

# Using 3D Microstructural Imaging to Produce Physically-Based Numerical Models for Concrete: Micromechanical Experiments

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Strategies for Sustainable Concrete Structures

Aix en Provence, France

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# Acknowledgements

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- Daisuke Asahina 
- Sean de Wolski 
- U.S. National Science Foundation
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# Issues for Presentation

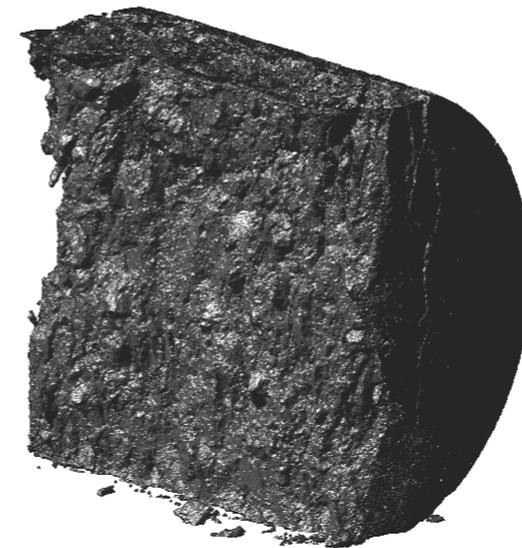
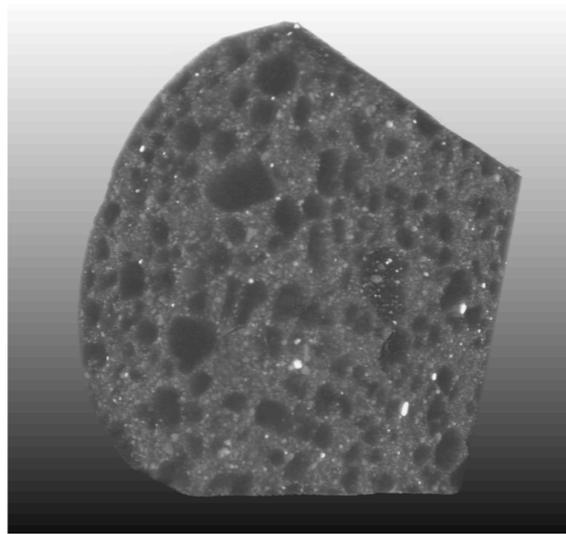
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- Problems with heterogeneous materials:
  - Characterization of internal structure
  - Representation of internal structure
- Value of microstructure-based models:
  - Model parameters extracted directly from measurements
  - Bulk properties follow directly from micromechanical phenomena

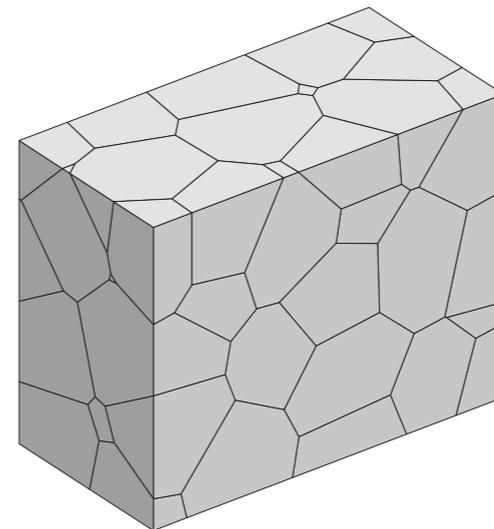
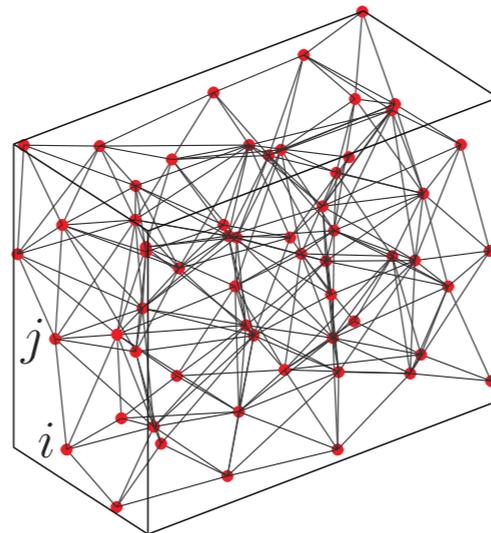
# Approach

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- High resolution 3D imaging



- Lattice modeling



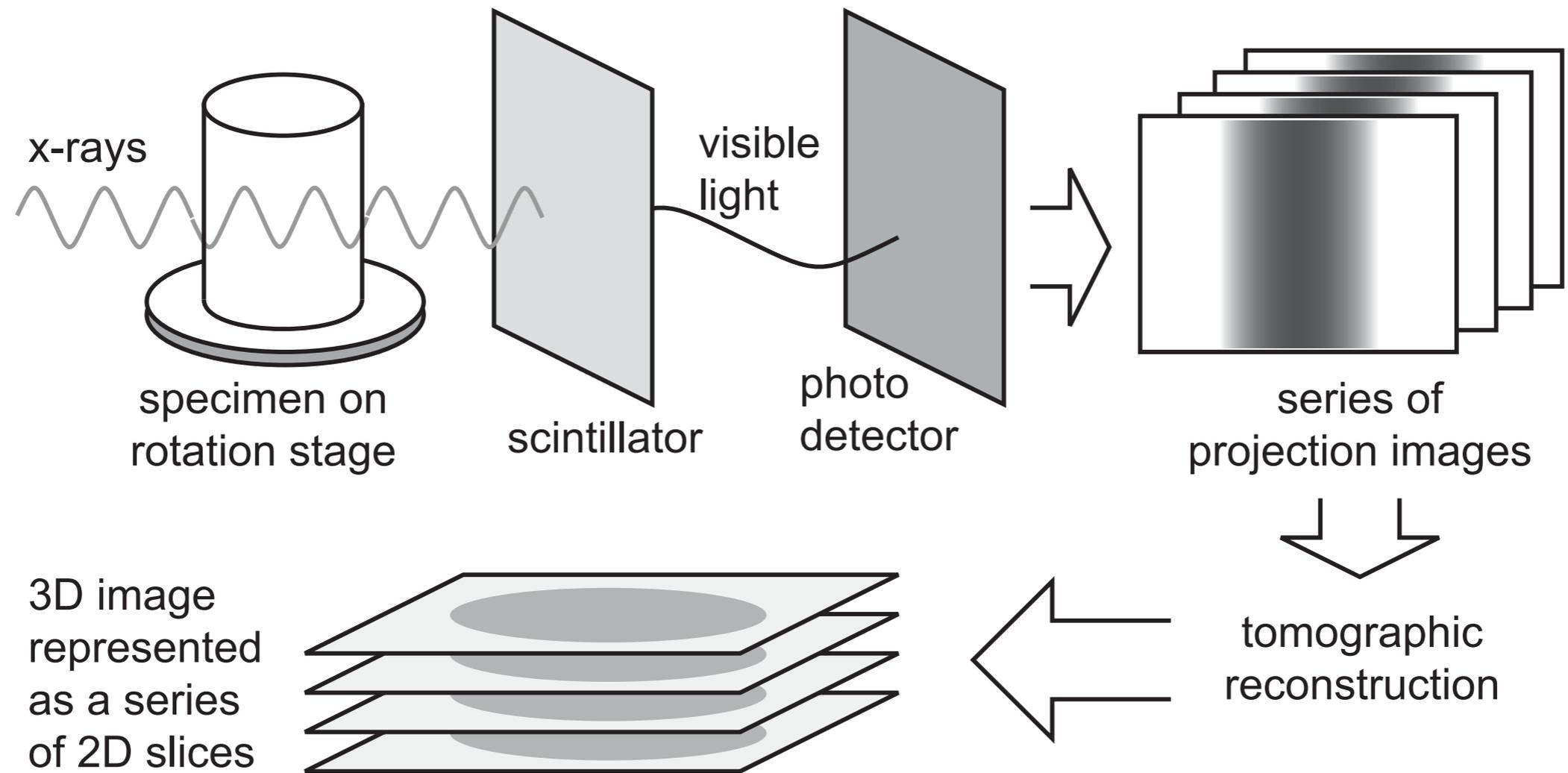
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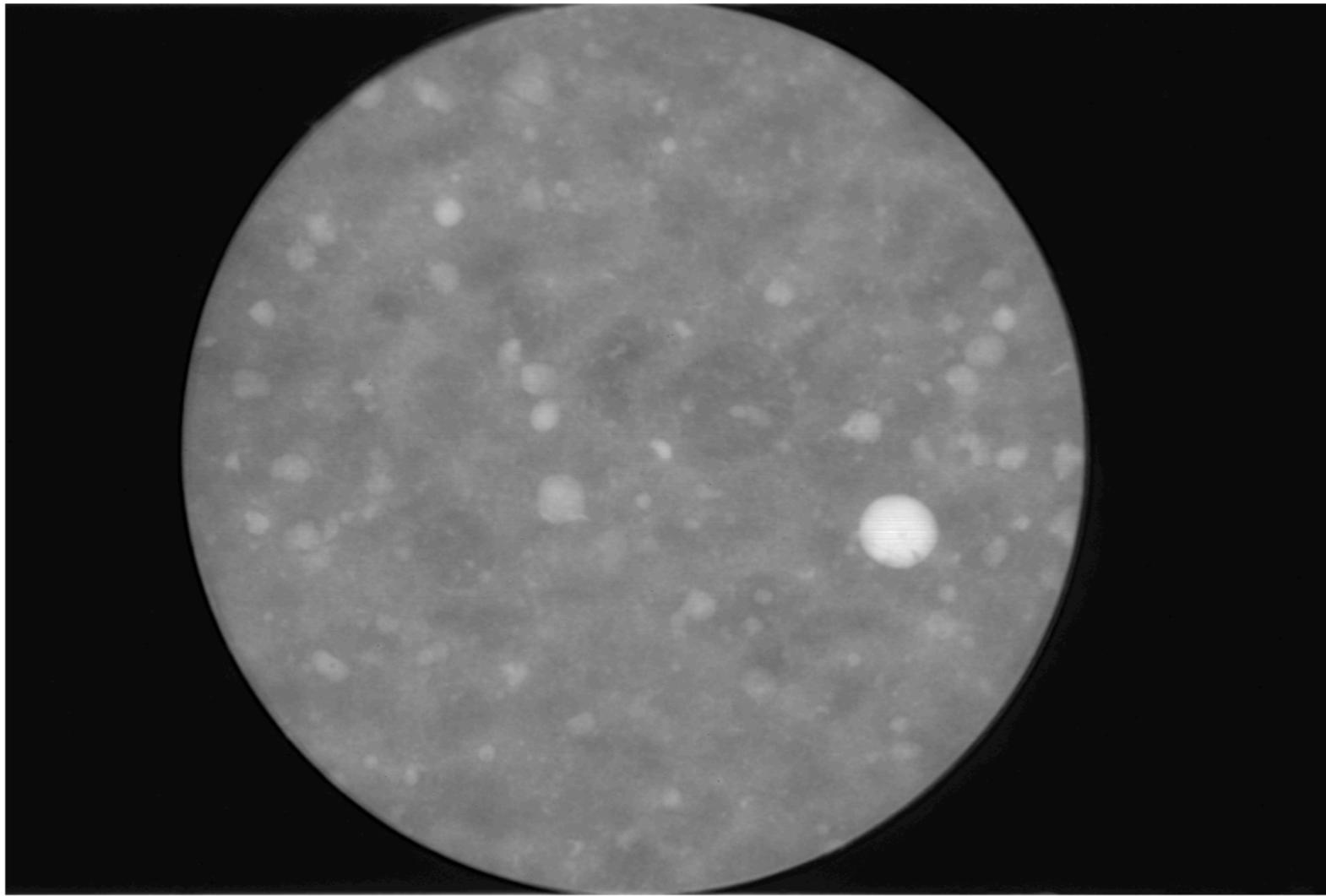
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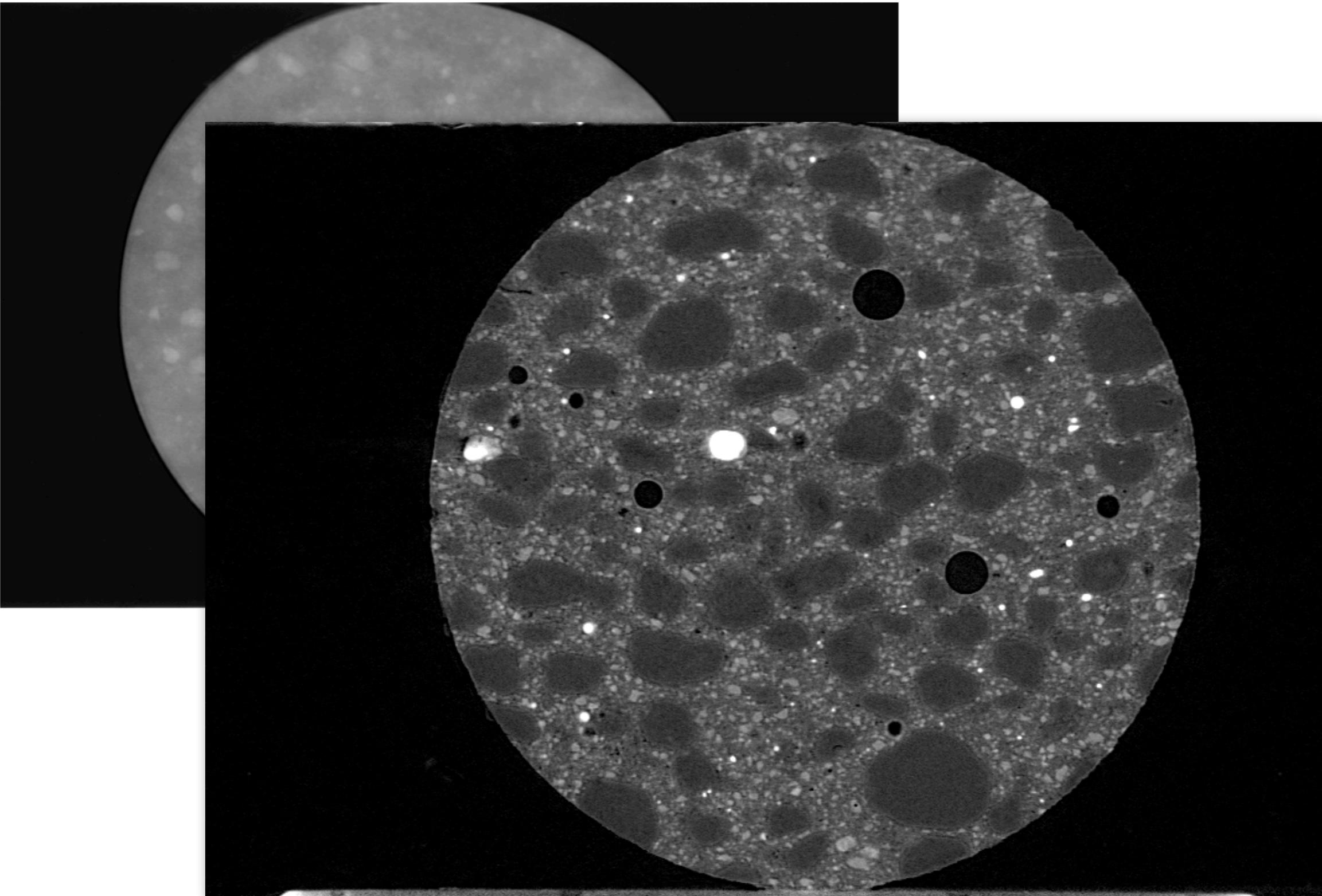
- 3D imaging with x-ray microtomography
  - data analysis
- Sample experiments and measurements
  - Need to integrate experiments with models
- Matched model specimens
  - Experiments and simulations

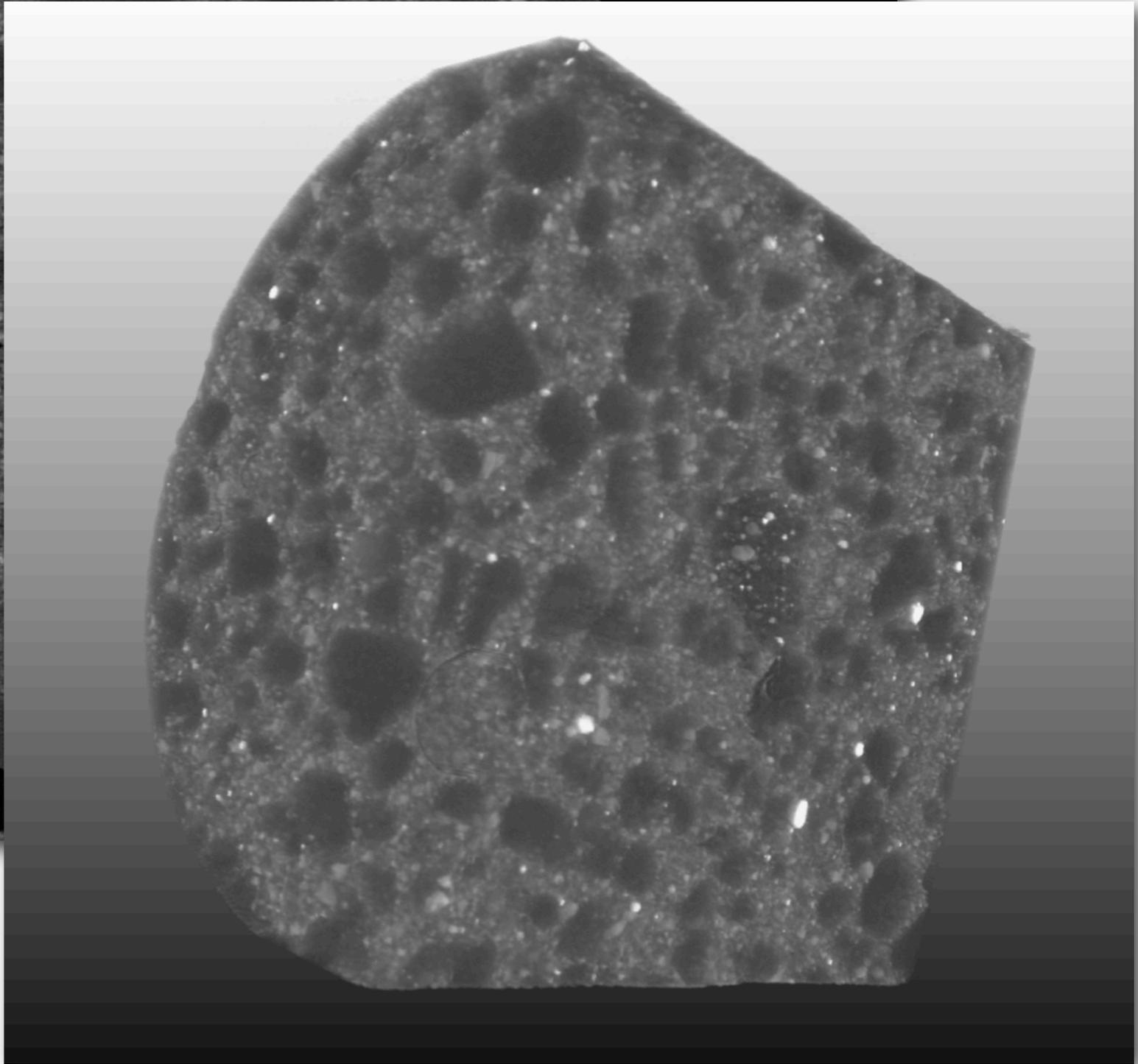
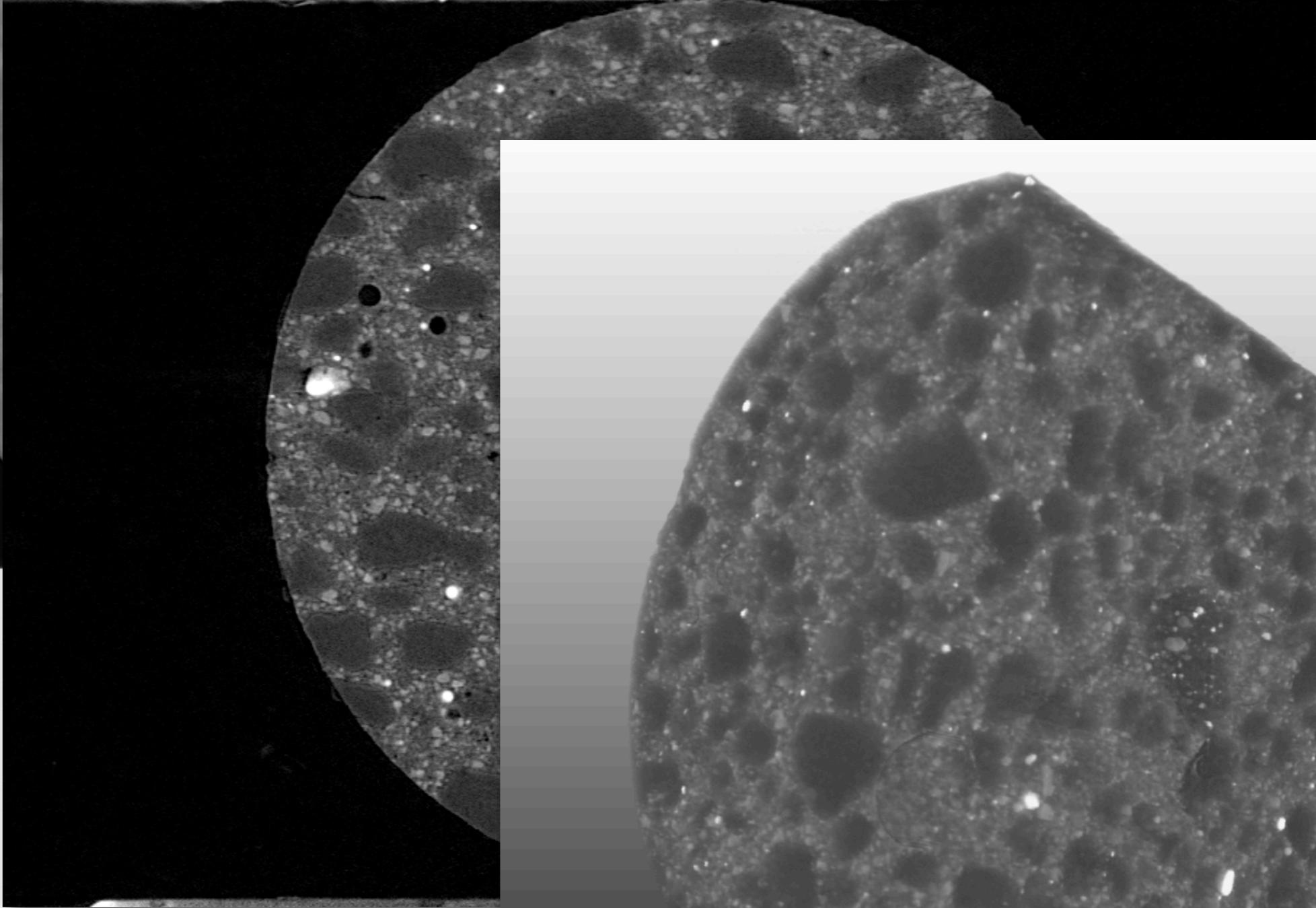
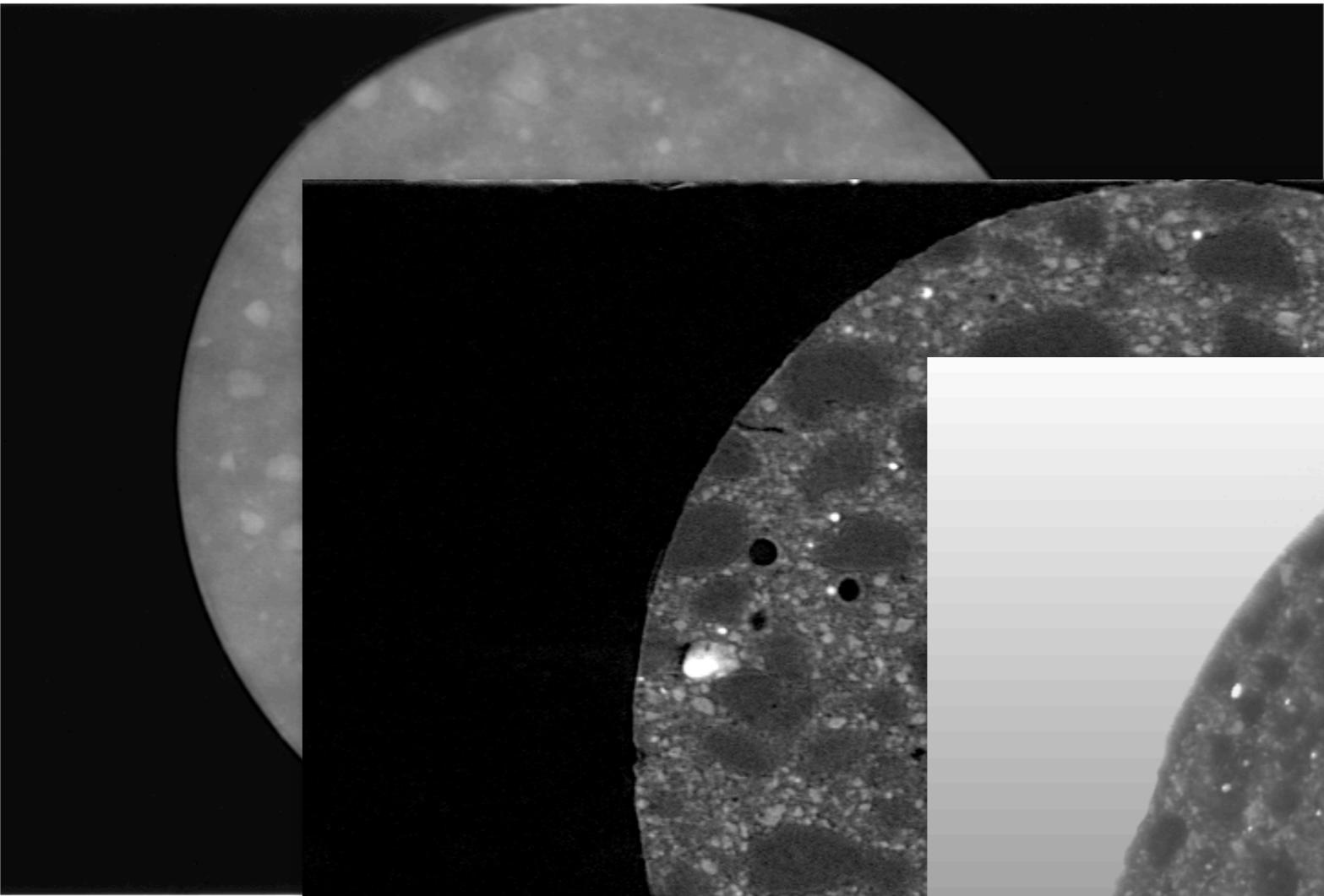
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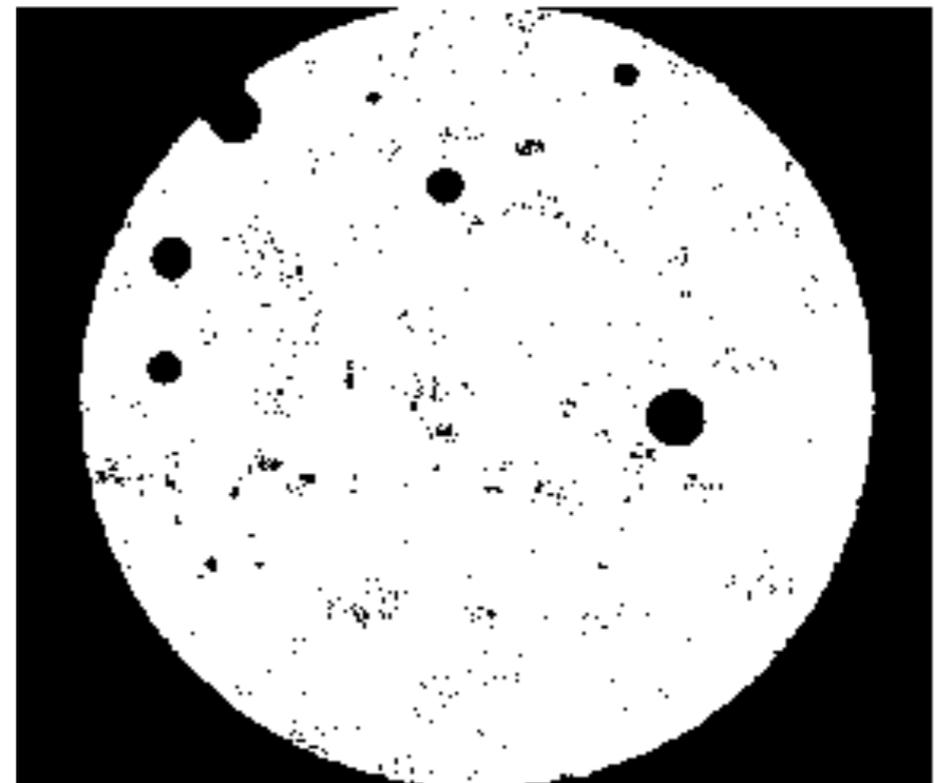
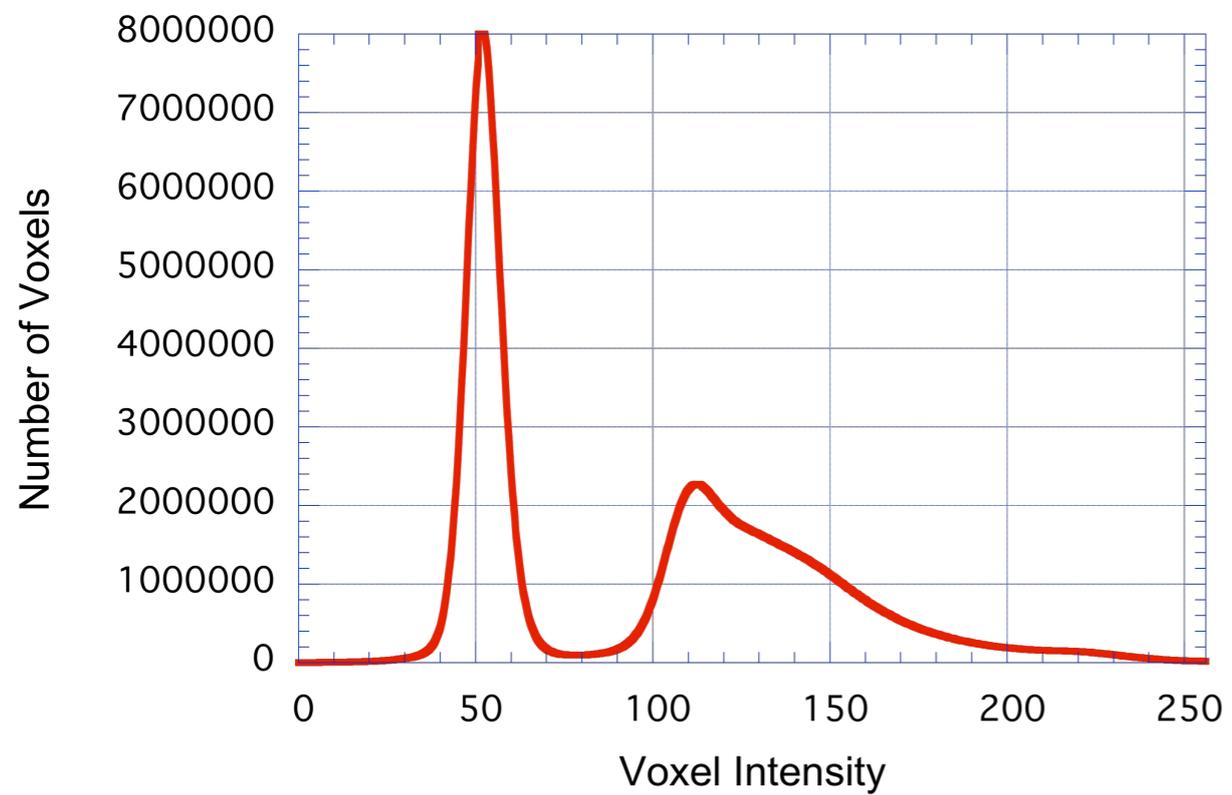
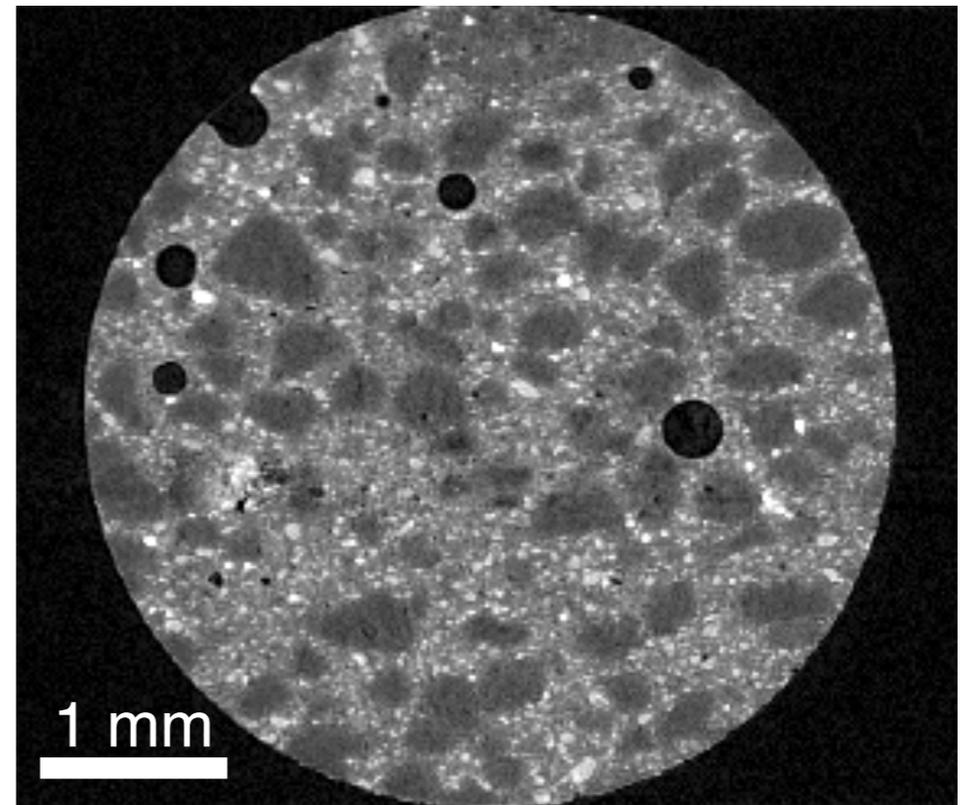
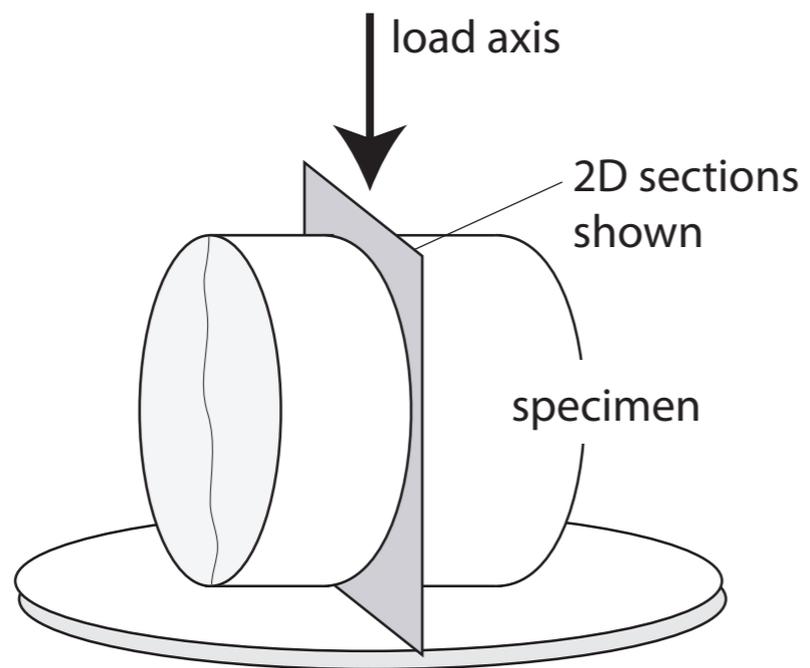
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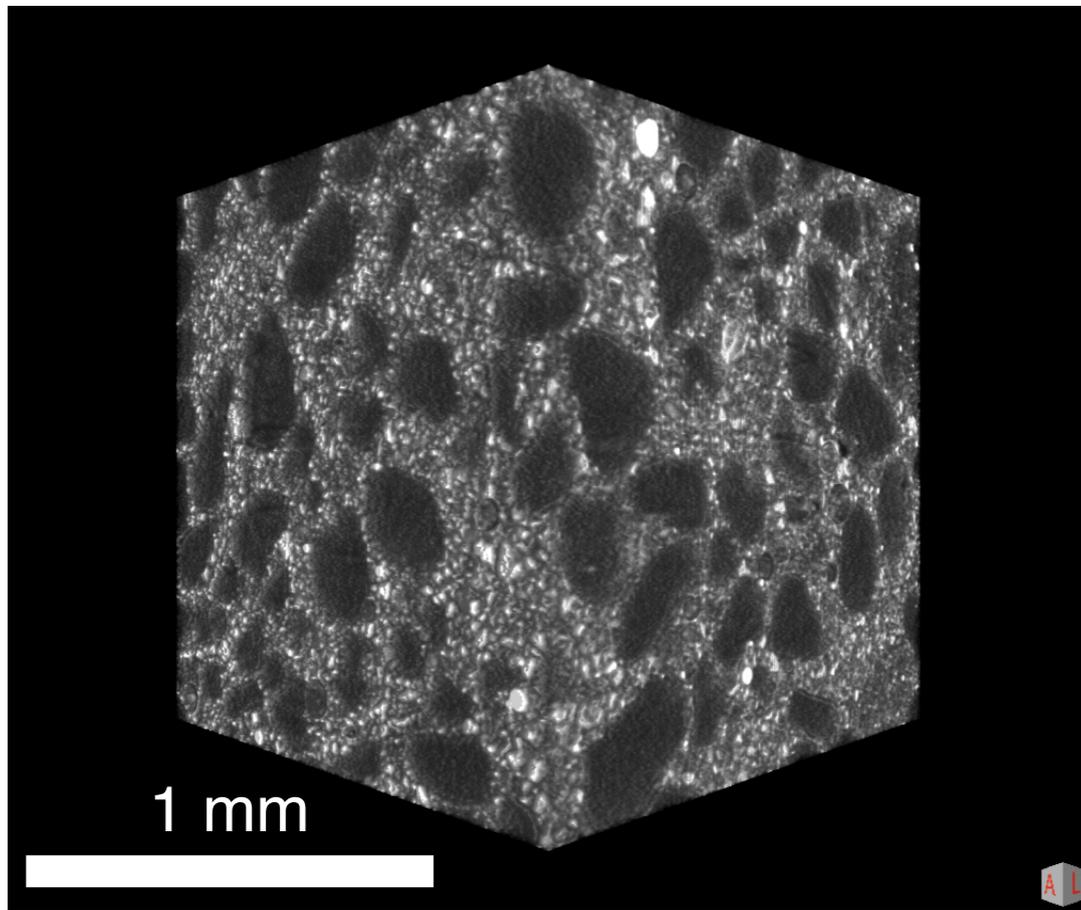


