EPSRC CENTRE OF ADVANCED METROLOGY

Extracting surface topography data of AM parts from computer tomography systems

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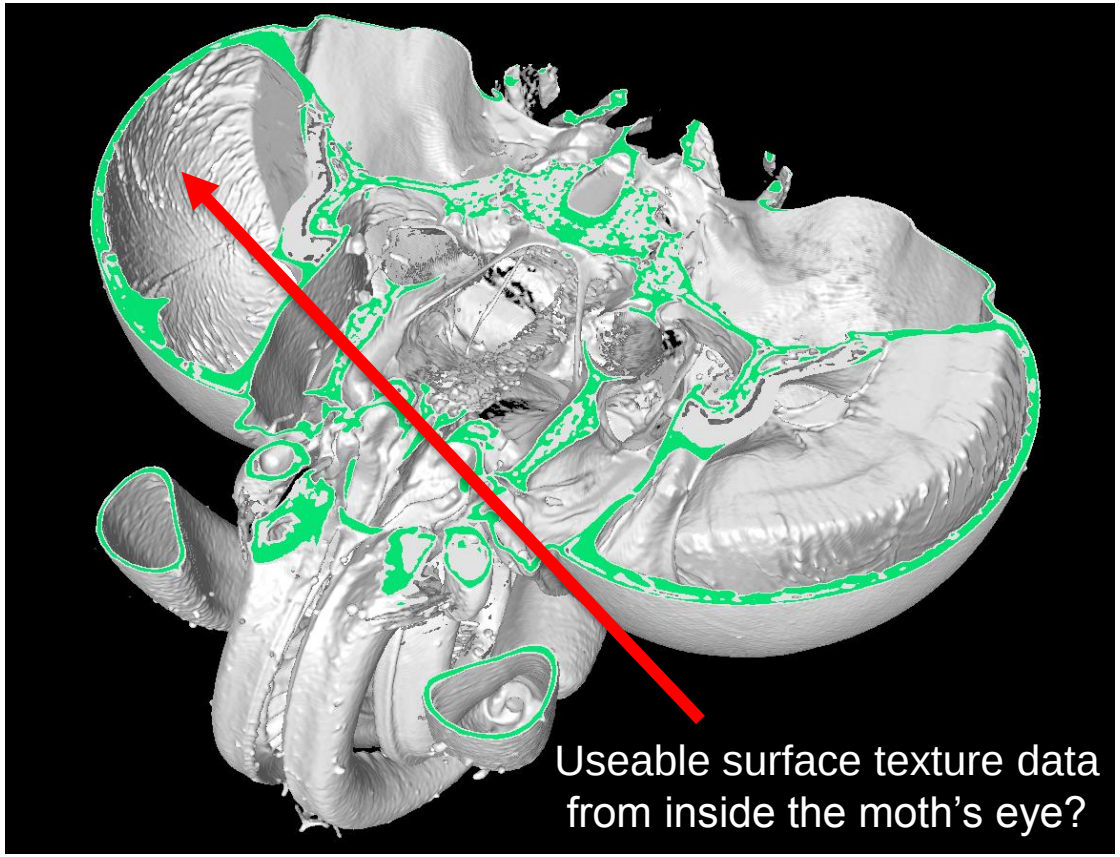
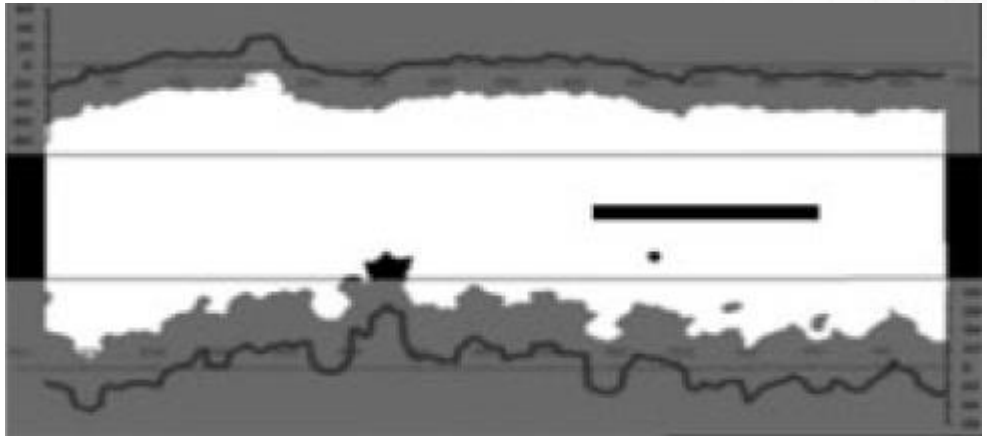
Outline

- Extraction of areal surface texture data per ISO 25178 from XCT scans
- Surface determination effects
- XCT internal / external surface result differences
- Surface-from-XCT interlaboratory comparison
- Analysis of XCT re-entrant features

