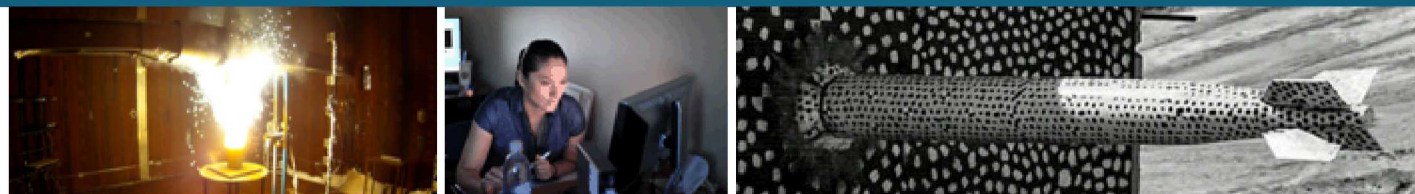


Using X-ray Micro-Computed Tomography and Digital Volume Correlation to Investigate the Microstructure of Elastomeric Foams



PRESENTED BY

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COAUTHORS

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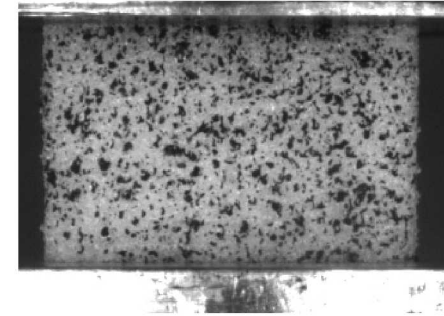


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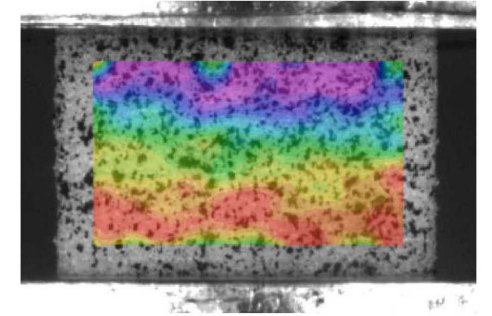
SAND2018-10903 A

Background: Digital Volume Correlation

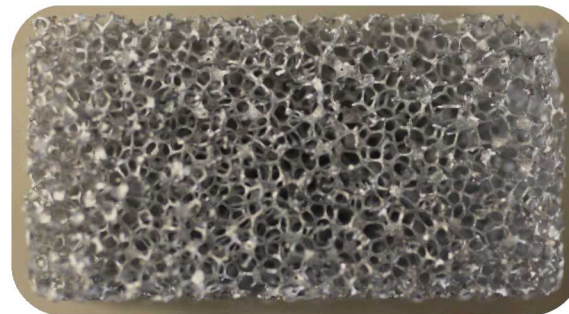
- Digital image correlation
 - Speckle pattern
 - 2D and 3D *surface* measurements
- DVC
 - 3D *volumetric* measurements
 - X-ray computed tomography (CT), confocal microscopy, & magnetic resonance imaging
 - Typically quasi-static, but synchrotron sources enable dynamic tests
 - Seed particles for speckle pattern
 - Naturally occurring speckle patterns
 - Bone, wood, composites, precipitate metals, foam



Speckle Pattern



Contour Plot



Aluminum Foam



Epoxy seeded with
aluminum spheres



Foam

Motivation

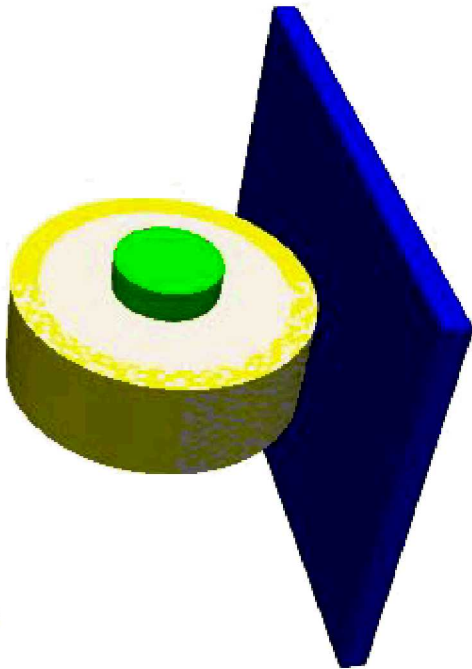
- Elastomeric foams (don't crush)
 - Used for insulation, flotation, packaging
- Crash scenario: rigid cylinder encased in foam within a cylindrical shell



