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

M2 Series 5 Titanium Ti-64 Grade 23

Parameters for GE Additive's Concept Laser M2 Series 5

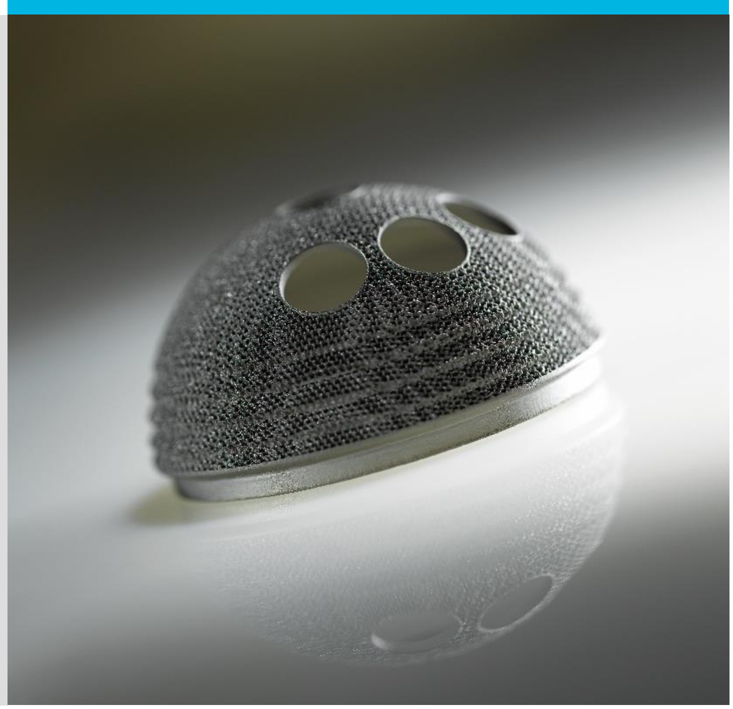
Data in this material datasheet represents material built with 30, 60 and 120 µm layer thicknesses in an argon atmosphere on a Concept Laser M2 Series 5 single-laser or dual-laser machine and requires build-plate heating. Values listed are typical.

Titanium

In general, titanium (Ti) and its alloys have been used extensively in many industries due to their low density, high corrosion resistance and oxidation resistance. Titanium alloys are used in additive manufacturing to produce a wide range of industrial components, including blades, fasteners, rings, discs, hubs and vessels. Titanium alloys are also used to produce high-performance race engine parts like gearboxes and connecting rods. Due to its proven biocompatibility and its long history in the medical industry, it is an established material used for medical applications such as medical implants.

M2 Series 5 Ti-64 Grade 23

The parameters for the Concept Laser M2 Series 5 are developed leveraging the performance of the previous M2 generations of Ti-64 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 productivity 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. Exceptional high productivity – reaching 61 cm^3/h for a dual-laser system – can be reached by the premium productivity parameter having a layer thickness of 120 µm. All parameters have outstanding tensile properties in stress relieved state and meet the ASTM F136-02a (ELI Grade 23)/ ASTM F3001 standard.



M2 Series 5 Titanium Ti-64 Grade 23

With an appropriate approval* Ti-64 Grade 23 can be used for aerospace, orthopedic, and dental applications.

Data in this material datasheet represent material built with 30, 60 and 120 µm layer thicknesses in an argon atmosphere on a Concept Laser M2 Series 5 single-laser or dual-laser machine and requires build-plate heating. Values listed are typical.

POWDER CHEMISTRY

Ti-64 Grade 23 powder chemical composition according to ASTM F136-02a (ELI Grade 23)/ ASTM F3001. For additional information on Ti-64 Grade 23 powder, visit https://www.advancedpowders.com/powders/titanium/ti-6al-4v-23.

MACHINE CONFIGURATION

- Concept Laser M2 Series 5 (single-laser or dual-laser)
- Argon gas
- Rubber/ Steel recoater blade

AVAILABLE PARAMETERS

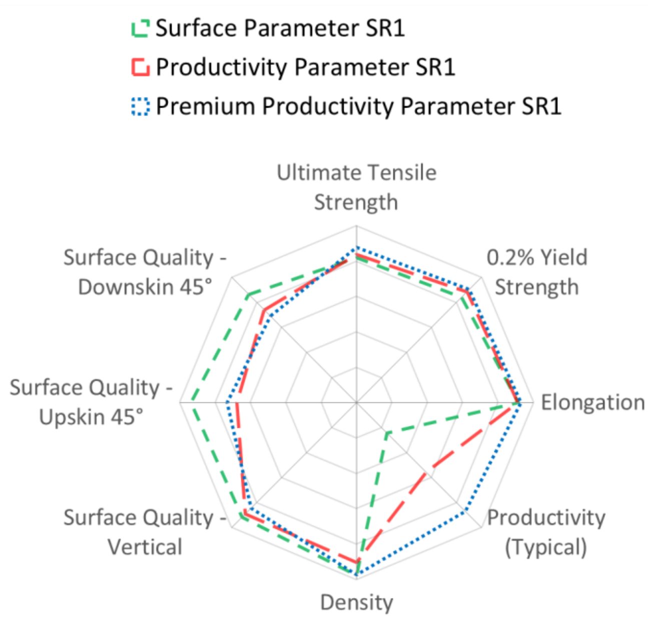
- **Surface Parameter 227 / 279**** — 30 µm layer thickness, rubber recoater
- **Productivity Parameter 114 / 277**** — 60 µm layer thickness, rubber recoater
- **Productivity Parameter 331**** — 60 µm layer thickness, steel recoater
- **Premium Productivity Parameter 120/353**** — 120 µm layer thickness, steel recoater

**Productivity optimized version (productivity bundle required)

THERMAL STATES

1. As-Built
2. Stress Relief (SR1)
SR1: 900°C, 1 hour in argon, furnace cooling
3. Stress Relief (SR2)
SR2: 840°C, 2 hours in argon, furnace cooling
4. Stress Relief (SR3)
SR3: 730°C, 2 hours in argon, furnace cooling

