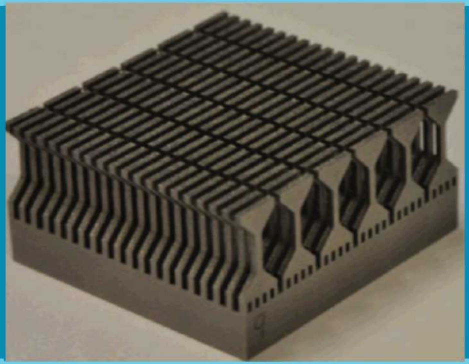
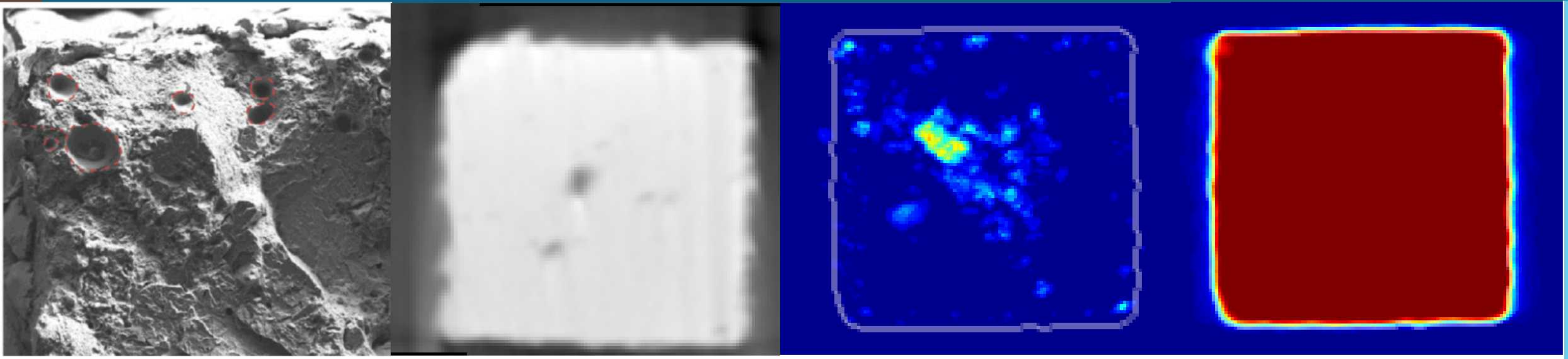
SAND2018-10436C

In-situ Micro-CT Observation of Void Evolution under Interrupted Tensile Loading in Additively Manufactured 316L Stainless Steel





PRESENTED BY

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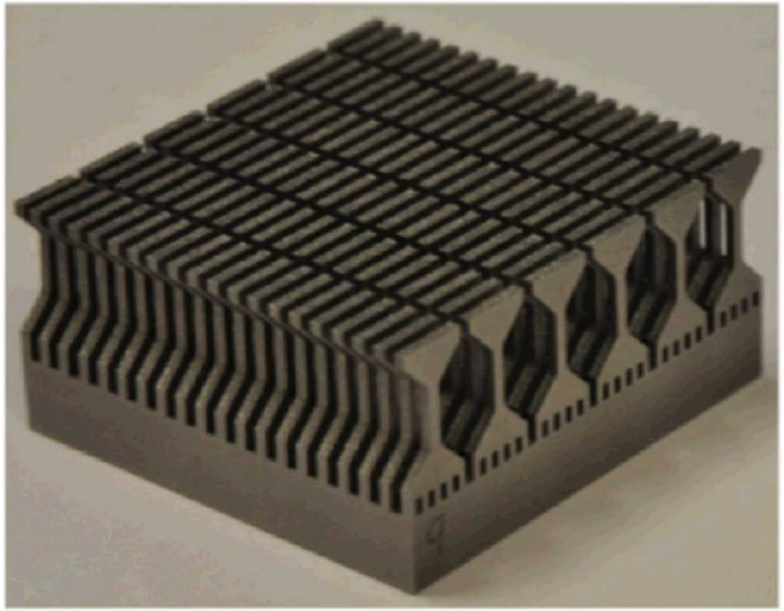
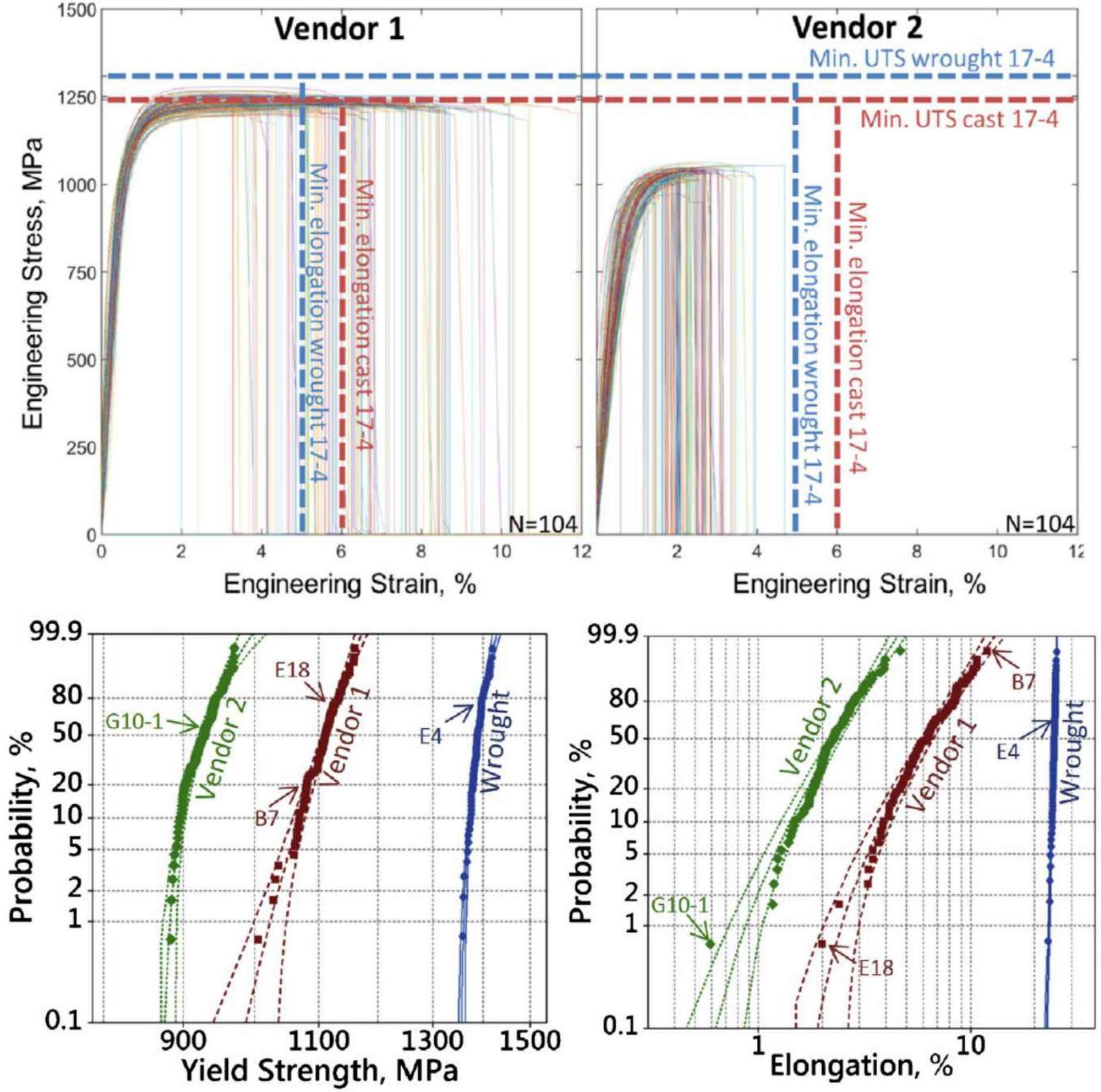
Background: Mechanical Properties of AM Metals

- Explored previously with high-throughput techniques on SLS AM steels (17-4)
- Materials show high variability
- Makes design/qualification of AM parts difficult – e.g. when will they fail?