Motivation for areal surface texture data from XCT



Extracted profile data

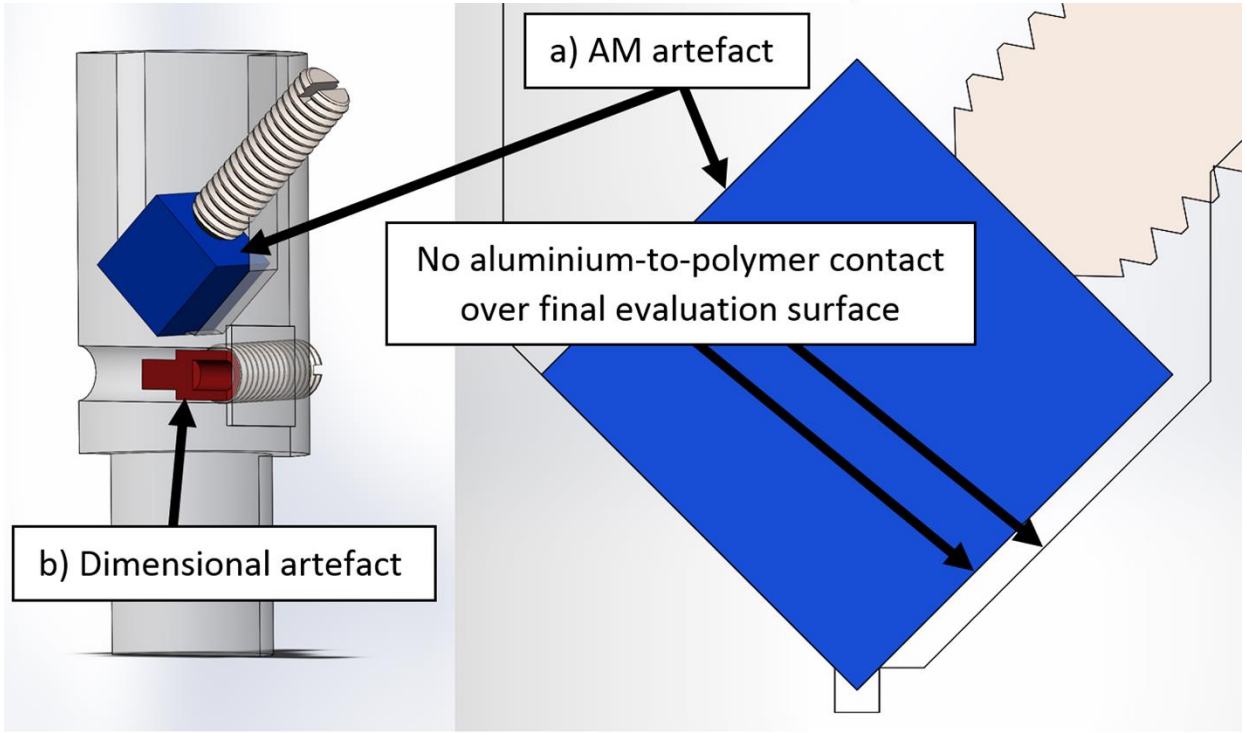


Kerckhofs G., Pyka G., Moesen M., Van Bael S., Schrooten J., and Wevers M., (2013), *High-Resolution Microfocus X-Ray Computed Tomography for 3D Surface Roughness Measurements of Additive Manufactured Porous Materials.* Advanced Engineering Materials. **15**(3): p. 153-158.

Moth head section (scanned using a Nikon XT H 225).

Townsend A, Senin N, Blunt L, Leach RK, Taylor JS (2016) *Surface texture metrology for metal additive manufacturing: a review.* Precision Engineering 46:34-47.

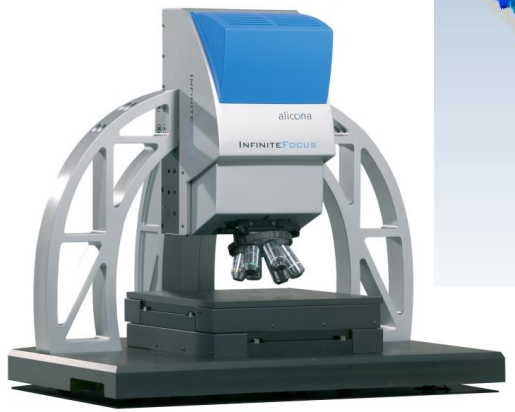
Areal surface texture data from XCT

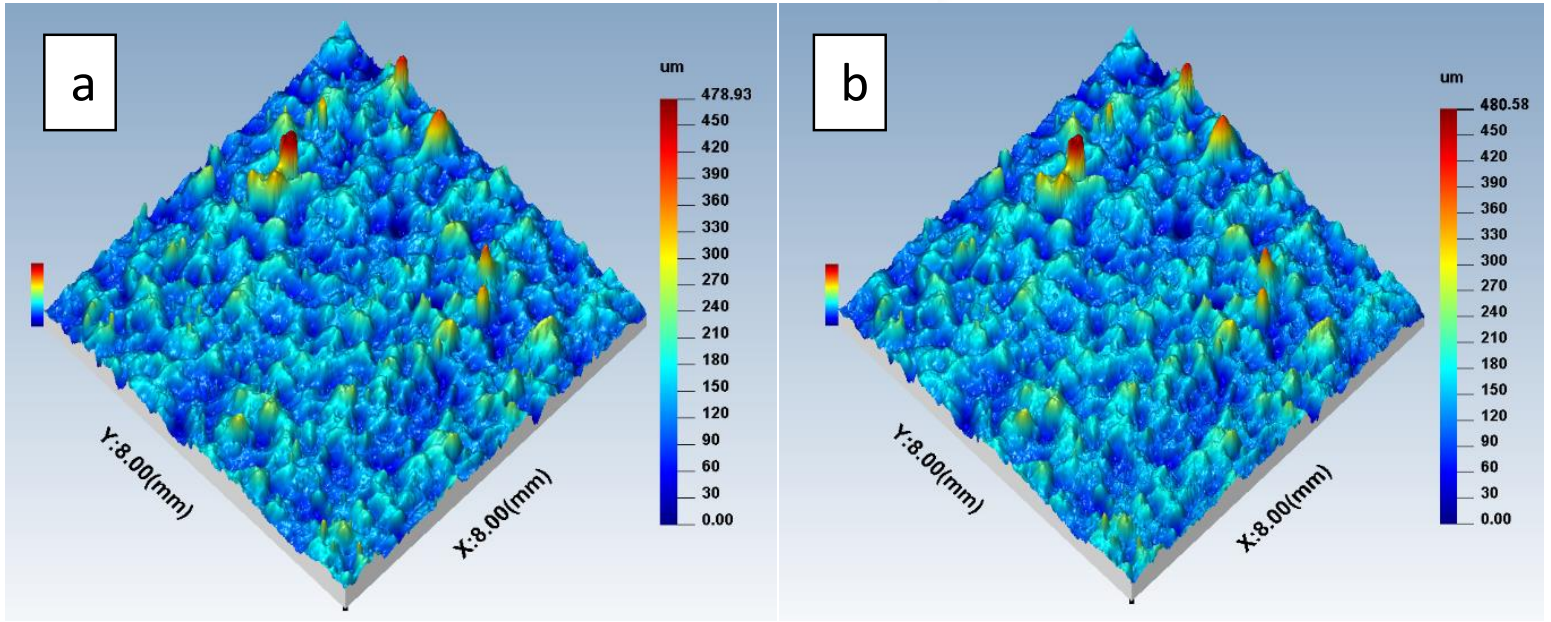


AlSi10Mg (a) surface artefact
(b) dimensional artefact in XCT fixture.

Townsend A, Pagani L, Scott P, Blunt L (2016)
Areal surface texture data extraction from x-ray computed tomography reconstructions of metal additively manufactured parts.
Precision Engineering in press. DOI: http://dx.doi.org/doi:10.1016/j.precisioneng.2016.12.008.

Areal surface texture data from XCT





(a) Alicona G4 focus variation (b) Nikon XT H 225 XCT
False colour height maps.

