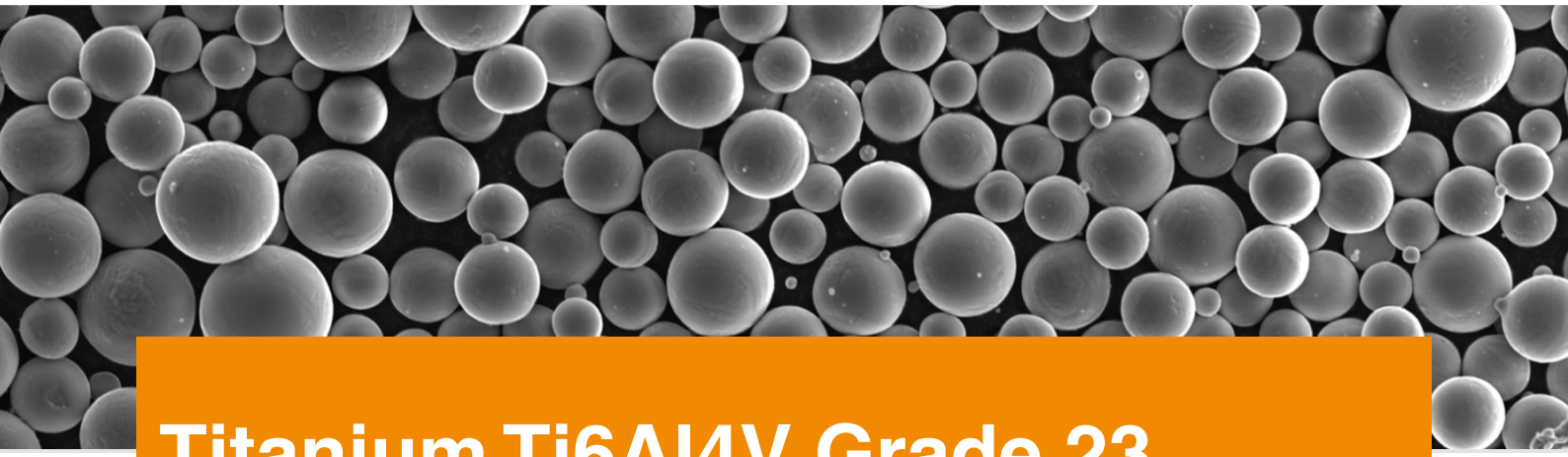
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Titanium Ti6Al4V Grade 23

This material is compatible with LIBERTAS™ technology.

This data sheet indicates the material properties achievable with additively manufactured (AM) parts made from Titanium Ti6Al4V Grade 23 powder. The data shown is only applicable to parts made on Renishaw's RenAM 500 series of Laser Powder Bed Fusion (LBPF) metal AM systems.

Ti6Al4V alloy comprises titanium, aluminium and vanadium, along with other minor elements. Ti6Al4V Grade 23 alloy is otherwise referred to as Extra Low Interstitial (ELI) because of its low content of interstitial impurities such as oxygen, carbon, and nitrogen.

Ti6Al4V alloy has excellent specific strength (strength to weight ratio), which makes it a suitable choice for load-bearing applications where weight reduction is a key requirement. It has good corrosion resistance and is biocompatible, making it suitable for a range of surgical and dental applications.

Material properties

- High specific strength
- High corrosion resistance
- Excellent biocompatibility
- Good osseointegration
- Low thermal expansion
- Low thermal conductivity

Applications

- Medical and dental
- Aerospace and defence
- Motorsport
- Jewellery and art
- Maritime applications
- High-end sports equipment

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1 Typical wrought material properties

The typical wrought material properties of Ti6Al4V Grade 23 that can be used as reference data to supportcomparison and material qualification.

Material property	Wrought material value
Density	4.4 g/cm^3
Thermal conductivity	6 W/mK to 8 W/mK
Melting temperature	1,635 °C to 1,665 °C
Coefficient of thermal expansion [1]	8×10^{-6} K^{-1} to 9×10^{-6} K^{-1}

NOTE: To learn more about the flag notes, refer to section 6 “Notes”.