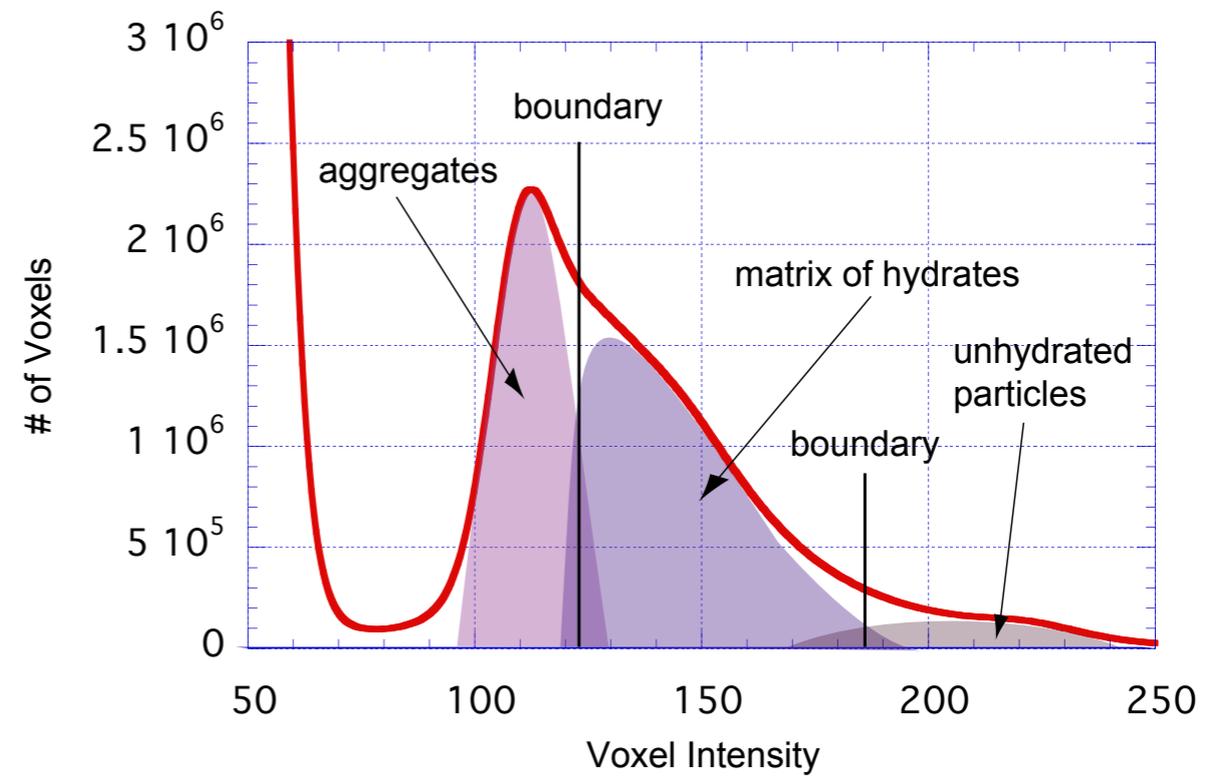
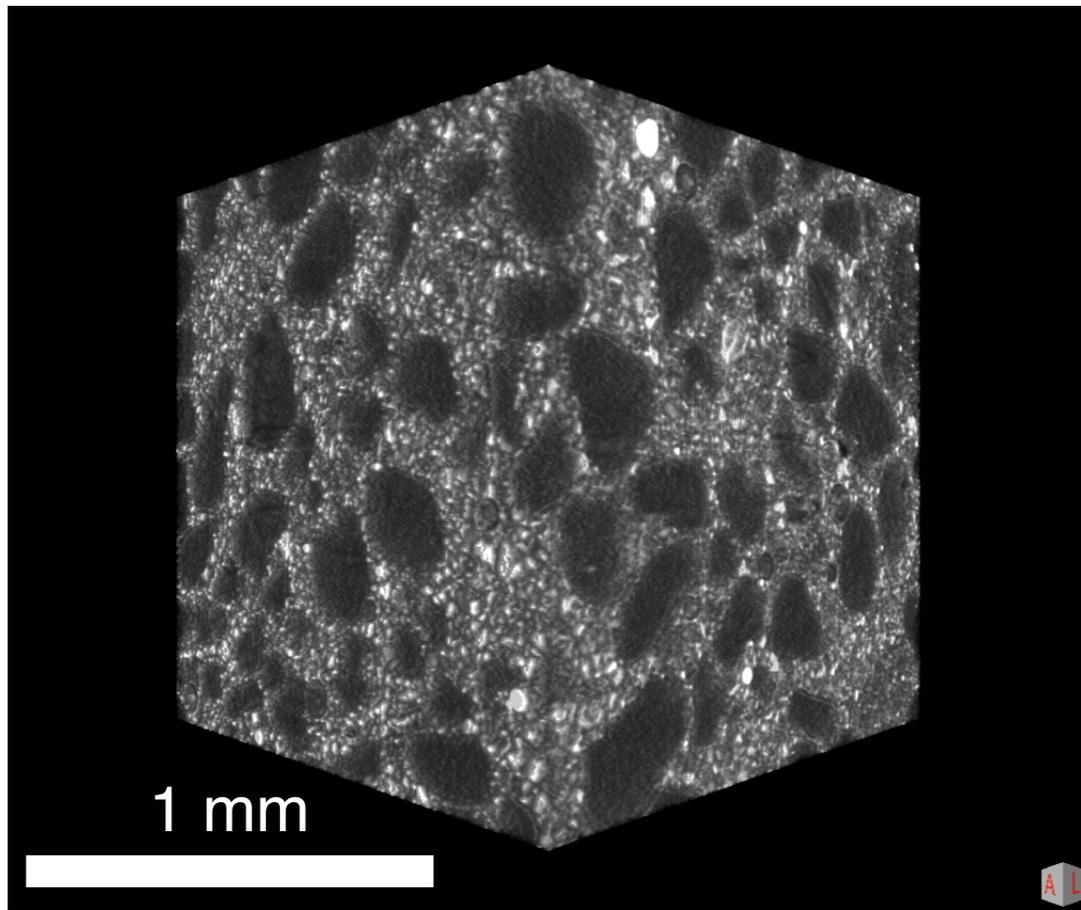


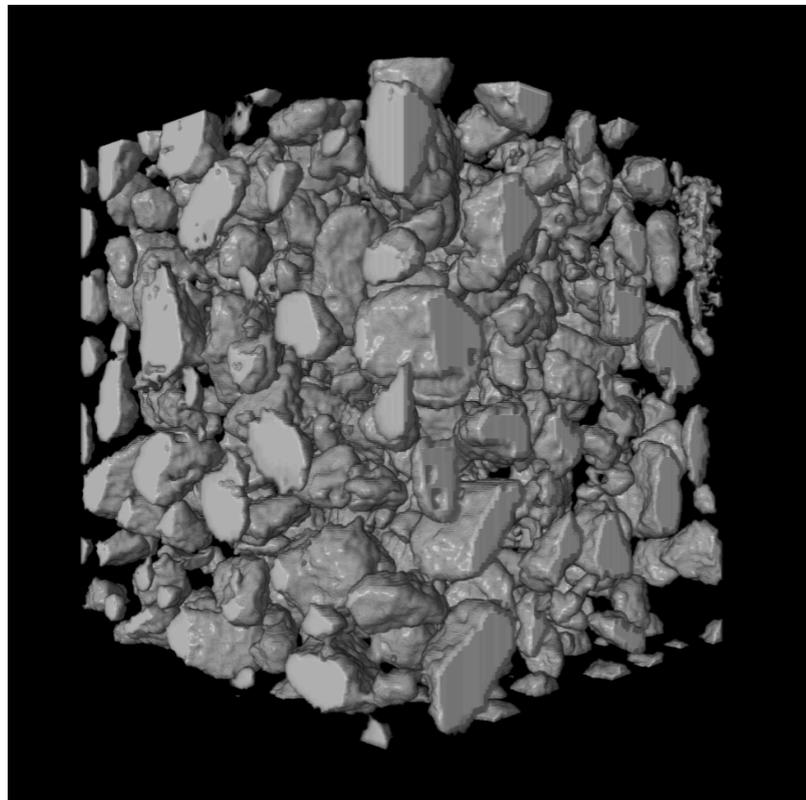
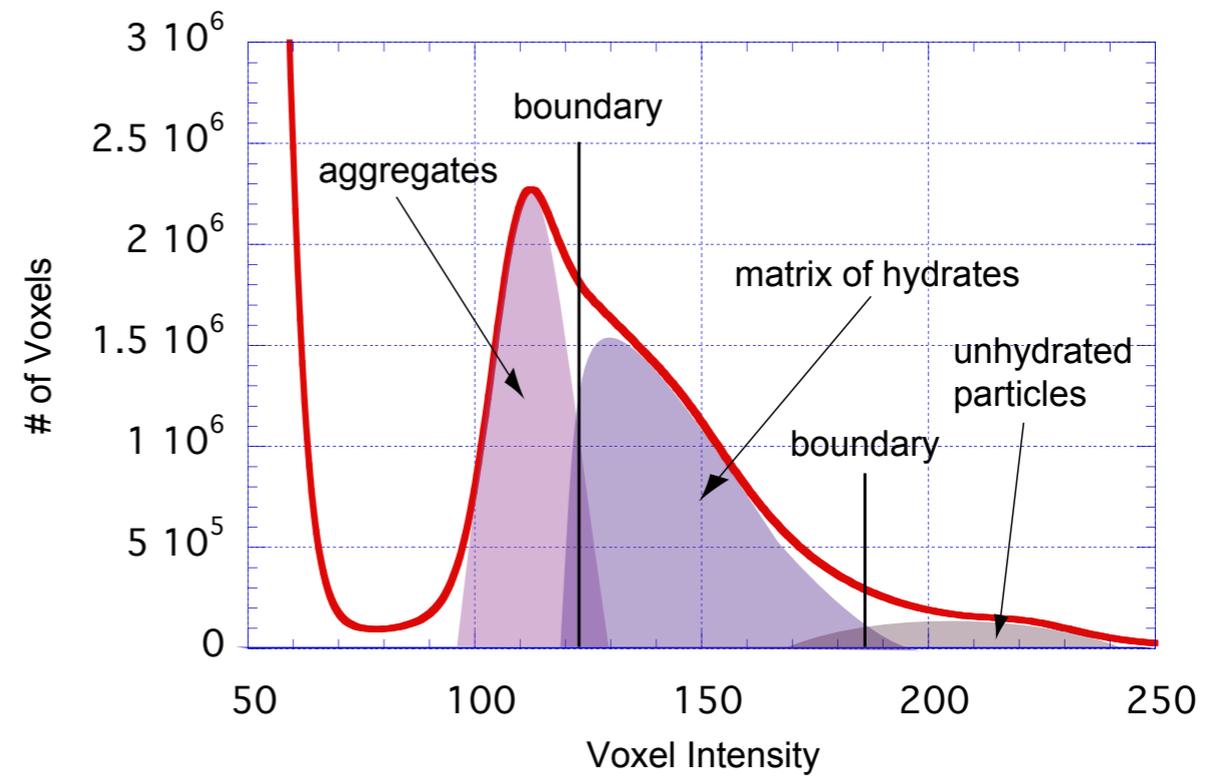
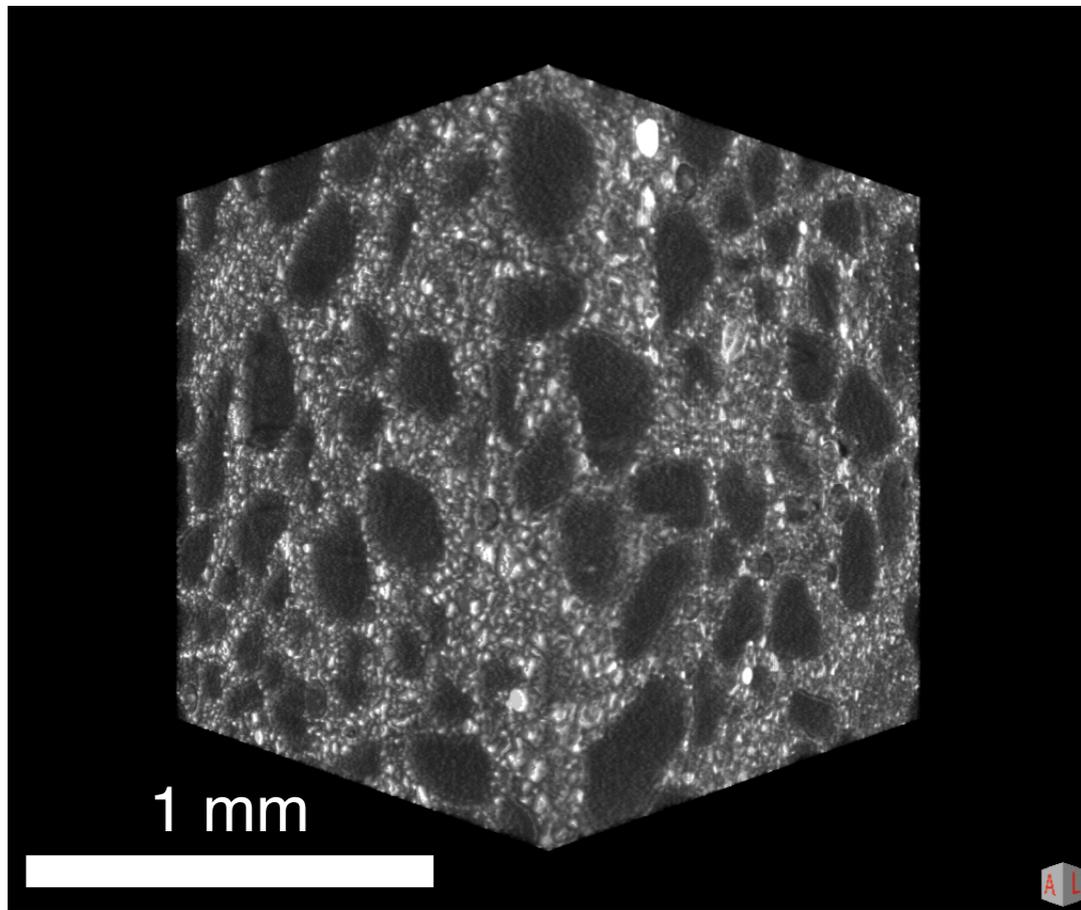


