Townsend, Andrew, Blunt, Liam and Bills, Paul J.

Investigating the capability of microfocus x-ray computed tomography for areal surface analysis of additively manufactured parts

Investigating the capability of micro-focus x-ray computed tomography for areal surface analysis of additively manufactured parts

June 30, 2016

A. Townsend, L. Blunt, P. Bills
EPSRC Centre for Innovative Manufacturing in Advanced Metrology,
University of Huddersfield, UK.

EPSRC Centre for Innovative Manufacturing in Advanced Metrology

Nationally funded centre of excellence in advance metrology. Based at the University of Huddersfield's Centre for Precision Technologies, with an international reputation in precision engineering, metrology research and standards development.

Key areas of research are:

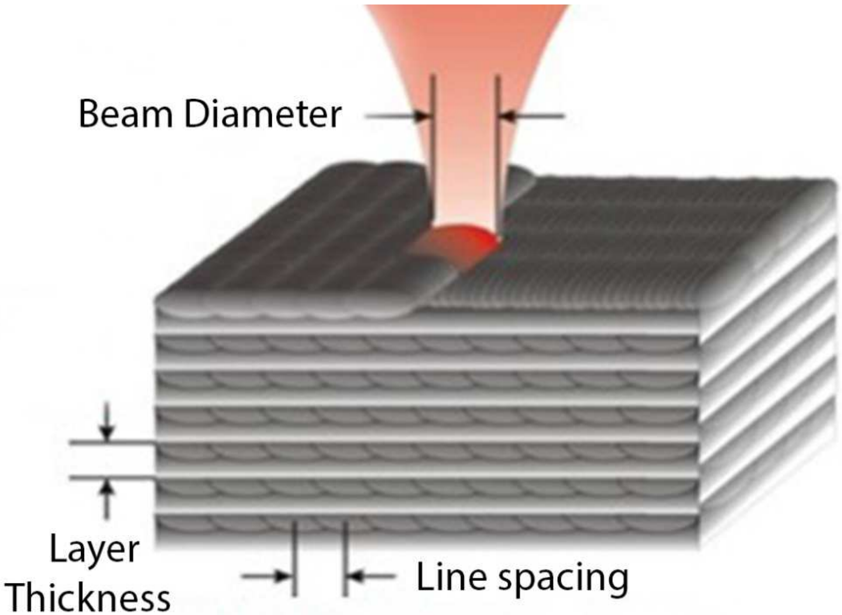
- Surface Metrology
- Additive Manufacturing
- Optical Metrology
- Ultra Precision Manufacturing
- Software Development
- Hardware Applications
- Industrial Metrology

University of Huddersfield, UK

Outline

- Importance of surface texture measurement for Additive Manufacturing (AM)
- Surface characterisation choices
- X-ray computed tomography (XCT) for AM surfaces
  - Rubert comparator plates
  - AlSi10Mg AM component
- Conclusions and future work

Embedded surface example (powder bed fusion)



- Cube 10 mm per side
- 100 µm build layer thickness
- 100 µm line spacing

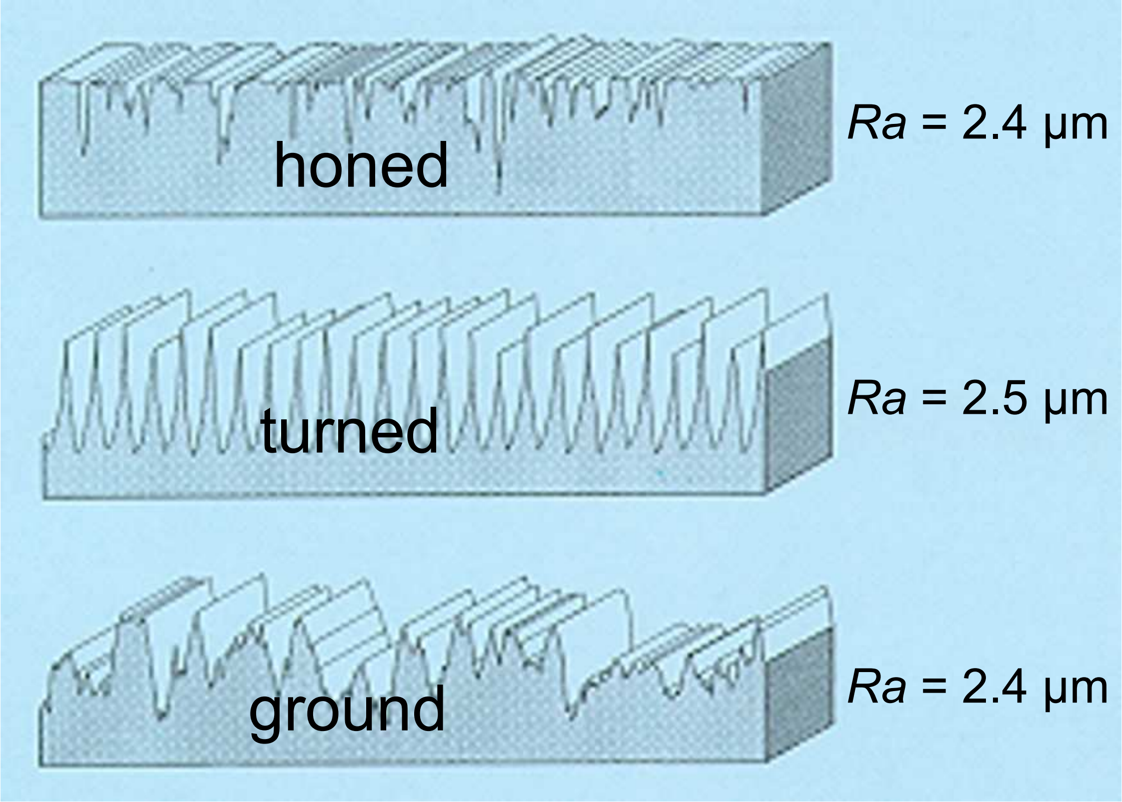
Approximate percentage of total surface area produced *during* the manufacturing process remaining as outside surface on completion:

3%

Defects embedded?
Surface irregularities magnified?

Surface characterisation choices
Is *Ra* best?

Comparing *Ra* values
for the profile of different surfaces

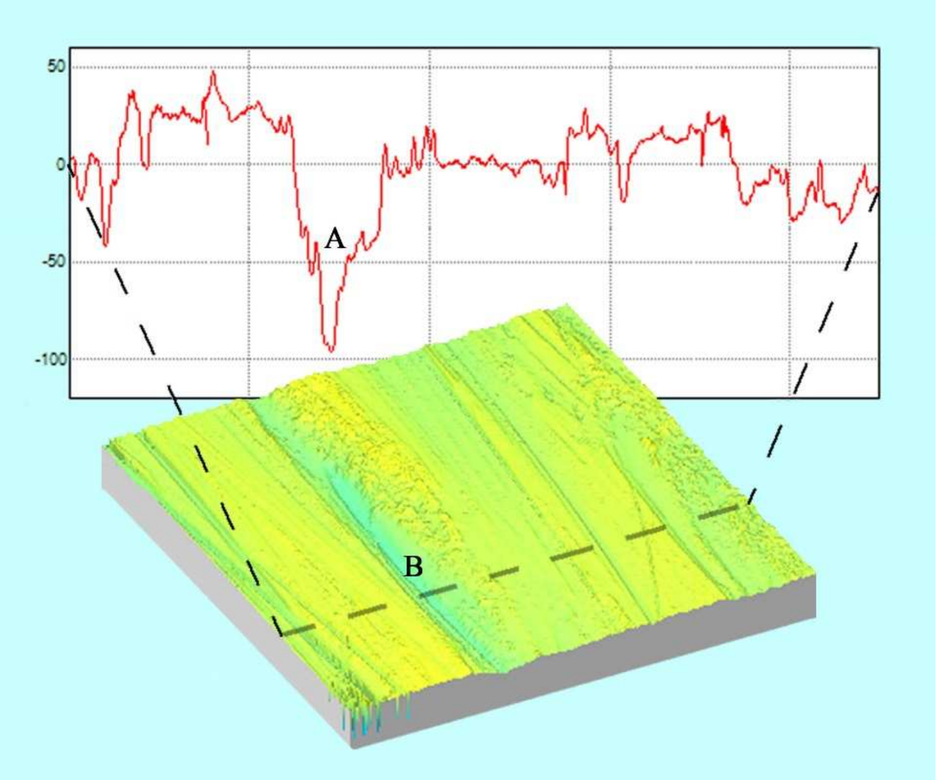


Mummery L., (1990), *Surface texture analysis: the handbook*. Hommelwerke Mulhausen.

Ra
Arithmetic mean deviation of the assessed profile

The *Ra* value **does not** provide any information as to the shape of the irregularities on the surface. It is possible to obtain similar *Ra* values for surfaces having very different profiles.