2 Recommended composition of powder

The recommended powder size distribution is 15 µm to 45 µm.

The values shown in this table are for ASTM standard composition powder. Renishaw powders are supplied to a tighter specification to minimise batch-to-batch variations. Results quoted in this data sheet are from samples produced using Renishaw’s tighter-specification powder. To purchase powder from Renishaw, visit the online store at **www.renishaw.com/shop**.

Please contact Renishaw for further information about specifications or if you require support in qualifying non-Renishaw powders.

Element	Ti	Al	V	Fe	O	C	N	H	Y	Residual elements
Mass (%)	Balance	5.50 to 6.50	3.50 to 4.50	≤ 0.25	≤ 0.13	≤ 0.08	≤ 0.03	≤ 0.01	≤ 0.01	≤ 0.10 each, ≤ 0.40 total

3 Recommended RenAM 500 series machine settings

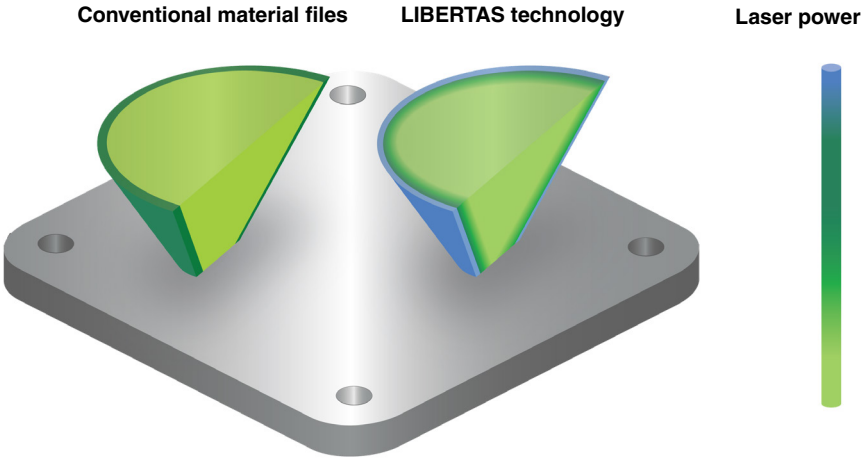
These system settings are intended for Renishaw specification powder at the recommended powder size distribution. See section 2 “Recommended composition of powder”.for more details.

Gas flow	190 m^3/h
Sieve size	80 µm
Differential pressure setting for the SafeChange™ filter	75 mbar

4 LIBERTAS technology

LIBERTAS technology is a laser control method developed by Renishaw that gives you freedom to dynamically adjust laser parameters (such as power and exposure time) during a build to meet the requirements of your part geometry.

Unlike conventional material files that use fixed laser settings for each type of area in a part (e.g. downskin, borders and bulk), LIBERTAS allows selected laser parameters to continuously vary between these areas. This results in better distribution of laser energy, meaning improved heat management and reduced internal stress in your parts.



4.1 Support Reduction Package

Building on the foundation of LIBERTAS technology, Renishaw has developed the Support Reduction Package (SRP). SRP leverages LIBERTAS technology to modify energy distribution across each layer, reducing the need for supports.

Traditionally, support structures are required for overhanging surfaces with a critical angle of 45° or less from the horizontal. Using SRP can reduce this critical angle to just 10° in some cases. To show the material performance at these low angles, material property data for SRP material files is shown at build angles of 90°, 50°, 40°, 30°, 20° and 10°.