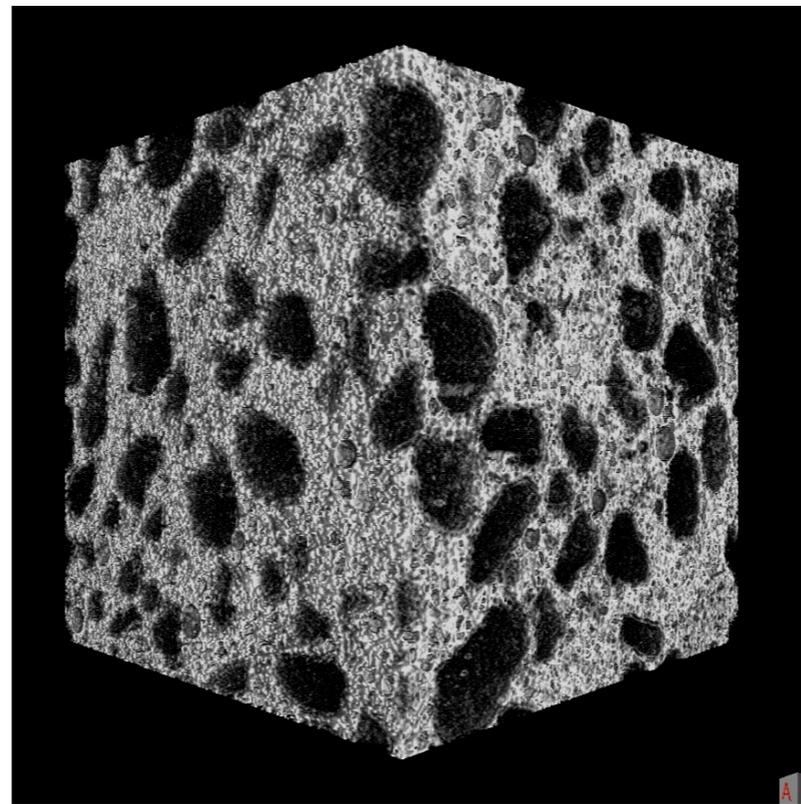
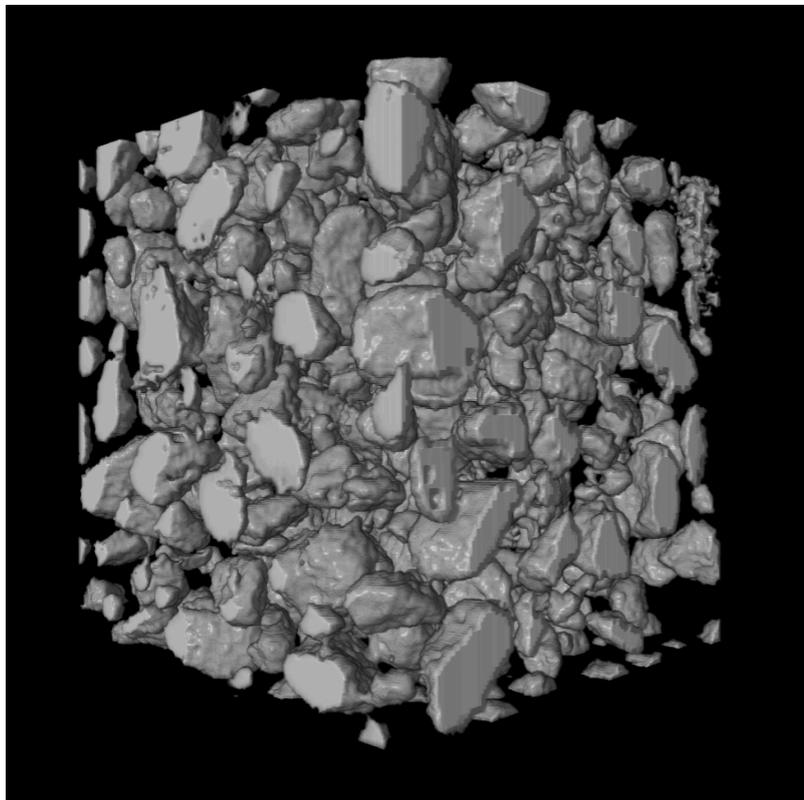
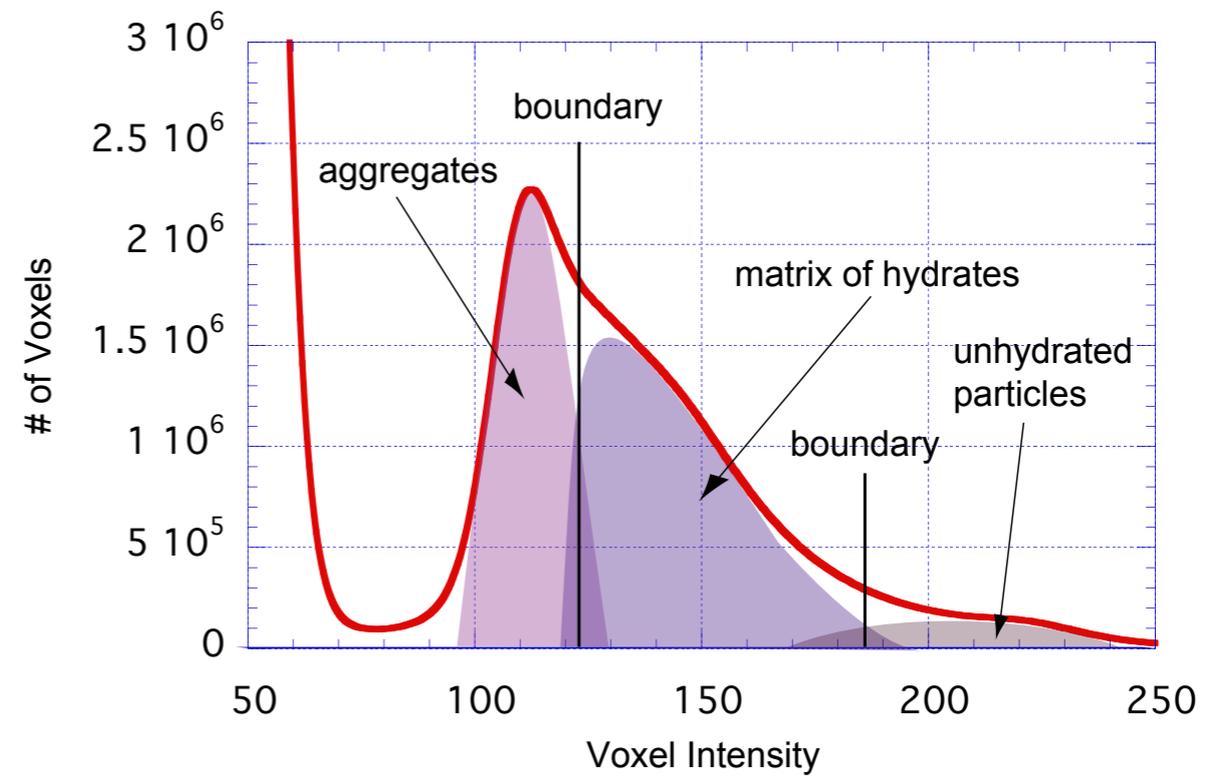
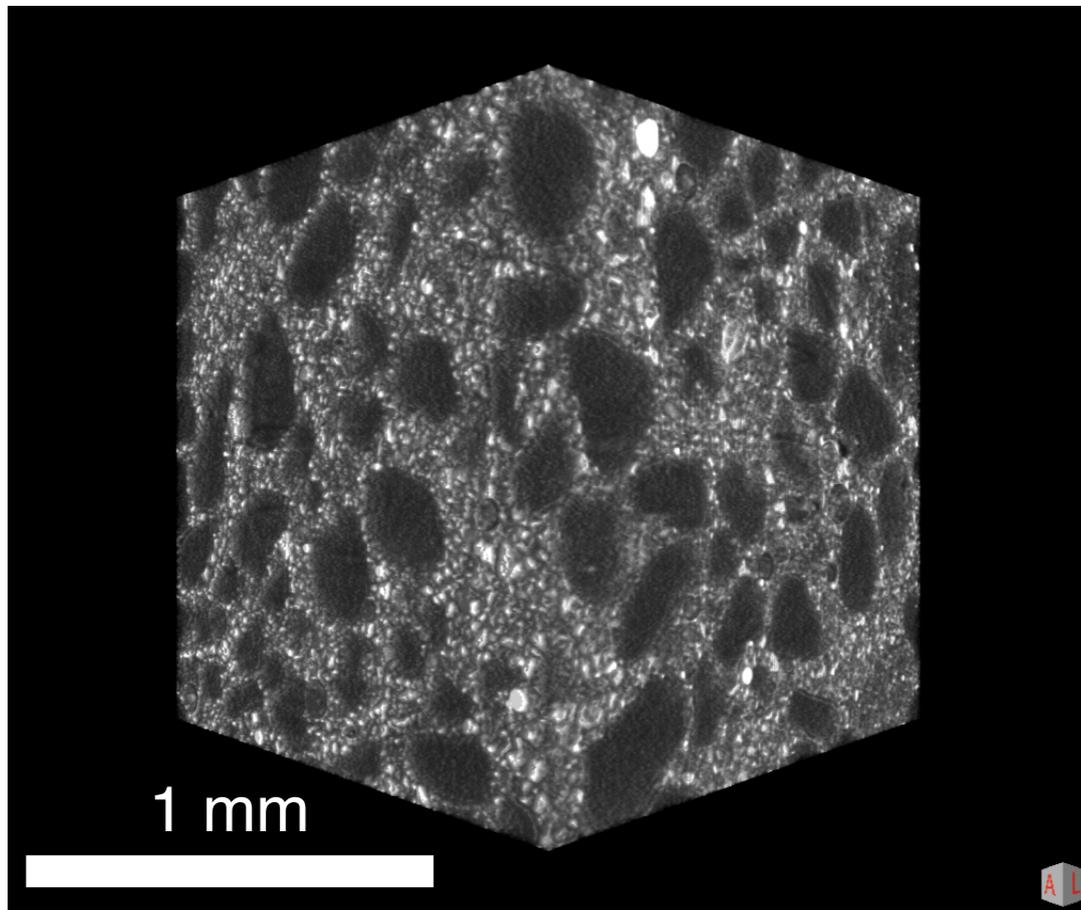


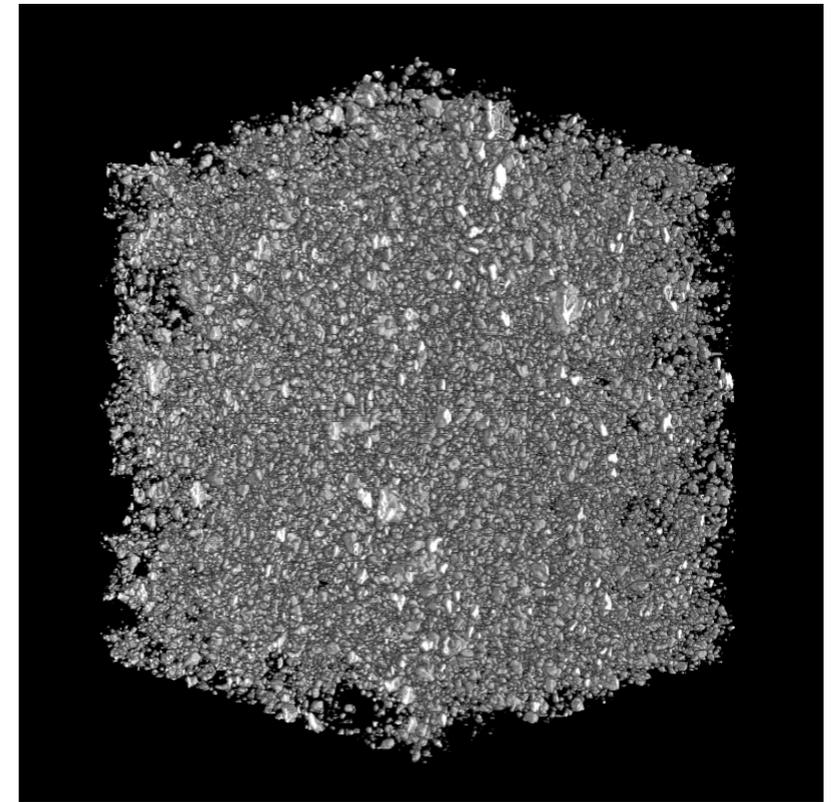
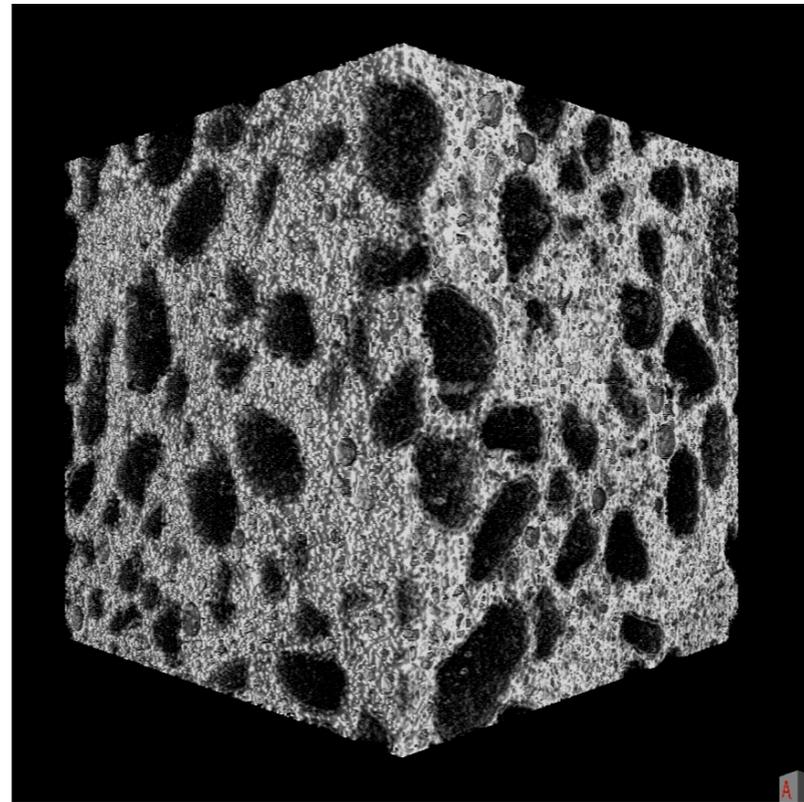
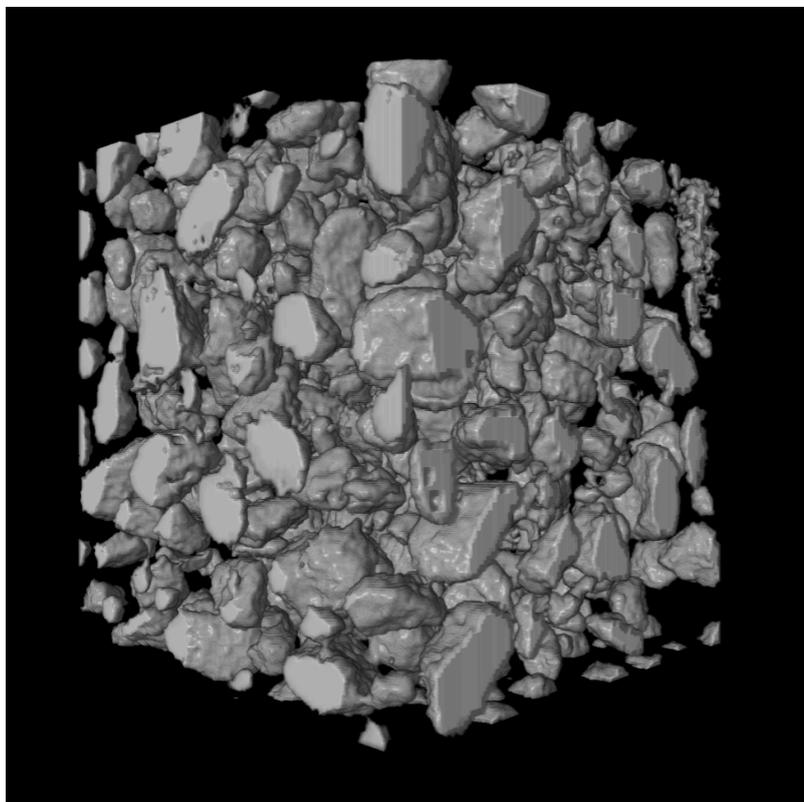
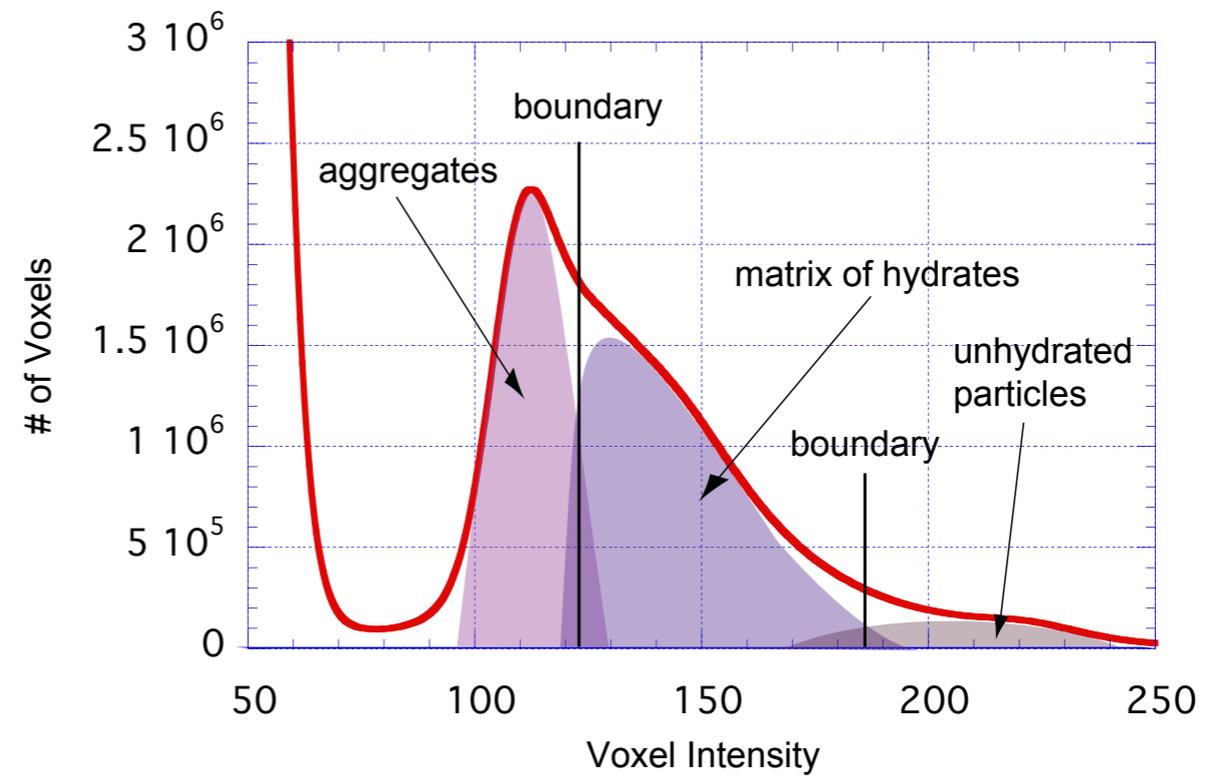
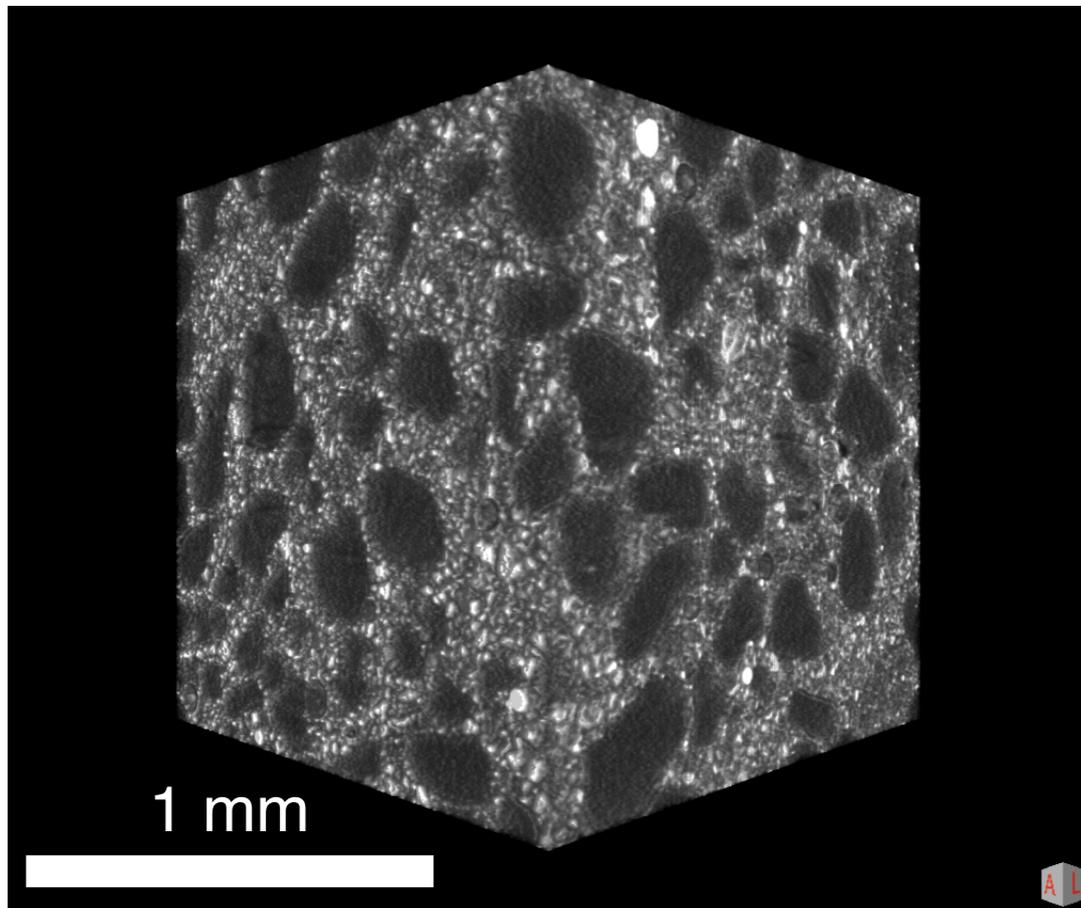




