SAND2017-11931C

Damage Evolution Of GMBs in Syntactic Foam

Helena Jin[1], Bernice Mills[1], Jay Carroll[2], Kevin Long[2], Judith Brown[2], Brendan Croom[3], Xiaodong Li[3]

[1]Sandia National Laboratories, Livermore, CA

[2] Sandia National Laboratories, Albuquerque, NM

[3] University of Virginia, Charlottesville

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Material: Sylgard® 184 Impregnated with A16 Glass Micro-Balloons (GMBs)

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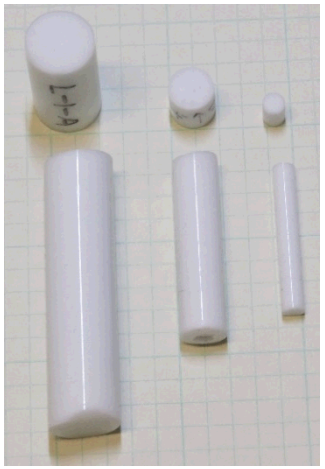
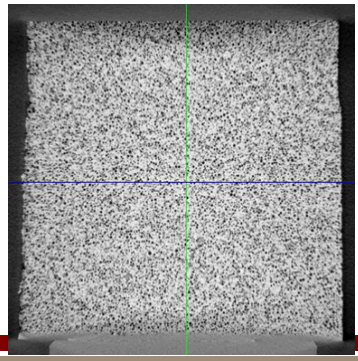
Sylgard 184 Impregnated with A16 GMBs:

- Sylgard absorbs a significant amount of mechanical energy and is used as a potting material at Sandia.
- GMBs may break within the microstructure under compression, which might change the mechanical response of the composite.

GMBs:

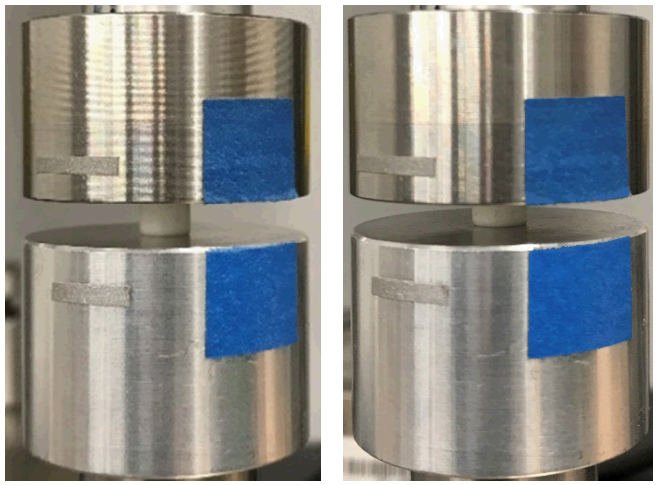
- Lower thermal coefficient;
- Lower cure shrinkage (mismatch) strains;
- Increase specific modulus;
- Increase energy dissipation.



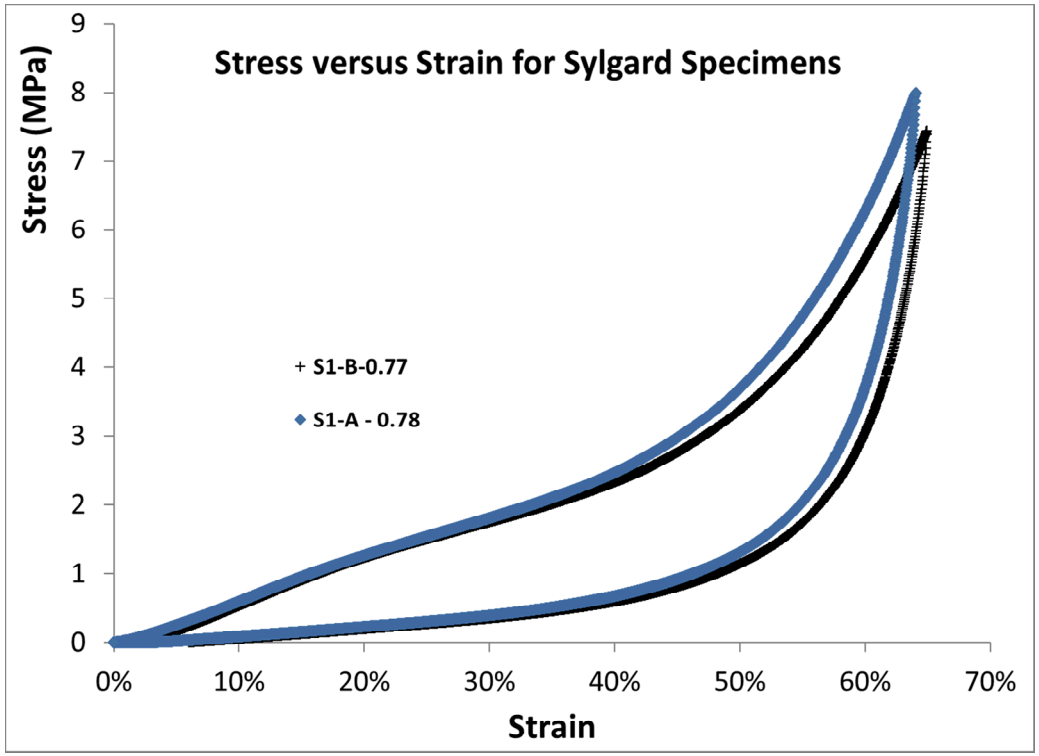


	Pure Sylgard	Sylgard GMB (undamaged)
Coefficient of Thermal Expansion (ppm/C)	270	185
Young's Modulus (MPa)	1.84	13
Bulk Modulus (MPa)	920	71
Glass Transition Temperature (°C)	-60	-45
Density (g/cc)	1.03	0.73

Compression of Sylgard Specimens



- GMBs mixed with Sylgard resin
- Slice syringe-molded cylinders into specimens



- ❑ Specimens with close density have similar stress ~ strain relationship.
- ❑ Three stages of Syntactic foam: elastic region, stress plateau and densification
- ❑ Relate the GMB failure to stress ~ strain curve

In-situ XCT Experiments to Study the Evolution of the GMBs during Compressive Loading

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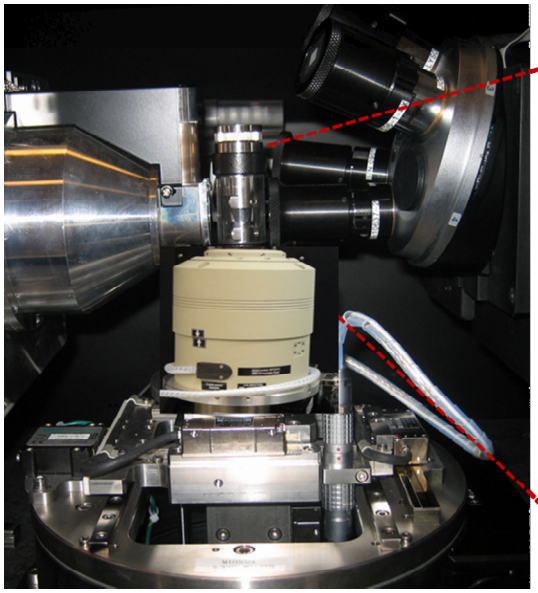
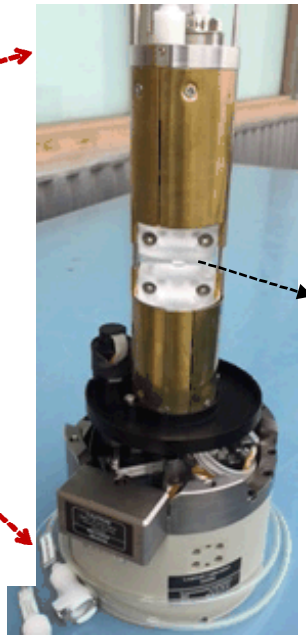
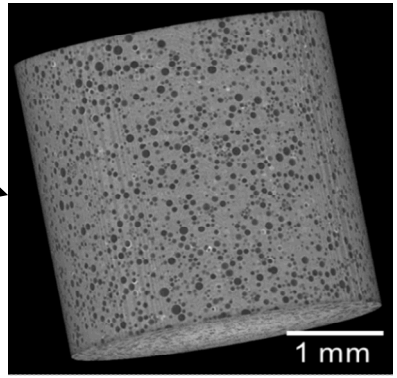
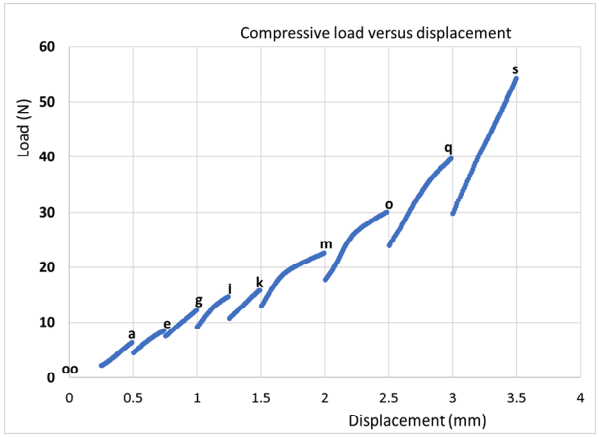




Sylgard specimens



- Cylindrical Sylgard specimen is compressed inside XCT.
- Stress-strain curves are obtained off-line as a reference for in-situ tests.
- X-ray tomographic images are acquired at selected loading levels during the compression of the specimen.
- Tomographic images enables the observation of the GMBs inside the matrix during compression.