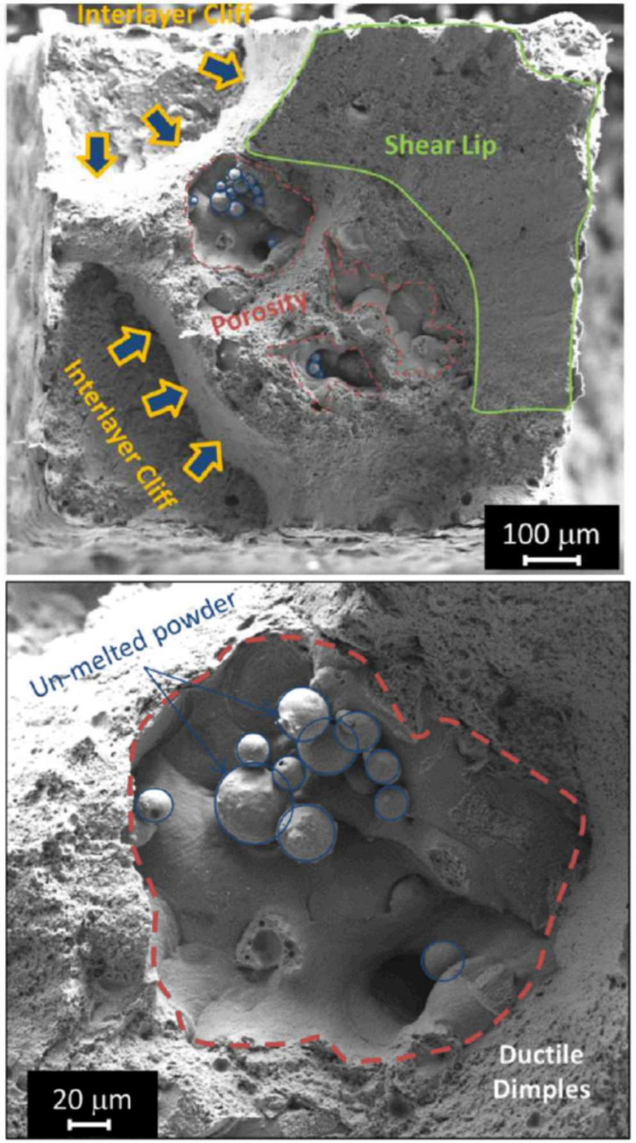




Salzbrenner, Bradley C., et al. *Journal of Materials Processing Technology* 2017

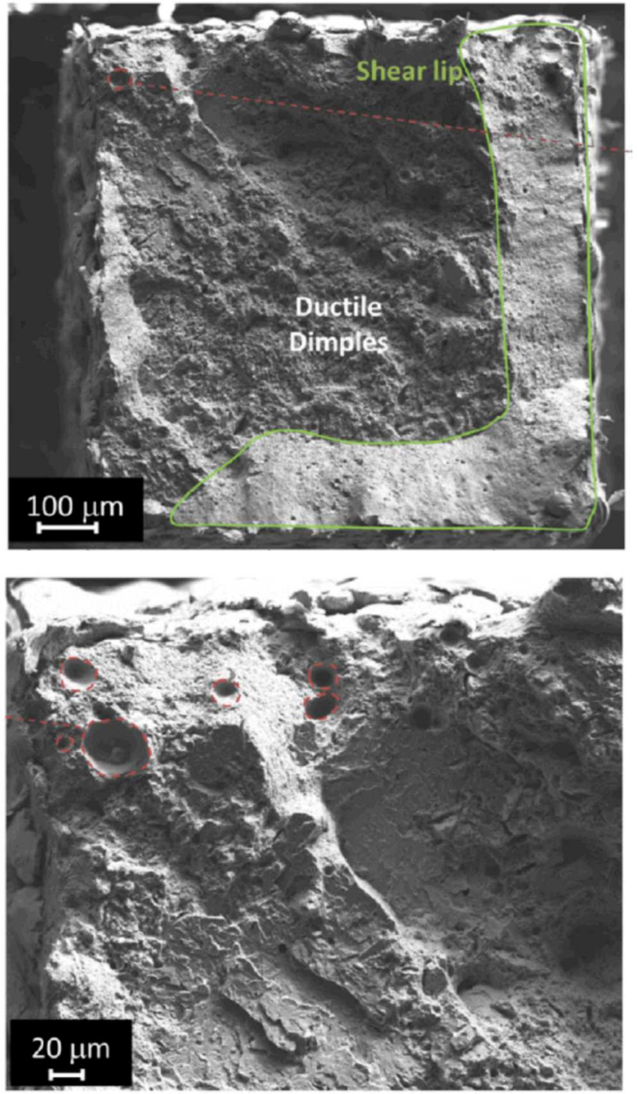
Background: Porosity Effects

Failure at 2% strain



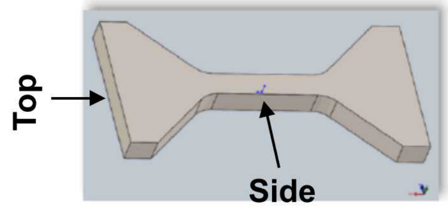
- Material failure appears to be associated with porosity
- On a basic level, “more” porosity seems to be correlated with earlier fracture
- It may be possible to predict behavior for or qualify parts based on porosity