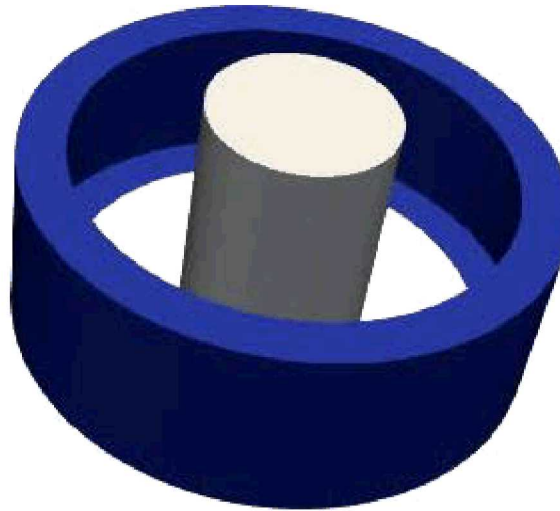
Wikipedia



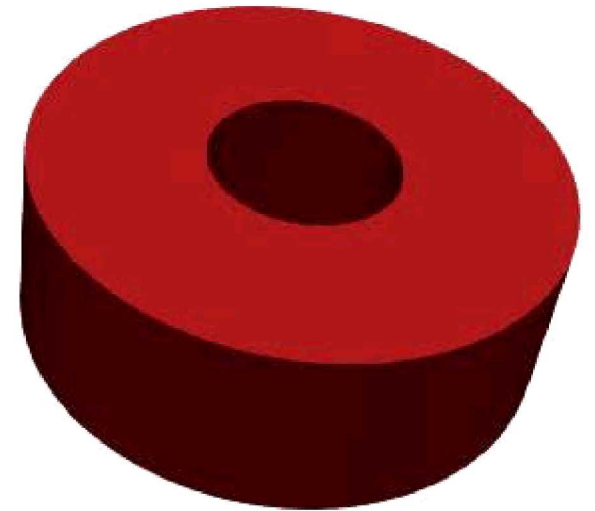
BriskHeat®



Crash Scenario

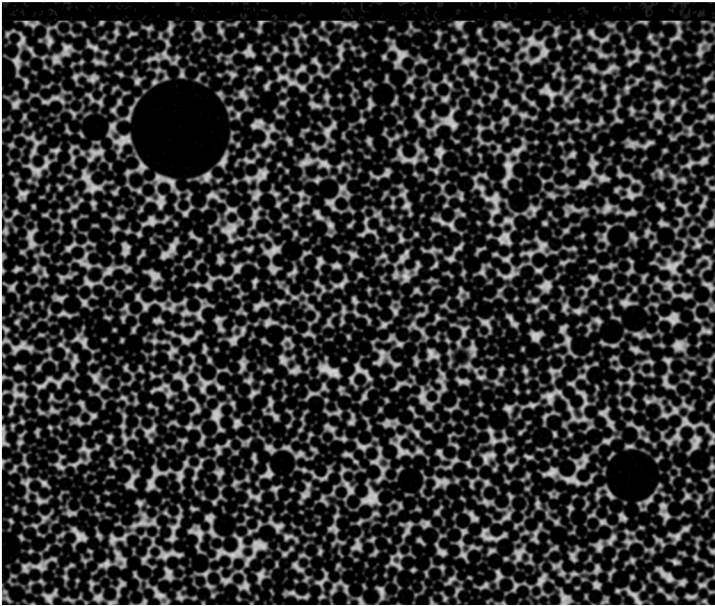


Shell Response

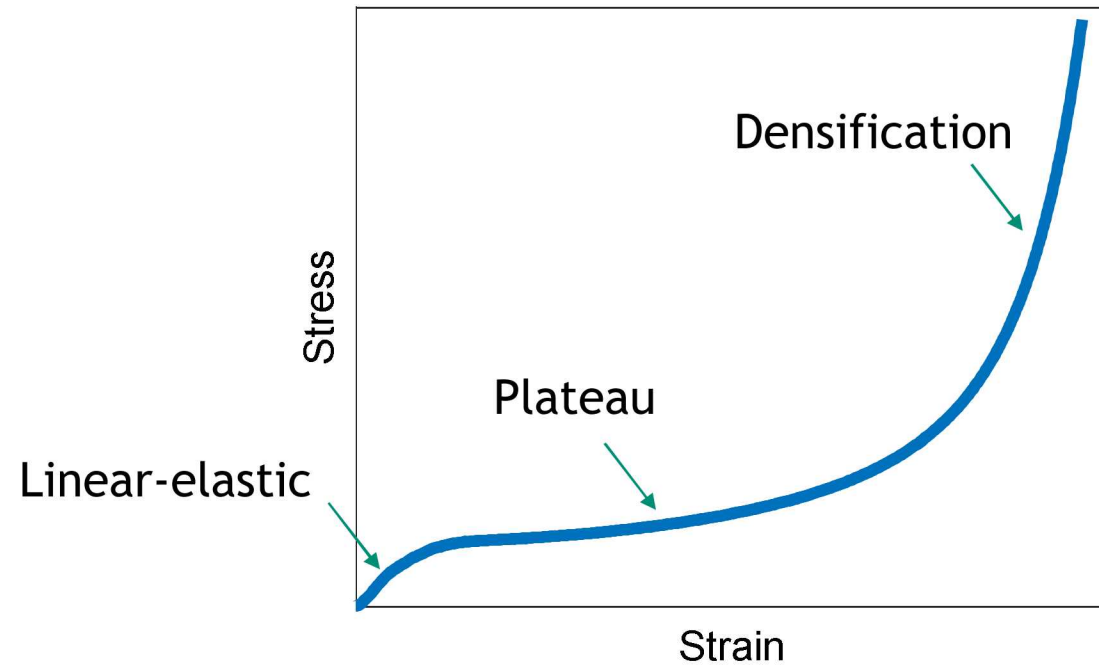


Shell Response

- Use X-ray CT and DVC to identify microstructural features that affect the overall response
 - Pore size & curvature distribution, mean strut thickness, etc.



Typical σ - ϵ profile for PU foam

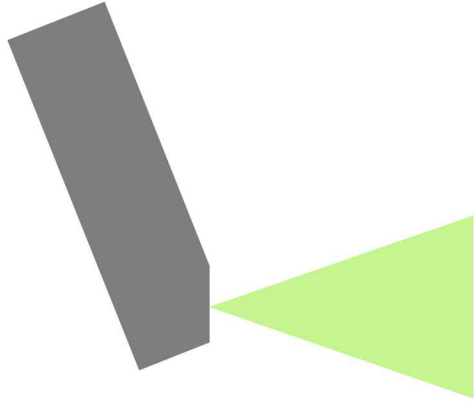


- Develop a new constitutive relationship using machine learning

$$\Psi_{\text{foam}} = \Psi_{\text{foam}} \left[\mathbf{E}, \Theta, \Psi_{\text{solid}}, \frac{\rho_{\text{foam}}}{\rho_{\text{solid}}}, \xi_1, \xi_2, \dots \right]$$

Experimental Setup

Fein Focus 225 kV

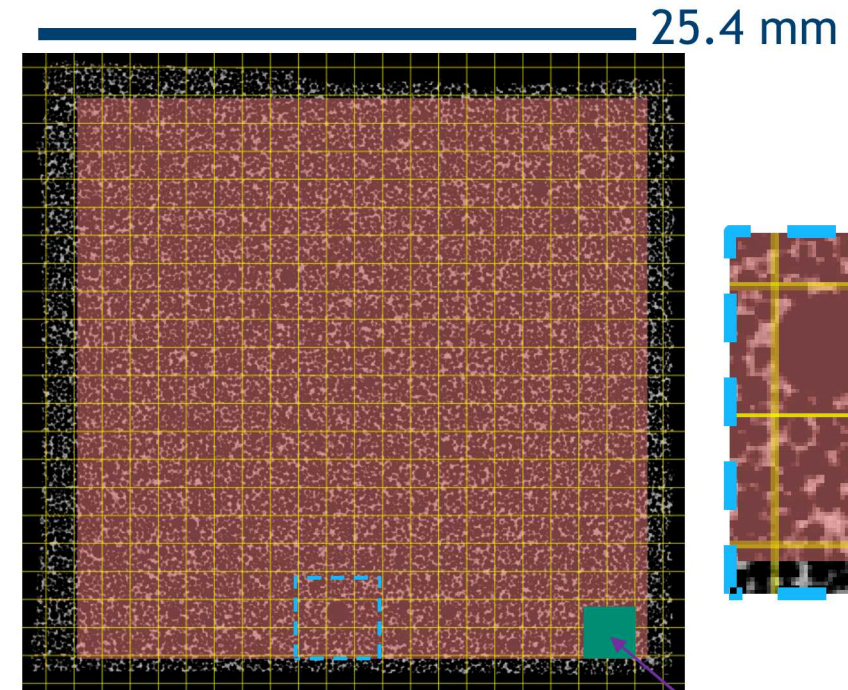
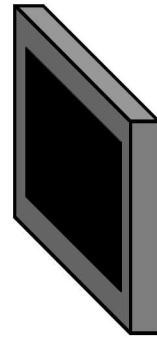


PU 15 pcf
(240 kg/m³)

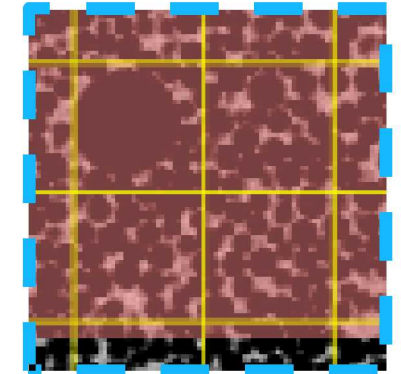


Deben.co.uk

Varian
PaxScan2520DX



- 3-5 voxels/feature
 - pore diameter: 200-500 μm
- 3-5 features/subset
- Correlated Solutions Vic-Volume