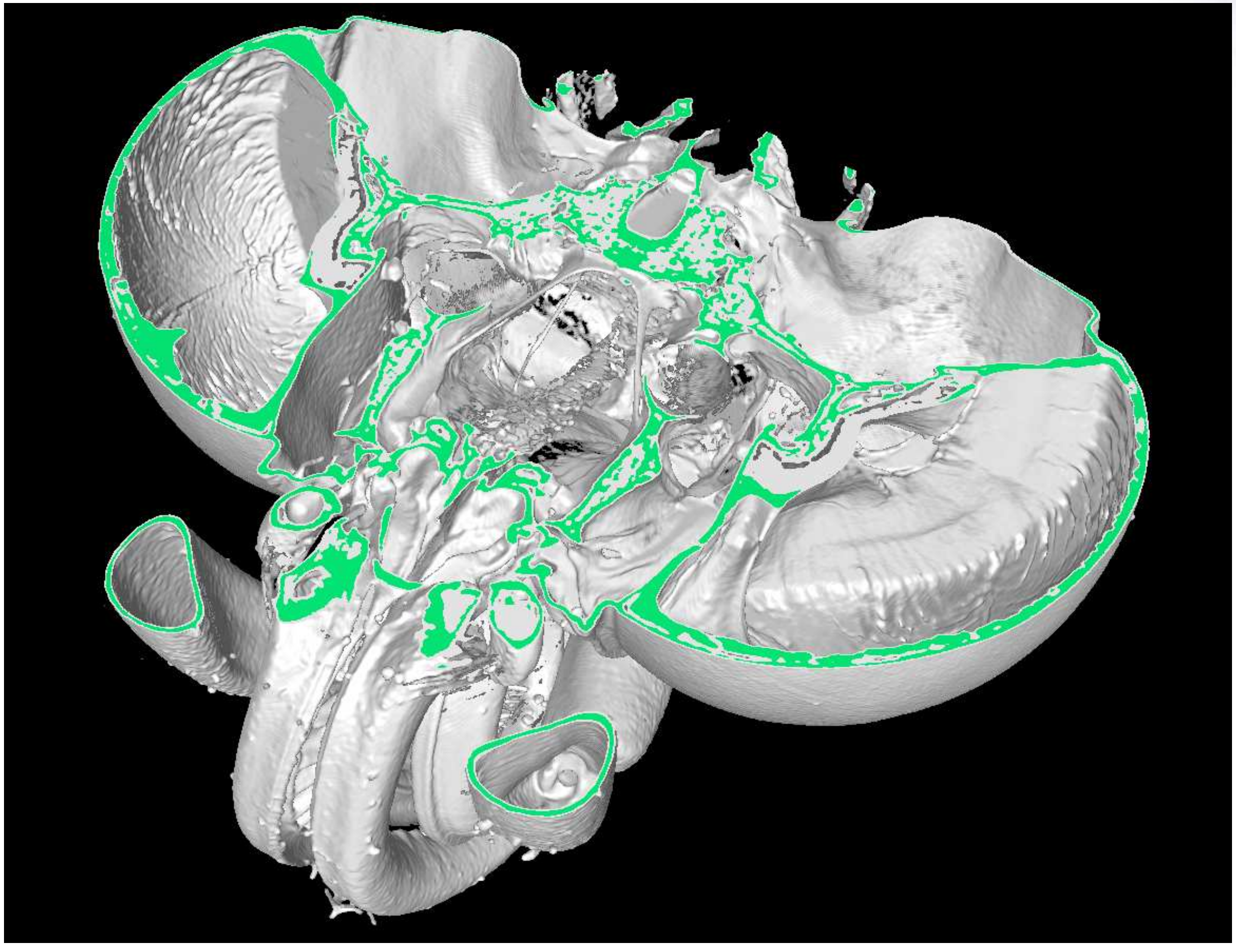
Surface characterisation choices
Profile or areal measurements?



Pit or valley?

AM surfaces are complex!
Simple profile roughness measurements may not be enough!

XCT for AM surfaces
Areal surface texture data from XCT



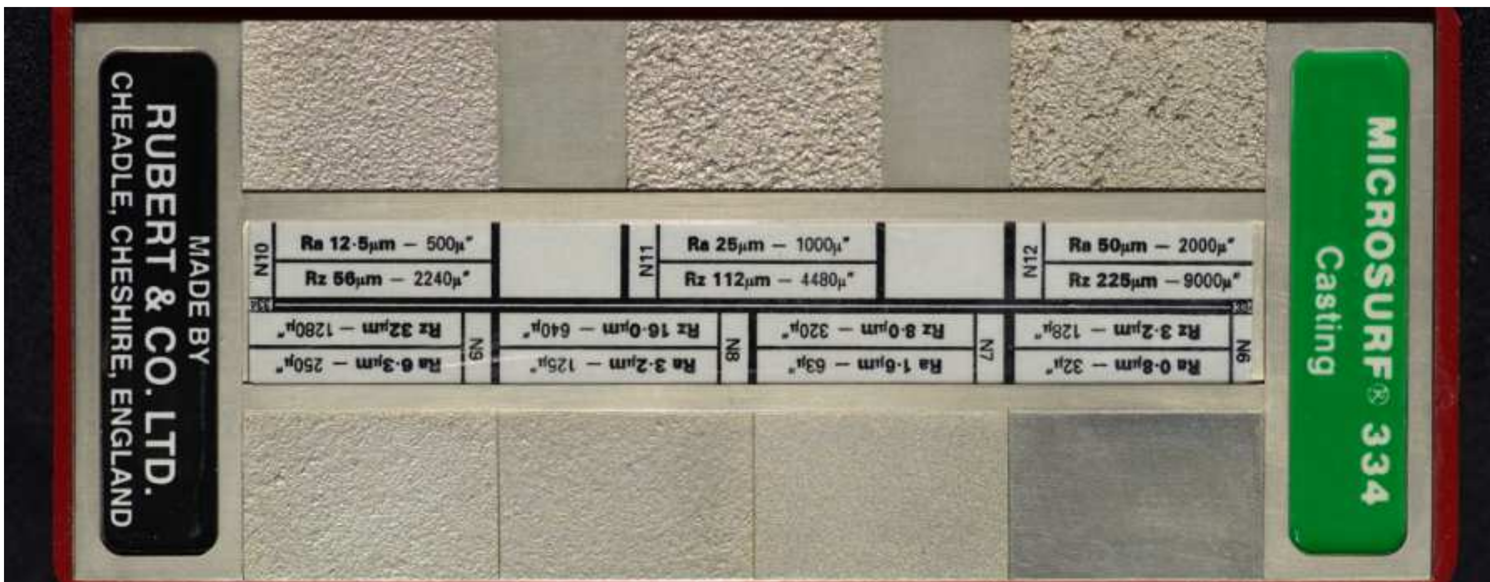
Moth head section (Nikon XT H 225).

XCT for AM surfaces
Areal surface texture data from XCT

Rubert comparator plates.

Focus variation.
Alicona G4.

X-ray computed tomography.
Nikon XT H 225.



Rubert & Co. Microsurf 334 comparator plate.
(Casting).

