On the collapse of micro lattice structures

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Sponsors: EPSRC, EU FP6 STREP CELPACT

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Motivation

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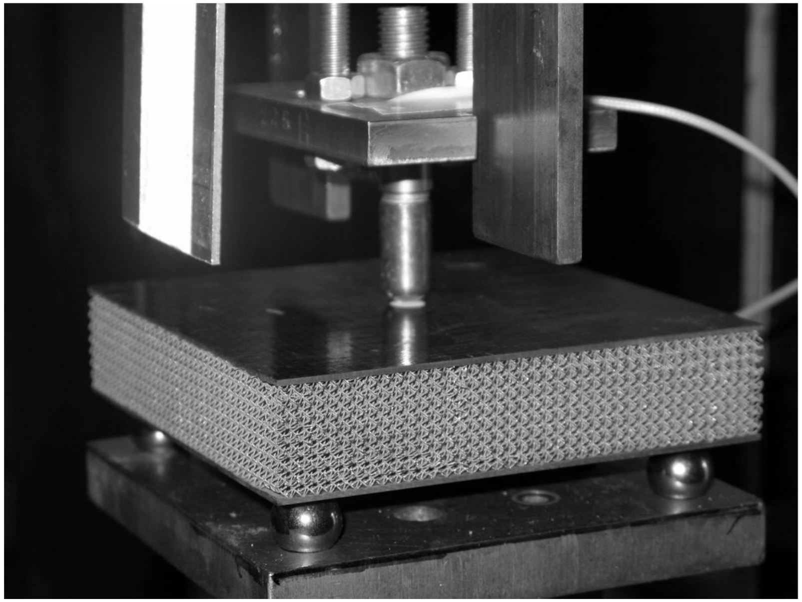
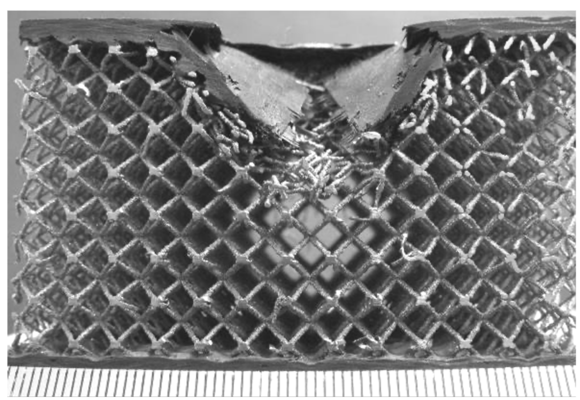
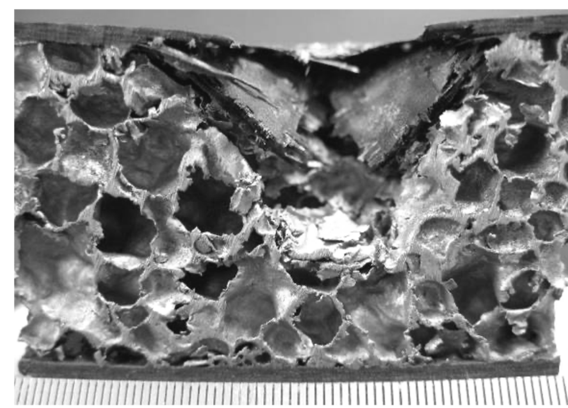


13.6J impact energy

20mm





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SLM RP
Manufacturing Process

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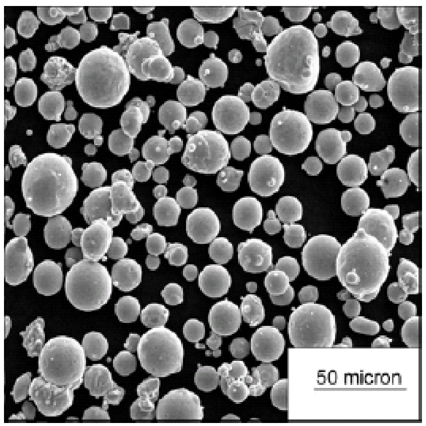
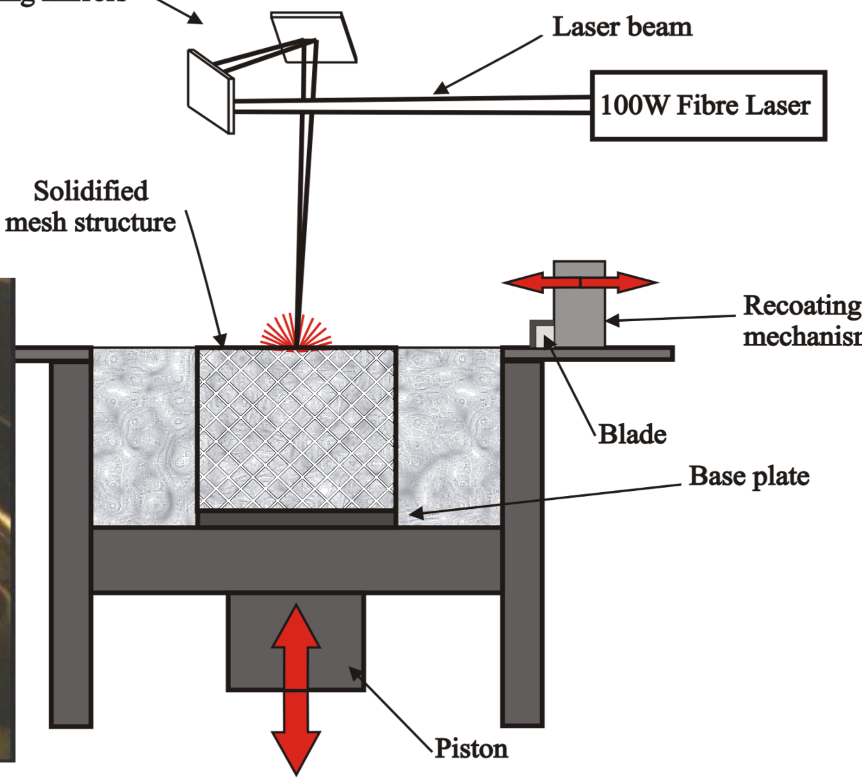
Selective Laser Melting (SLM) Rapid Prototyping (RP) process

- **Stainless Steel 316L** (Sandvik-Osprey supplier)
- 30 to 50 micron powder layer:IR laser melted





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The SLM Machine at Liverpool

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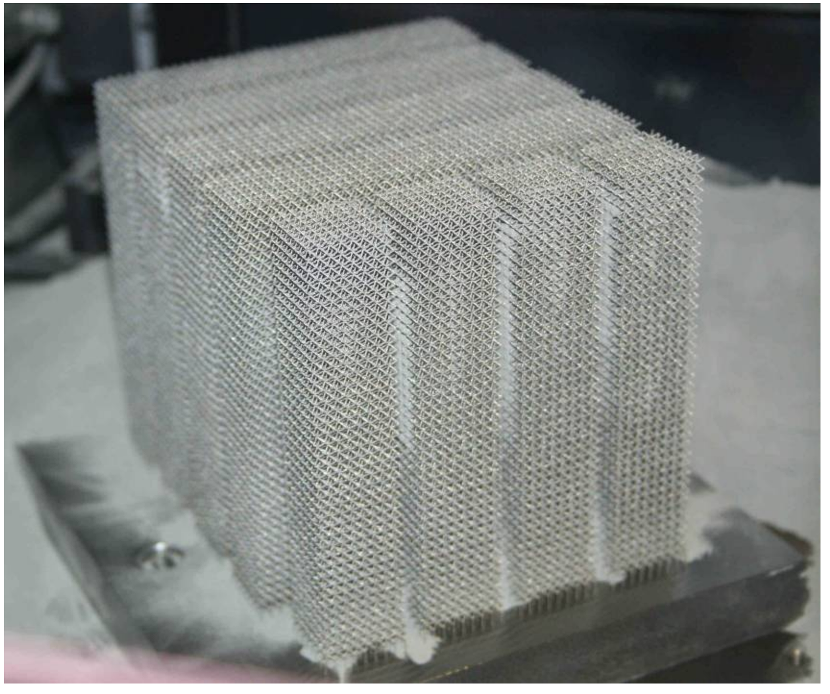
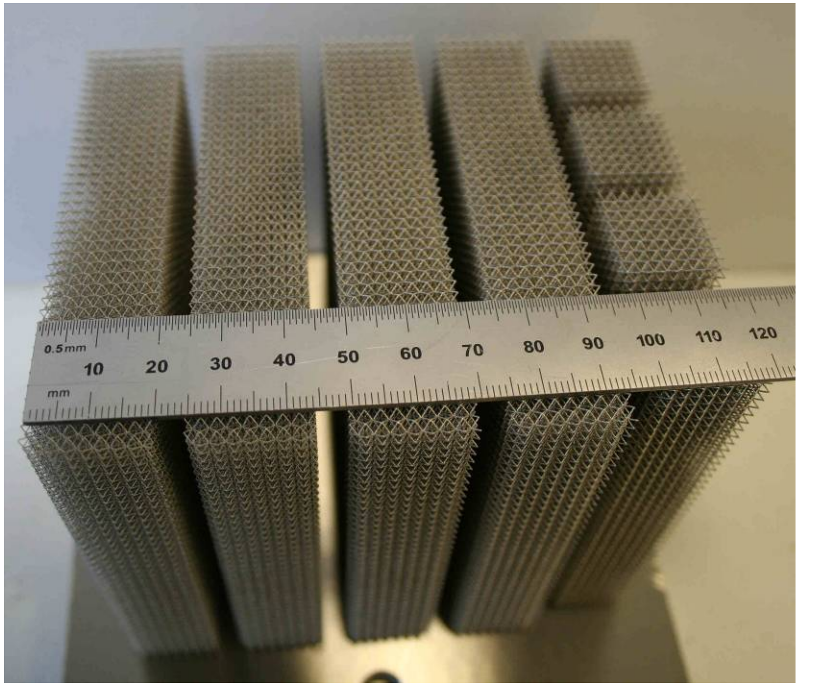
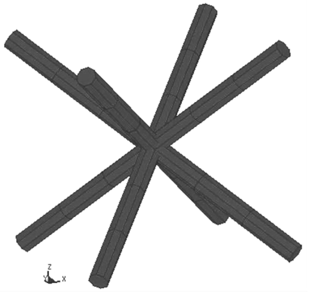
Examples of SLM RP Builds

