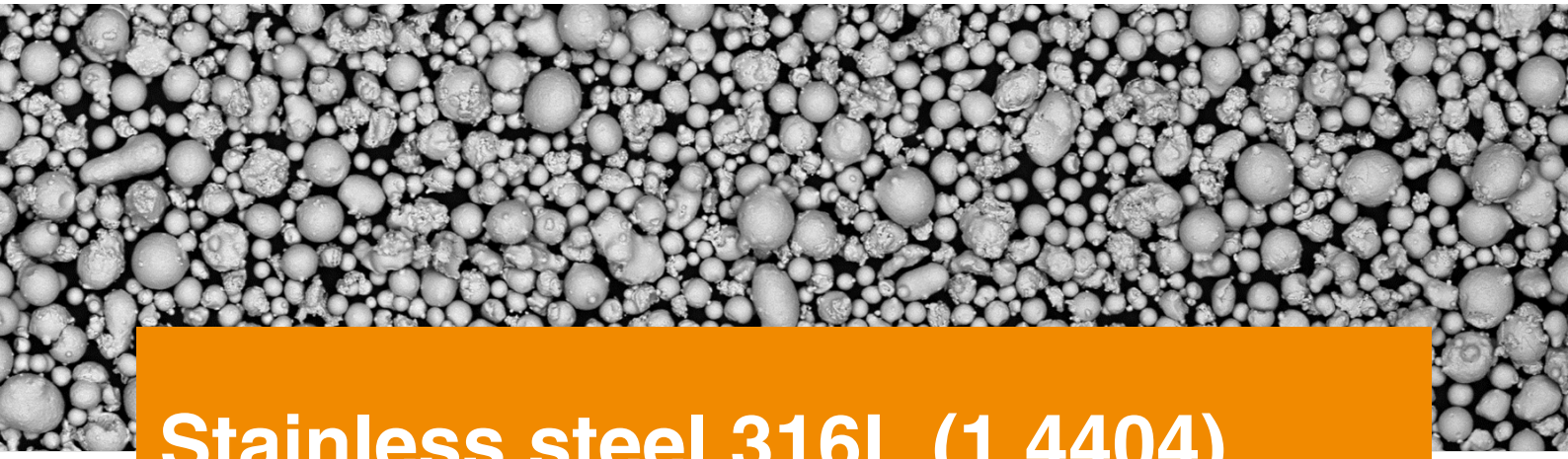
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Stainless steel 316L (1.4404)

This material is compatible with LIBERTAS™ technology.

This data sheet indicates the material properties achievable with additively manufactured (AM) parts made from Stainless Steel 316L 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.

Stainless steel 316L alloy (EN/W.Nr.: 1.4404) is an austenitic stainless steel consisting primarily of iron, alloyed with chromium up to 18% by mass, nickel up to 14%, and molybdenum up to 3%, along with other minor elements. The material's low carbon content reduces susceptibility to sensitisation from carbide precipitation at grain boundaries.

The material exhibits good welding characteristics and maintains high stress-to-rupture performance and tensile strength at elevated temperatures.

Material properties

- High hardness and toughness
- High corrosion resistance
- High machinability
- Can be highly polished

Applications

- Plastic injection, pressure die-casting moulds and extrusion dies
- Surgical tools
- Cutlery and kitchenware
- Maritime components
- Spindles and screws
- General engineering

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1 Typical wrought material properties

The typical wrought material properties of stainless steel 316L alloy (EN/W.Nr.: 1.4404) that can be used as reference data to support comparison and material qualification.

Material property	Wrought material value
Density	8 g/cm3
Thermal conductivity	16 W/mK
Melting temperature	1 371 °C to 1 399 °C
Coefficient of thermal expansion [1]	16×10^{-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	Fe	Cr	Ni	Mo	Mn	Si	N	O	P	C	S
Mass (%)	Balance	16.00 to 18.00	10.00 to 14.00	2.00 to 3.00	≤ 2.00	≤ 1.00	≤ 0.10	≤ 0.10	≤ 0.05	≤ 0.03	≤ 0.03