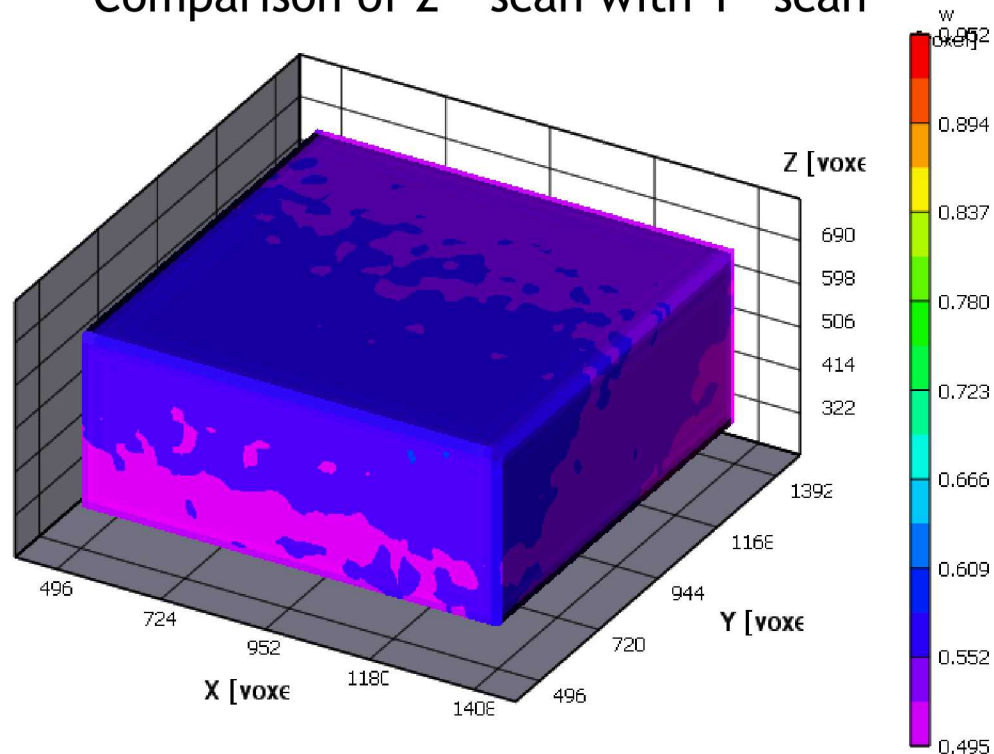
Virtual Strain
Gage (VSG)

Resolution	Subset	Step	Filter	VSG
20 $\mu\text{m}^3/\text{vox}$	47 vox	16 vox	5 vox	2.7 mm ³