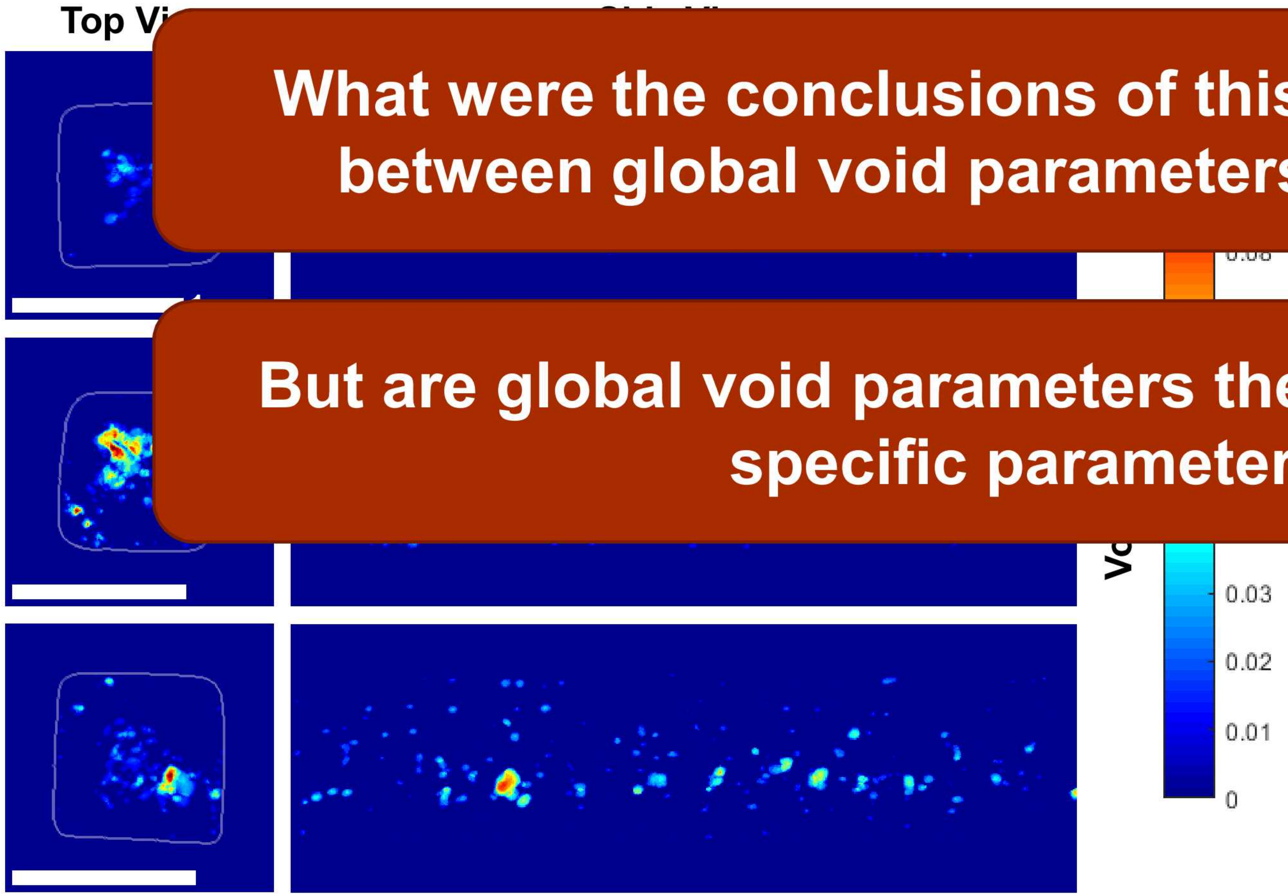
Failure at 12% strain

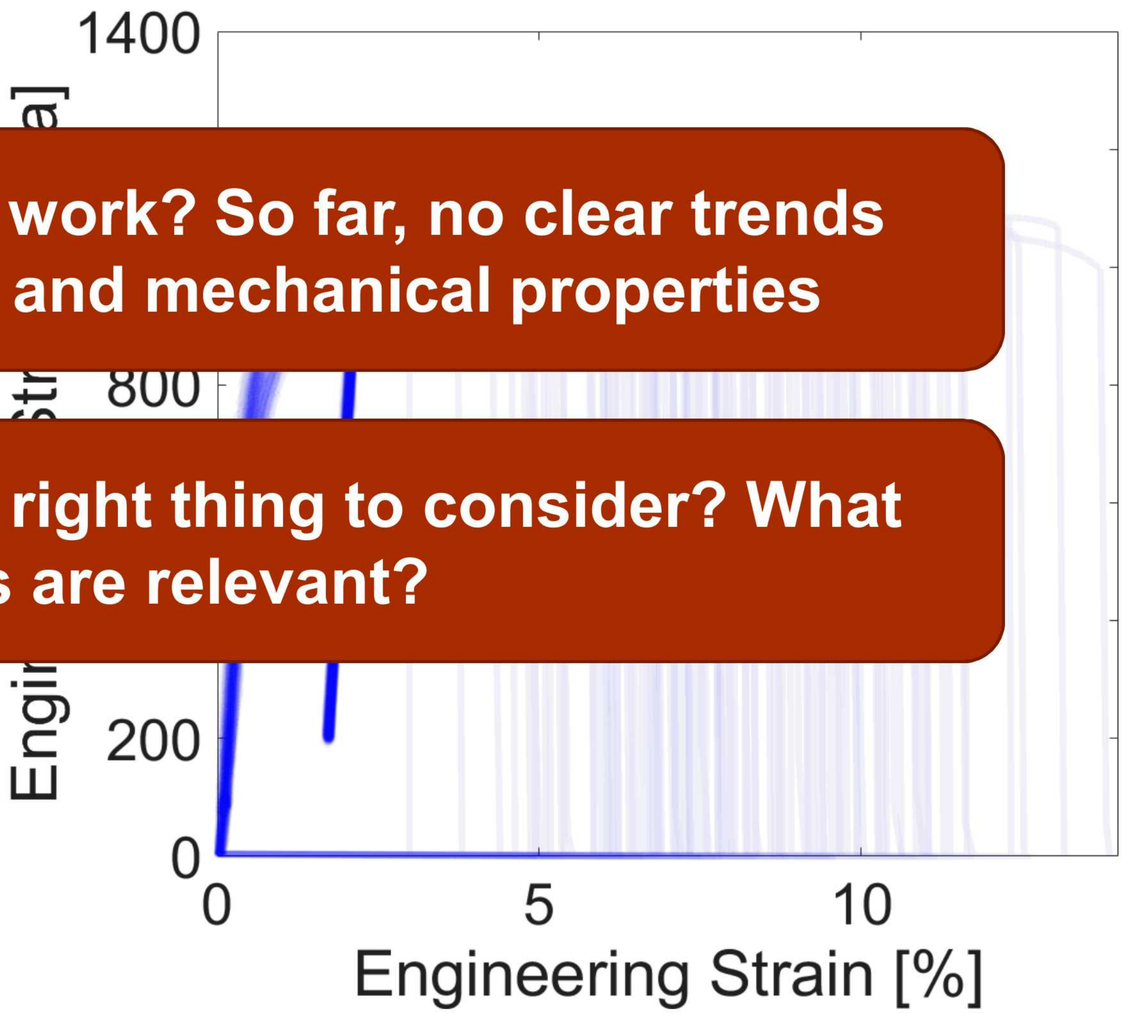


Salzbrenner, Bradley C., et al. *Journal of Materials Processing Technology* 2017

Previous Work: Micro CT Coupled with High Throughput Testing





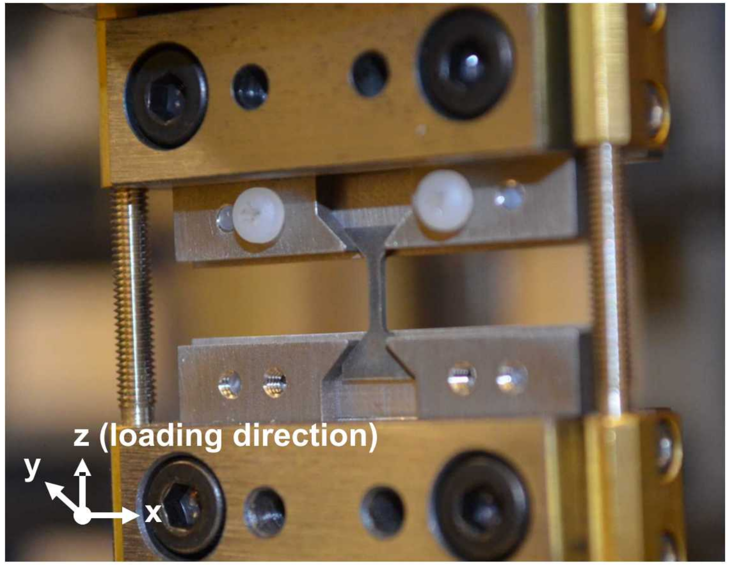


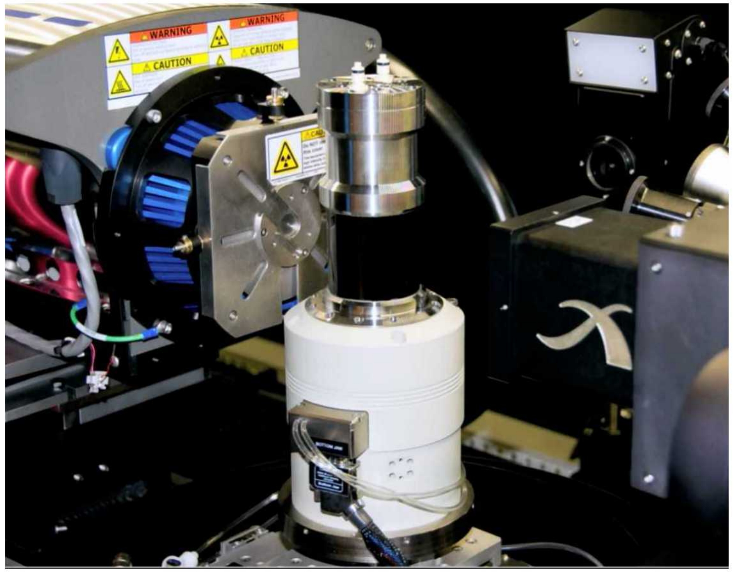
What were the conclusions of this work? So far, no clear trends between global void parameters and mechanical properties

But are global void parameters the right thing to consider? What specific parameters are relevant?