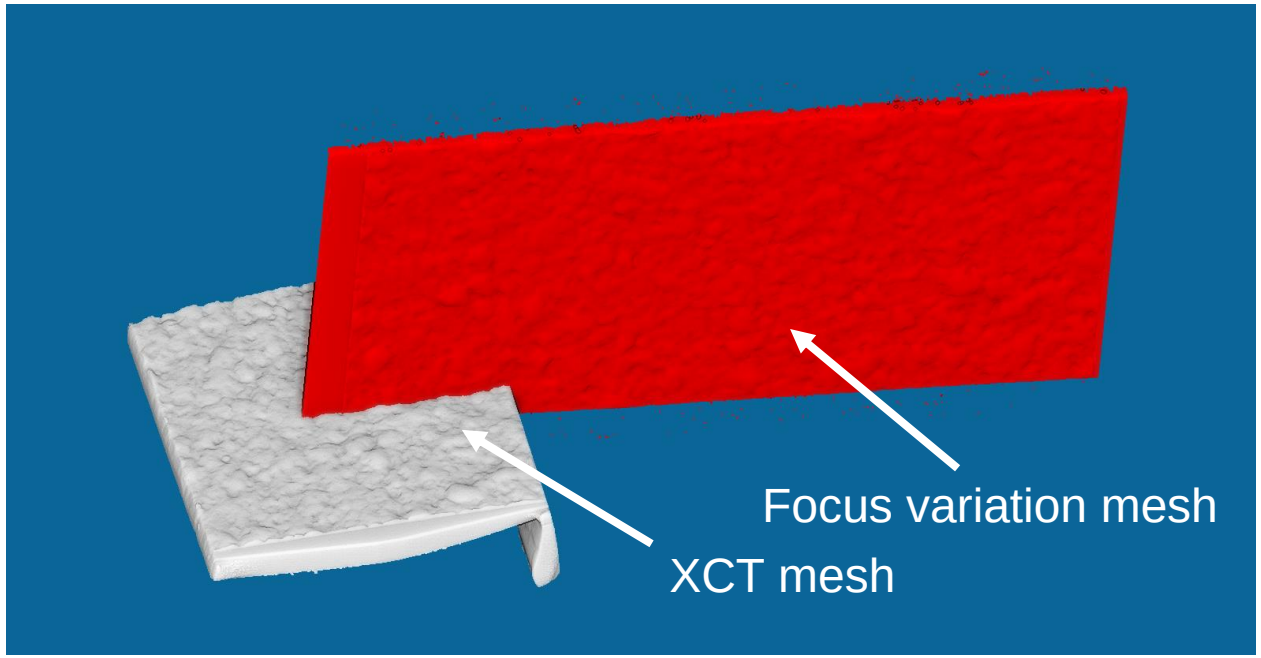
Filtering per ISO 25178-3	
L-filter nesting index	8.0 mm
S-filter nesting index	0.025 mm

Circa -2.5% difference between XCT and Alicona mean *Sa* value (*Sa ≈ 30 µm)*

Townsend A, Pagani L, Scott P, Blunt L (2016)
Areal surface texture data extraction from x-ray computed tomography reconstructions of metal additively manufactured parts.
Precision Engineering in press. DOI: http://dx.doi.org/doi:10.1016/j.precisioneng.2016.12.008.

Areal surface texture data from XCT

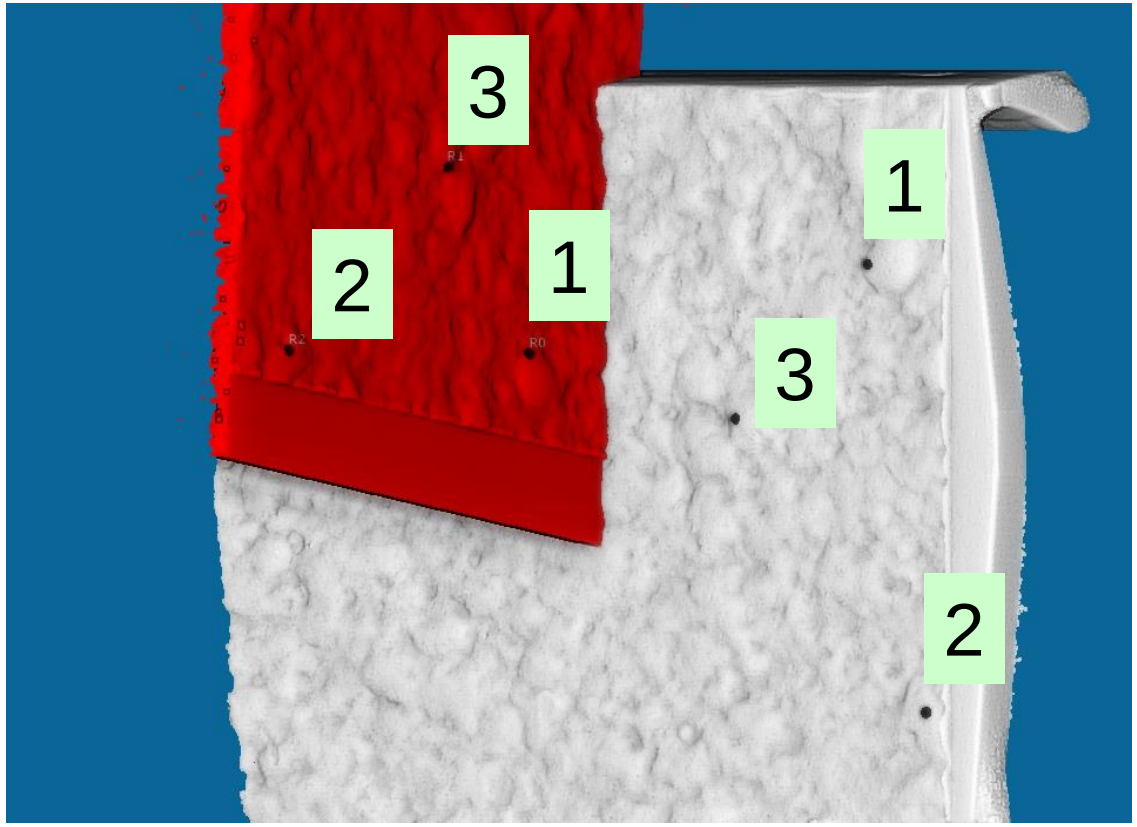
Rubert *Ra* 25 µm comparator plate.



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

Areal surface texture data from XCT

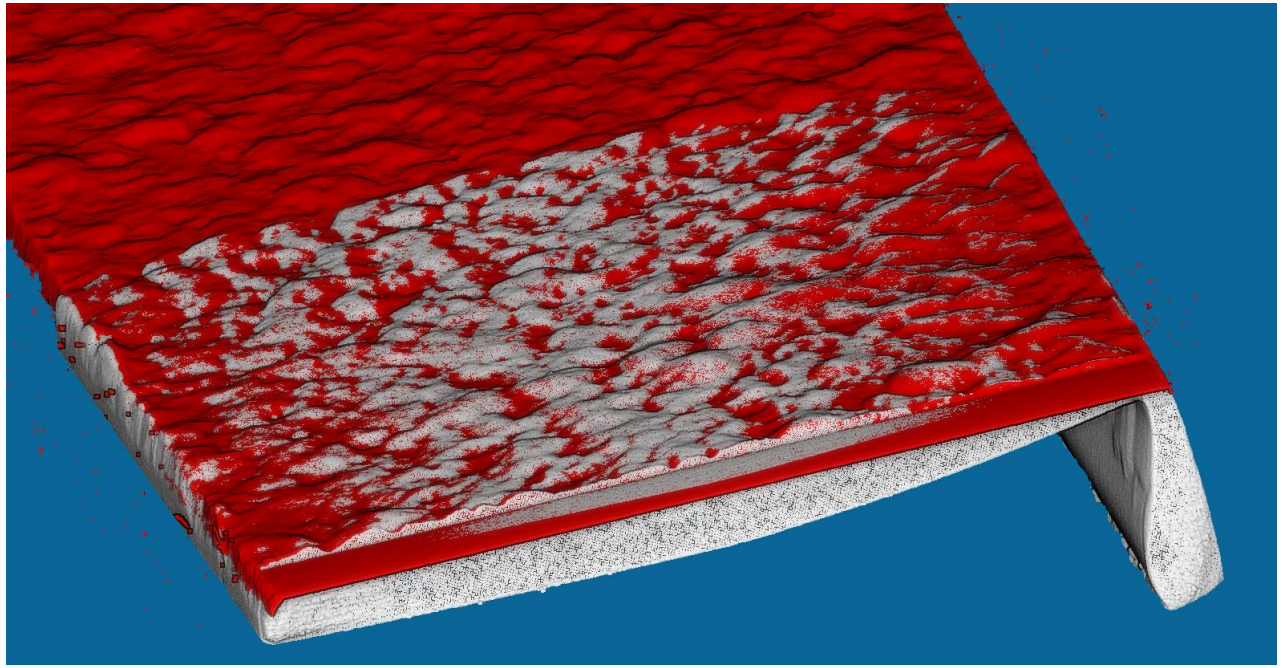
Rubert *Ra* 25 µm comparator plate.