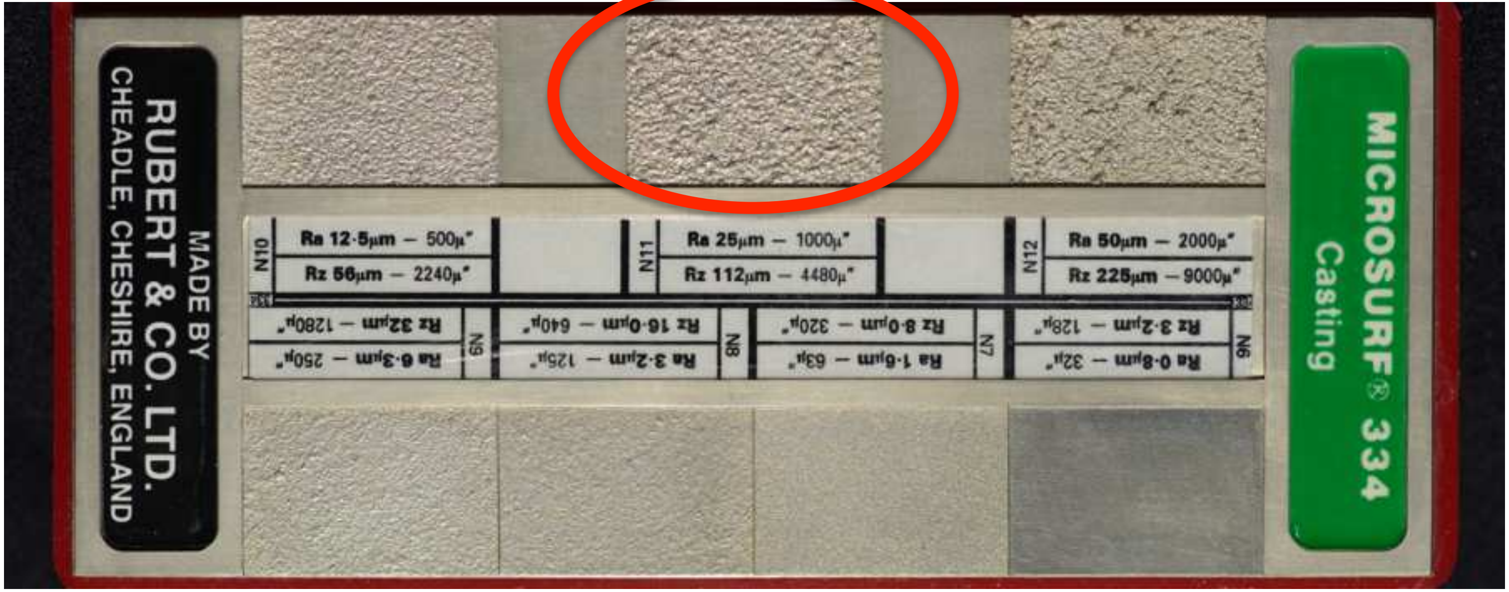
University of Huddersfield

XCT for AM surfaces
Areal surface texture data from XCT

EPSRC
Pioneering research and skills

Rubert comparator plates.

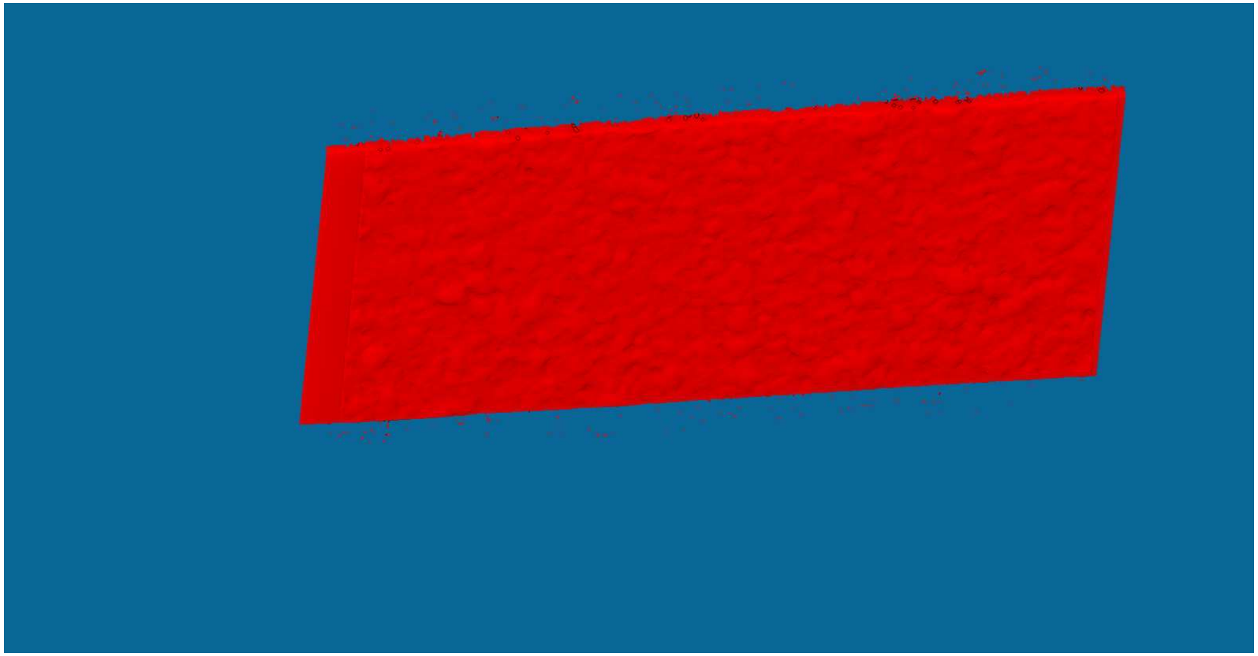
Ra 25 µm sample.



Rubert & Co. Microsurf 334 comparator plate.
(Casting).

XCT for AM surfaces
Areal surface texture data from XCT

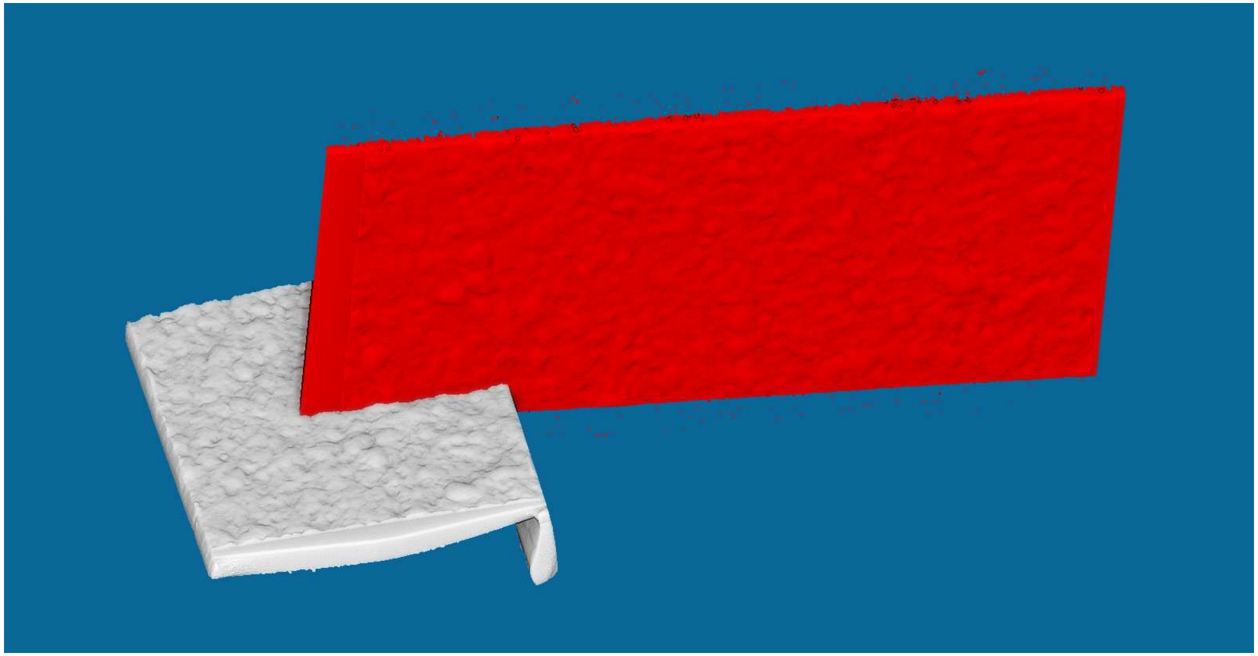
Rubert *Ra* 25 µm comparator plate.



Ra 25 µm focus variation mesh.
(CloudCompare).

XCT for AM surfaces
Areal surface texture data from XCT

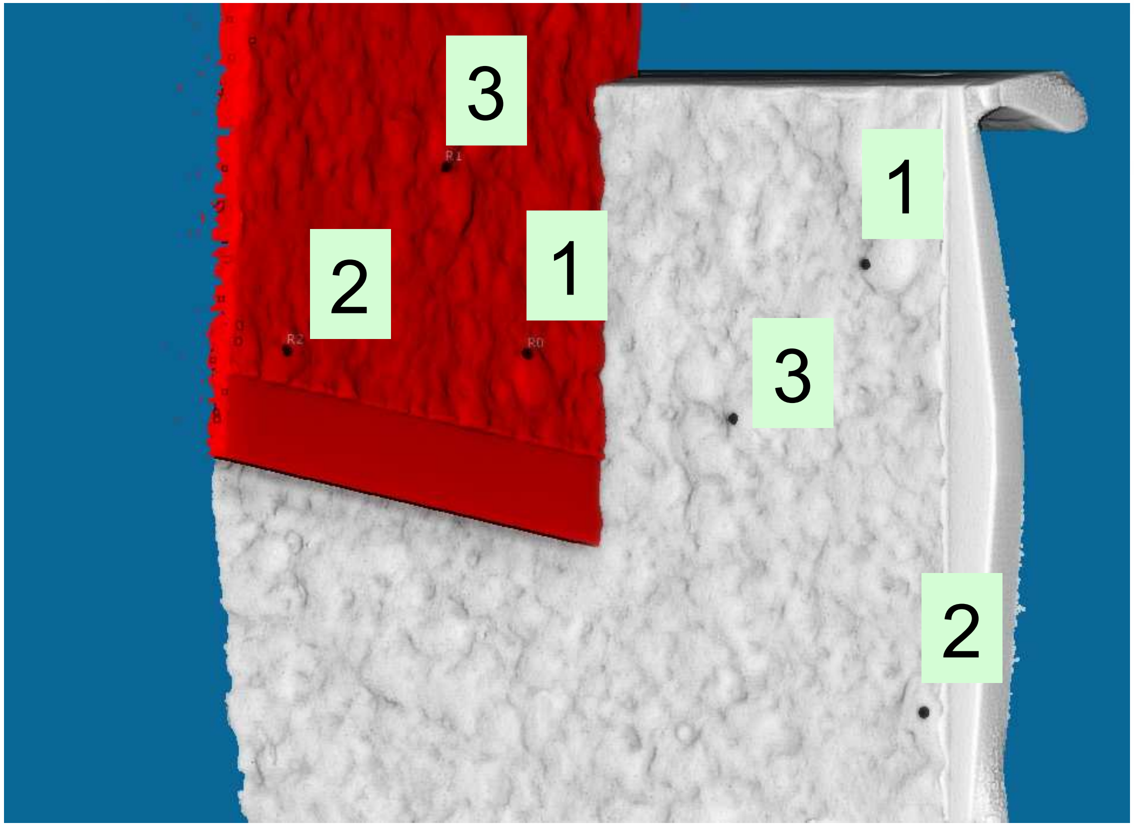
Rubert *Ra* 25 μm comparator plate.