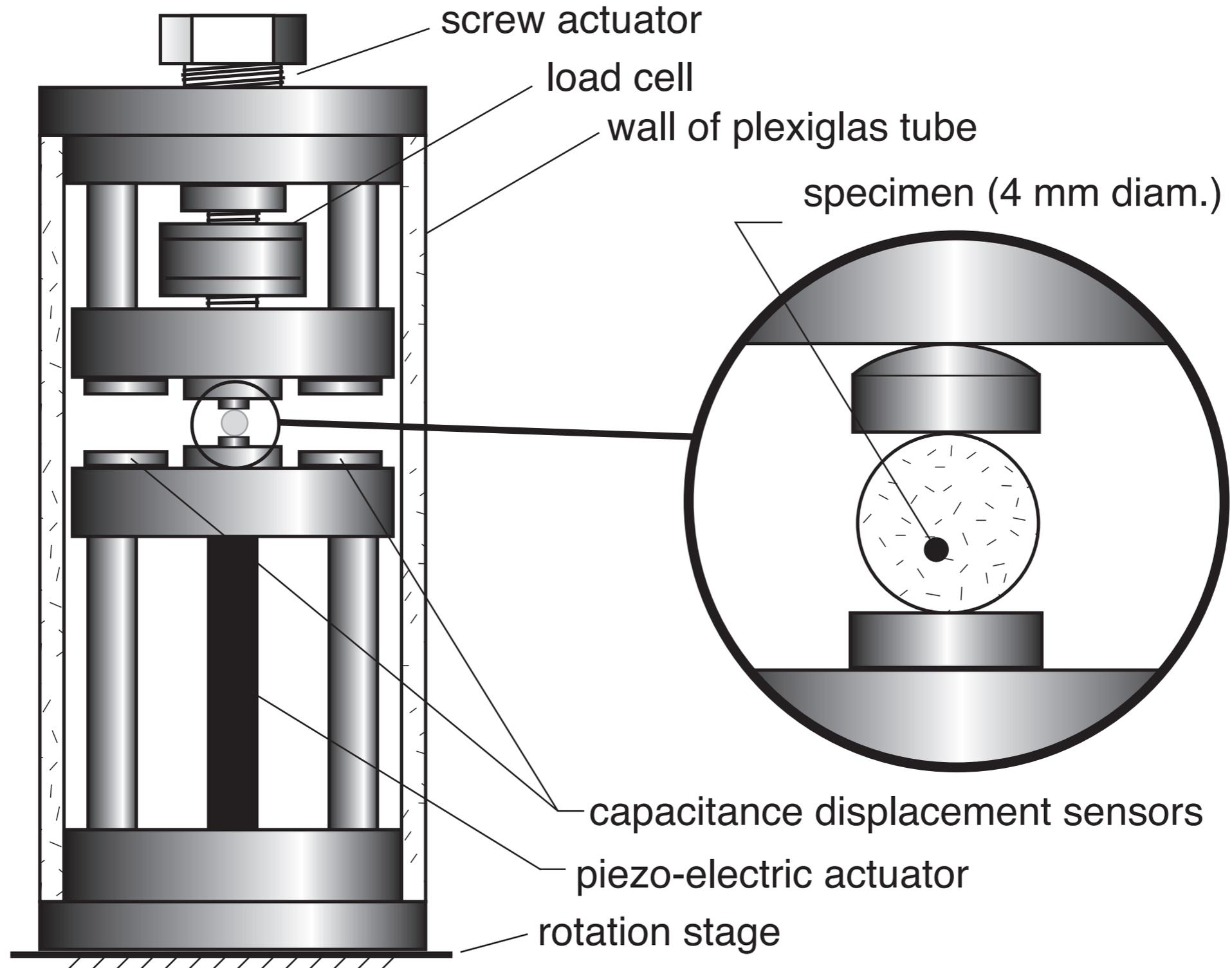


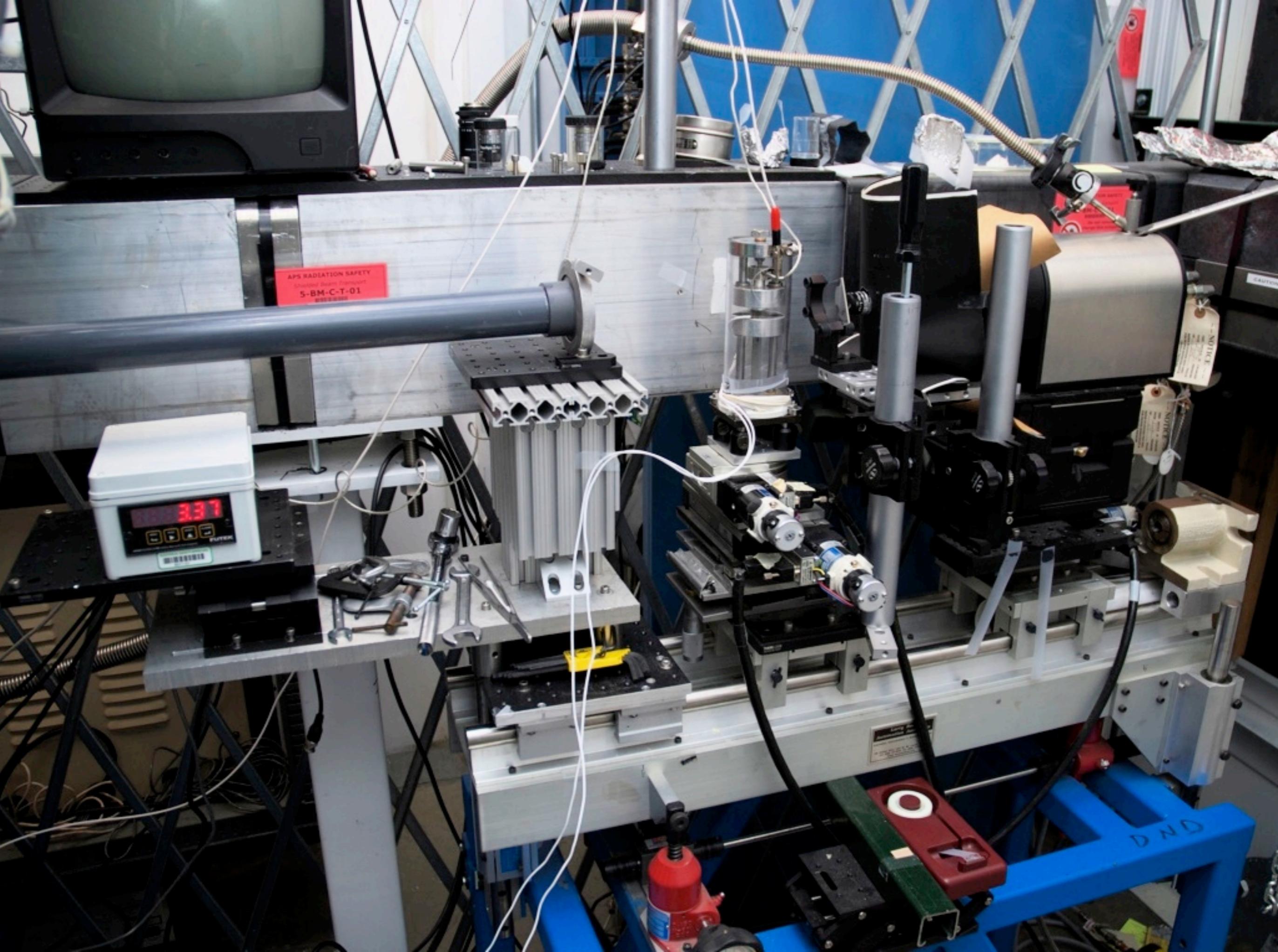






# In situ Loading





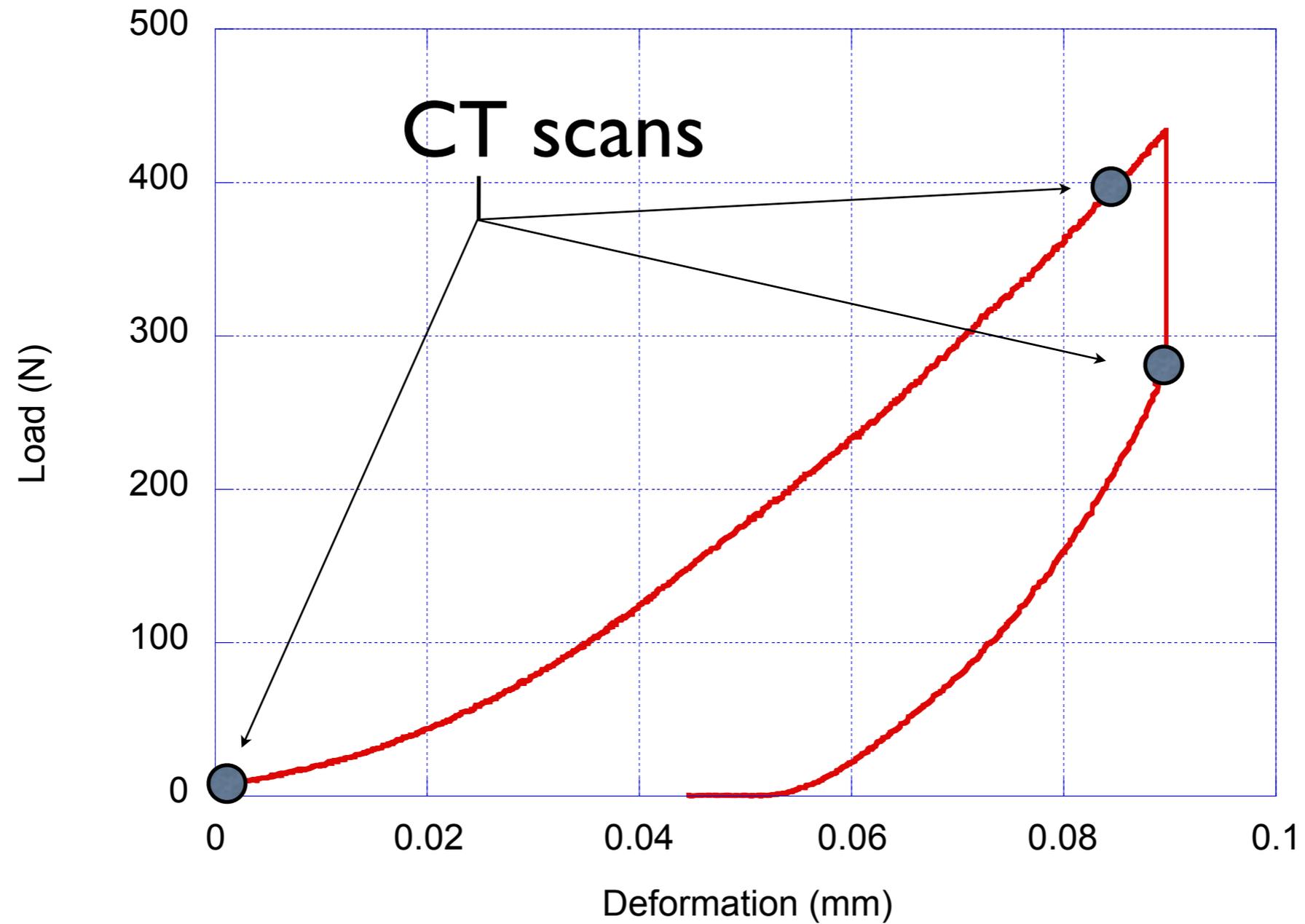
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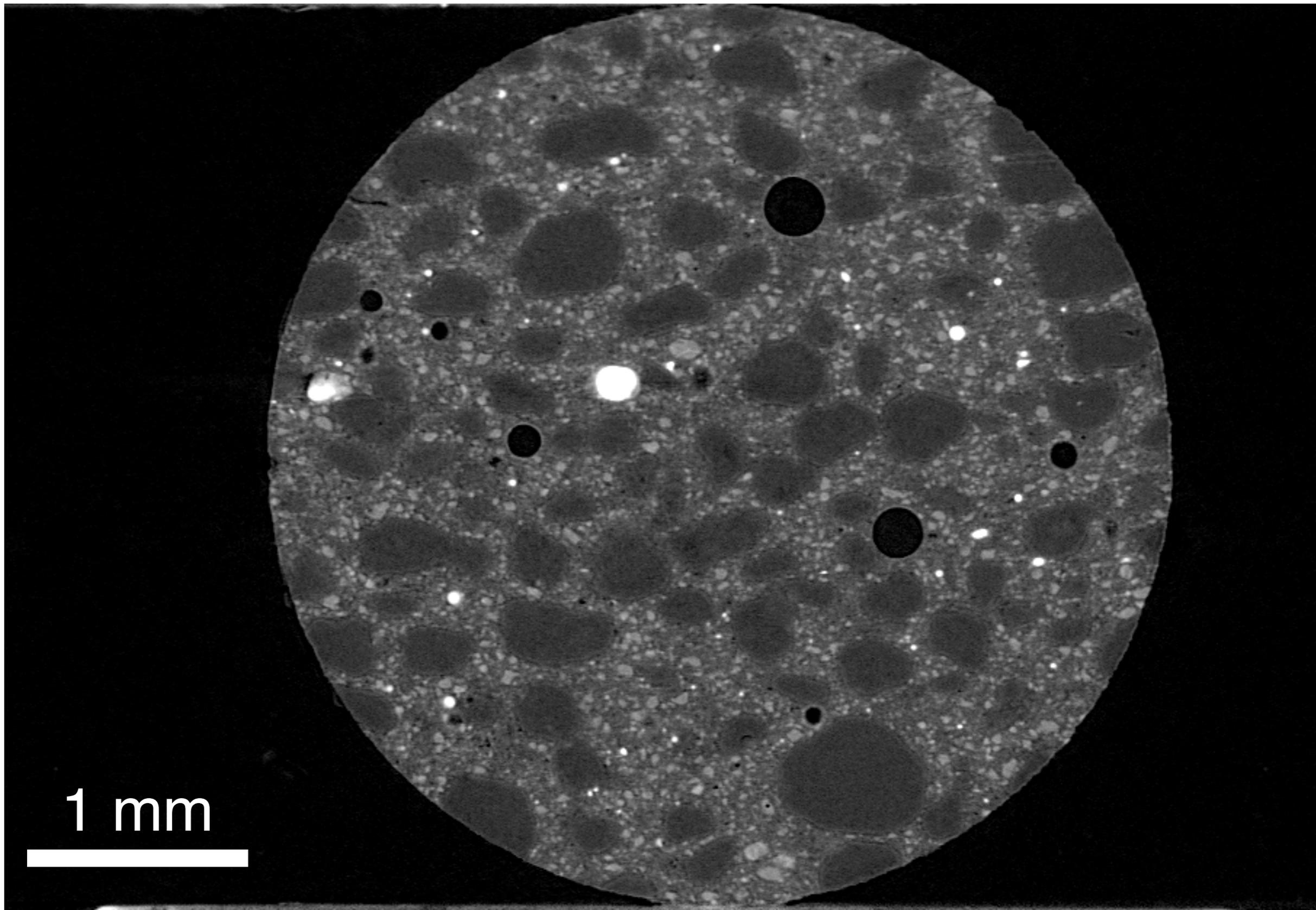
3.37  
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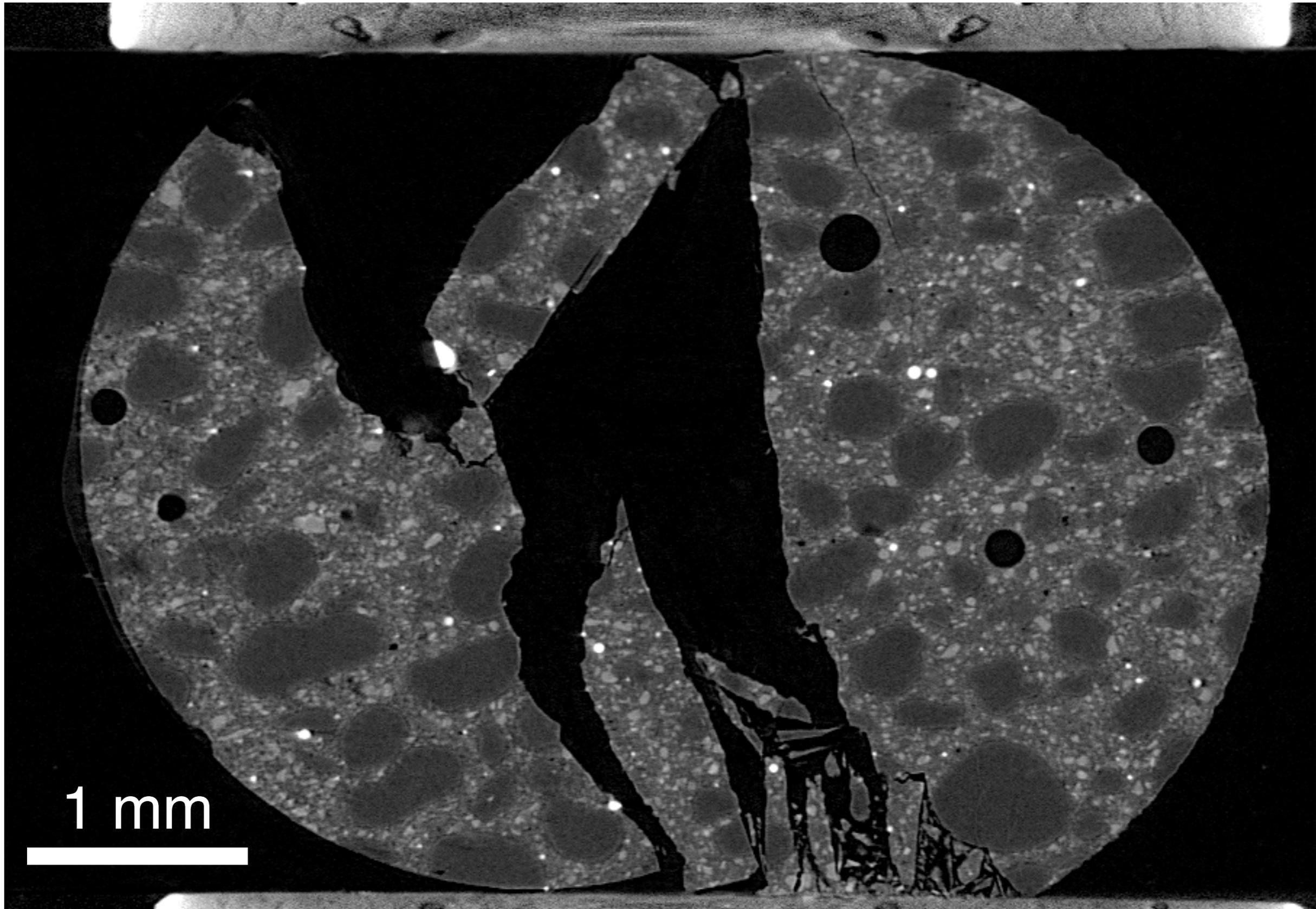


# Scanning Protocol

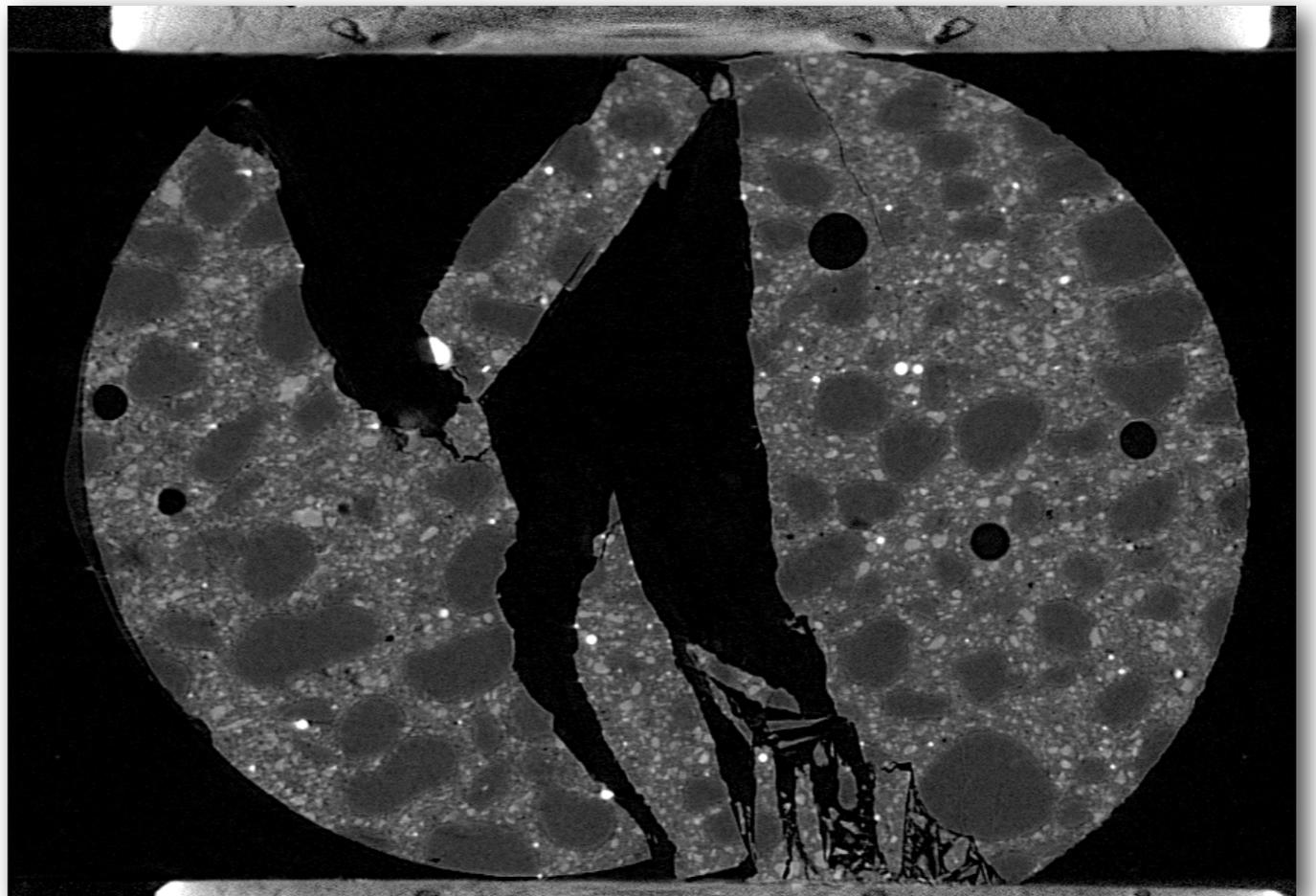
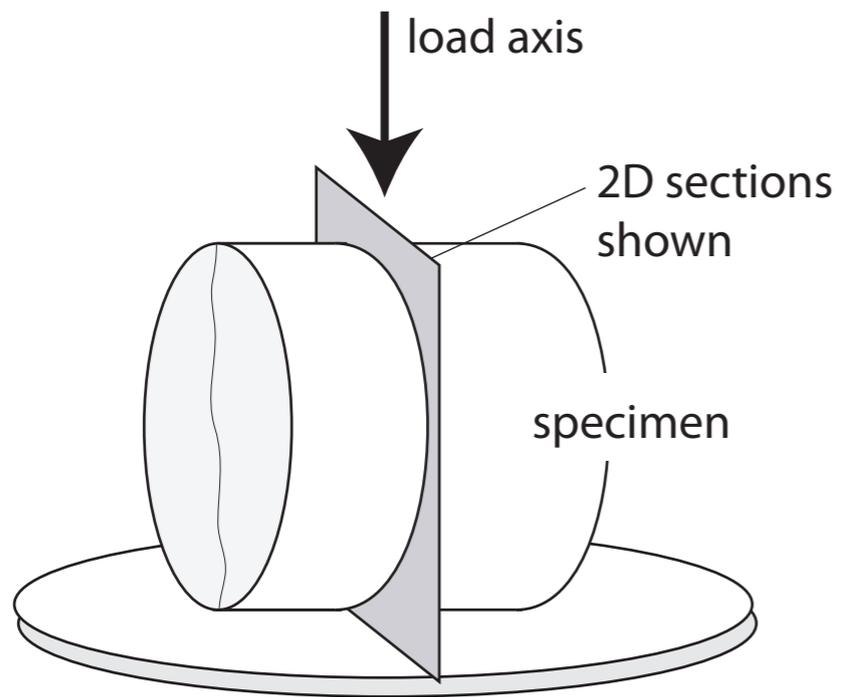
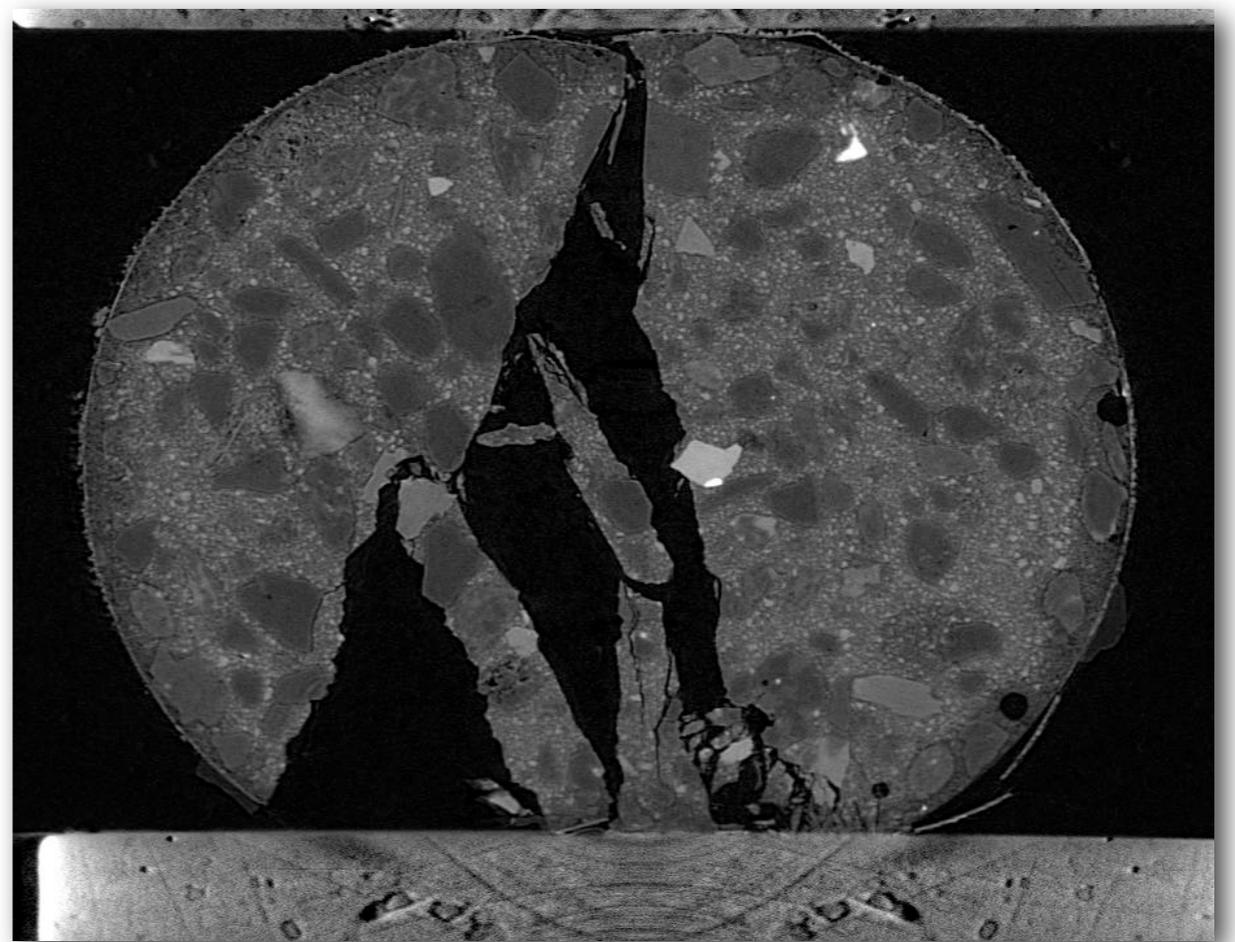
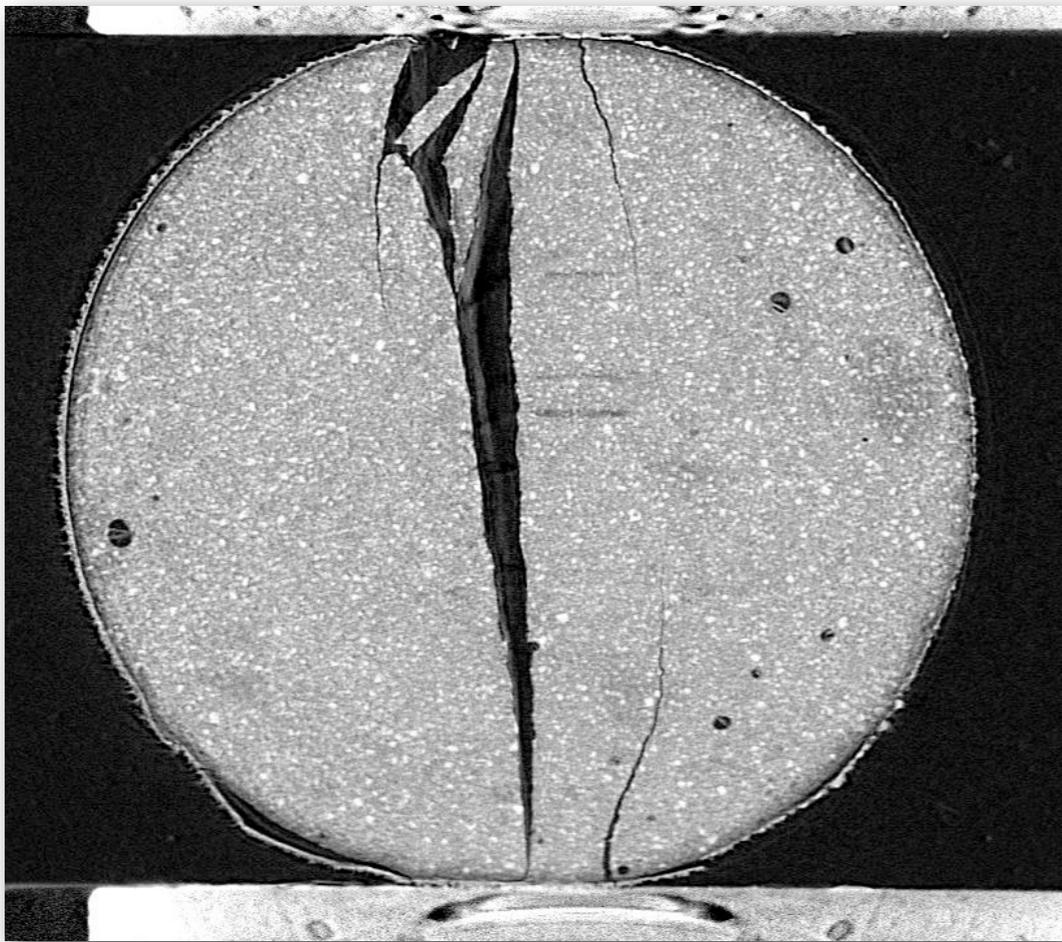




1 mm



1 mm



# Fracture Analysis

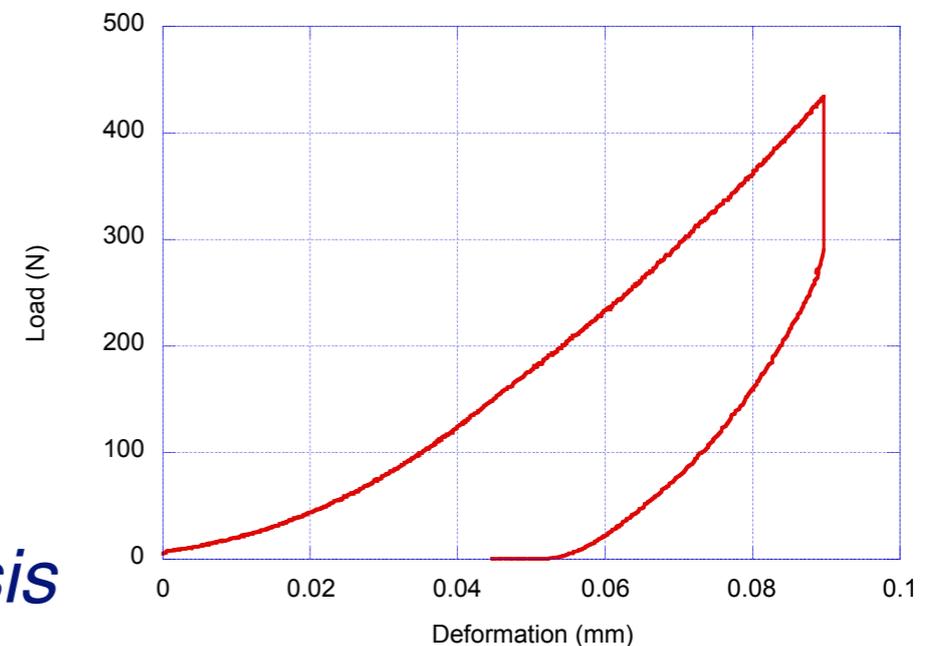
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- Fracture Energy

- Net work of load,  $dU$
- new surface area,  $dA$ 
  - *connected components analysis*
- $G = dU/dA$

- Fragmentation

- estimated through segmented distance transform



# Fracture Analysis

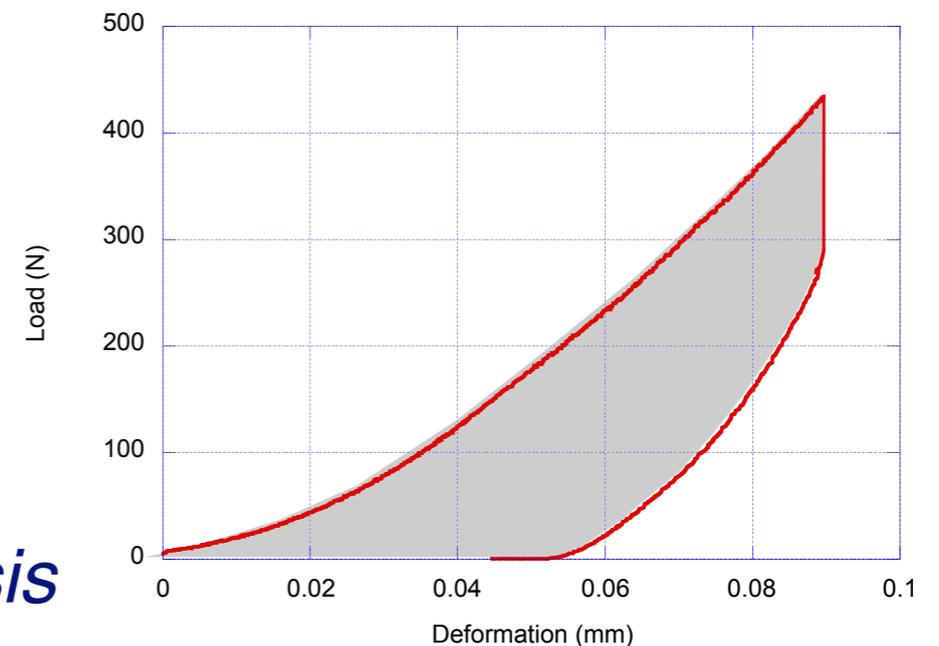
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- Fracture Energy