PARAMETER COMPARISON



Spider Plot is generated by normalizing typical material data (containing both horizontal and vertical data) against a range defined for each material family. For **Ti-64**, the ranges are as follows: UTS: 600-1100 MPa, 0.2%YS: 500-1000 MPa, Elongation: 0-20 %, Density: 99-100 %, Productivity: 0-70 cm³/h, Surface Quality (all): 50-5 µm

TYPICAL BUILD RATE

Surface Parameter

	Standard (cm³/h)	Productivity optimized (cm³/h)
Typical build rate[1] w/coating	13.1	17.1
Theoretical melting rate[2] bulk per Laser	16.8	16.8

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

PHYSICAL DATA AT ROOM TEMPERATURE

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

	Surface Roughness Ra** (µm)
H	12
V	9

Thermal State	Relative Density (%) H	V	Hardness (HV10) H	V	Poisson's Ratio H	V
As-Built	99.9	99.9	353	--	--	--
SR1	99.9	99.9	334	--	--	--

TENSILE DATA

Tensile testing done in accordance with ASTM E8 and ASTM E21

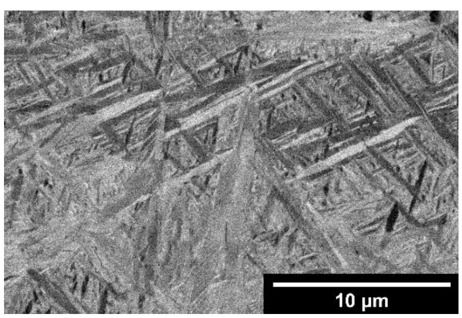
Test Temperature: RT

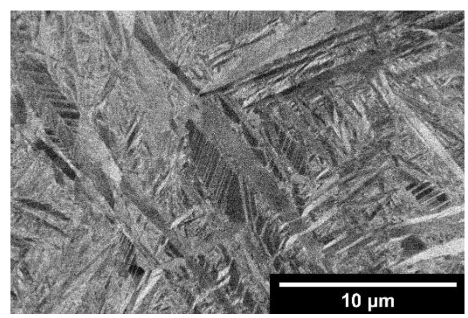
Thermal State	Modulus of Elasticity (GPa) H	V	0.2% Yield Strength (MPa) H	V	Ultimate Tensile Strength (MPa) H	V	Elongation (%) H	V	Reduction of Area (%) H	V
As-Built	111	110	1145	1140	1295	1270	8.0	8.5	27	30
SR1	116	118	920	915	1010	1005	15.5	15.0	44	42

SEM IMAGES

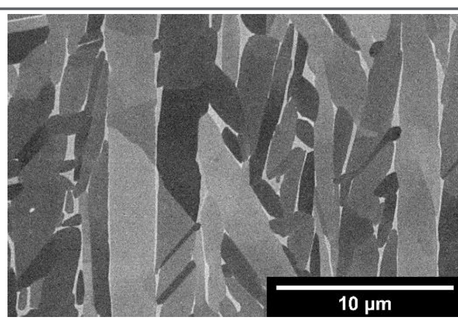
Horizontal | Vertical

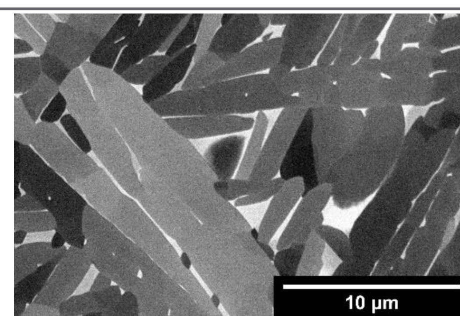
As-Built





SR1



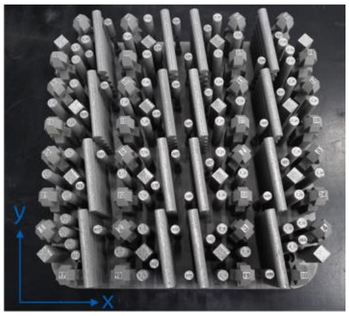


H: HORIZONTAL (XY) orientation
V: VERTICAL (Z) orientation

* All of the figures contained herein are approximate only. The figures provided are dependent on a number of factors, including but not limited to, process and machine parameters, and the approval is brand specific and/or application specific. The information provided on this material data sheet is illustrative only and cannot be relied on as binding.
** 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.

The platform stability build evaluates porosity, 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.

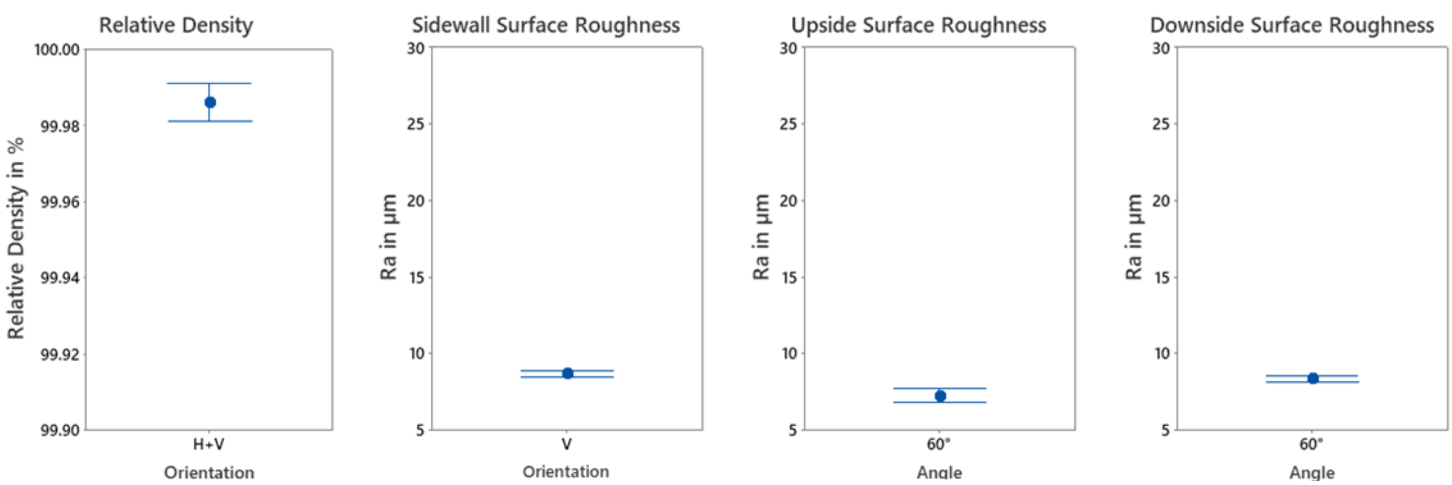
BUILD JOB DESIGN AND SUMMARIZED DATA (STRESS RELIEF SR1)