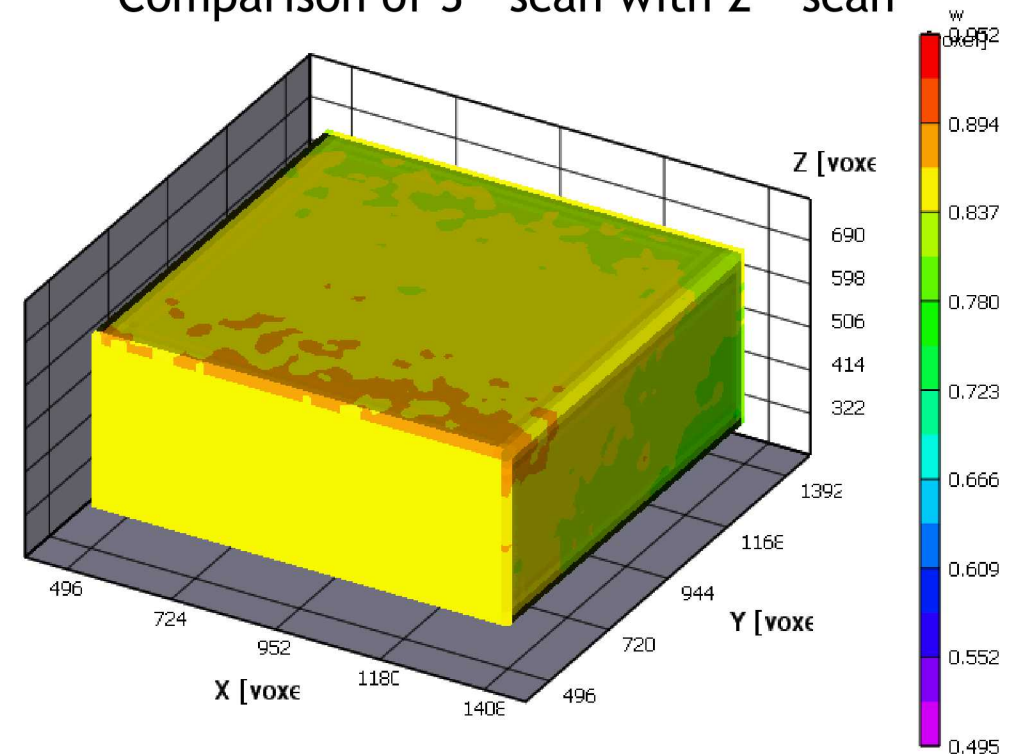
Noise Floor Scans

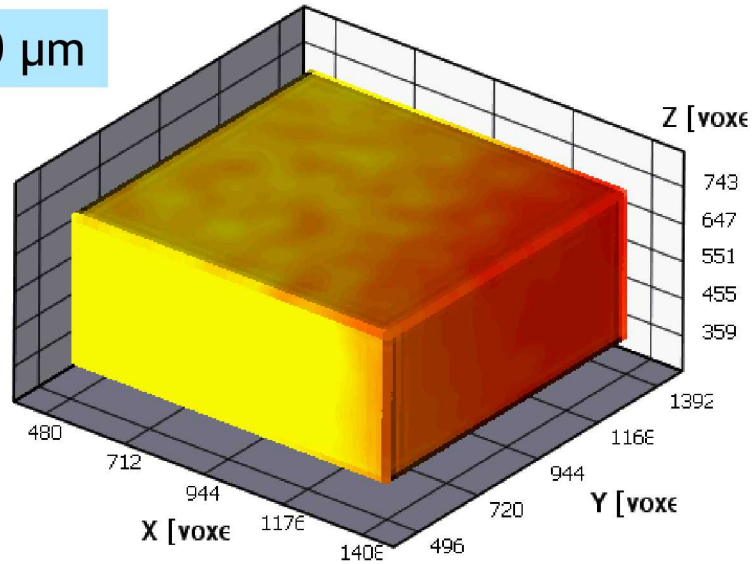
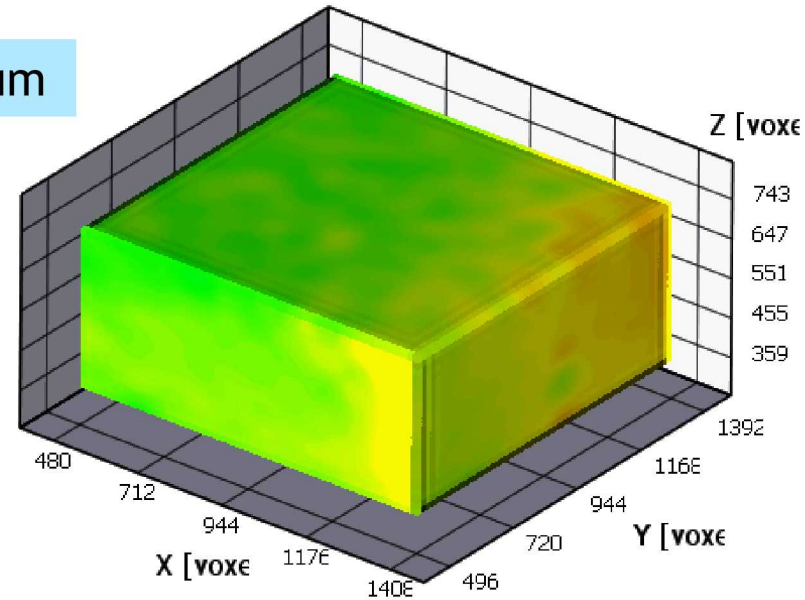
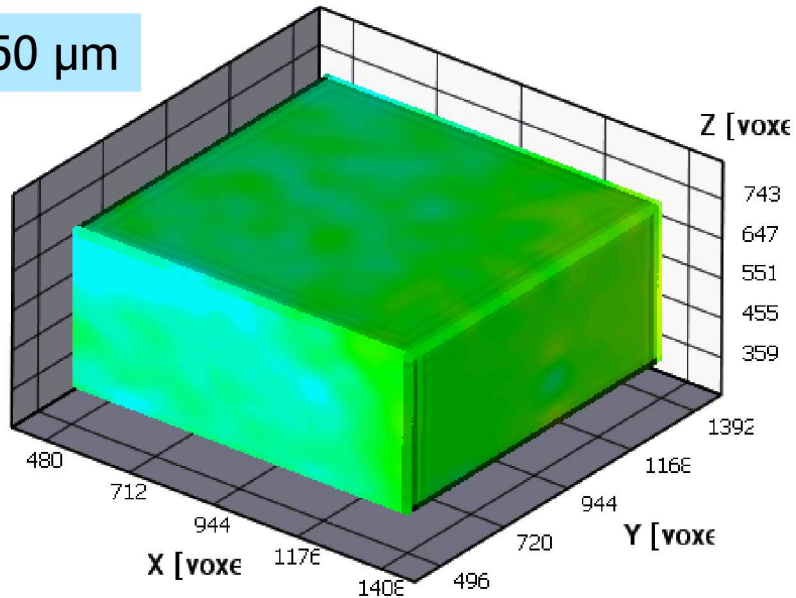
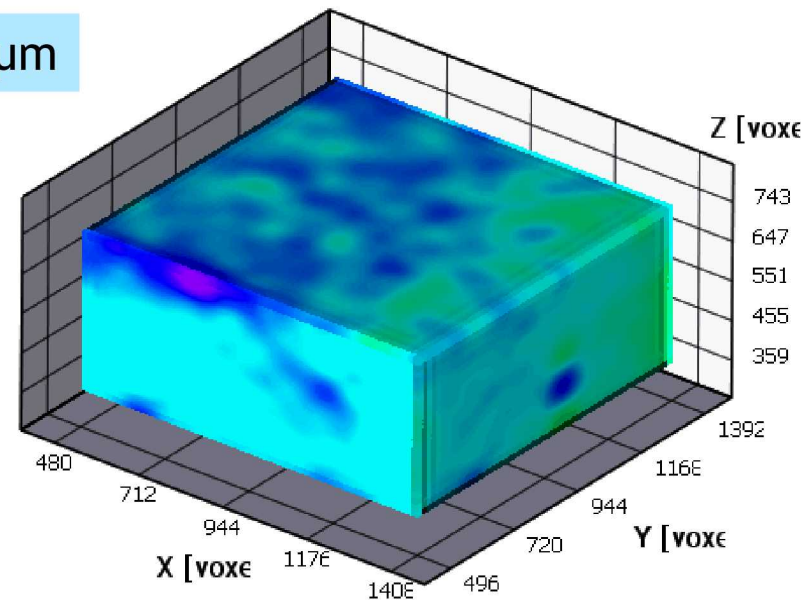
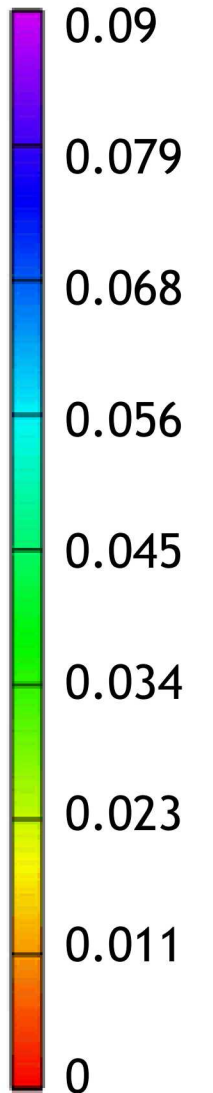
- Series of identical scans to determine baseline inaccuracies
- Sources of error: thermal drift, rotation stage precision, detector response