Pre-test micro CT and Tensile Testing performed on 108 tensile dogbones (SS 17-4)

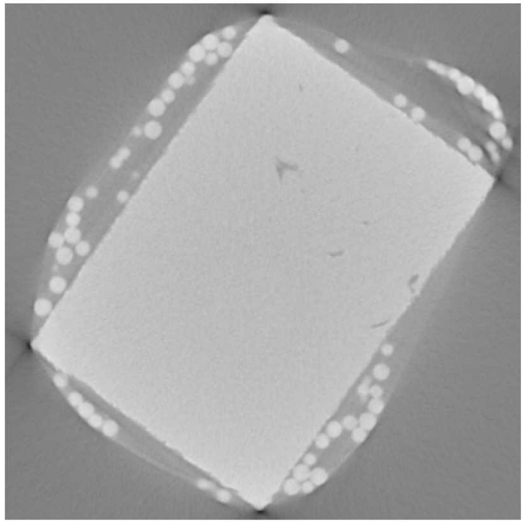
This Work: Couple *in-situ* Micro CT with Tensile Test

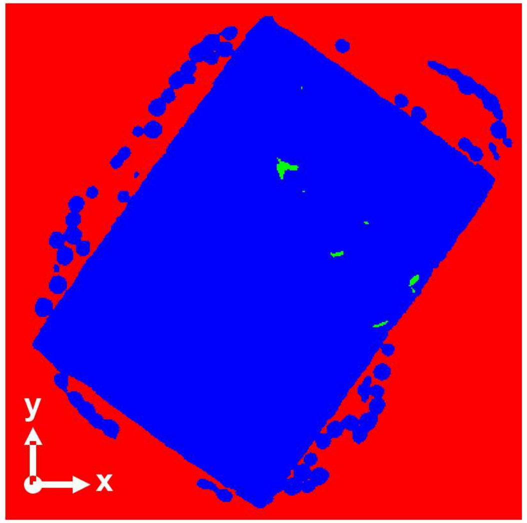




deben.co.uk

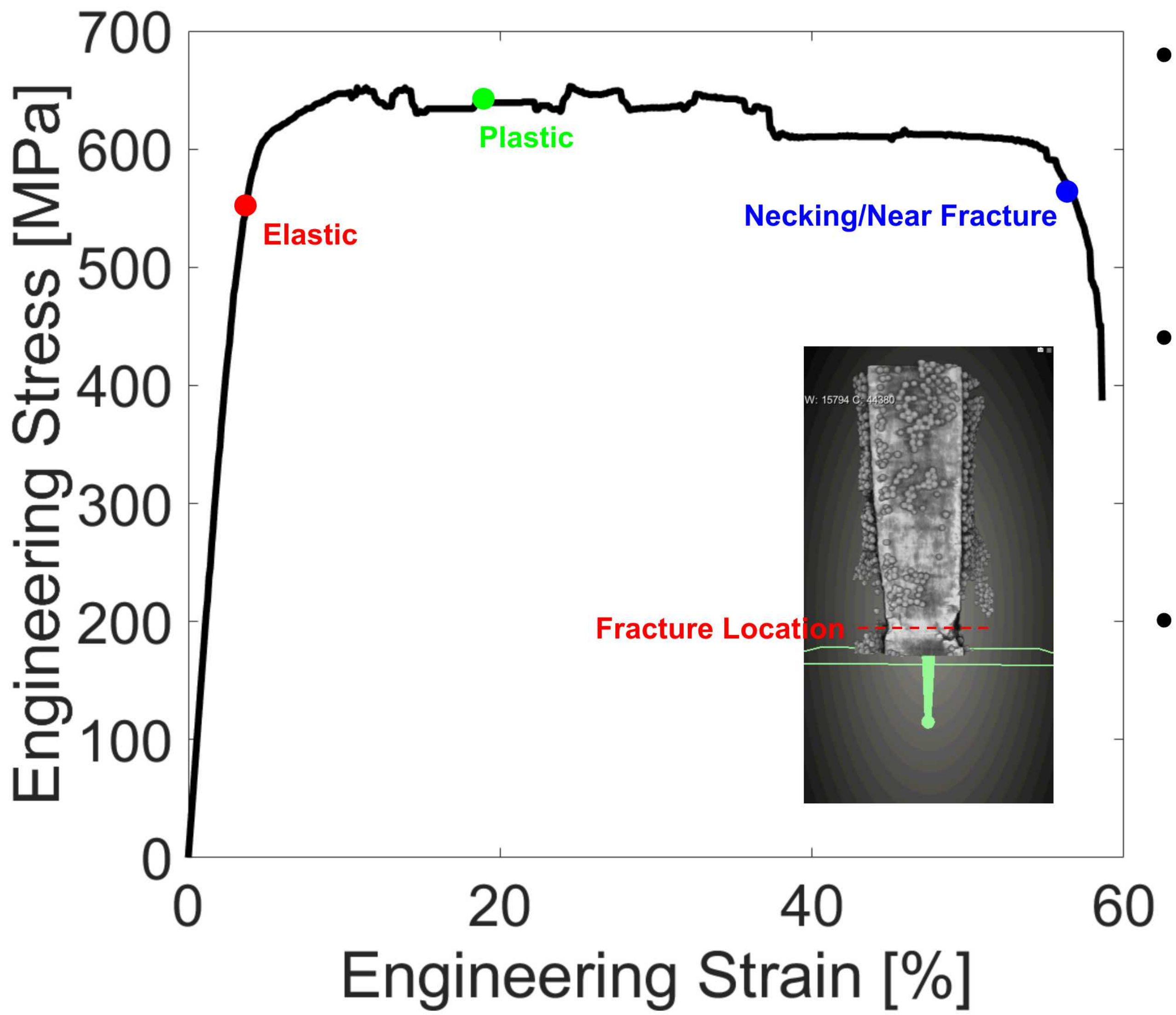
- Test performed on AM 316L sample to fracture with 1x0.75x5 mm gage section with Deben *in-situ* tester
- Micro CT scans performed during test at 160kV, no filter, 3 μm voxel size
- Custom MATLAB script used for segmentation and void characterization





