COLIBRIUM ADDITIVE
a GE Aerospace company

13 Al

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

L-PBF Ti6Al4V Grade 23

Parameters for Colibrium Additive's X Line 2000R

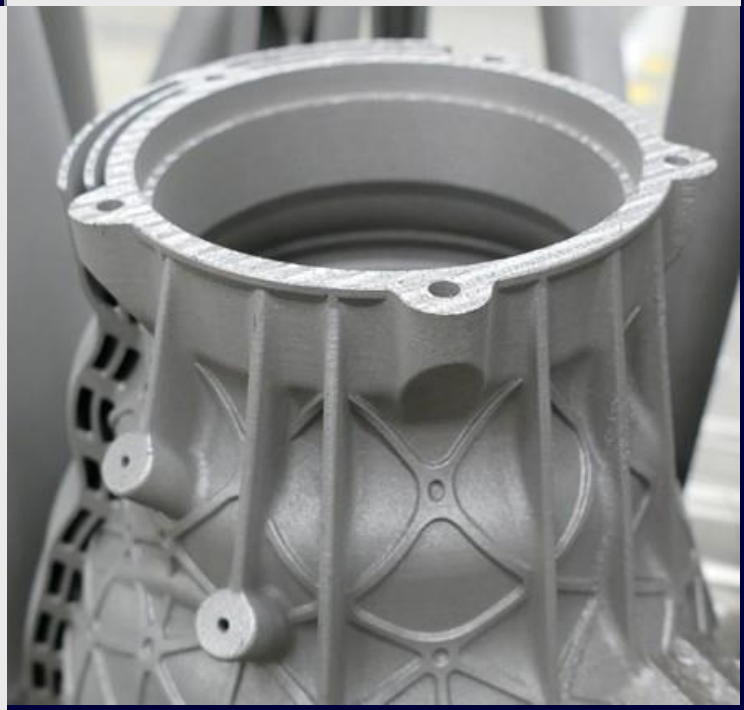
Titanium Ti6Al4V Grade 23 (ELI)

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.

X Line 2000R Ti6Al4V

The Ti-64 Grade 23 parameters for the Colibrium Additive X Line 2000R are developed leveraging the performance of the previous X Line generations. The balanced parameters deliver a good balance between surface quality and productivity. Furthermore, the parameter offers a very good density as well as strength and elongation. To achieve high productivity, the productivity parameter with higher laser power is the better choice.

Moreover, the mechanical properties succeed the limits specified in ASTM F3001 for additive manufactured parts. A large variety of heat treatments have been evaluated, in order to offer the best solution depending on the mechanical properties' requirements.



M2 Series 5 Ti6Al4V

Machine Configuration

X Line 2000R

Dual-laser architecture

Argon gas

Platform heating: 200°C

Powder Chemistry

Ti6Al4V Grade 23 powder chemical composition according to ASTM F3001

Particle size: 15-45 µm

For more information, visit: AP&C

Thermal States

As-Built (AB)

Stress Relief (SR1)

900°C for 1 hour in argon; furnace cooling

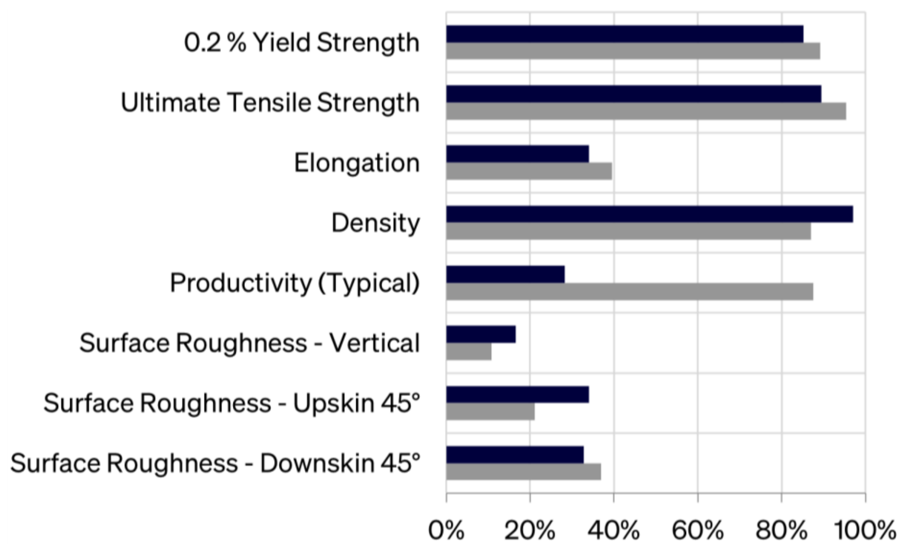
Stress Relief (SR2) + Hot Isostatic Pressing (HIP)