3 Recommended RenAM 500 series machine settings

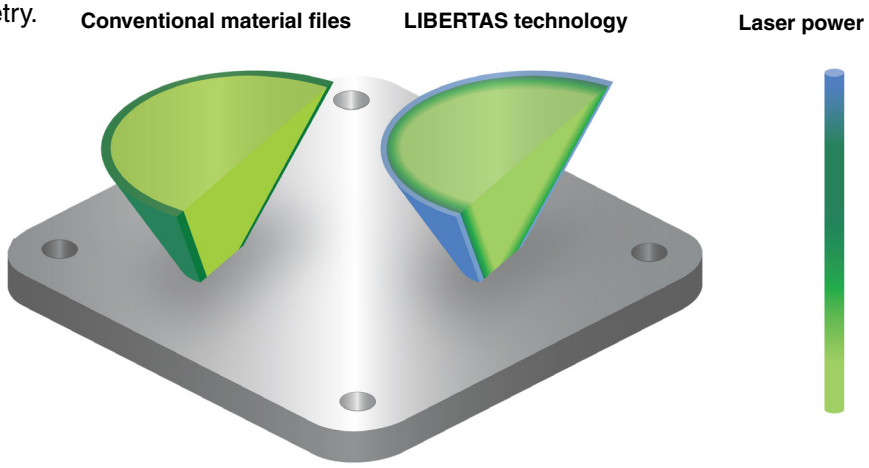
These system settings are intended for Renishaw specification powder at the recommended powder size distribution. See section 2 “Recommended composition of powder” for details.

Gas flow	190 m^3/h
Sieve size	63 µm
Differential pressure setting for the SafeChange filter	95 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°.

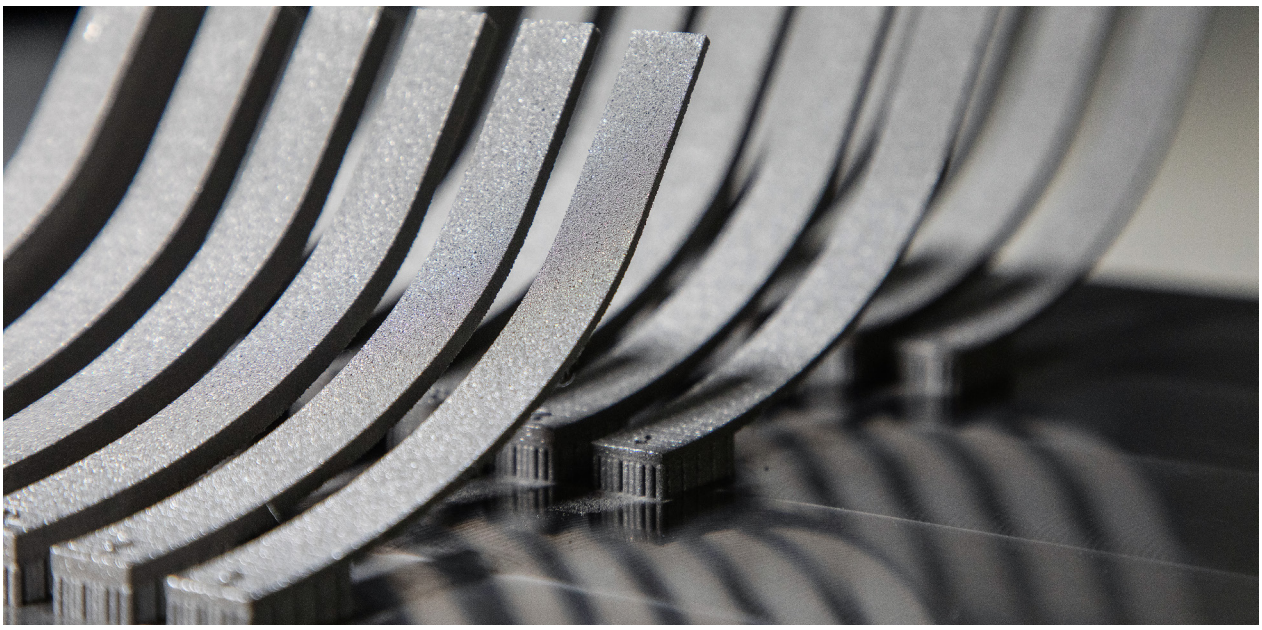


Figure 1 Complex curve SRP build used to test low-angle performance

5 Material files

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: SS316L_500QS_B30_M_02_A (meander scan strategy)
SS316L_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: 12.5 cm^3/h	Four lasers: 50.0 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, single lasers per sample and with no downstream processing. Meander scan strategy was used for vertical samples. Stripe scan strategy was used for horizontal samples.

