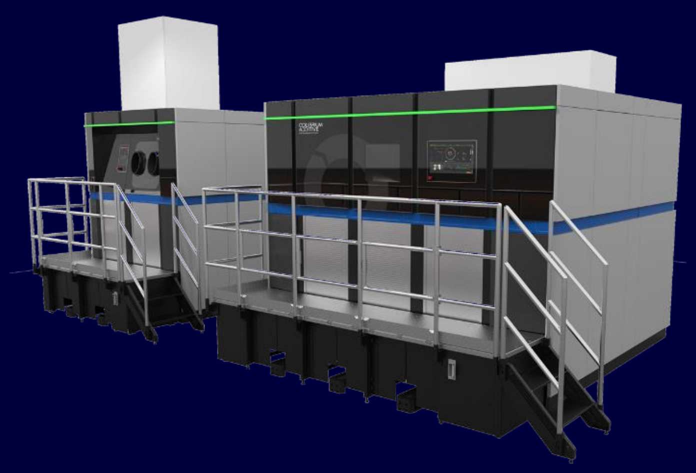
a GE Aerospace company

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

L-PBF Nickel X

Parameter for Colibrium Additive's M Line

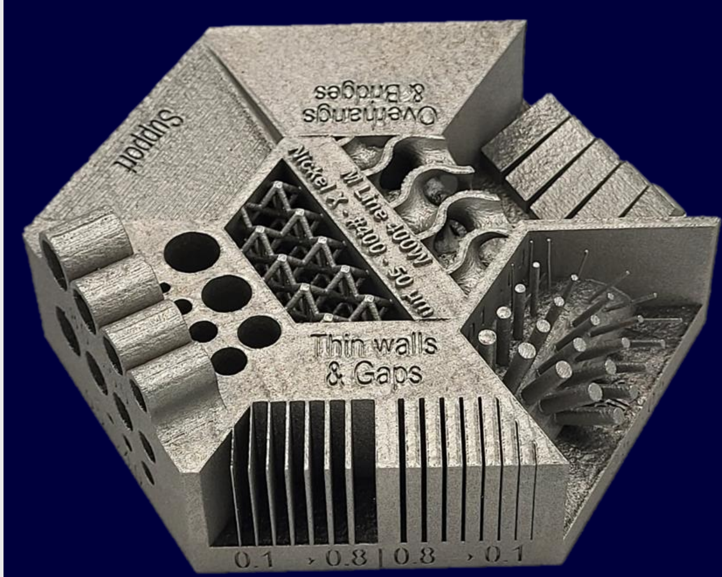


Nickel X

Nickel-Chromium-Iron-Molybdenum based superalloys like Nickel X (UNS N06002) have an exceptional combination of oxidation resistance, fabricability and high-temperature strength. The outstanding resistance to oxidizing, reducing, and neutral atmospheres up to 1200 °C makes Nickel X an ideal candidate for high-temperature applications across different industries. Typical applications include gas turbine combustion zone components, aircraft parts, industrial furnace systems, chemical process industry and petrochemical process equipment.

M Line Nickel X

The Nickel X parameter with 50 µm layer thickness was specifically developed for Colibrium Additive's M Line. This parameter combines fine feature resolution with the productive capability of the M Line 400 W quad-laser system. This parameter set is suitable for producing complex geometries and intricate part designs which are suitable for the most demanding high-temperature environments.



M Line Nickel X

Machine Configuration

M Line

Quad-laser architecture

Nitrogen gas

Powder Chemistry

Nickel X powder chemical composition according to AMS7008.

Particle Size: 15-45 µm

Thermal States

As-Built (AB)

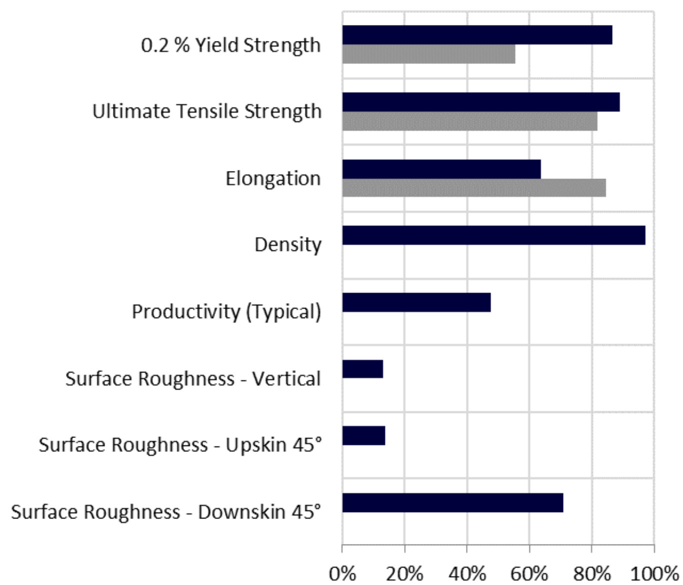
Solution Anneal (SOLN)