Comparison of 2nd scan with 1st scan

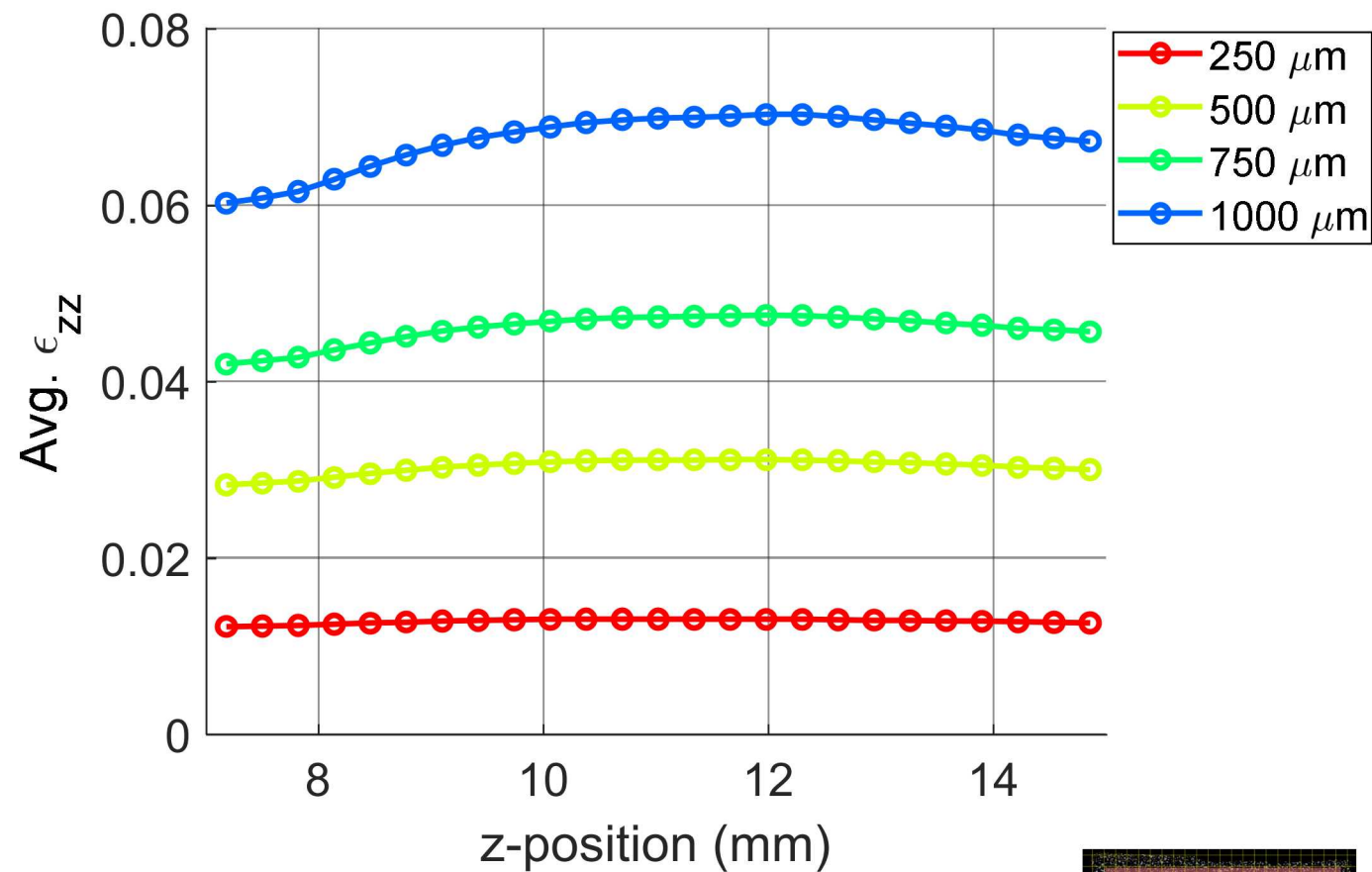
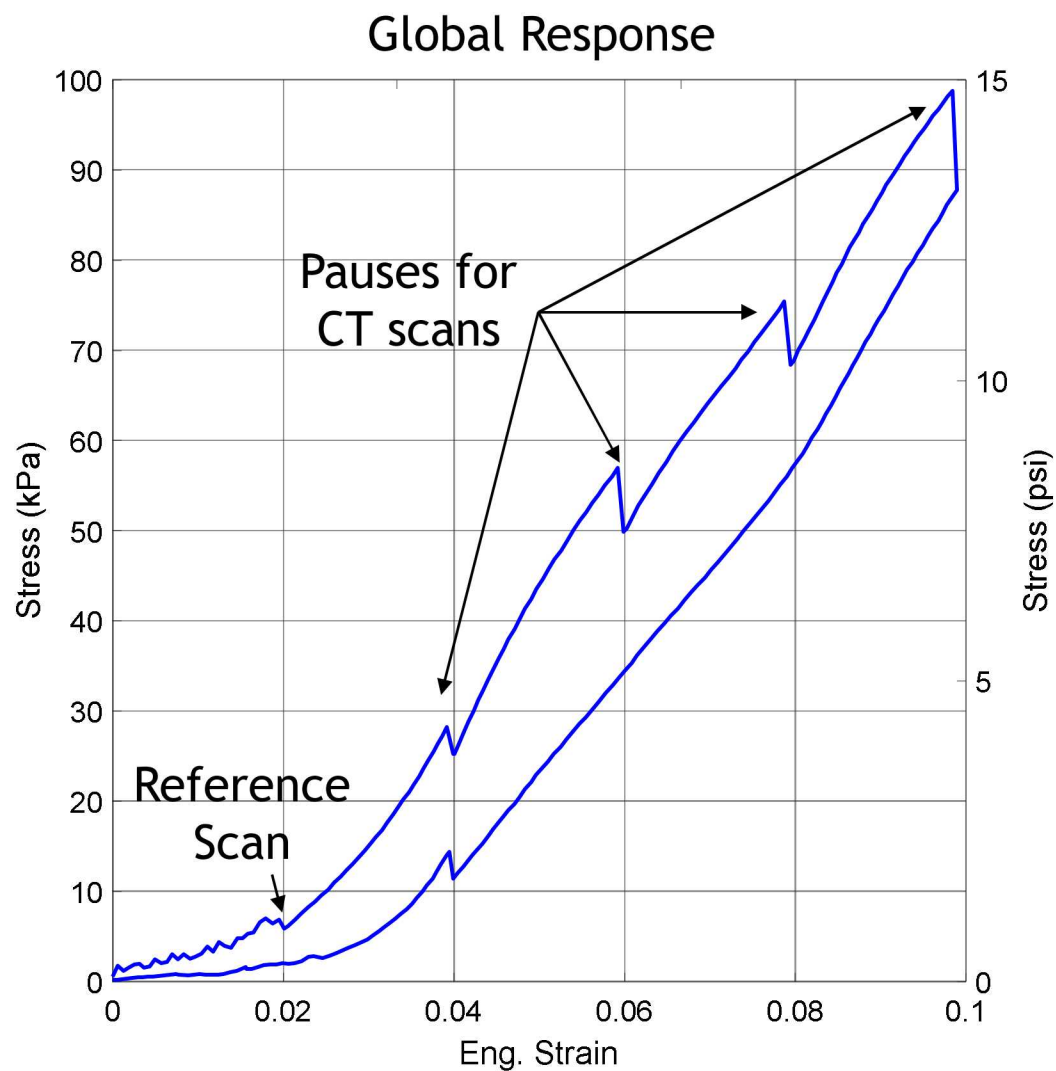


Comparison of 3rd scan with 2nd scan

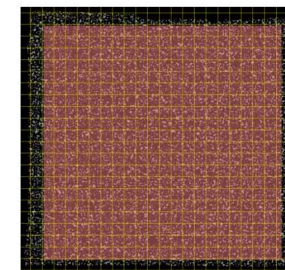


Compression of $25.4 \times 25.4 \times 12.7 \text{ mm}^3$ polyurethane250 μm 500 μm 750 μm 1000 μm  ϵ_{zz} (Lagrange)