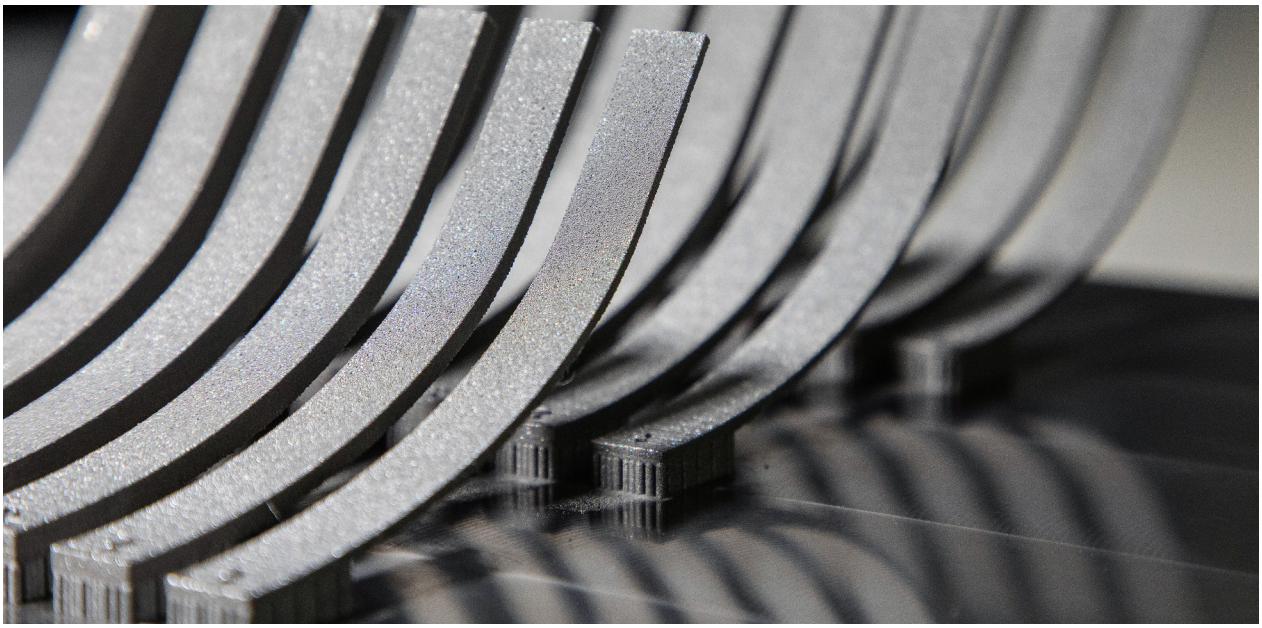


Figure 1 Complex curve SRP build used to test low-angle performance

5 Material file properties

Material files contain the validated laser parameters used by Renishaw AM systems to build a specific alloy at a defined layer thickness and laser mode. Each file defines how the machine applies laser energy to achieve the intended material performance, which is indicated in the material property data below.

To download the latest material files for the RenAM 500 series, visit **www.renishaw.com/softwaredownloads.**

5.1 30 µm – single laser per part – continuous wave

Material files: Ti6Al4V_500QS_B30_M_02_A (meander scan strategy)
Ti6Al4V_500QS_B30_S_02_A (stripe scan strategy)

LIBERTAS technology	Layer thickness	Optimised for	Laser mode	Build rate	
No	30 µm	Single laser per part	Continuous wave	One laser: 10.26 cm^3/h	Four lasers: 41.04 cm^3/h

Properties of additively manufactured components

This parameter set is optimised for bulk density. The material properties in this table are indicative only. Further modification of the material file may be required to suit your application.

Mechanical test samples were created using four lasers, one laser per sample and with no downstream processing. Meander scan strategy was used for vertical samples. Stripe scan strategy was used for horizontal samples.