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

Areal surface texture data from XCT

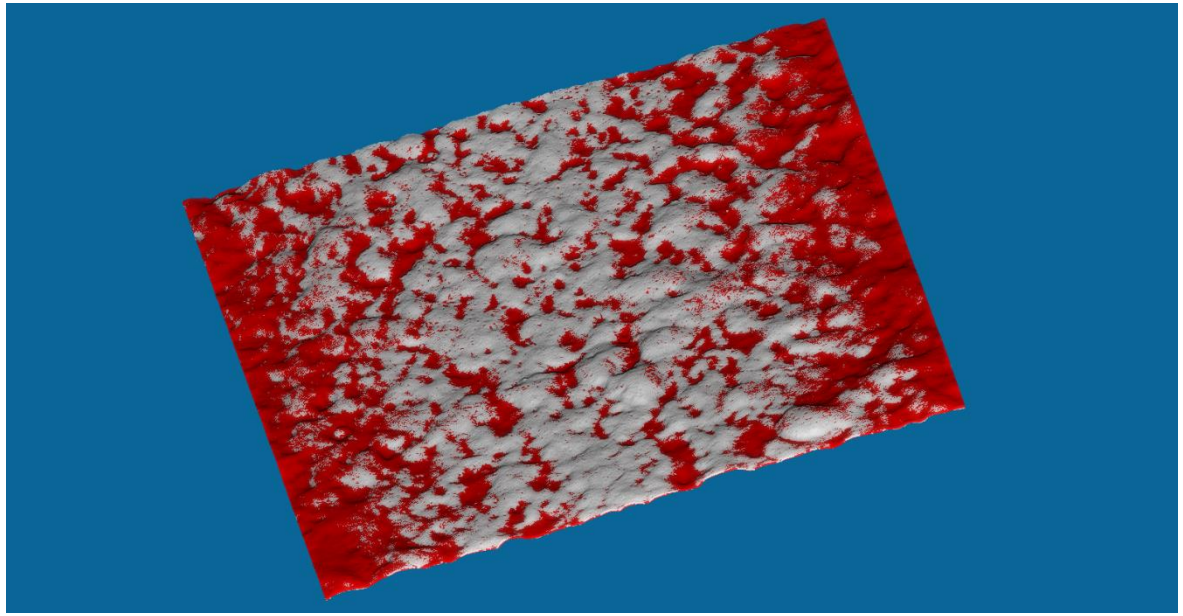
Rubert *Ra* 25 µm comparator plate.



Manual, followed by Iterative Closest Point (ICP) alignment.

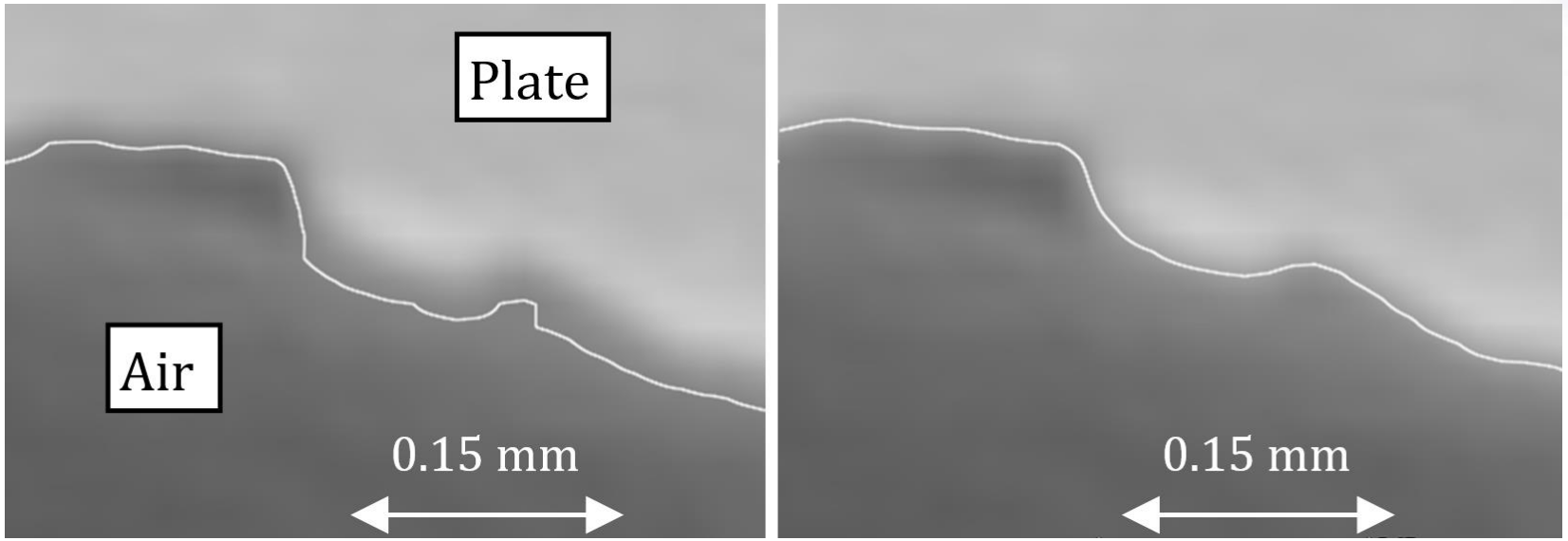
Areal surface texture data from XCT

Rubert *Ra* 25 µm comparator plate.