(a) (b)

Sylgard specimens at (a) 15% unloaded; (b) 30% of compression;

Failure of GMBs inside Sylgard

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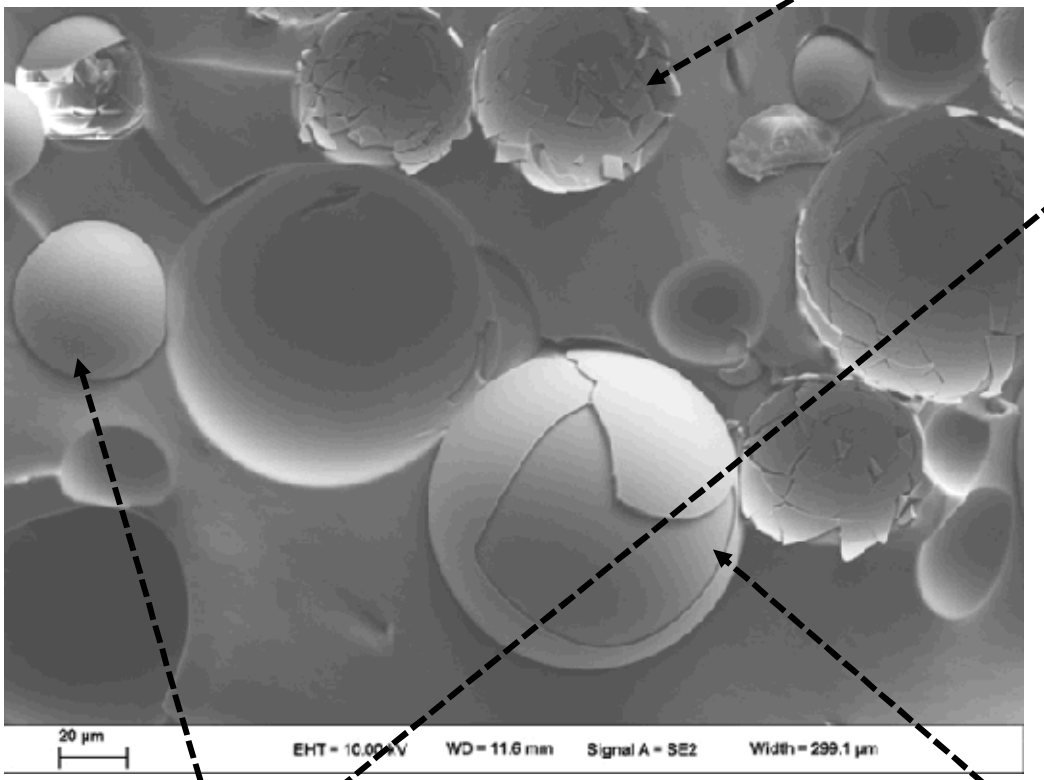
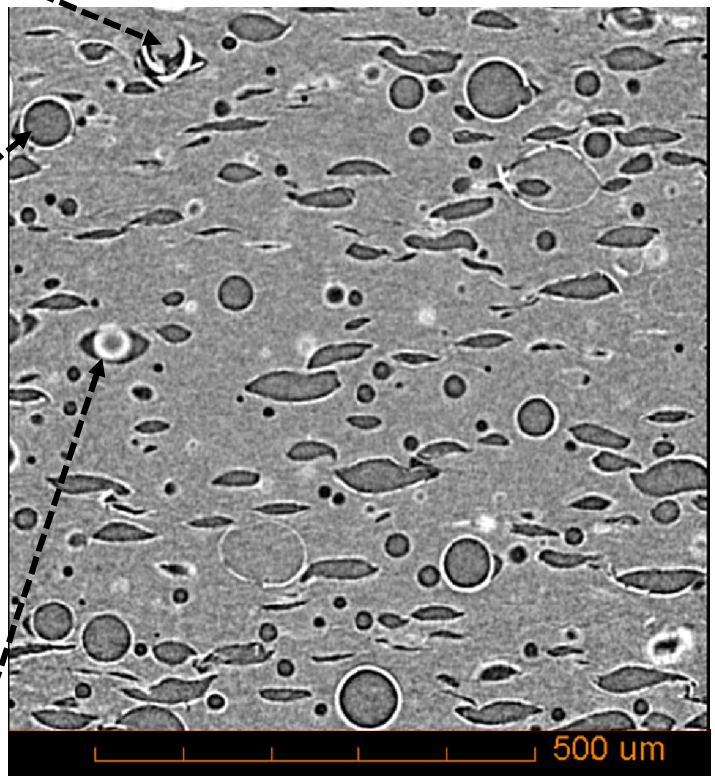
SEM Cross section

Broken GMBs

XCT Slice





Intact GMB.

"Hard-boiled egg" structure indicates GMB was broken before gel point and Sylgard flowed into GMB void.

- ❑ GMB failure
- ❑ Size distribution of broken GMBs
- ❑ Spatial distribution of GMBs

Identify Proper Imaging Parameters for the in-situ XCT Experiments

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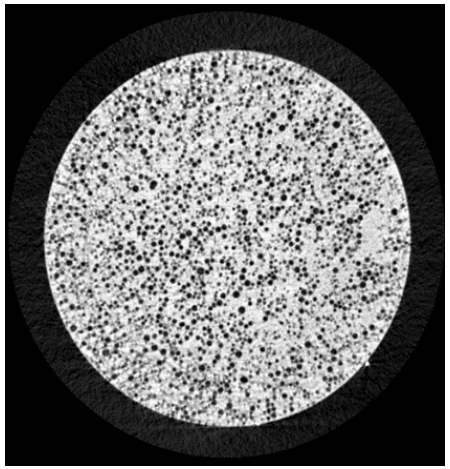
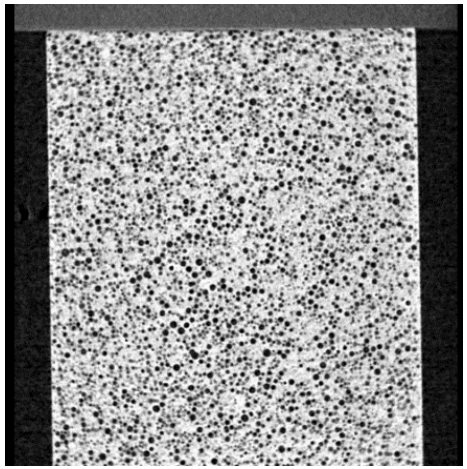
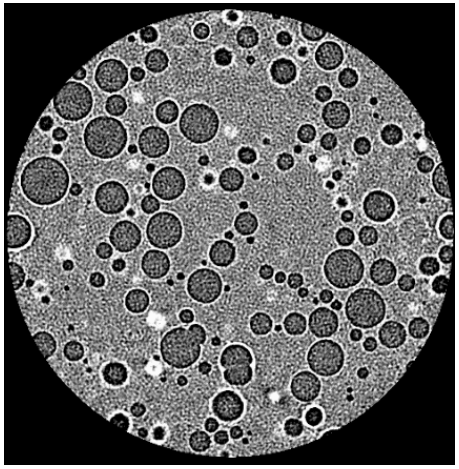
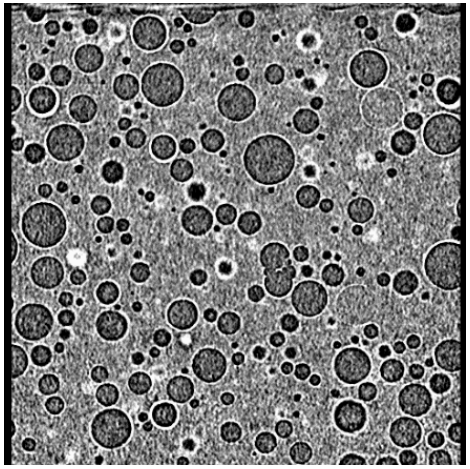




Low spatial resolution image of whole specimen (~ 10μm/voxel)





High spatial resolution image showing GMBs inside the specimen (~ 1.7 μm/voxel)

- ❑ GMB size range: 35~110 μm;
- ❑ Average GMB size: ~70 μm ;
- ❑ Large compression of Sylgard specimen up to 50%;
- ❑ XCT images with spatial resolution ~ 10 μm provides most suitable features for DVC
- ❑ High resolution images enable observation of each individual GMB.

Low-Res XCT Images at different loading levels

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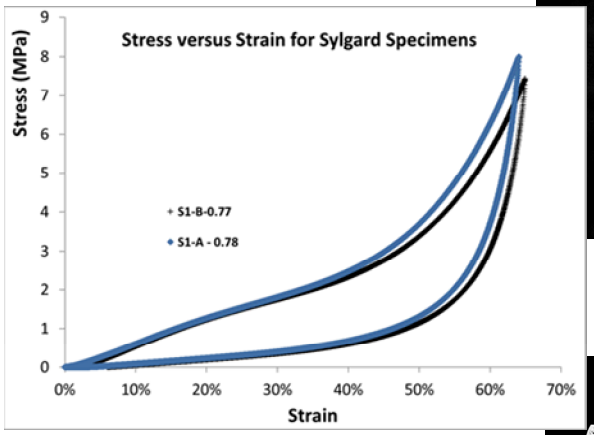
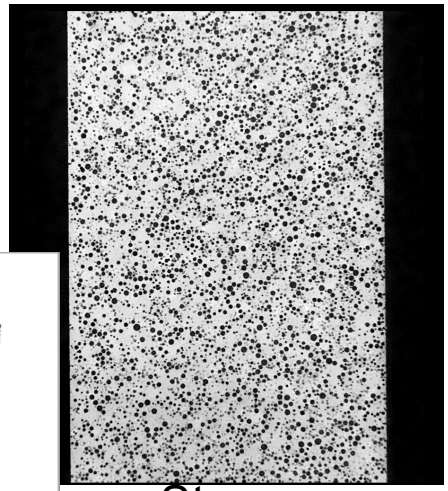
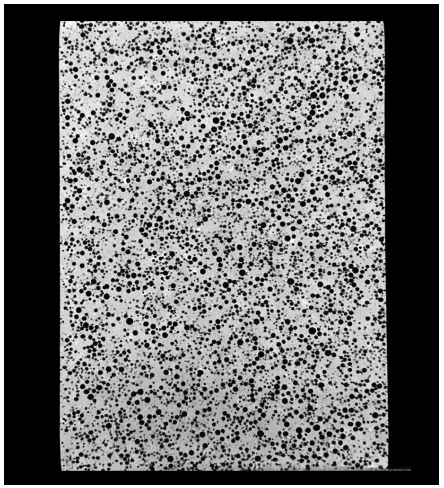