		Annealed [2]
Bulk density [3]		≥ 99.8%
Ultimate tensile strength [4]	Horizontal (XY)	1 054 MPa ±3 MPa
	Vertical (Z)	996 MPa ±12 MPa
Yield strength [4]	Horizontal (XY)	990 MPa ±12 MPa
	Vertical (Z)	851 MPa ±22 MPa
Elongation after fracture [4]	Horizontal (XY)	17% ±1%
	Vertical (Z)	22% ±1%
Modulus of elasticity [4]	Horizontal (XY)	123 GPa ±10 GPa
	Vertical (Z)	118 GPa ± 8 GPa
Hardness (Vickers) [5]	Horizontal (XY)	347 HV0.5 ±5 HV0.5
	Vertical (Z)	351 HV0.5 ±4 HV0.5
Surface roughness (Ra) [6]	Vertical (Z) (Median Ra)	12 µm ±1 µm
	Vertical (Z) (Median Rz)	79 µm ±7 µm

NOTE: To learn more about the flag notes, refer to section 6 “Notes”.

5.2 60 µm – single laser per part – continuous wave

Material files: Ti6Al4V_500QS_B60_M_02_A (meander scan strategy)
Ti6Al4V_500QS_B60_S_02_A (stripe scan strategy)

LIBERTAS technology	Layer thickness	Optimised for	Laser mode	Build rate	
No	60 µm	Single laser per part	Continuous wave	One laser: 30.8 cm^3/h	Four lasers: 123.2 cm^3/h

Properties of additively manufactured components

This parameter set is optimised for bulk density. The material properties in this table are indicative only. Further modification of the material file may be required to suit your application.

Mechanical test samples were created using four lasers, one laser per sample and with no downstream processing. The scan strategy used for vertical samples is indicated in the table below. Stripe scan strategy was used for horizontal samples.

		Annealed [2]
Bulk density [3]		≥ 99.8%
Ultimate tensile strength [4]	Horizontal (XY)	1 033 MPa ±3 MPa
	Vertical (Z) – Meander	1 065 MPa ±5 MPa
	Vertical (Z) – Stripe	1 063 MPa ±4 MPa
Yield strength [4]	Horizontal (XY)	938 MPa ±10 MPa
	Vertical (Z) – Meander	956 MPa ±9 MPa
	Vertical (Z) – Stripe	994 MPa ±17 MPa
Elongation after fracture [4]	Horizontal (XY)	16% ±1%
	Vertical (Z) – Meander	18% ±1%
	Vertical (Z) – Stripe	22% ±1%
Modulus of elasticity [4]	Horizontal (XY)	115 GPa ±2 GPa
	Vertical (Z) – Meander	115 GPa ±3 GPa
	Vertical (Z) – Stripe	123 GPa ±5 GPa
Hardness (Vickers) [5]	Horizontal (XY)	353 HV0.5 ±5 HV0.5
	Vertical (Z)	349 HV0.5 ±6 HV0.5
Surface roughness (Ra) [6]	Vertical (Z) (Median Ra)	9 µm ±1 µm
	Vertical (Z) (Median Rz)	60 µm ±7 µm

NOTE: To learn more about the flag notes, refer to section 6 “Notes”.

5.2.1 LIBERTAS SRP – 60 µm – single laser per part – continuous wave

Material file: Ti6Al4V_500QS_E60_M_01_A (meander scan strategy)

LIBERTAS technology	Layer thickness	Optimised for	Laser mode	Build rate	
Yes	60 µm	Single laser per part	Continuous wave	One laser: 30.8 cm^3/h	Four lasers: 123.2 cm^3/h

Properties of additively manufactured components

This parameter set is optimised for support reduction. The material properties in the following table and graphs are indicative only. Further modification of the material file may be required to suit your application.