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

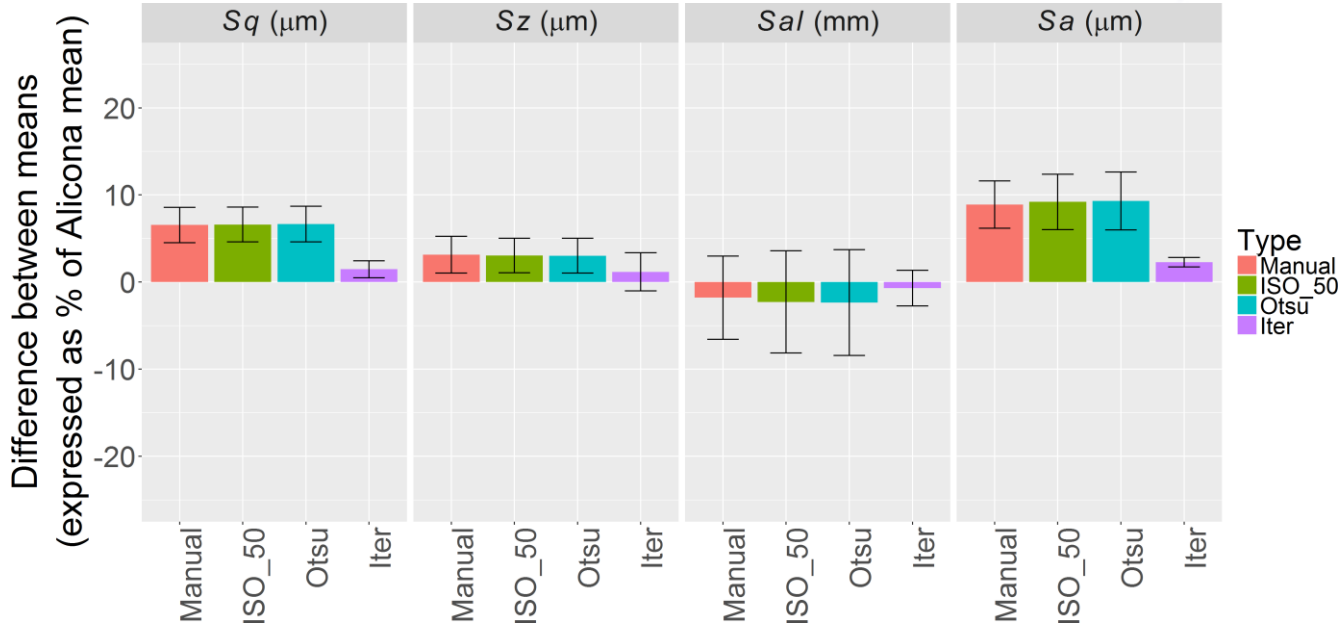
XCT surface determination



Rubert 50 µm plate surface determination (VGStudio Max 2.2)
(a) ISO 50 surface determination (b) local iterative surface determination

Townsend A, Pagani L, Blunt L, Scott P, Jiang X (2017) *Factors affecting the accuracy of areal surface texture data extraction from X-ray CT.* Annals of CIRP 66-1. Submitted.

XCT surface determination



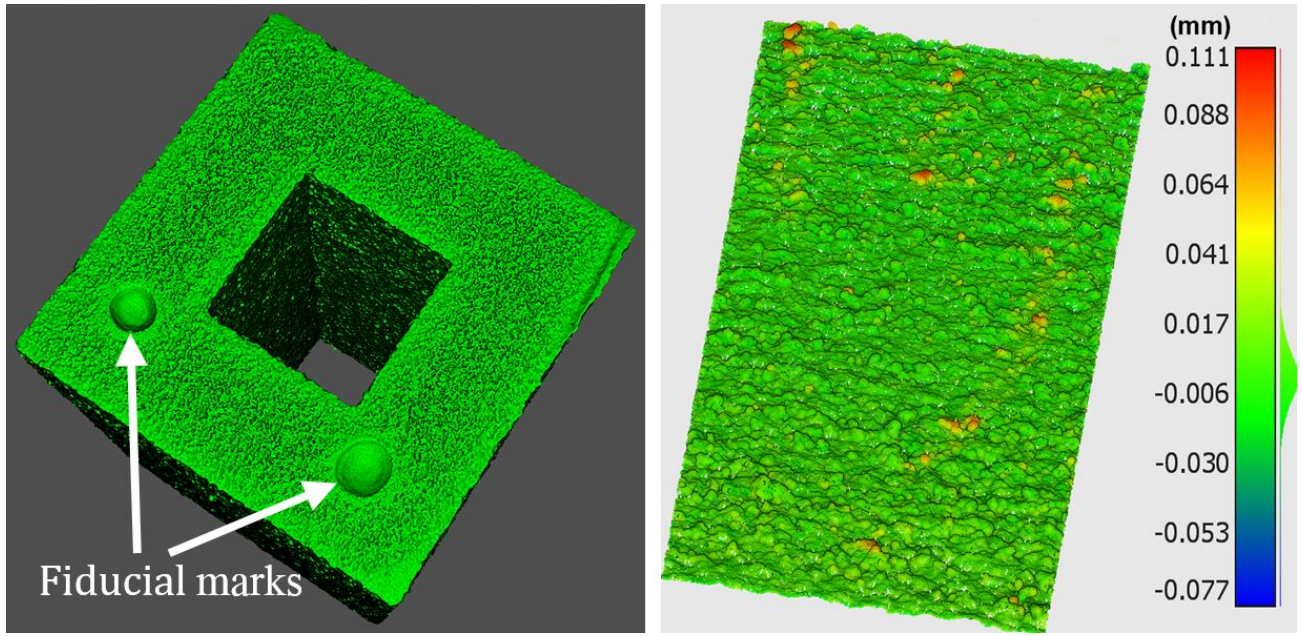
	Δ to Alicona G4 *Sa* mean (50.90 µm)
Manual	8.88%
ISO 50	9.20%
OTSU	9.31%
Local Iterative	2.28%

Filtering per ISO 25178-3	
L-filter nesting index	5.0 mm
S-filter nesting index	0.020 mm

Rubert 50 µm plate extracted surface parameters per ISO 25178-2
Showing global surface determination methods, Manual, ISO 50 and Otsu
And iterative local surface determination (purple bars)
Error bars are 95% confidence interval for the mean.

Townsend A, Pagani L, Blunt L, Scott P, Jiang X (2017) *Factors affecting the accuracy of areal surface texture data extraction from X-ray CT.* Annals of CIRP 66-1. Submitted.

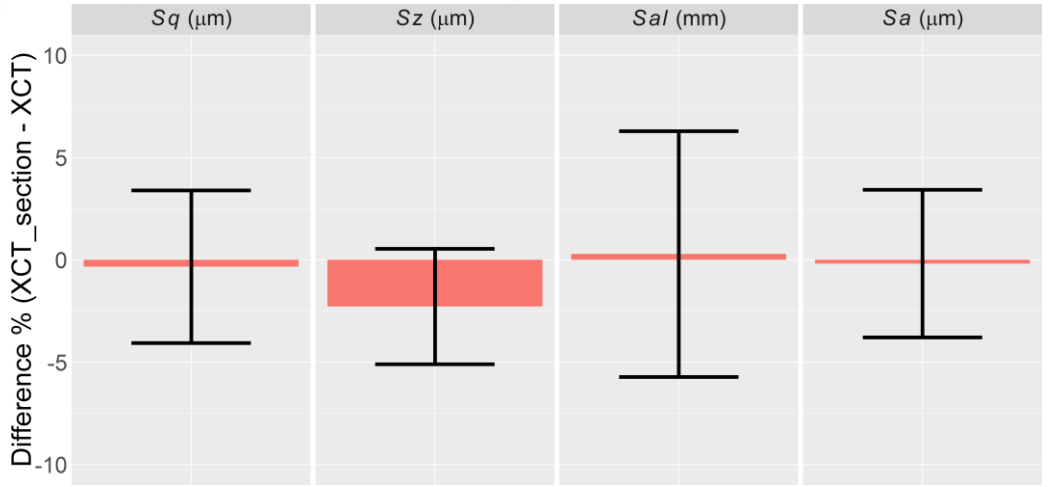
Internal and External surface measurement



Ti6Al4V SLM part (10 mm x 10 mm x 50 mm).