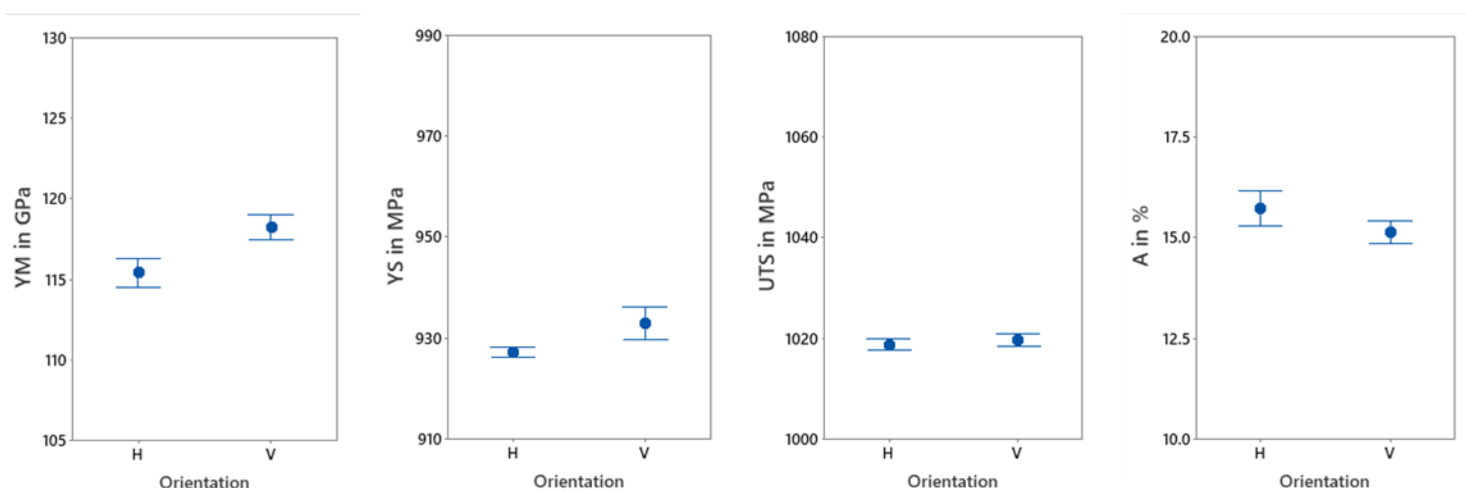
	Sample Size	Mean	St.Dev.
Rel. Density in %	32	99.99	0.01
Sidewall Roughness Ra in µm	64	8.7	0.9
Upside Roughness Ra in µm (60°)	64	7.3	1.8
Downside Roughness Ra in µm (60°)	64	8.4	0.8

	Sample Size	Mean	St.Dev.
YM in GPa (H/V)	16/16	115/118	2/1
YS in MPa (H/V)	16/16	927/933	2/6
UTS in MPa (H/V)	16/16	1019/1020	2/2
Elongation in % (H/V)	16/16	15.7/15.1	0.8/0.5

RESULTS – RELATIVE DENSITY AND SURFACE QUALITY



RESULTS - MECHANICAL PROPERTIES IN STRESS RELIEF SR1 CONDITION



Data points represent the mean value, intervals the 95% confidence level.

H: HORIZONTAL (XY) orientation
V: VERTICAL (Z) orientation

TYPICAL BUILD RATE

	Standard (cm^3/h)	Productivity optimized (cm^3/h)
Typical build rate[1] w/coating	26.5	39.0
Theoretical melting rate[2] bulk per Laser	40.4	40.4

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

PHYSICAL DATA AT ROOM TEMPERATURE

	Surface Roughness Ra** – Overhang (µm) 45°	60°	75°
Upskin	20	17	13
Downskin	19	13	10

	Surface Roughness Ra** (µm)
H	18
V	10

	Relative Density (%)		Hardness (HV10)		Poisson's Ratio	
Thermal State	H	V	H	V	H	V
As-Built	99.9	99.9	357	--	--	--
SR1	99.9	99.9	342	--	--	--

TENSILE DATA

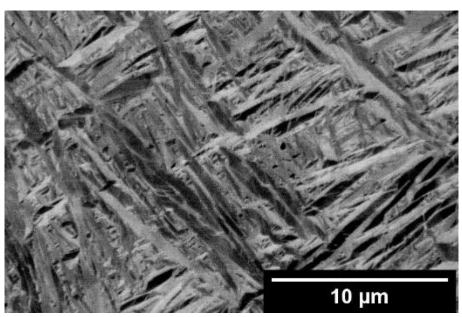
Tensile testing done in accordance with ASTM E8 and ASTM E21

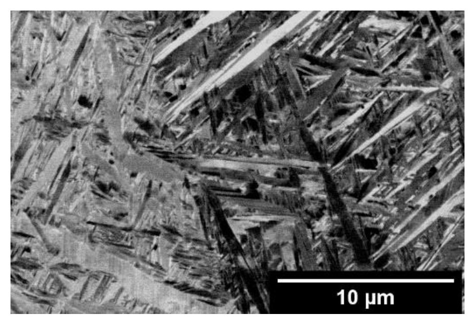
Test Temperature: RT	Modulus of Elasticity (GPa)		0.2% Yield Strength (MPa)		Ultimate Tensile Strength (MPa)		Elongation (%)		Reduction of Area (%)	
Thermal State	H	V	H	V	H	V	H	V	H	V
As-Built	113	112	1115	1125	1255	1275	7.0	8.0	--	--
SR1	121	118	940	940	1015	1015	16.0	14.5	--	--
SR2	118	119	995	995	1050	1050	13.5	14.5	--	--
SR3	119	120	1080	1075	1135	1130	12.0	11.5	--	--