Ra 25 μm focus variation mesh and XCT mesh.
(CloudCompare).

XCT for AM surfaces
Areal surface texture data from XCT

Rubert *Ra* 25 µm comparator plate.



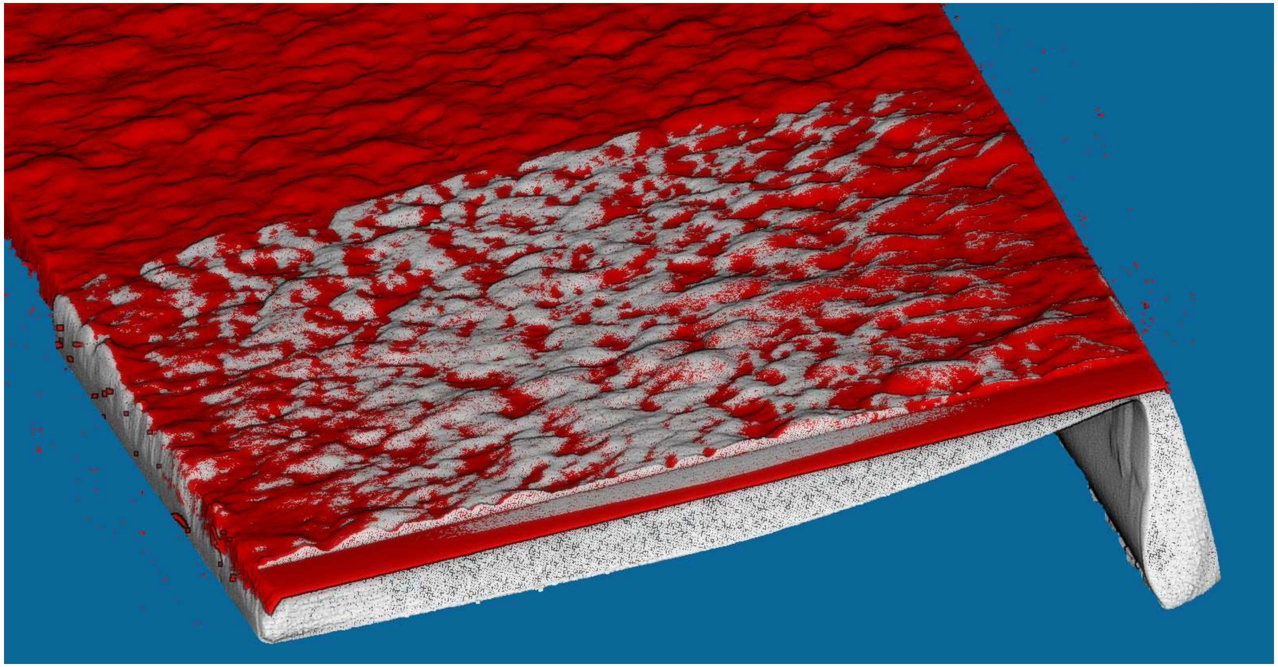
Selection of points (minimum three) for initial mesh alignment.
(CloudCompare).

University of Huddersfield

XCT for AM surfaces
Areal surface texture data from XCT

EPSRC
Pioneering research and skills

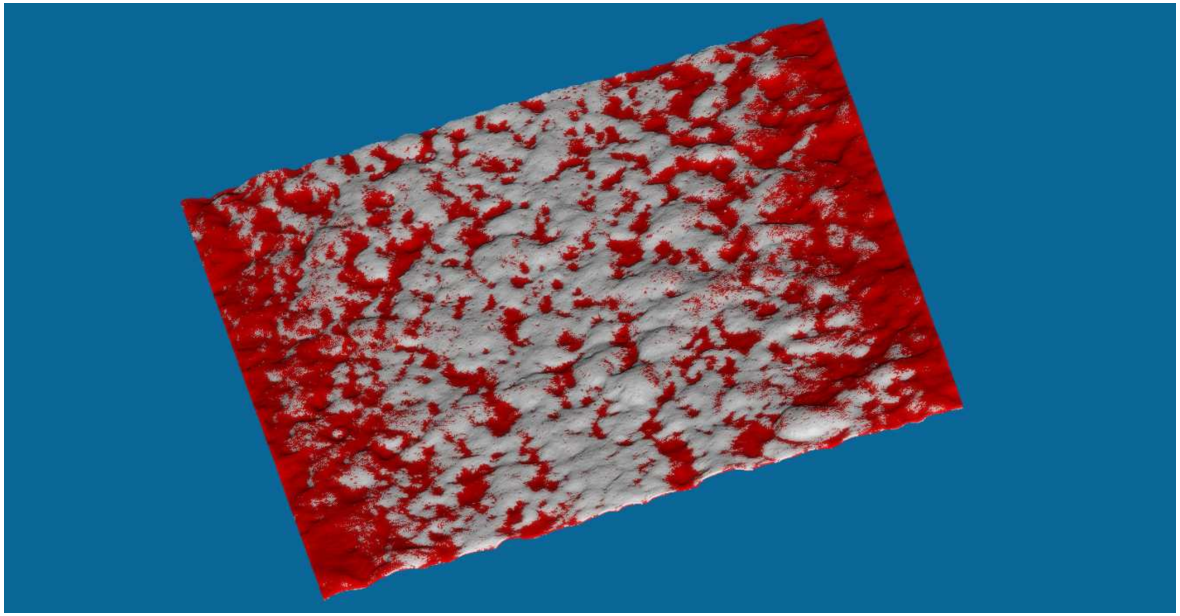
Rubert *Ra* 25 µm comparator plate.



Manual, followed by ICP alignment.

XCT for AM surfaces
Areal surface texture data from XCT

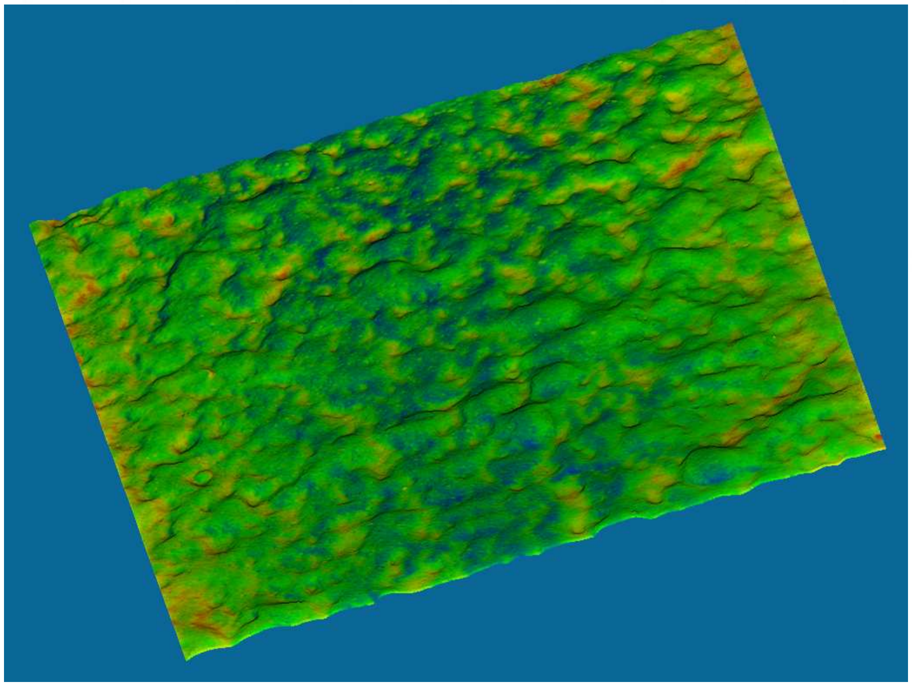
Rubert *Ra* 25 µm comparator plate.