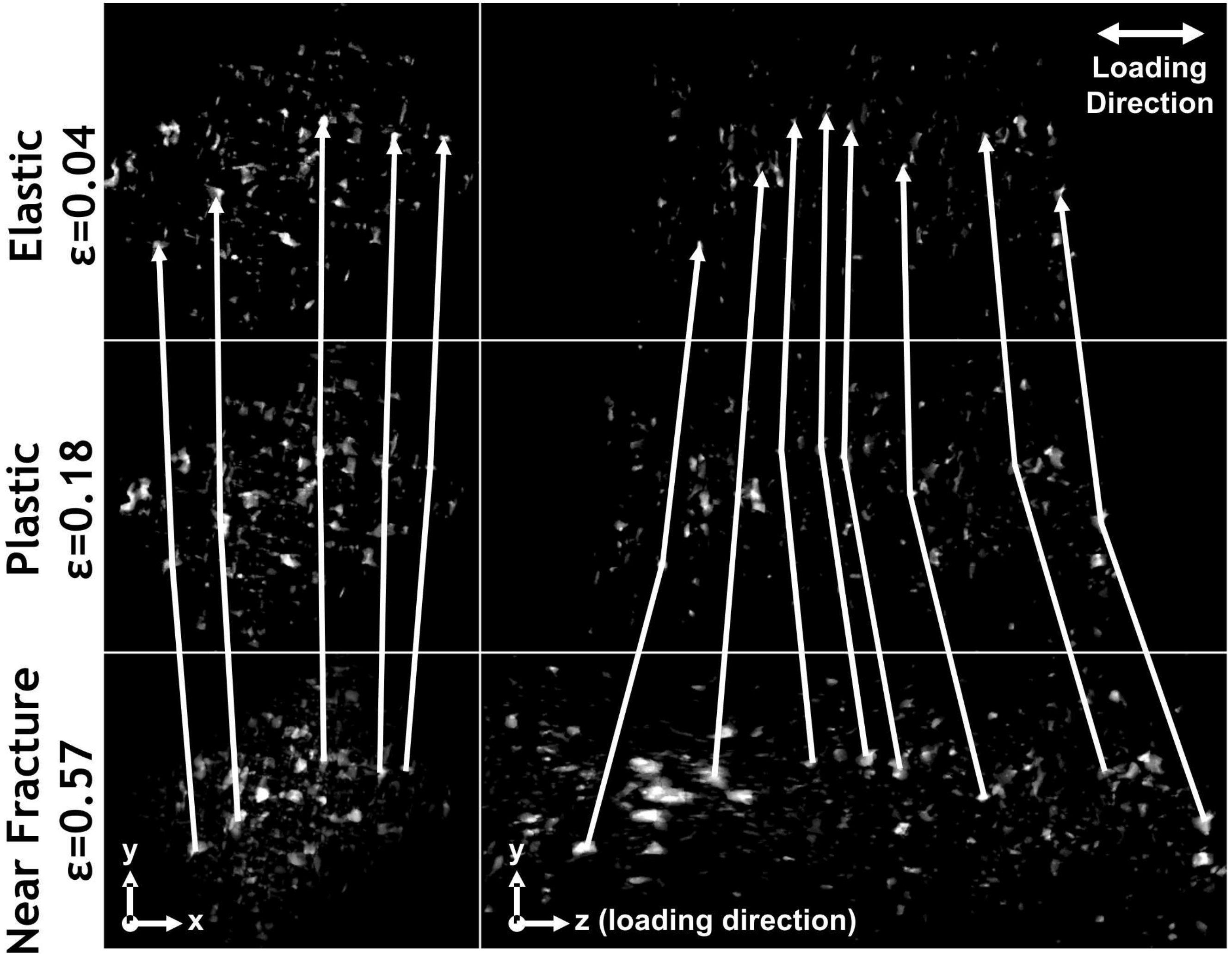
Solid Material
External Region Void

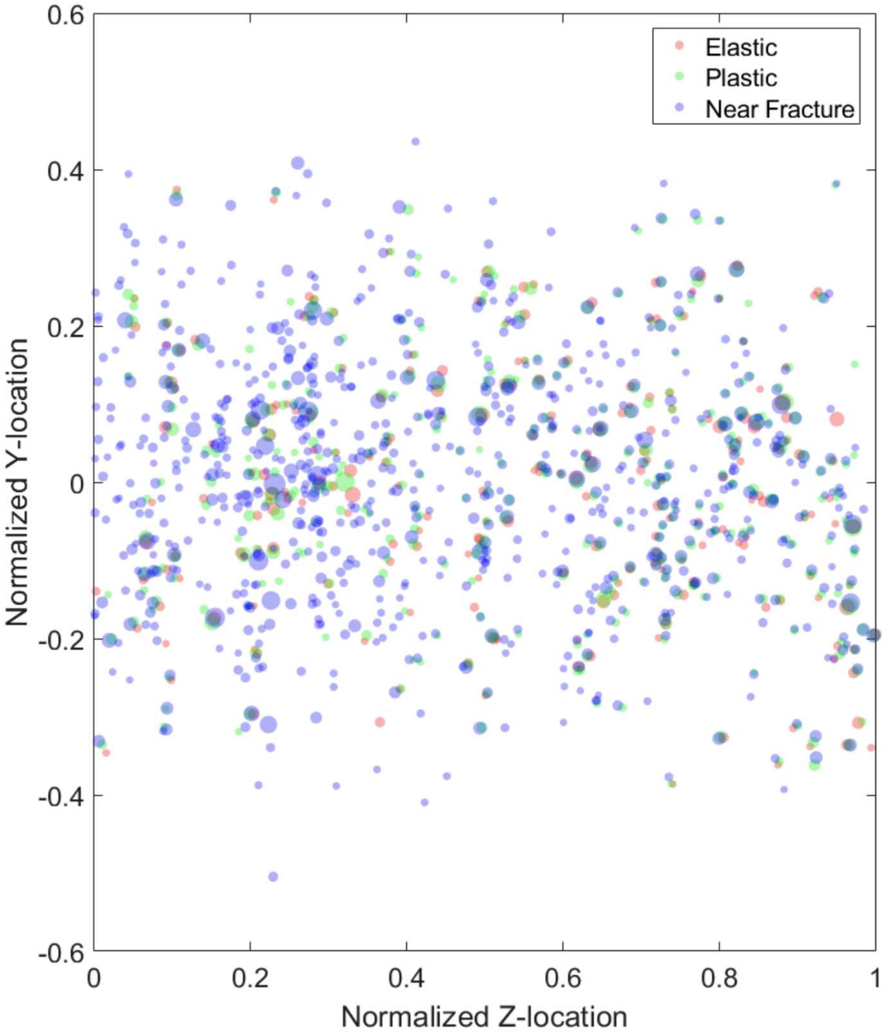
Tensile Behavior



- Interrupted tensile test performed with a total of 10 micro CT scans
- Scans capture region where necking and ultimate fracture occurred
- Focus on three scans from different tensile regimes:
  - **Elastic Regime**
  - **Plastic Regime**
  - **Necking/Near Fracture Regime**