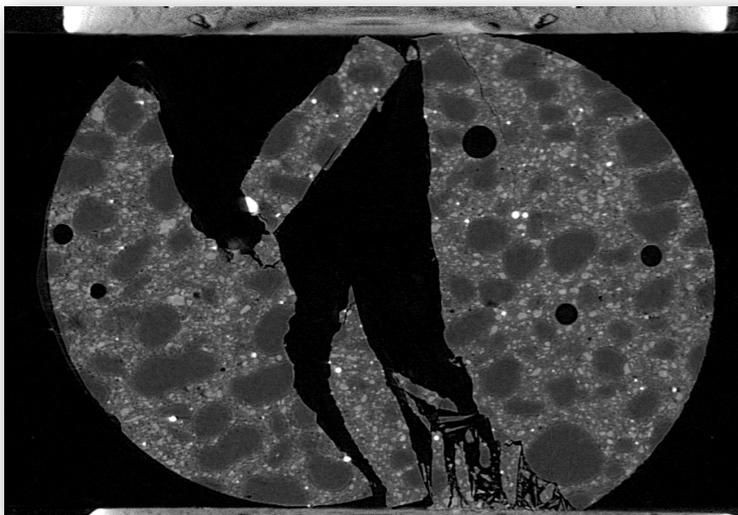
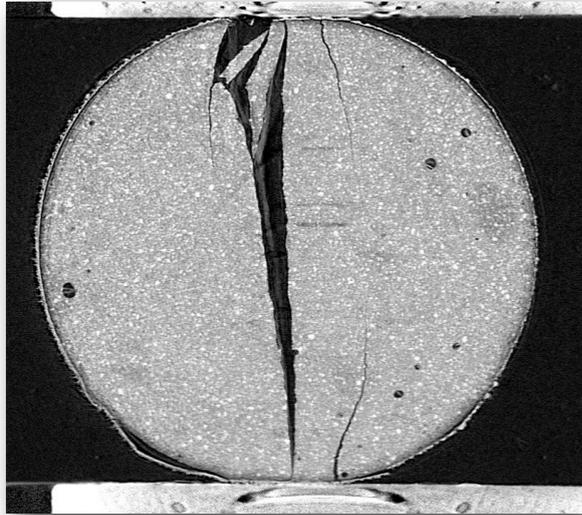
- Net work of load,  $dU$
- new surface area,  $dA$ 
  - *connected components analysis*
- $G = dU/dA$

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# Measurements

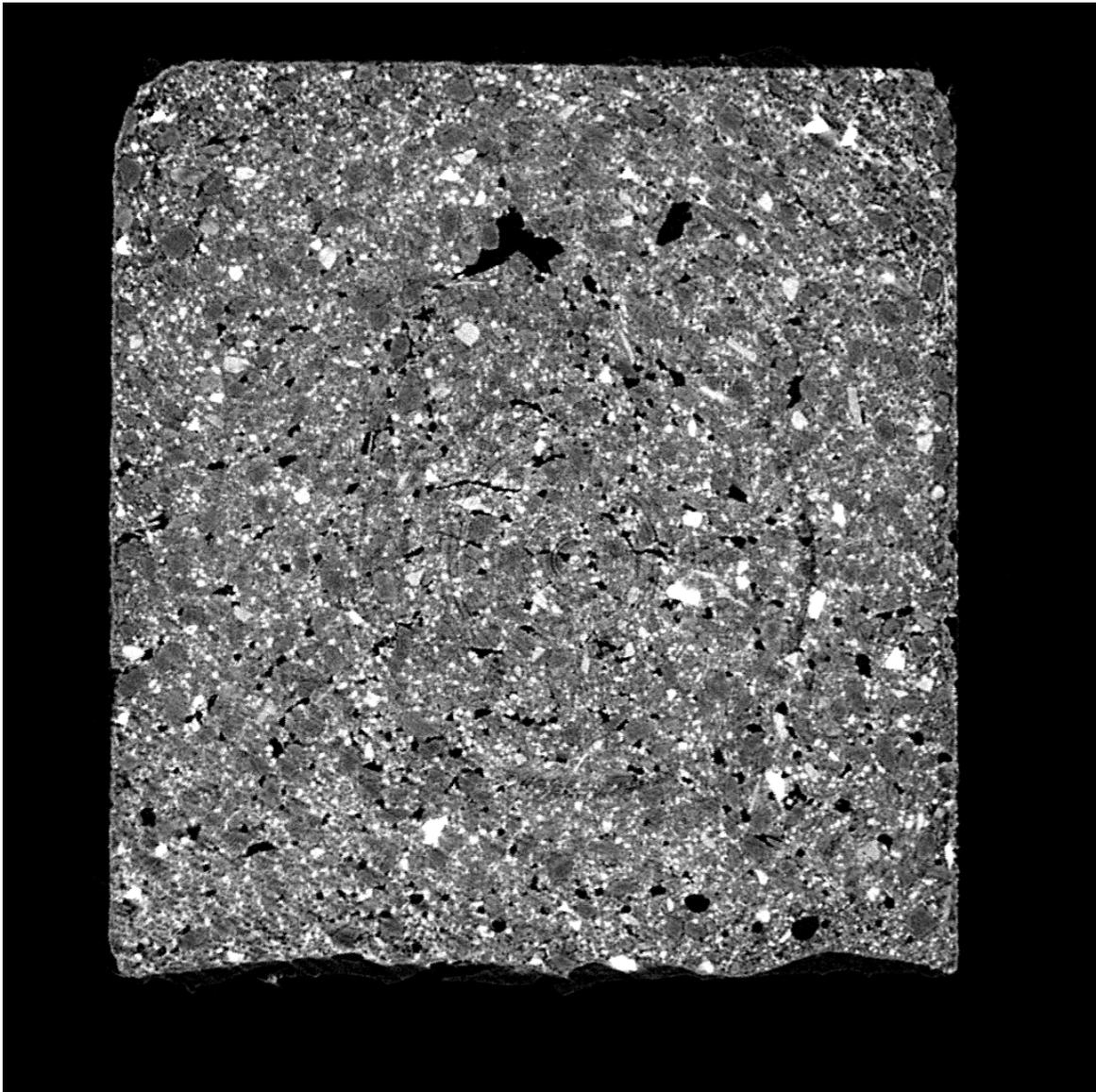


Material	Net work of load (mJ)	New surface area (mm <sup>2</sup> )	Fracture energy (J/m <sup>2</sup> )	Number of fragments
Paste	5.0	167	30	12
Mortar	11.2	294	38	4041
UHP Concrete	13.0	260	50	3655

# Microstructure-Property Relationships

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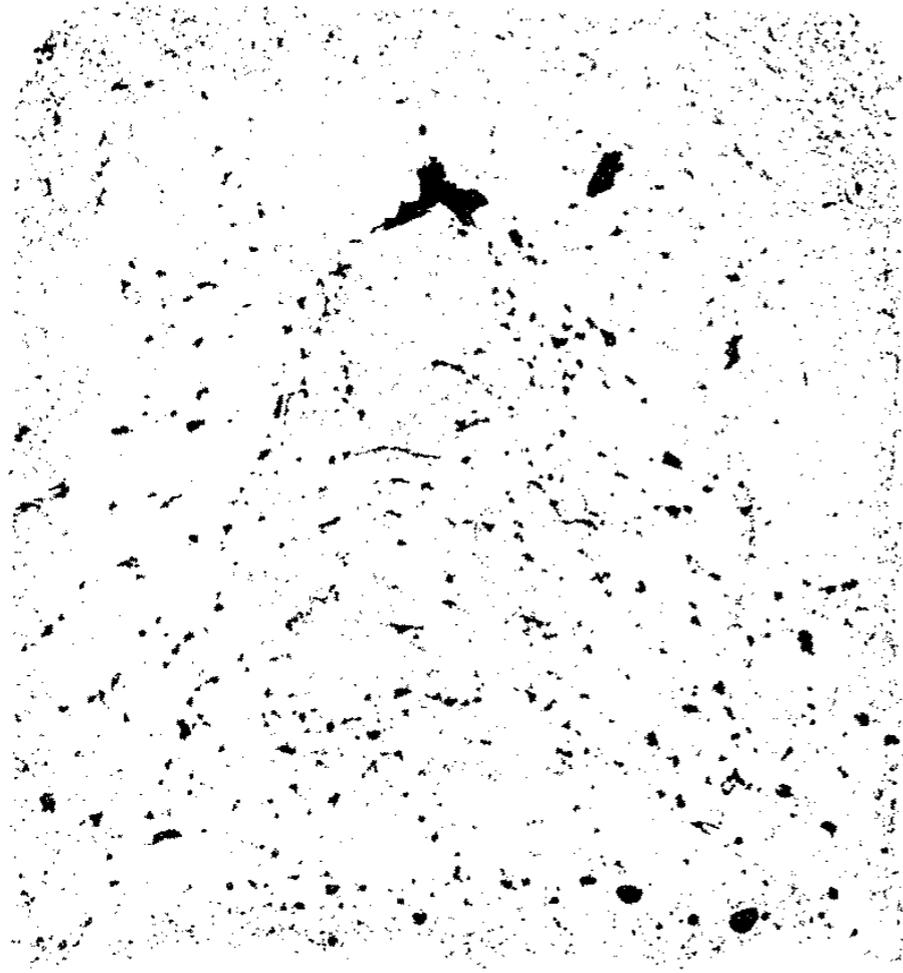
## Porosity and pore-size distribution



# Microstructure-Property Relationships

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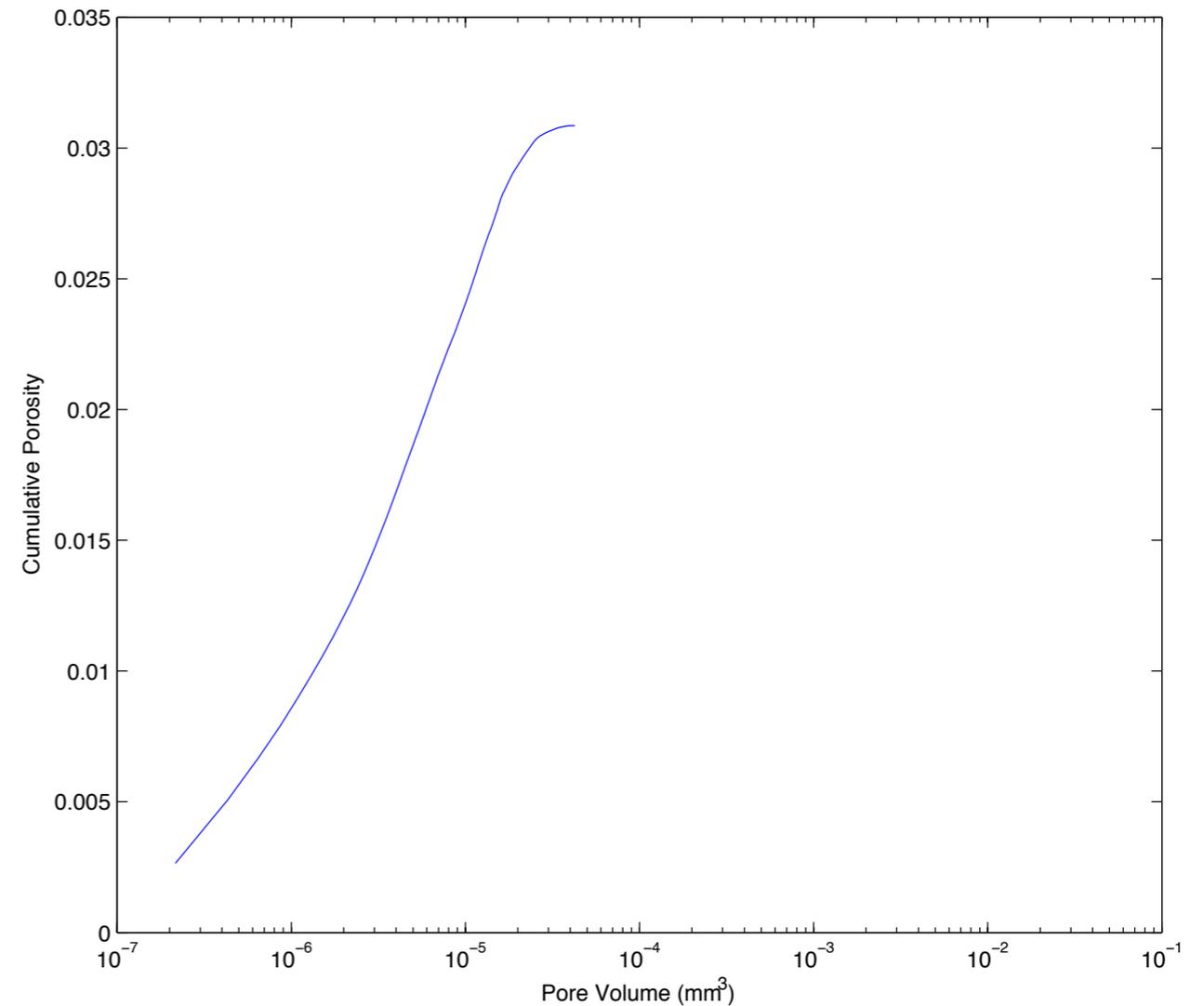
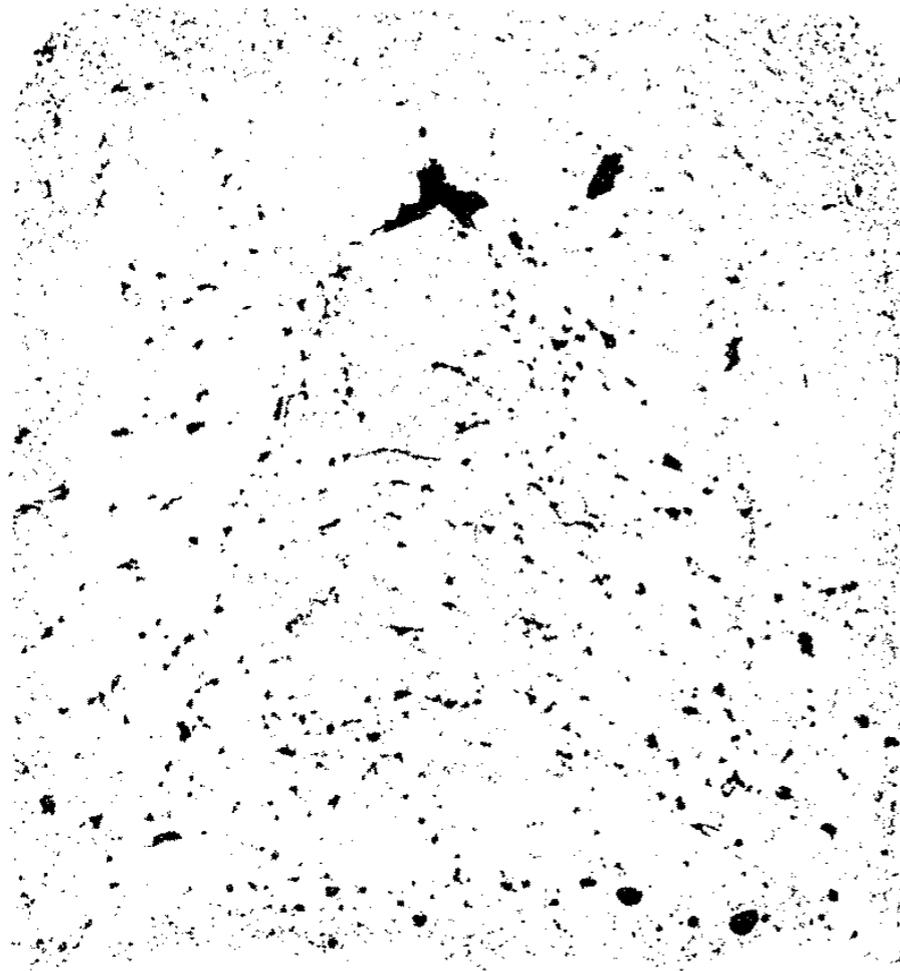
## Porosity and pore-size distribution



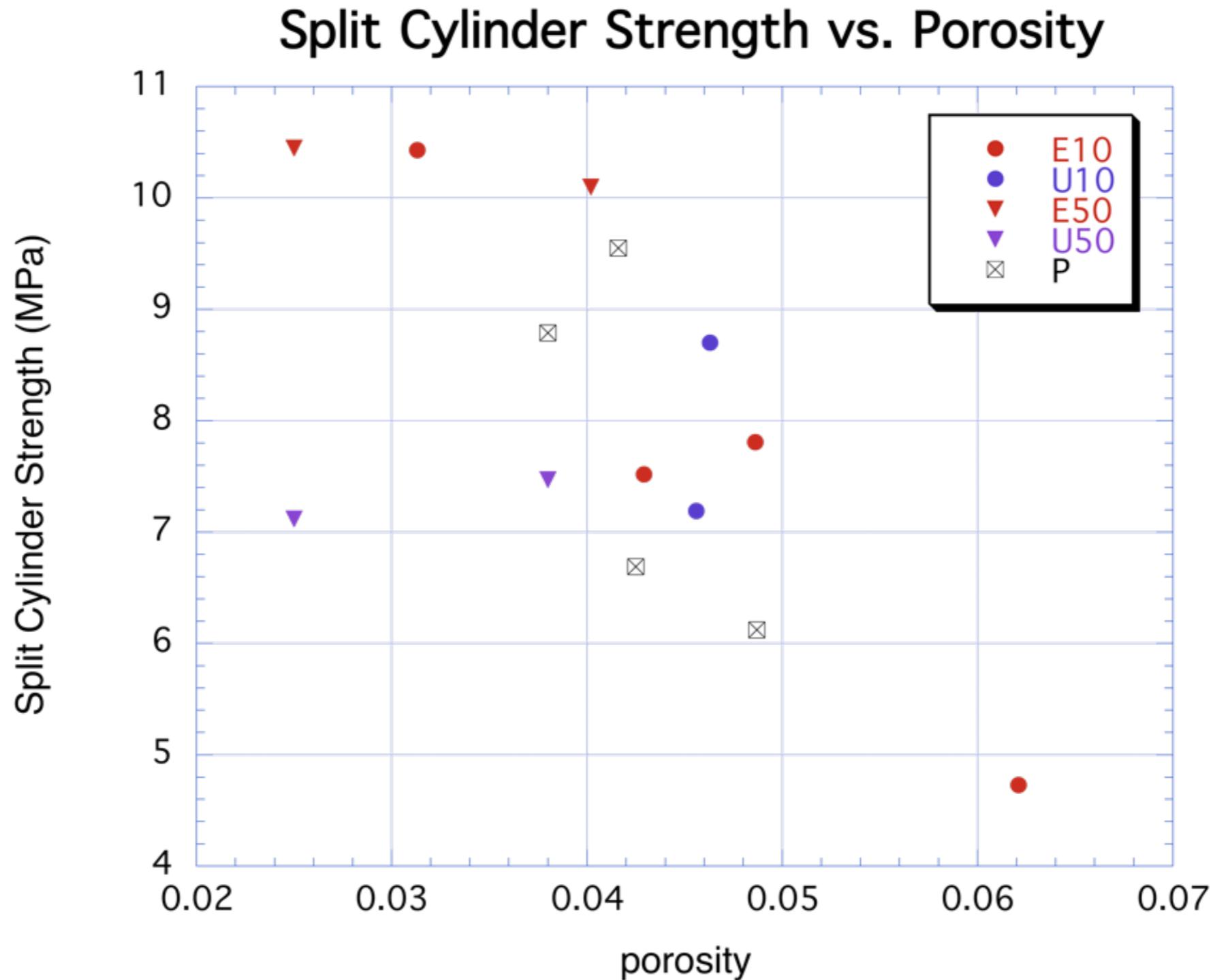
# Microstructure-Property Relationships

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## Porosity and pore-size distribution



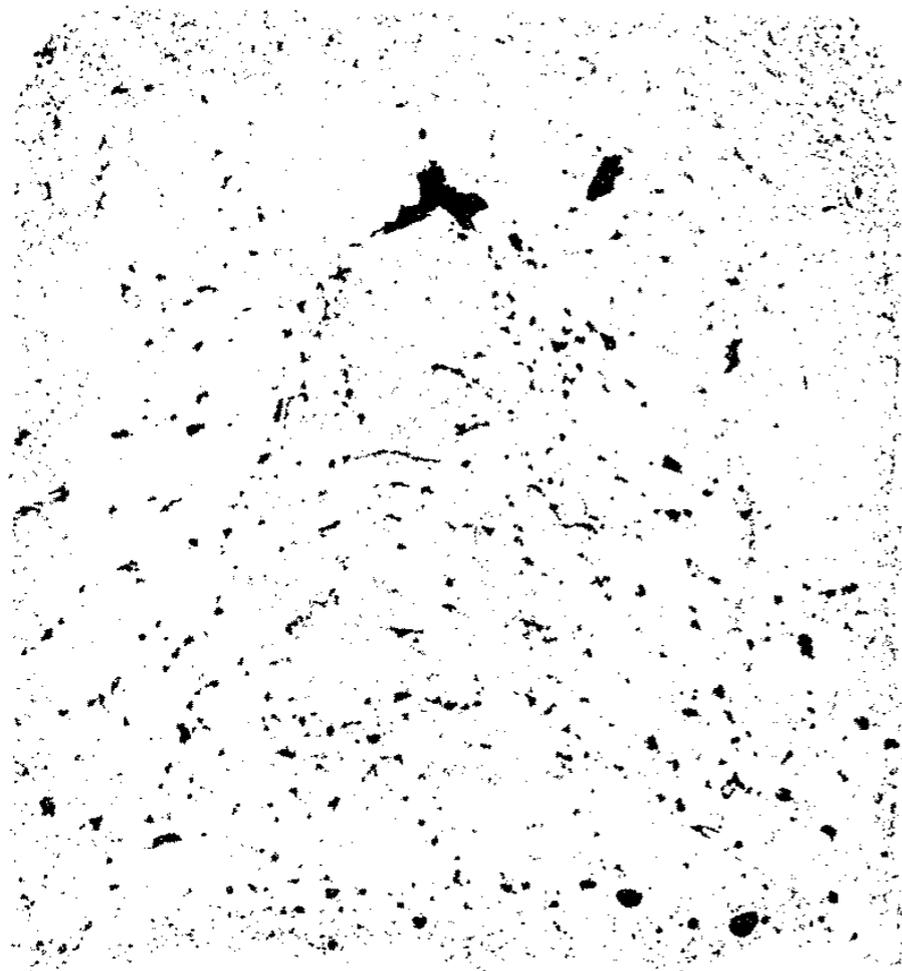
# Microstructure-Property Relationships



# Microstructure-Property Relationships

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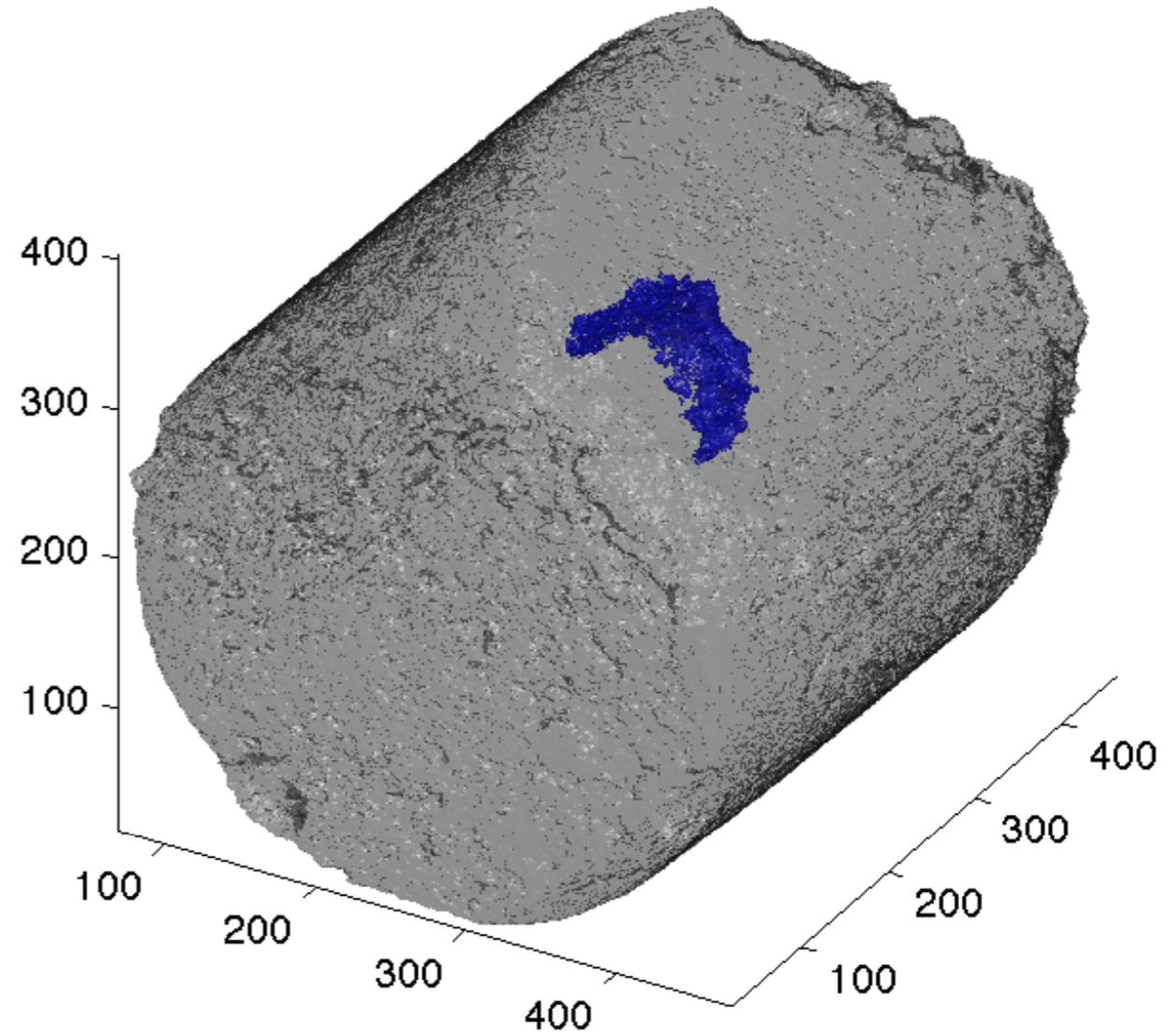
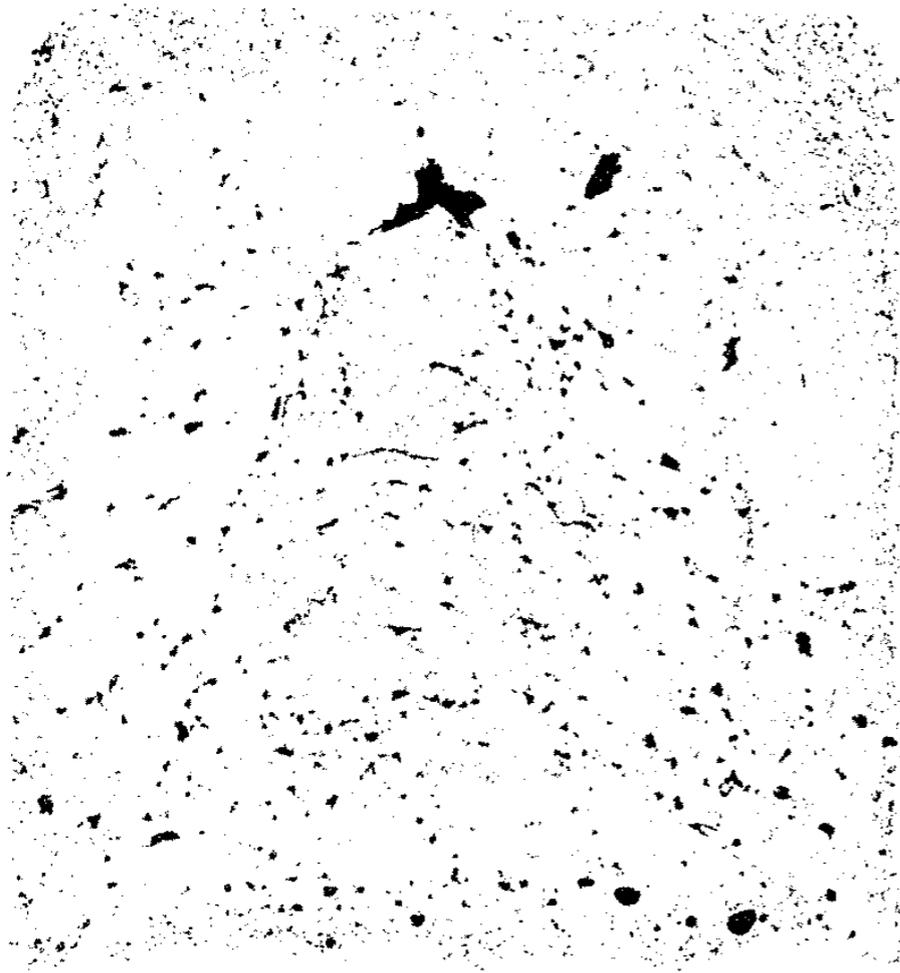
Largest void object...