		As built	Solution annealed [2]
Bulk density [3]		≥ 99.8%	–
Ultimate tensile strength [4]	Horizontal (XY)	708 MPa ±2 MPa	667 MPa ±3 MPa
	Vertical (Z)	651 MPa ±4 MPa	629 MPa ±3 MPa
Yield strength [4]	Horizontal (XY)	591 MPa ±3 MPa	420 MPa ±3 MPa
	Vertical (Z)	532 MPa ±5 MPa	395 MPa ±2 MPa
Elongation after fracture [4]	Horizontal (XY)	48% ±2%	53% ±1%
	Vertical (Z)	60% ±2%	66% ±2%
Modulus of elasticity [4]	Horizontal (XY)	191 GPa ±14 GPa	185 GPa ±10 GPa
	Vertical (Z)	199 GPa ±18 GPa	192 GPa ±15 GPa
Hardness (Vickers) [5]	Horizontal (XY)	209 HV0.5 ±5 HV0.5	204 HV0.5 ±3 HV0.5
	Vertical (Z)	214 HV0.5 ±6 HV0.5	203 HV0.5 ±5 HV0.5
Surface roughness [6]	Vertical (Z) (Median Ra)	9 µm ±2 µm	10 µm ±2 µm
	Vertical (Z) (Median Rz)	71 µm ±9 µm	73 µm ±8 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: SS316L_500QS_B60_M_02_A (meander scan strategy)
SS316L_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: 23.8 cm^3/h	Four lasers: 95.2 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. Meander scan strategy was used for vertical samples. Stripe scan strategy was used for horizontal samples.

		As built	Solution annealed [2]
Bulk density [3]		≥ 99.8%	–
Ultimate tensile strength [4]	Horizontal (XY)	699 MPa ±6 MPa	673 MPa ±3 MPa
	Vertical (Z)	631 MPa ±3 MPa	635 MPa ±4 MPa
Yield strength [4]	Horizontal (XY)	564 MPa ±6 MPa	418 MPa ±3 MPa
	Vertical (Z)	495 MPa ±3 MPa	396 MPa ±3 MPa
Elongation after fracture [4]	Horizontal (XY)	40% ±2%	55% ±1%
	Vertical (Z)	47% ±1%	65% ±3%
Modulus of elasticity [4]	Horizontal (XY)	198 GPa ±8 GPa	196 GPa ±8 GPa
	Vertical (Z)	208 GPa ±19 GPa	189 GPa ±7 GPa
Hardness (Vickers) [5]	Horizontal (XY)	214 HV0.5 ±3 HV0.5	200 HV0.5 ±4 HV0.5
	Vertical (Z)	226 HV0.5 ±5 HV0.5	201 HV0.5 ±3 HV0.5
Surface roughness [6]	Vertical (Z) (Median Ra)	9 µm ±1 µm	14 µm ±1 µm
	Vertical (Z) (Median Rz)	67 µm ±10 µm	89 µm ±8 µm
Plastometrex yield strength [7]	Horizontal (XY)	–	338 MPa ±10 MPa
Plastometrex ultimate tensile strength [7]	Horizontal (XY)	–	723 MPa ±27 MPa

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: SS316L_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: 23.8 cm^3/h	Four lasers: 95.2 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.