Void Network Definition - 1



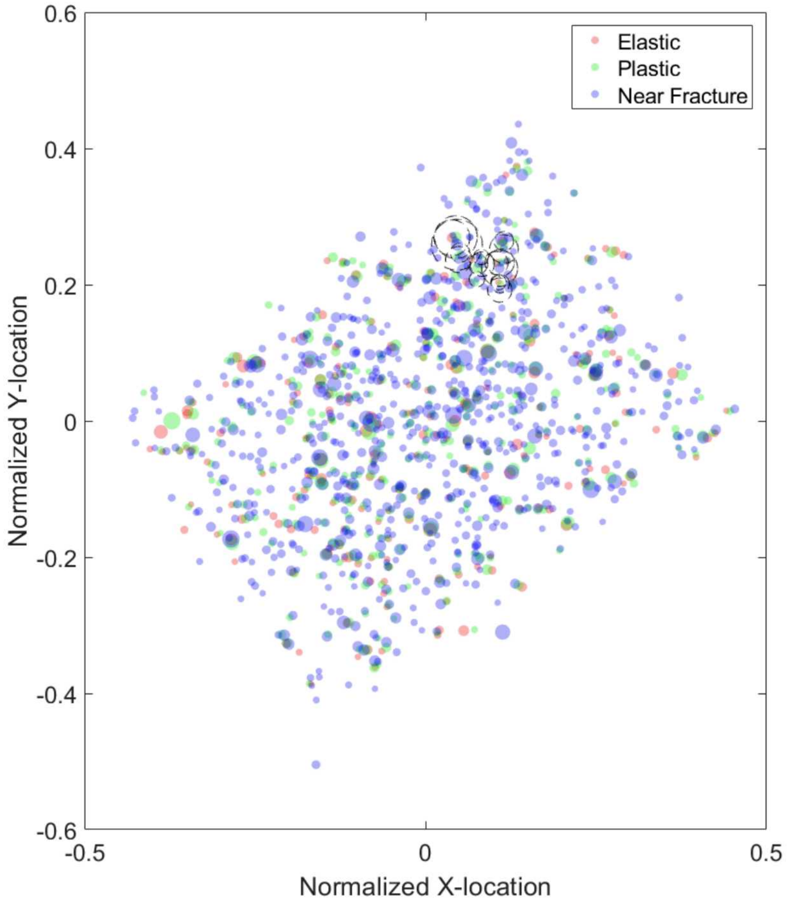


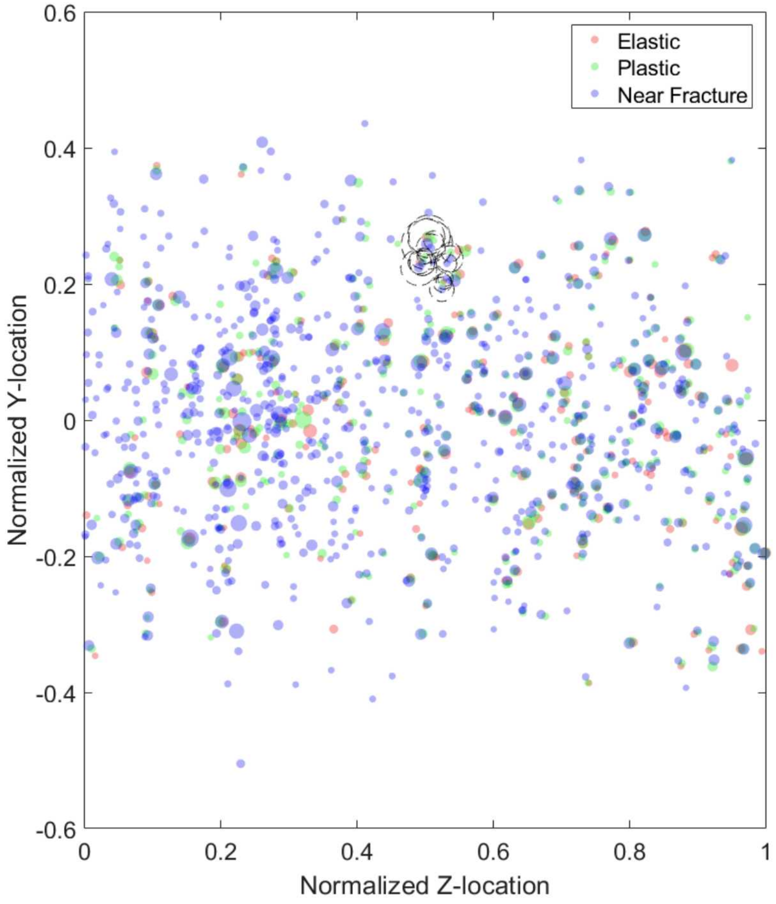
Void correlation and linear interpolation utilized to find normalized void position relative to initial state

Brighter image regimes correspond to higher void density

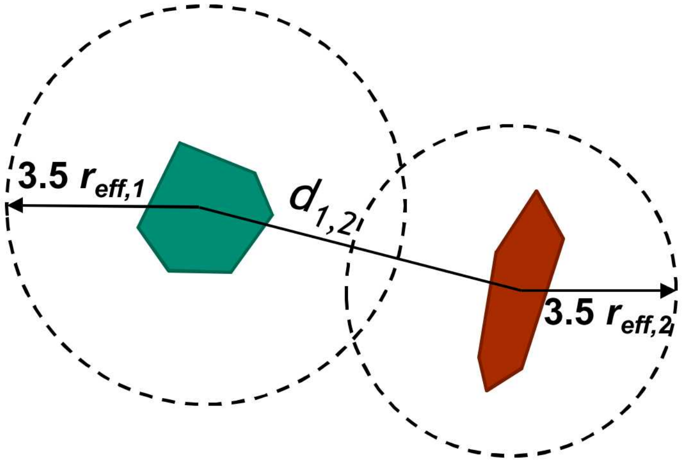
*Point radius equal to normalized effective radius of each void

Void Network Definition - 2



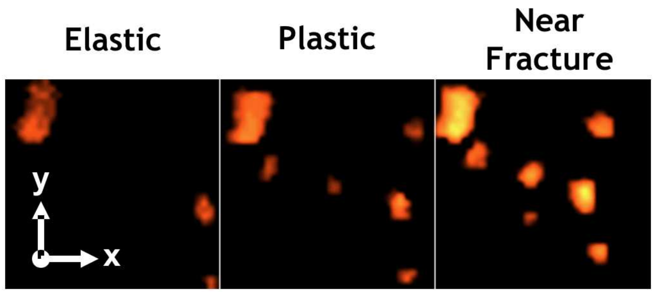


Void Network Criterion:



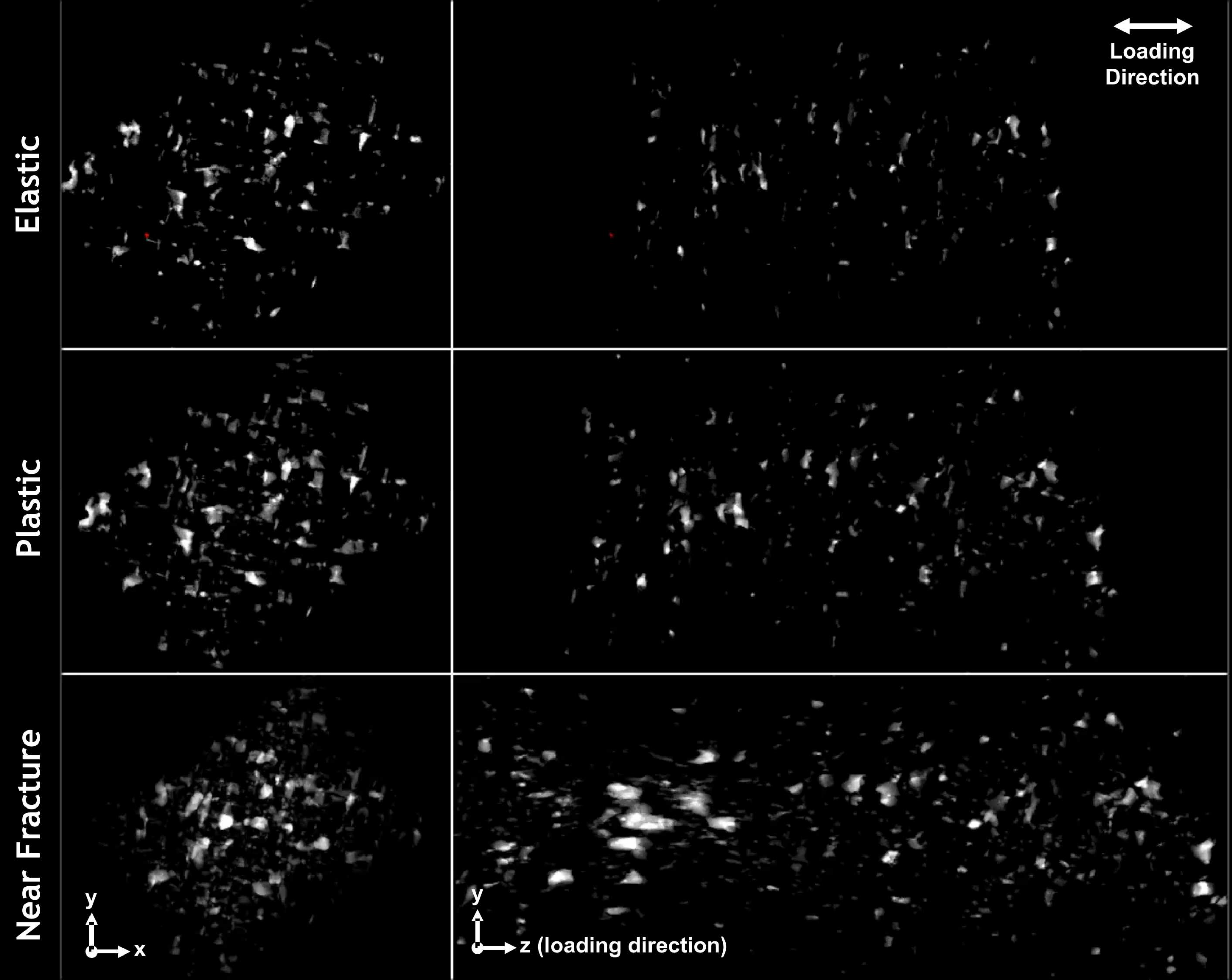
$$d_{n,m} < 3.5\,(r_{eff,n} + r_{eff,m})$$

