SAND2019-11172C

Damage micromechanics in syntactic foams: Role of particle interactions

Brendan Croom
Materials and Manufacturing Directorate
Air Force Research Laboratory

Helena Jin · Judith Brown · Jay Carroll · Kevin Long
Sandia National Laboratories

Xiaodong Li
Mechanical and Aerospace Engineering
University of Virginia

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

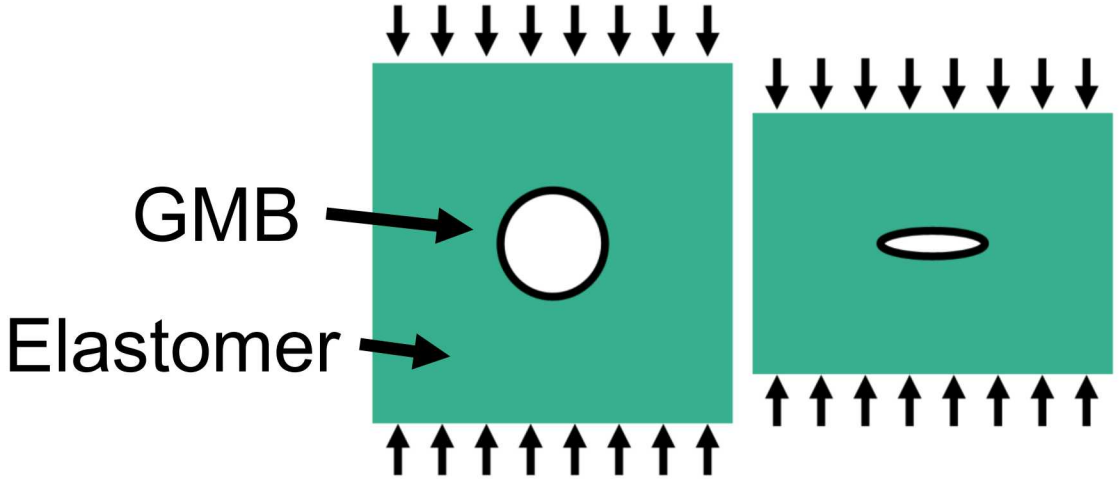
Acknowledgement

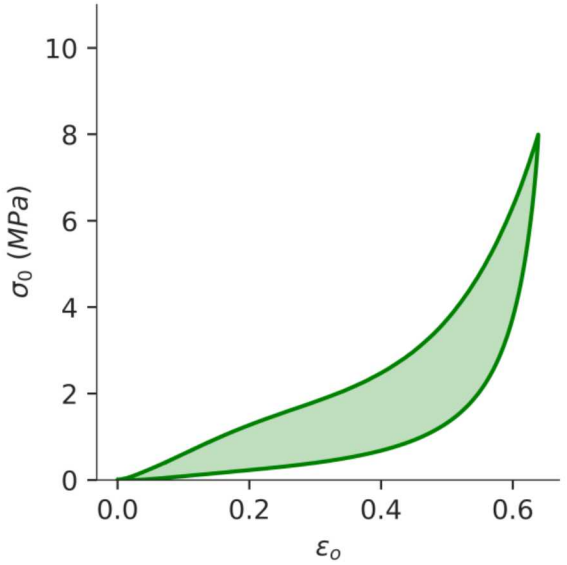
This work is co-funded by NSF, Air Force Research Laboratory, and Sandia National Laboratories. BPC acknowledges support by National Science Foundation (NSF) Graduate Research Fellowship Program (DGE-1842490). This research was performed while the author held an NRC Research Associateship award at Air Force Research Laboratory. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525. This talk describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Introduction

