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Damage micromechanics in syntactic foams: Role of particle interactions

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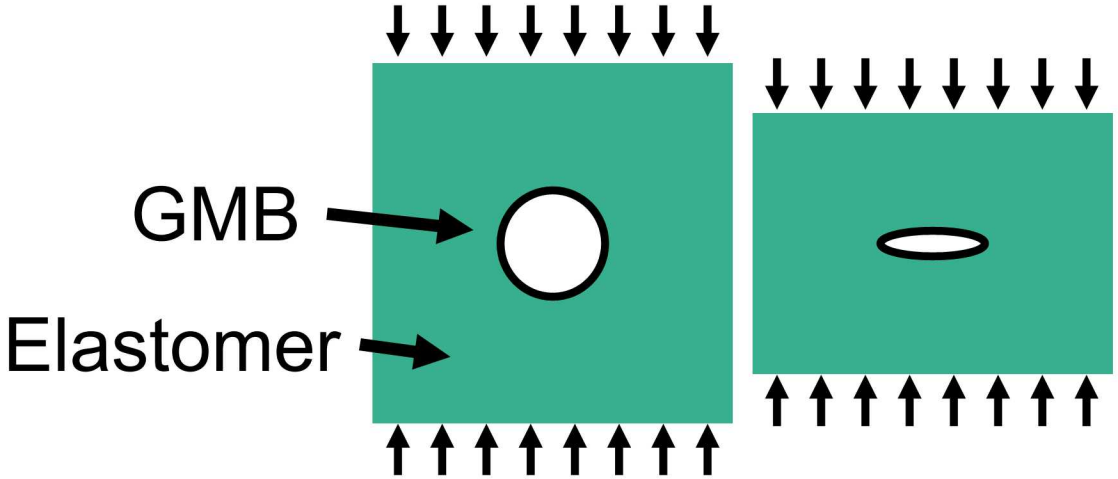
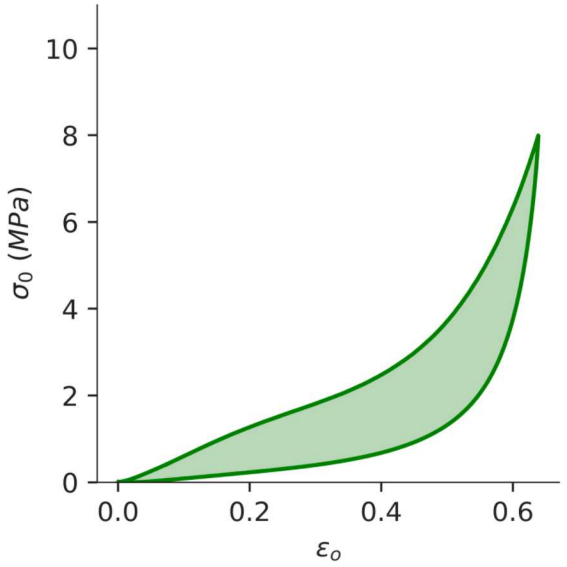
Introduction