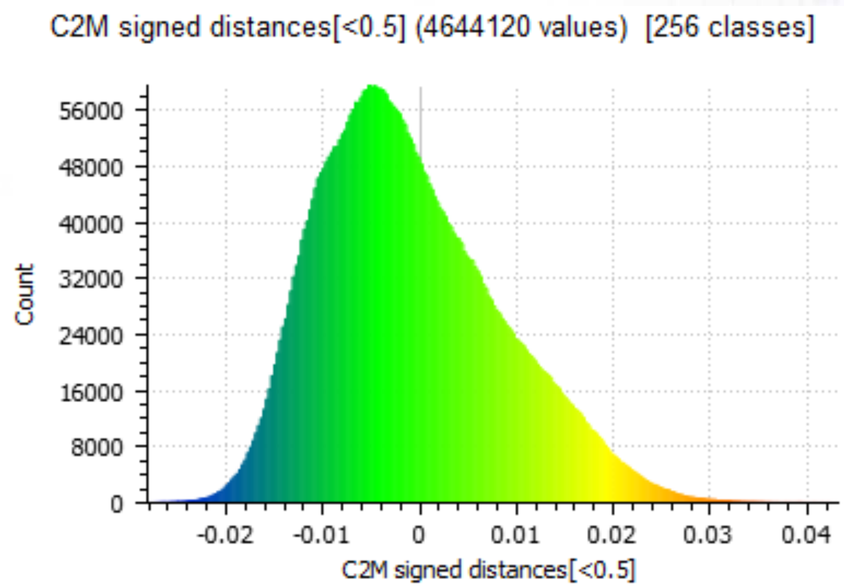
Cropped meshes prior to conversion to height map (SDF) format (in Matlab).

XCT for AM surfaces
Areal surface texture data from XCT

Rubert *Ra* 25 µm comparator plate.



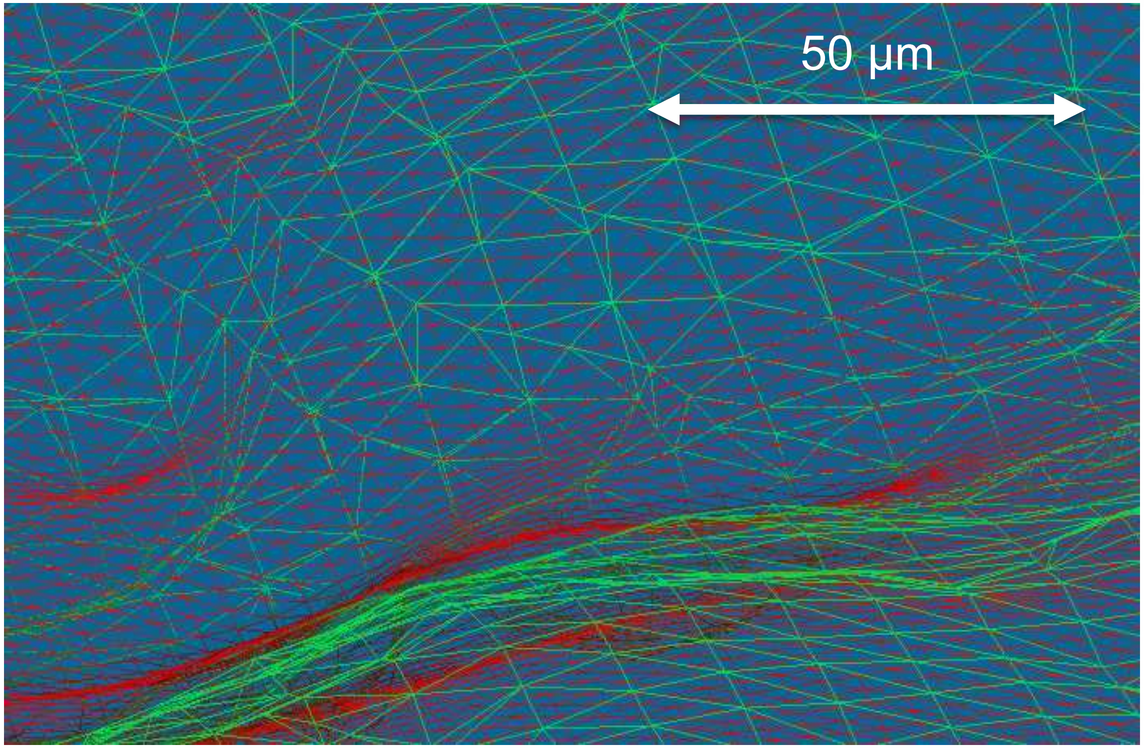
10 mm x 11 mm
Mesh – mesh distance +40 µm – -30 µm.



Mesh – mesh distance distribution.

XCT for AM surfaces
Areal surface texture data from XCT

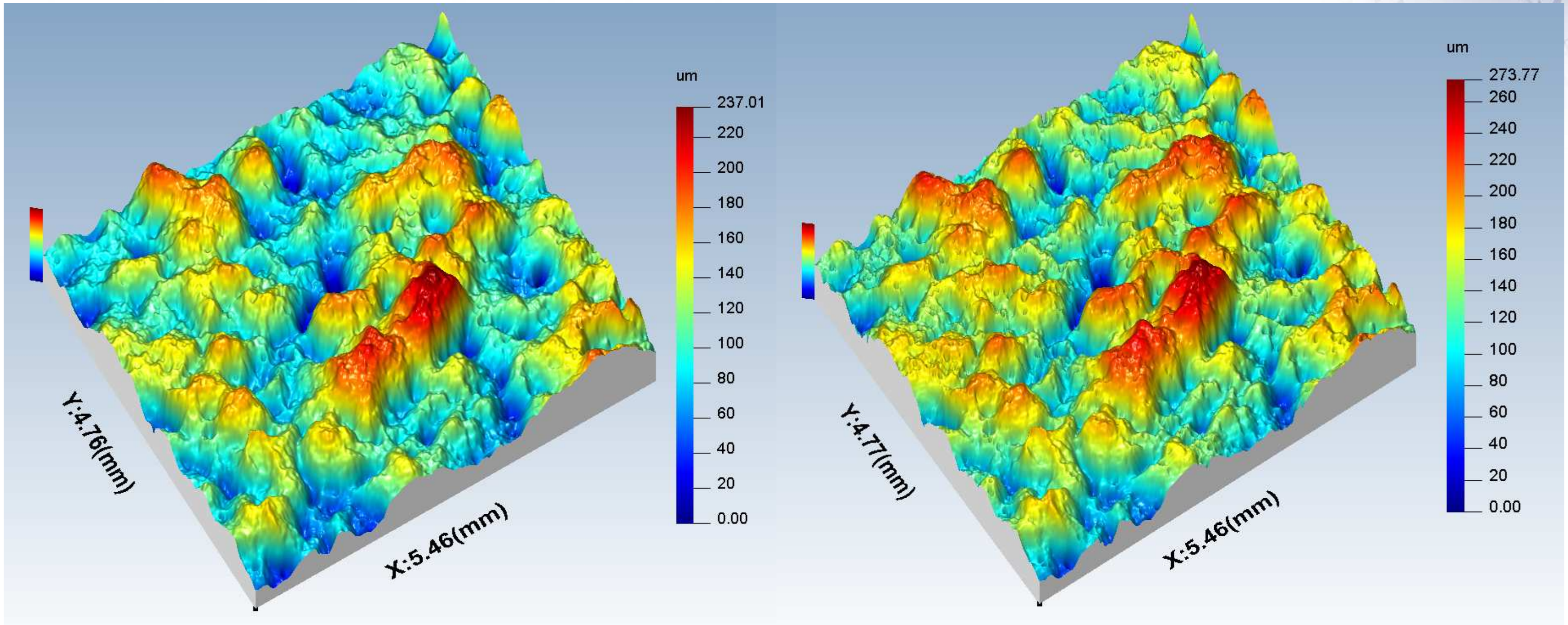
Rubert *Ra* 25 µm comparator plate.



Focus variation mesh (red).
XCT mesh (green).

XCT for AM surfaces
Areal surface texture data from XCT

Rubert *Ra* 25 μm comparator plate.



Focus variation.
Alicona G4.
False color height map.
(SurfStand)

X-ray computed tomography.
Nikon XT H 225.
False color height map.
(SurfStand)

XCT for AM surfaces
Areal surface texture data from XCT

Rubert comparator plates.