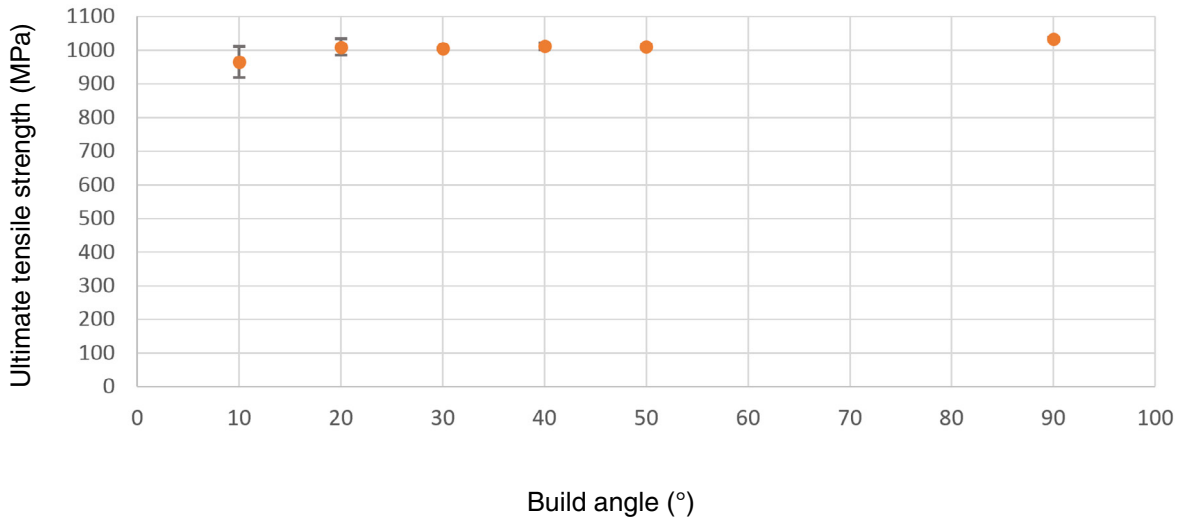
Mechanical test samples were created using two lasers, one laser per sample and with no downstream processing.

	Annealed [2]
Bulk density [7]	≥ 99.8%
Modulus of elasticity [4]	Refer to section 5.2 “60 µm – single laser per part – continuous wave”.

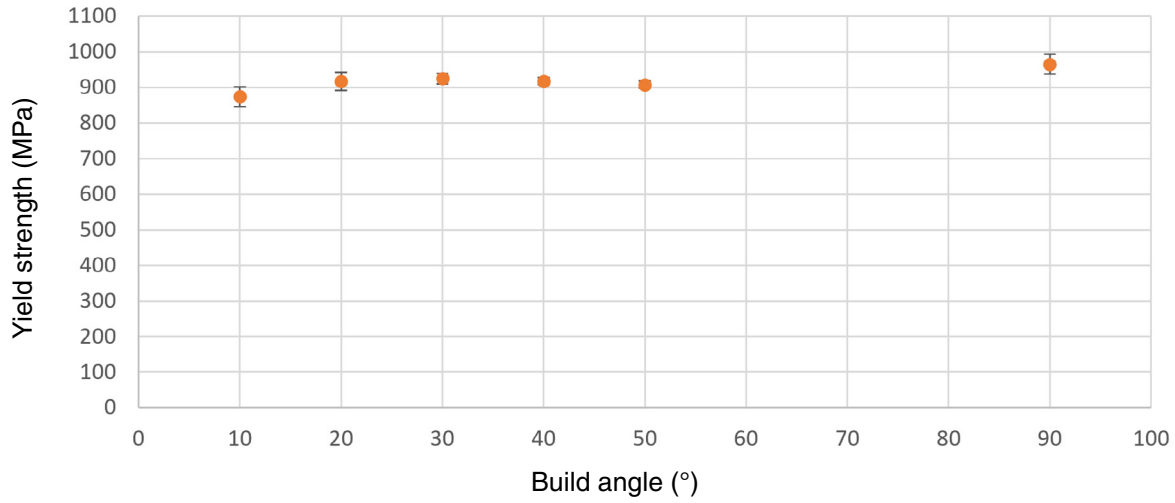
NOTE: To learn more about the flag notes, refer to section 6 “Notes”.

Material properties are presented as mean values achieved at each build angle. Error bars indicate standard deviation.