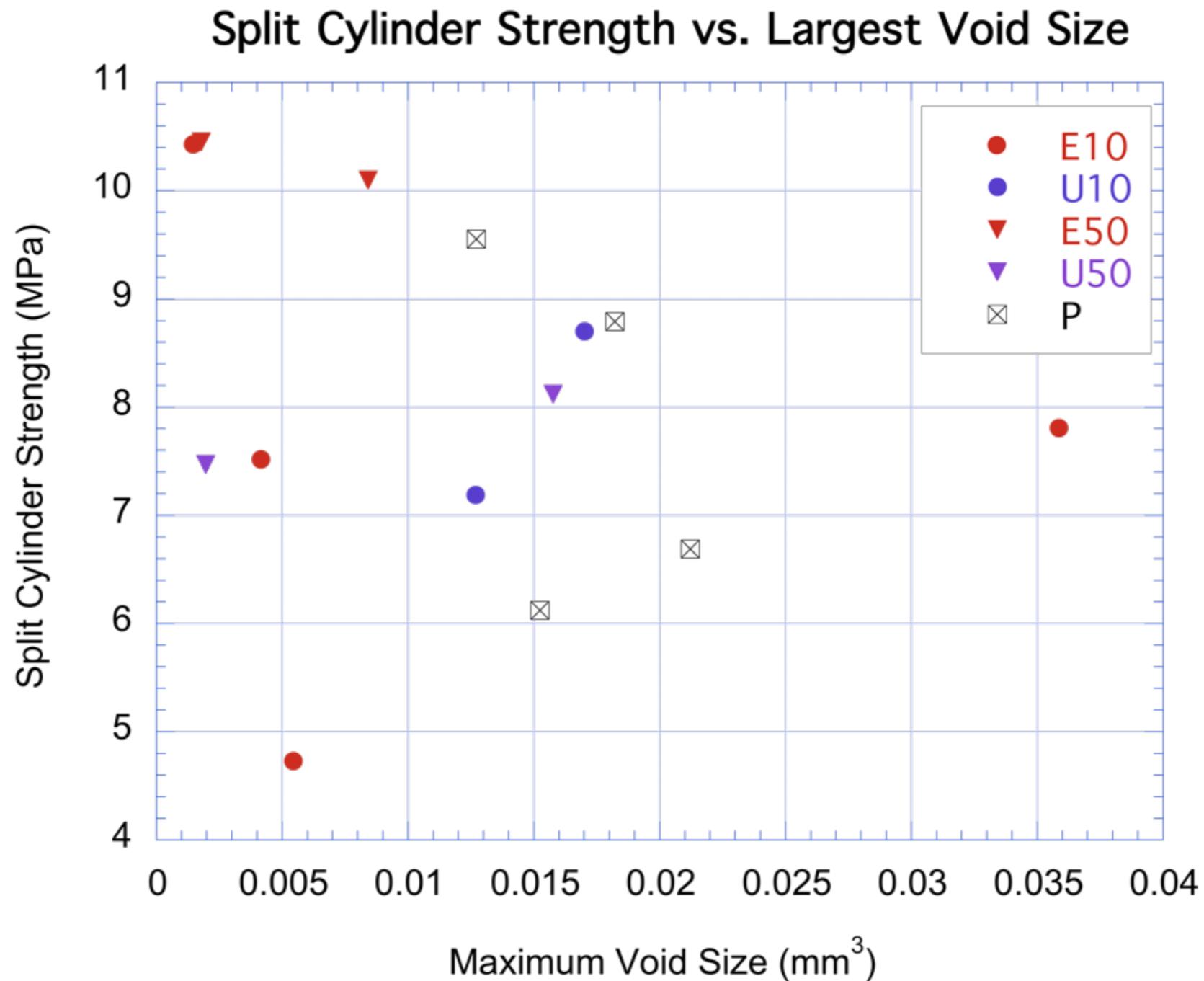
# Microstructure-Property Relationships

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Largest void object...



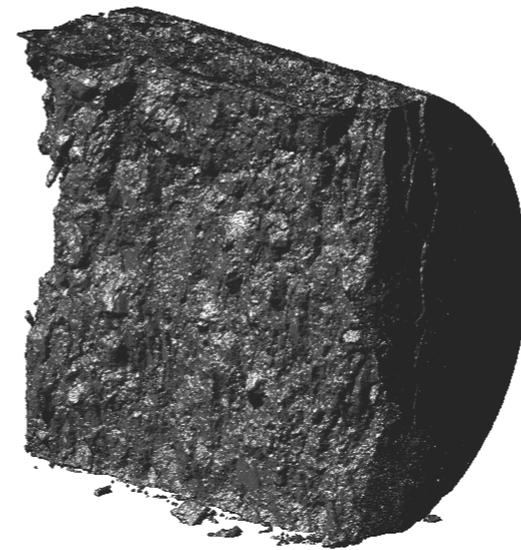
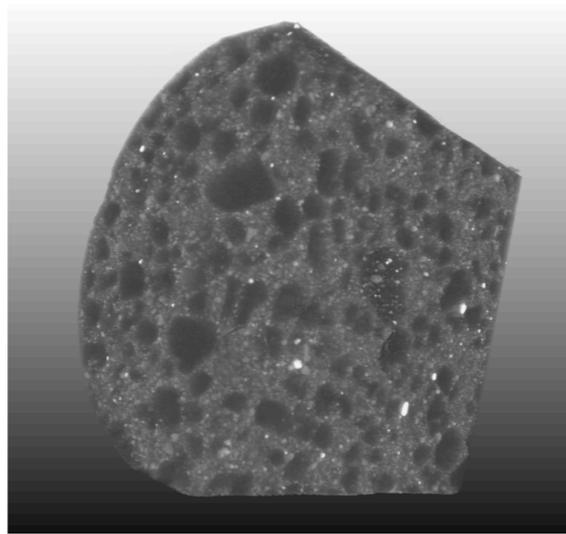
# Microstructure-Property Relationships



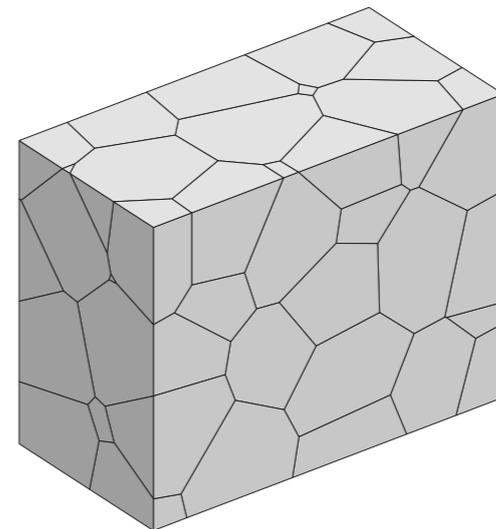
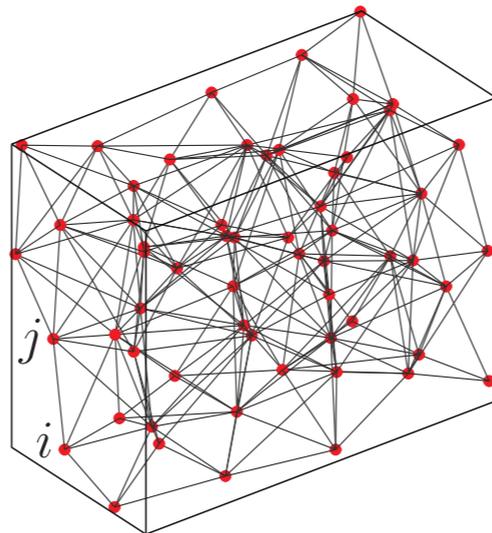
# Model Integration

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- High resolution 3D imaging

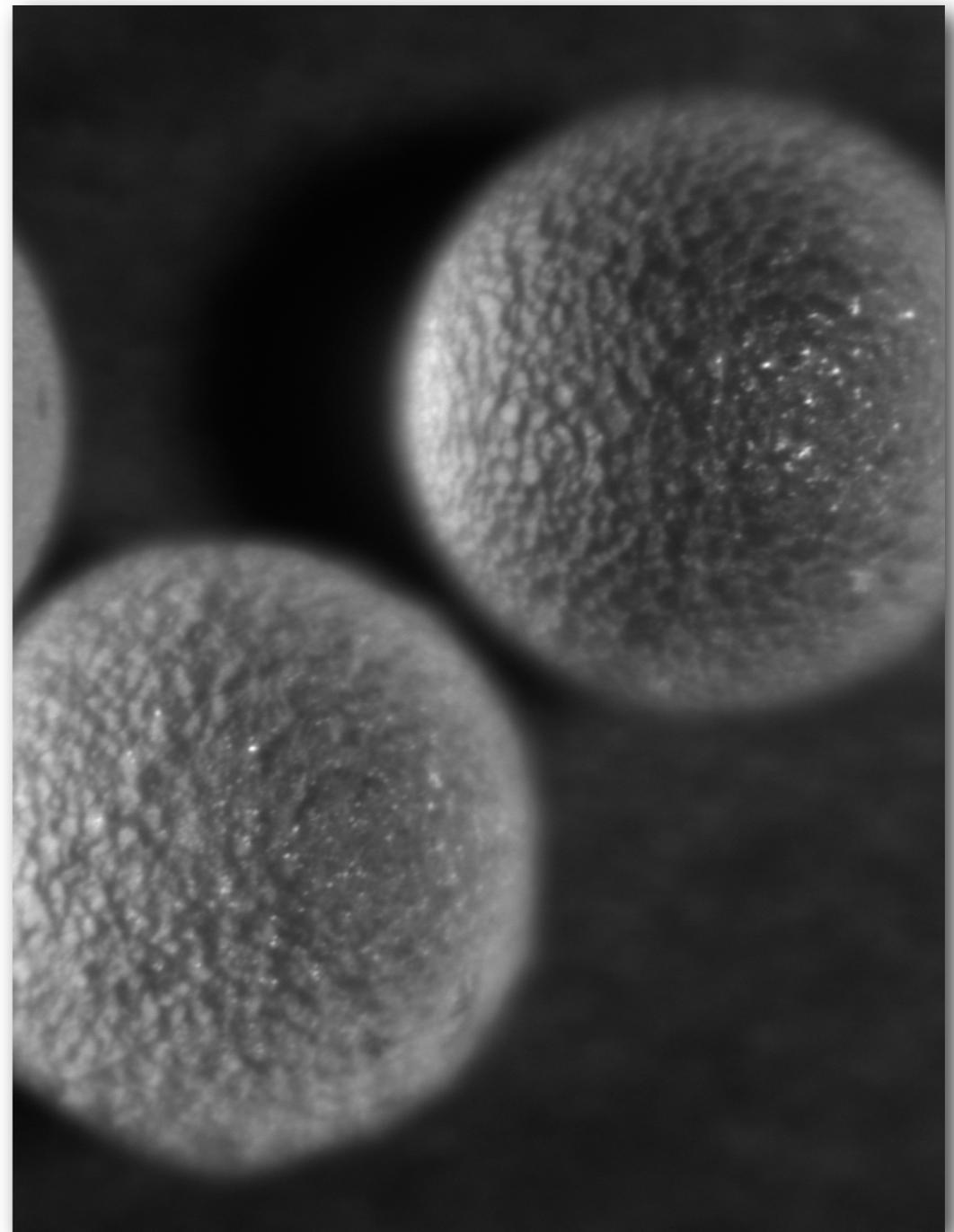
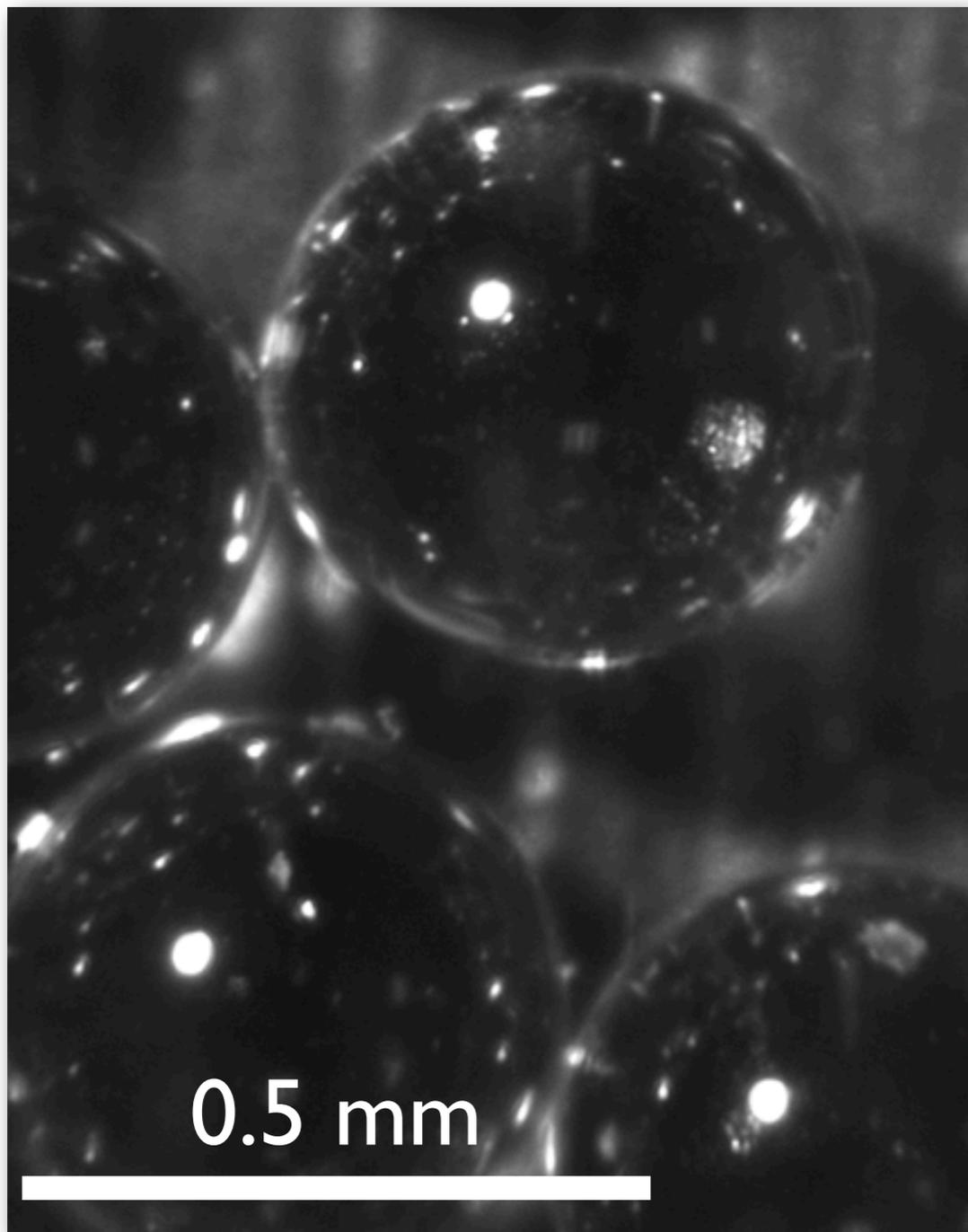


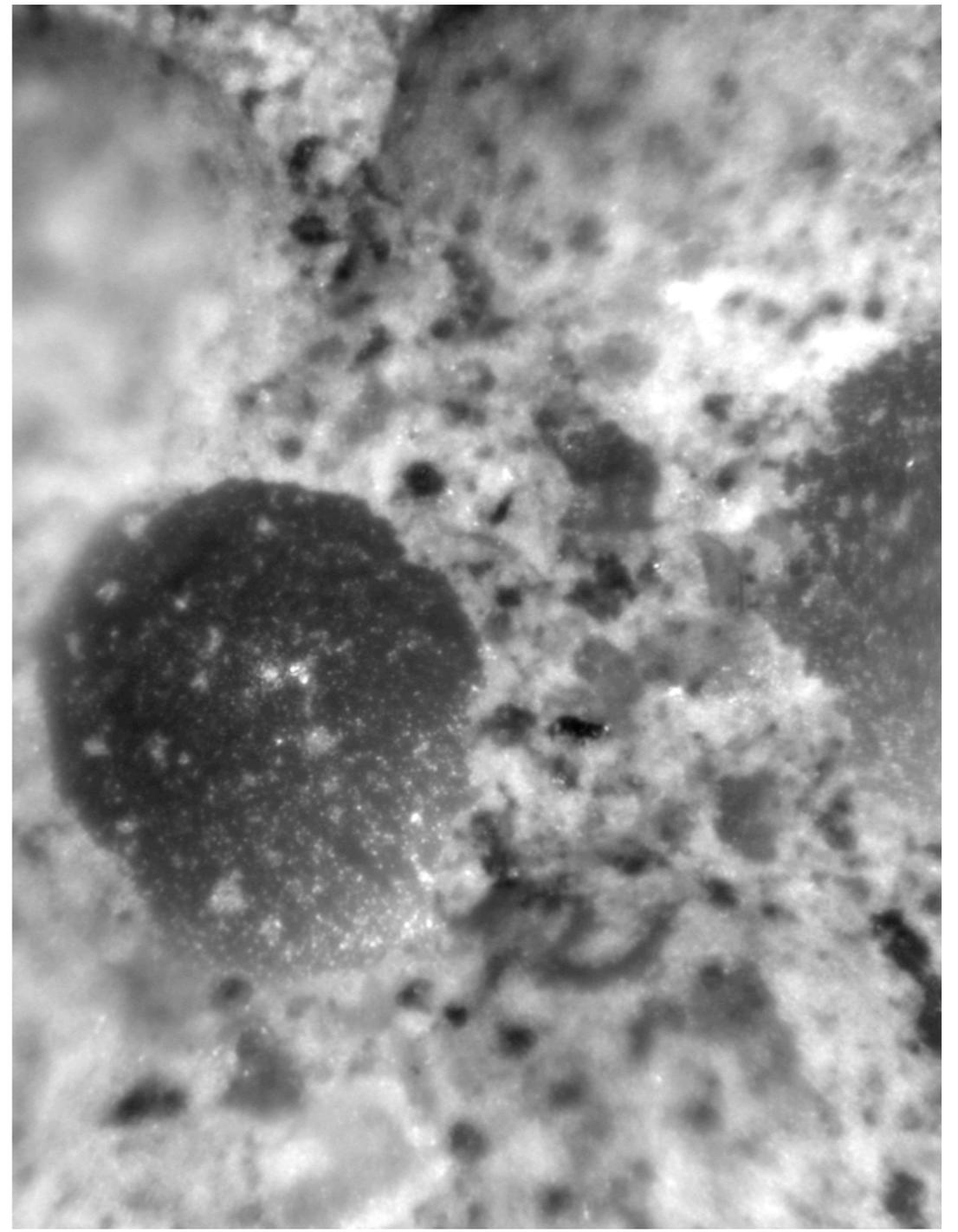
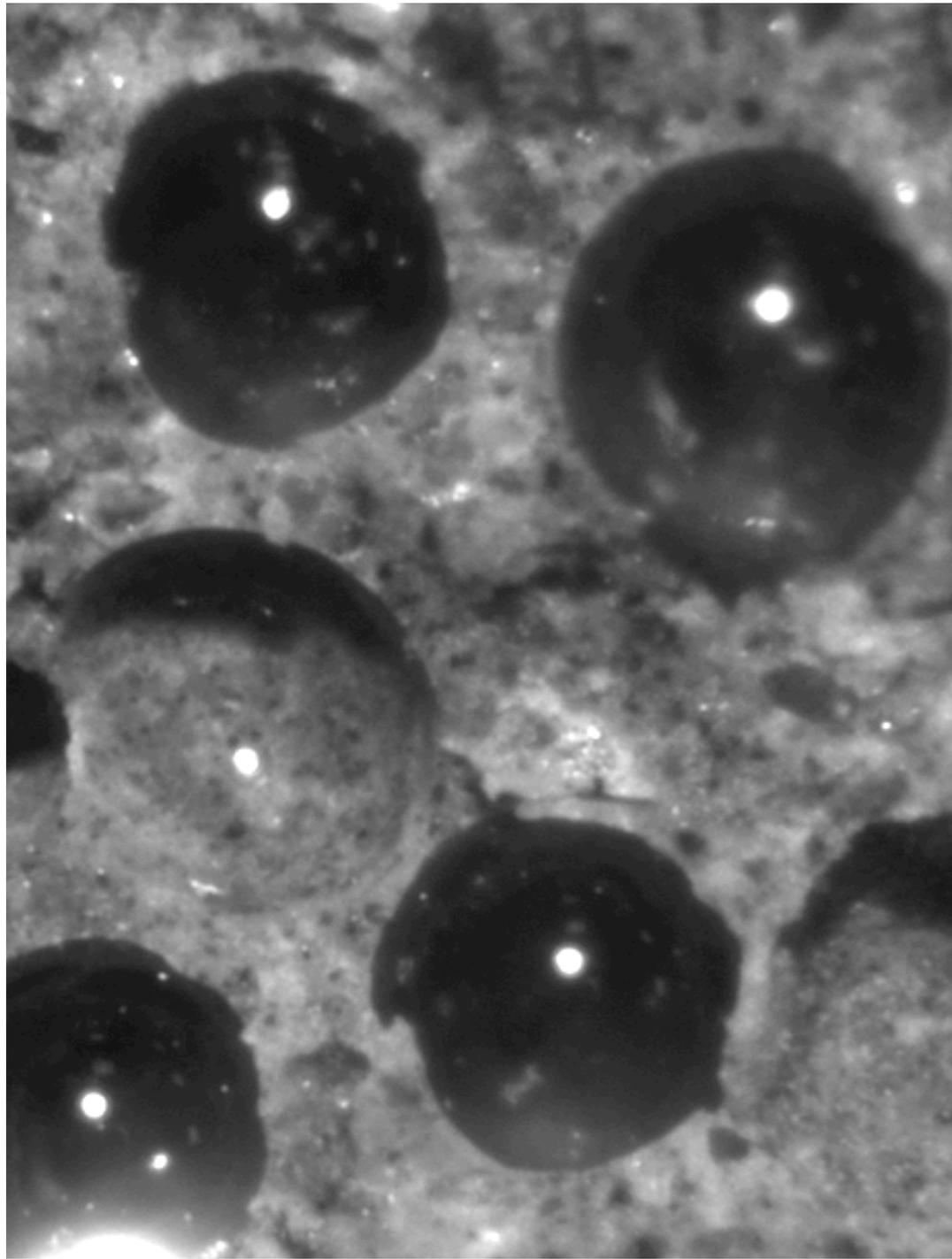
- Discrete element modeling



# “Model” Aggregates

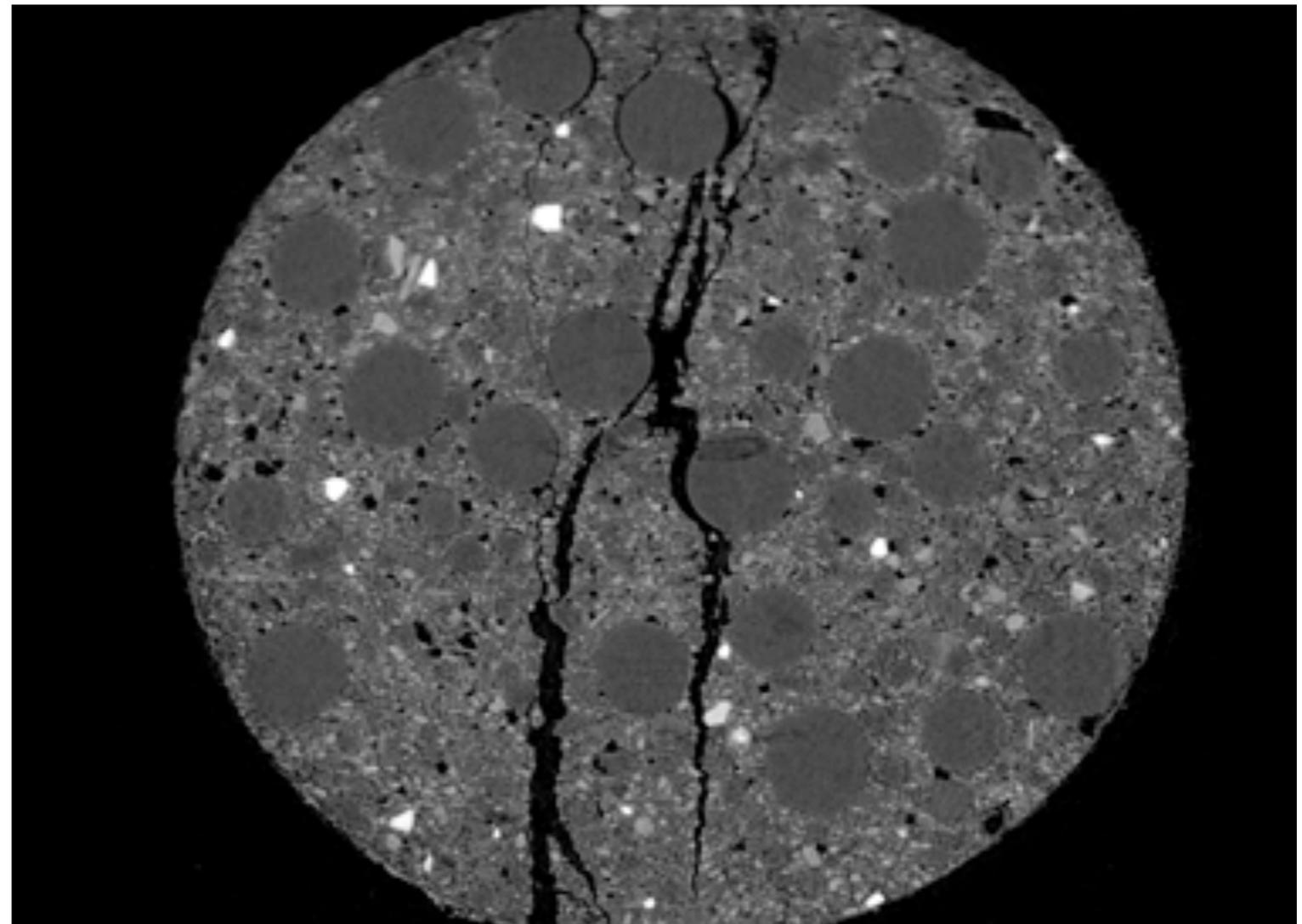
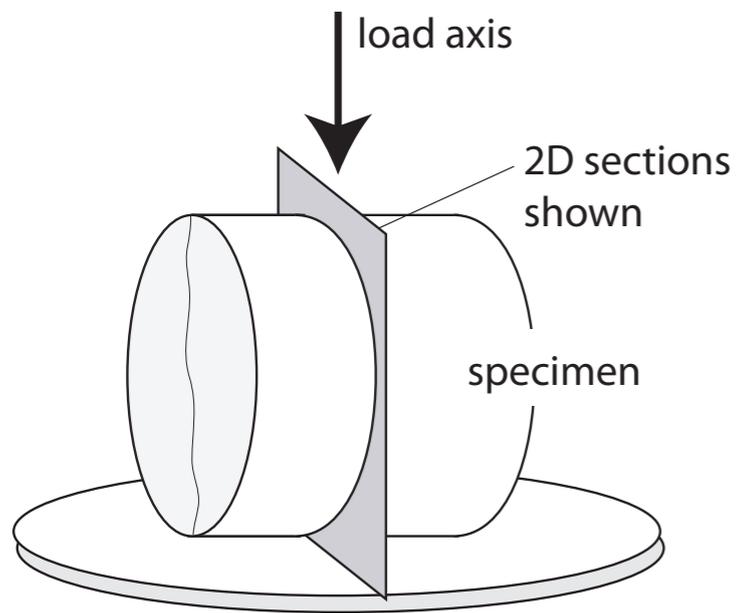
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# Example Slice Image