Syntactic foams, Damage mechanisms, and GMB interactions

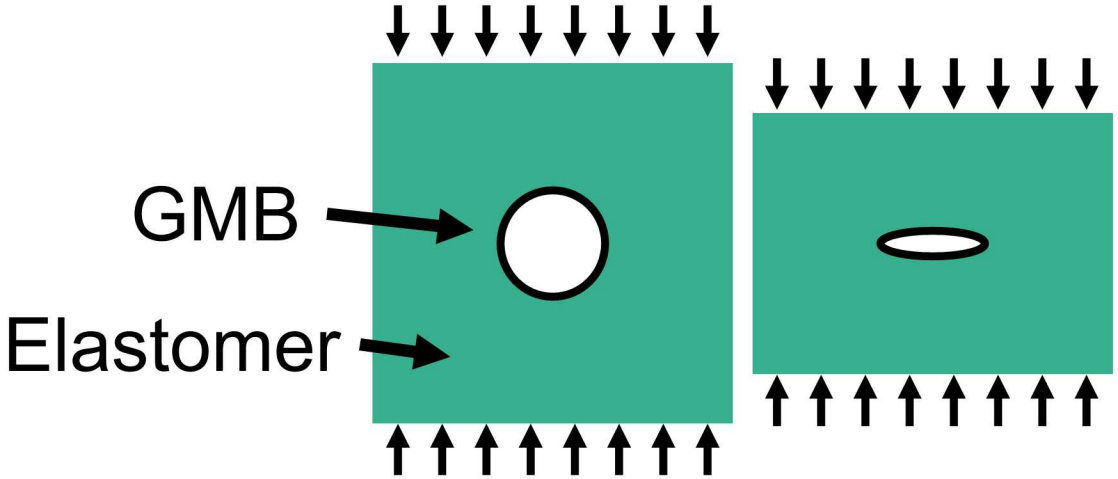
Mechanics of Syntactic Foam

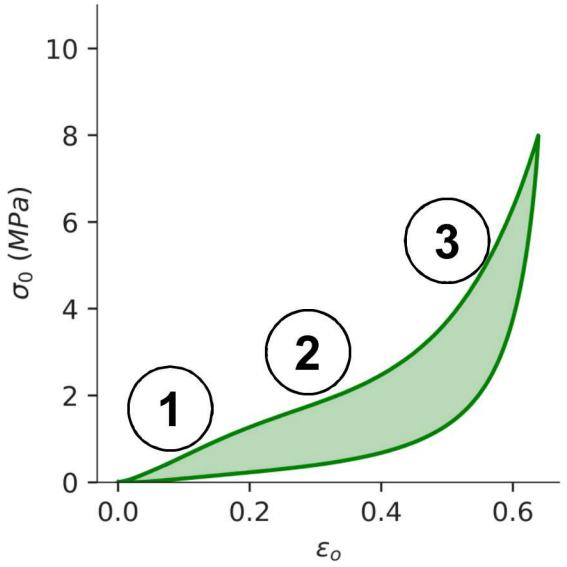


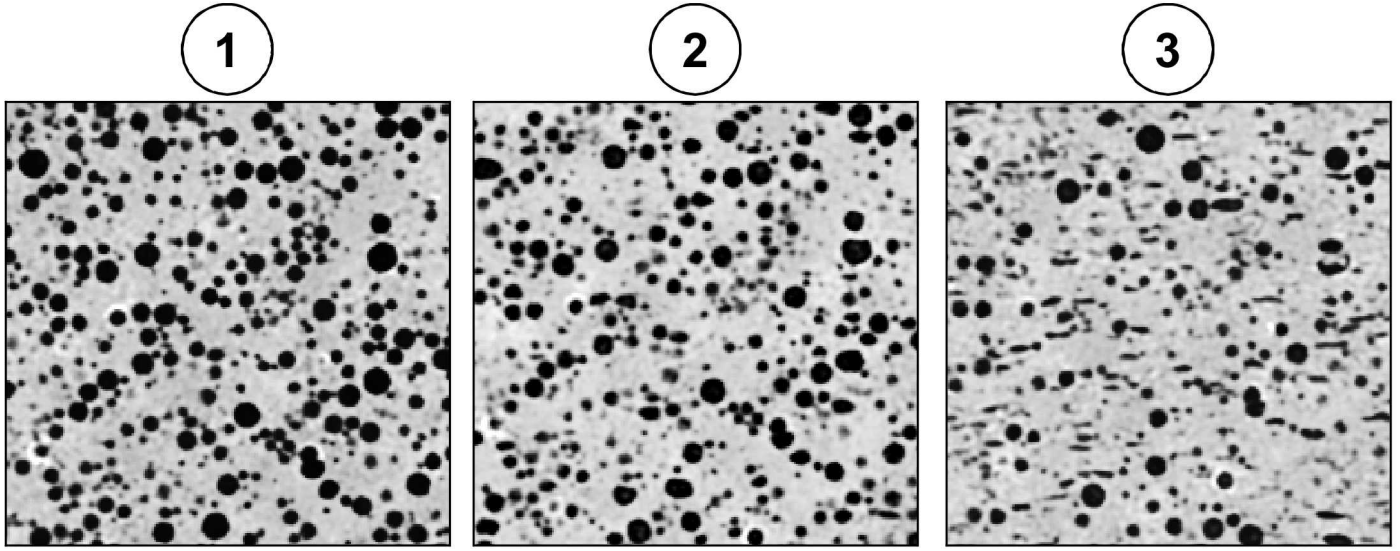


Stress-strain behavior is
defined by damage to GMBs

Mechanics of Syntactic Foam

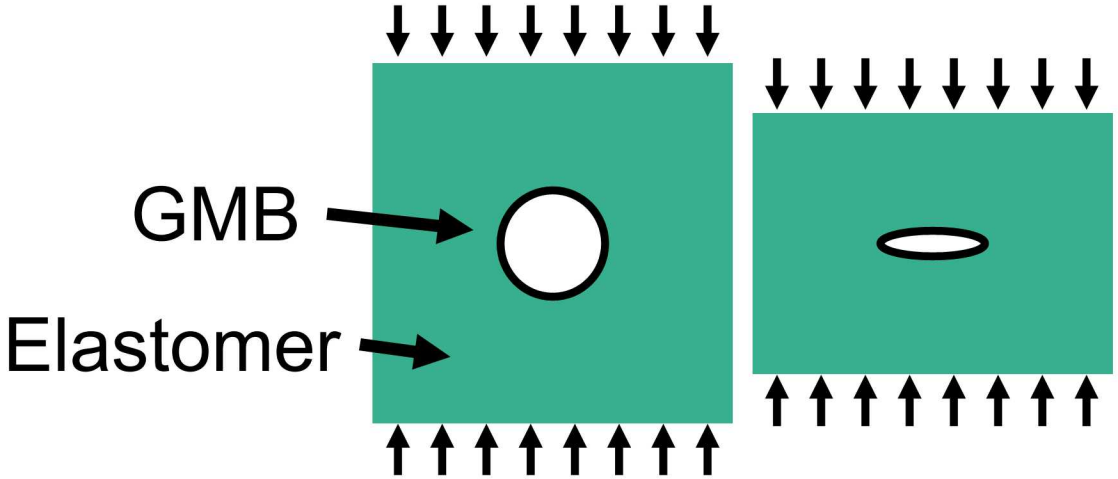


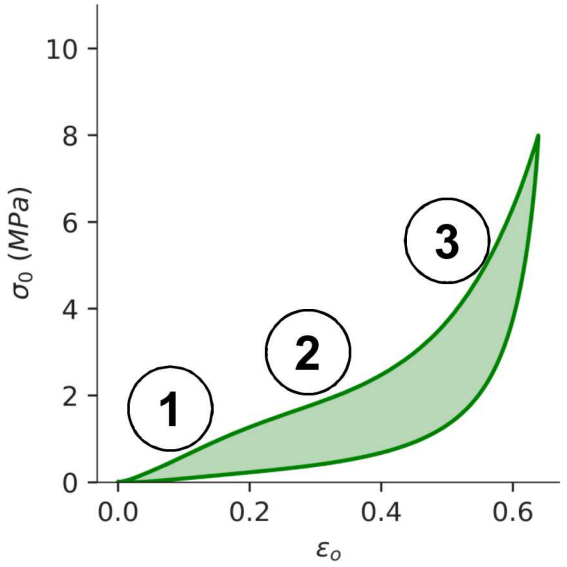


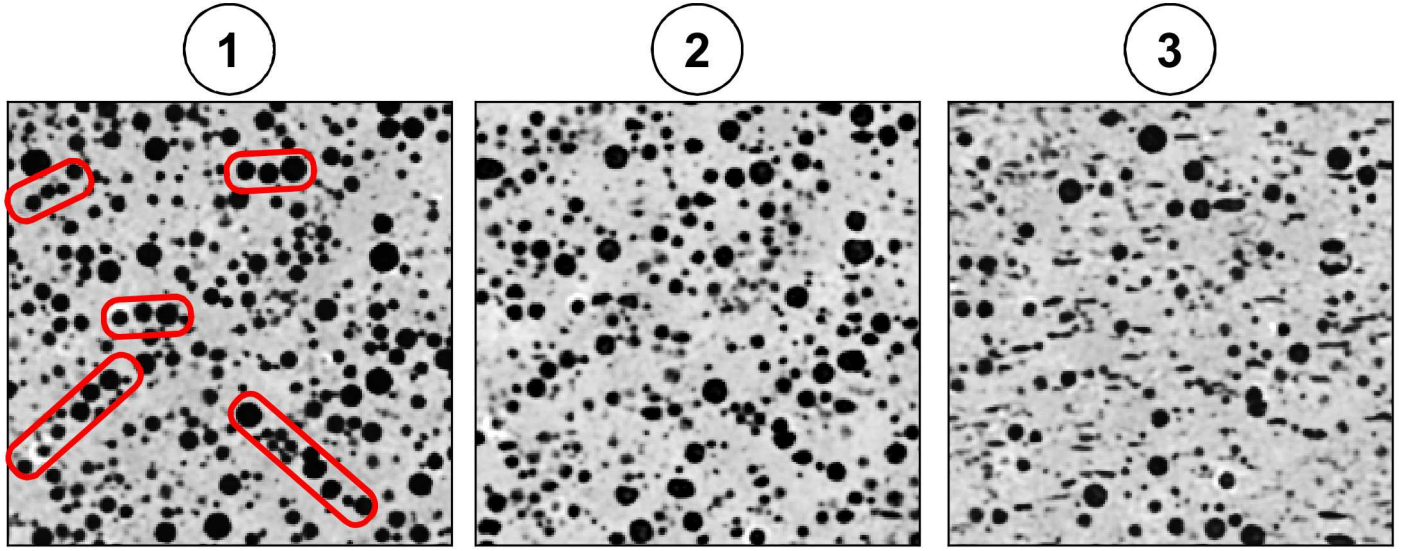


500 μm

Mechanics of Syntactic Foam







Role of GMB interactions

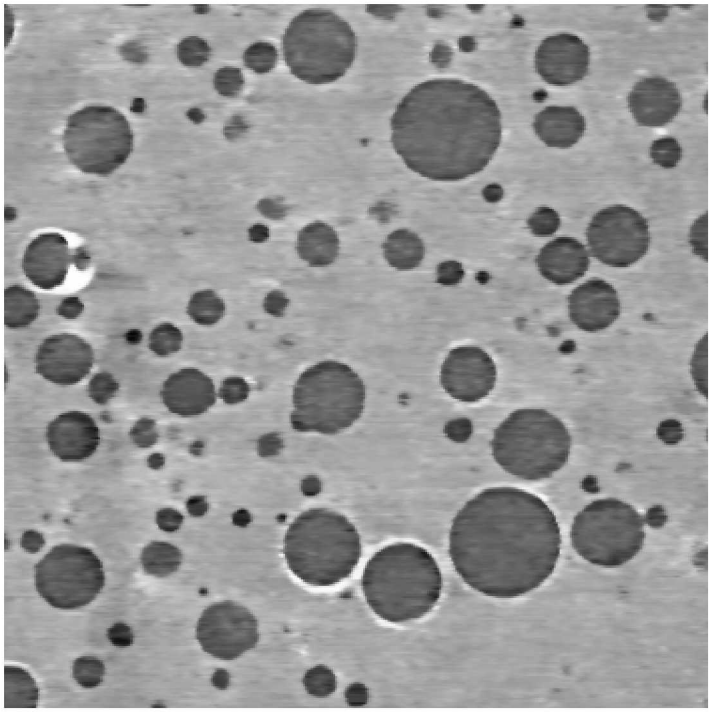
GMBs are *irregularly* distributed

What does that mean for the damage mechanisms?