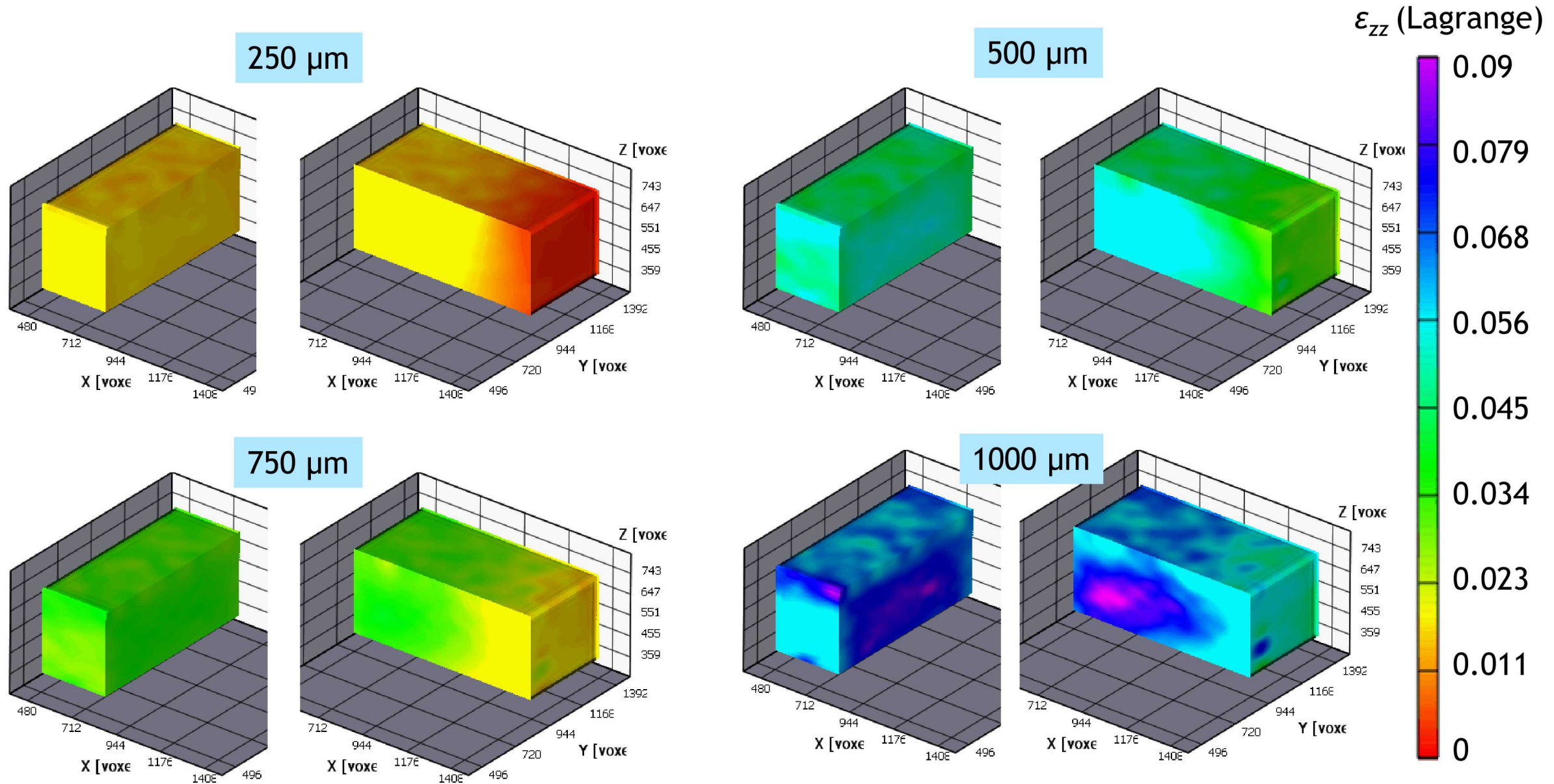
Compression of Polyurethane Foam



- Average vertical strain at each slice
- Homogeneous response until $\sim 10\%$ total strain



Internal view at different compression steps



Compression of Cellular Silicone

- Same setup, different foam
- Larger pore size $\rightarrow$ lower spatial resolution in DVC results

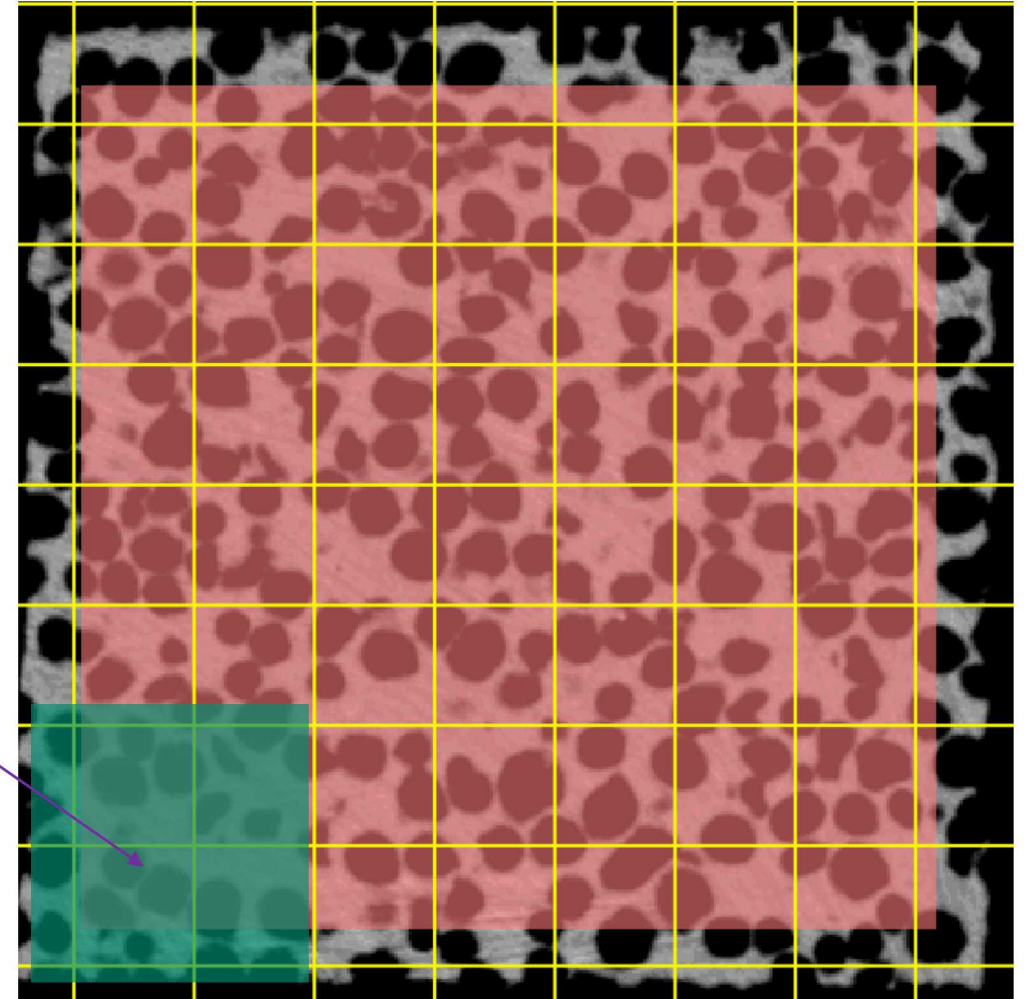


Cellular Silicone
37 pcf (592 kg/m³)
Porosity: 47%

Virtual Strain
Gage (VSG)