Townsend A, Pagani L, Blunt L, Scott P, Jiang X (2017) *Factors affecting the accuracy of areal surface texture data extraction from X-ray CT.* Annals of CIRP 66-1. Submitted.

Internal and External surface measurement



Sa 17.1 µm (internal)
Δ external – internal 0.18%

Filtering per ISO 25178-3	
L-filter nesting index	2.0 mm
S-filter nesting index	0.005 mm

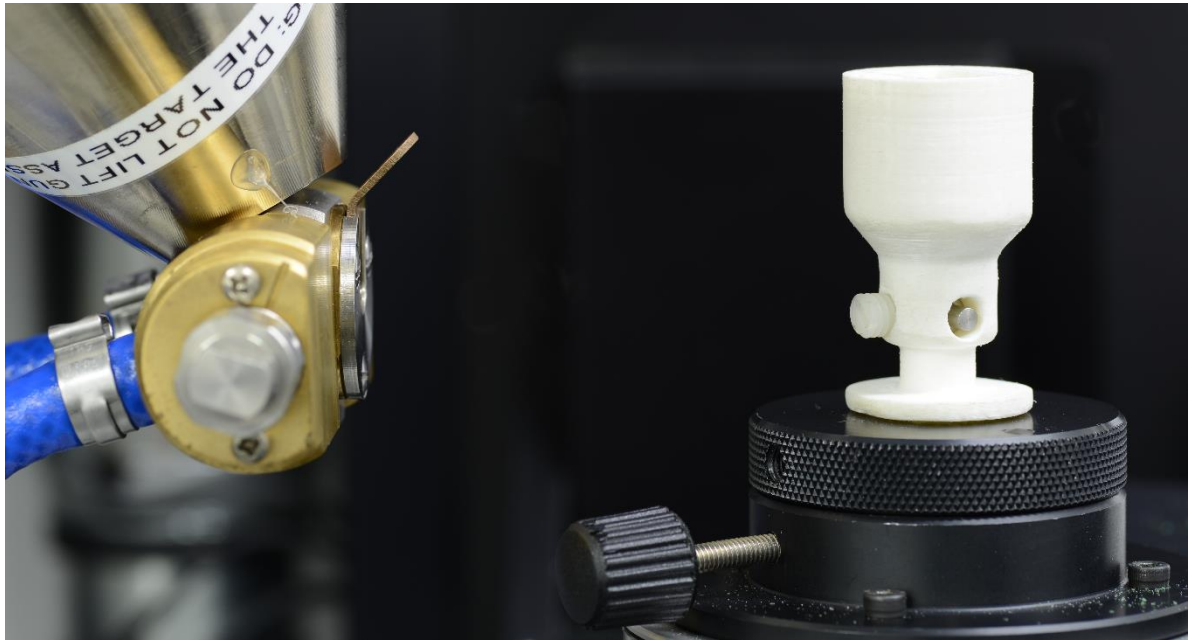
Percentage difference between the same surface section as an internal and external surface showing insignificant difference. (error bars are 95% confidence interval for the mean)

Townsend A, Pagani L, Blunt L, Scott P, Jiang X (2017) *Factors affecting the accuracy of areal surface texture data extraction from X-ray CT.* Annals of CIRP 66-1. Submitted.

Surface from XCT interlaboratory comparison

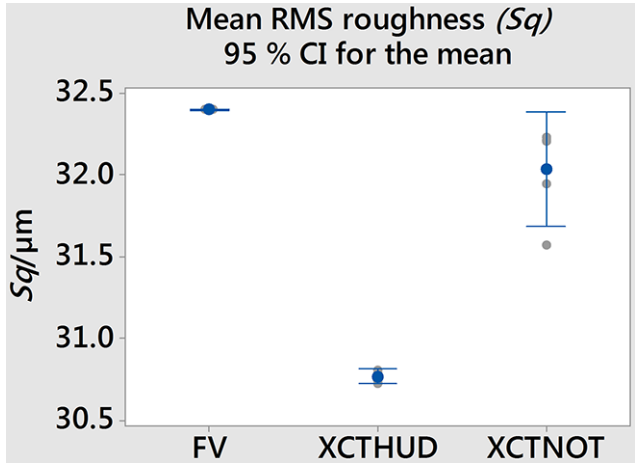
CT-STARR

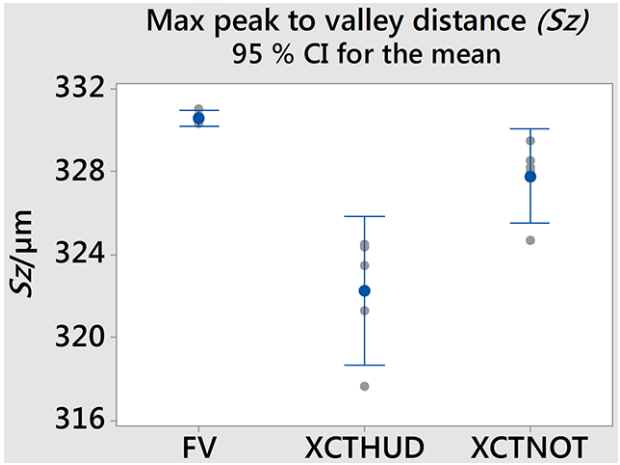
CT-SURFACE TEXTURE FOR ADDITIVE ROUND ROBIN



Townsend A, Racasan R, Bills P, Blunt L (2017) *Development of an interlaboratory comparison investigating the generation of areal surface texture data per ISO 25178 from XCT.* 7th conference on industrial computed tomography, Leuven (Belgium), February 7th – 9th, 2017. Accepted.

Surface from XCT interlaboratory comparison





Artefact: Ti6Al4V ELI EBM

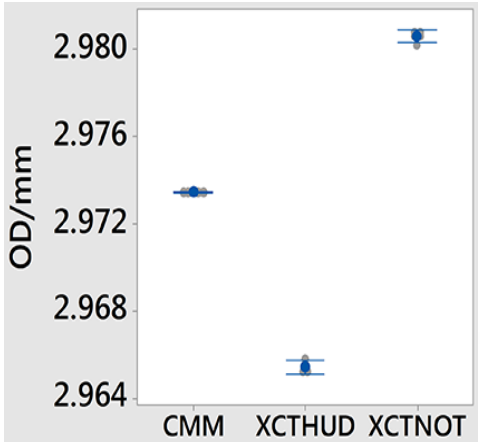
XCTHUD: Nikon XT H 225
XCTNOT: Nikon MCT225