Post Manufacture

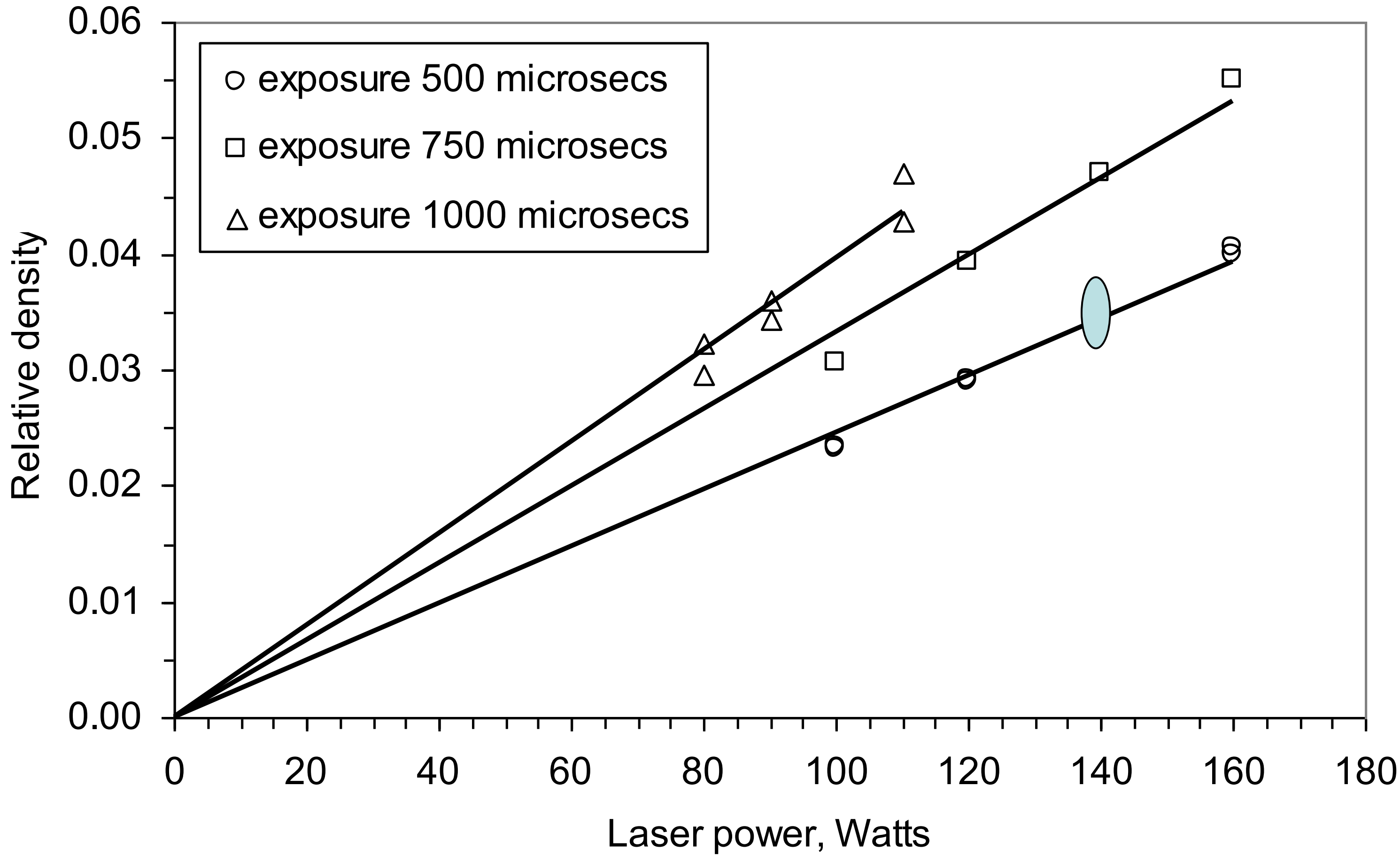




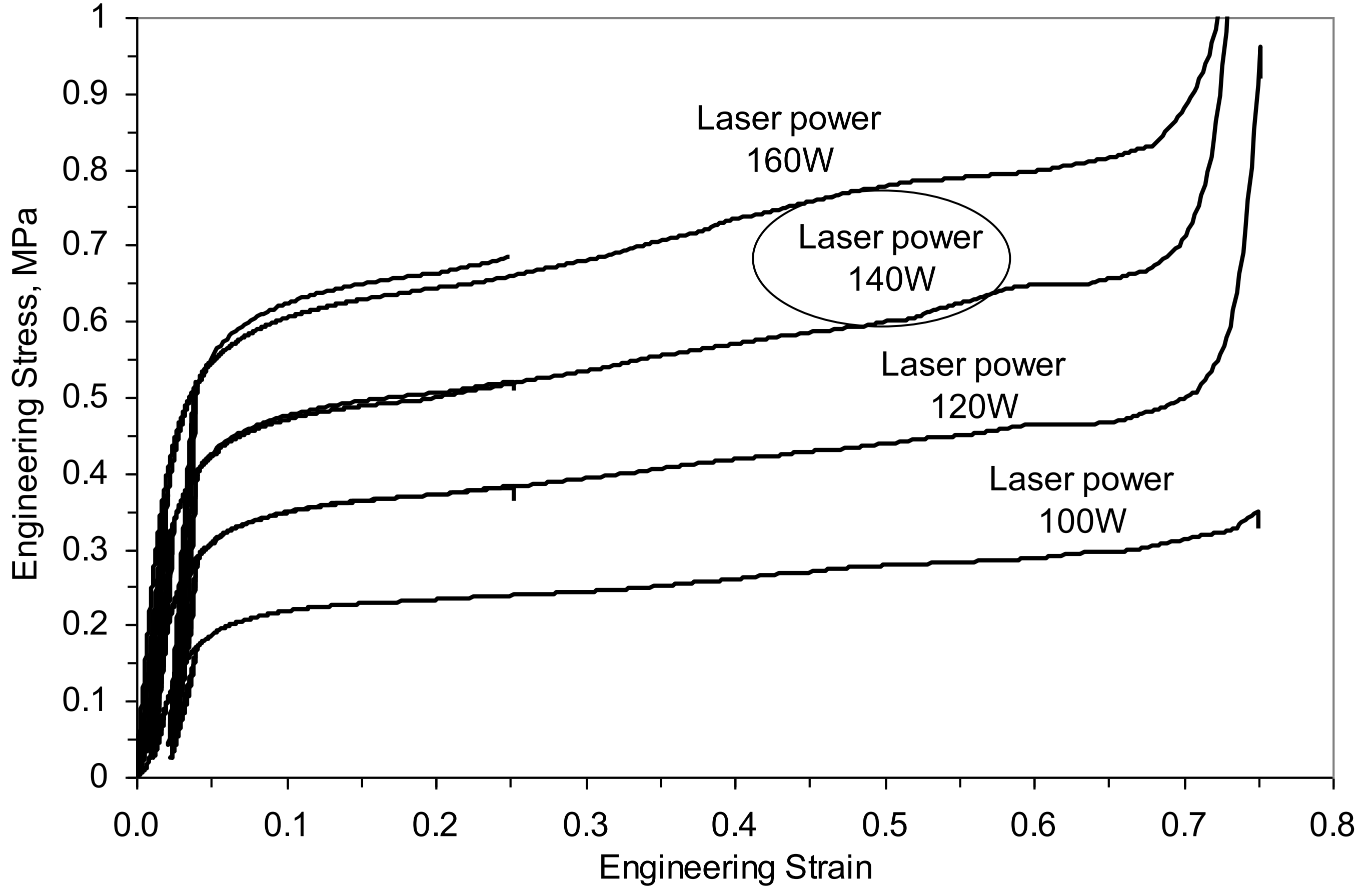
Cell Dimension 2mm



Manufacturing Parameters 1

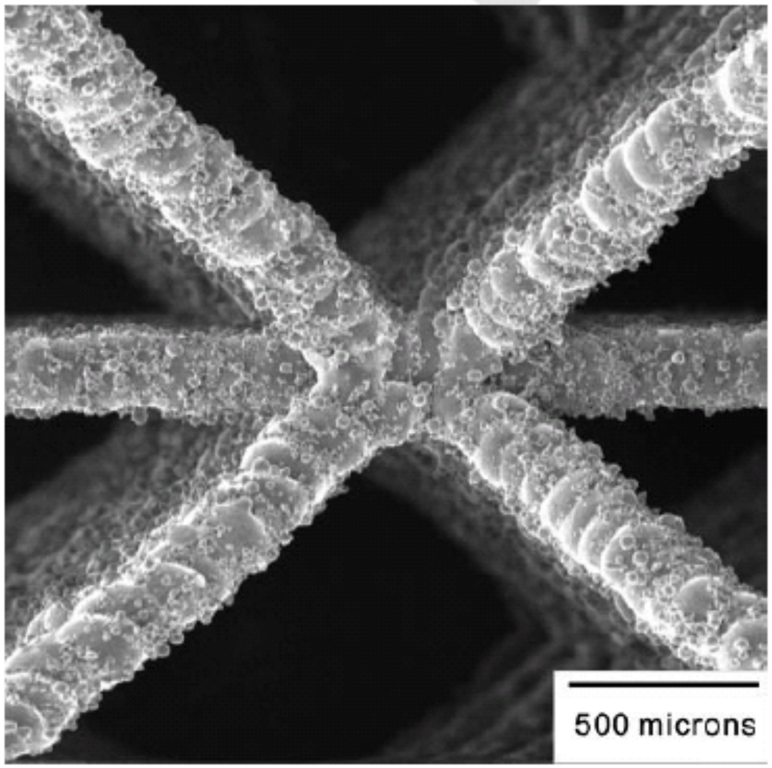


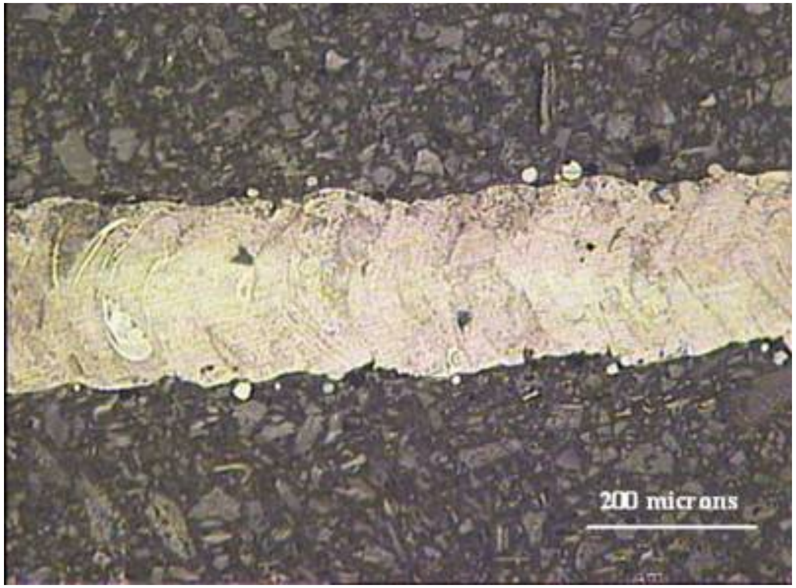
Manufacturing parameters 2



500 microseconds exposure time

Strut Quality



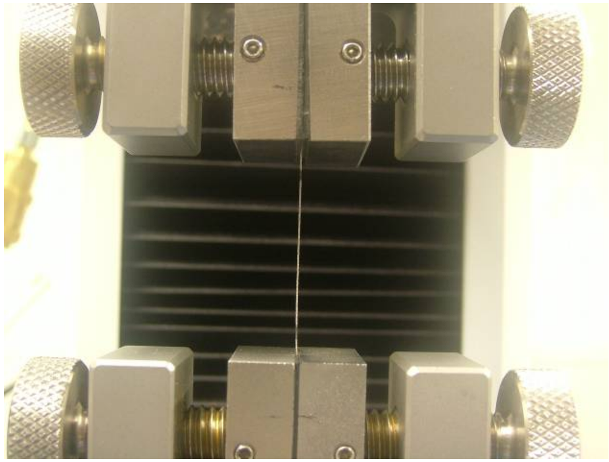


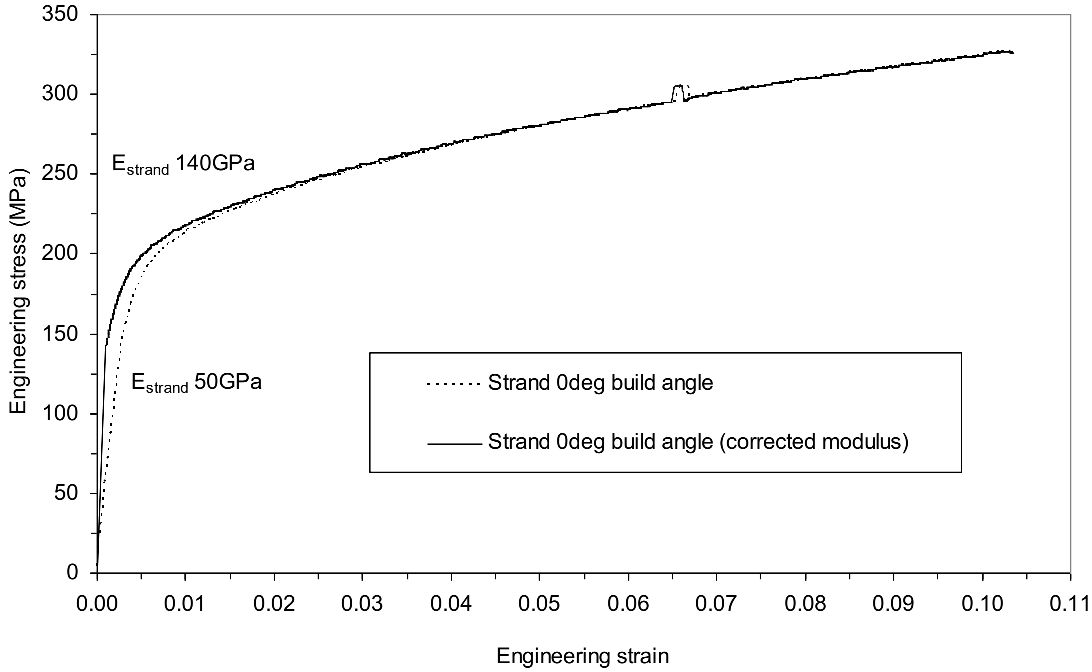
Grain structure and average strut diameter for finite element analysis