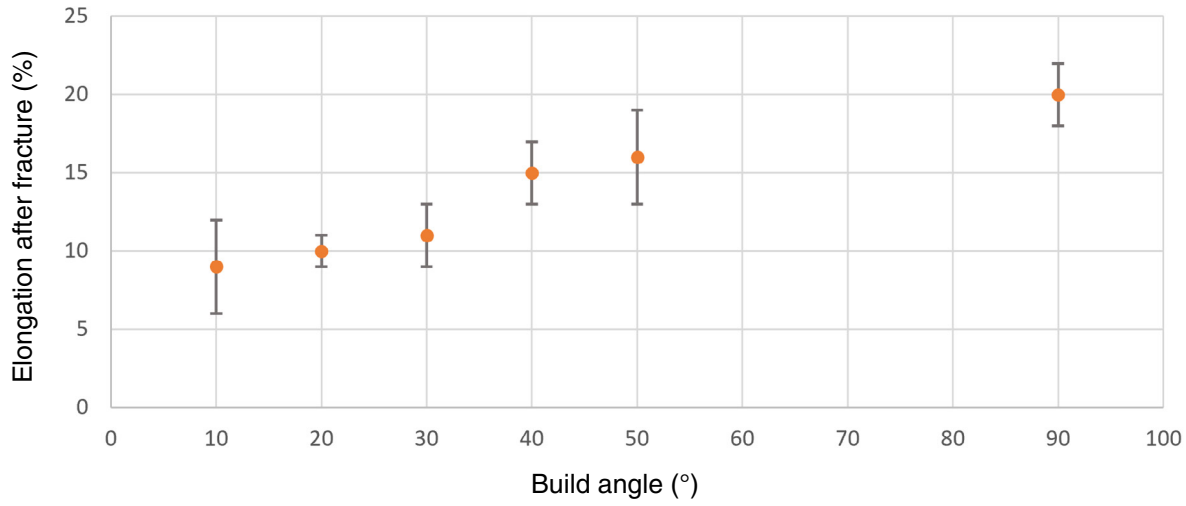
Ultimate tensile strength by build angle [8]



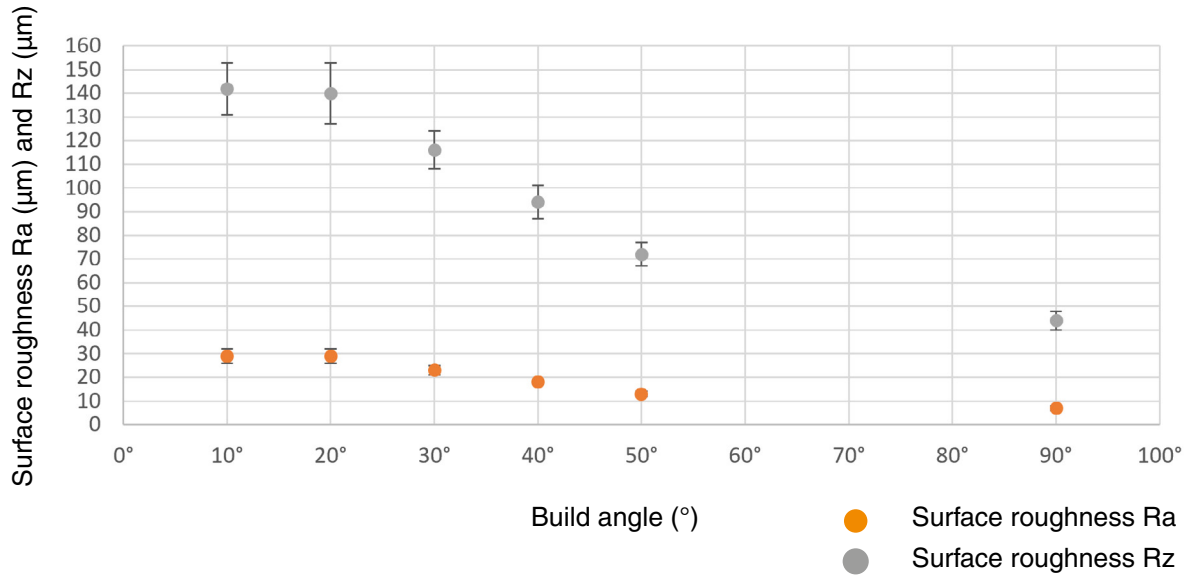
Yield strength by build angle [8]