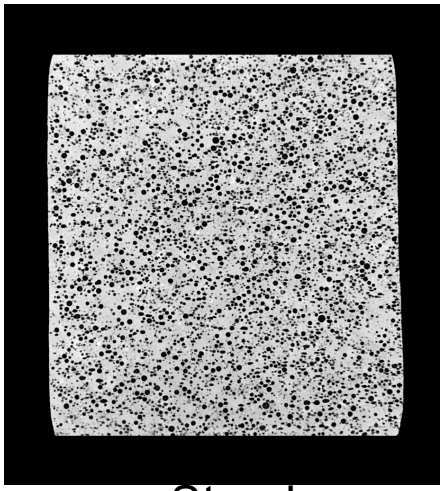
Stress~Strain



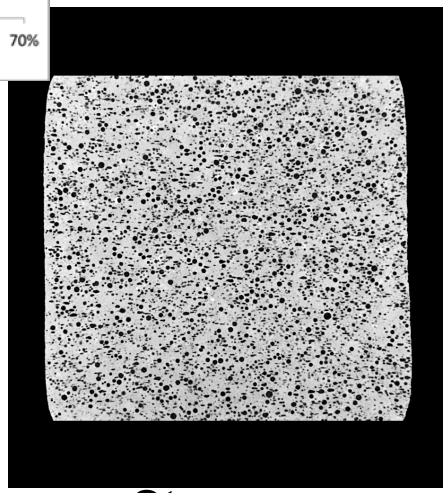
Step-oo
(0%)



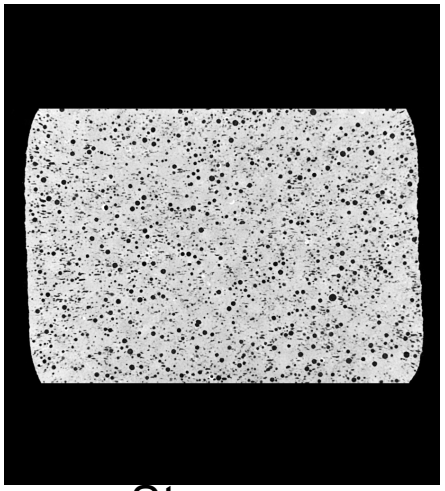
Step-a
(7%)



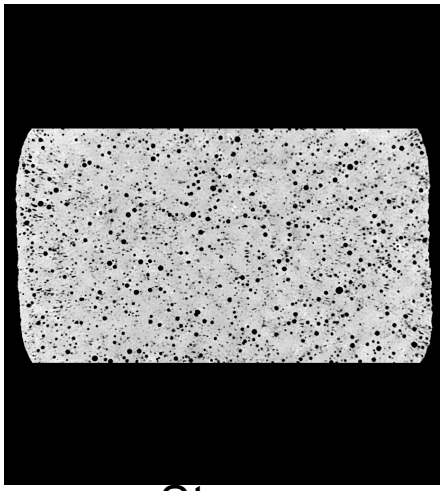
Step-k
(21%)



Step-m
(28%)



Step-q
(42%)



Step-s
(50%)

High-Res XCT Images at different loading levels

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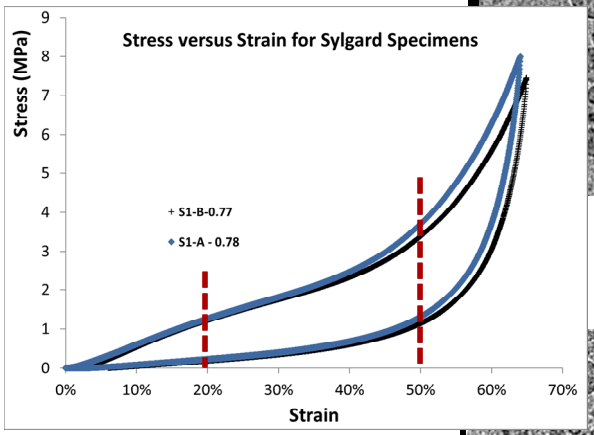
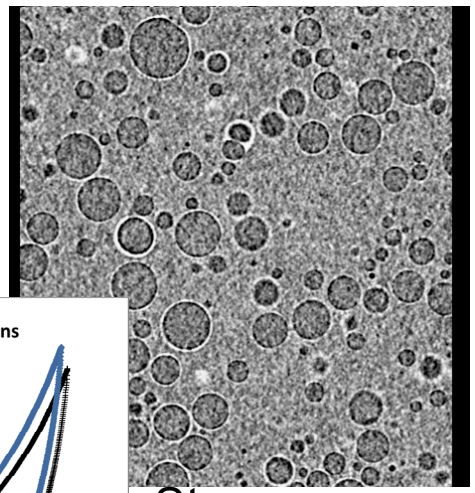
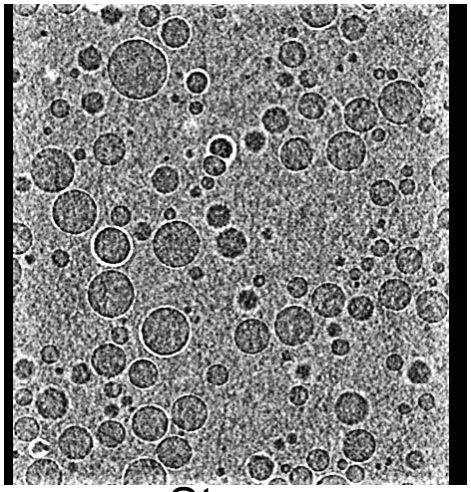


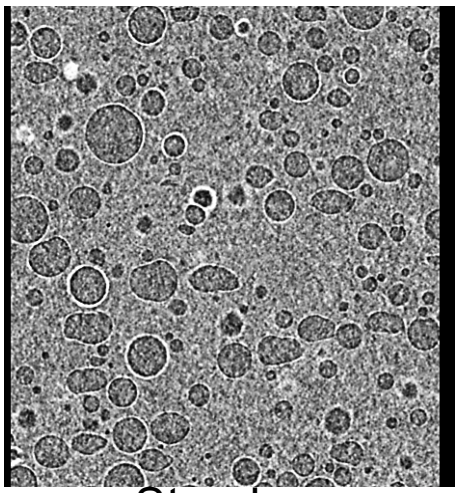
Stress~Strain



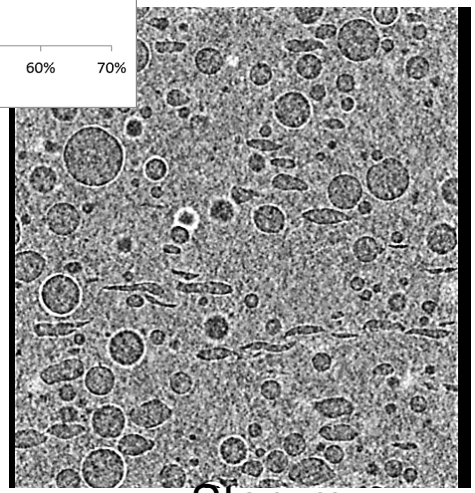
Step-oo
(0%)



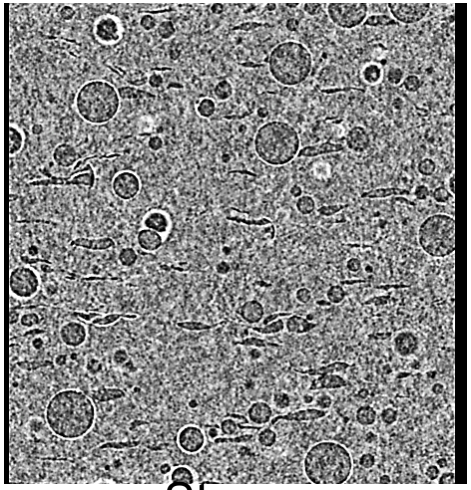
Step-a
(7%)



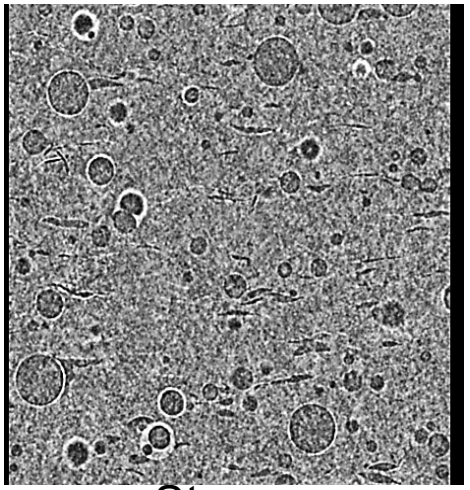
Step-k
(21%)



Step-m
(28%)



Step-q
(42%)



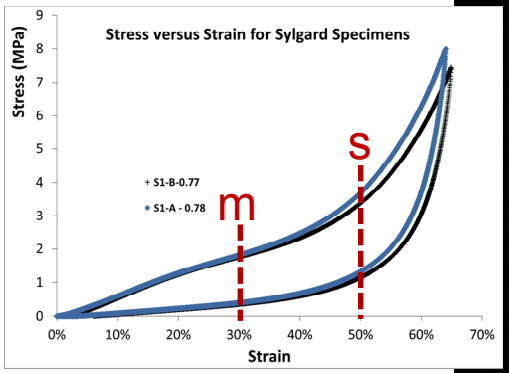
Step-s
(50%)