What are implications of:

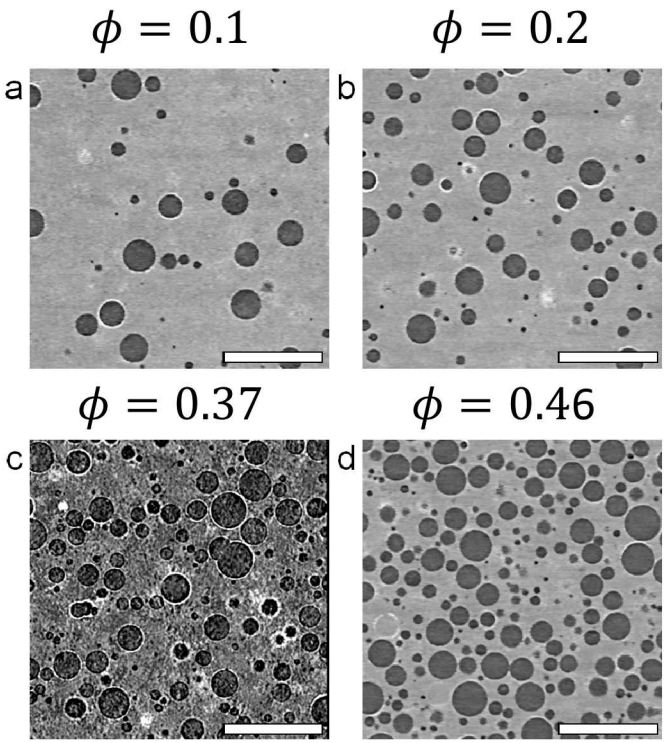
- Volume fraction (long-range interactions)?
- GMB clustering (short-range interactions)?

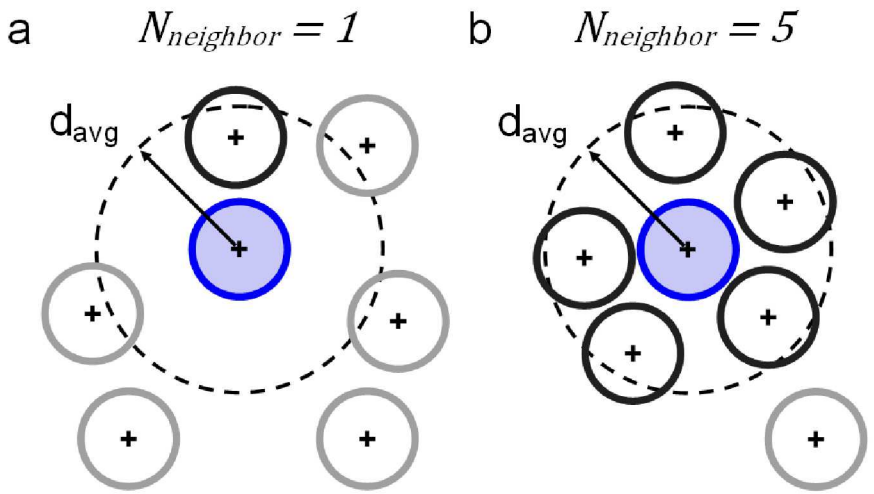
XCT cross-section:



Research Motivation

What is the role of global and local GMB density on the damage micromechanics?





Croom, *Composites Part B*, 2019

Research Outline

1. Finite element study of GMB clustering
2. Statistical analysis of *in situ* XCT damage measurements

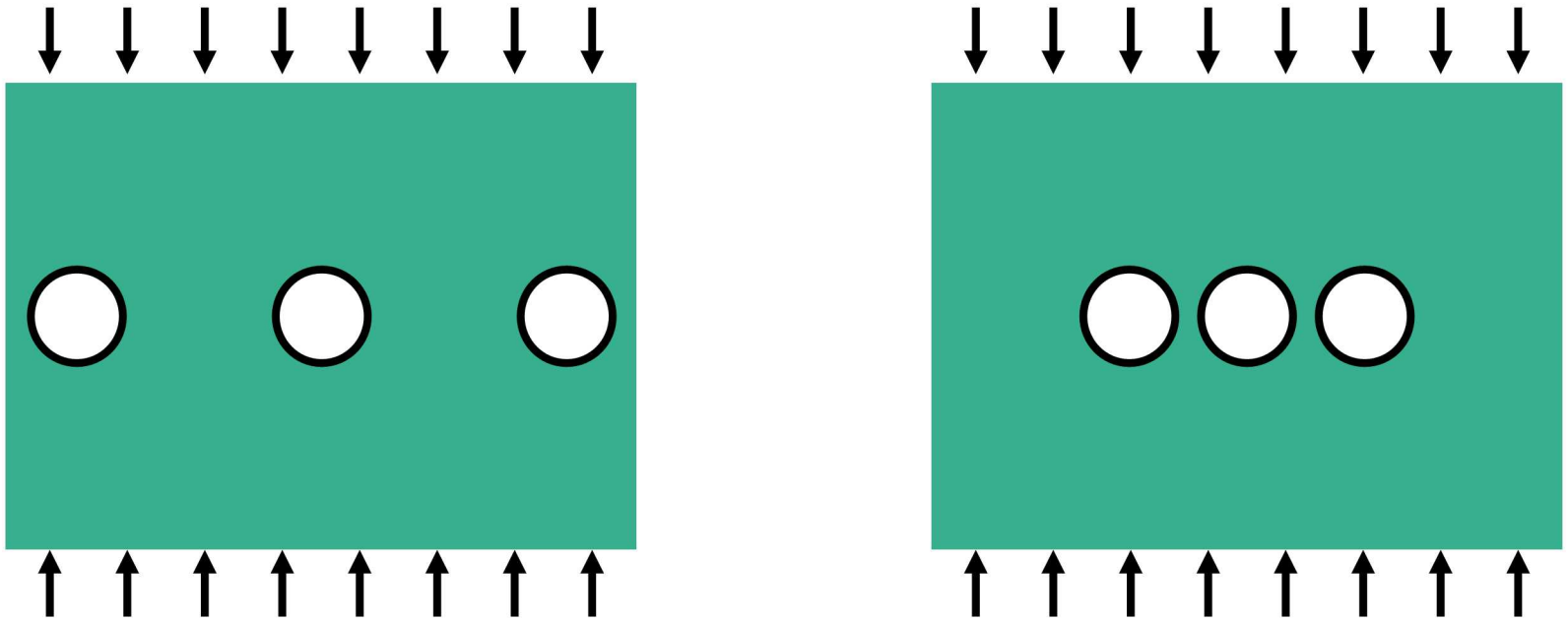
FE study of GMB clustering

Role of GMB interactions

GMB thought experiment:

Sparsely-packed GMBs

Closely-packed GMBs



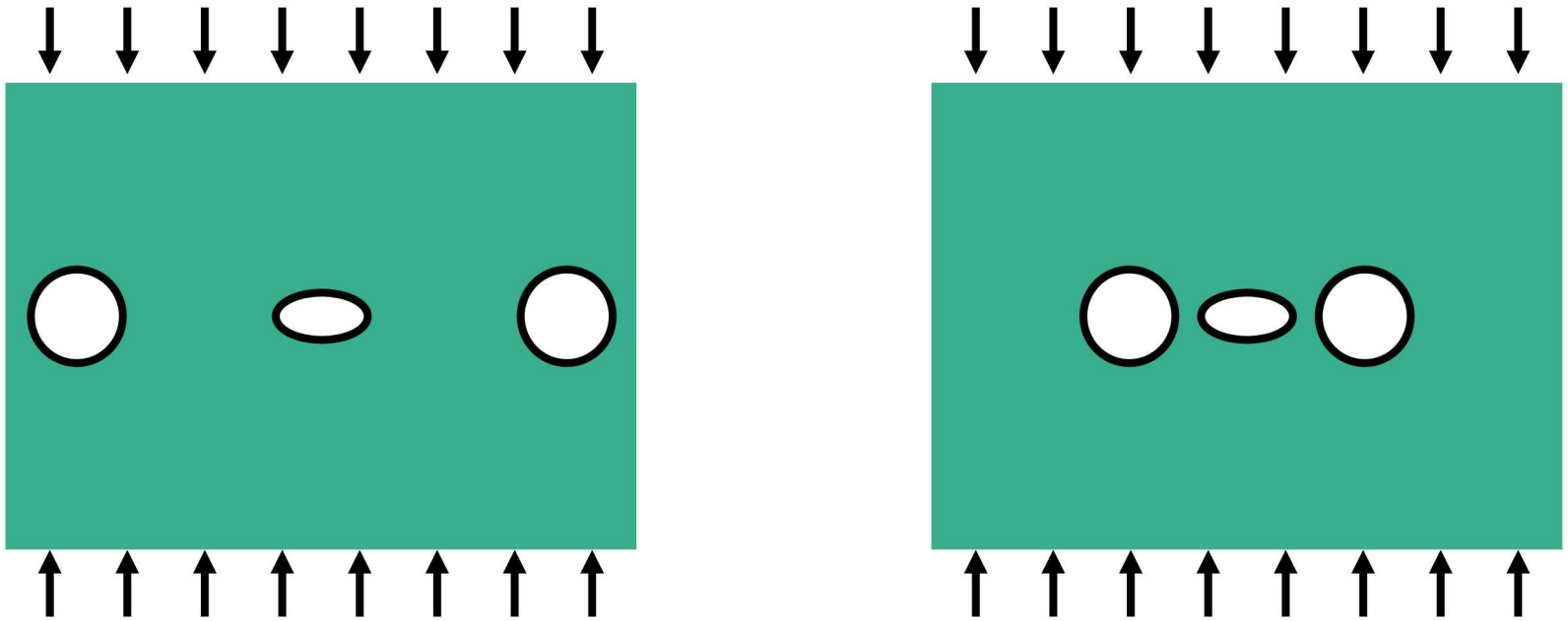
Which GMBs have higher stress?