SEM IMAGES

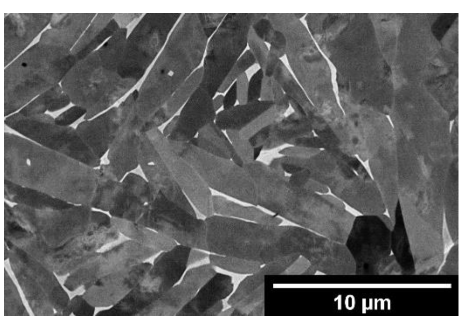
Horizontal | Vertical

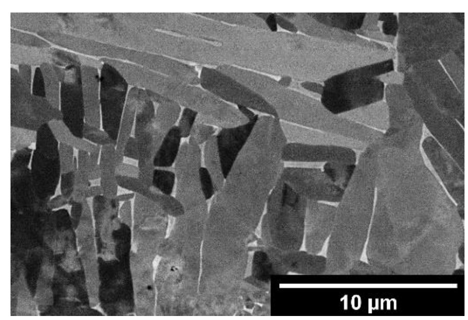
As-Built





SR1





H: HORIZONTAL (XY) orientation
V: VERTICAL (Z) orientation

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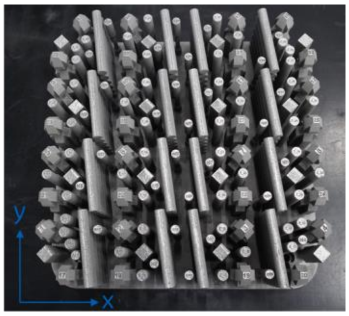
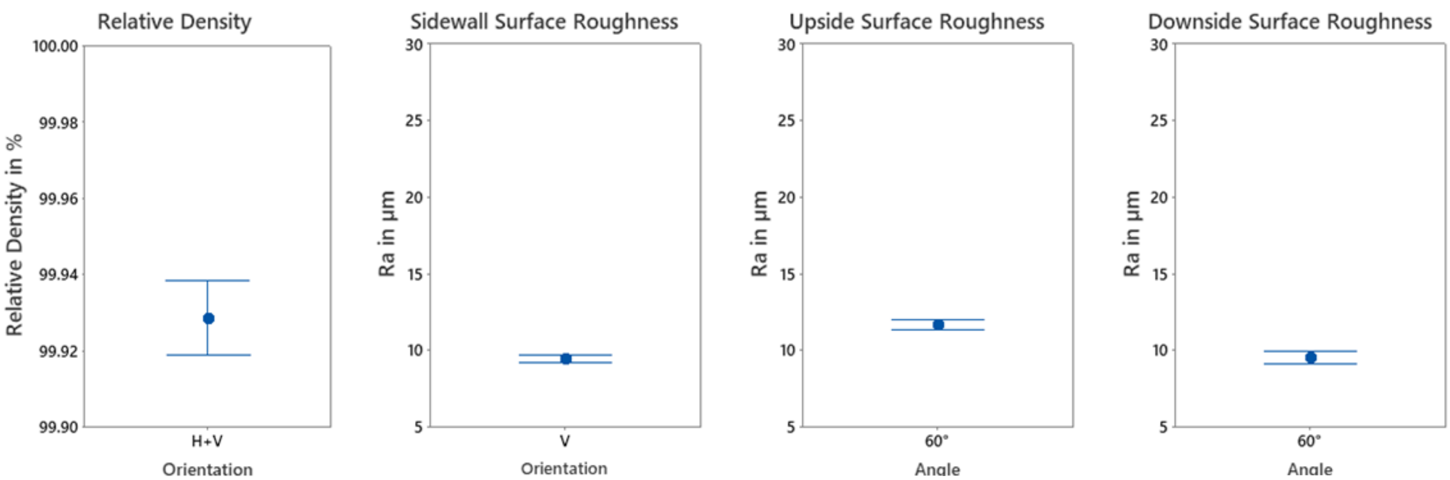
BUILD JOB DESIGN AND SUMMARIZED DATA (STRESS RELIEF SR1)



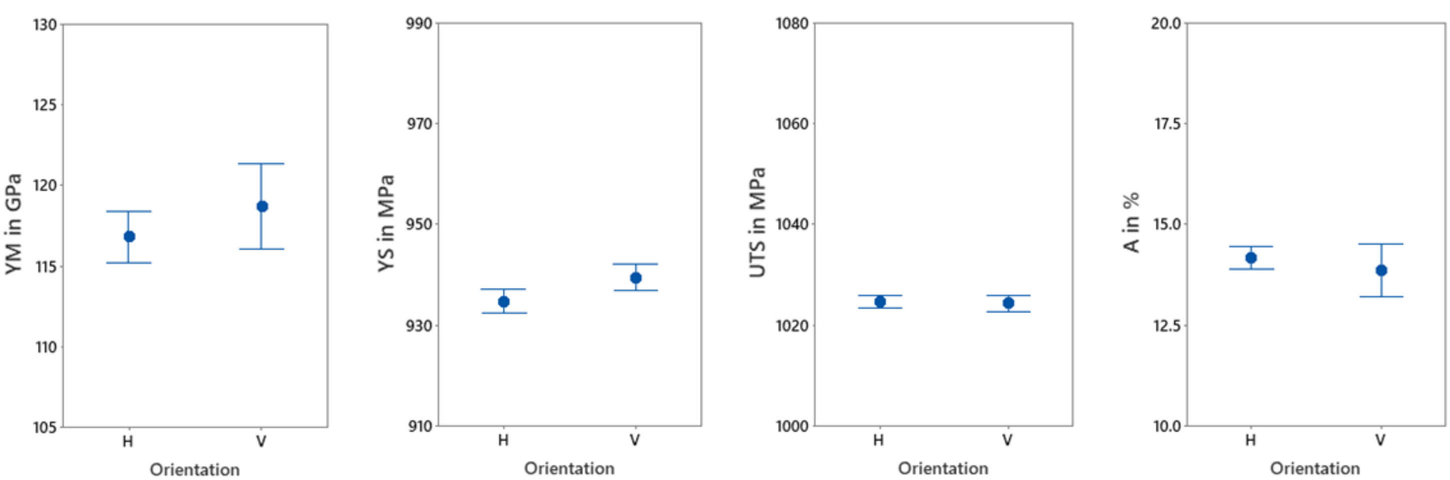
	Sample Size	Mean	St.Dev.
Rel. Density in %	32	99.93	0.03
Sidewall Roughness Ra in µm	64	9.5	1.0
Upside Roughness Ra in µm (60°)	64	11.7	2.0
Downside Roughness Ra in µm (60°)	64	9.6	1.5