Strand Material Behaviour

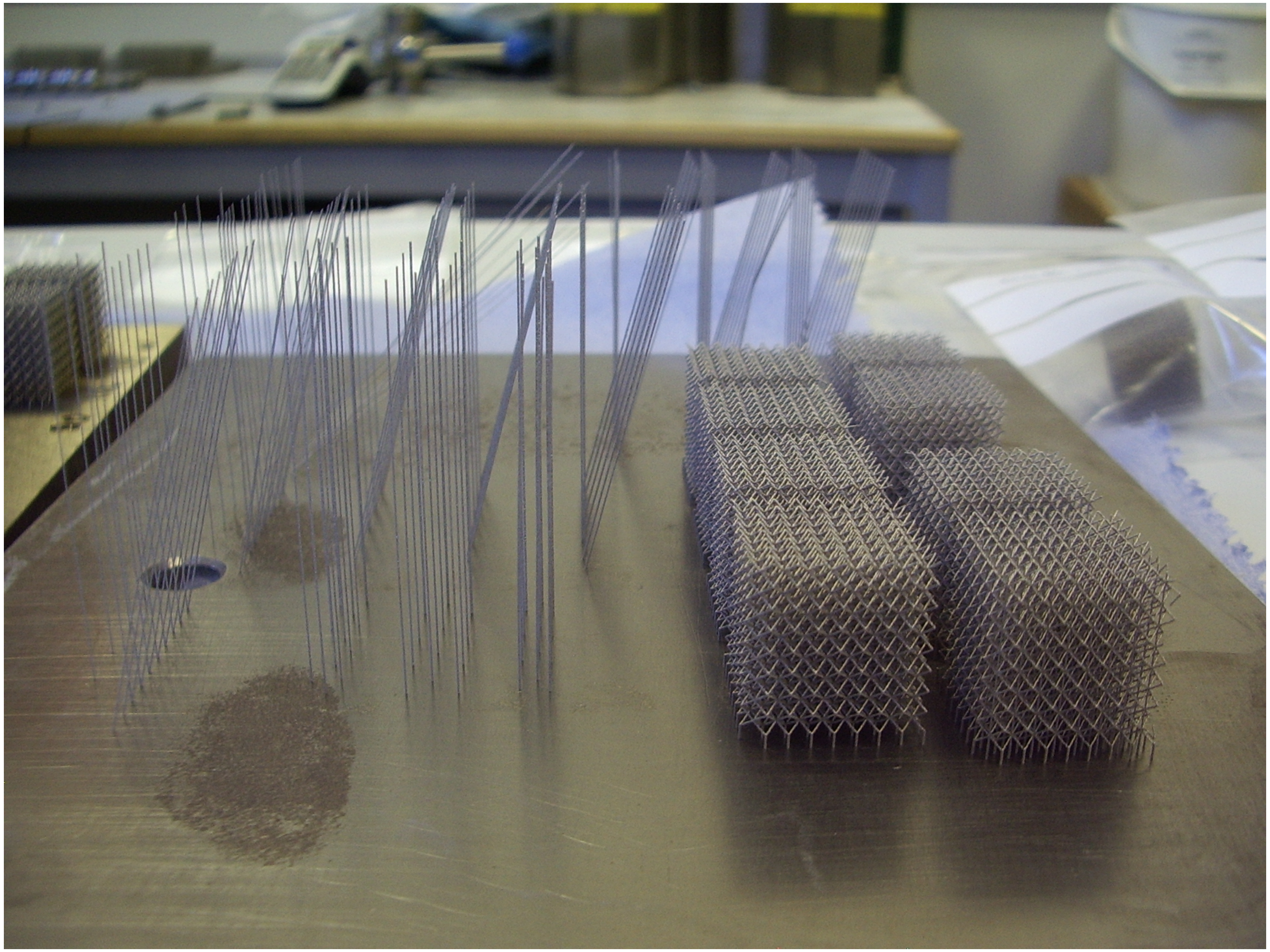
Strand material behaviour

- 316L typically E = 190 GPa, Yield 250 – 300 MPa
- Tensile tests on individual strands
- E estimated from calibration of FE simulation to compression test data





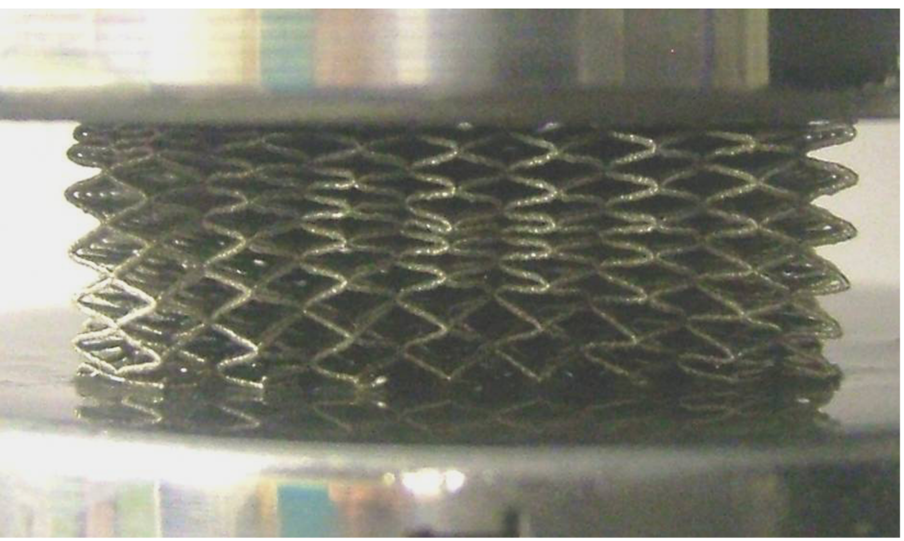
Single strut manufacture

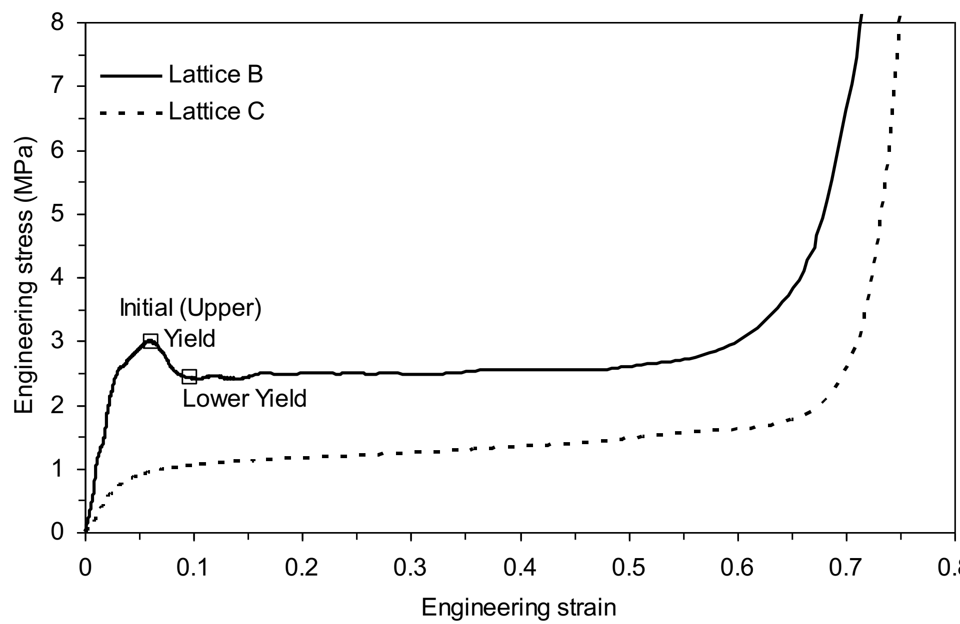


Compression BCC

Compression (Unconstrained)