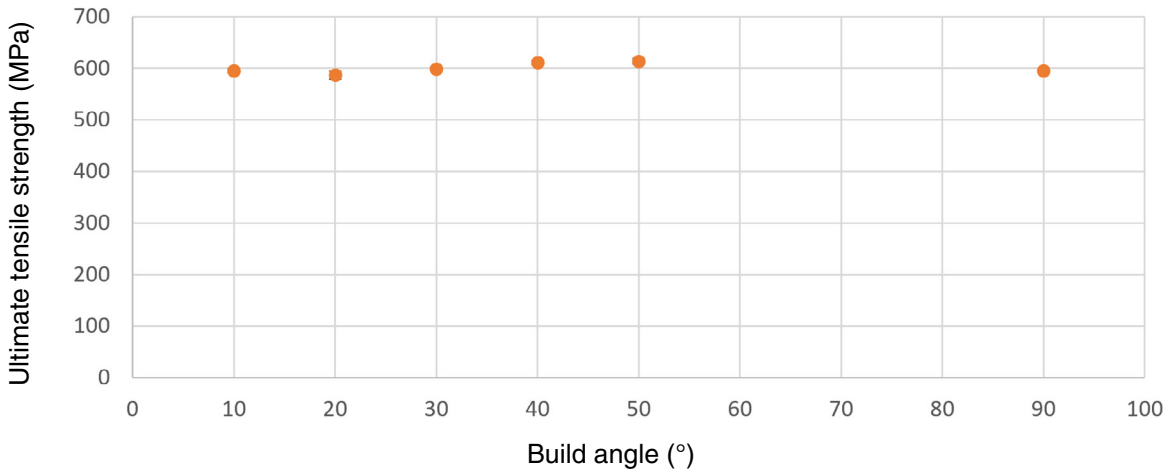
Mechanical test samples were created using two lasers, one laser per sample and with no downstream processing.

	Solution annealed [2]
Bulk density [8]	≥ 99.8%
Modulus of elasticity [4]	Refer to section 5.2 “60 µm – single laser per part – continuous wave”

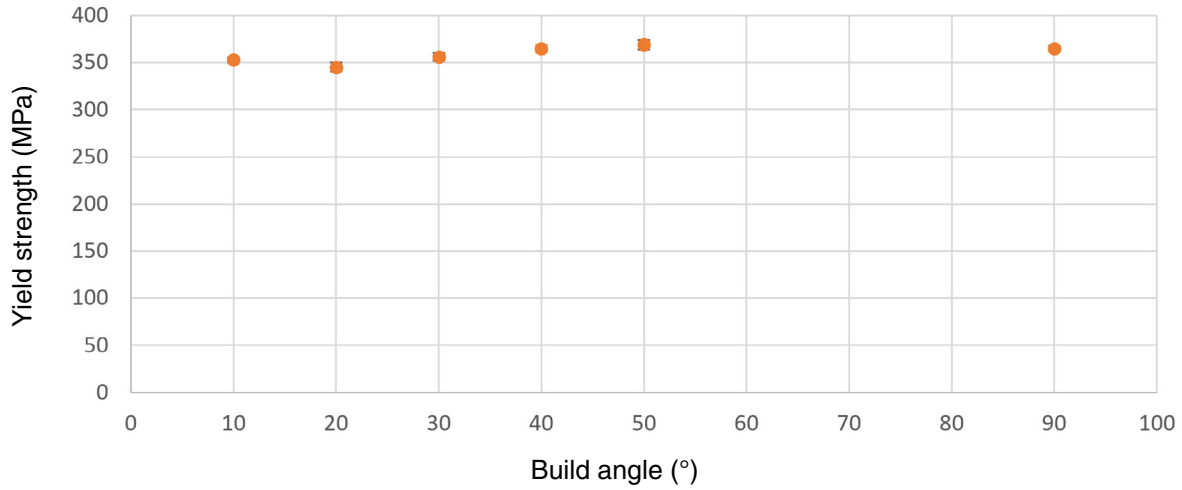
NOTE: To learn more about the flag notes, refer to section 6 “Notes”.