*Using normalized positions and radii at any strain value

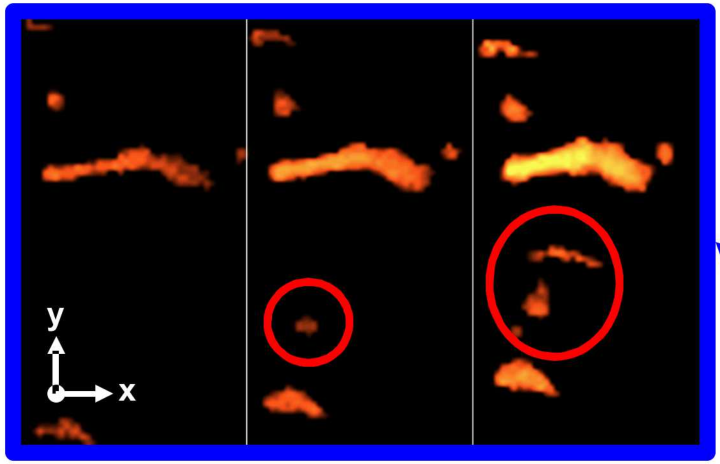


Find networks of voids positionally related at *any* strain

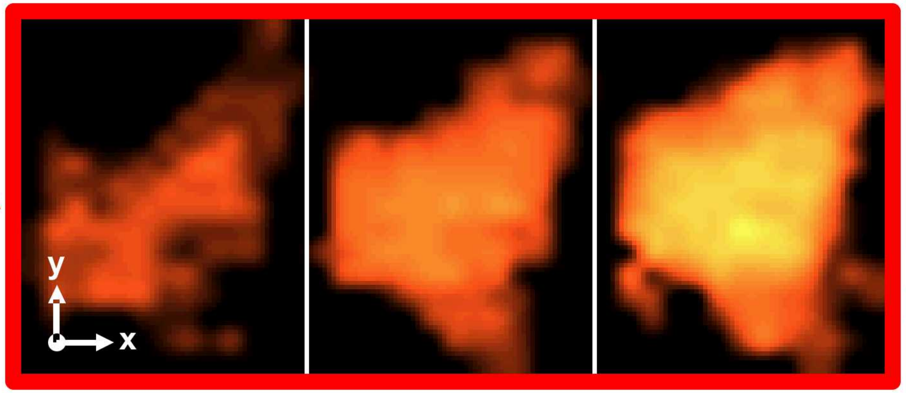
➔ Total of 443 Void Networks


Loading Direction
Elastic
Plastic
Near Fracture
y
x
y
z (loading direction)

Void-based Deformation Mechanisms

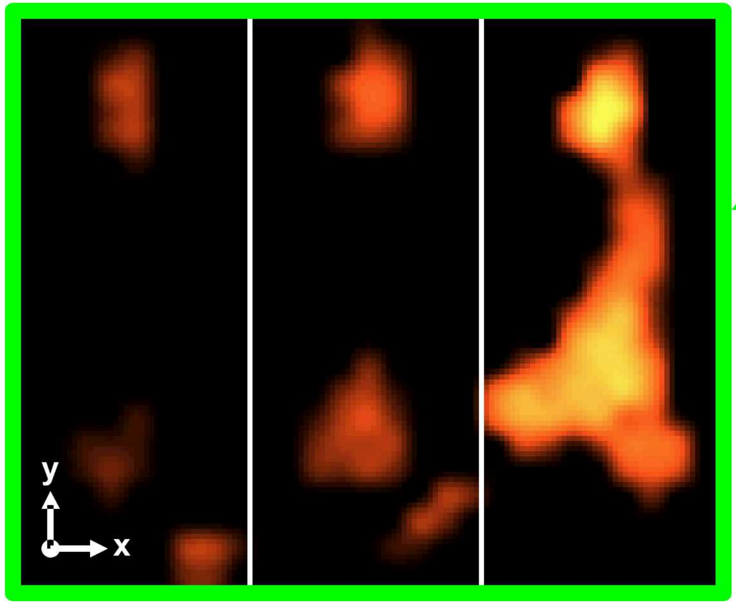


1) Void Growth

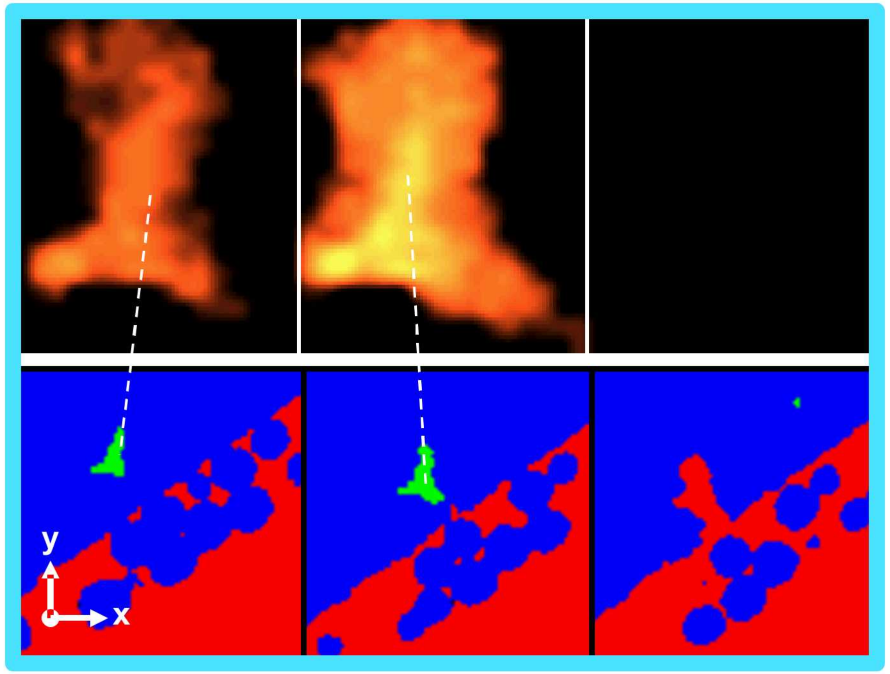


2) Void Emergence (formation/growth)