Syntactic foams, Damage mechanisms, and GMB interactions

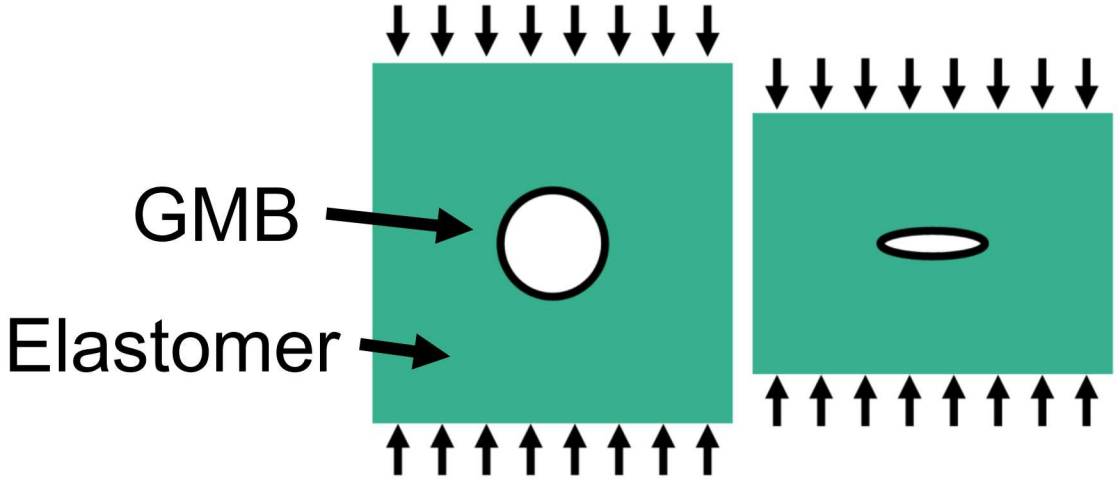
Mechanics of Syntactic Foam

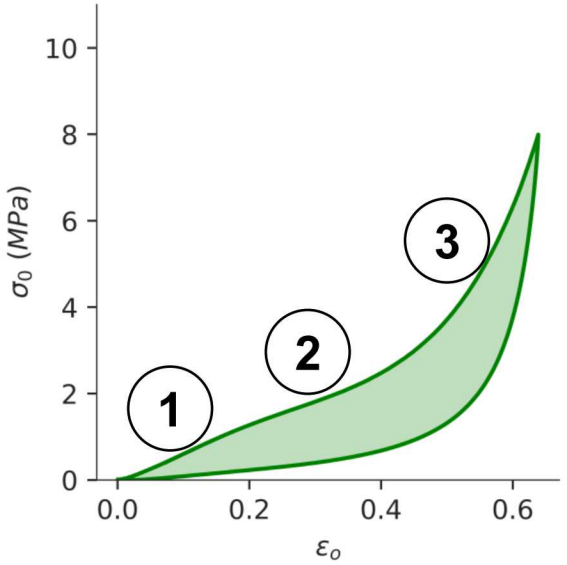


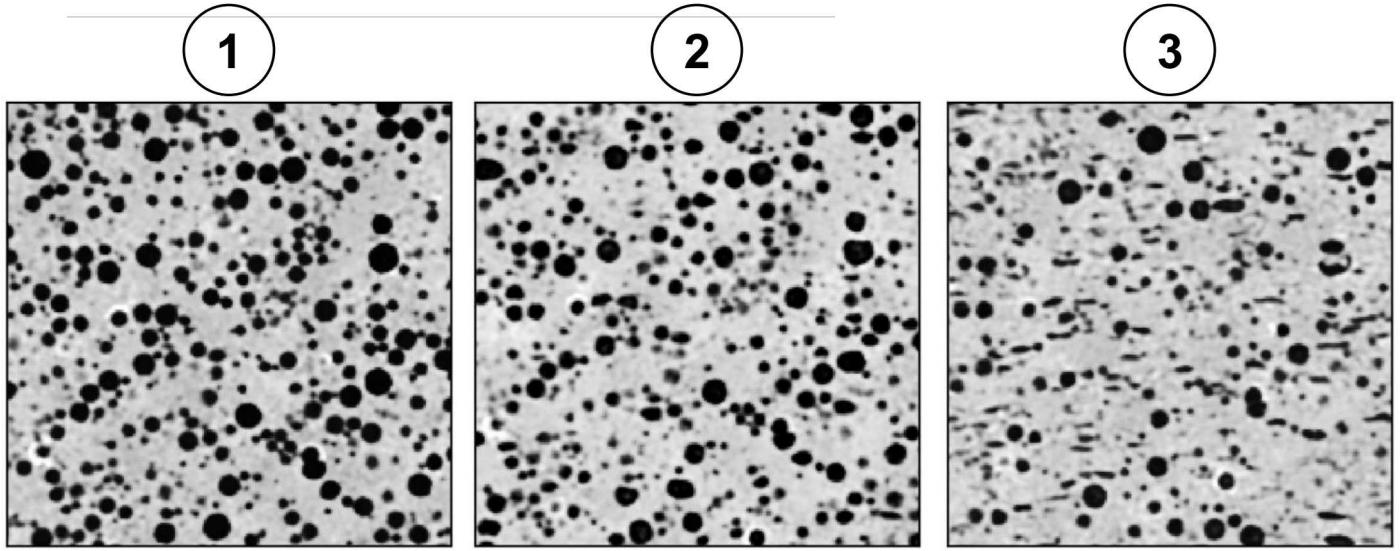


Stress-strain behavior is
defined by damage to GMBs

Mechanics of Syntactic Foam







500 μm

Role of GMB interactions

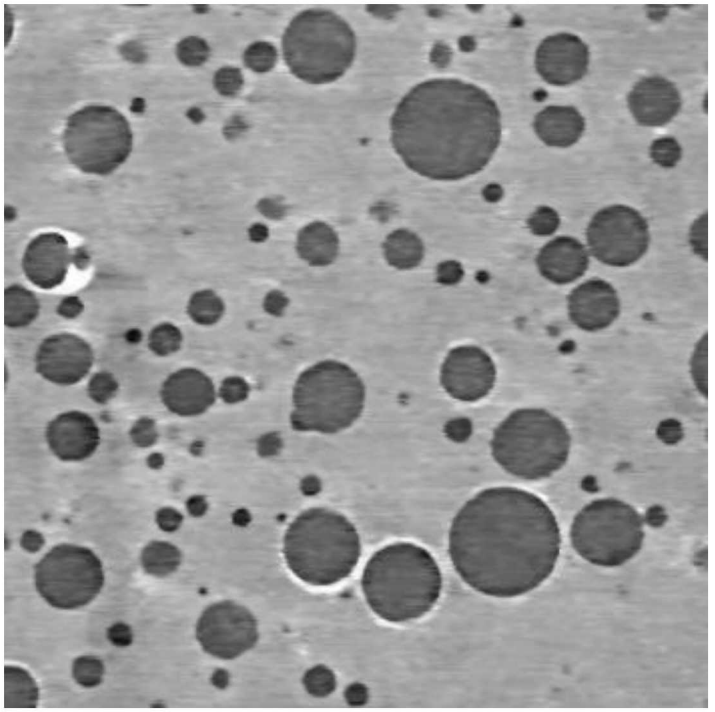
GMBs are *irregularly* distributed

What does that mean for the damage mechanisms?

What are implications of:

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

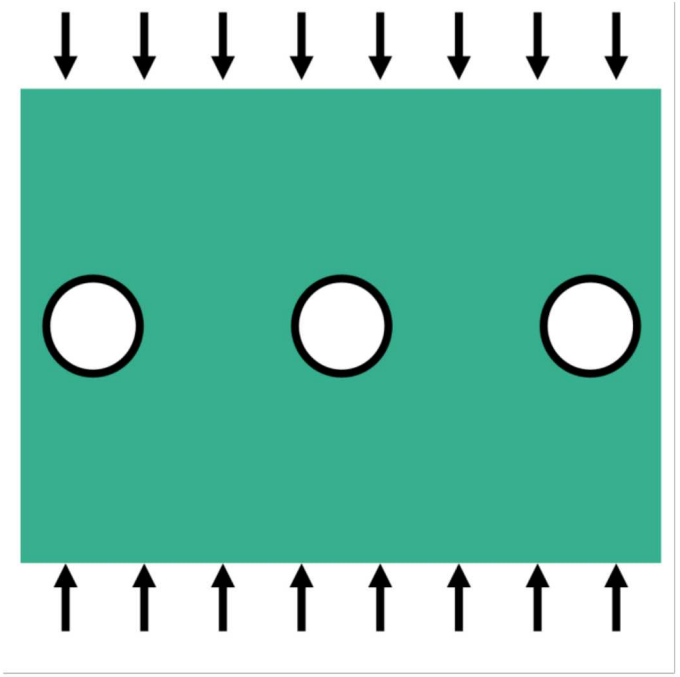
XCT cross-section:



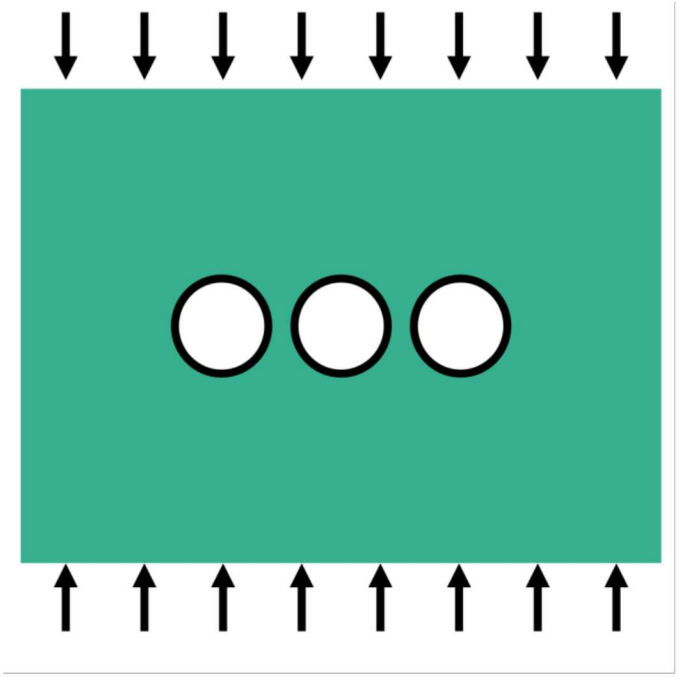
Role of GMB interactions

GMB thought experiment:

Sparsely-packed GMBs



Closely-packed GMBs

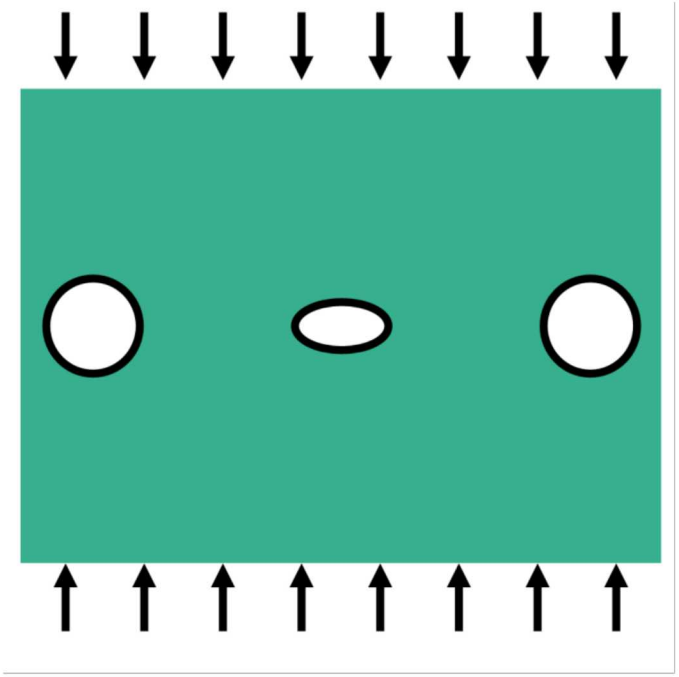


Which GMBs have higher stress?

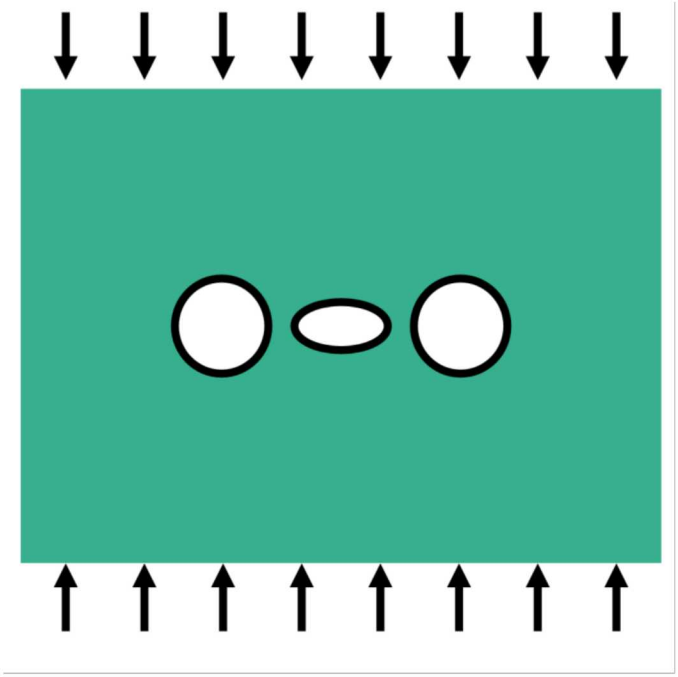
Role of GMB interactions

GMB thought experiment:

Sparsely-packed GMBs



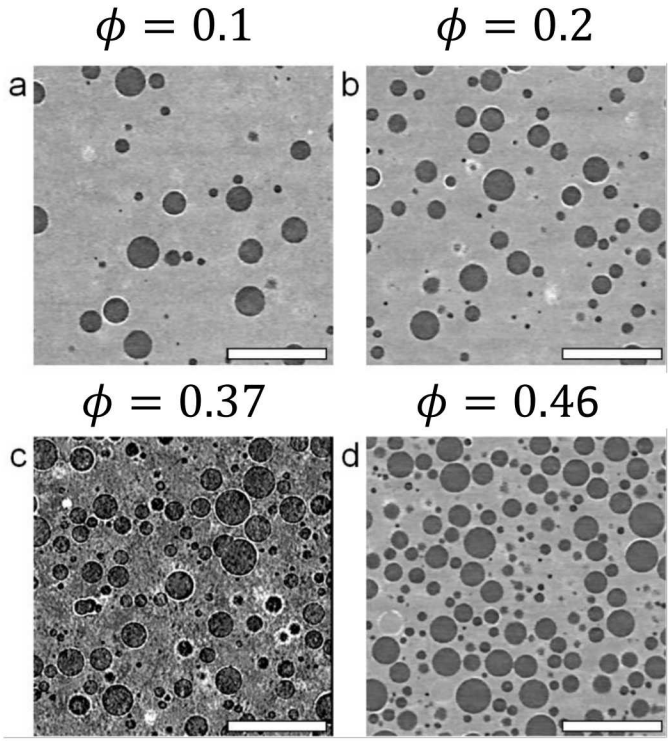
Closely-packed GMBs

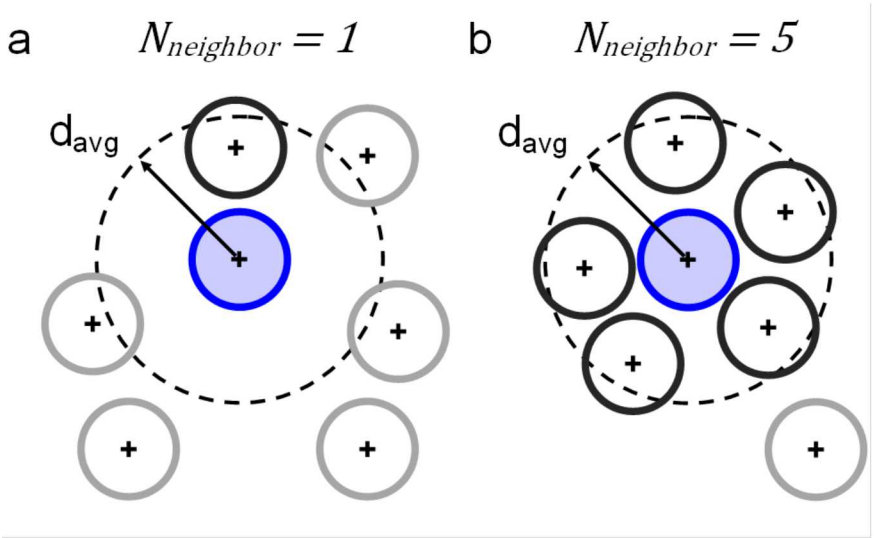


What happens after one GMB collapses?

Research Motivation

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





Croom, *Composites Part B*, 2019

Research Outline

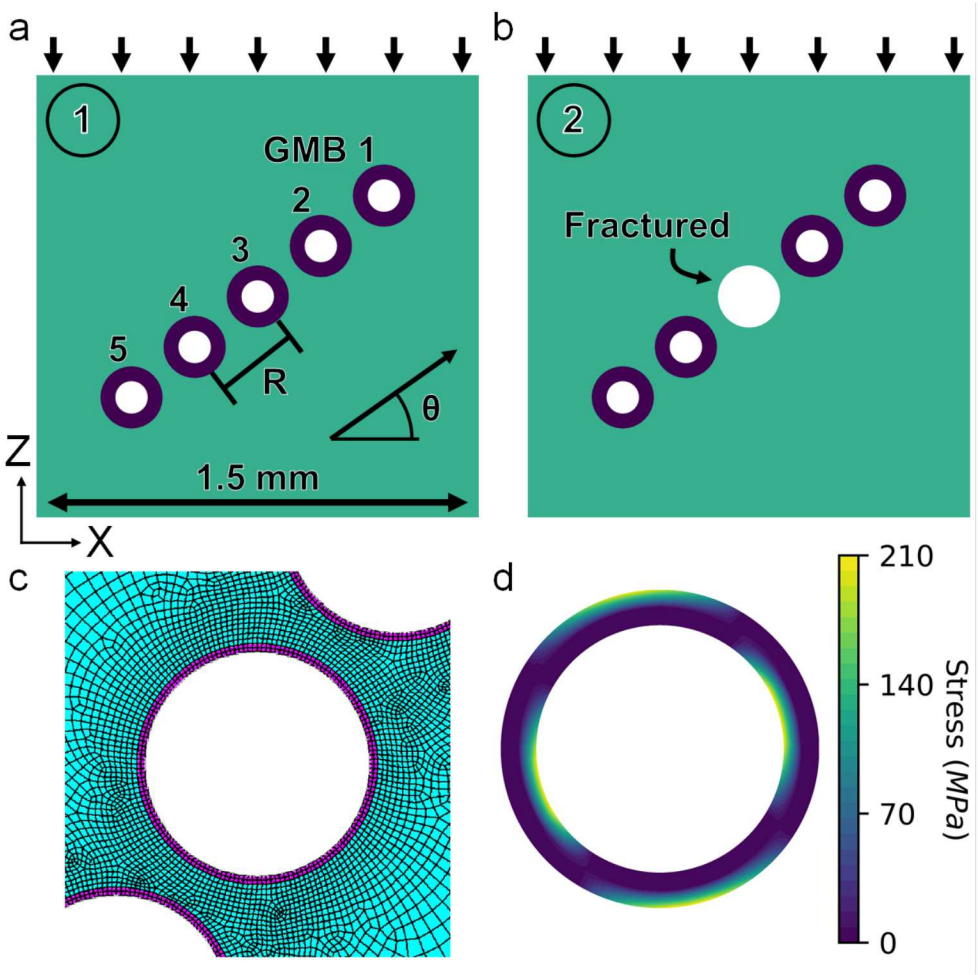
1. Finite element study of GMB clustering
2. Statistical analysis of *in situ* XCT damage measurements

FE study of GMB clustering

Model development

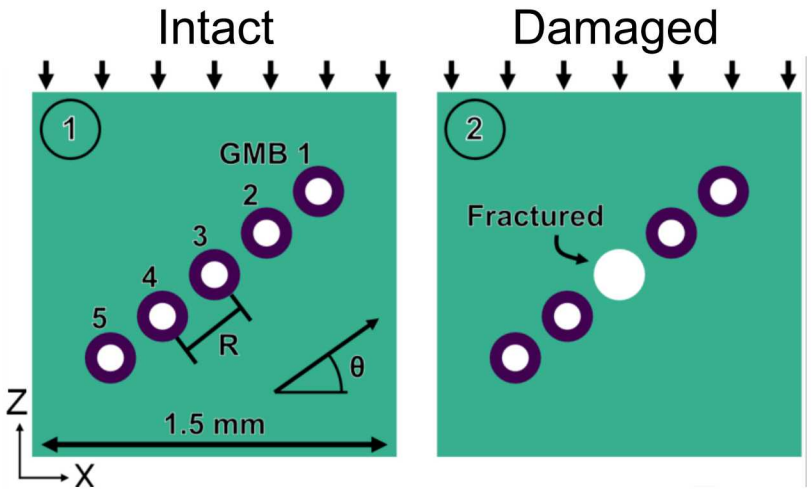
FE model to address:

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

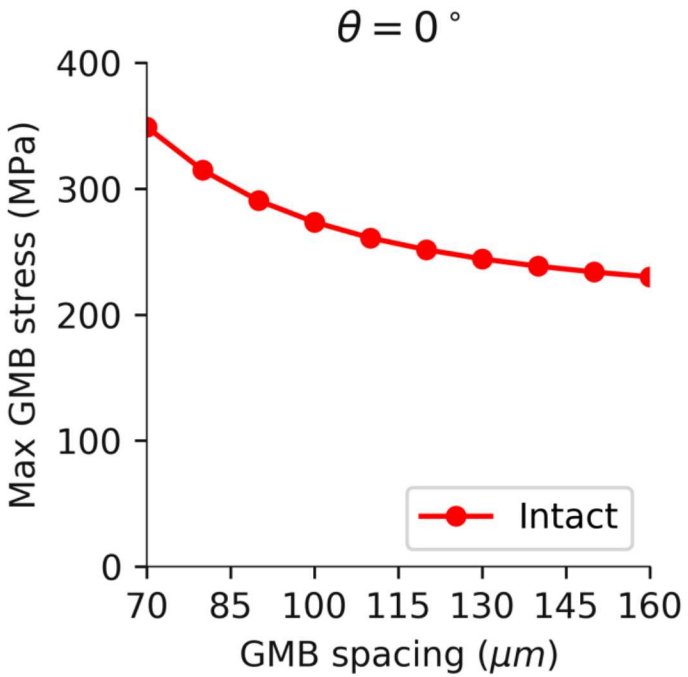


Croom, *Comp Sci Tech*, 2019

GMB stress distribution



Effect of GMB spacing

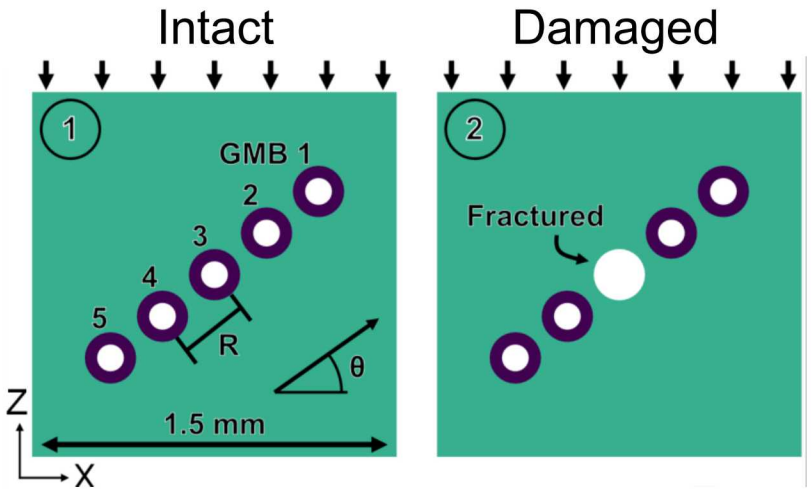


Note:

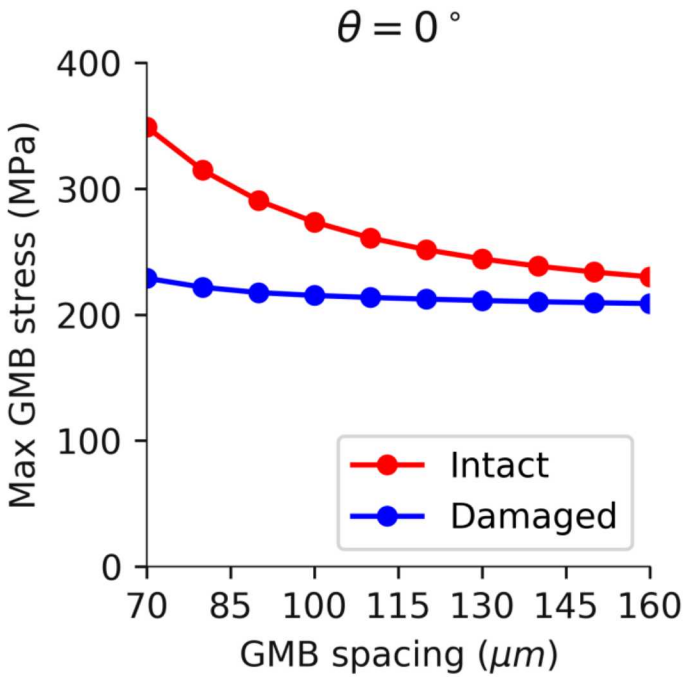
- $R_{GMB} = 30\ \mu m$
- GMB = borosilicate glass
- Matrix = PDMS
- ε_avg = -0.07

Croom, *Comp Sci Tech*, 2019

GMB stress distribution



Effect of GMB spacing

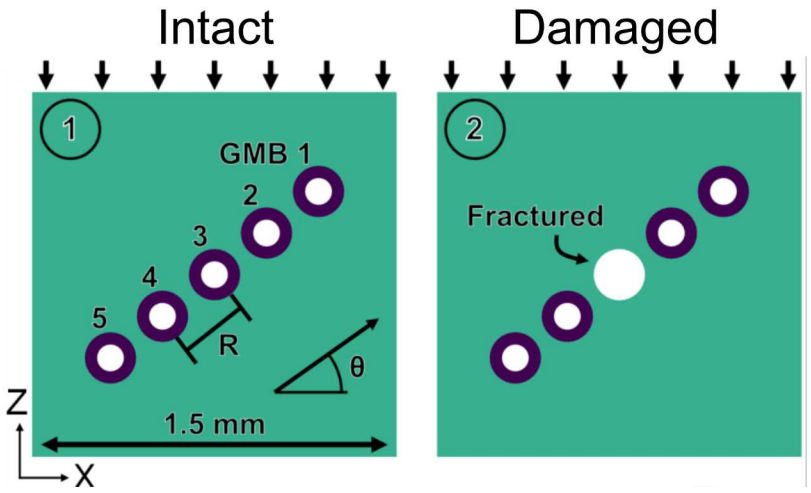


Note:

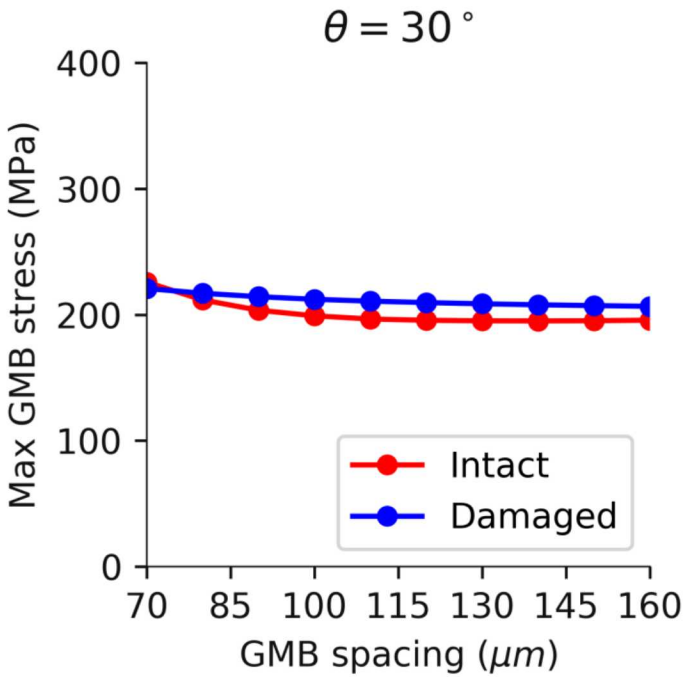
- $R_{GMB} = 30\ \mu m$
- GMB = borosilicate glass
- Matrix = PDMS
- ε_avg = -0.07

Croom, *Comp Sci Tech*, 2019

GMB stress distribution



Effect of GMB spacing

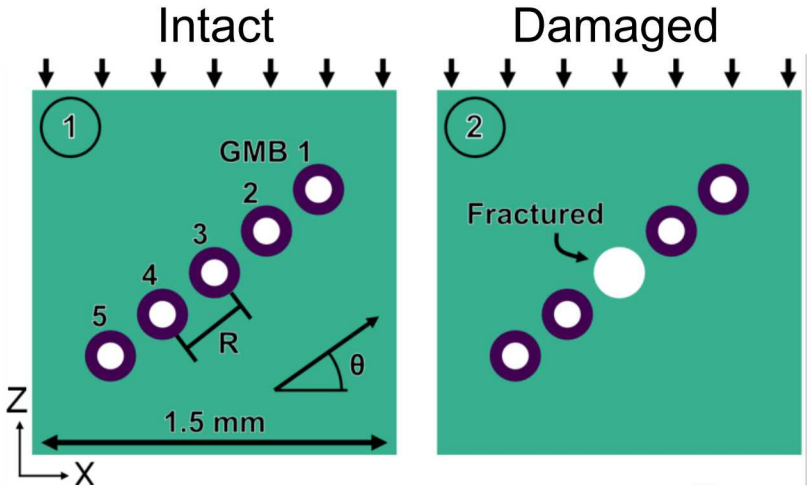


Note:

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

Croom, *Comp Sci Tech*, 2019

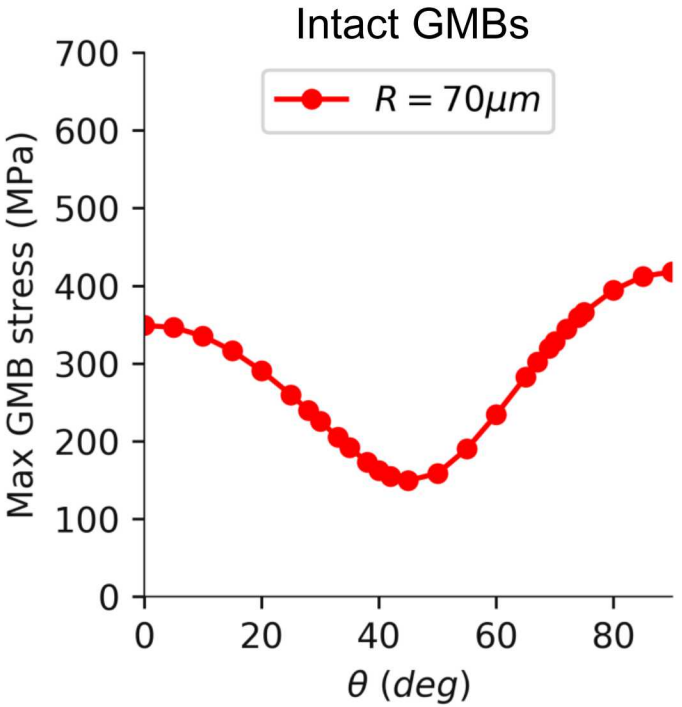
GMB stress distribution



Note:

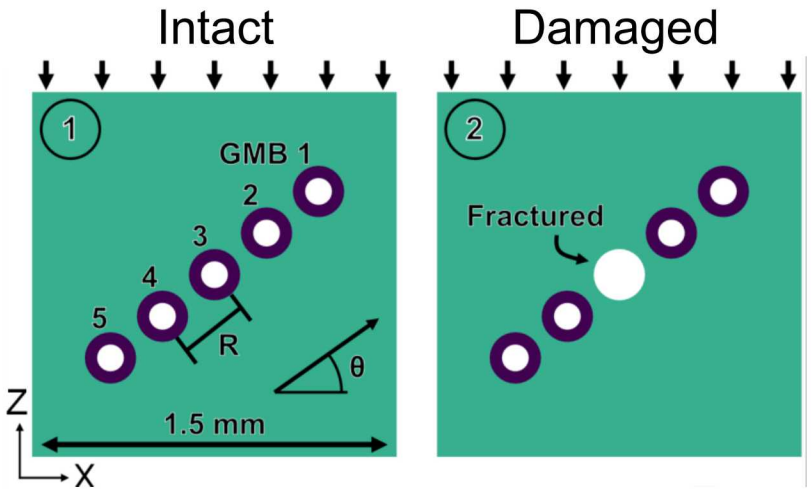
- $R_{GMB} = 30\ \mu m$
- GMB = borosilicate glass
- Matrix = PDMS
- ε_avg = -0.07

Effect of GMB orientation



Croom, *Comp Sci Tech*, 2019

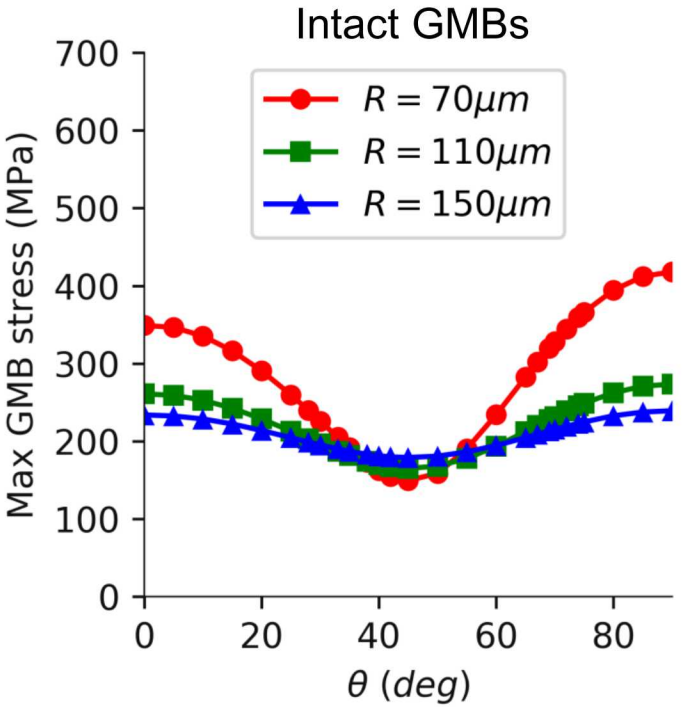
GMB stress distribution



Note:

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

Effect of GMB orientation



Croom, *Comp Sci Tech*, 2019

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

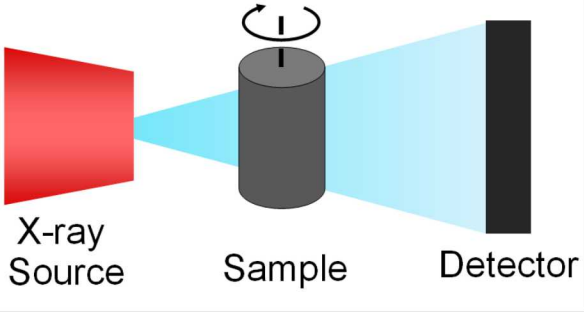
Analysis of ϕ and $N_{neighbor}$

In situ XCT experiments

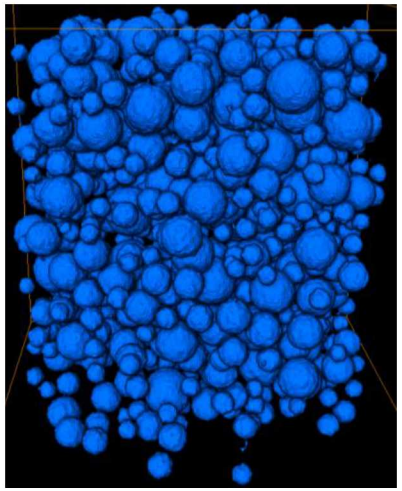
In situ XCT experiments performed on four volume fractions:

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

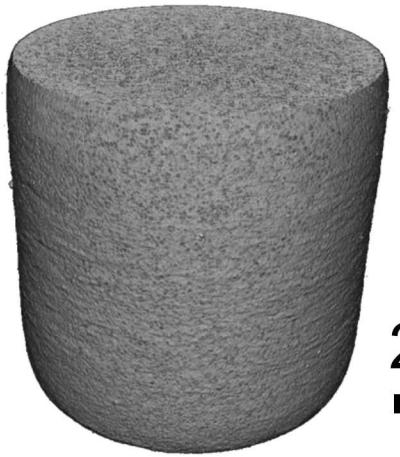
In situ X-ray Computed Tomography



Specimens imaged at two resolutions:

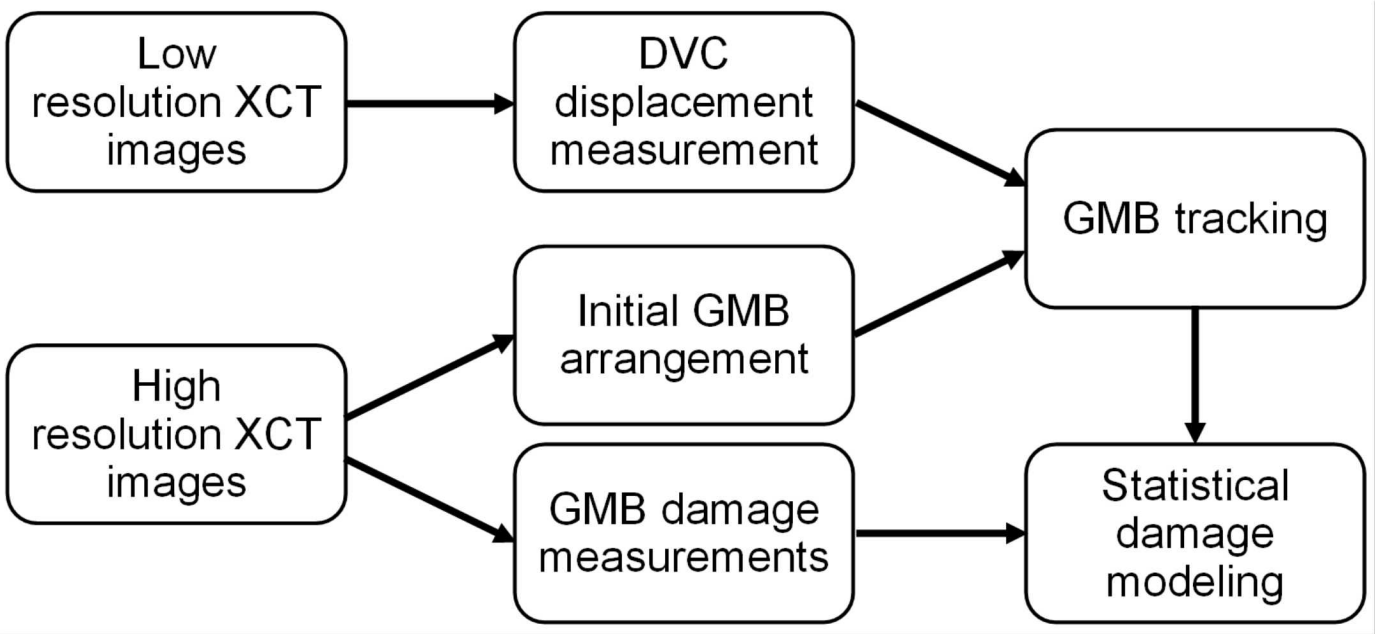


500 µm



2 mm

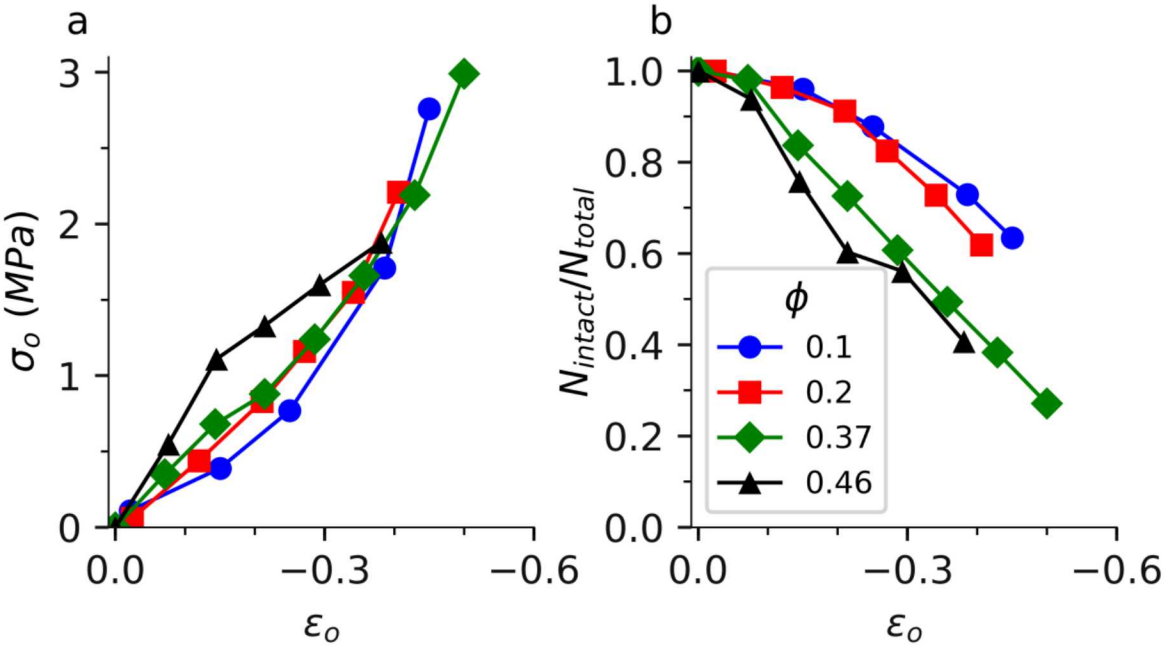
Analysis framework



Croom, *Composites Part B*, 2019

Effects of Volume Fraction

Macroscopic damage response:

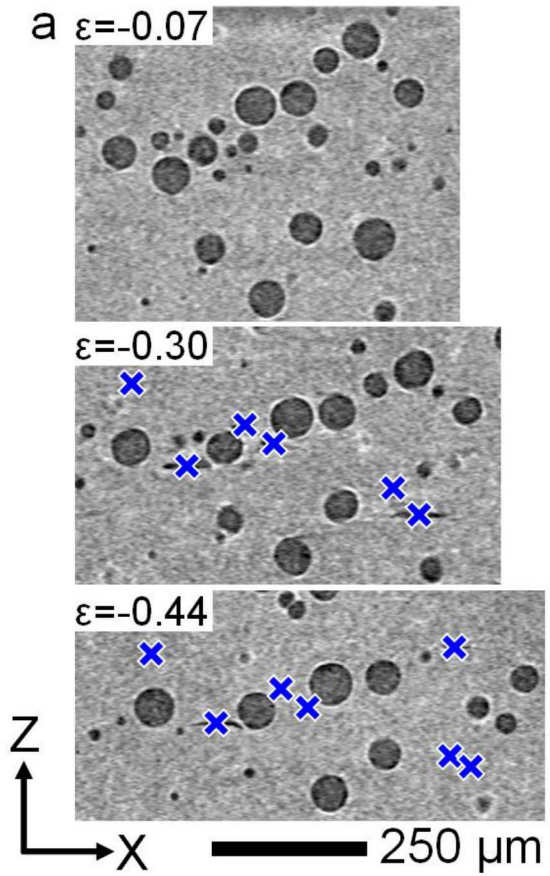


Croom, *Composites Part B*, 2019

Effects of Volume Fraction

Damage measurement:

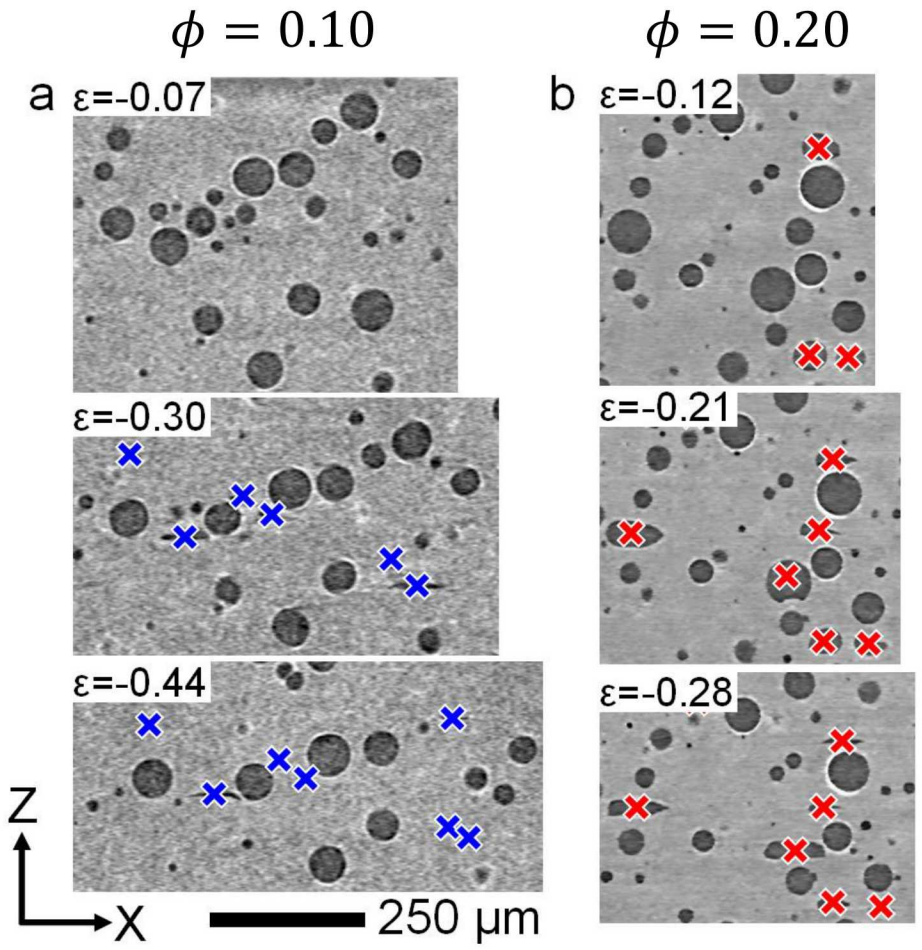
$\phi = 0.10$



Croom, *Composites Part B*, 2019

Effects of Volume Fraction

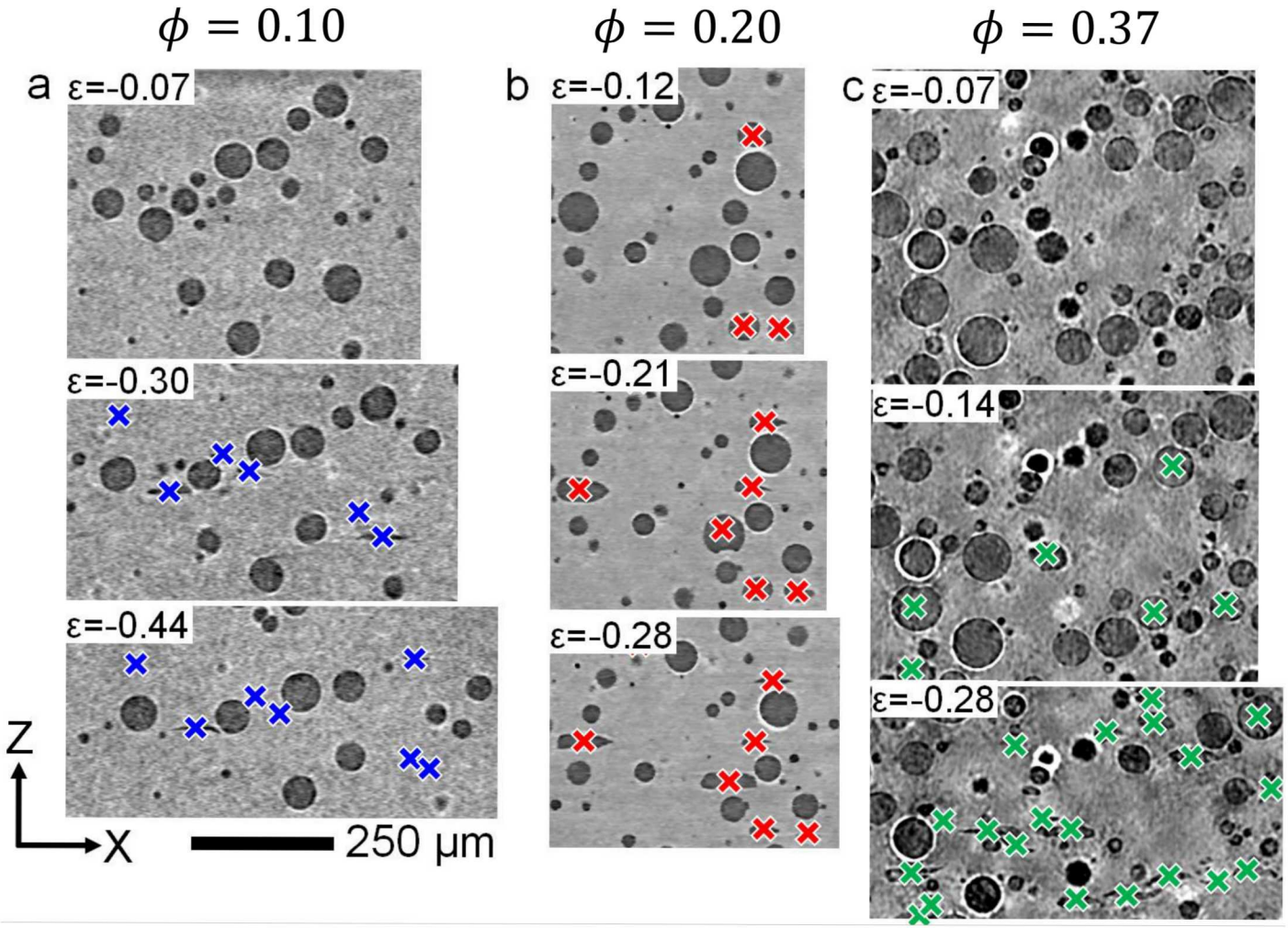
Damage measurement:



Croom, *Composites Part B*, 2019

Effects of Volume Fraction

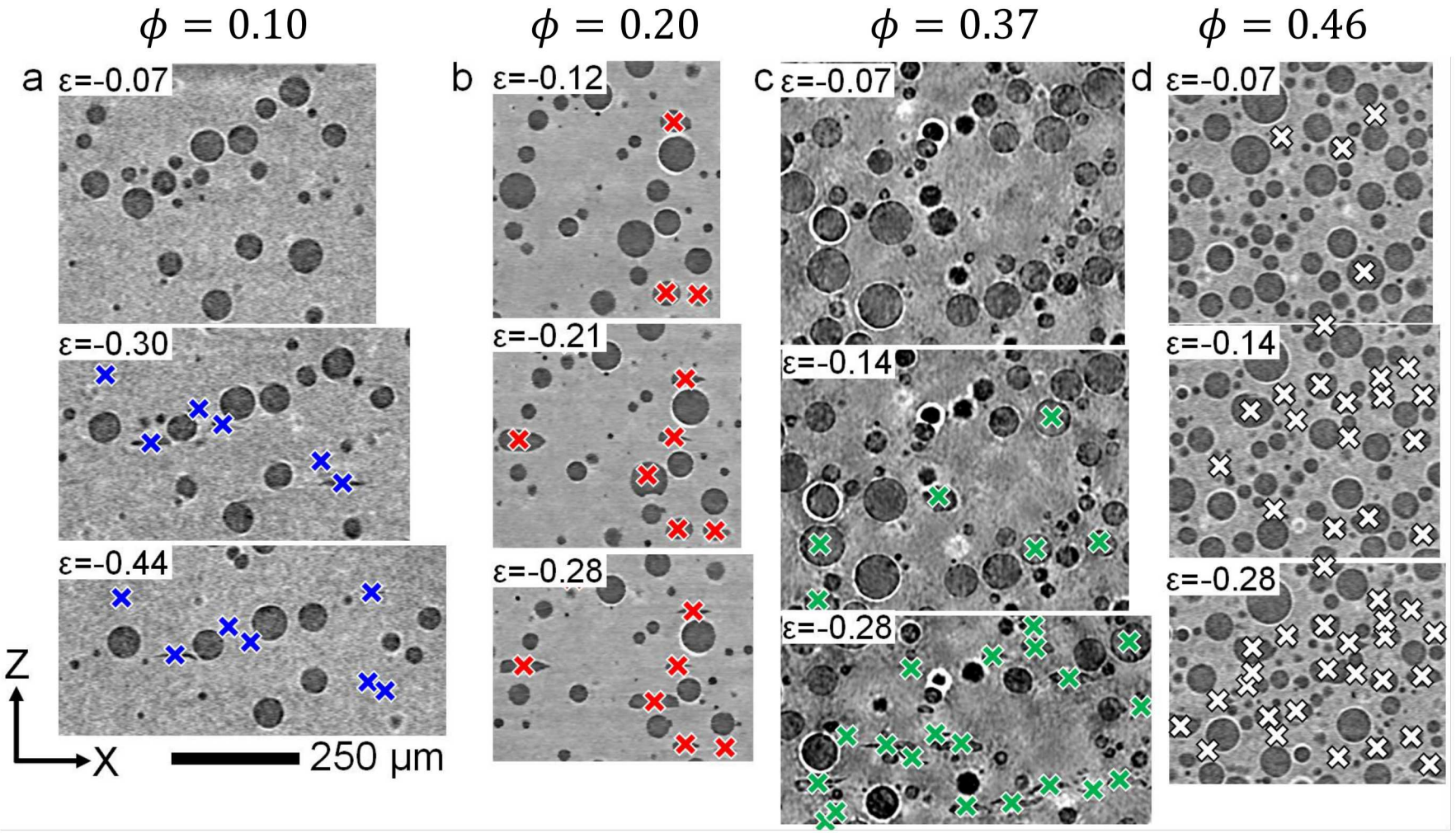
Damage measurement:



Croom, *Composites Part B*, 2019

Effects of Volume Fraction

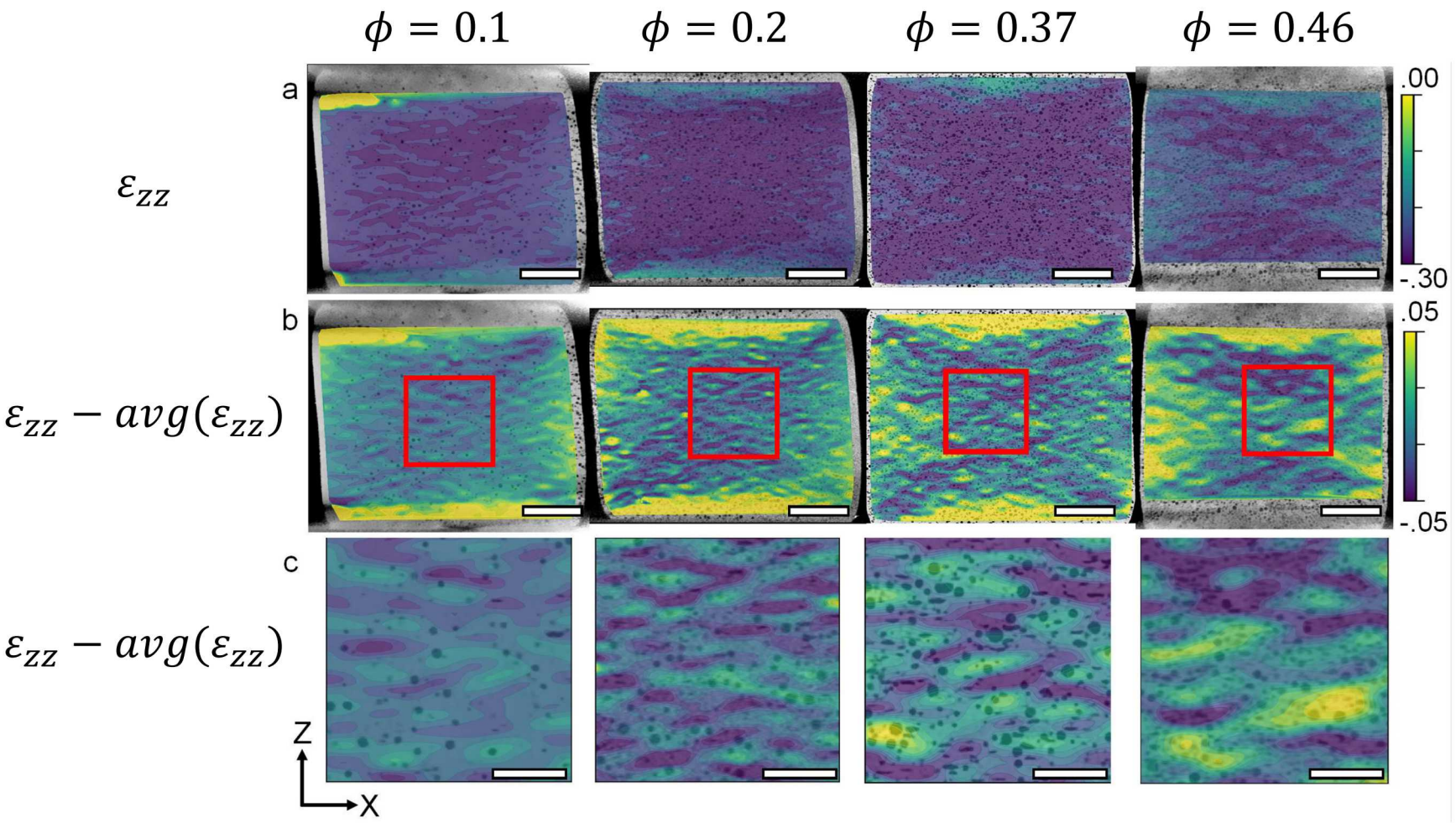
Damage measurement:



Croom, *Composites Part B*, 2019

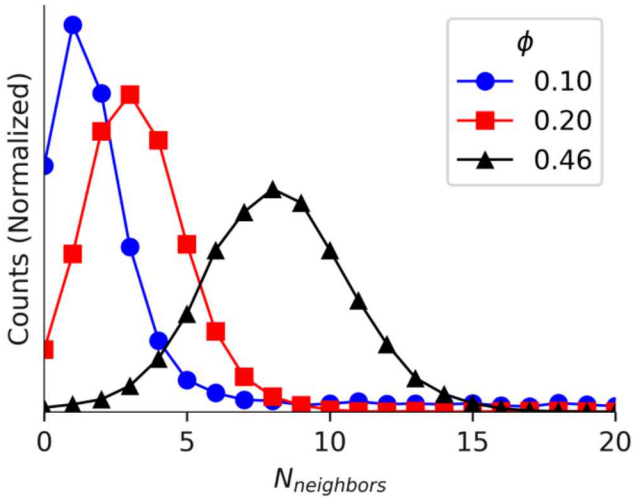
Effects of Volume Fraction

DVC strain measurement:



Croom, *Composites Part B*, 2019

Effects of $N_{neighbor}$

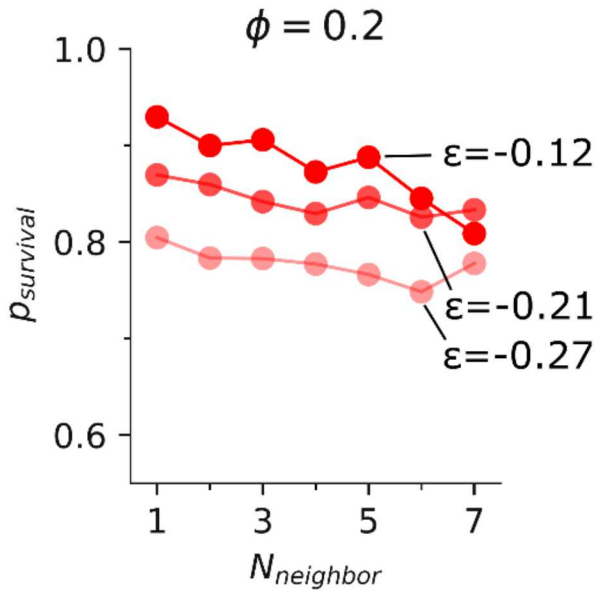


Irregular GMB arrangement leads to variation in $N_{neighbor}$

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

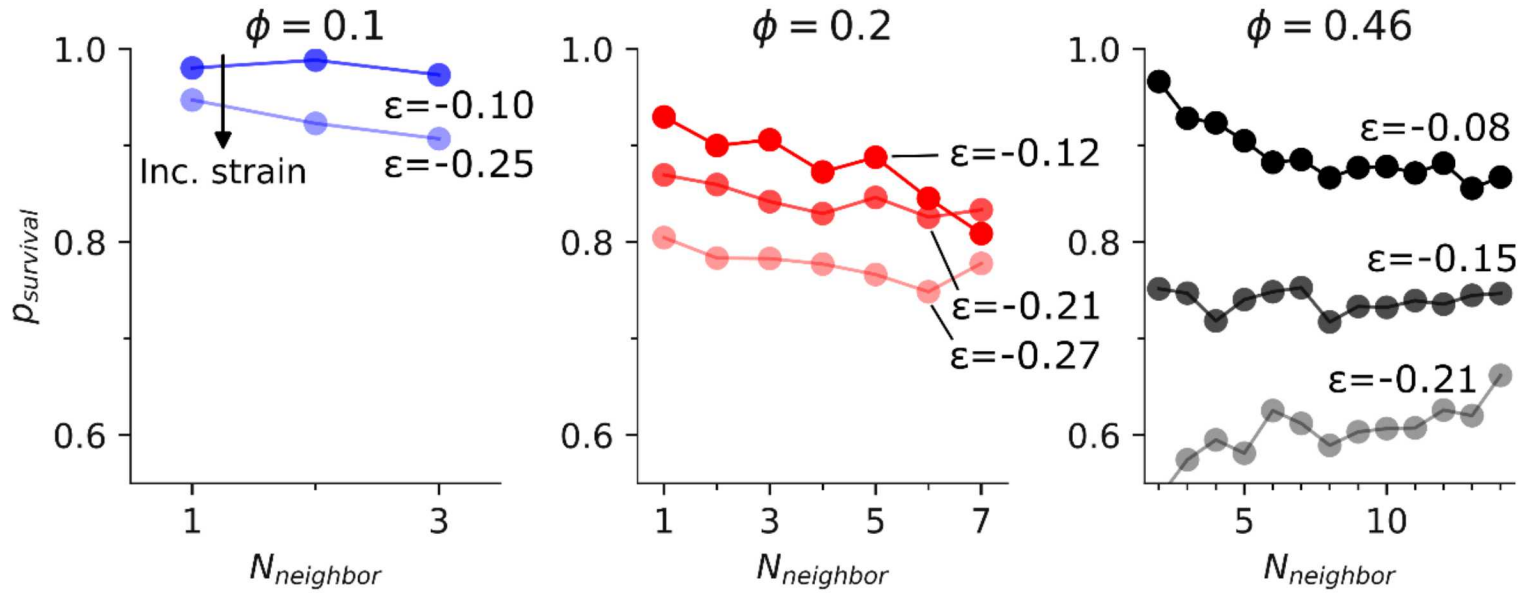
Croom, *Composites Part B*, 2019

Effects of $N_{neighbor}$



Croom, *Composites Part B*, 2019

Effects of $N_{neighbor}$



Decreasing survival at large $N_{neighbor}$

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

Croom, *Composites Part B*, 2019

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
- GMB clustering / agglomeration has strong implications for mechanical response of syntactic foams