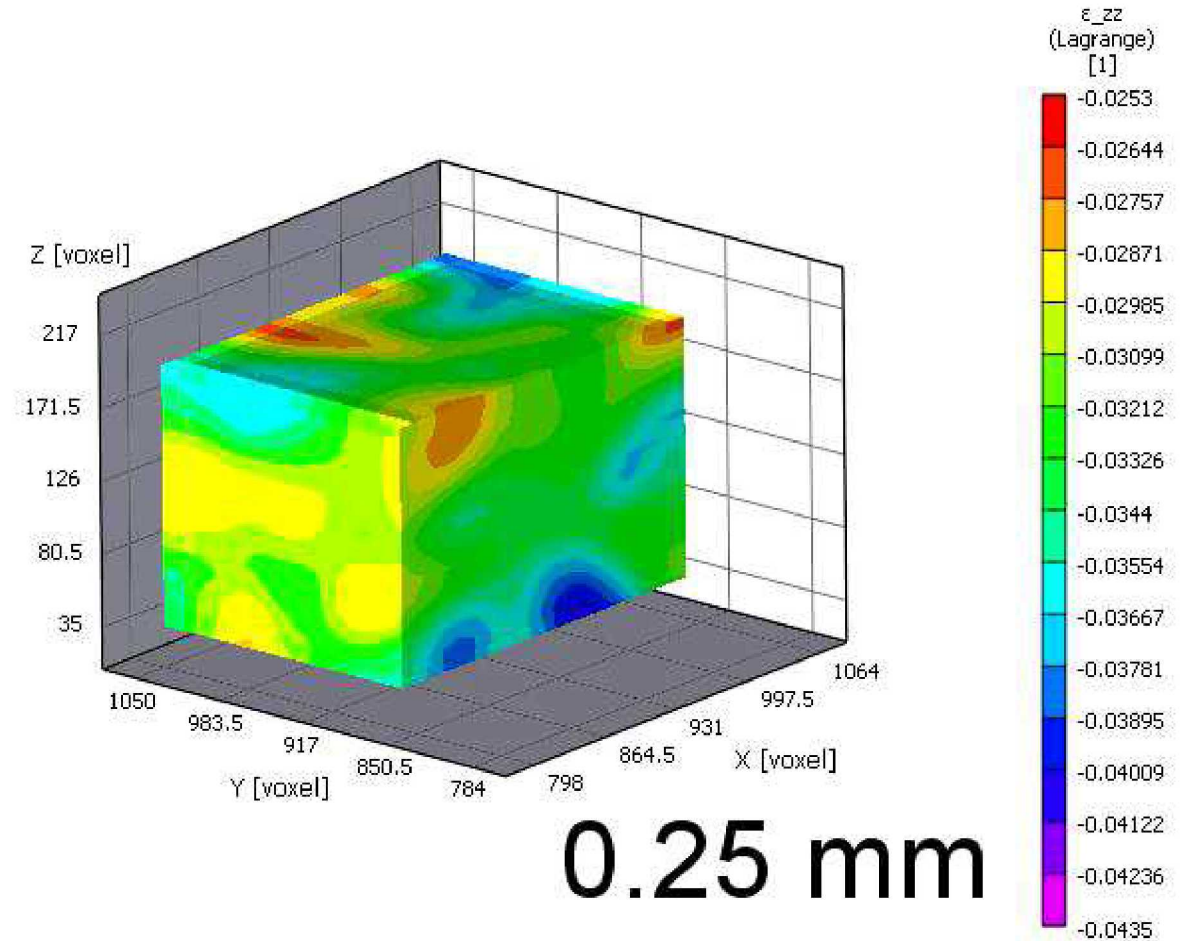
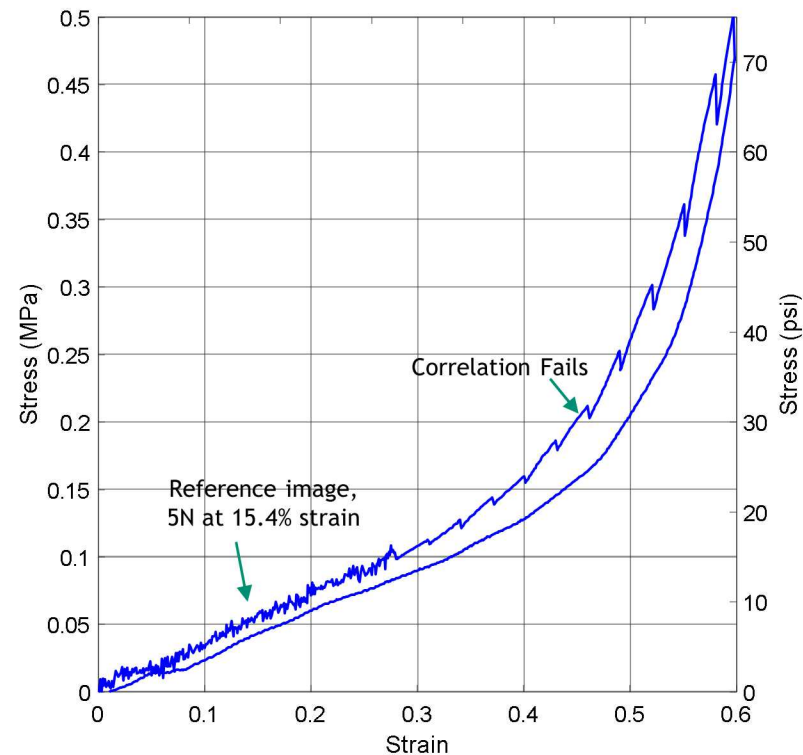
9 mm

Resolution	Subset	Step	Filter	VSG
26 $\mu\text{m}^3/\text{vox}$	43 vox	14 vox	5 vox	2.6 mm ³



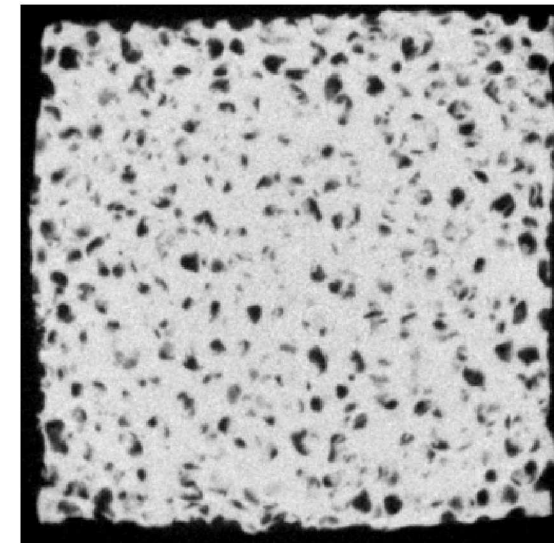
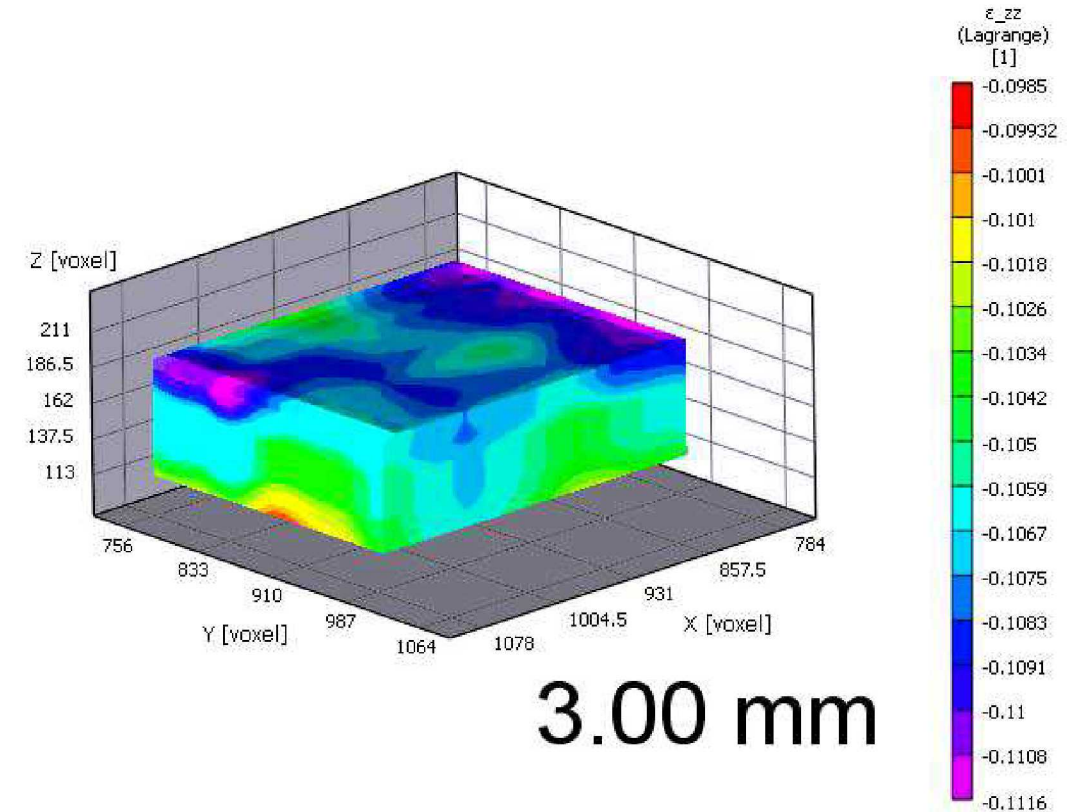
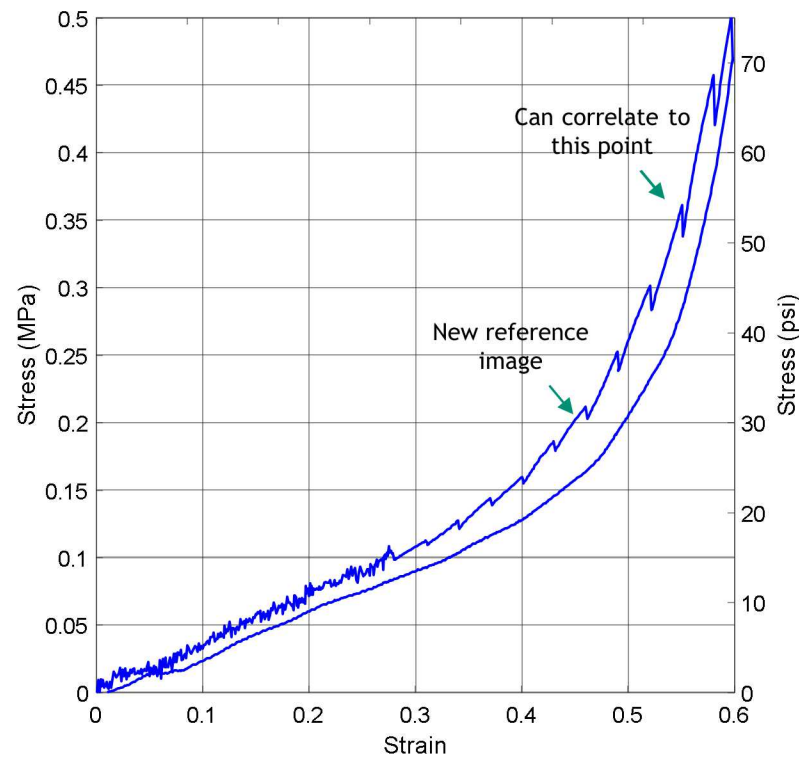
Vertical Strain at Various Compression Steps