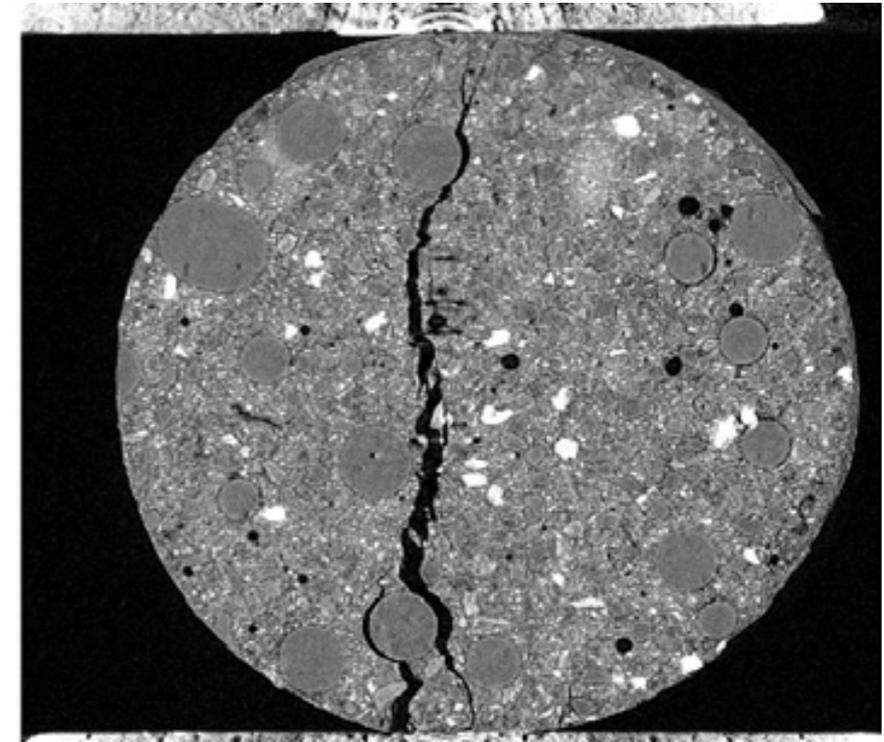
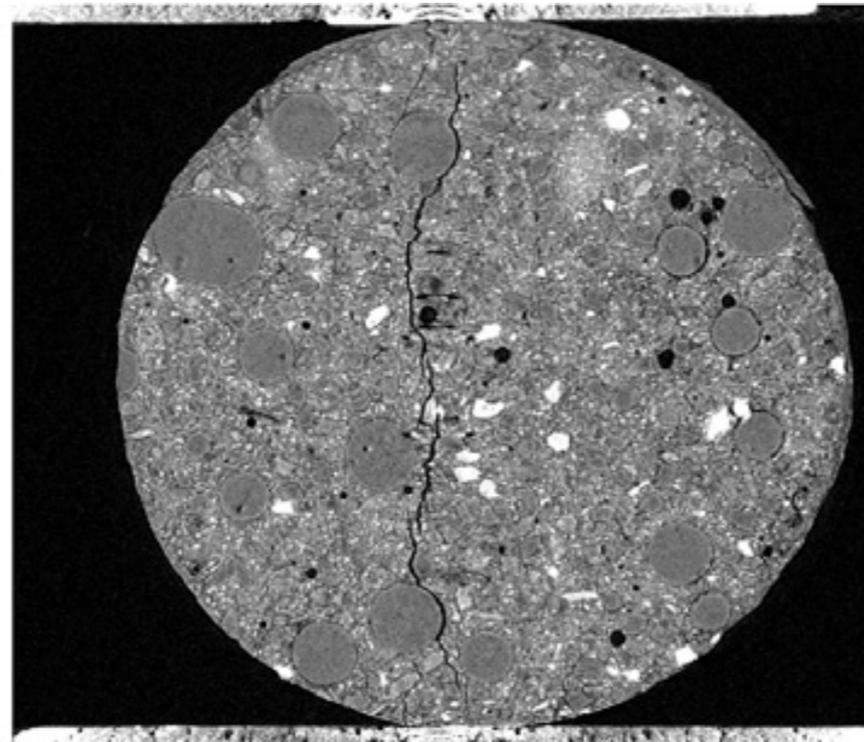
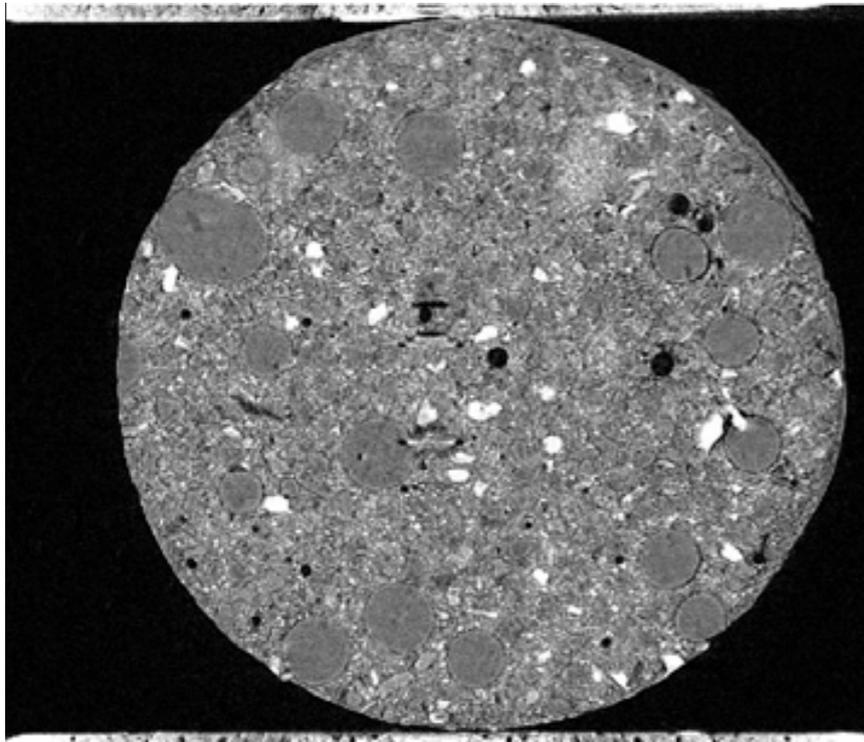
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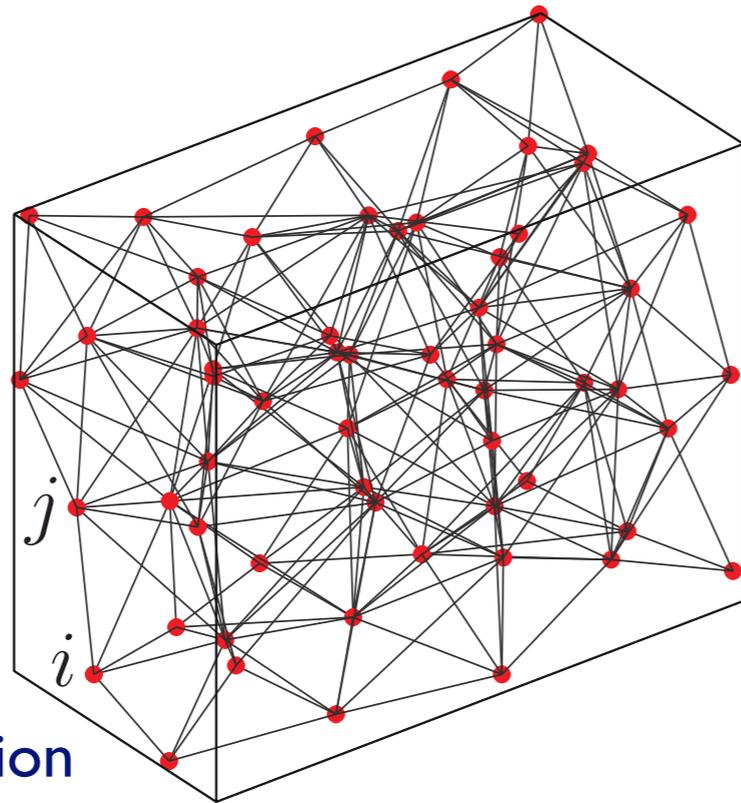
weak interface

# Fracture Sequence

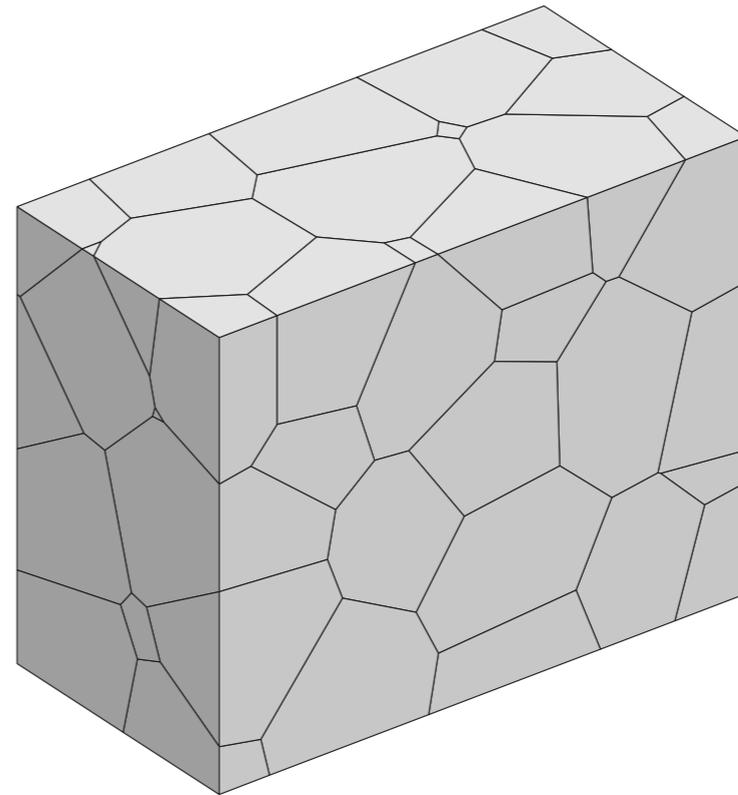
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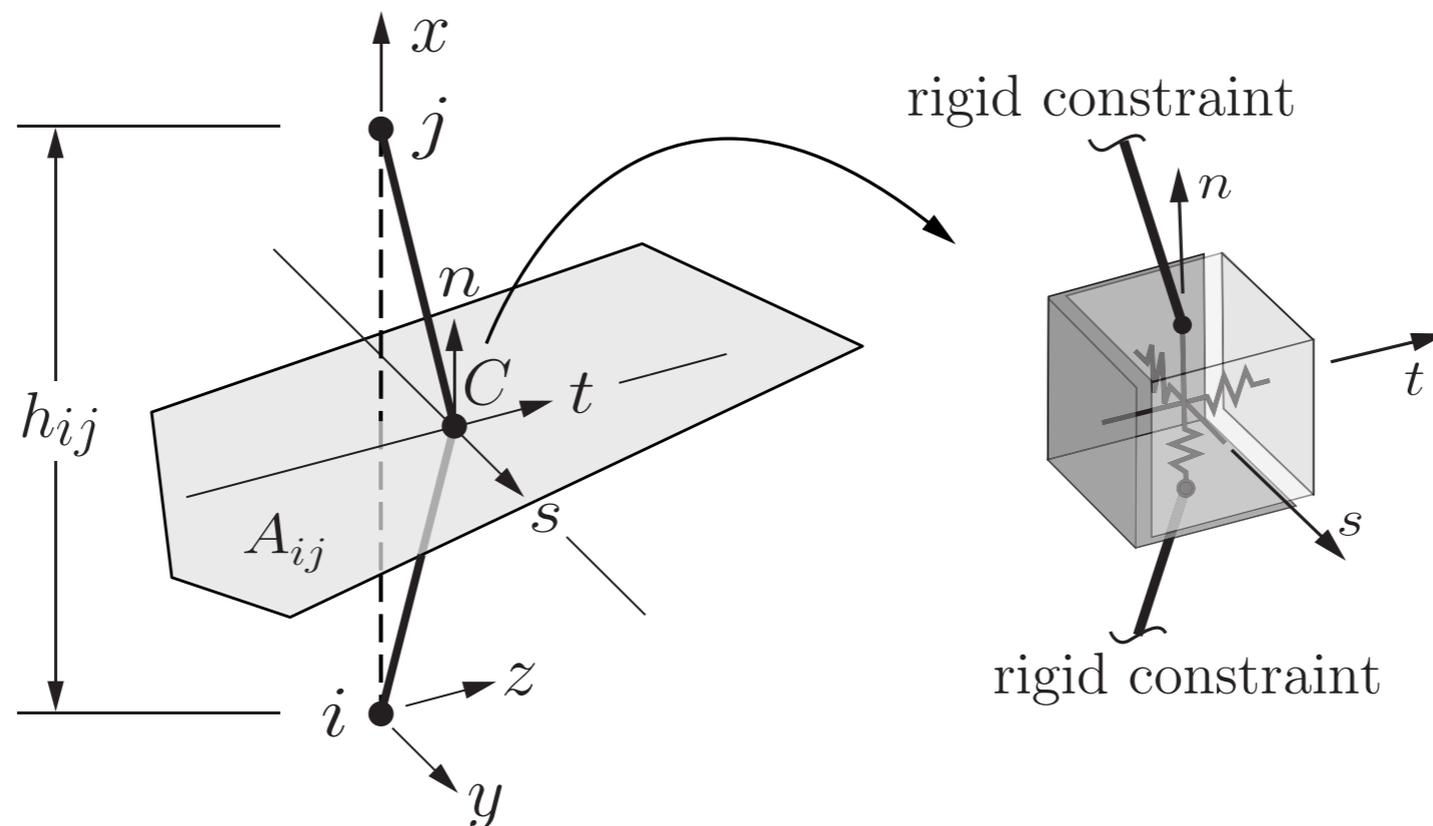
# Modeling with Rigid body-spring lattice network



Delaunay tessellation  
of nodal points

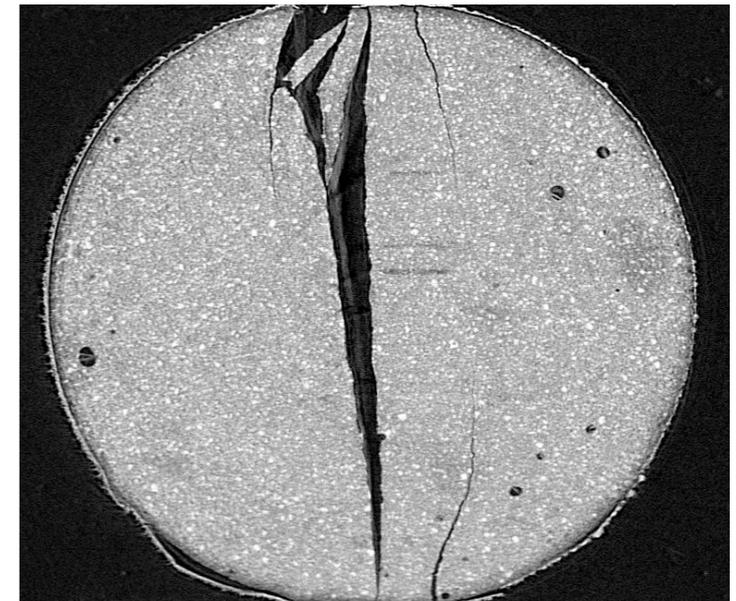
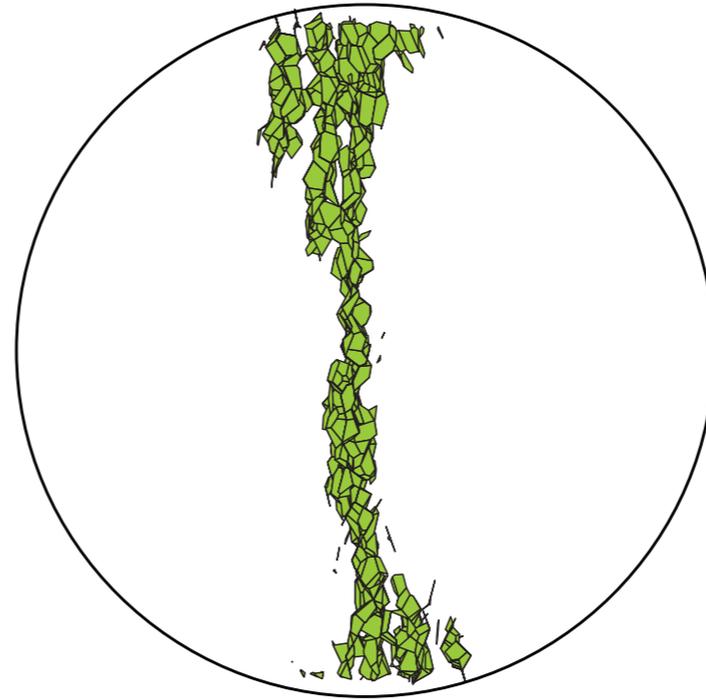
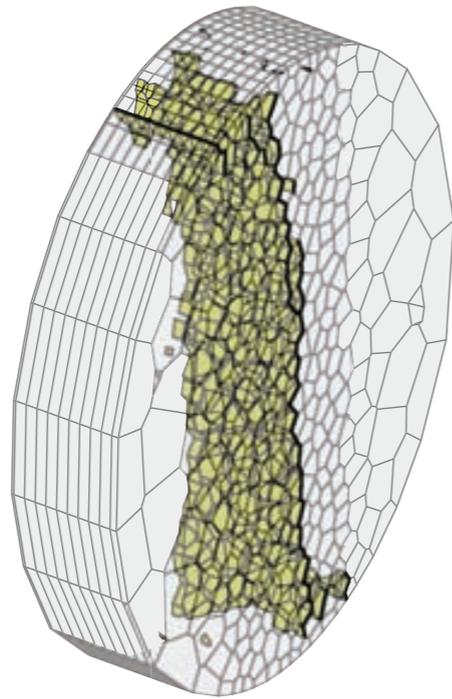
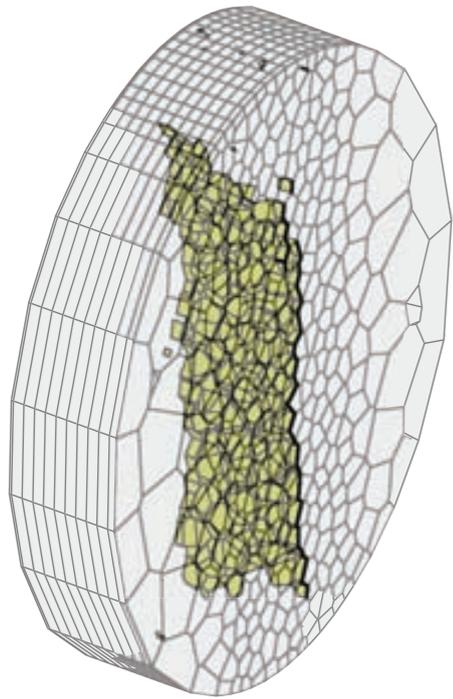


Dual Voronoi  
tessellation



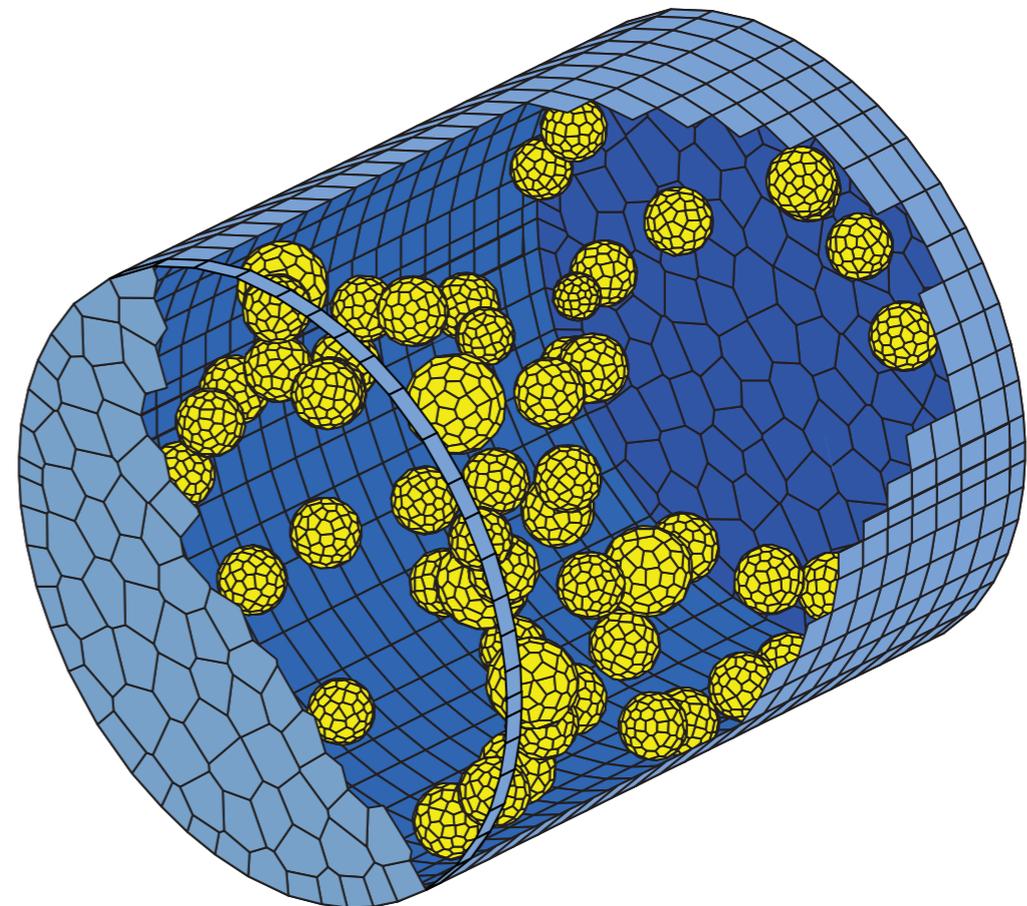
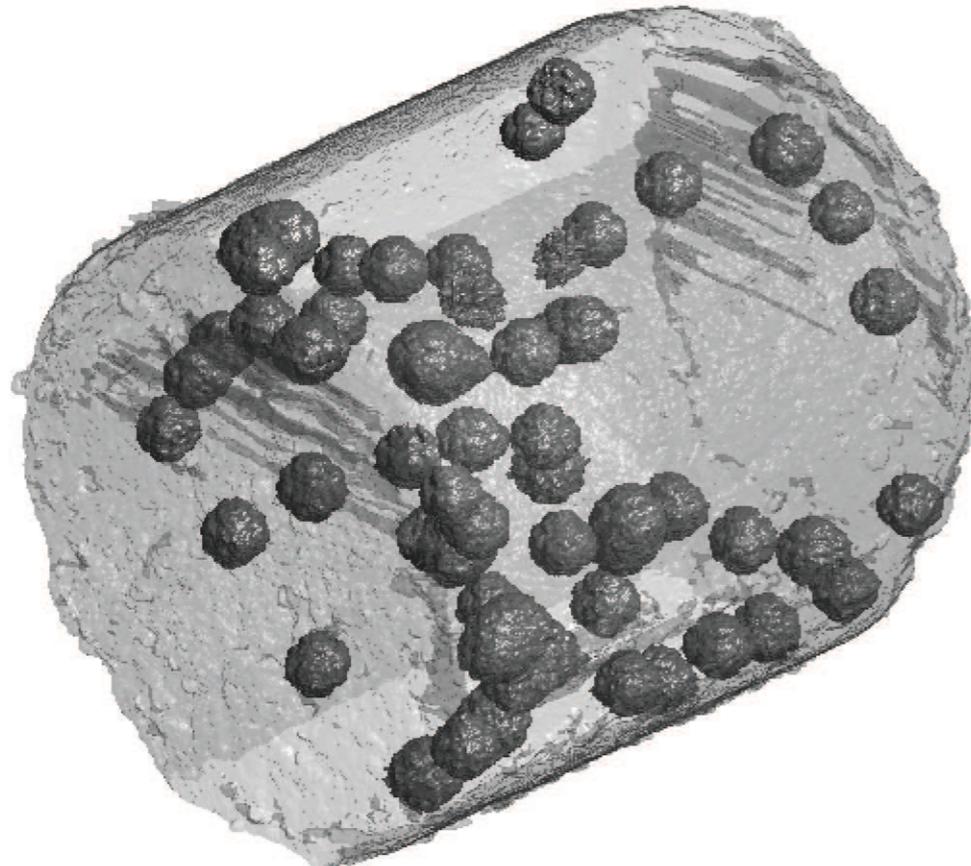
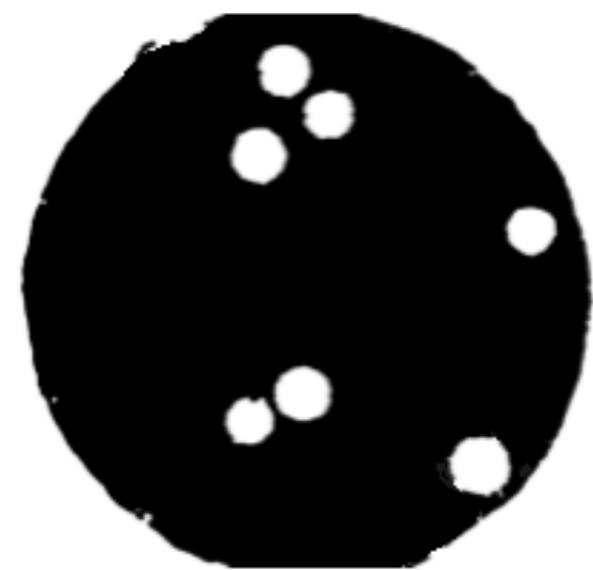
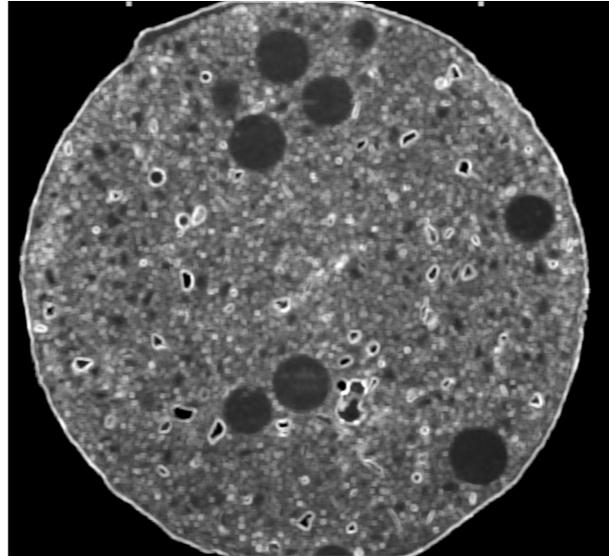
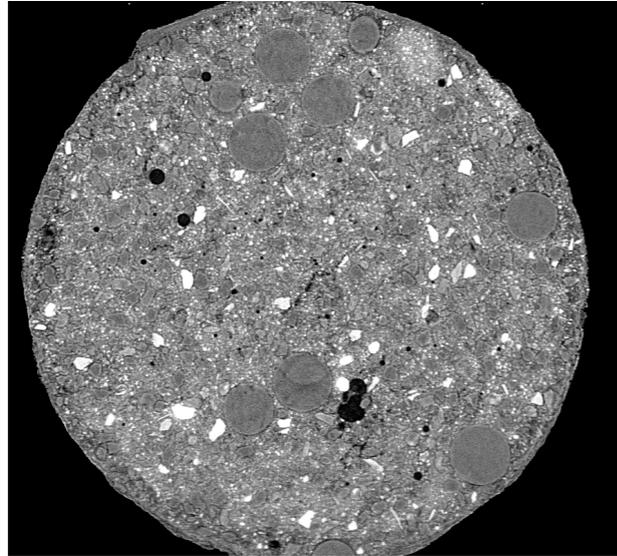
# Modeling Cement Paste