SR2:730°C for 2 hours in argon, furnace cooling

HIP: 920°C, 2 hours, 100 MPa

Parameter Availability and Thermal State Comparison

- Balanced Parameter 321 AB
  400 W, 60 µm layer thickness, carbon brush
- Productivity Parameter 314 AB
  1 kW, 60 µm layer thickness, carbon brush



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 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 321 - 400 W / 60 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	17.9
Theoretical melting rate bulk per laser[2]	31.1

[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	112	111	1085	1040	1225	1185
SR1	115	112	925	865	1015	990
SR2+HIP	115	112	915	850	1010	990

Thermal State	Elongation (%)	
	H	V
As-Built	5.7	7.9
SR1	13.3	13.7
SR2+HIP	13.8	15.4

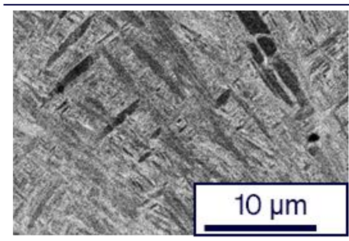
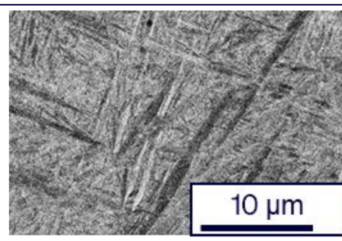
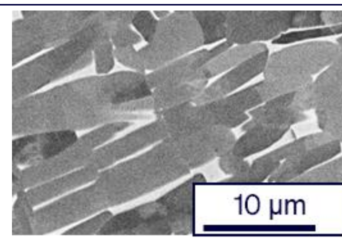
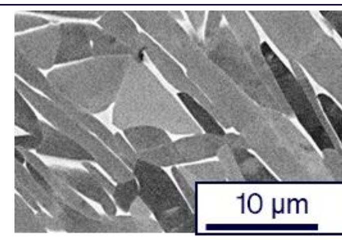
Physical Properties at Room Temperature

	Overhang Surface Roughness, Ra (µm)		
	45°	60°	75°
Upskin	17	13	10
Downskin	17	13	10

Surface Roughness, Ra (µm)	
H	-
V	11

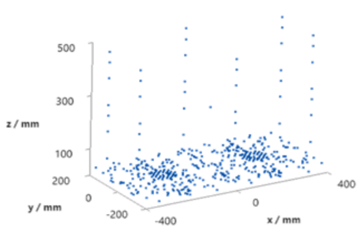
Thermal State	Relative Density (%)		Hardness (HV10)
	H	V	H
As-Built	99.9	99.9	362