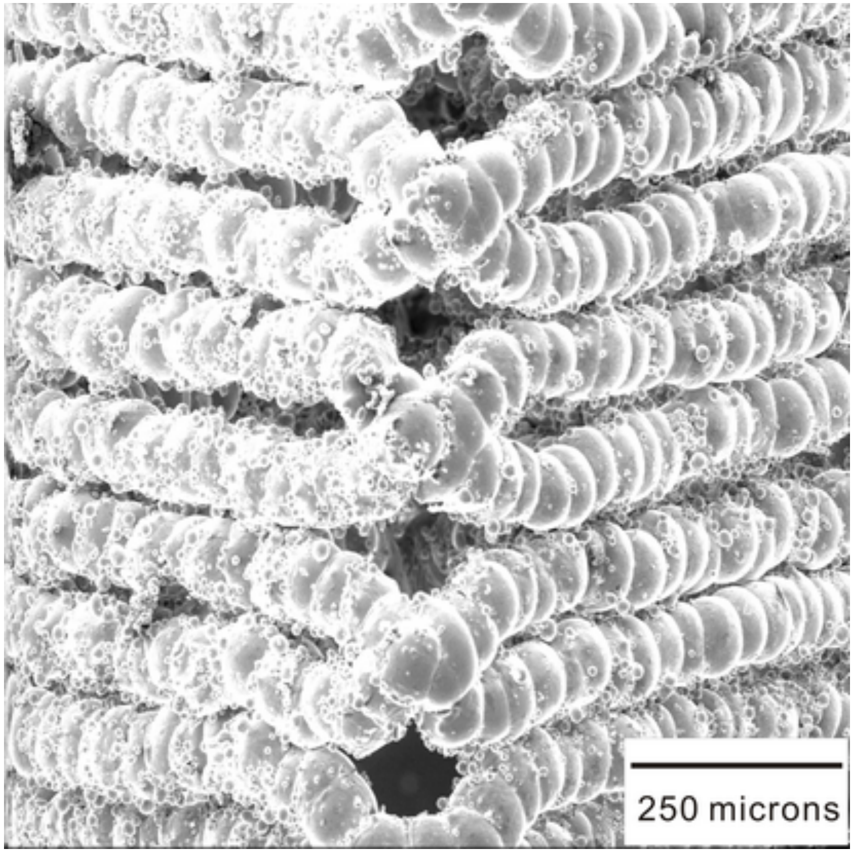
- BCC deformation – elastic/plastic bending at nodes
- Density range 0.4 to 1 Mg/m^3





Compression SEM

Deformed BCC lattice



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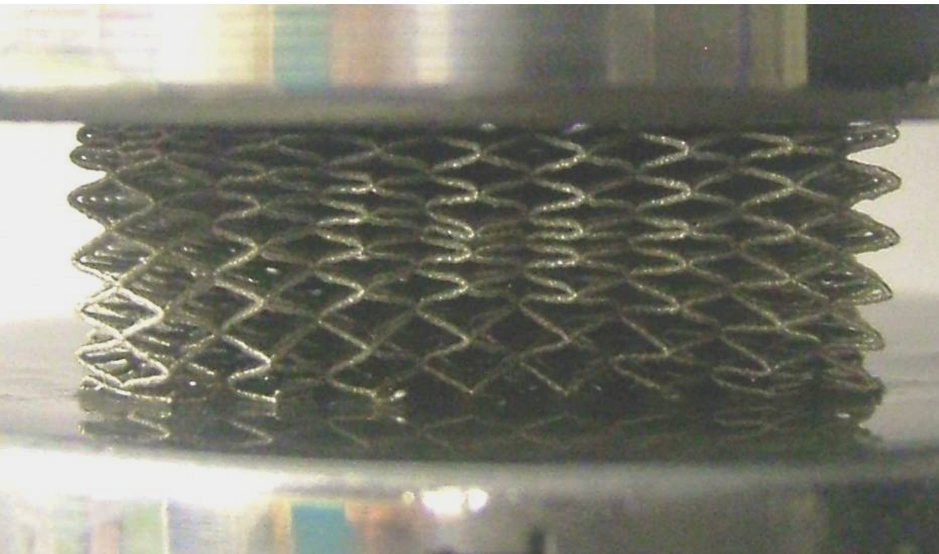
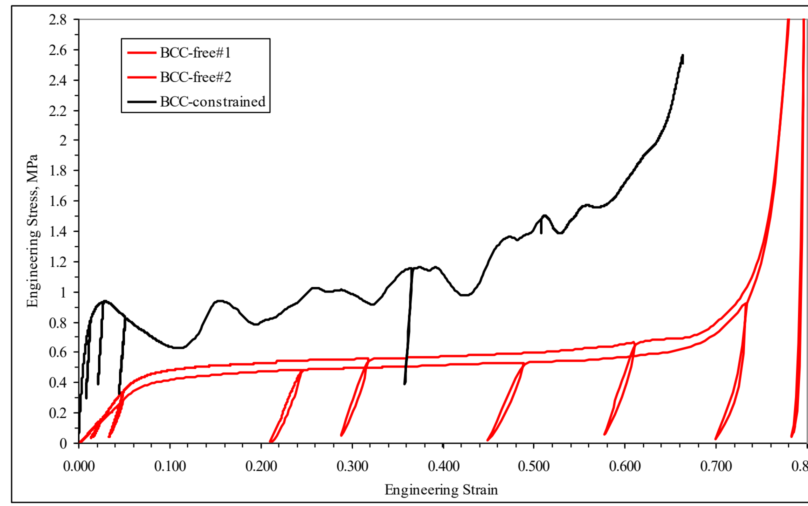
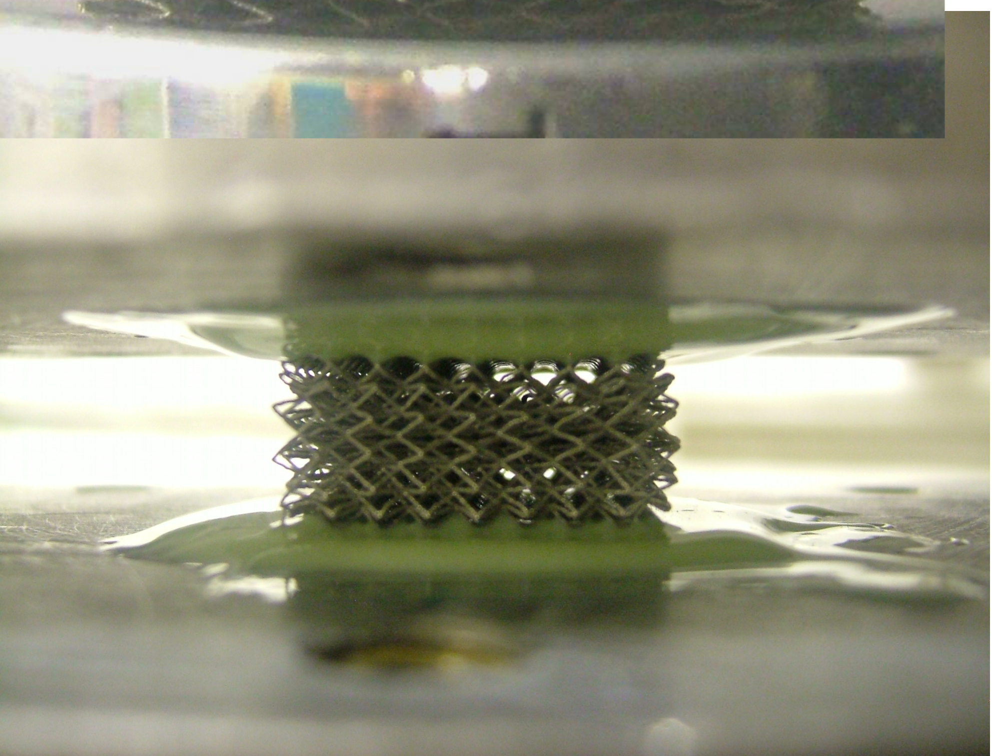
Compression Constrained



Unconstrained





Constrained

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Arcan Test

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Issues:

1. Measurement of force
2. Measurement of displacement

Specimen

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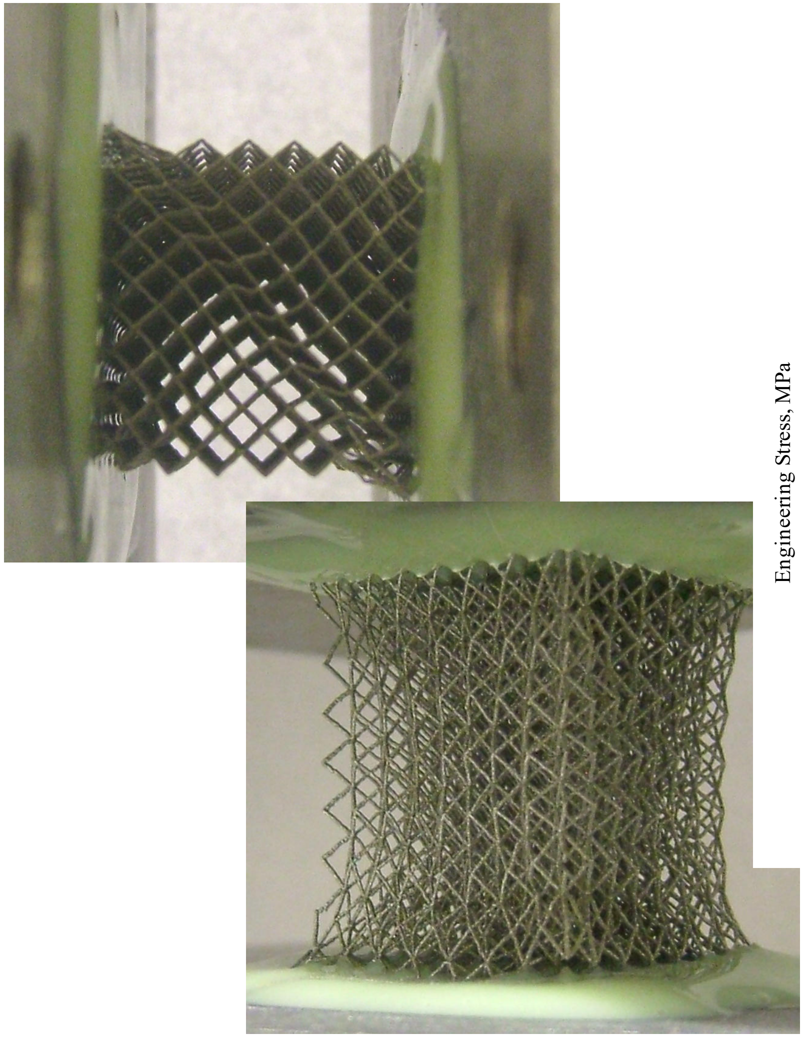
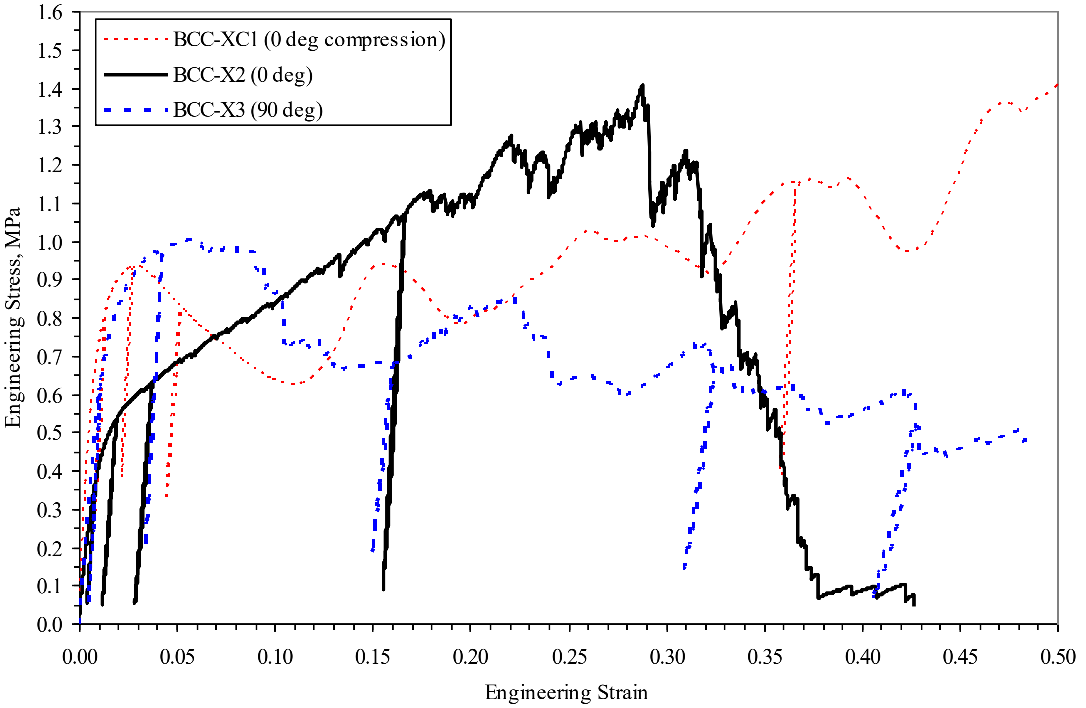
Shear and Tension

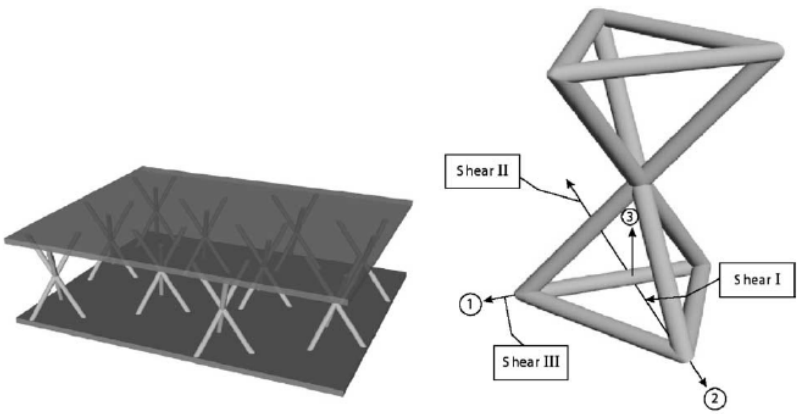




Conclusions 1

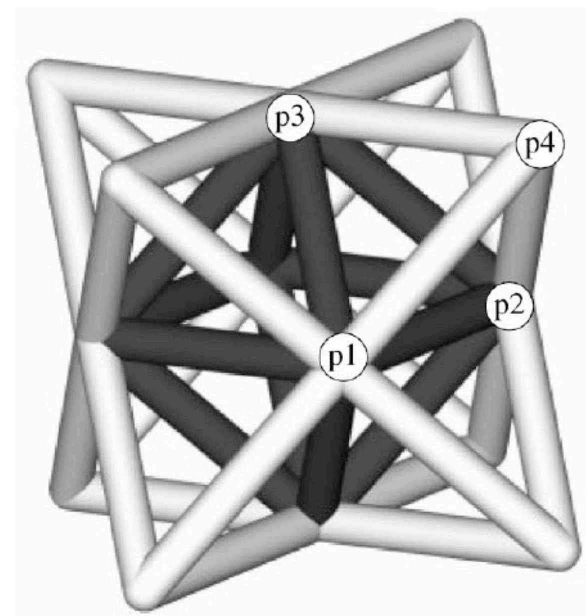
1. BCC SS micro lattice structures are reproducible and manufacturing parameters have been optimised
2. BCC SS micro lattice structures collapse in a stable manner
3. Can we ‘optimise’ micro lattice structures?

Synthesis and optimisation of micro lattice structures



(a) Truss Core Panel (b) Unit Cell

Wang et al IJSS, 2003



Deshpande, Fleck, Ashby, Mech. Phys. Sol., 2001

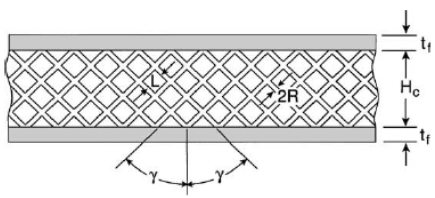
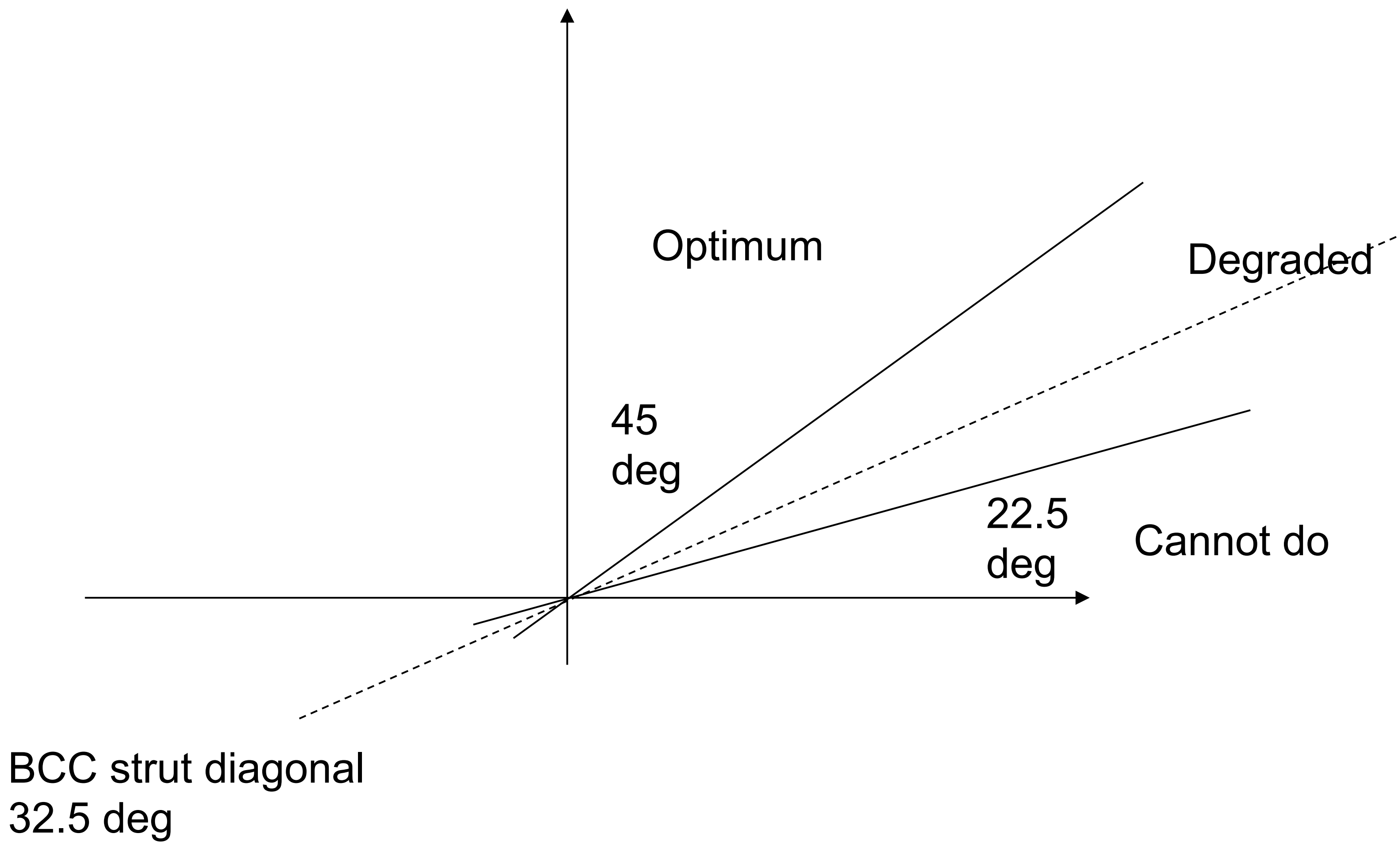


Fig. 3. Schematic of the textile core sandwich panel.