Elongation after fracture by build angle [8]



Surface roughness (Ra and Rz) by build angle [9]



5.3 60 µm – multiple lasers per part – continuous wave

Material file: Ti6Al4V_500QS_C60_S_02_A (stripe scan strategy)

LIBERTAS technology	Layer thickness	Optimised for	Laser mode	Build rate
No	60 µm	Multiple lasers per part	Continuous wave	Four lasers: 123 cm^3/h

Properties of additively manufactured components

This parameter set is optimised for bulk density. The material properties in this table are indicative only. Further modification of the material file may be required to suit your application.

Mechanical test samples were created using four lasers, multiple lasers per sample and with no downstream processing. Stripe scan strategy was used for all samples.

		Annealed [2]
Bulk density [3]		≥ 99.8%
Ultimate tensile strength [4]	Horizontal (XY)	1 031 MPa ±5 MPa
	Vertical (Z)	1 057 MPa ±4 MPa
Yield strength [4]	Horizontal (XY)	938 MPa ±11 MPa
	Vertical (Z)	986 MPa ±16 MPa
Elongation after fracture [4]	Horizontal (XY)	16% ±1%
	Vertical (Z)	21% ±1%
Modulus of elasticity [4]	Horizontal (XY)	115 GPa ±2 GPa
	Vertical (Z)	122 GPa ±7 GPa
Hardness (Vickers) [5]	Horizontal (XY)	348 HV0.5 ±7 HV0.5
	Vertical (Z)	344 HV0.5 ±6 HV0.5
Surface roughness (Ra) [6]	Vertical (Z) (Median Ra)	10 µm ±1 µm
	Vertical (Z) (Median Rz)	67 µm ±5 µm

NOTE: To learn more about the flag notes, refer to section 6 “Notes”.

5.4 90 µm – single laser per part – continuous wave

Material files: Ti6Al4V_500QS_B90_M_02_A (meander scan strategy)
Ti6Al4V_500QS_B90_S_02_A (stripe scan strategy)

LIBERTAS technology	Layer thickness	Optimised for	Laser mode	Build rate	
No	90 µm	Single laser per part	Continuous wave	One laser: 63.5 cm^3/h	Four lasers: 254 cm^3/h

Properties of additively manufactured components

This parameter set is optimised for bulk density. The material properties in this table are indicative only. Further modification of the material file may be required to suit your application.

Mechanical test samples were created using four lasers, one laser per sample and with no downstream processing. Meander scan strategy was used for vertical samples. Stripe scan strategy was used for horizontal samples.

		Annealed [2]
Bulk density [3]		≥ 99.8%
Ultimate tensile strength [4]	Horizontal (XY)	1 043 MPa ±3 MPa
	Vertical (Z)	1 038 MPa ±8 MPa
Yield strength [4]	Horizontal (XY)	961 MPa ±8 MPa
	Vertical (Z)	969 MPa ±15 MPa
Elongation after fracture [4]	Horizontal (XY)	16% ±1%
	Vertical (Z)	19% ±1%
Modulus of elasticity [4]	Horizontal (XY)	118 GPa ±6 GPa
	Vertical (Z)	118 GPa ±8 GPa
Hardness (Vickers) [5]	Horizontal (XY)	351 HV0.5 ±5 HV0.5
	Vertical (Z)	351 HV0.5 ±7 HV0.5
Surface roughness (Ra) [6]	Vertical (Z) (Median Ra)	9 µm ±1 µm
	Vertical (Z) (Median Rz)	60 µm ±5 µm

NOTE: To learn more about the flag notes, refer to section 6 “Notes”.

6 Notes

1 In the range of 20 °C to 100 °C.

2 Annealing method used for testing: Under vacuum, heat at 13 °C/min to 800 °C ±10 °C, then hold temperature for 4 hours. Furnace cool to room temperature.