Role of GMB interactions

GMB thought experiment:

Sparsely-packed GMBs

Closely-packed GMBs

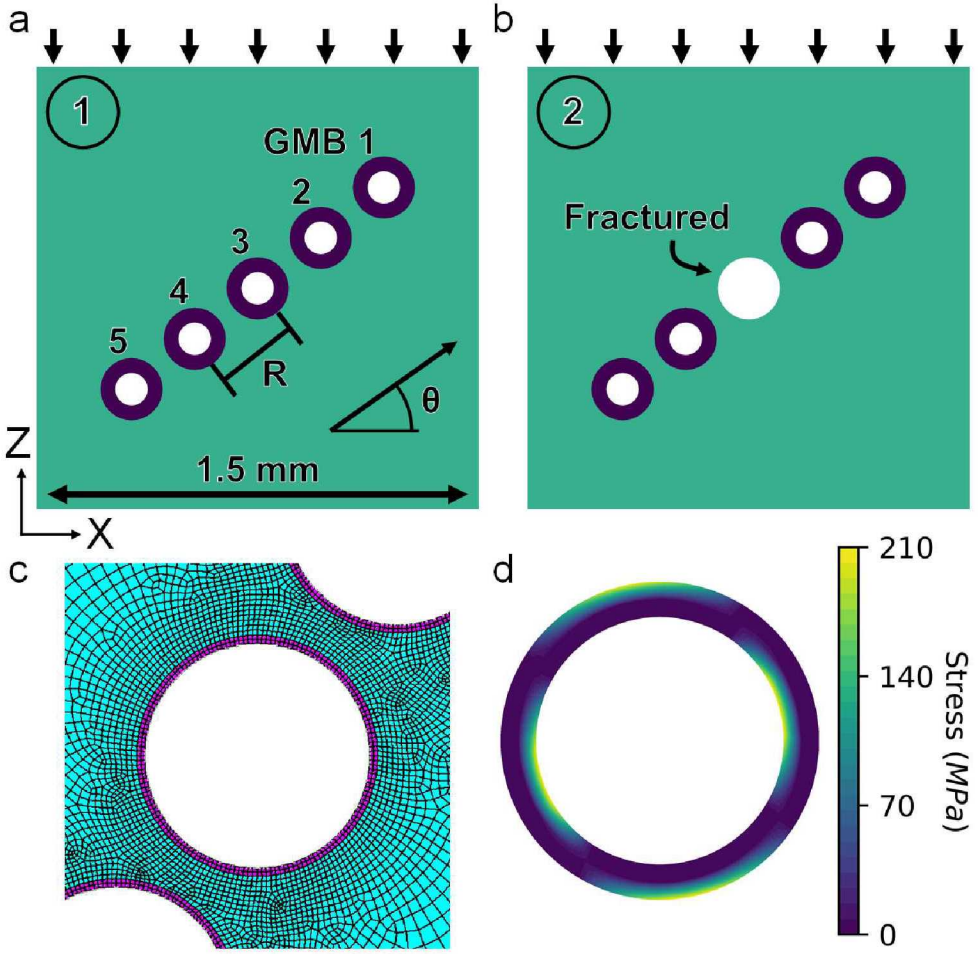


What happens after one GMB collapses?

Model development

FE model to address:

- Spacing between GMBs
- Stress redistribution after fracture
- Cluster orientation



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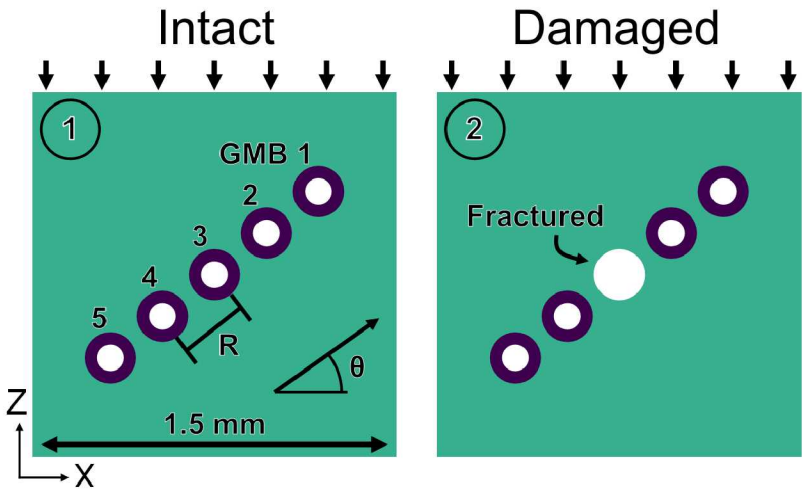
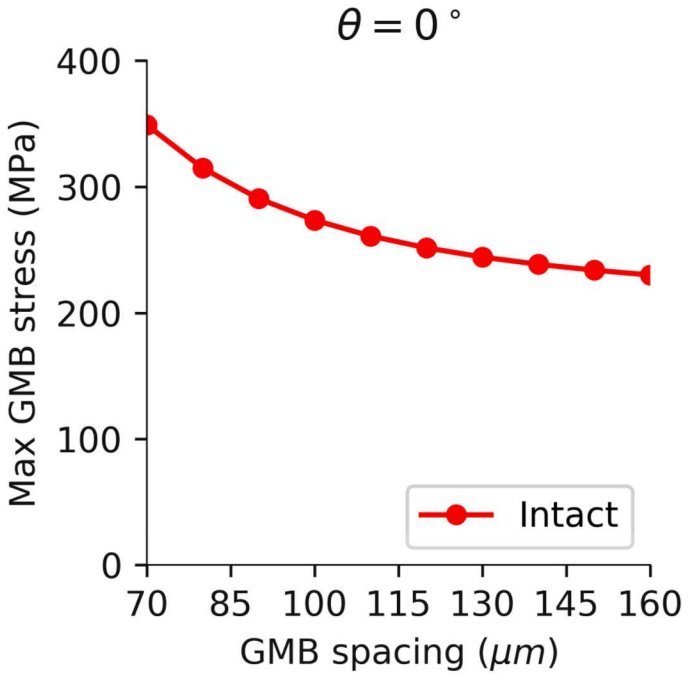
GMB stress distribution



Effect of GMB spacing



Note:

- $R_{GMB} = 30\ \mu m$
- GMB = borosilicate glass
- Matrix = PDMS
- ε_avg = -0.07