	Sample Size	Mean	St.Dev.
YM in GPa (H/V)	16/16	117/119	3/5
YS in MPa (H/V)	16/16	935/940	4/5
UTS in MPa (H/V)	16/16	1025/1024	2/3
Elongation in % (H/V)	16/16	14.2/13.9	0.5/1.3

RESULTS – RELATIVE DENSITY AND SURFACE QUALITY



RESULTS - MECHANICAL PROPERTIES IN STRESS RELIEF SR1 CONDITION



Data points represent the mean value, intervals the 95% confidence level.

H: HORIZONTAL (XY) orientation
V: VERTICAL (Z) orientation

TYPICAL BUILD RATE

	Standard (cm³/h)	Productivity optimized (cm³/h)
Typical build rate[1] w/coating	53.4	60.8
Theoretical melting rate[2] bulk per Laser	56.4	56.2

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

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

PHYSICAL DATA AT ROOM TEMPERATURE

	Surface Roughness Ra** - Overhang (µm)		
	45°	60°	75°
Upskin	18	14	13
Downskin	19	13	10

	Surface Roughness Ra** (µm)
H	10
V	12

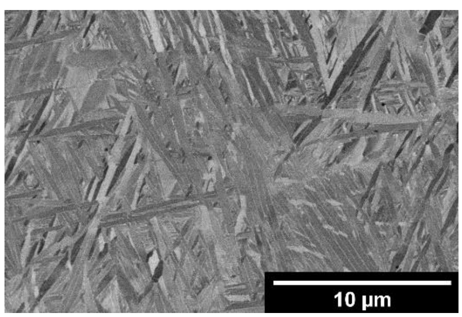
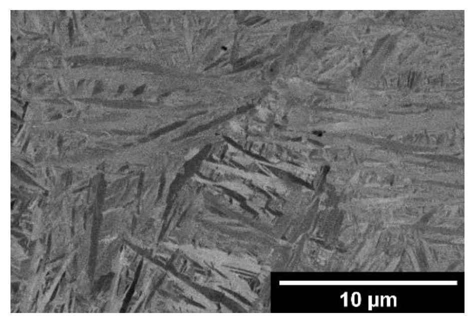
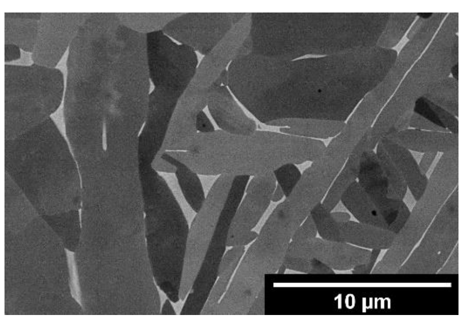
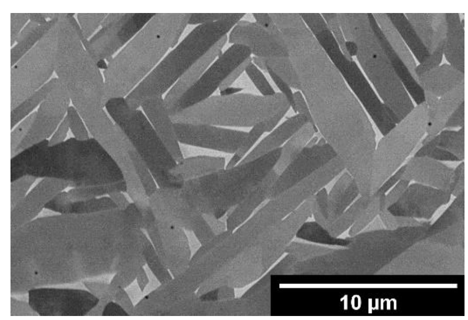
	Relative Density (%)		Hardness (HV10)		Poisson's Ratio	
Thermal State	H	V	H	V	H	V
As-Built	99.9	99.9	365	--	--	--
SR1	99.9	99.9	345	--	--	--

TENSILE DATA

Tensile testing done in accordance with ASTM E8 and ASTM E21

Test Temperature: RT	Modulus of Elasticity (GPa)		0.2% Yield Strength (MPa)		Ultimate Tensile Strength (MPa)		Elongation (%)		Reduction of Area (%)	
Thermal State	H	V	H	V	H	V	H	V	H	V
As-Built	113	113	1115	1160	1225	1275	8.5	6	34	33
SR1	116	119	945	950	1035	1035	16	16.5	45	47

SEM IMAGES

	Vertical	Horizontal
As-Built		
SR1		

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V: VERTICAL (Z) orientation

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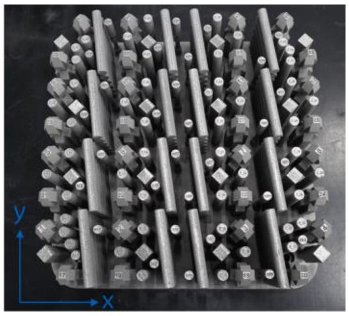
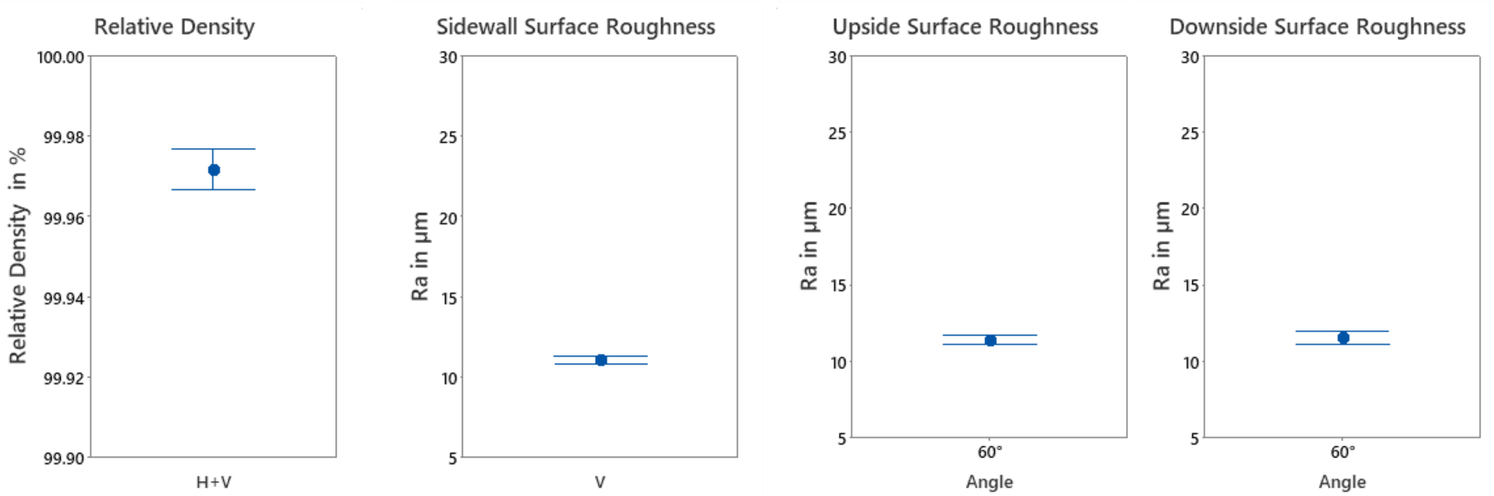
BUILD JOB DESIGN AND SUMMARIZED DATA (STRESS RELIEF SR1)