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# Matched Specimens

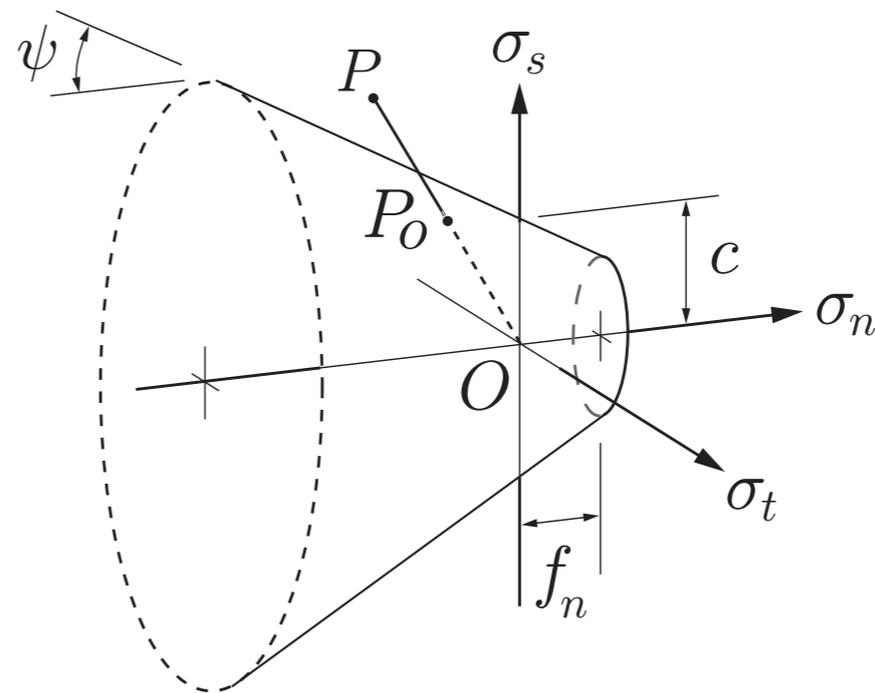
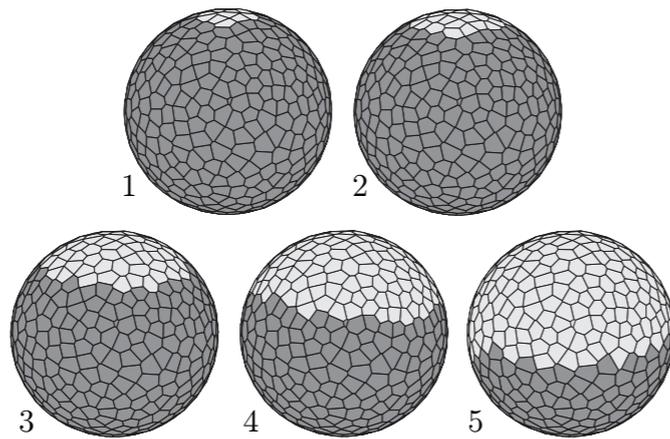
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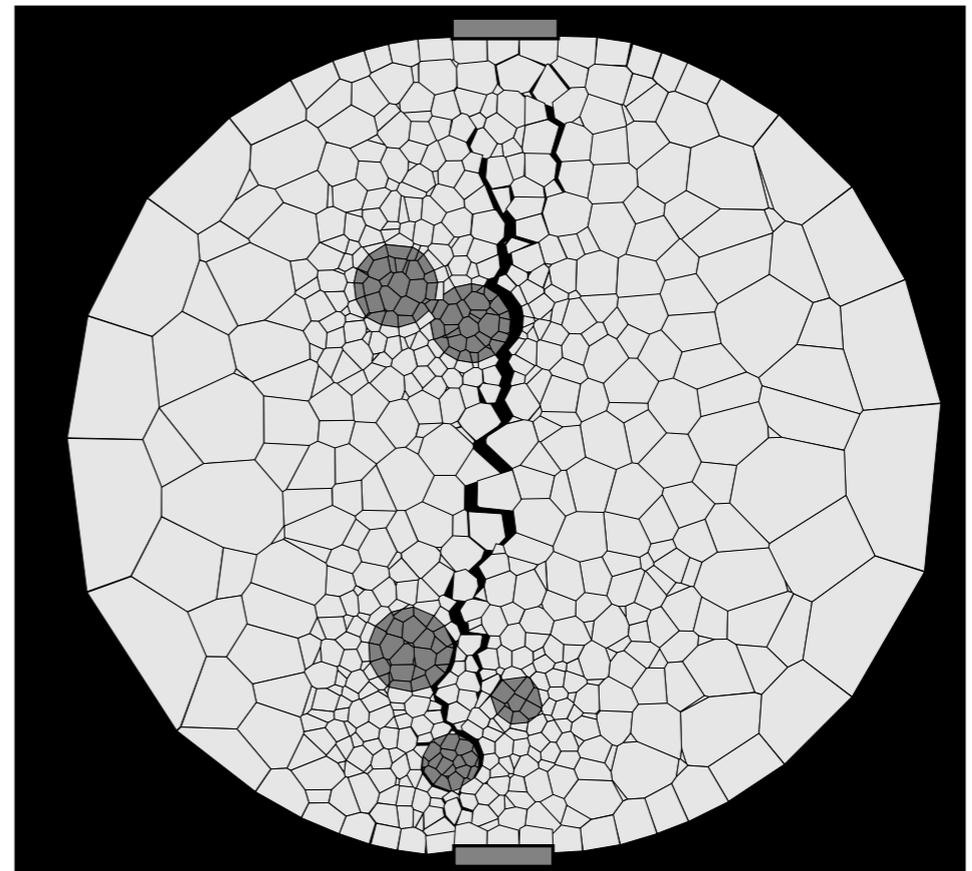
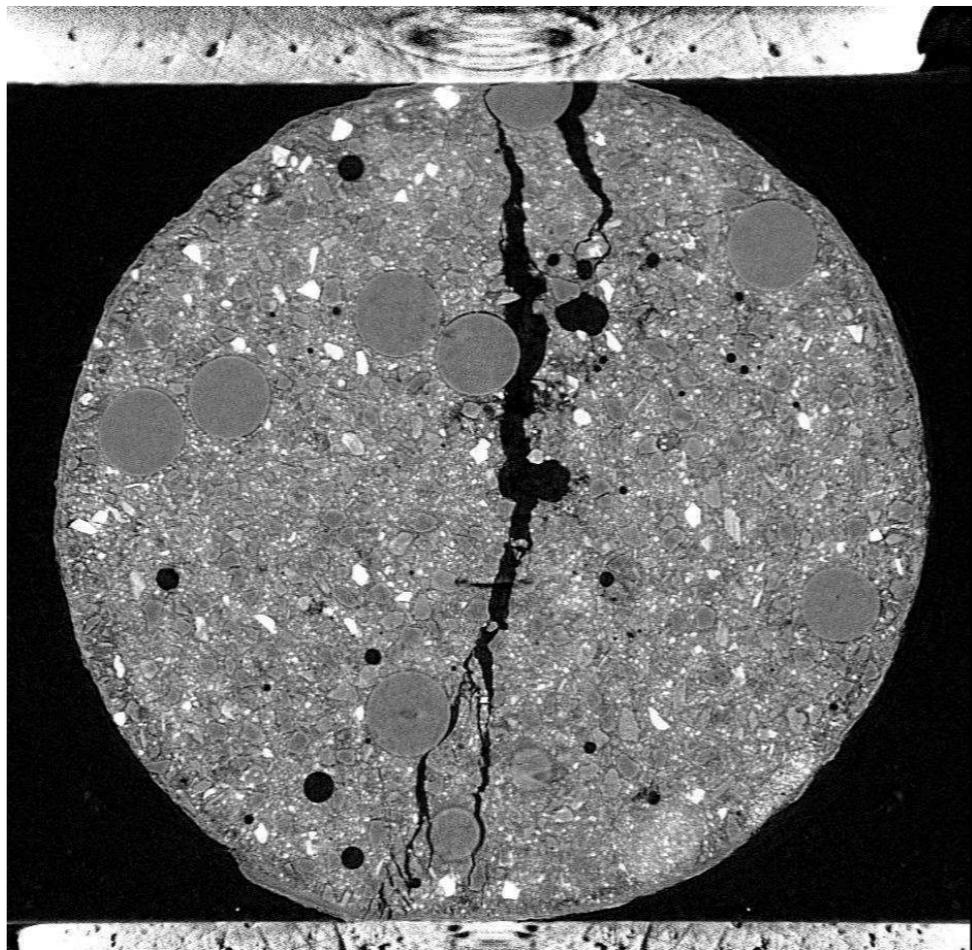
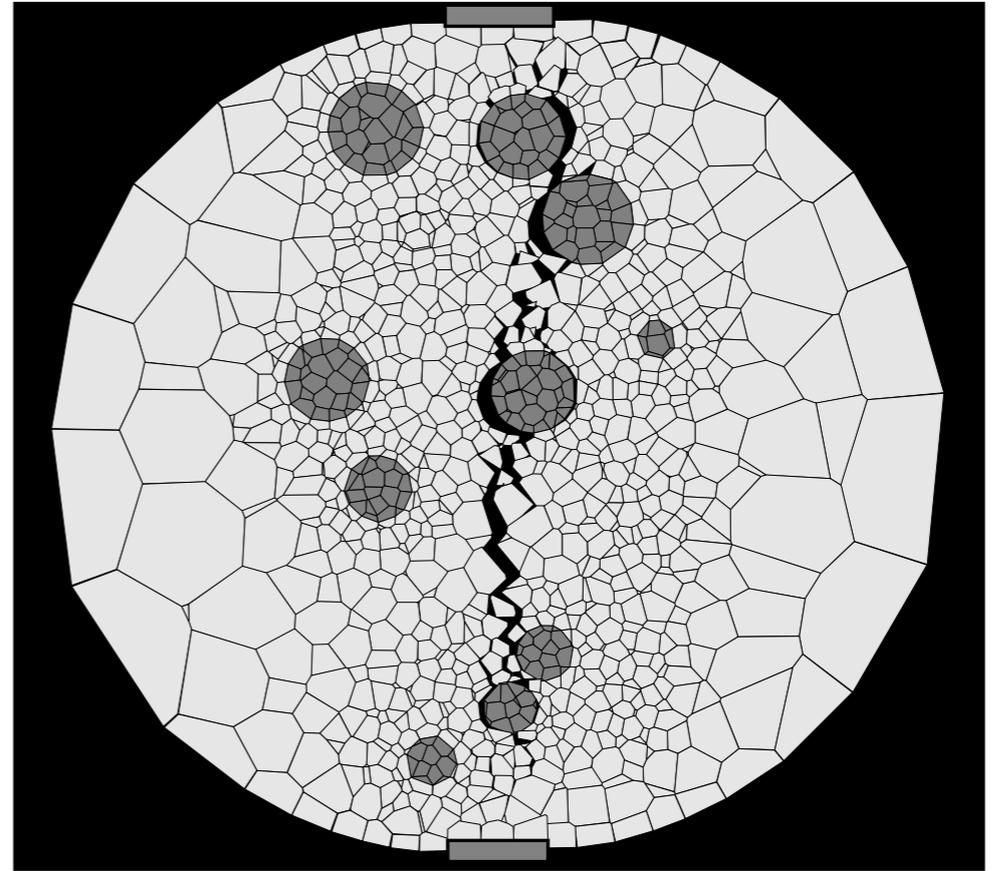
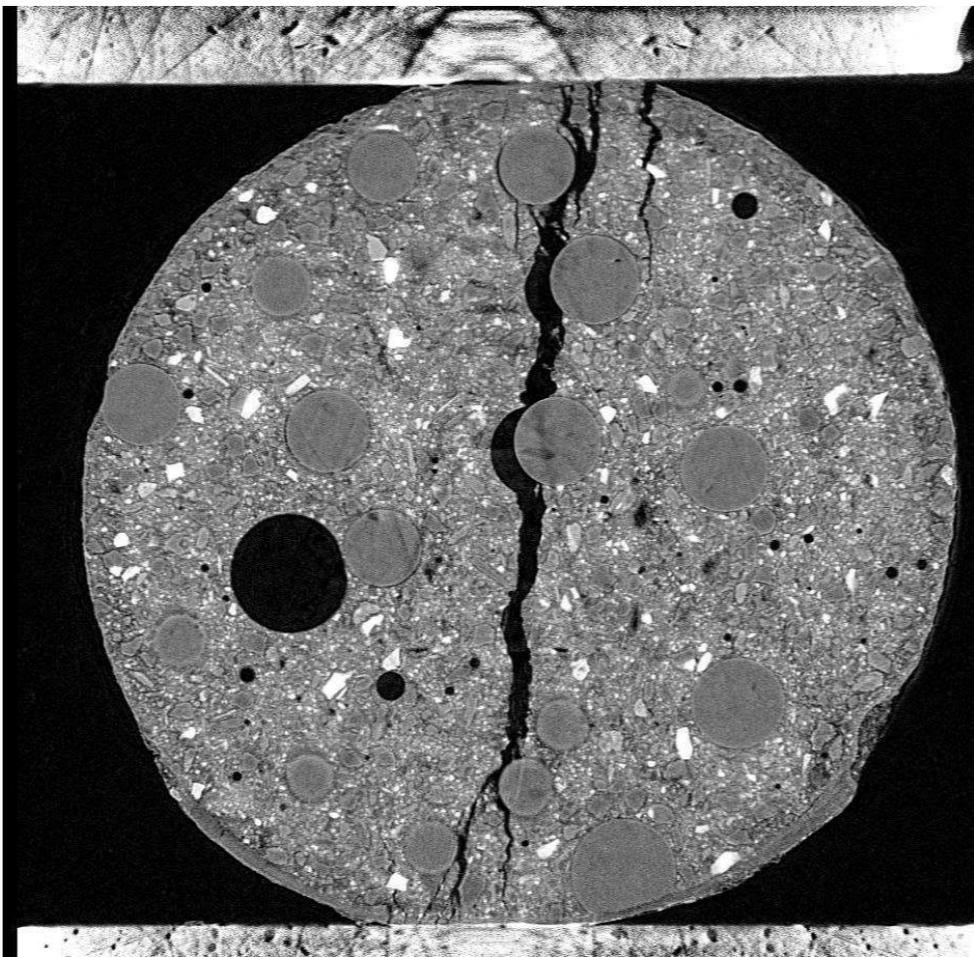


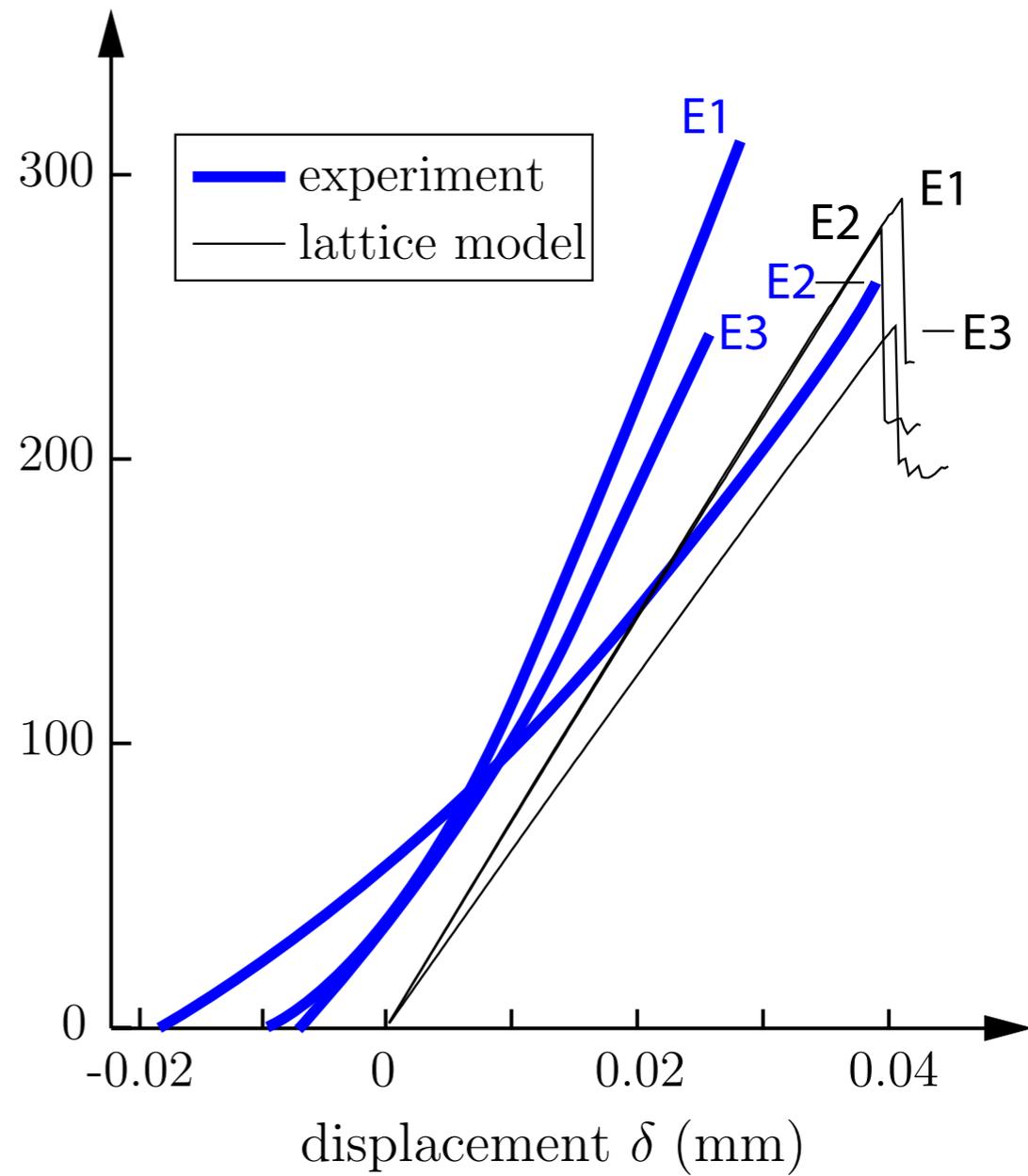
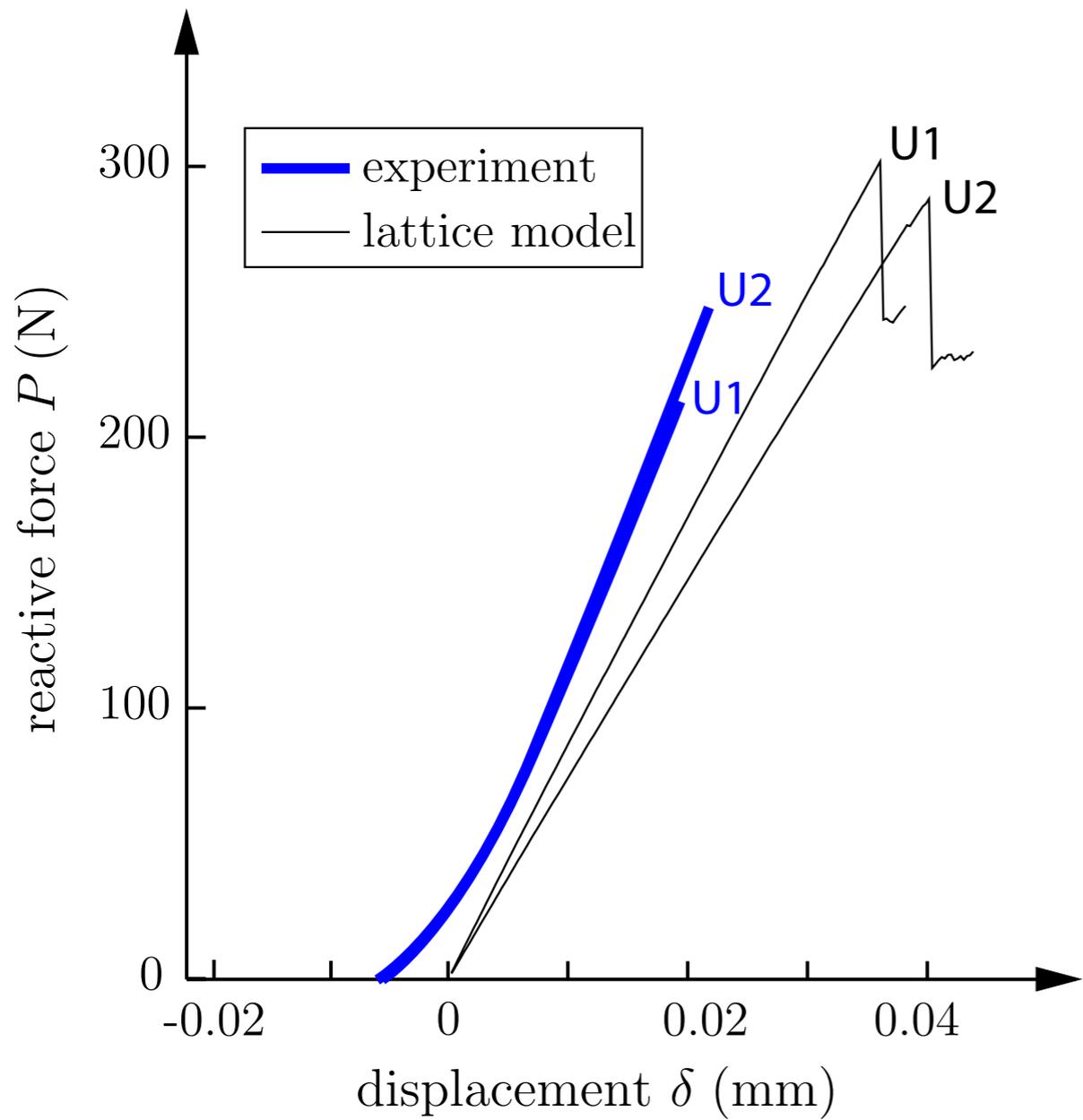
# Model Features

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- Three phase: matrix, inclusions, interface
- Failure criteria:
  - Matrix and inclusions: max principal tensile failure
  - Interface: Mohr-Coulomb with tensile cut-off

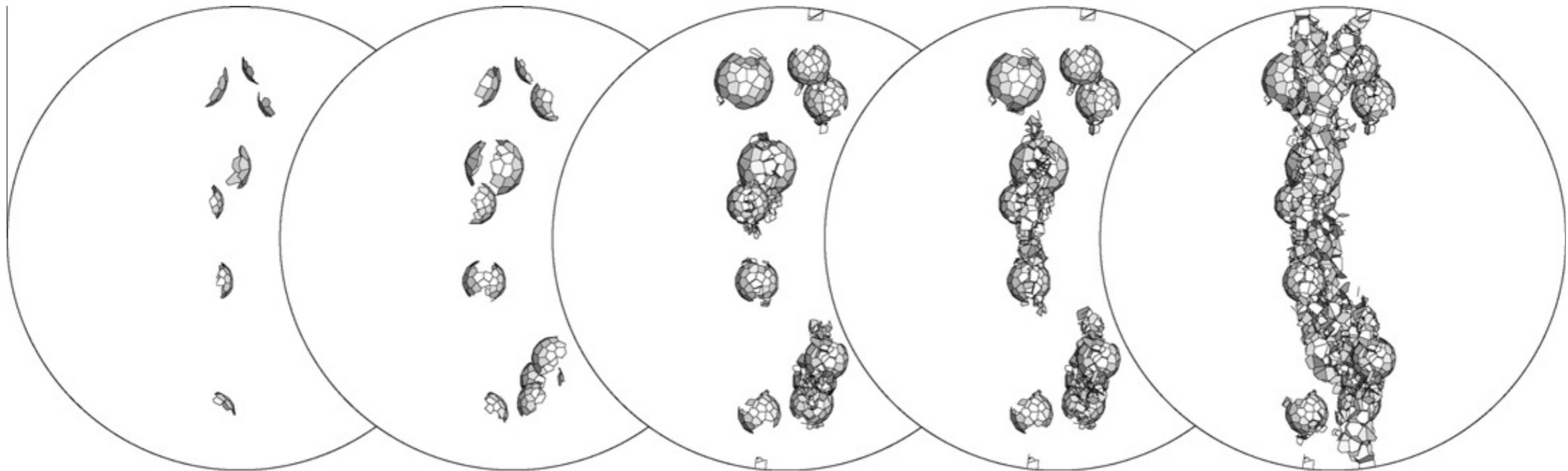






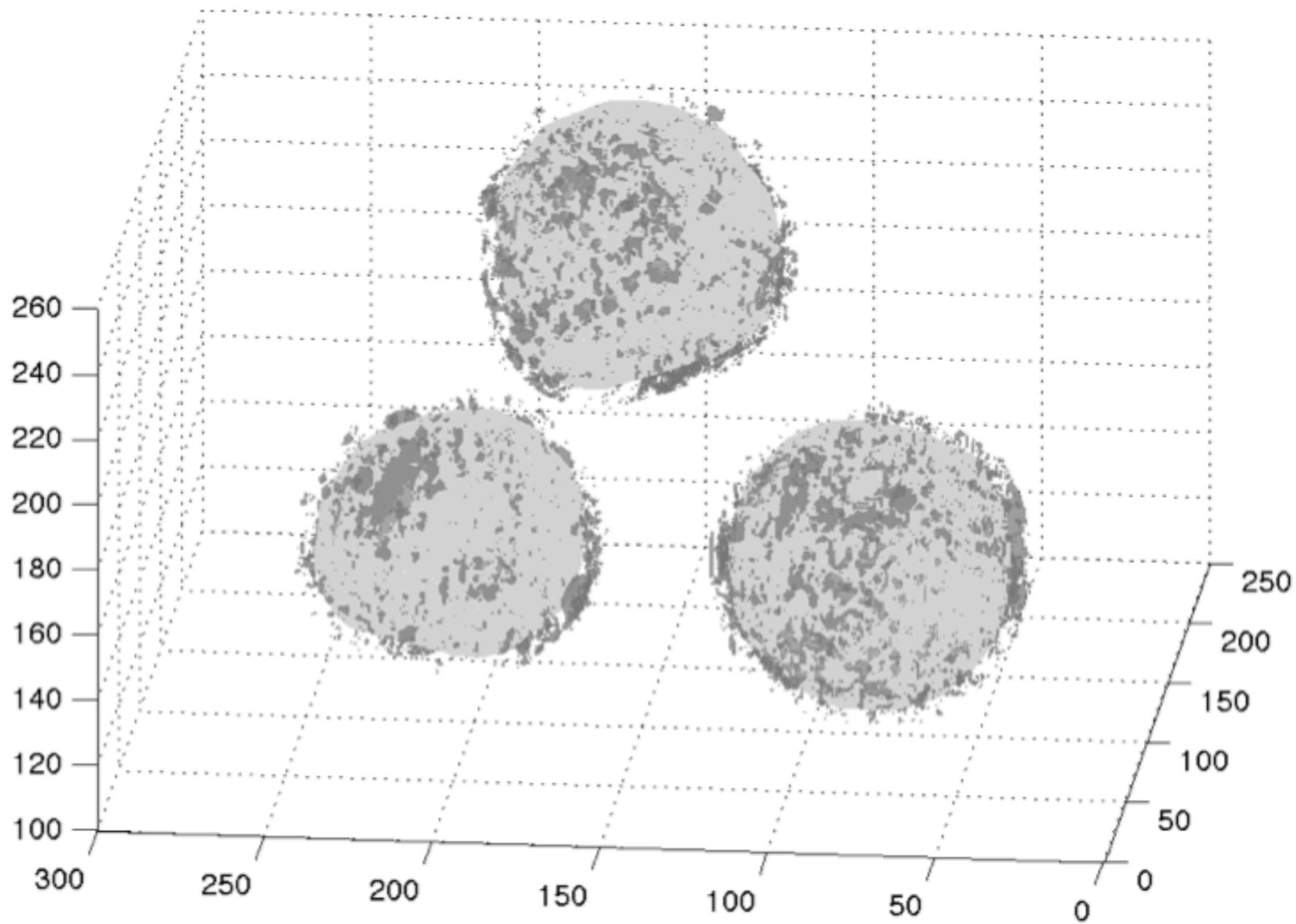
# Crack Progression

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# Current Work: Interfaces

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# Conclusions

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- Work shows a way to integrate models and experiments through 3D imaging of internal structure.
- Tomography allows quantitative analysis of material structure.
- Lattice explicitly captures heterogeneities.
- Through use of matched specimens we can examine microstructural basis for material performance.