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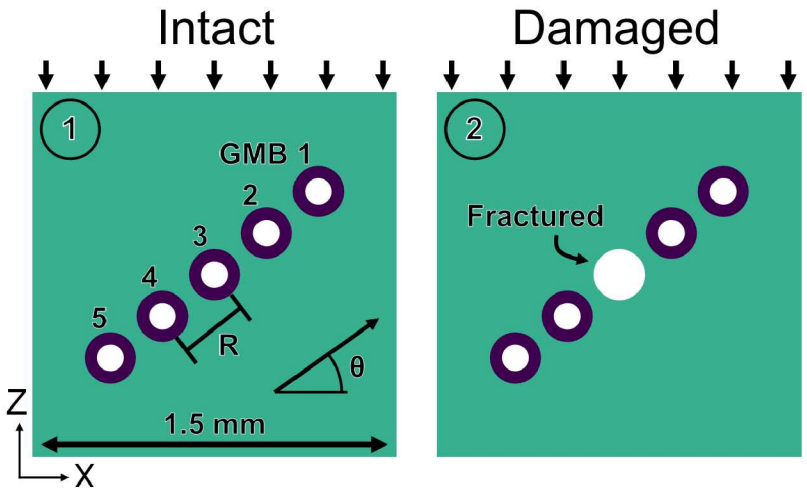
GMB stress distribution



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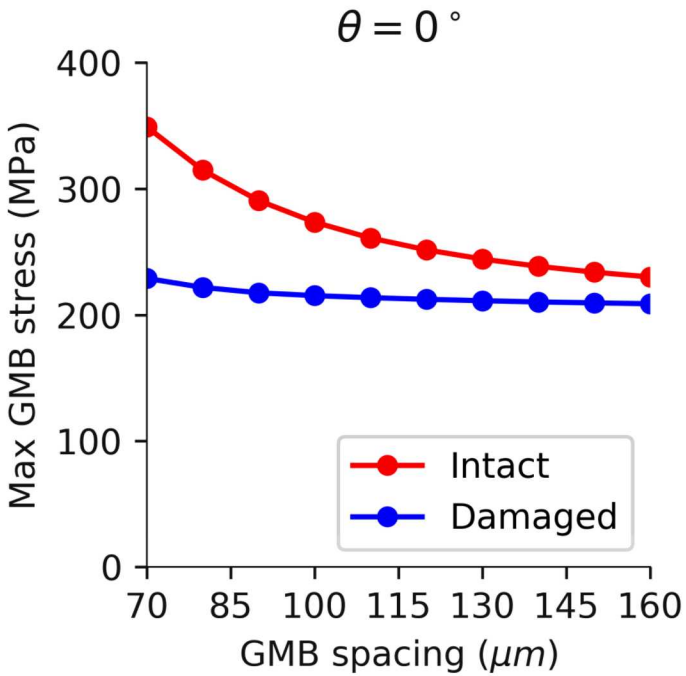

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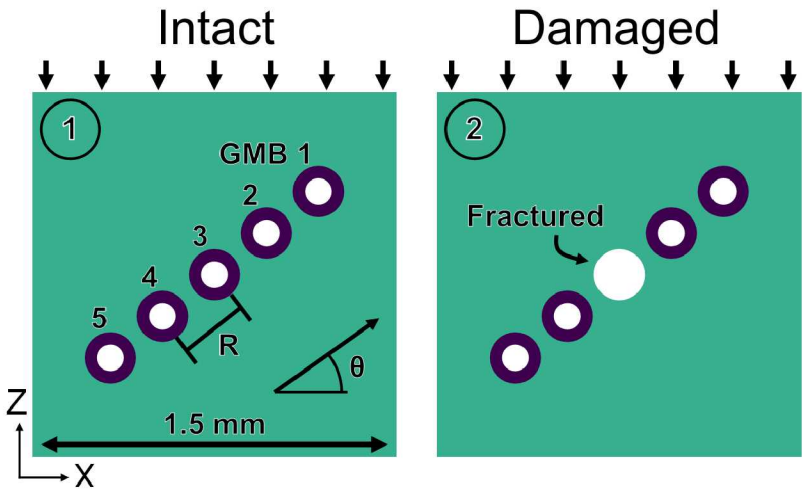

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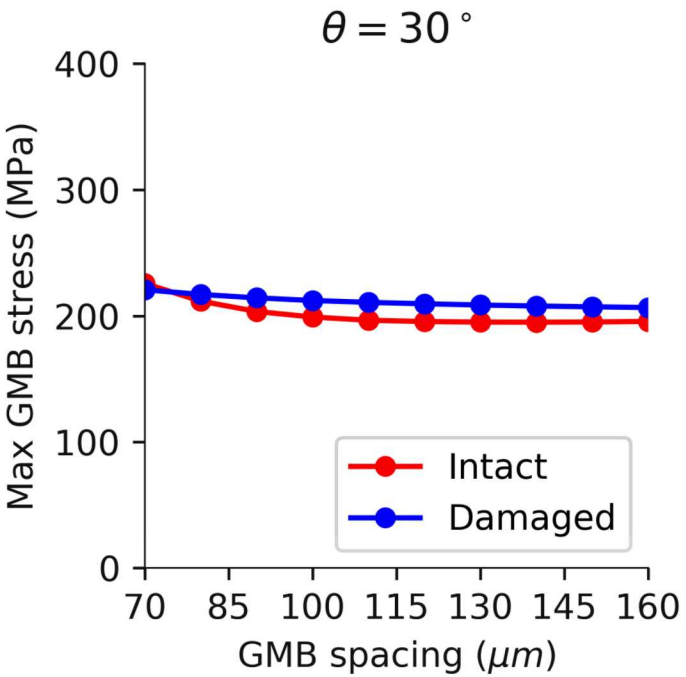

Note:

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Summary of FE results

- Particle clustering strongly influences GMB stress:
  - Stress is higher for closely-spaced GMBs
  - Significant stress redistribution around damaged GMBs
    - In some cases… can increase stress on adjacent GMBs!
  - Significant influence of cluster orientation

XCT analysis of short- and long-range GMB interactions

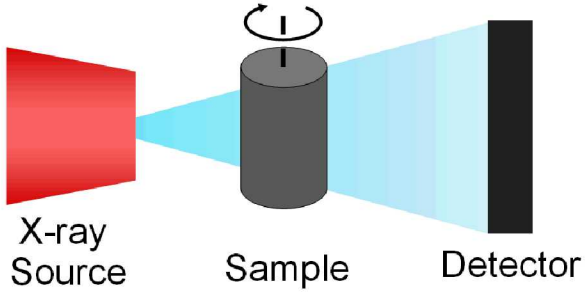
Analysis of ϕ and $N_{neighbor}$

In situ XCT experiments

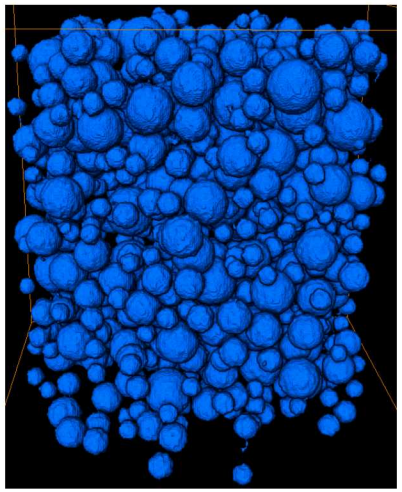
Compression experiments performed on four volume fractions:

$$\phi = 0.10, 0.2, 0.37, 0.46$$

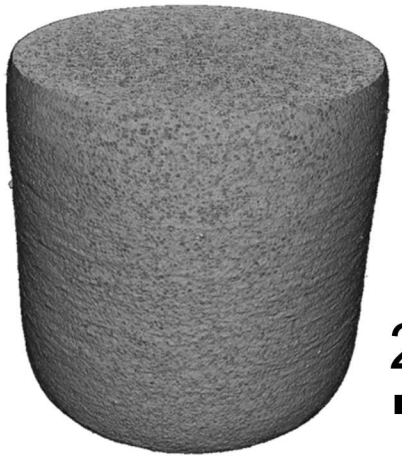
In situ X-ray Computed Tomography



Specimens imaged at two resolutions:

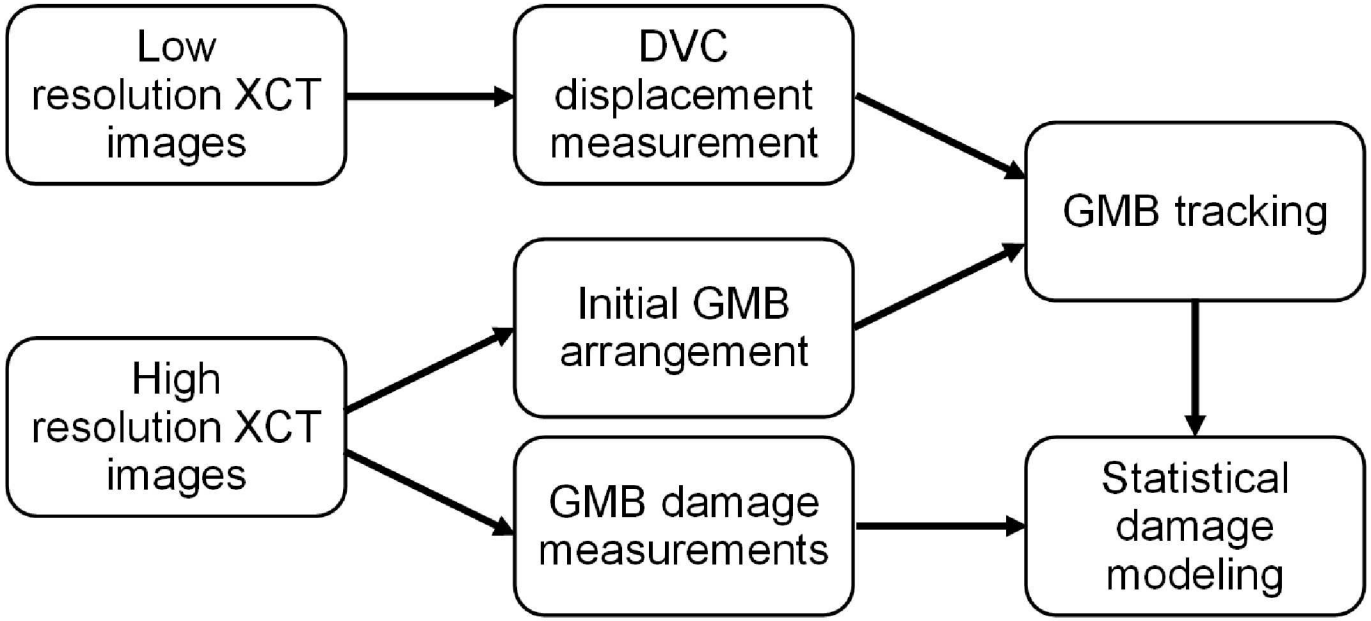


500 μm



2 mm

Analysis framework



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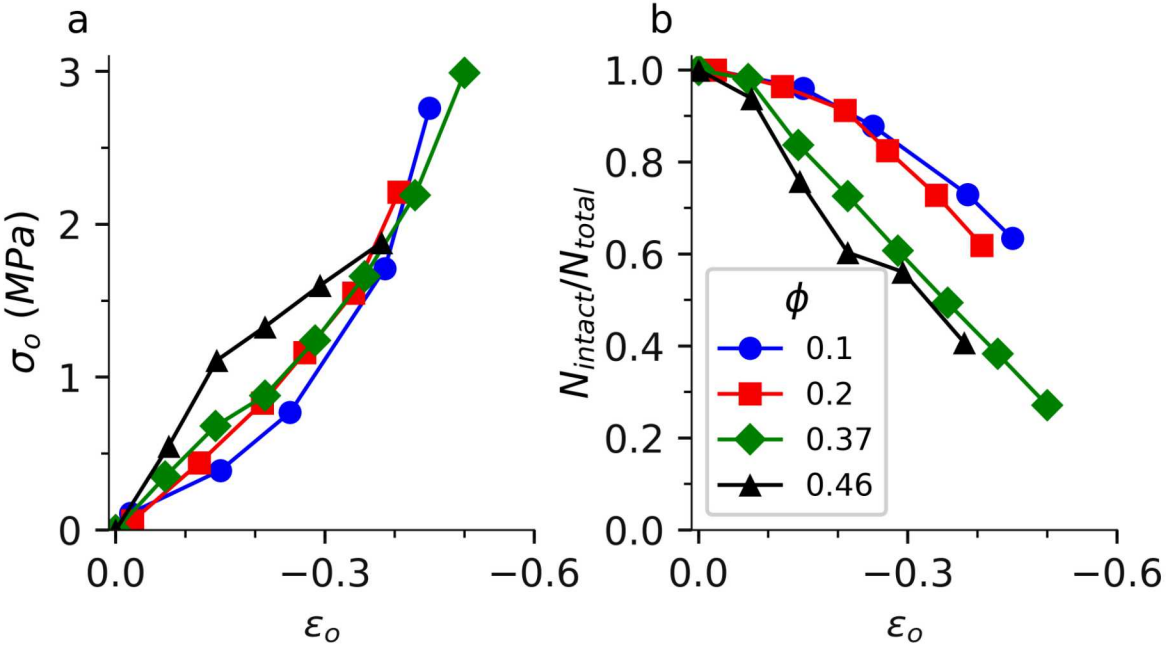
Effects of Volume Fraction

Macroscopic damage response:



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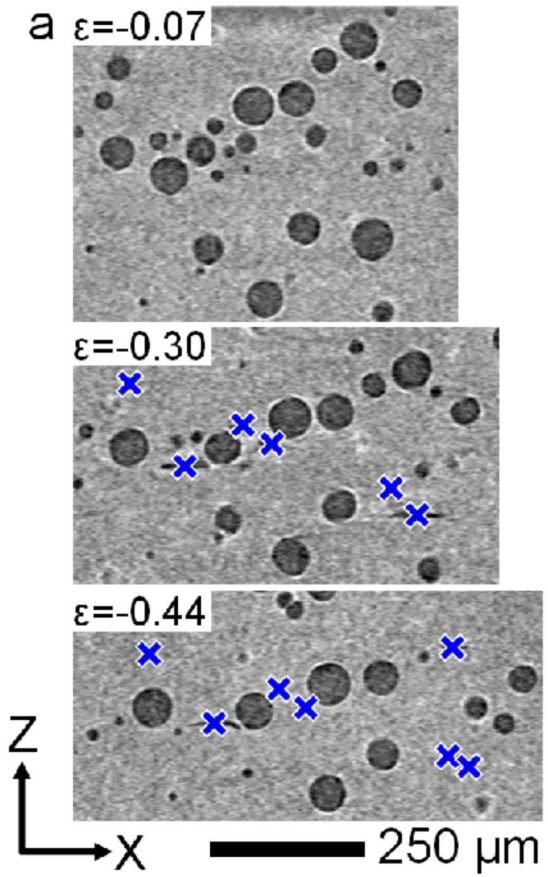
Effects of Volume Fraction

Damage measurement:

$\phi = 0.10$



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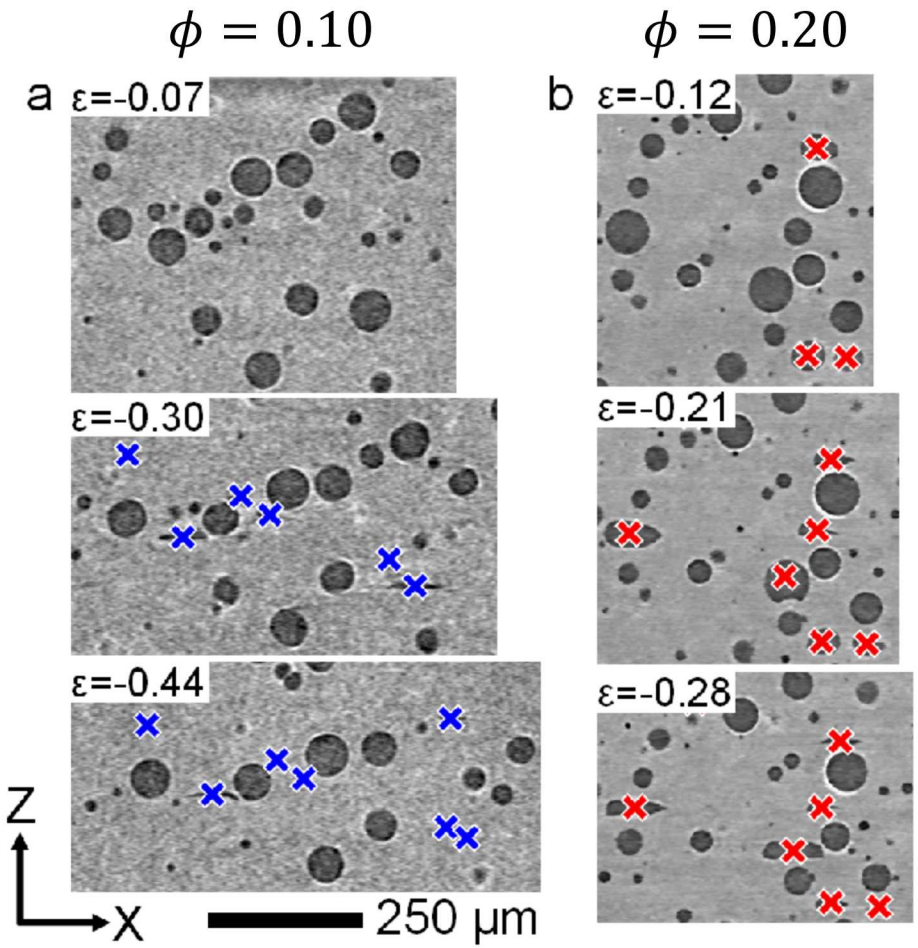
Effects of Volume Fraction

Damage measurement:



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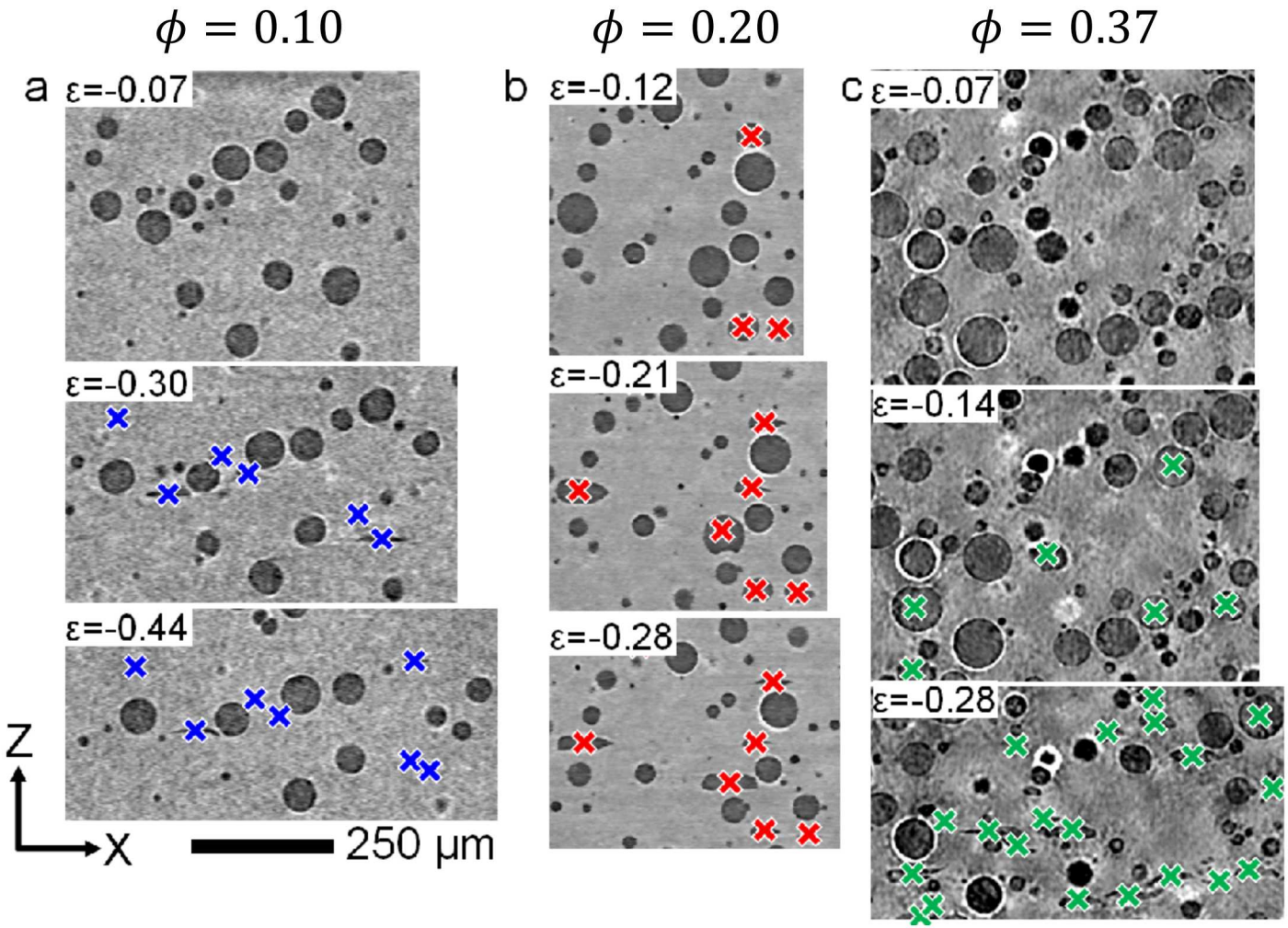
Effects of Volume Fraction

Damage measurement:



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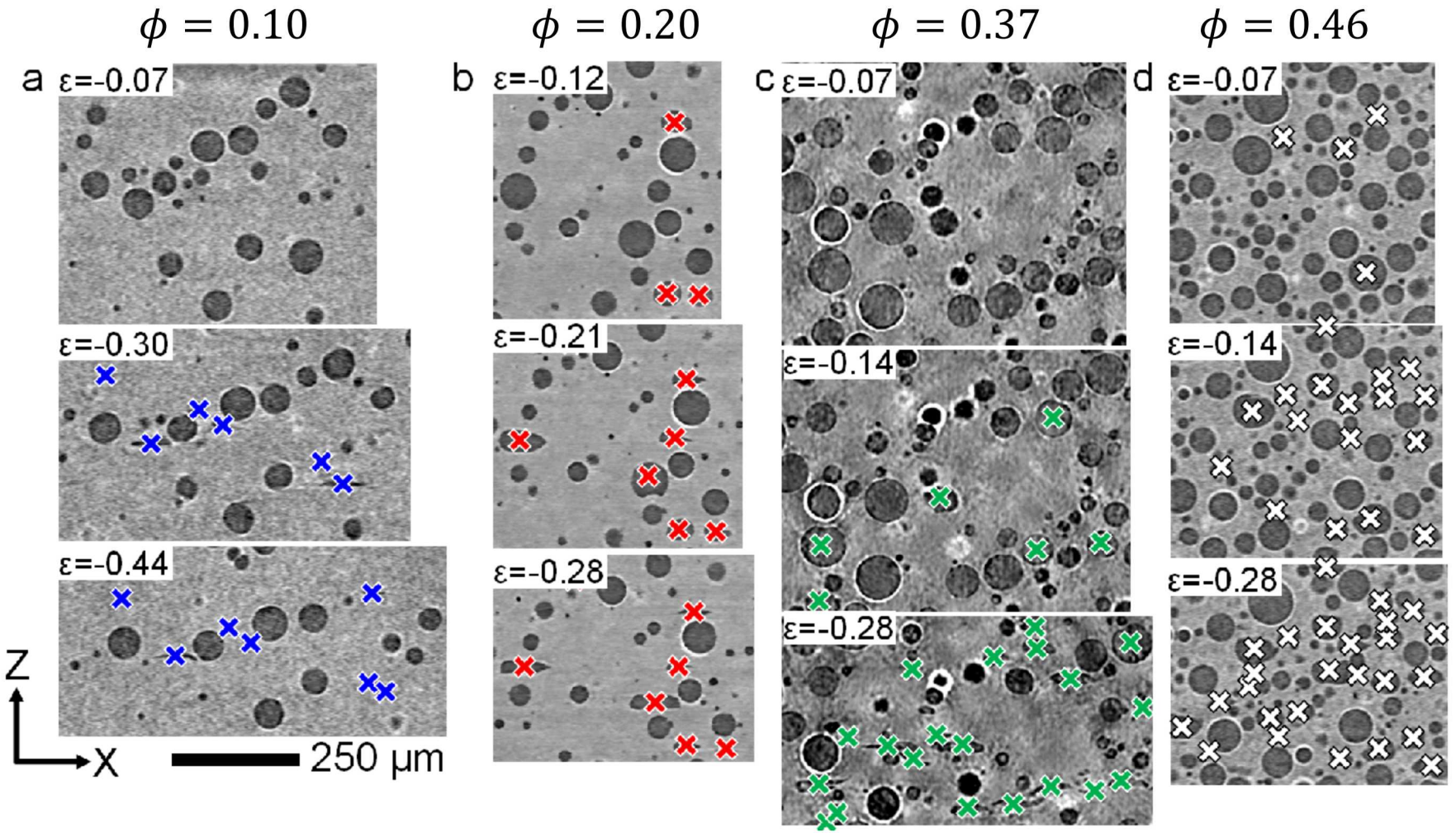
Effects of Volume Fraction

