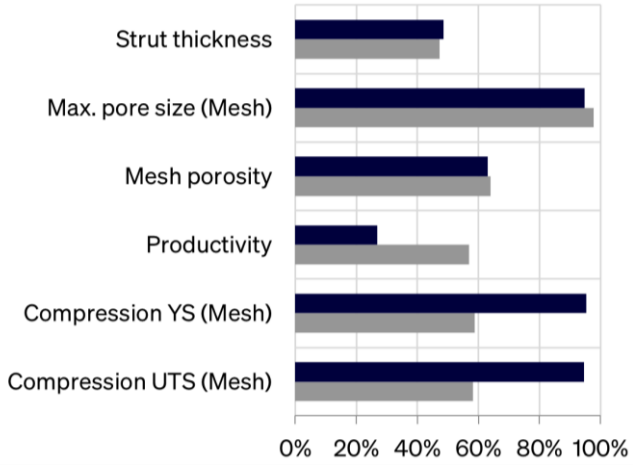
900°C for 1 hour in argon; furnace cooling

Hot Isostatic Pressing (HIP)

900°C, 2 hours, pressure 100 MPa

Parameter Availability and Thermal State Comparison

- Surface Mesh Parameter 307 SR1
  400 W, 30 µm layer thickness, rubber recoater
- Balanced Mesh Parameter 308 SR1
  400 W, 60 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 titanium-based alloys, the ranges are as follows: Compression UTS (Mesh): 0-110 MPa, 0.2%YS (Mesh): 0-85 MPa, Productivity: 5-70 cm^3/h, Mesh porosity: 0-100 %, Max. pore size (Mesh): 0-500 µm, Strut thickness: 0-500 µm. 0% in the Bar Plot indicates the lower range value, 100% indicates the upper range value

Surface Mesh+ Parameter - 400 W / 30 µm

Typical Build Rate

Item	(cm^3/h)
Theoretical melting rate bulk per laser[2]	17.5

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

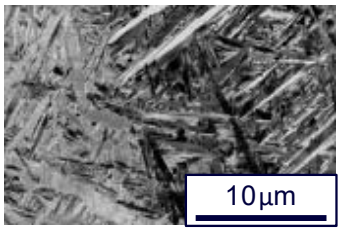
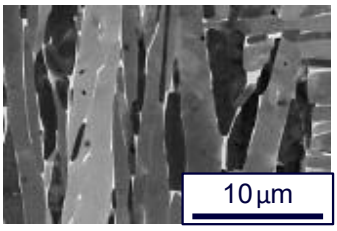
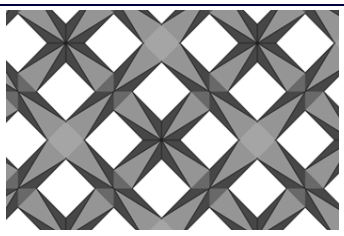
Compression Strength of Mesh Structure**

Thermal State	Modulus of Elasticity (Compression) (GPa)	Yield Strength (Compression) (MPa)	Compressive Strength (MPa)
As-Built	2.2	80	104
SR1	2.5	81	104
HIP	2.3	76	100

Mesh Dimensions**

Thermal State	Mesh Porosity (%)	Strut Thickness (µm)	Max. Grid Size (µm)
As-Built	63	250	480

Microstructure + CAD images

As-Built	SR1	CAD	SEM Image (post-processed)
V	V	Mesh design** V	V
			

Scanning electron microscope images in As-Built and Stress Relief (SR1) condition as defined previously.
** Data demonstrating results of special mesh design. Different designs could lead to changes in properties.

Balanced Mesh+ Parameter - 400 W / 60 µm

Typical Build Rate

Item	(cm^3/h)
Theoretical melting rate bulk per laser[2]	36.9

[1] Using standard Factory Acceptance Test layout and 2 lasers

[2] Calculated (layer thickness × scan velocity × hatch distance)

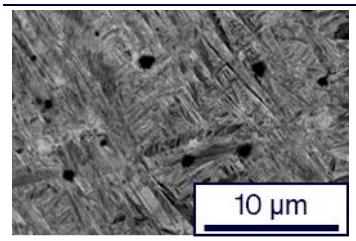
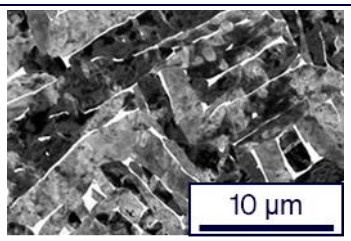
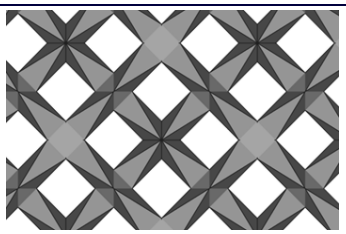
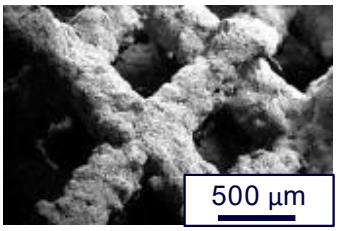
Compression Strength of Mesh Structure**

Thermal State	Modulus of Elasticity (Compression) (GPa)	Yield Strength (Compression) (MPa)	Compressive Strength (MPa)
As-Built	1.2	51	60
SR1	1.3	50	60
HIP	1.3	47	64

Mesh Dimensions**

Thermal State	Mesh Porosity (%)	Strut Thickness (µm)	Max. Grid Size (µm)
As-Built	64	240	490

Microstructure + CAD images

As-Built	SR1	CAD	SEM Image (post-processed)
V	V	Mesh design** V	V
			

Scanning electron microscope images in As-Built and Stress Relief (SR1) condition as defined previously.

** Data demonstrating results of special mesh design. Different designs could lead to changes in properties.

Data Sheet Nomenclature and Notation

IFU: Instruction For Use - provided with powder.

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.