GMB Evolution at different loading levels

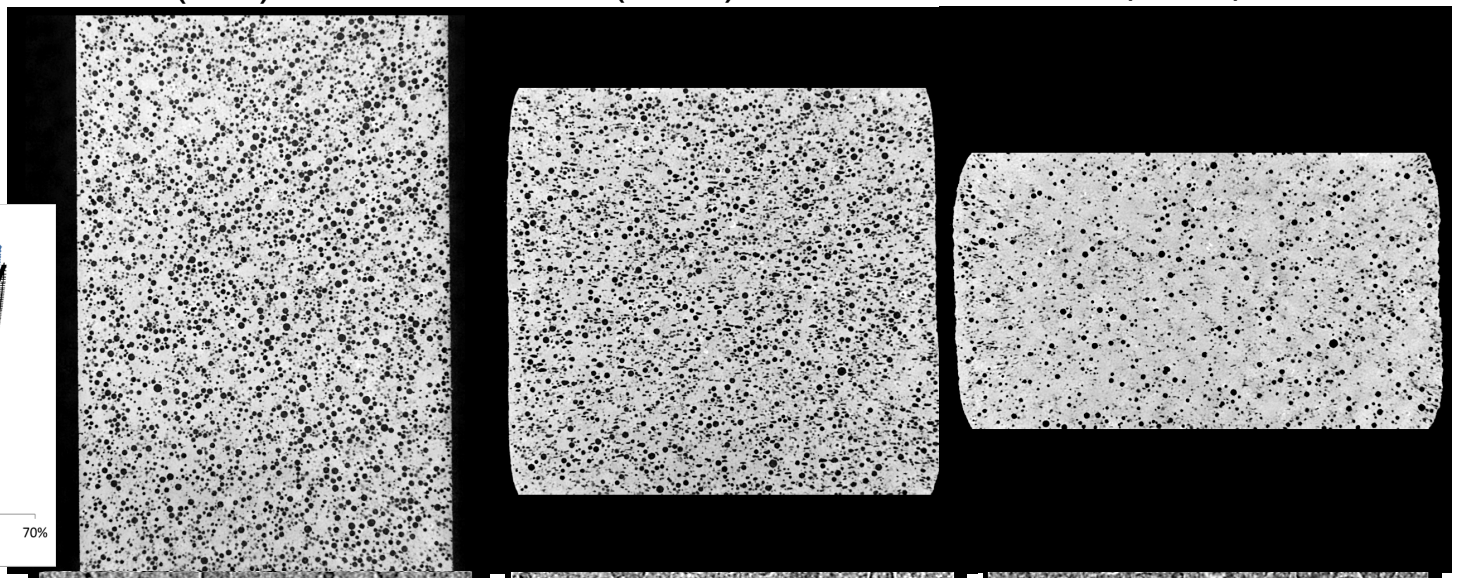
Step-oo (0%)

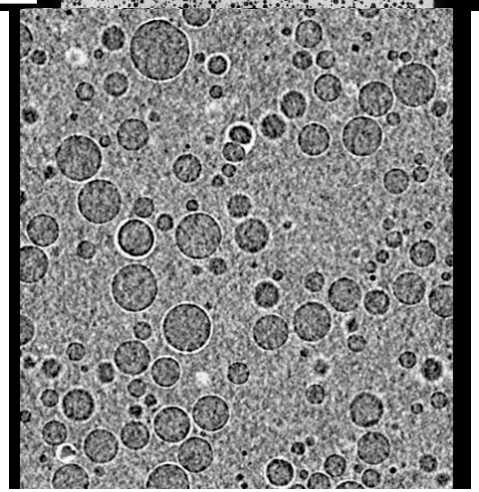
Step-m (28%)

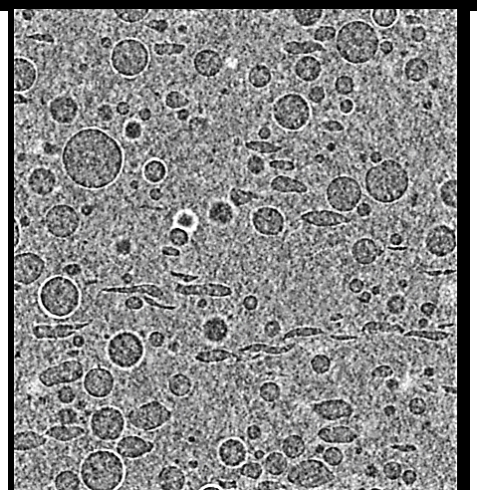
Step-s (50%)

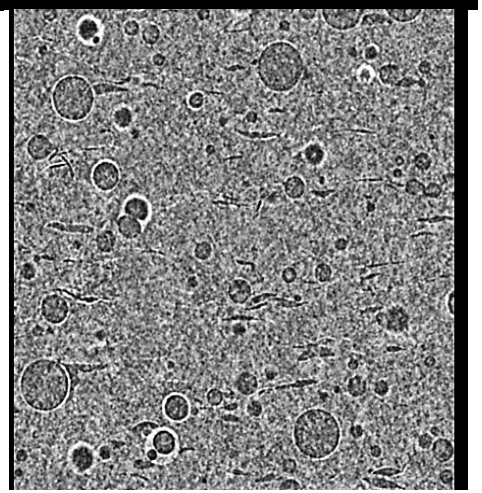


Stress ~ Strain









GMBs Feret Shape at Different Loading Steps

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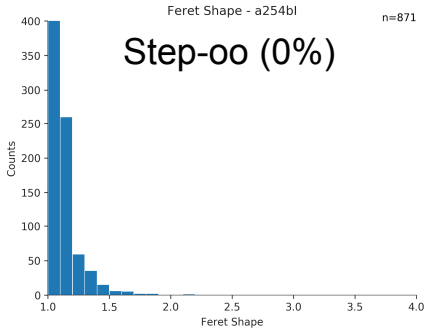
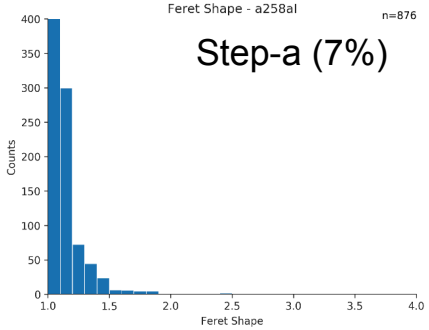
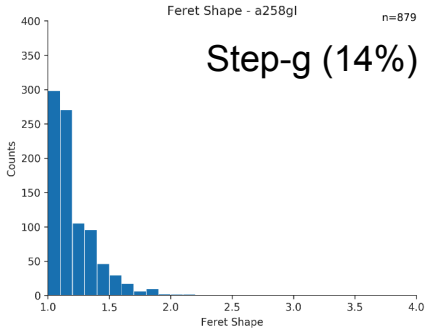
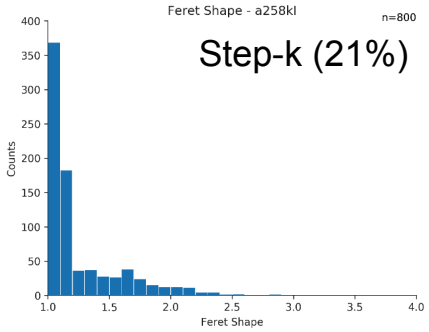
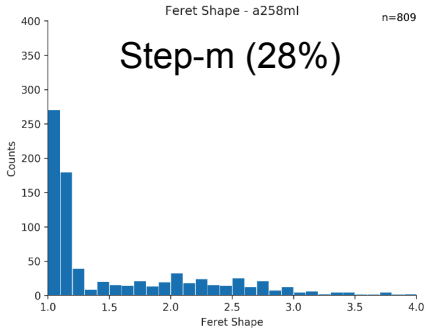
$$\text{Feret Shape } x = \frac{1}{\frac{\chi_{F,\min}}{\chi_{F,\max}}}$$

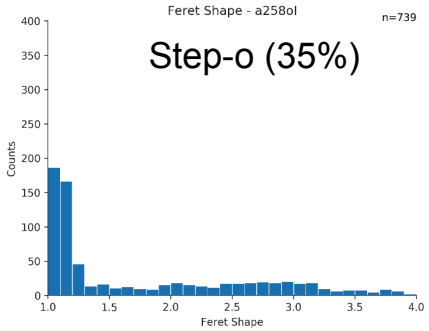


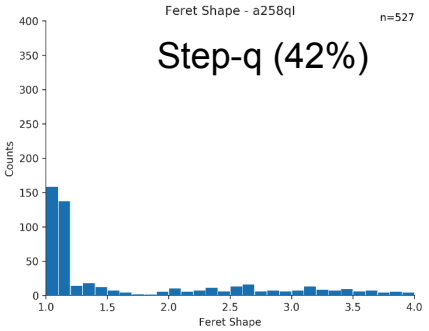


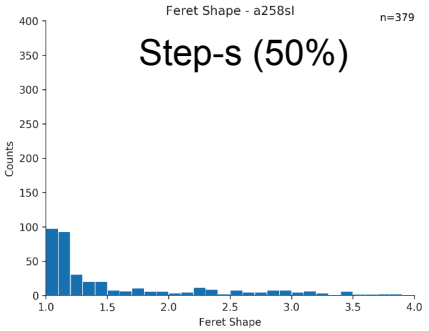




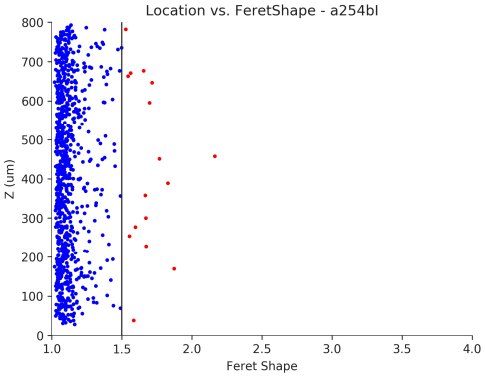




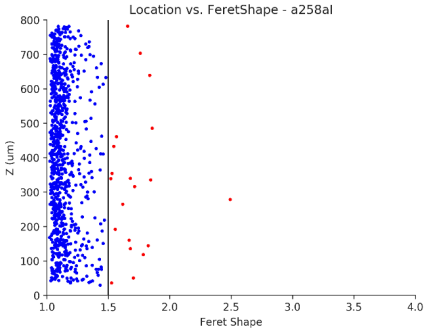




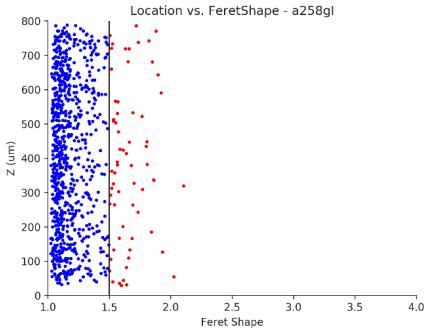
Feret Shape vs Z Location



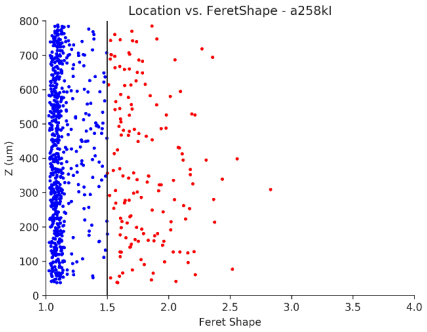
Step-oo (0%)