3 Measured optically on a 10 mm × 10 mm × 10 mm sample at 75× magnification.

4 Tested at ambient temperature to ASTM E8. Machined prior to testing. Values based on 16 samples. Yield strength values report the 0.2% yield strength.

5 Tested to ASTM E384-11 after polishing.

6 Tested on as-built vertical surfaces using laser interferometry. Tested to JIS B 0601-2001 (ISO 4287:1997).

7 Measured optically on a 40 mm × 10 mm × 3 mm Z-plane overhang sample at 75× magnification.

8 Tested at ambient temperature to ASTM E8. Samples bead-blasted prior to testing with no machined surfaces. Values based on 8 dog-bone samples per build angle (4 tilted into and 4 away from the wiper) using minimal supports.

9 Tested on bead-blasted downskin surfaces using laser interferometry. Tested to JIS B 0601-2001 (ISO 4287:1997). Values based on 8 dog-bone samples per build angle (4 tilted into and 4 away from the wiper) using minimal supports.

7 Disclaimer

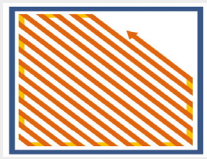
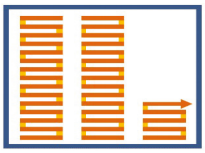
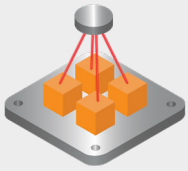
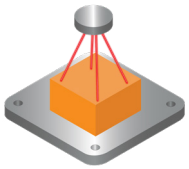
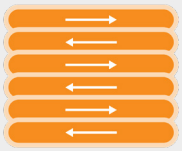
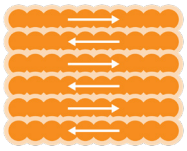
The mechanical property data featured in this document was obtained from tests performed in Renishaw's laboratories and only indicate the mechanical properties that can be achieved. The data is not intended as a guaranteed minimum specification.

8 Training and support

For training, application guidance, and technical support related to LIBERTAS and associated material parameter development, contact our Renishaw applications team. Renishaw can provide support to assist with material selection, parameter usage, and the effective application of LIBERTAS-enabled workflows within your manufacturing environment.

Phone number:	+44 (0) 1453 524 524 Hours of work: Monday to Friday 08:00 to 1700 hr (UTC and DST)
Email:	**am_applications@renishaw.com**
Service address:	Renishaw plc New Mills Wotton-under-Edge Gloucestershire GL12 8JR United Kingdom

9 Glossary of terms

Term	Definition
Scan strategy	Determines the path the laser will take to melt the cross-sectional area of the parts featured in each layer of the build process.
Meander 	A scan strategy that takes the form of a straight-line vector path that bounces back and forth from each side of the part border. Meander strategy is quick and ideal for parts with a small XY cross section.
Stripe 	A scan strategy where the area within the part border is split into strips and a meander technique is used within each strip. Stripe is ideal for parts with a large XY cross section.
Single laser per part 	Material files optimised for “single laser per part” are ideal for building many smaller parts simultaneously on a single build plate. They are best used by making sure each part is processed by only one dedicated laser throughout the entire build process.
Multiple laser per part 	Material files optimised for “Multiple lasers per part” are ideal for builds that feature only one or two large parts on the build plate. The scan paths of each laser have increased overlap with one another to ensure homogeneous melting of parts made with multiple lasers at once.
Continuous wave (CW) 	A laser strategy where a continuous laser beam delivers uninterrupted energy as it scans across the powder bed. It forms overlapping melt tracks to create a solid structure. This approach produces a stable and relatively broad melt pool, making it suitable operating at higher power and speeds. It is typically used for bulk regions where fast build rates and efficient material deposition are required.
Modulated wave (MW) 	A laser strategy where the laser is modulated, switching on and off to deliver energy as a series of discrete exposures. The laser modulation enables greater control over melt behaviour. This approach is well suited to detailed features where precision and controlled heat input are important.

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