1177 °C for 1 hour; air cooling

Parameter Availability and Thermal State Comparison

- Balanced Parameter 400 As-Built
- Balanced Parameter 400 SOLN

  400 W, 50 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 Nickel alloy, the ranges are as follows: 0.2% YS: 0-700 MPa, UTS: 0-900 MPa, Elongation: 0-60%, 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 400 - 400 W / 50 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	31.1
Theoretical melting rate bulk per laser[2]	20.5

[1] Using standard Factory Acceptance Test layout and 4 lasers
[2] Calculated (layer thickness × scan velocity × hatch distance)

Tensile Performance at Room Temperature

Thermal State	Sample Size	YM (GPa)	0.2% YS (MPa)	UTS (MPa)	Elongation (%)	Area Reduction (%)
As-Built H	12	197	640	835	35.0	68.0
As-Built H - ST	12	195	635	835	34.0	65.0
As-Built V	63	170	565	760	41.5	71.5
SOLN H	12	202	395	760	47.5	69.5
SOLN H - ST	12	195	385	755	45.5	65.0
SOLN V	36	201	380	710	54.0	73.5

Tensile Performance at 820 °C

Thermal State	Sample Size	YM (GPa)	0.2% YS (MPa)	UTS (MPa)	Elongation (%)	Area Reduction (%)
SOLN H	8	101	270	420	28.0	22.5
SOLN V	8	101	250	390	46.5	35.0

Physical Properties at Room Temperature

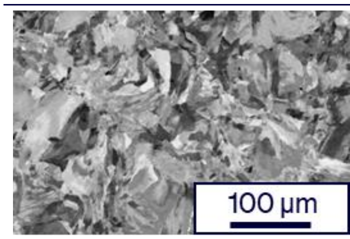
	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	10	8	6
Downskin	30	17	9

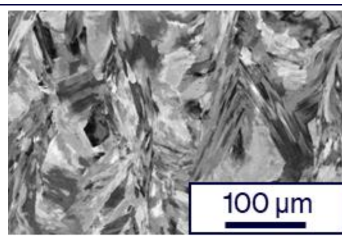
Surface Roughness, Ra (µm)	
H	---
V	10

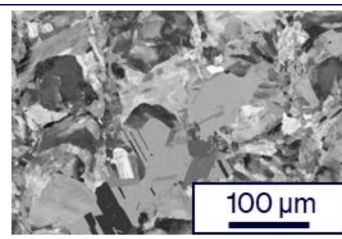
Thermal State	Relative Density (%)		Hardness (HV10)
	H	H	H
As-Built	99.9	99.9	234
SOLN	---	---	193

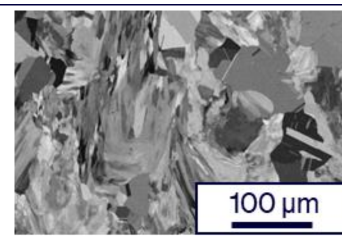
Microstructure

As-Built		SOLN	
H	V	H	V



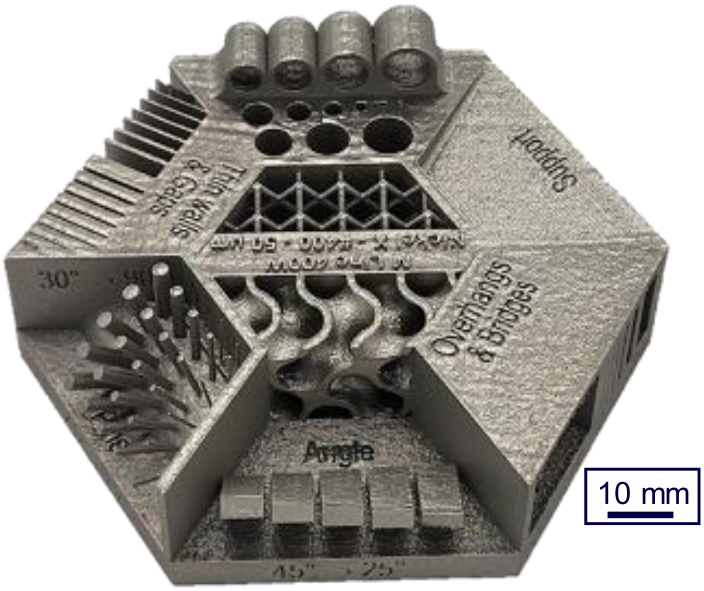






Scanning electron microscope images in As-Built and Solution Annealed (SOLN) condition as defined previously.