Zok et al, IJSS, 2003

Quality of Strut



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Octet truss geometry investigated

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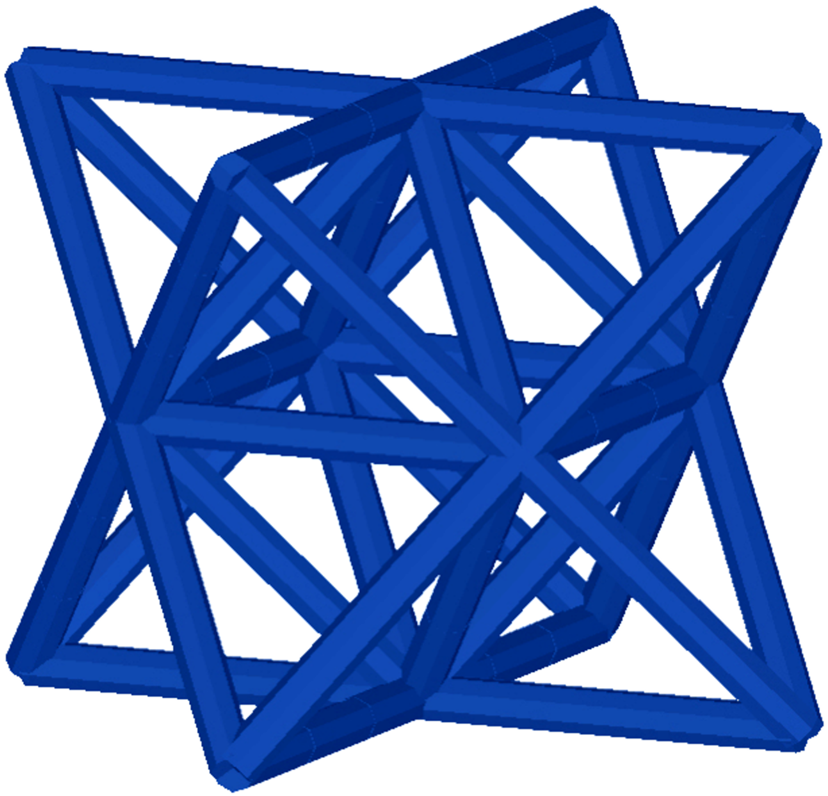
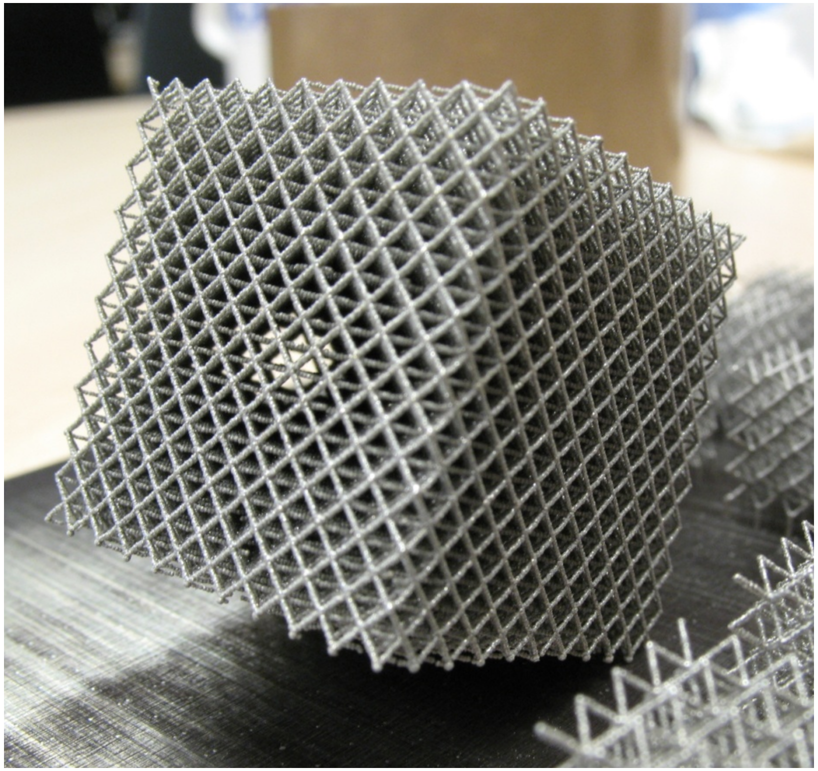




Inevitable low angle links result in unstable structure.

Configurations Studied

Configurations Tested

			Cell Size (mm)	Density (kgm-3)
bcc	ss	Ti	2	250/144
bcc,z	ss		2	300
f2bcc	ss		4	250
f2cc,z	ss		1.25/2.50	424/983
Alporas			2 to 10	230

Significance of micro strut aspect ratio?

Constant diameter of strut ….200-250 microns

Optimal manufacture conditions: spot size (200/250 microns), power (140W/180W), duration (500 microsecs)

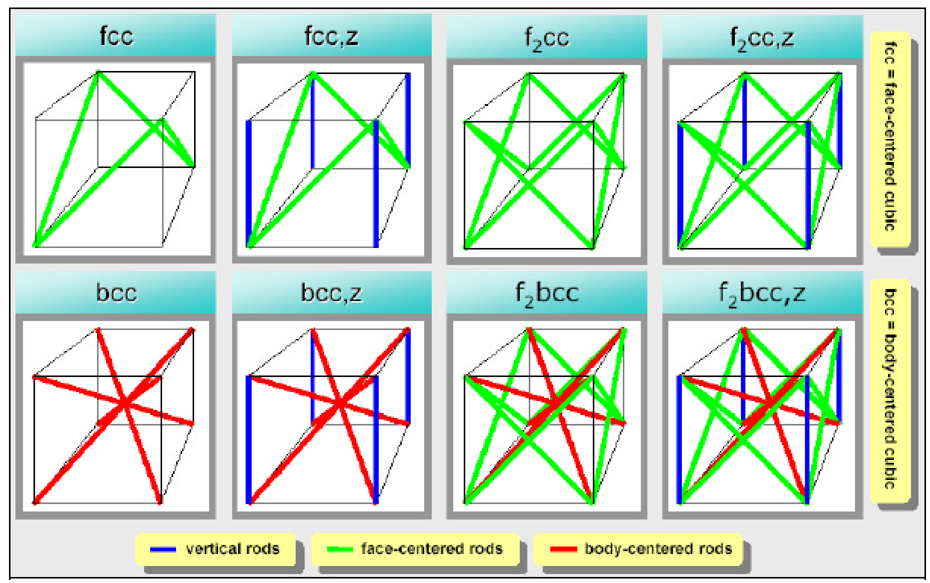
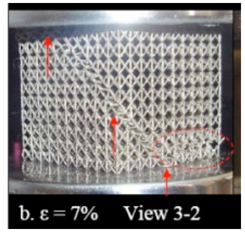