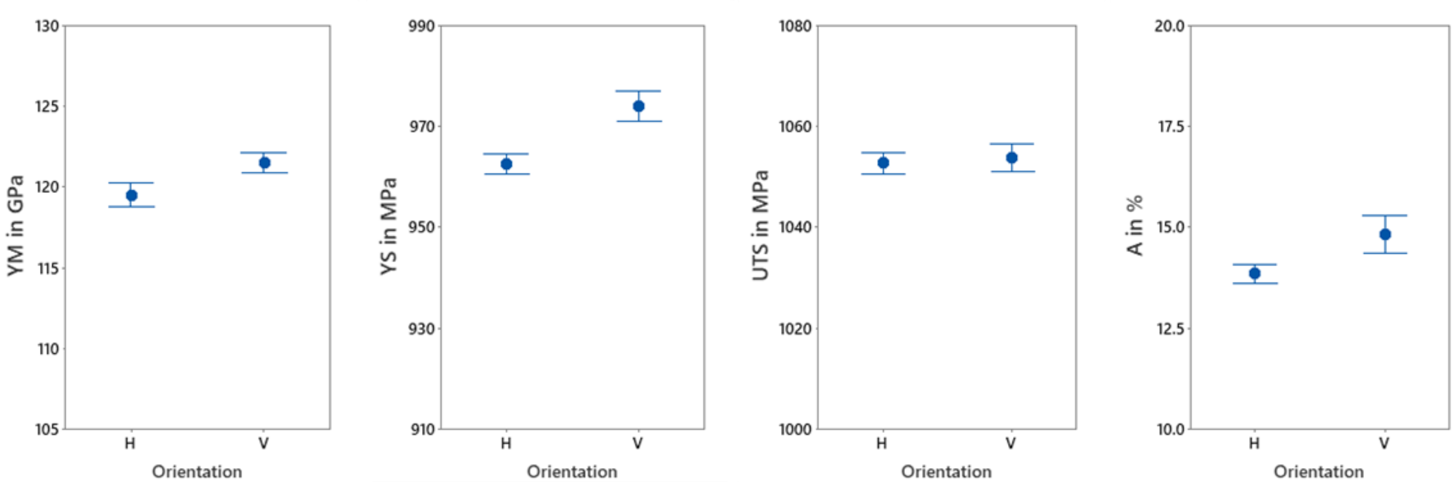
	Sample Size	Mean	St.Dev.
Rel. Density in %	32	99.97	0.01
Sidewall Roughness Ra in µm	64	11.1	1.0
Upside Roughness Ra in µm (60°)	64	11.4	1.2
Downside Roughness Ra in µm (60°)	64	11.5	1.8

	Sample Size	Mean	St.Dev.
YM in GPa (H/V)	16/16	120/122	1/1
YS in MPa (H/V)	16/16	963/974	4/6
UTS in MPa (H/V)	16/16	1053/1054	4/5
Elongation in % (H/V)	16/16	13.9/14.8	0.4/0.9

RESULTS – RELATIVE DENSITY AND SURFACE QUALITY



RESULTS – MECHANICAL PROPERTIES IN STRESS RELIEF SR1 CONDITION

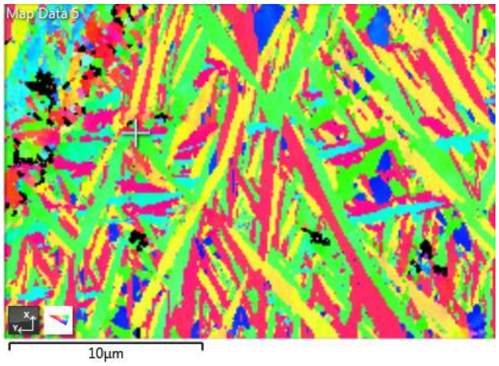


Data points represent the mean value, intervals the 95% confidence level.

H: HORIZONTAL (XY) orientation
V: VERTICAL (Z) orientation

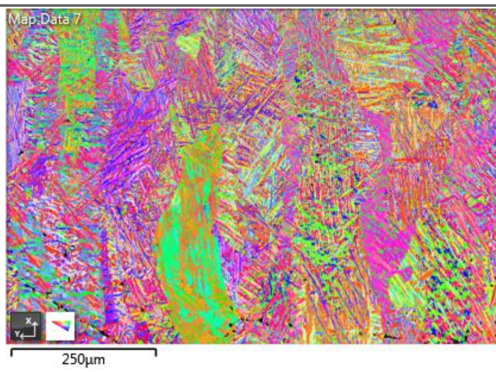
As-Built condition, vertical direction

5000x



High magnification grain misorientation map.

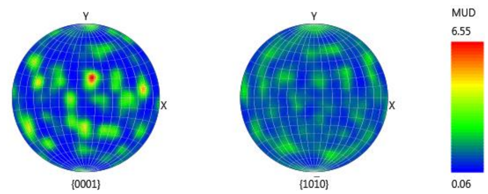
150x



Grain misorientation map showing prior β boundaries as well as a preferential {0001} texture.