- Strain concentrations observed within sample
 - Can also look at other strain components
- Correlation can no longer relate image to the reference at 46% strain

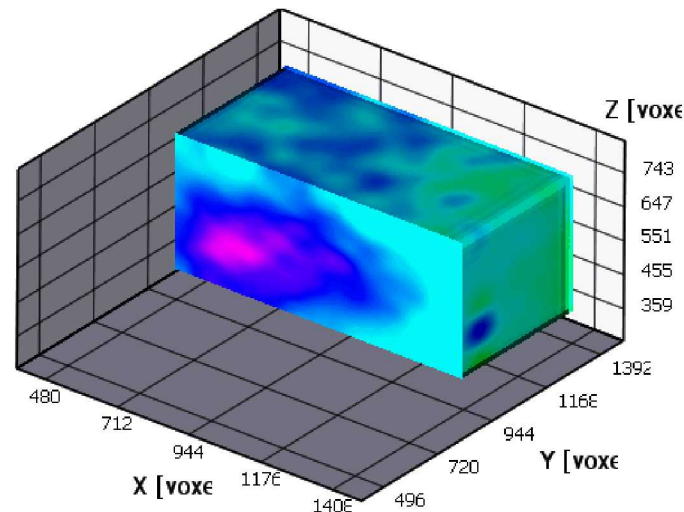
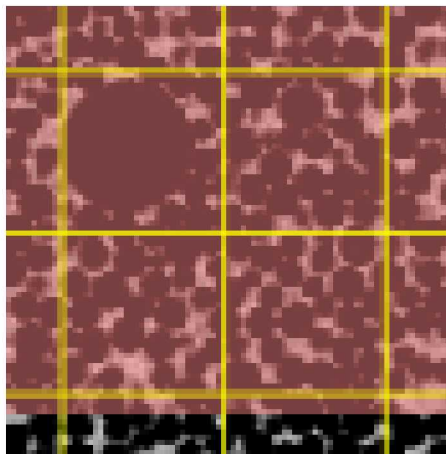


Incremental DVC

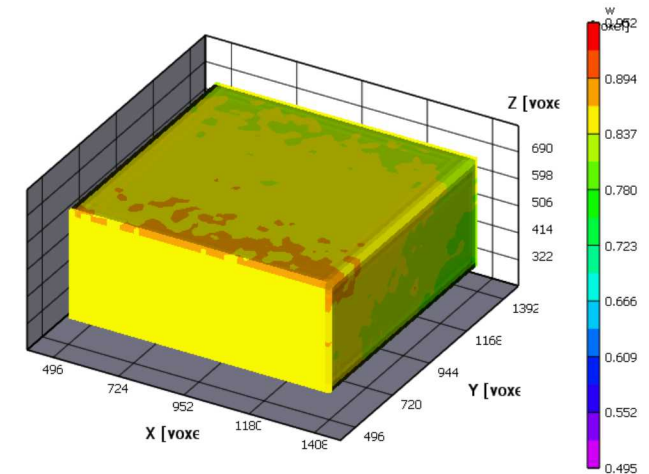
- Select new image as reference to further correlation
 - Introduces errors
- May need to increase subset
- Correlation will not be possible with closed pores



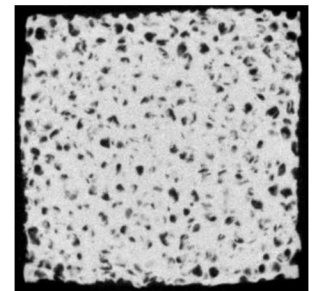
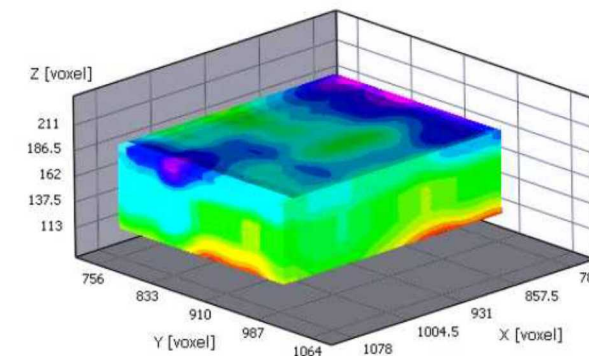
- Care must be taken during setup to minimize artificial gray-scale variations
- Speckle pattern determines spatial resolution
- DVC identifies strain concentrations within sample
- Correlation results can be extended by choosing new reference image



Noise floor



Correlation at 55% strain



3.50 mm