Nominal Rubert plate *Ra* (µm)	Mean FV *Sa* (µm)	Mean XCT *Sa* (µm)	Difference between mean XCT and FV *Sa* (% of FV)
50	51.1	55.6	8.8 %
25	27.4	31.3	14.5 %
12.5	12.4	14.6	17.2 %
6.3	6.6	9.0	34.5 %
3.2	4.0	5.6	40.5 %
1.6	2.5	3.5	43.1 %
0.8	0.56	1.09	95 %

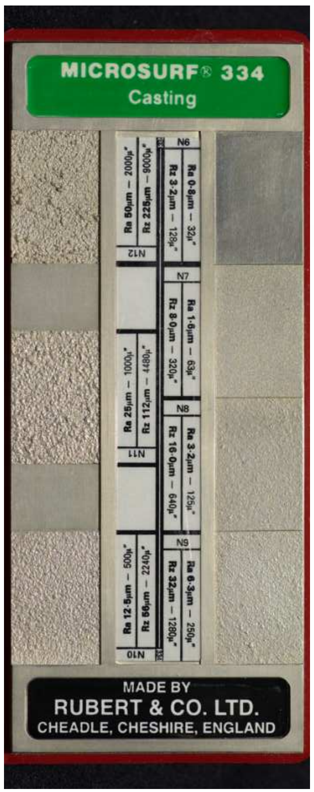
Rubert *Ra*	ISO 25178-3	ISO 25178-3
(µm)	Gaussian L filter nesting Index (mm)	Gaussian S filter nesting Index (µm)
50	5	20
25	5	20
12.5	5	10
6.3	2.5	8
3.2	2	5
1.6	1	5
0.8	0.8	2.5

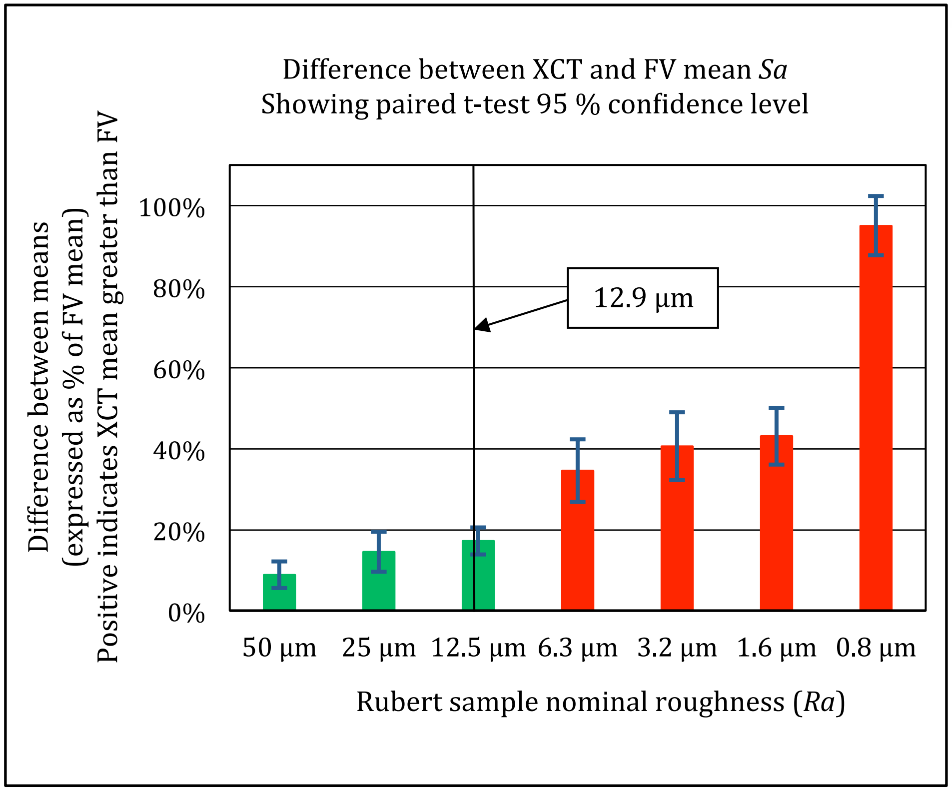
XCT for AM surfaces
Areal surface texture data from XCT

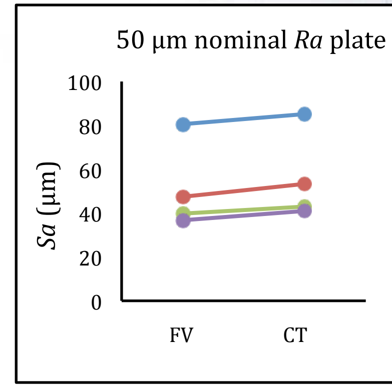
University of Huddersfield

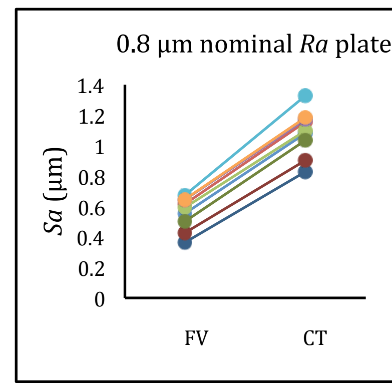
EPSRC
Pioneering research and skills

Rubert comparator plates.





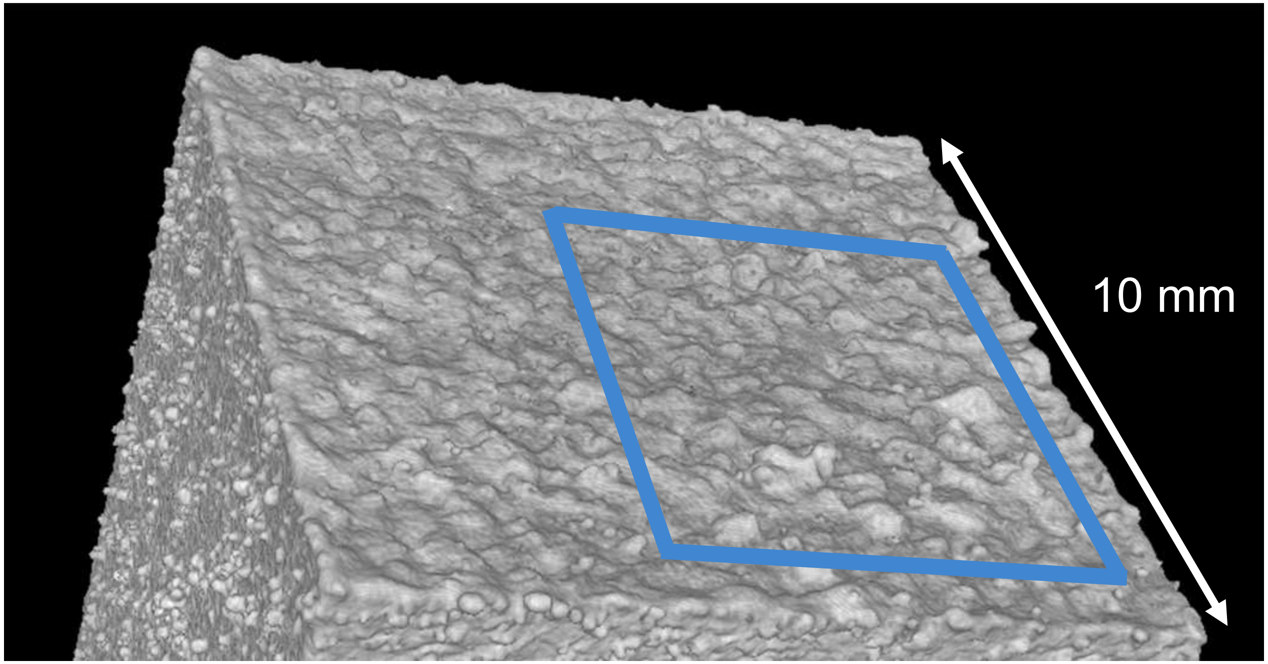




XCT for surface inspection - XCT limited use when *Sa* less than XCT voxel size?

XCT for AM surfaces
Areal surface texture data from XCT

AlSi10Mg SLM AM sample.