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

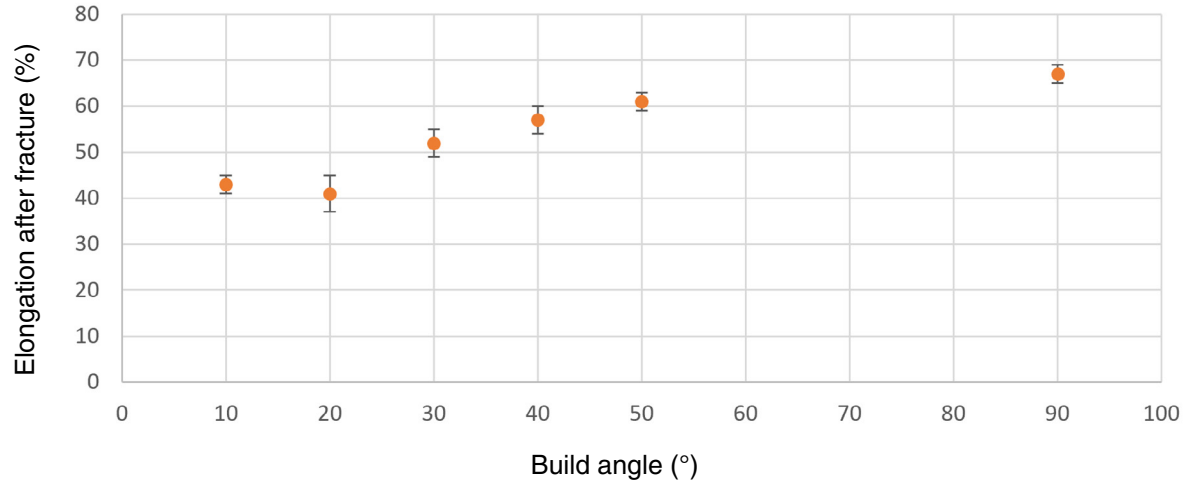
Ultimate tensile strength by build angle [9]



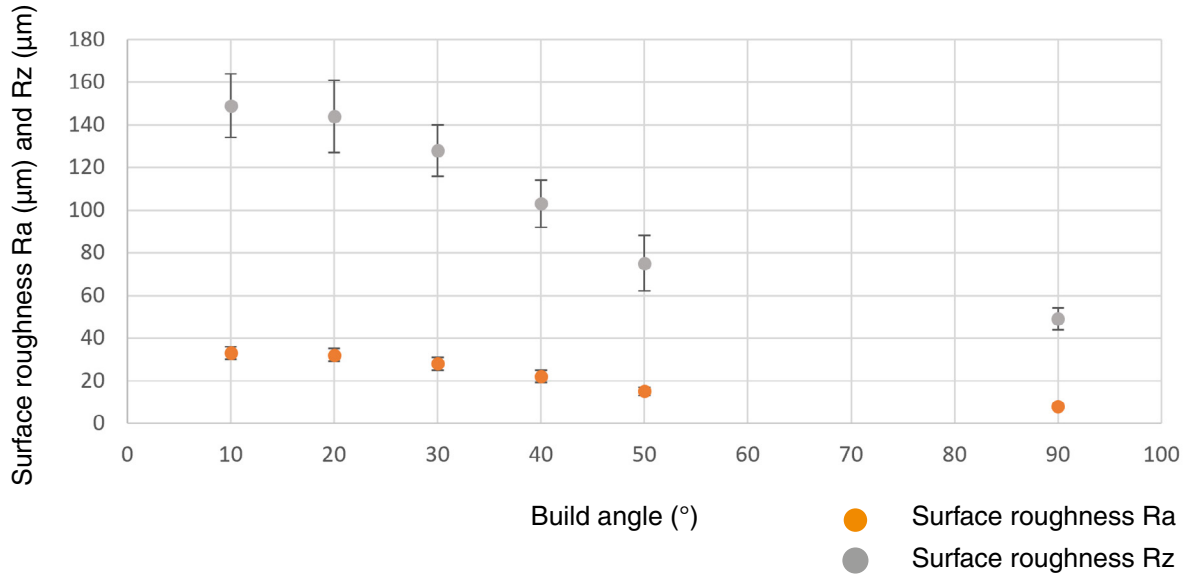
Yield strength by build angle [9]



Elongation after fracture by build angle [9]



Surface roughness (Ra and Rz) by build angle [10]



5.3 60 µm – multiple lasers per part – continuous wave

Material files: SS316L_500QS_C60_S_03_A (stripe scan strategy)

LIBERTAS technology	Layer thickness	Optimised for	Laser mode	Build rate
No	60 µm	Multiple laser per part	Continuous wave	Four lasers: 95.2 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, multiple lasers per sample and with no downstream processing. Stripe scan strategy was used for all samples.