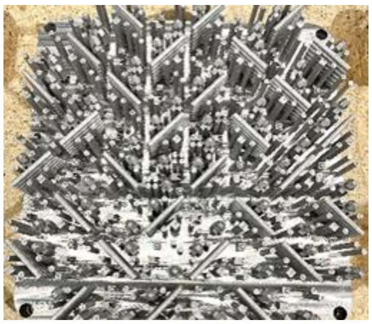
The minimum feature resolution part was designed to demonstrate parameter capability to produce specific features such as minimum wall thickness, minimum gap width, minimum pin diameter, minimum drill hole diameter (horizontal and vertical), minimum unsupported downskin angle, and maximum unsupported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



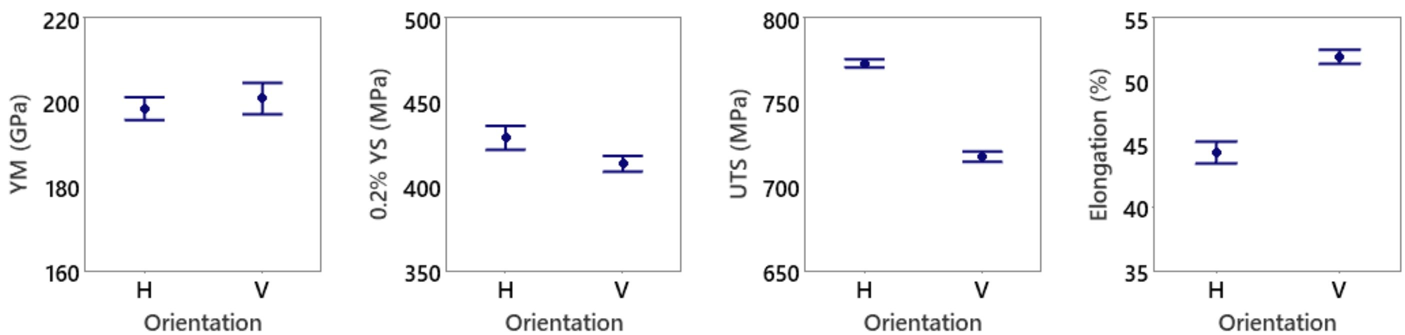
Feature	Result
Minimum Wall Thickness (mm)	0.3
Minimum Gap Width (mm)	0.1
Minimum Pin Diameter (mm)	0.3
Minimum Drill Hole Diameter, V (mm)	0.5
Minimum Drill Hole Diameter, H (mm)	1
Minimum Printable Angle (°)	35
Maximum Bridge Length (mm)	4

Platform Stability

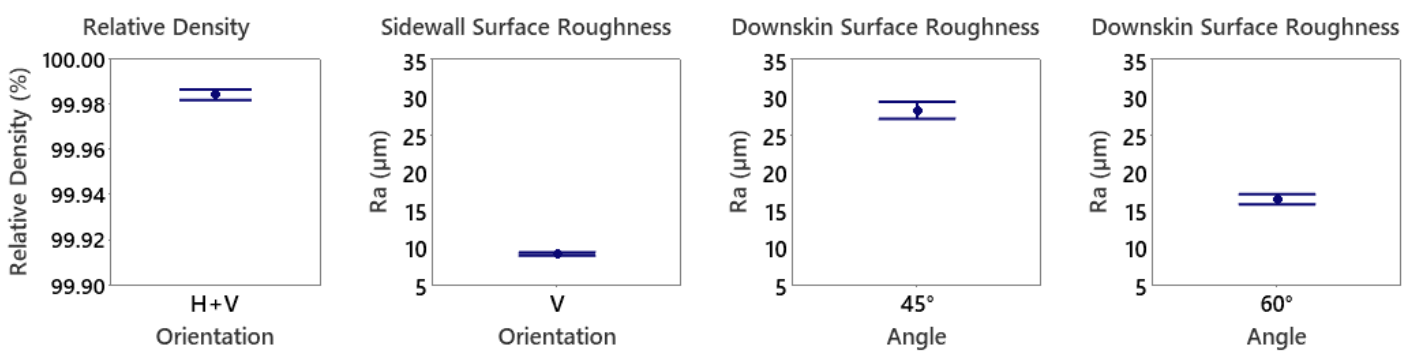
The platform stability build evaluates relative density, roughness and tensile properties across different positions and orientations. To illustrate the position dependency of the M Line, the samples were homogenously distributed across the platform on 30 different positions. Regarding surface quality 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	30/30	198/200	7.5/10	Rel. Density (%)	60	99.98	0.01
	0.2% YS (MPa) H/V - SOLN	30/30	425/410	19/13	Sidewall Roughness Ra (µm)	120	9.5	1.5
	UTS (MPa) H/V - SOLN	30/30	770/715	6.5/8.5	45° Downskin Roughness Ra (µm)	104	28.5	6.0
	Elongation (%) H/V - SOLN	30/30	44.0/51.5	2.5/1.5	60° Downskin Roughness Ra (µm)	120	16.5	4.0

Results Platform Stability: Mechanical properties in SOLN 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.

ST: Stitched, parts built by multiple optical systems

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.