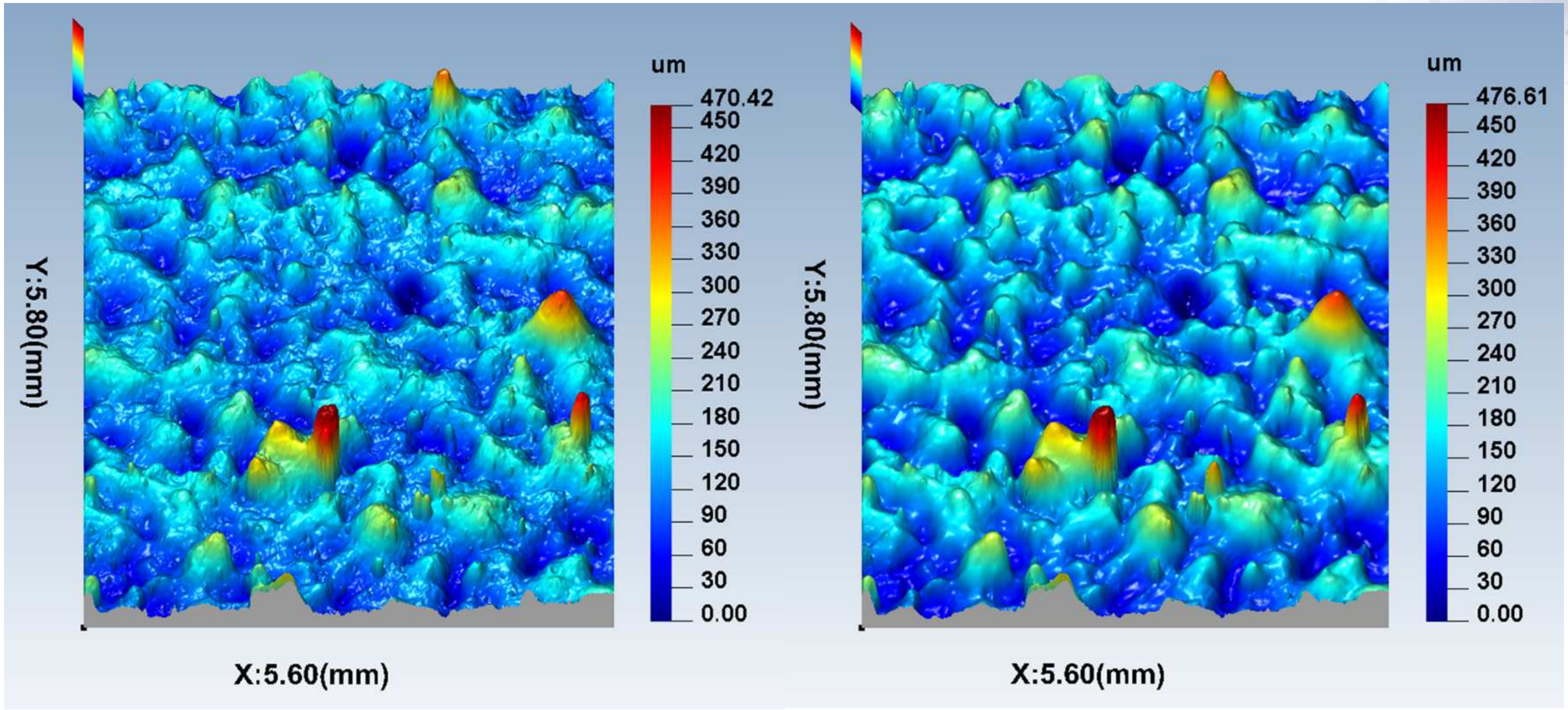
AlSi10Mg sample, Renishaw AM250 SLM.
Top surface.

XCT for AM surfaces
Areal surface texture data from XCT

University of Huddersfield

EPSRC Pioneering research and skills

AlSi10Mg SLM AM sample.



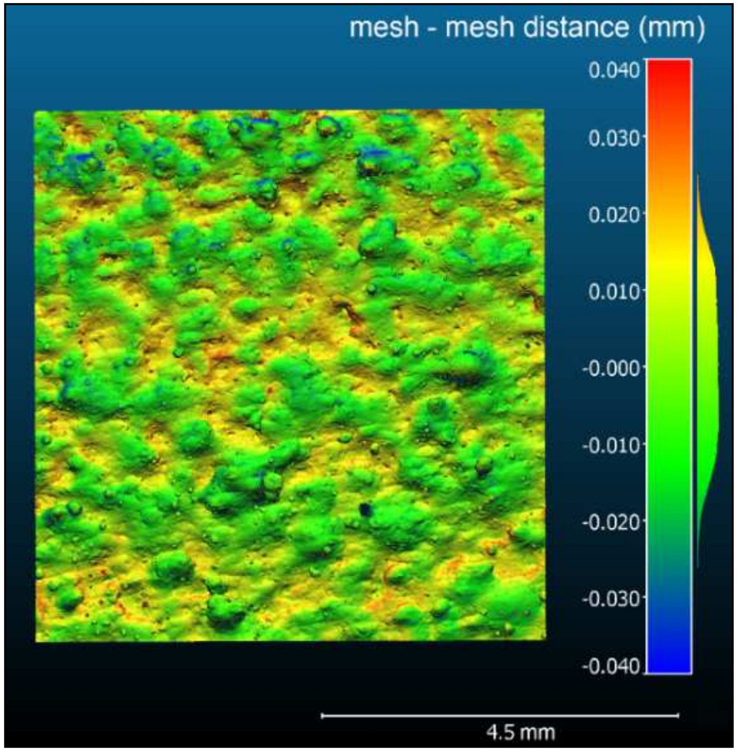
Focus variation.
Alicona G4.
False color height map.

X-ray computed tomography.
Nikon XT H 225.
False color height map.

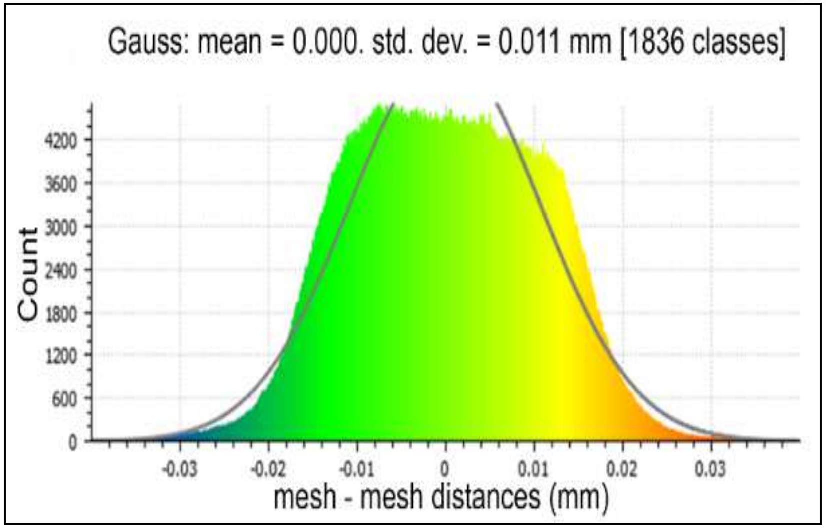
Gaussian L-filter nesting index: 5.0 mm
S filter nesting index 0.02 mm (per ISO 25178-3:2012)

XCT for AM surfaces
Areal surface texture data from XCT

AlSi10Mg SLM AM sample.



5.6 mm x 5.8 mm sample.
Mesh – mesh distance ± 40 µm.



Mesh – mesh distance distribution.

XCT for AM surfaces
Areal surface texture data from XCT

AlSi10Mg SLM AM sample.

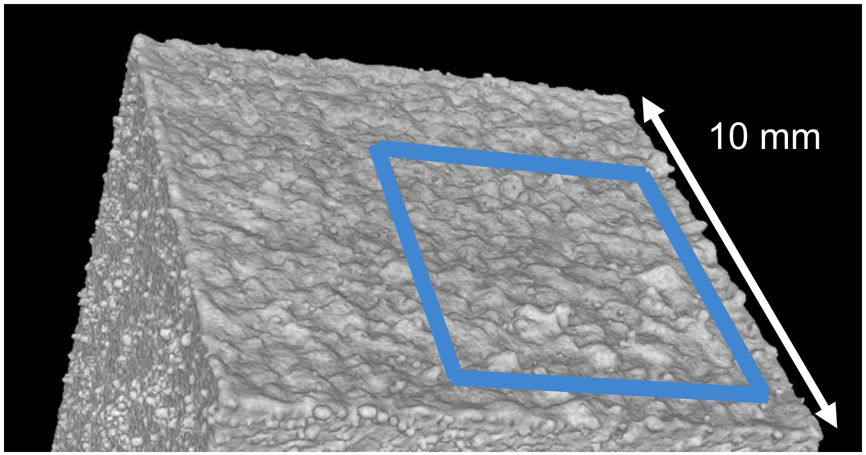
Parameter	Description	FV	CT	Delta (% of FV)
Amplitude				
Sa	Arithmetic mean height	31.7 μm	40.7 μm	28.4%
Sq	Root mean square height	44.5 μm	53.2 μm	19.6%
Ssk	Skewness	1.72	1.13	-34.3%
Sku	Kurtosis	10.7	6.6	-38.3%
Sz	Maximum height	470 μm	477 μm	1.5%
Spatial				
Sal	Fastest decay autocorrelation length	0.27 mm	0.28 mm	3.7%
Hybrid				
Sdr	Developed interfacial area ratio	21.0%	21.4%	1.9%
Functional				
Smr2	Areal material ratio (dales)	90.8%	93.5%	3.0%

Areal parameters per ISO 25178-2.
(After filtering per ISO 25178-3).