Fig. 3. Definition of cubic cell types

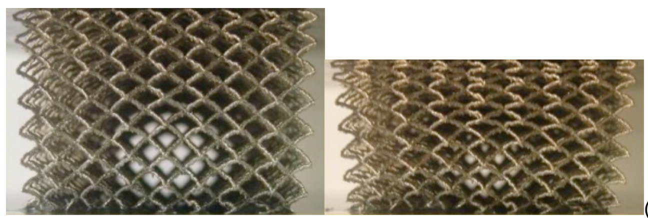
Rehme et al

Block Comparison Tests – Unconstrained Compression



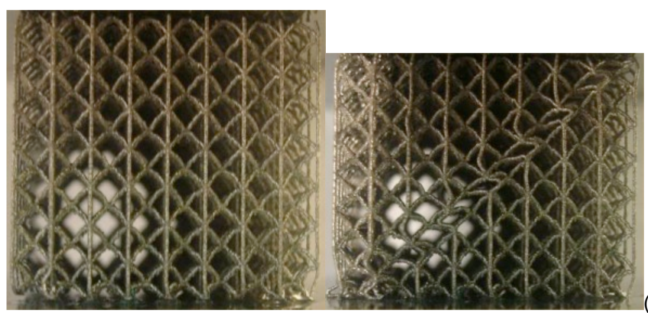
(a) 7 % strain

F2fcc,z



(b) 16% strain

bcc

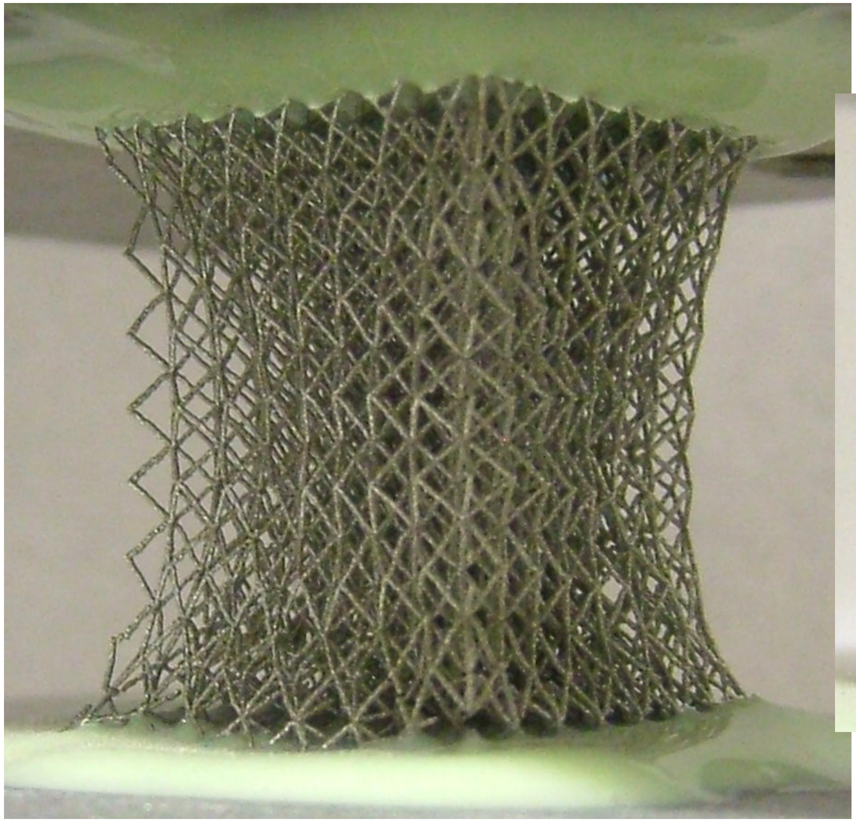


(c) 16% strain

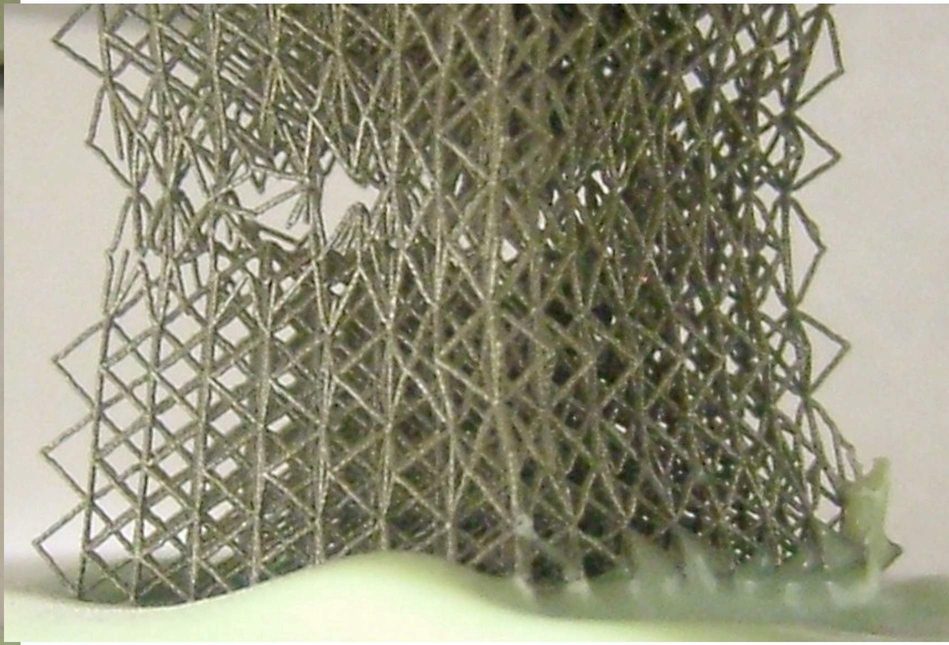
bcc,z

Figure 1. Photos of progressive collapse of micro lattice structures: (a) $f_2$fcc,z-l, (b) bcc-l, (c) bcc,z-l

Block comparison tests – tension



BCC



BCC,Z

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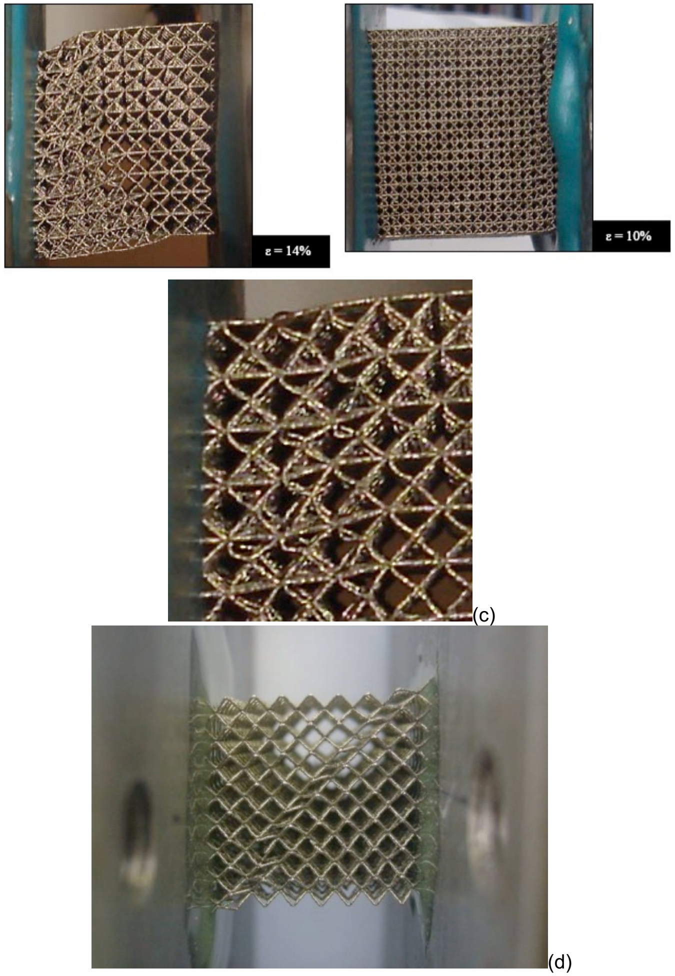
Block comparison tests - shear



F2fcc,z

bcc

Figure 2. Failure modes for pure shear: (a) Alporas foam, (b) $f_2$fcc,z-l and h, (c) detail $f_2$fcc,z-l,(d) bcc-l

Block Comparison - Summary

Summary of data (unconstrained compression)

Configuration	Material	Density	Specific Stiffness	Specific Strength
		kgm-3	MPakg-1	MPakg-1
bcc	ss	250	73	1.9
bcc	Ti	144	174	17.4
bcc,z	ss	300	1176	4.9
f2bcc	ss	250	48	1.6
f2cc,z	ss	424/983	2620/1923	15.3/24.1
Alporas*	Al	230	438	7

*Constrained

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Ti 6Al 4V (Background)

- High strength-to-weight ratio
- Corrosion resistant
- Good mechanical properties to ~300 ^{o}C
- $\alpha + \beta$ Titanium alloy
- Major application area: Aircraft industry

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Ti 6Al 4V (Titanium Grade 5 ASTM) by **TLS**

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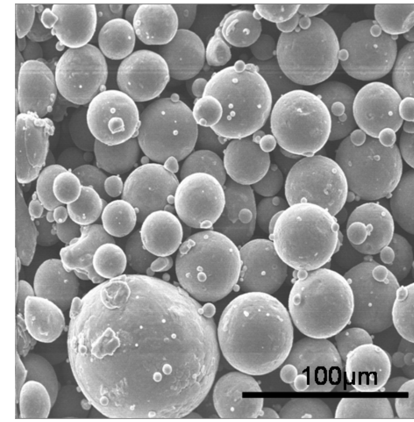
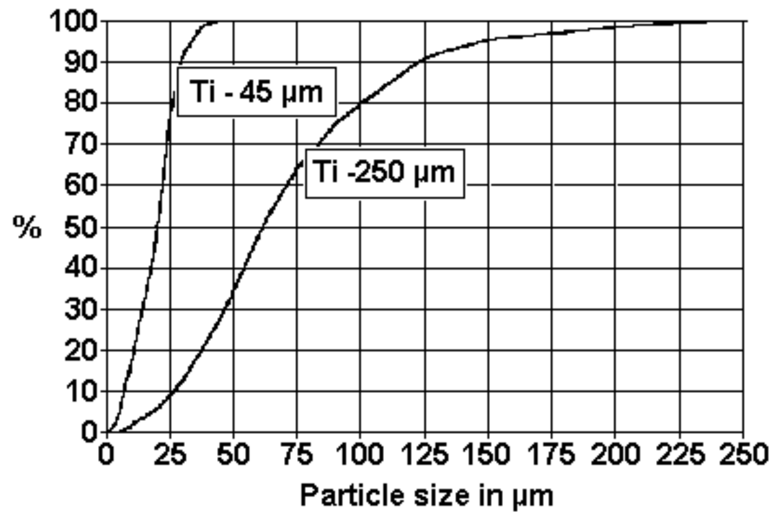
Chemical Analysis *(contents in weight-%)*

Element	Al	V	Fe	Si	O	C	N	H
Ti 5 max.	5,5-6,5	3,4-4,5	0,25	n.a.	0,13	0,08	0,05	0,012
Ti 5 typical	5,9	3,[illegible]						





Particle size distribution of Ti powder

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Hot Isostatic Pressing (HIP)

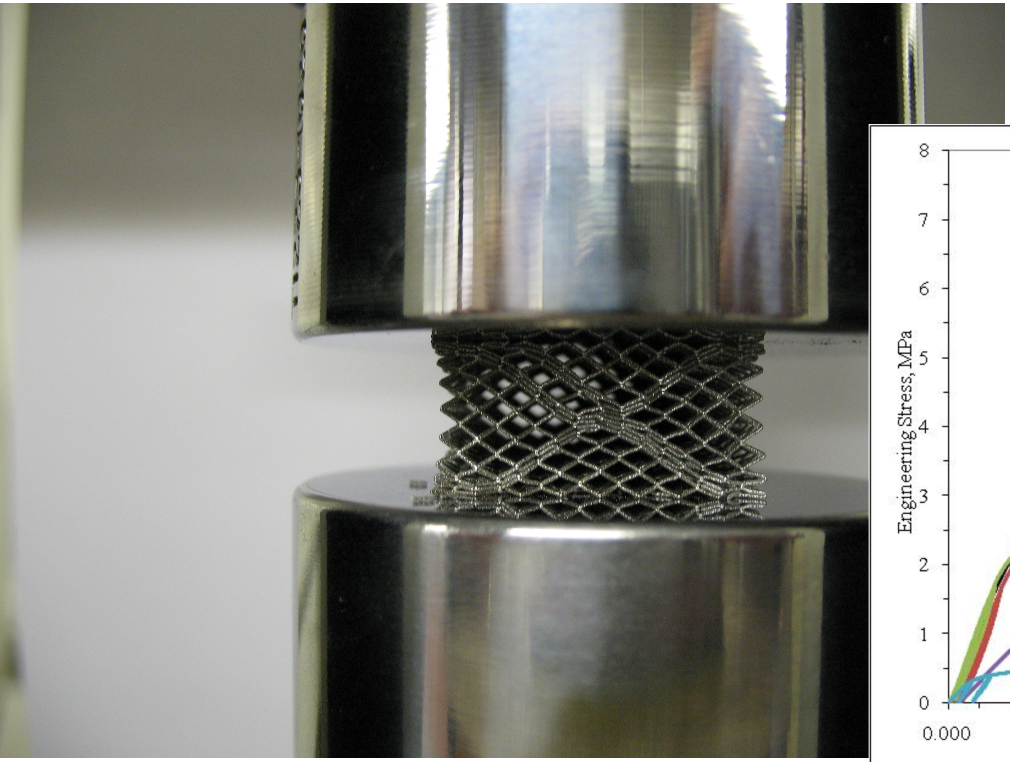
- Hot isostatic pressing (HIP) is a manufacturing process used to reduce the porosity of metals. This improves the mechanical properties and workability.