Damage measurement:



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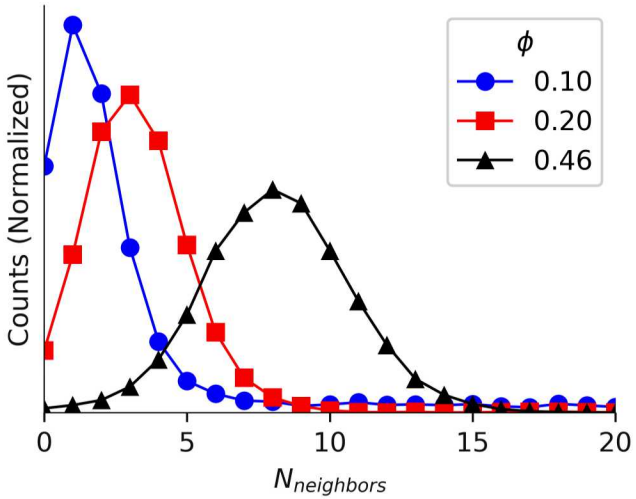
Effects of $N_{neighbor}$



Irregular GMB arrangement leads to variation in $N_{neighbor}$

- Can isolate effects of ϕ vs $N_{neighbor}$ on damage

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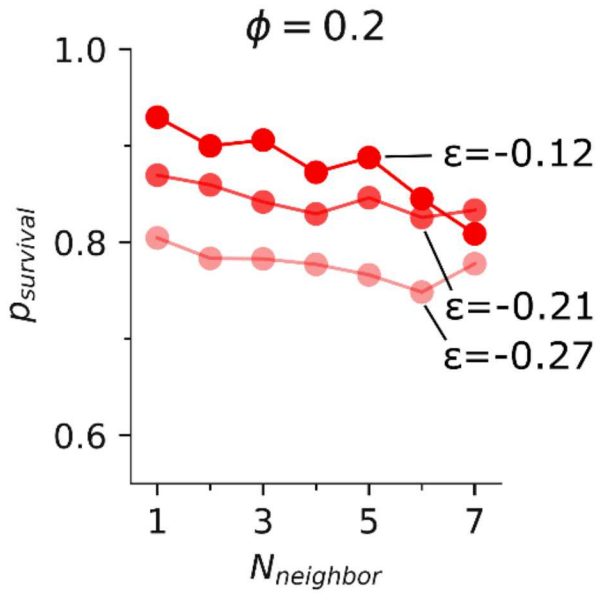
Effects of $N_{neighbor}$



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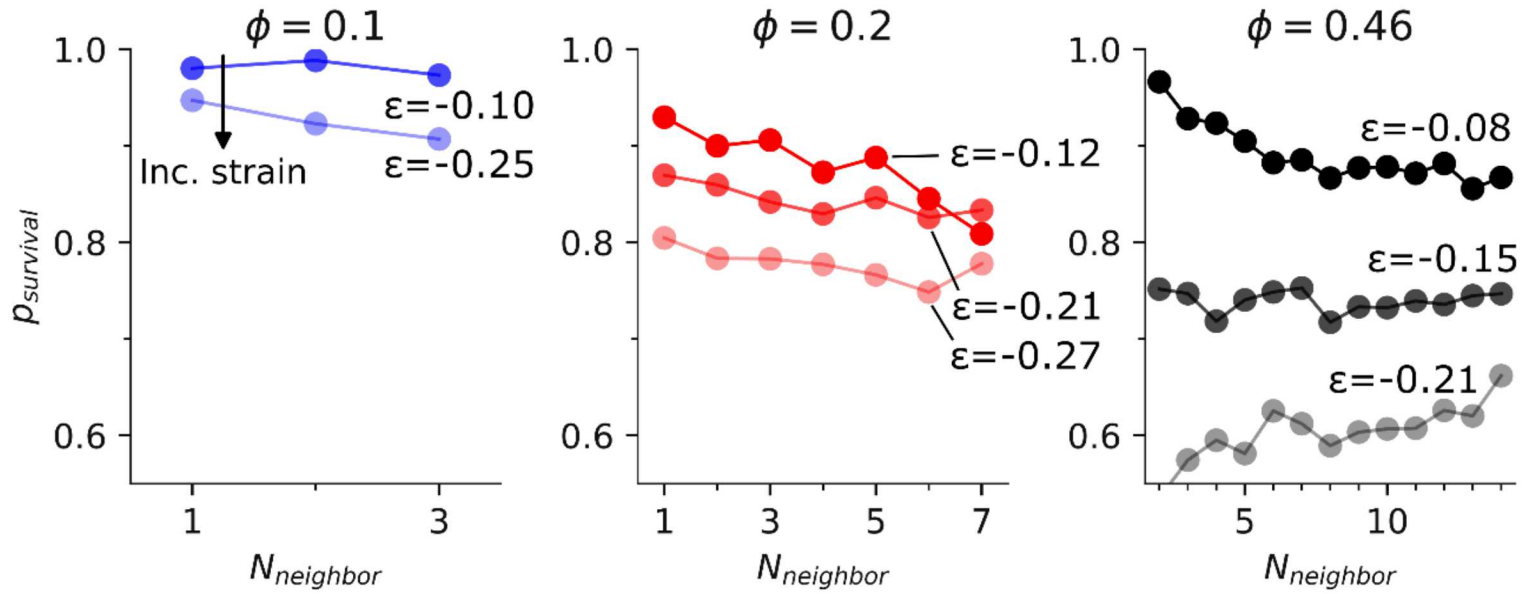
Effects of $N_{neighbor}$



Decreasing survival at large $N_{neighbor}$

- Consistent across VF
- Negligible change for $N_{neighbor} > 10$

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Summary for XCT experiments

Volume fraction ϕ and $N_{neighbor}$ have similar effects:

- Large ϕ = damage occurs at smaller strain, clustered damage in tightly-packed regions
- Large $N_{neighbor}$ = decreased $p_{survival}$

However:

- Damage still occurs faster at higher ϕ for same $N_{neighbor}$
- $N_{neighbor}$ is especially important at low ϕ

Conclusions

Conclusions

In situ XCT experiments reveal the effects of volume fraction and GMB clustering

- Multiscale XCT + DVC analysis enables tracking of individual GMBs
- Large ϕ and $N_{neighbor}$ have similar effects (accelerated GMB collapse), but both are needed to predict failure
- GMB clustering / agglomeration has strong implications for mechanical response of syntactic foams