150x – PF

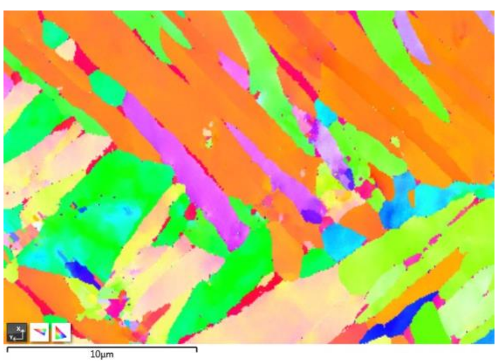
α-phase



Pole figure verifying presence of {0001} texture. This is also reflected in the directional tensile properties.

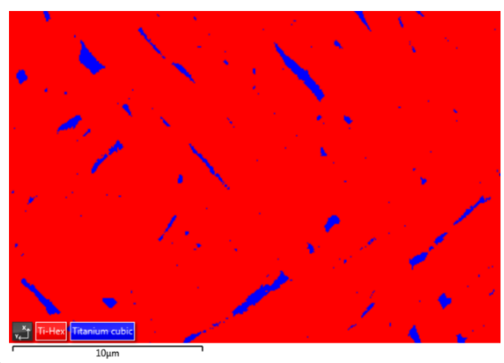
SR1 condition, vertical direction

5000x



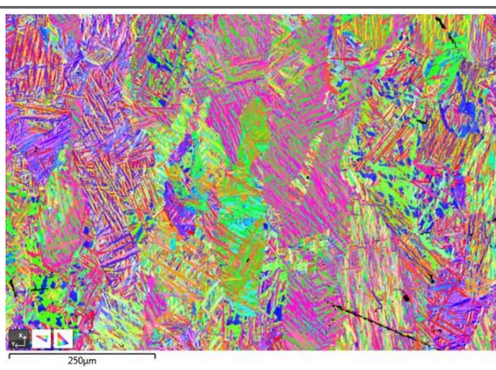
High magnification grain misorientation map.

5000x



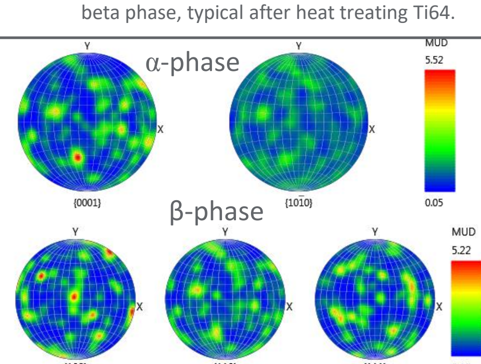
α-β-phase content map showing microstructure with a small amount of beta phase, typical after heat treating Ti64.

150x



Grain misorientation map showing some visible prior β boundaries, as well as a reduction in preferential orientation compared to the as-built condition.

150x – PF



Pole figure verifying presence of {0001} texture in the α phase, as well as some texture in the remaining β-phase.

M2 Series 5 Titanium Ti-64 Mesh+ Parameters

Premium+ Parameters for GE Additive's Concept Laser M2 Series 5

Data in this material datasheet represent material built with 30 and 60 µm layer thicknesses and in an argon atmosphere on a Concept Laser M2 Series 5 single-laser or dual-laser machine and requires build-plate heating. Values listed are typical.

Titanium Ti-64

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). It also requires a well-balanced parameter set to optimize the build process fulfilling the productivity and quality requirements .

M2 Series 5 Ti-64 Mesh+ Parameters

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 Concept Laser M2 Series 5 Ti-64 parameters to create parts with both solid and mesh volumes to create hybrid components.

M2 Series 5 Titanium Ti-64 Grade 23 Mesh+

With an appropriate approval* Ti-64 Grade 23 can be used for medical applications.

Data in this material datasheet represent material built with 30 and 60 µm layer thicknesses in an argon atmosphere on a Concept Laser M2 Series 5 single-laser or dual-laser machine and requires build-plate heating. Values listed are typical.

POWDER CHEMISTRY

Ti-64 Grade 23 powder chemical composition according to ASTM F136-02a (ELI Grade 23)/ ASTM F3001. For additional information on Ti-64 Grade 23 powder, visit https://www.advancedpowders.com/powders/titanium/ti-6al-4v-23.

MACHINE CONFIGURATION

- Concept Laser M2 Series 5 (single-laser or dual-laser)
- Argon gas
- Rubber recoater blade

AVAILABLE PARAMETERS

- **Mesh Parameter 113 / 284**** 30 µm layer thickness, rubber recoater
- **Mesh Parameter 110 / 278**** 60 µm layer thickness , rubber recoater

**productivity optimized version (productivity bundle required)

THERMAL STATES

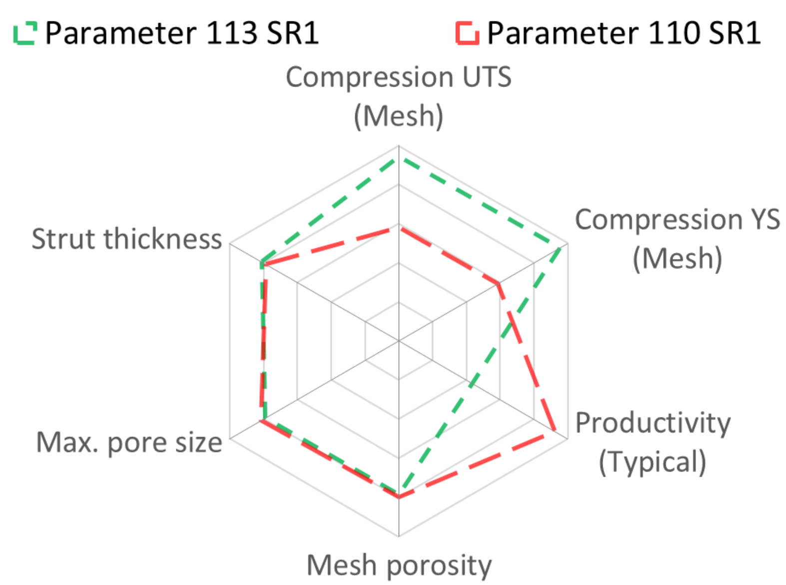
1. As-Built
2. Stress Relief (SR1)