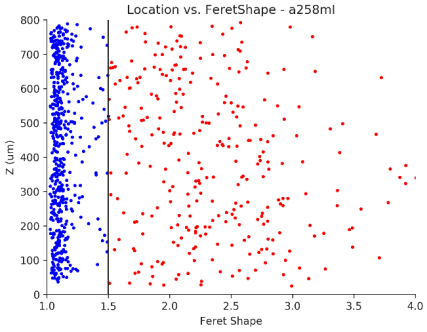
Step-a (7%)



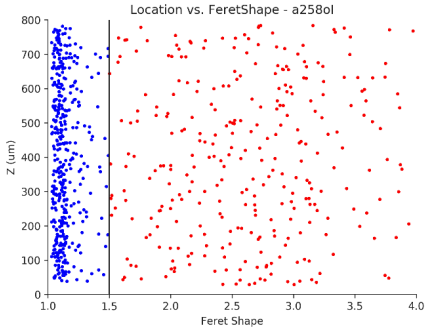
Step-g (14%)



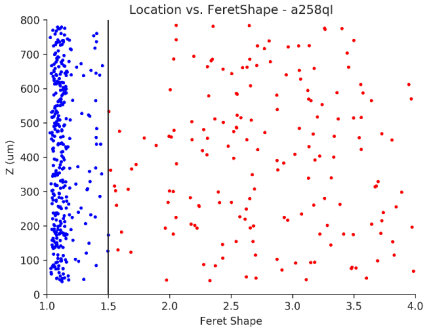
Step-k (21%)



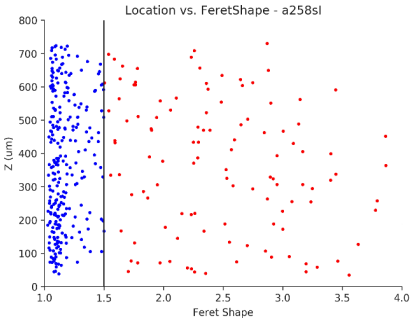
Step-m (28%)



Step-o (35%)

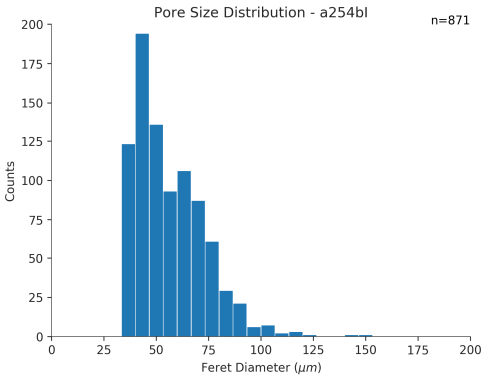


Step-q (42%)

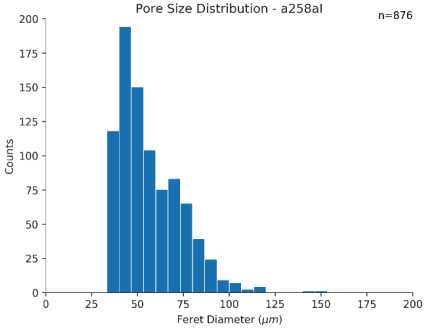


Step-s (50%)

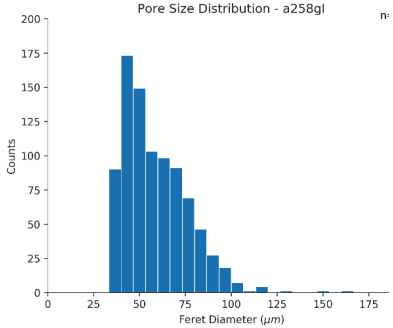
GMB Size Histogram



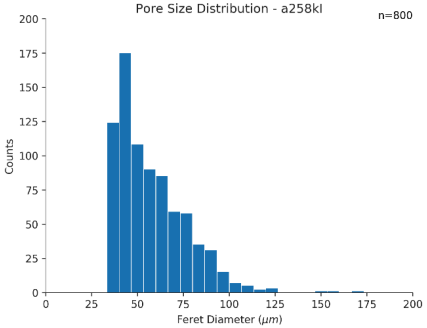
Step-oo (0%)



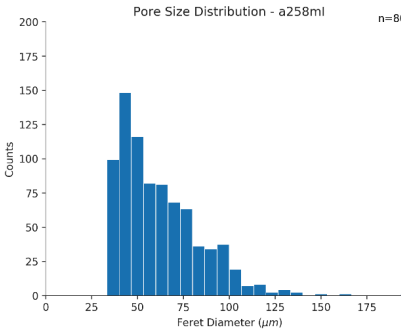
Step-a (7%)



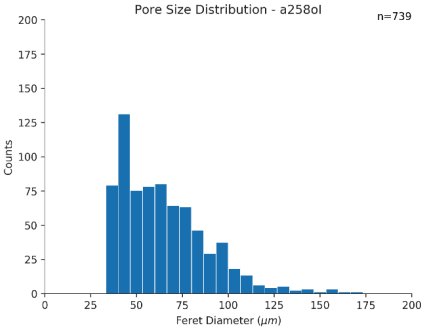
Step-g (14%)



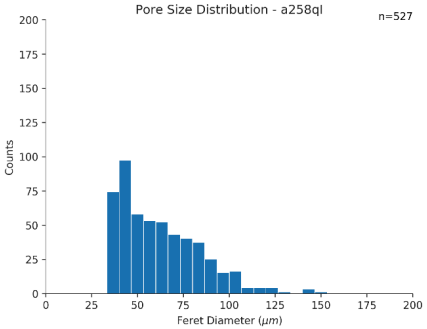
Step-k (21%)



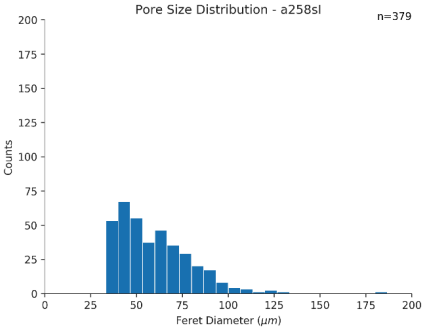
Step-m (28%)



Step-o (35%)

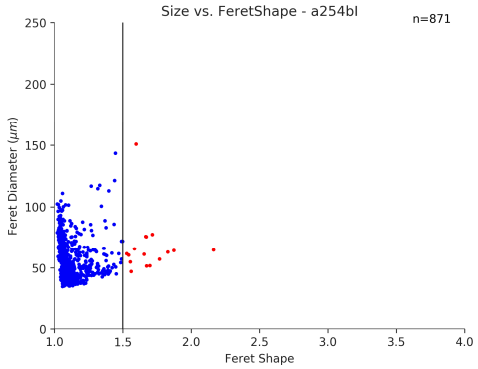


Step-q (42%)

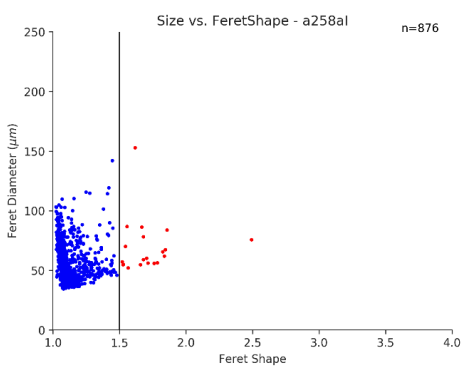


Step-s (50%)

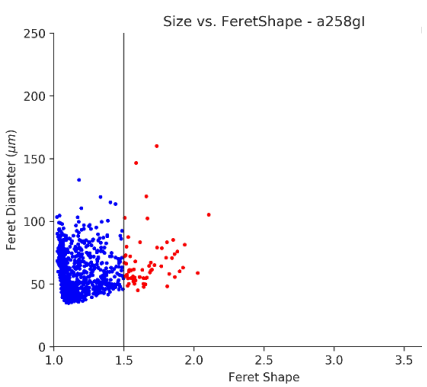
GMB Size vs Fret Shape



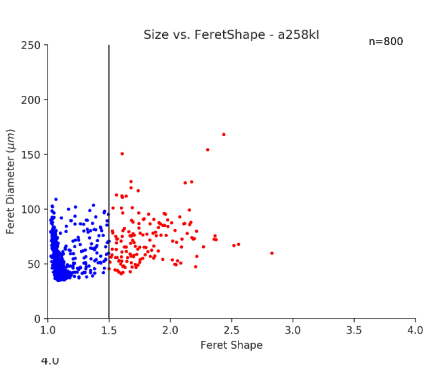
Step-oo (0%)



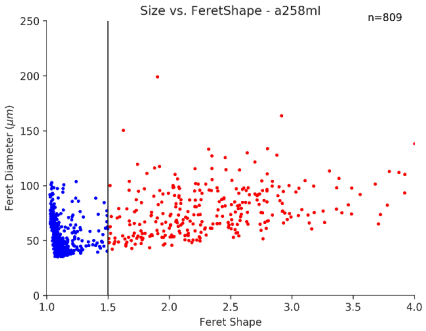
Step-a (7%)



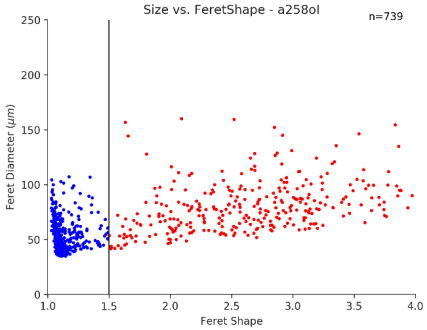
Step-g (14%)