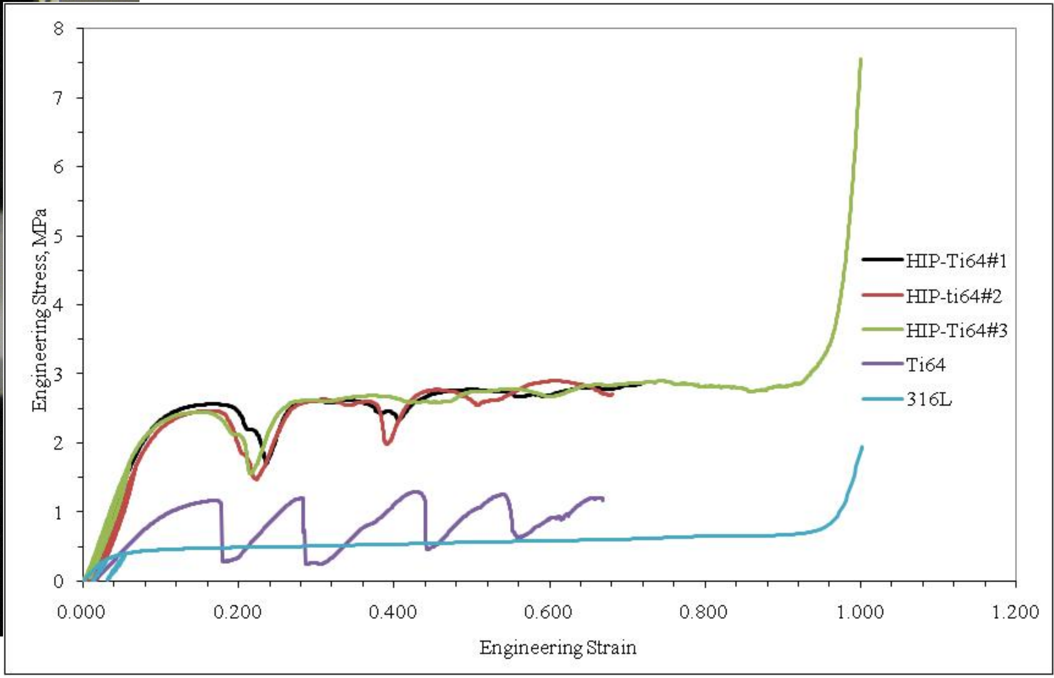
- A component is subjected to both elevated temperature and isostatic gas pressure in a high pressure containment vessel. The pressurizing gas most widely used is argon (no chemical reaction).

Courtesy of : Xinhua Wu , Birmingham University

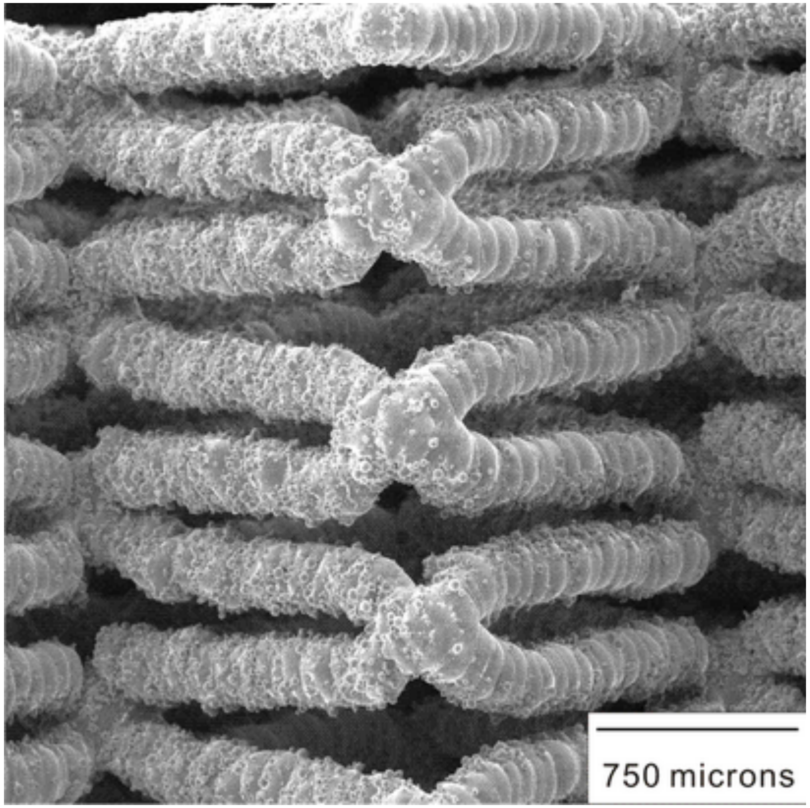
Ti 6Al 4V - Post processed (HIPped results)

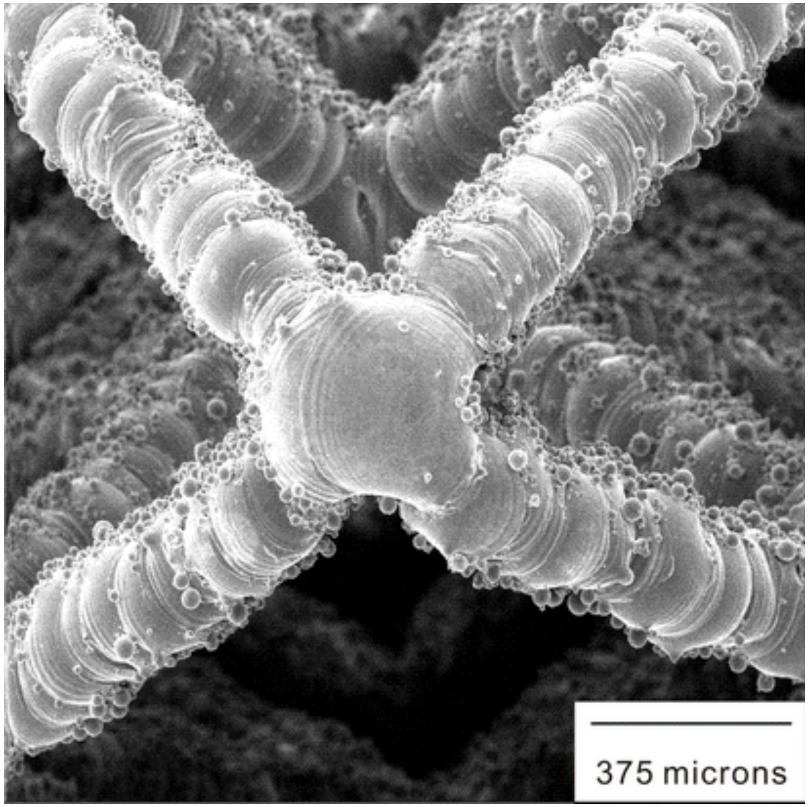
HIPped at 930^{0}C and 100MPa for 4 hours.





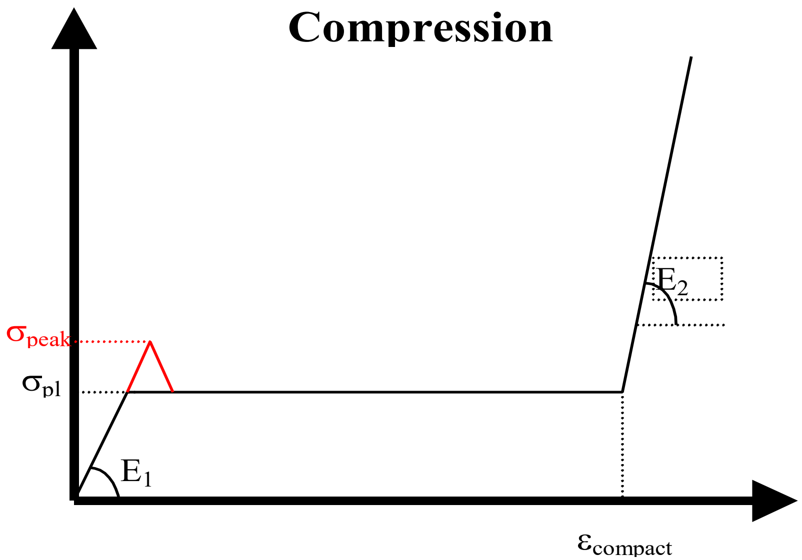
Ti 6Al 4V - Post processed (HIPped results)

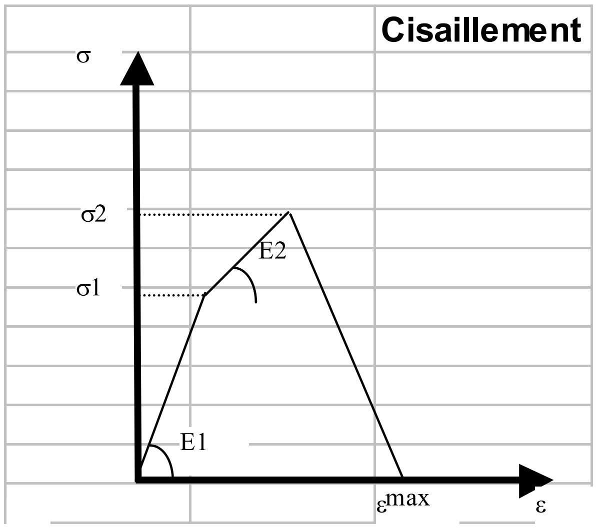




EADS Criterion 1

Static





Material parameters in compression (E1, σpeak, σpl., E2) and shear (E1, E2,σmax, εmax)

EADS Criterion 2

	Density	Specific Stiffness	Specific Strength
	kgm-3	MPa/kgm-3	MPa/kgm-3
Unconstrained compression			
Al Honeycomb (5056)	37	7378	18.9
Alporas foam*	230	438	7
BCC SS	250	73	1.9
BCC TiAl	170	174	17.4
Shear			
Al Honeycomb (5056)	37	3405	18
Alporas foam*	230	261	3.9
BCC SS	250	384	4
BCC TiAl	170	?	?

Final Conclusions

1. Ti Al BCC a competitor to Al Honeycomb
2. There is opportunity to ‘optimise’
3. There is opportunity for graded structures
4. Other work at ULIV – panel tests, computer simulation….see Bob’s Plenary at SEM XI !

Thank you!