SR1: 900°C, 1 hour in argon, furnace cooling

3. HIP

HIP: 900°C, 2 hours, pressure 100 MPa

PARAMETER COMPARISON



Spider Plot is generated by normalizing typical material data (containing both horizontal and vertical data) against a range defined for each material family. For **Ti-64 (mesh parameter)**, the ranges are as follows: Compression UTS (Mesh): 0-110 MPa, Compression YS (Mesh): 0-85 MPa, Density: 0-80%, Productivity: 5-40 cm³/h, Max. Pore Size: 0-600 µm, Strut Thickness: 0-300 µm

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

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

COMPRESSION STRENGTH OF MESH STRUCTURE**

Compression testing done in accordance with ISO 13314

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

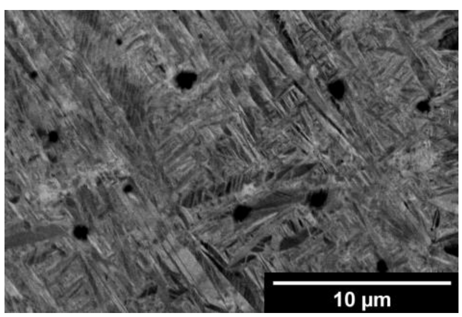
MESH DIMENSIONS**

	Mesh porosity (%)	Strut thickness (µm)	Max. pore size (µm)
As-Built	63	250	480

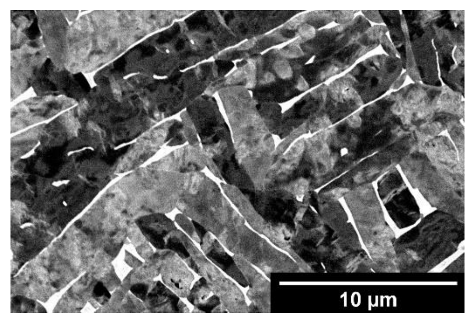
SEM & CAD IMAGES

Vertical (bulk)

As-Built

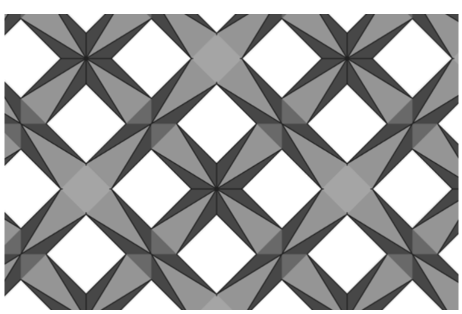


SR1



Mesh design**

CAD



SEM image

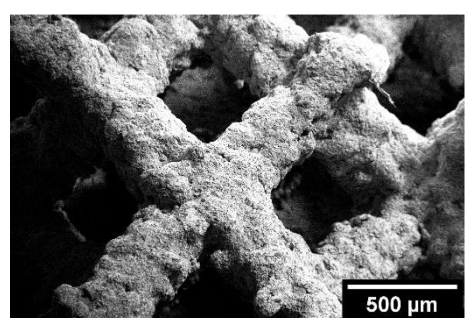


Image shows the post-processed condition

V: VERTICAL (Z) orientation

*All of the figures contained herein are approximate only. The figures provided are dependent on a number of factors, including but not limited to, process and machine parameters, and the approval is brand specific and/or application specific. The information provided on this material data sheet is illustrative only and cannot be relied on as binding.
** Data demonstrating results of special mesh design. Different designs could lead to changes in properties.

	(cm³/h)
Theoretical melting rate[2] bulk per Laser	36.9

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

COMPRESSION STRENGTH OF MESH STRUCTURE**

Compression testing done in accordance with ISO 13314

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

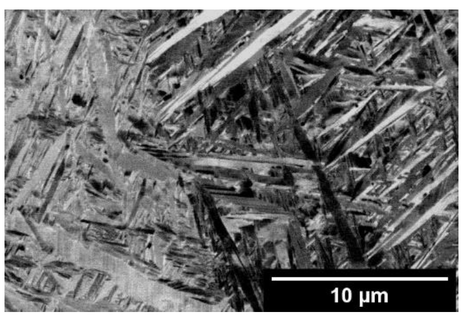
MESH DIMENSIONS**

	Mesh porosity (%)	Strut thickness (µm)	Max. pore size (µm)
As-Built	64	240	490

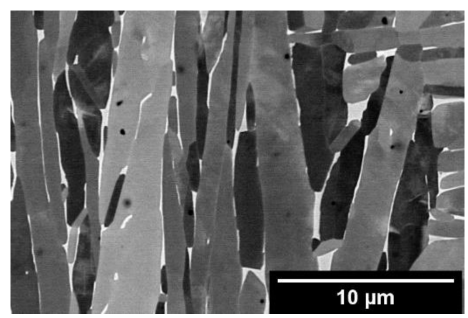
SEM & CAD IMAGES

Vertical (bulk)

As-Built

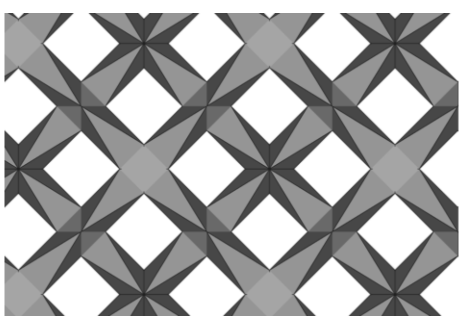


SR1



Mesh design**

CAD



SEM image

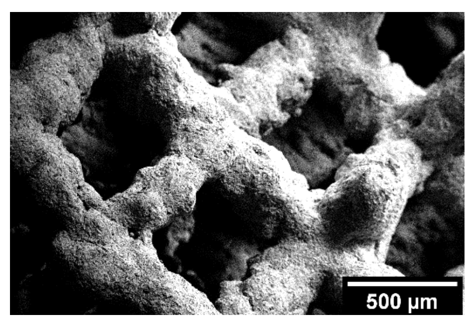


Image shows the post-processed condition

V: VERTICAL (Z) orientation

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