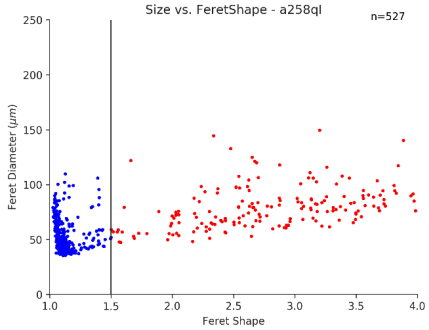
Step-k (21%)



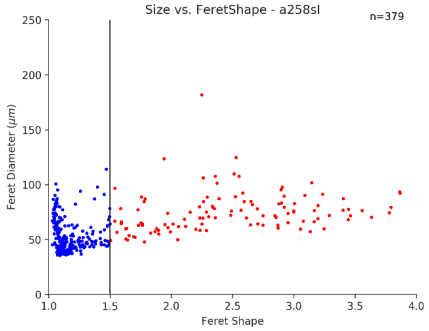
Step-m (28%)



Step-o (35%)

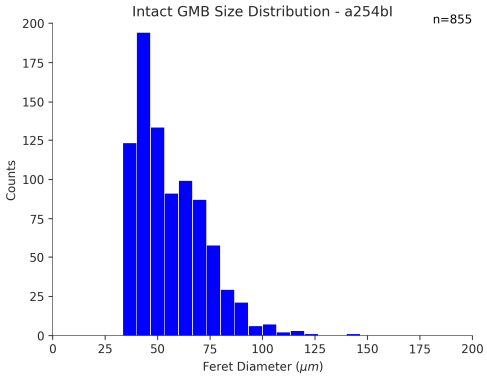


Step-q (42%)

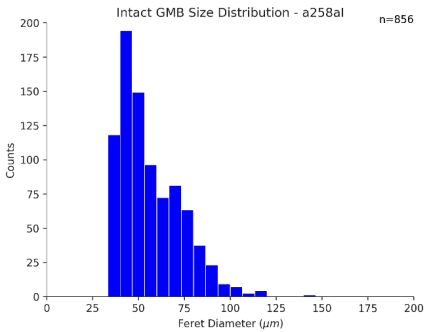


Step-s (50%)

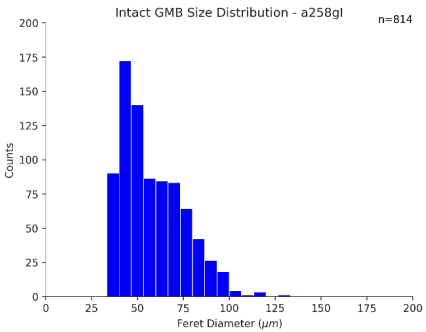
Intact GMB Distribution at Different Loading Levels



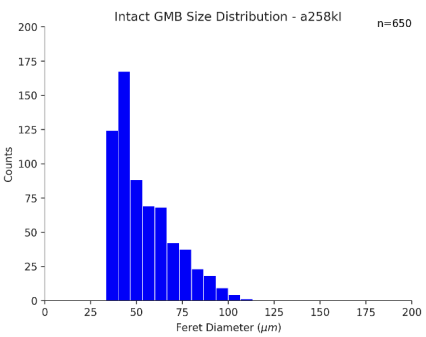
Step-oo (0%)



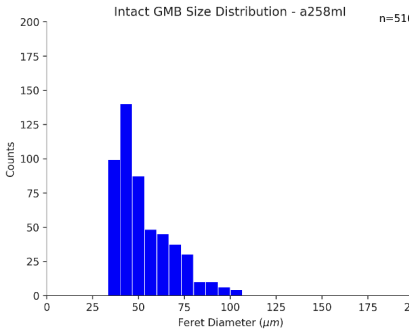
Step-a (7%)



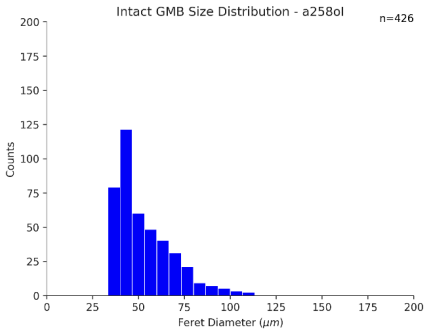
Step-g (14%)



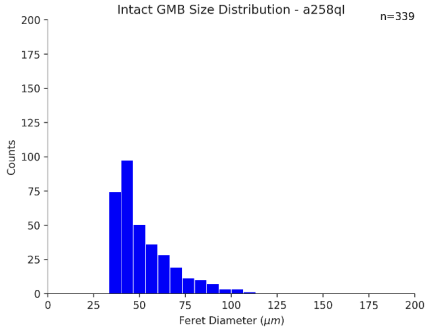
Step-k (21%)



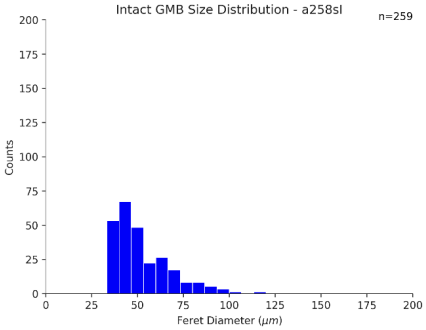
Step-m (28%)



Step-o (35%)



Step-q (42%)



Step-s (50%)

GMB Evolution at Different Loading Steps

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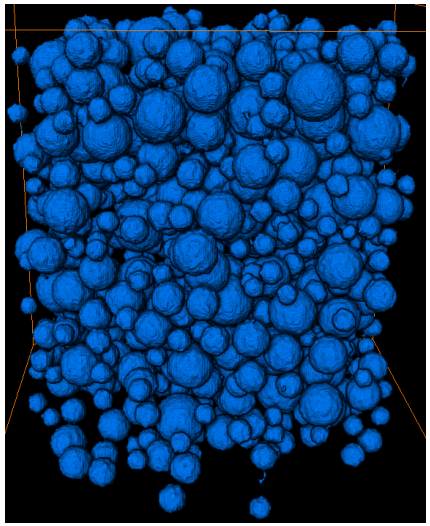
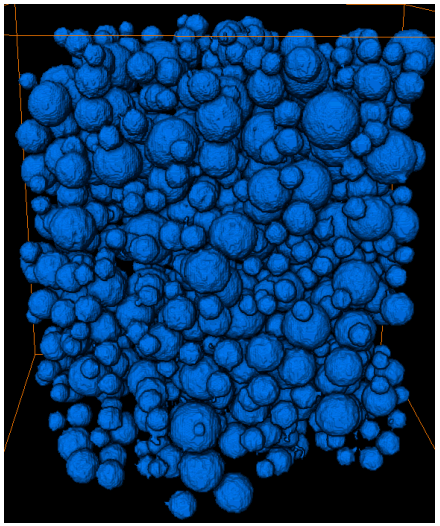
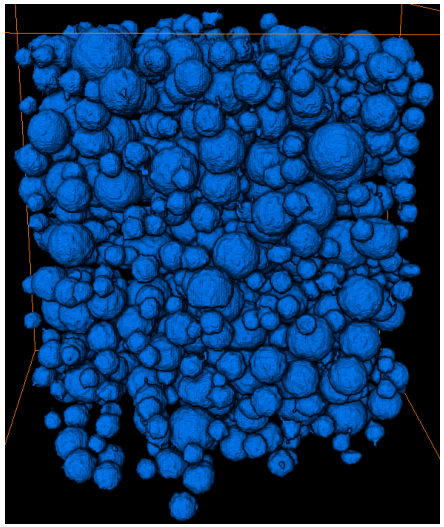


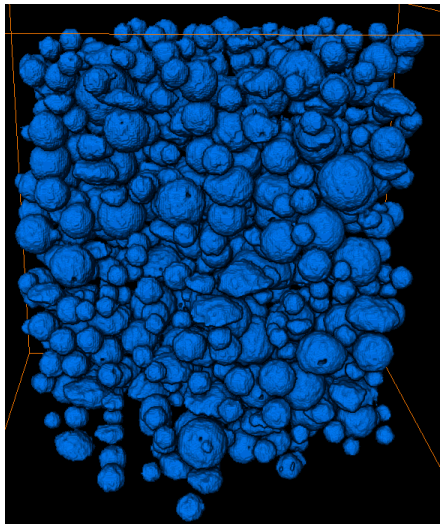
Step-oo (0%)



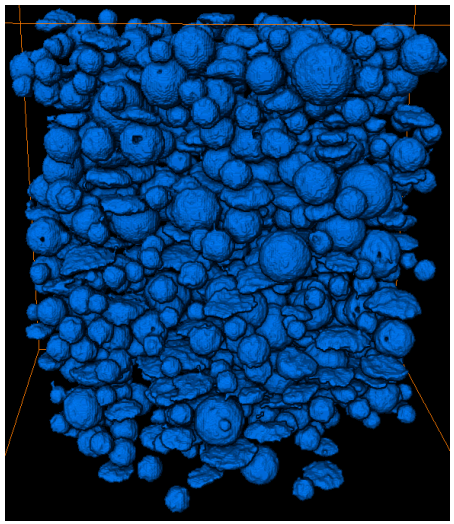
Step-a (7%)



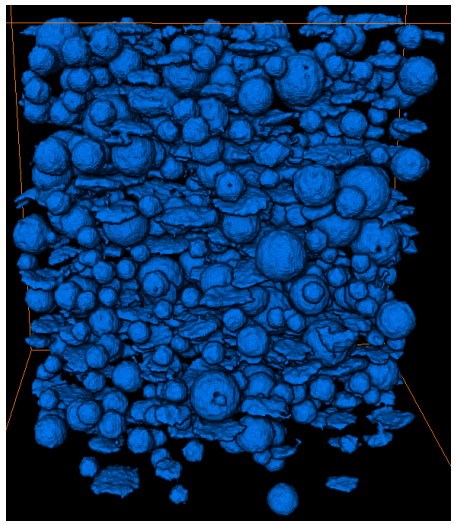
Step-g (14%)