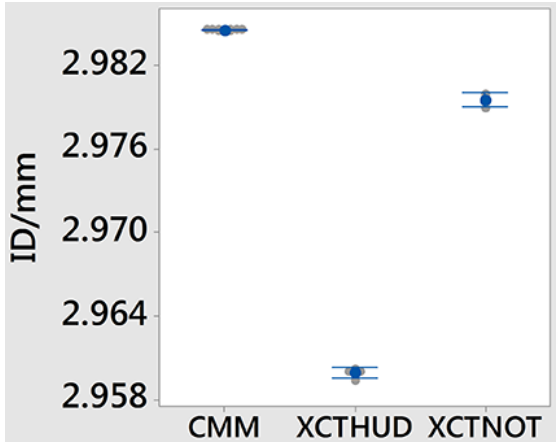
Filtering per ISO 25178-3	
L-filter nesting index	8.0 mm
S-filter nesting index	0.025 mm

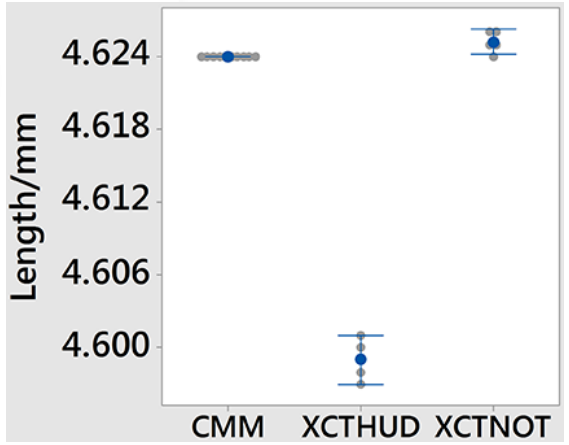
Parameter (ISO 25178-2)	Mean FV	SD FV	Mean XCTHUD	SD XCTHUD	Mean XCTNOT	SD XCTNOT	Δ, XCTHUD to FV	Δ, XCTNOT to FV
Sq/µm	32.40	0.001	30.77	0.036	32.03	0.252	**-5.0%**	**-1.1%**
Sa/µm	25.33	0.001	24.05	0.031	25.07	0.241	**-5.1%**	**-1.0%**
Sz/µm	330.59	0.306	322.27	2.889	327.80	1.644	**-0.85%**	**-0.85%**
Ssk	0.246	<0.001	0.08	0.016	0.202	0.008	**-0.238**	**-0.044**
Sku	3.70	<0.001	3.67	0.009	3.66	0.040	**-0.03**	**-0.04**

Townsend A, Racasan R, Bills P, Thompson A, Senin N, Leach RK, Blunt L (2016) *Results from an interlaboratory comparison of areal surface texture parameter extraction from X-ray computed tomography of additively manufactured parts.* Euspen's international conference & exhibition, Hannover, DE, May 2017. Submitted.

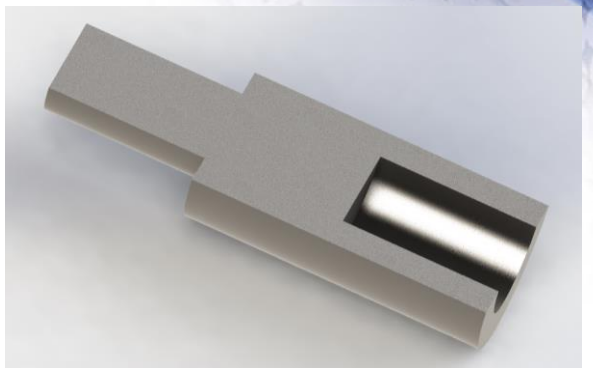
Surface from XCT interlaboratory comparison

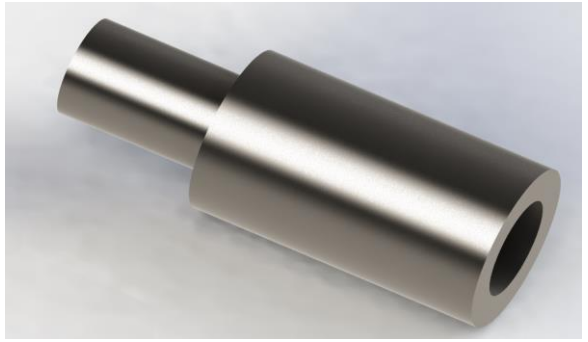






Feature	Mean CMM (mm) (10 ea)	SD CMM (mm)	Mean XCTNOT (5 ea)	SD XCTNOT	Δ XCT to CMM	After 3 µm surface determination compensation
OD	2.97345	0.000053	2.9806	0.0002	**+0.24%**	**+0.04 %**
ID	2.98457	0.001438	2.9796	0.0004	**-0.17%**	**+0.03 %**
Length	4.62400	0.000377	4.6252	0.0008	**+0.03%**	**+0.03 %**





Artefact: Ti6Al4V ELI

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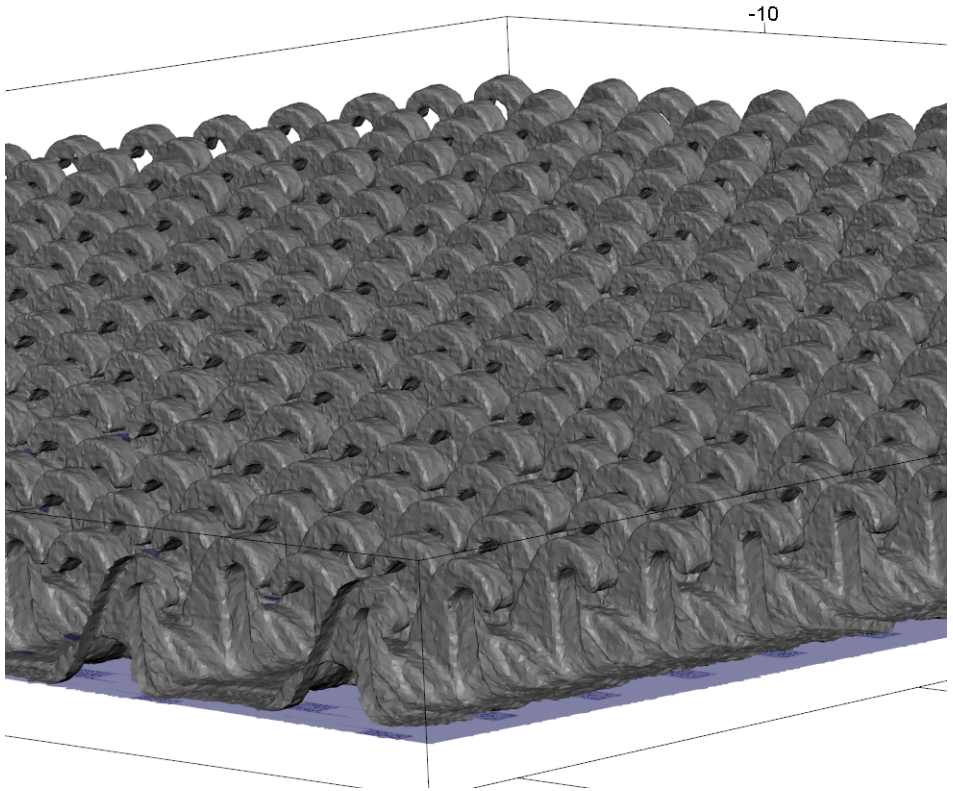
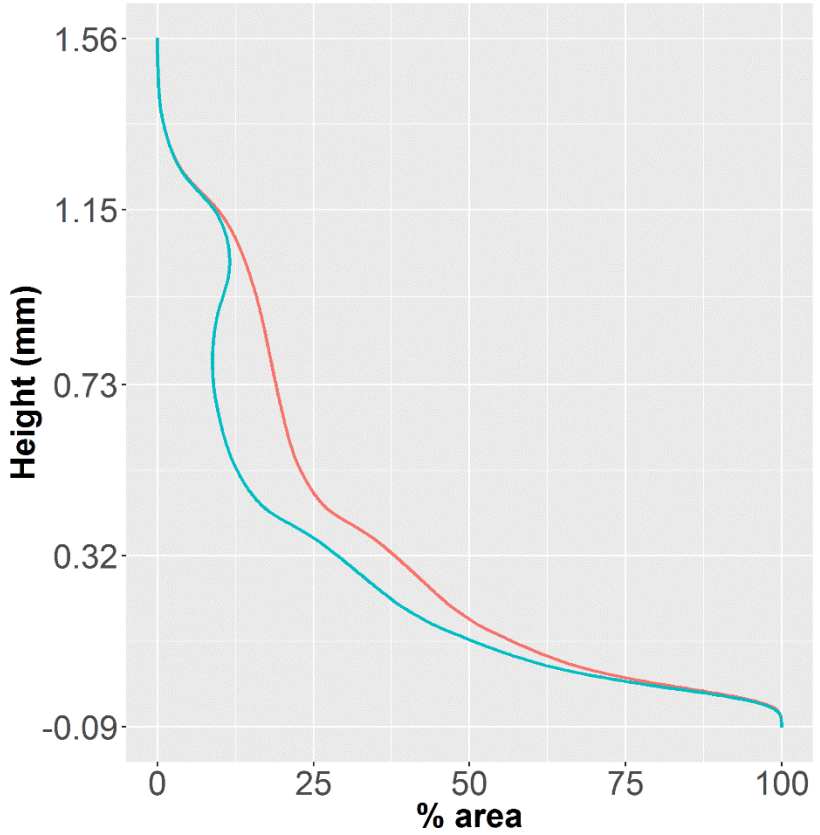
Overhanging and re-entrant features