Microstructure

As-Built		SR2+HIP	
H	V	H	V
			

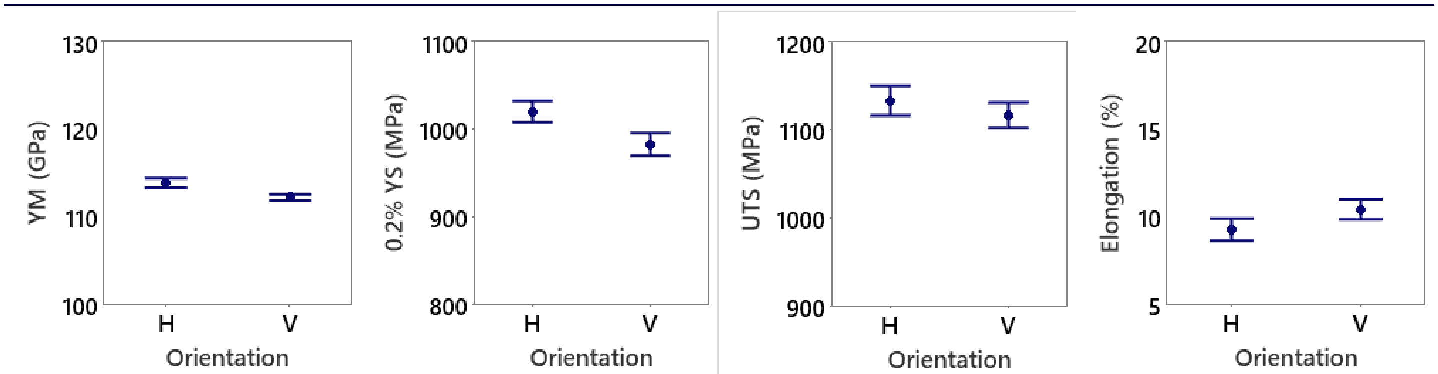
Scanning electron microscope images in As-Built and SR2+ HIP condition as defined previously.

Within 3 platform stability builds relative density, roughness and tensile properties across different positions and orientations are evaluated. To illustrate the position dependency of the X Line 2000R, the samples were homogenously distributed across the platform and height. 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.

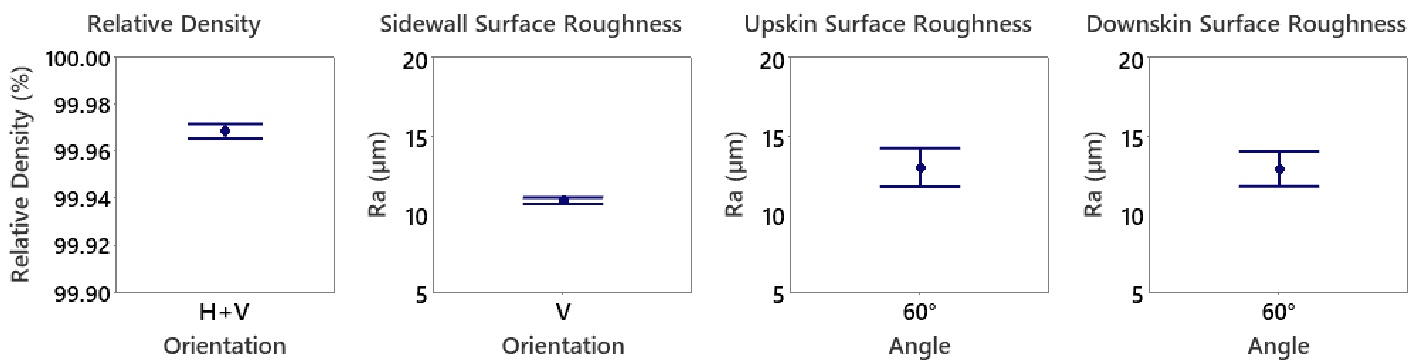


	Sample Size	Mean	Std. Dev.		Sample Size	Mean	Std. Dev.
YM (GPa) H/V - AB	79/94	112/111	3/2	Rel. Density (%)	236	99.97	0.02
0.2% YS (MPa) H/V - AB	79/94	1087/1045	11/15	Sidewall Roughness Ra (µm)	552	10	2
UTS (MPa) H/V - AB	79/94	1230/1188	10/14	60° Upskin Roughness Ra (µm)	16	13	3
Elongation (%) H/V - AB	79/94	5.7/8.0	0.9/2.0	60° Downskin Roughness Ra (µm)	16	12	3

Results Platform Stability: Mechanical properties in AB condition



Results Platform Stability: Relative Density and Surface Quality



Productivity Parameter 314 - 1 kW / 60 µm

Typical Build Rate

	(cm^3/h)
Typical build rate with coating[1]	61.9
Theoretical melting rate bulk per laser[2]	62.2

[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	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
	V	V	V
As-Built	1115	1285	7.5

Physical Properties at Room Temperature

	Overhang Surface Roughness, Ra (µm)
	45°
Upskin	13
Downskin	18

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

Thermal State	Relative Density (%)
As-Built	99.8

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.