		As built	Solution annealed [2]
Bulk density [3]		≥ 99.8%	–
Ultimate tensile strength [4]	Horizontal (XY)	693 MPa ±3.5 MPa	674 MPa ±3 MPa
	Vertical (Z)	631 MPa ±3 MPa	636 MPa ±3 MPa
Yield strength [4]	Horizontal (XY)	565 MPa ±3.5 MPa	421 MPa ±2 MPa
	Vertical (Z)	495 MPa ±3 MPa	395 MPa ±3 MPa
Elongation after fracture [4]	Horizontal (XY)	53% ±2%	57% ±2%
	Vertical (Z)	47% ±1%	67% ±1%
Modulus of elasticity [4]	Horizontal (XY)	205 GPa ±12 GPa	193 GPa ±5 GPa
	Vertical (Z)	208 GPa ±19 GPa	170 GPa ±24 GPa
Hardness (Vickers) [5]	Horizontal (XY)	199 HV0.5 ±3 HV0.5	191 HV0.5 ±5 HV0.5
	Vertical (Z)	213 HV0.5 ±5 HV0.5	193 HV0.5 ±4 HV0.5
Surface roughness [6]	Vertical (Z) (Median Ra)	11 µm ±2 µm	11 µm ±2 µm
	Vertical (Z) (Median Rz)	77 µm ±14 µm	71 µm ±9 µm

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

5.4 70 µm – single laser per part – continuous wave

Material files: SS316L_500QS_B70_M_02_A (meander scan strategy)
SS316L_500QS_B70_S_02_A (stripe scan strategy)

LIBERTAS technology	Layer thickness	Optimised for	Laser mode	Build rate	
No	70 µm	Single laser per part	Continuous wave	One laser: 36.3 cm^3/h	Four lasers: 145.2 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, multiple lasers per sample and with no downstream processing. Meander scan strategy was used for vertical samples. Stripe scan strategy was used for horizontal samples.

		As built
Bulk density [3]		≥ 99.8%
Ultimate tensile strength [4]	Horizontal (XY)	594 MPa ±5 MPa
	Vertical (Z)	669 MPa ±7 MPa
Yield strength [4]	Horizontal (XY)	555 MPa ±5 MPa
	Vertical (Z)	513 MPa ±5 MPa
Elongation after fracture [4]	Horizontal (XY)	49% ±3%
	Vertical (Z)	55% ±3%
Modulus of elasticity [4]	Horizontal (XY)	185 GPa ±10 GPa
	Vertical (Z)	177 GPa ±16 GPa
Hardness (Vickers) [5]	Horizontal (XY)	204 HV0.5 ±5 HV0.5
	Vertical (Z)	–
Surface roughness [6]	Vertical (Z) (Median Ra)	10 µm ±2 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] Solution annealing method used for testing: Under vacuum, heat at 13 °C/min to 900 °C ±15 °C, then hold temperature for 2 hours. Gas quench with argon at 1 bar to room temperature.

[3] Measured optically on 10 mm × 10 mm × 10 mm samples 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] Plastometrex's standard indentation procedure was used to generate the data. Indents were carried out on 10 mm × 10 mm × 10 mm samples. Values are based on 5 indents from 3 samples.

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

[9] 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.

[10] 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

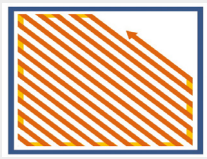
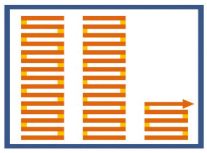
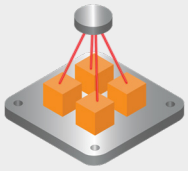
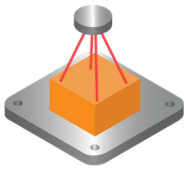
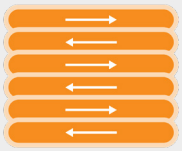
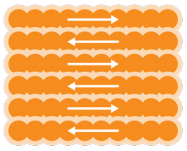
The mechanical property data featured in this document was obtained from tests performed in Renishaw's laboratories and only indicate the mechanical properties that can be achieved. The data is not intended as a guaranteed minimum specification.

8 Training and support

For training, application guidance, and technical support related to LIBERTAS and associated material parameter development, contact Renishaw directly. 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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