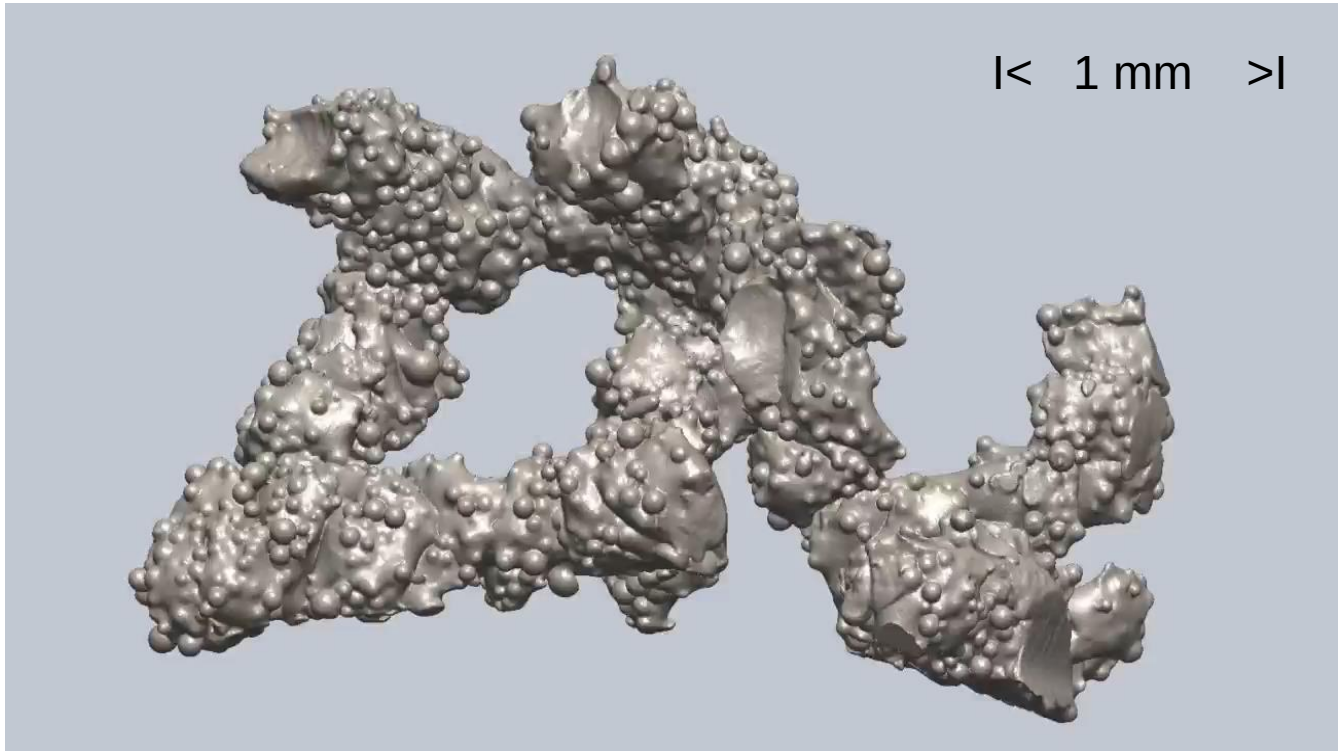


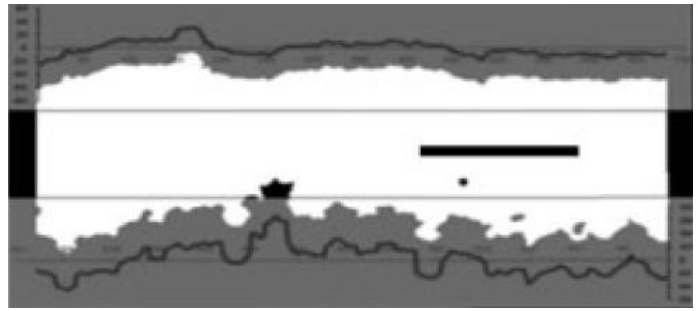
Next stage: areal parameters from highly re-entrant AM surfaces

XCT reconstruction of Velcro®

Pagani L, Scott PJ (2017) *On the characterisation of free-form surfaces*. The 16th international conference on metrology and properties of engineering surfaces, Gothenburg, Sweden, June 2017. Submitted.

Overhanging and re-entrant features





XCT reconstruction of a Ti6Al4V orthopaedic prototype lattice.

Conclusions

- Areal surface texture data per ISO 25178 can be extracted from XCT scans of AM parts
- 1% difference for value of *Sa* between XCT and focus variation possible
- XCT surface determination will affect parameter value
- Insignificant difference between surface data from internal and external surfaces
- Calculation of actual surface area of component with re-entrant features can calculated

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) and funding of the EPSRC Fellowship in Manufacturing: Controlling Variability of Products for Manufacturing (Ref: EP/K037374/1).

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