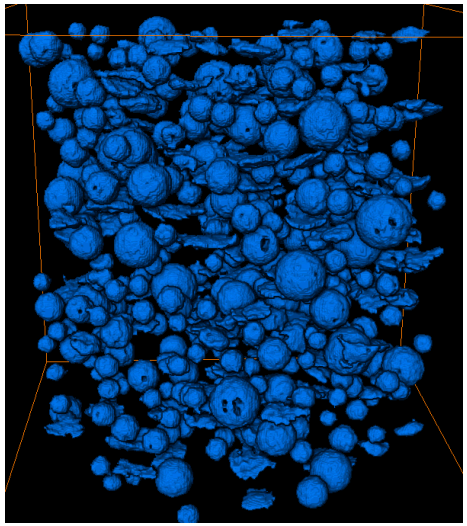
Step-k (21%)



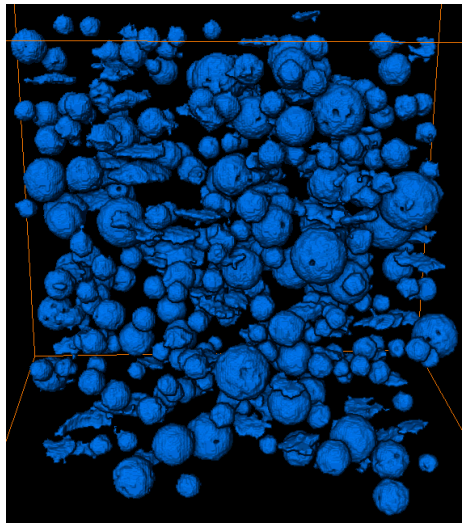
Step-m (28%)



Step-o (35%)



Step-q (42%)



Step-s (50%)

Sieved GMBs at Different Loading Levels

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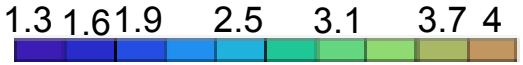
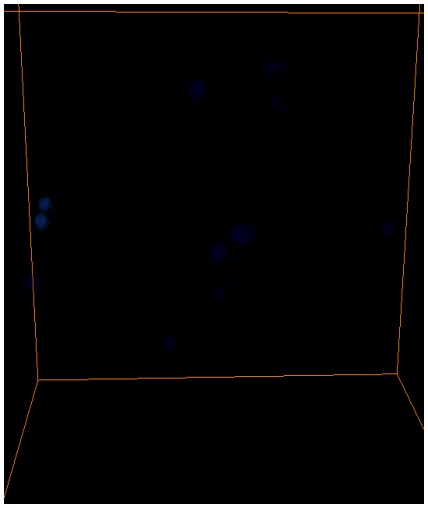
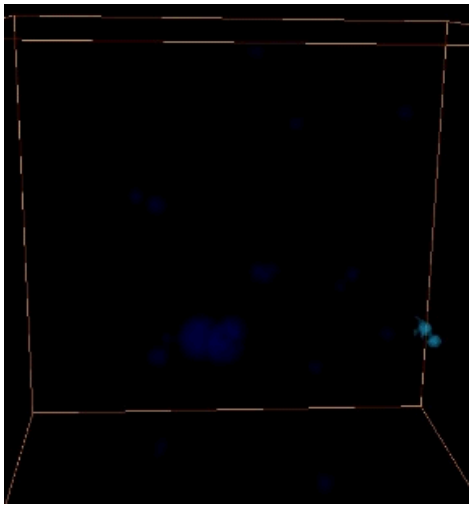
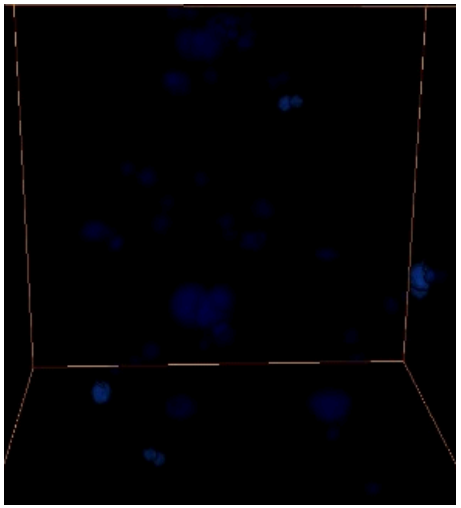




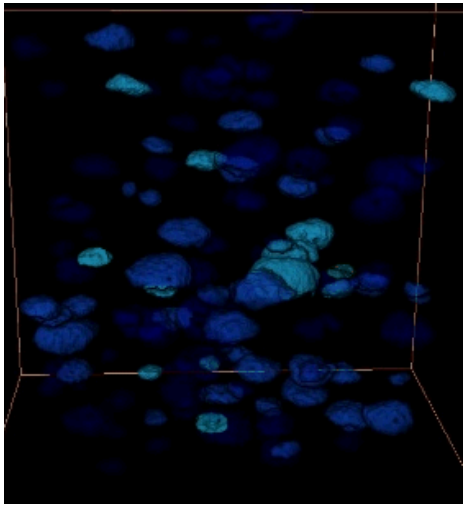
Step-oo (0%)



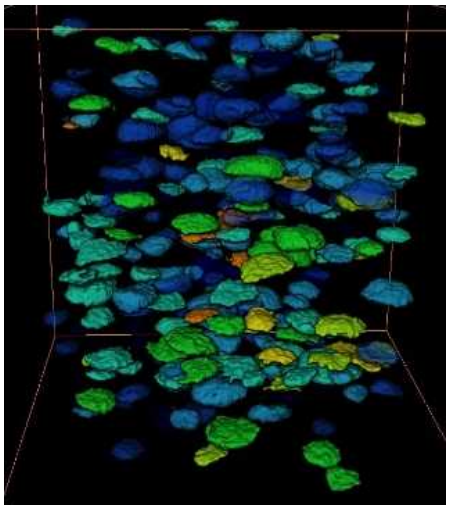
Step-a (7%)



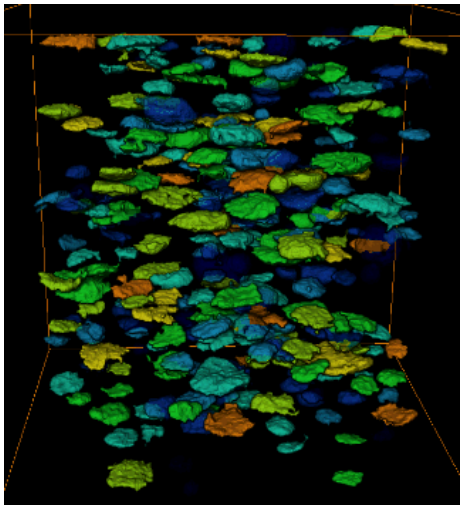
Step-g (14%)



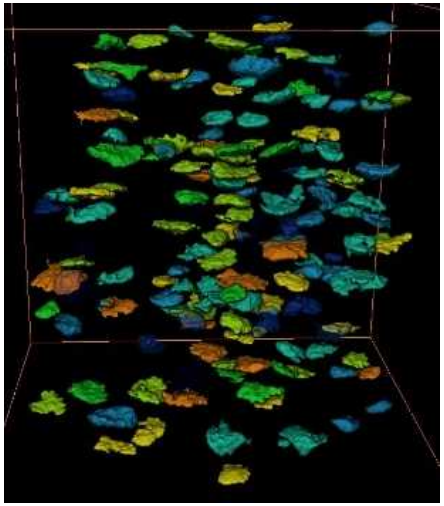
Step-k (21%)



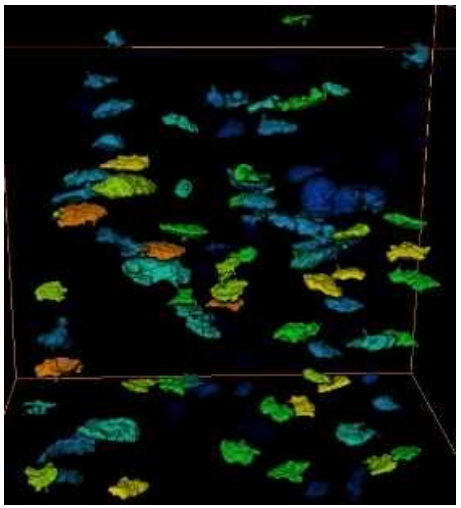
Step-m (28%)



Step-o (35%)



Step-q (42%)



Step-s (50%)

Quantifying the DVC Error from Consecutive Scans

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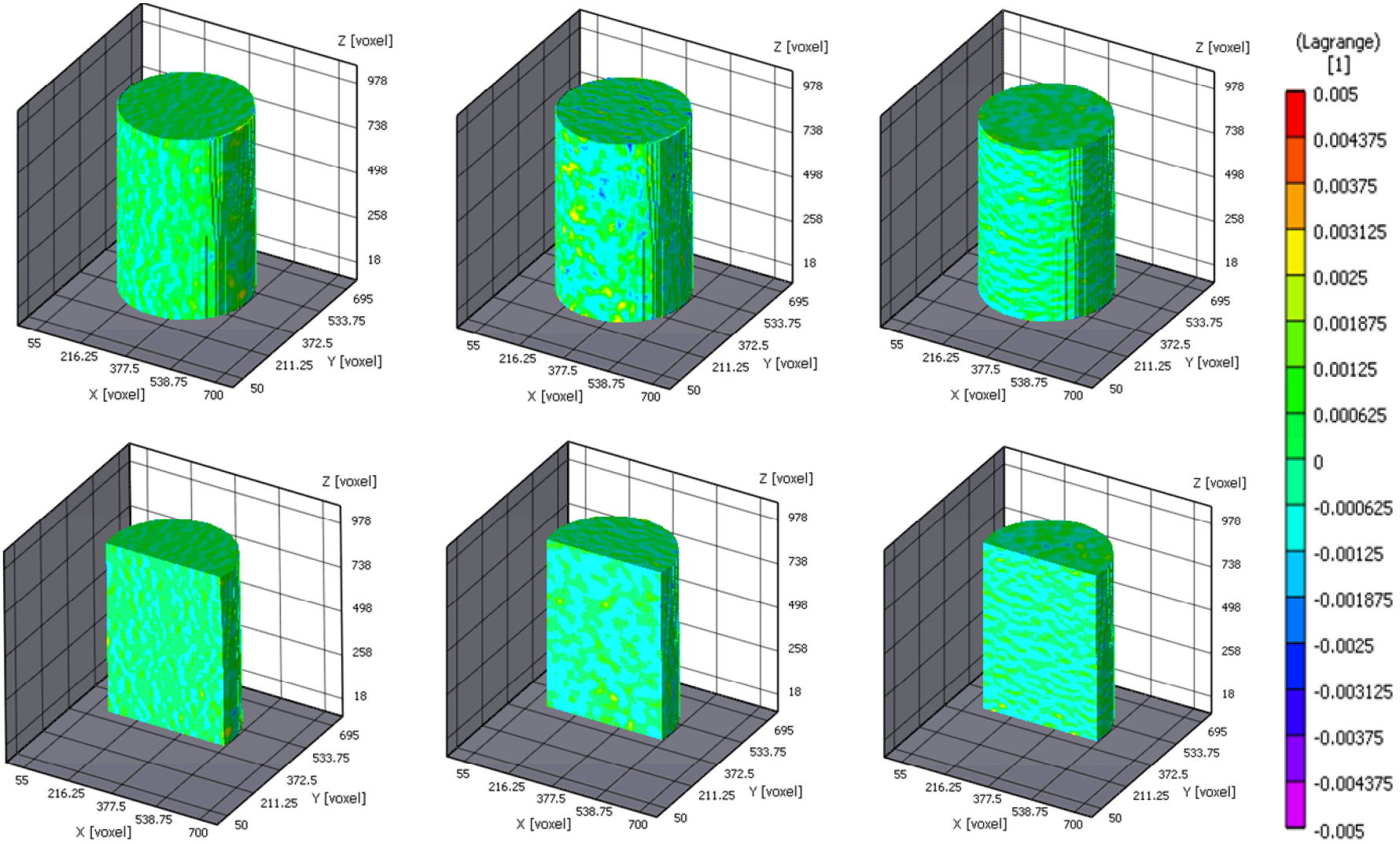