University of Huddersfield

EPSRC Pioneering research and skills

XCT for AM surfaces
Areal surface texture data from XCT

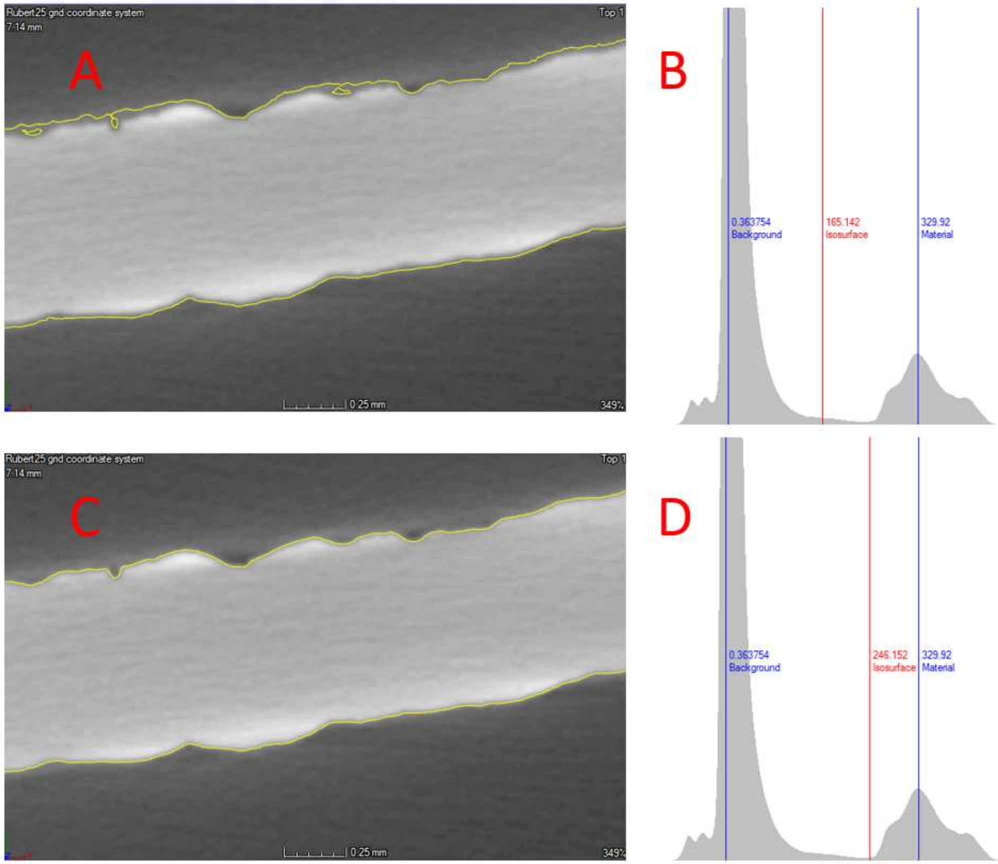


Test sample	FV *Sa* (μm)	XCT *Sa* (μm)	Voxel Size (μm)	Percentage difference
AlSi10Mg SLM	31.7	40.7	17	28.4 %
25 μm *Ra* Rubert plate	27.4	31.3	12.9	14.5 %

Gaussian L-filter nesting index: 5.0 mm
S filter nesting index 0.02 mm (per ISO 25178-3:2012)

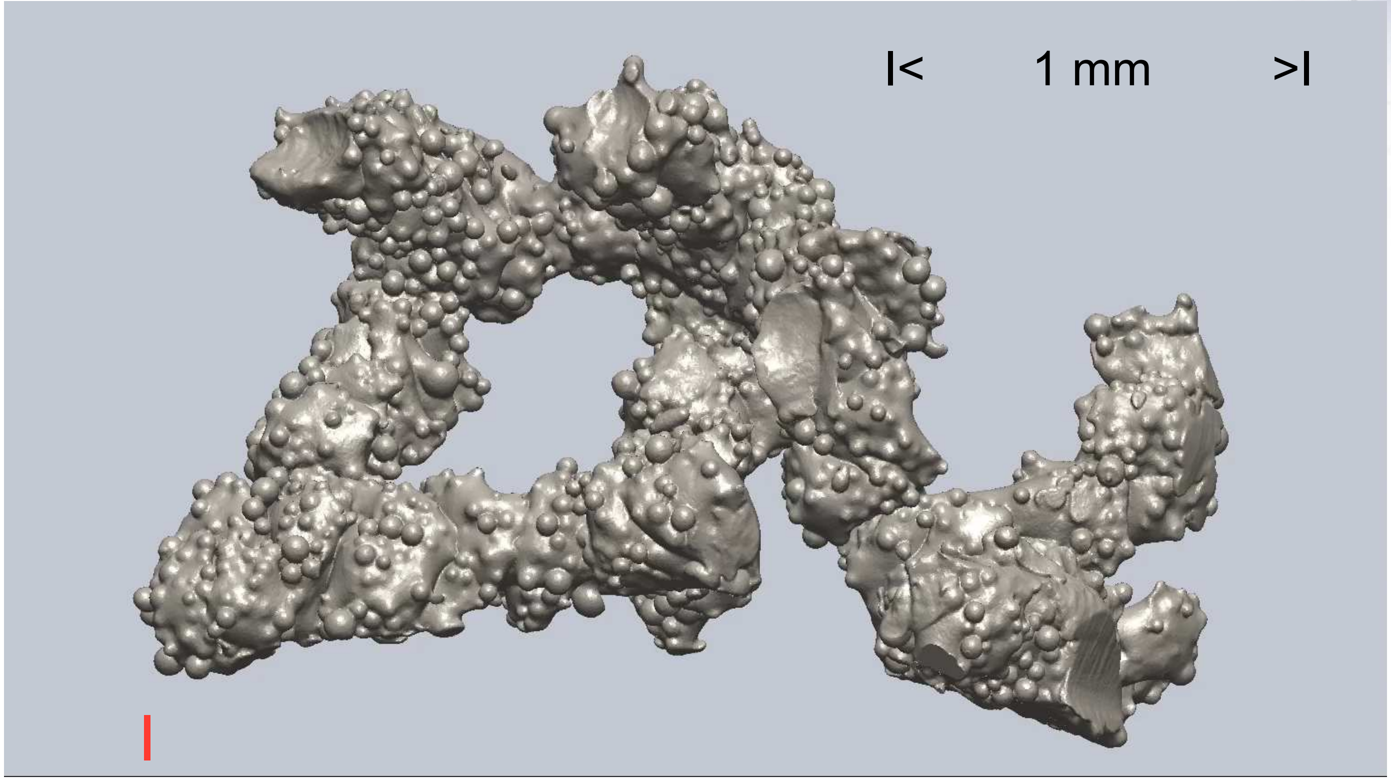
AlSi10Mg AM part and Rubert 25 μm *Ra* plate XCT – FV mean *Sa* comparison

Future work
XCT surface determination



Rubert 25 µm *Ra* plate ISO50 (A&B) and manual (C&D) surface determination. (VGStudio MAX). Local adaptive surface determination?

Future work
Medical lattice structures



Ti6Al4V orthopaedic prototype component.
XCT reconstruction

Conclusions

- Large surface area produced during AM manufacturing – most is “embedded”
- Areal surface texture measurements provide advantages over profile
- Not just *Ra* - spatial, hybrid, functional parameters
- XCT can be a good match for AM component inspection
  - NDT of internal or overhanging surfaces
- Fluid channels, coating adhesion, bio-attachment + cryostat tubes
- Have shown the extraction of areal surface texture data (per ISO 25178-2) from XCT

Future work

- Surface determination effects and solutions to be investigated
- Investigate causes of differences between XCT and FV results
- Compare with raster scan stylus measurements
- Calibration
- Material and AM build effects
- Investigate XCT part position effects – map the chamber
- Medical lattice structures
- Surface-specific artefacts
- Round robin project – XCT / surface texture capability analysis

Future work

Acknowledgements

The authors gratefully acknowledge the UK's Engineering and Physical Sciences Research Council (EPSRC) funding of the EPSRC Centre for Innovative Manufacturing in Advanced Metrology (grant EP/I033424/1).

University of HUDDERSFIELD

EPSRC
Pioneering research and skills

Andy Townsend
a.townsend@hud.ac.uk

Thank you!