Exx

Eyy

Ezz

Quantifying the DVC Error from Rigid Body Motion

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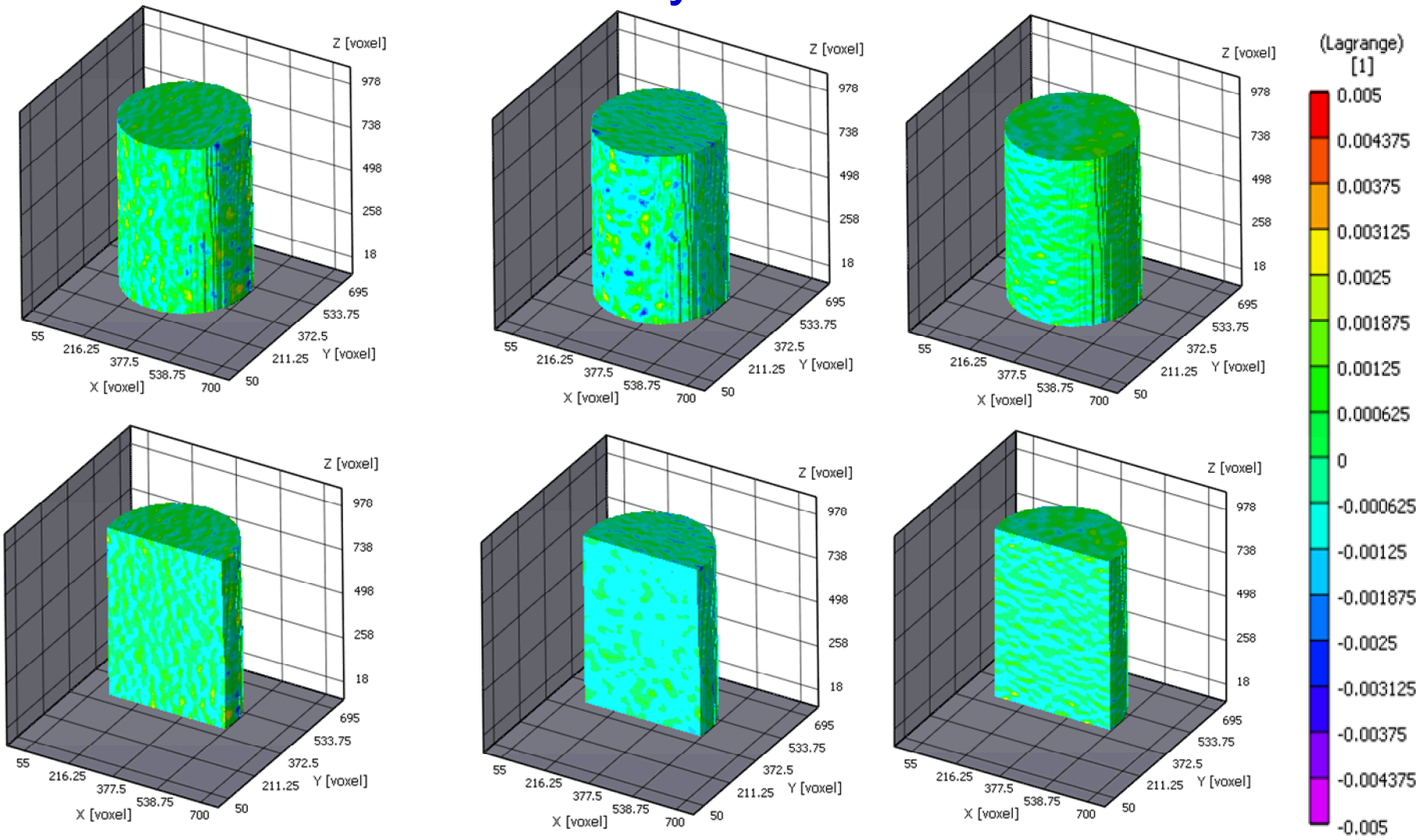

Exx

Eyy

Ezz

Calculate the Full-field Deformation using CT Images

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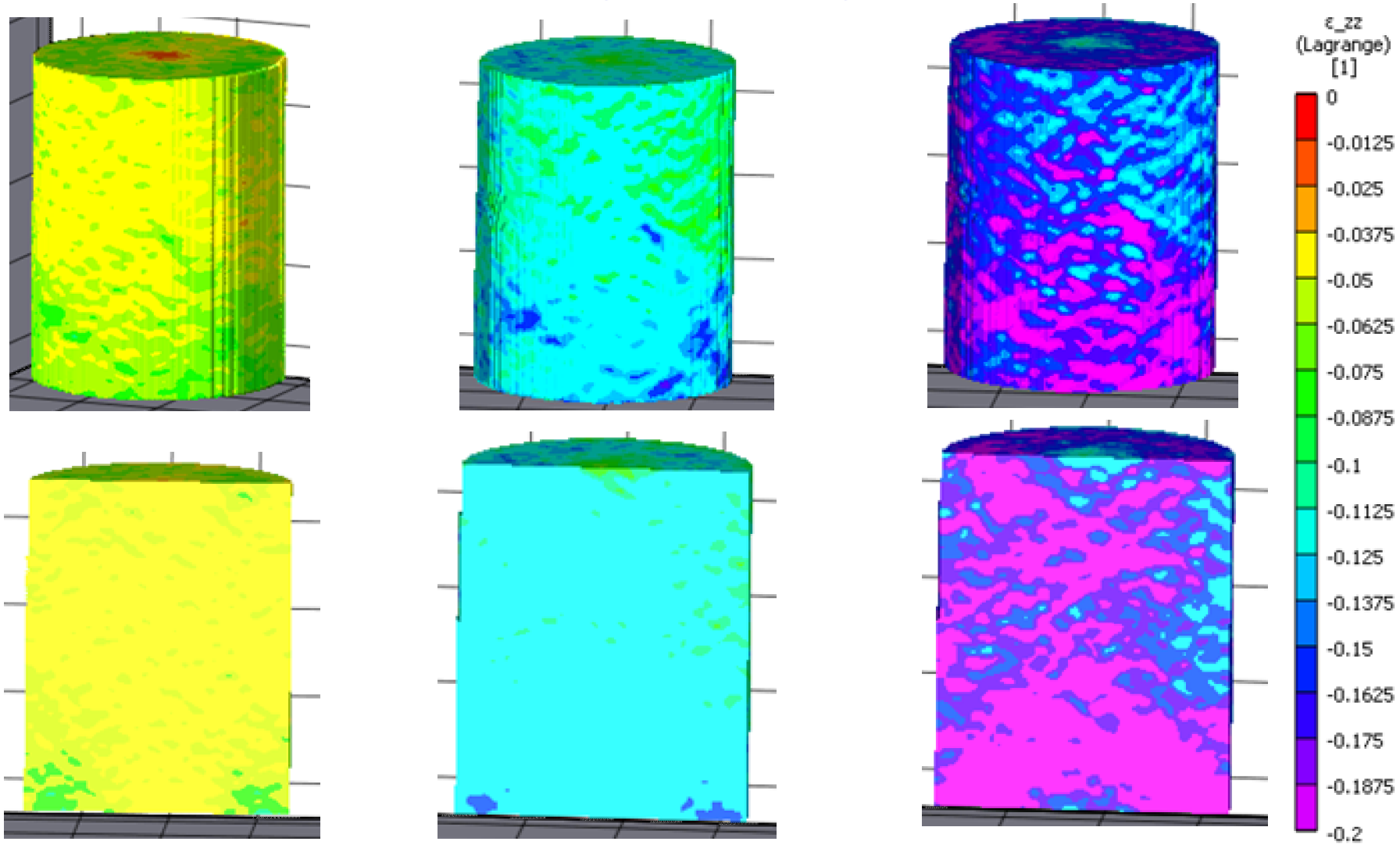

Step-a (7%)

Step-g (14%)

Step-k (21%)

Summary

- In-situ XCT experiment is performed to study the behavior of GMBs inside the Sylgard.
- Two sets of tomographic images with high and low spatial resolution were acquired during the in-situ XCT experiments.
- DVC algorithms are able to apply to the tomographic images to calculate the deformation field inside the material body, using the GMBs as patterns for DVC.
- In-situ XCT experiment provided data on the GMBs size distribution and failure during the compressive loading of Sylgard.

Future Study

- Different GMB volume fraction
- Confined compression / different loading boundaries

Thank you!

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Questions?