3) Void Coalescence



4) Free-Surface Absorption

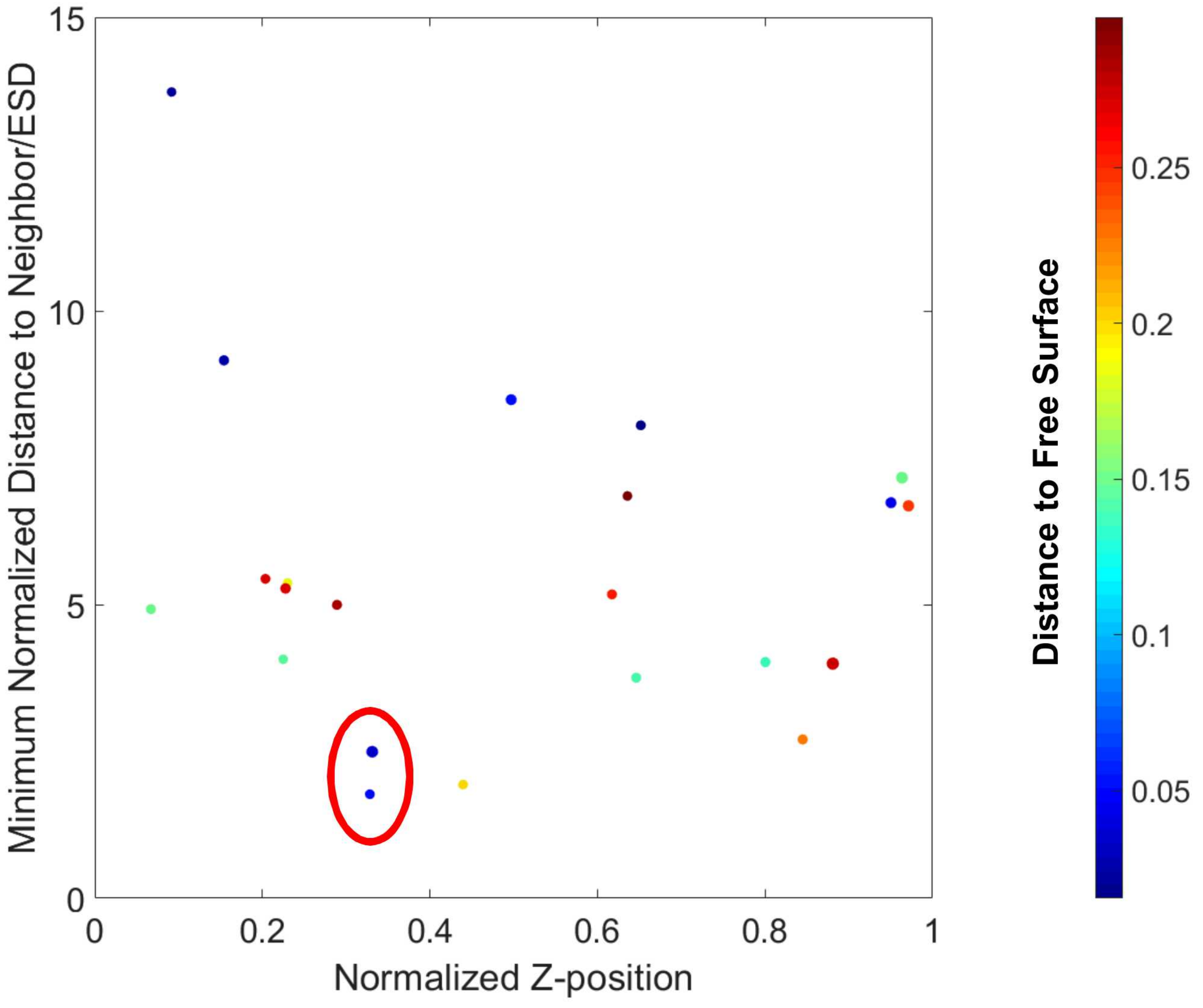


Note for void network evolution images, brighter image corresponds to higher void density

Relevant Void Parameters

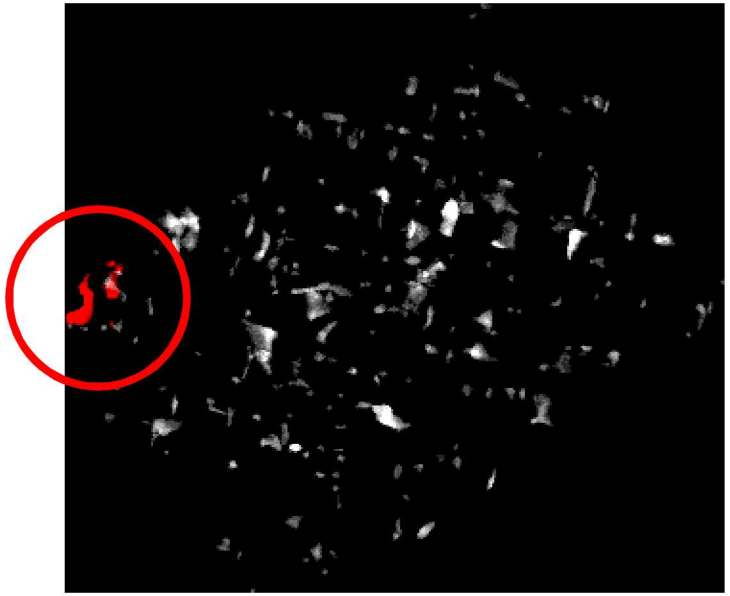
What parameters might influence local deformation behavior?

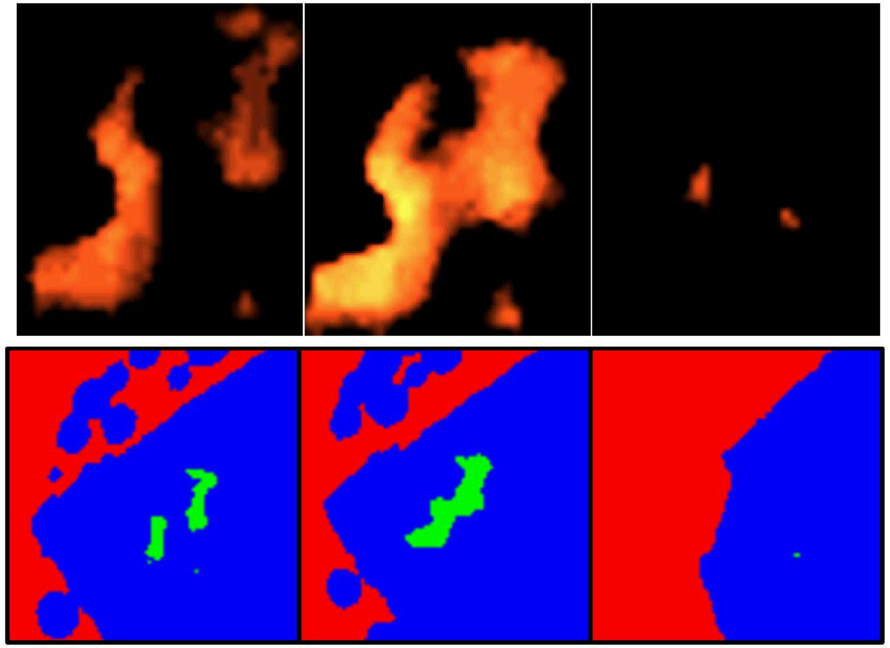
- Void Size
- Distance to neighbor
  - Greater influence from large neighbors
- Void location
- This leaves one void network which satisfies the following conditions:
  - Large void size
  - Close to large neighbors
  - Close to free surface



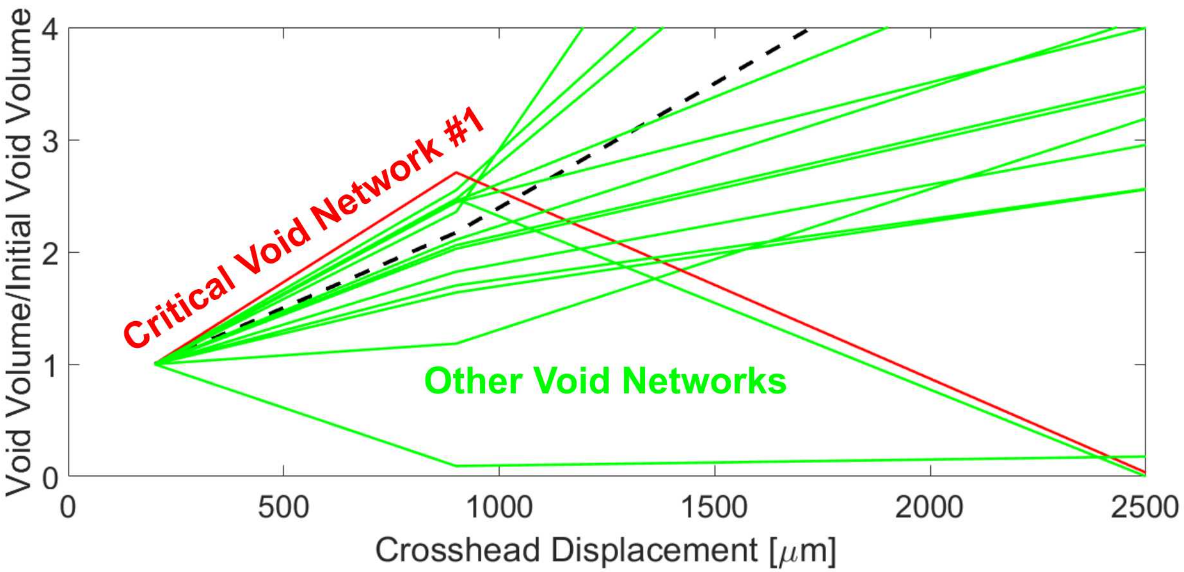
Point Radius ~ Effective Radius
ESD = Equivalent Spherical Diameter

Critical Void Network #1:

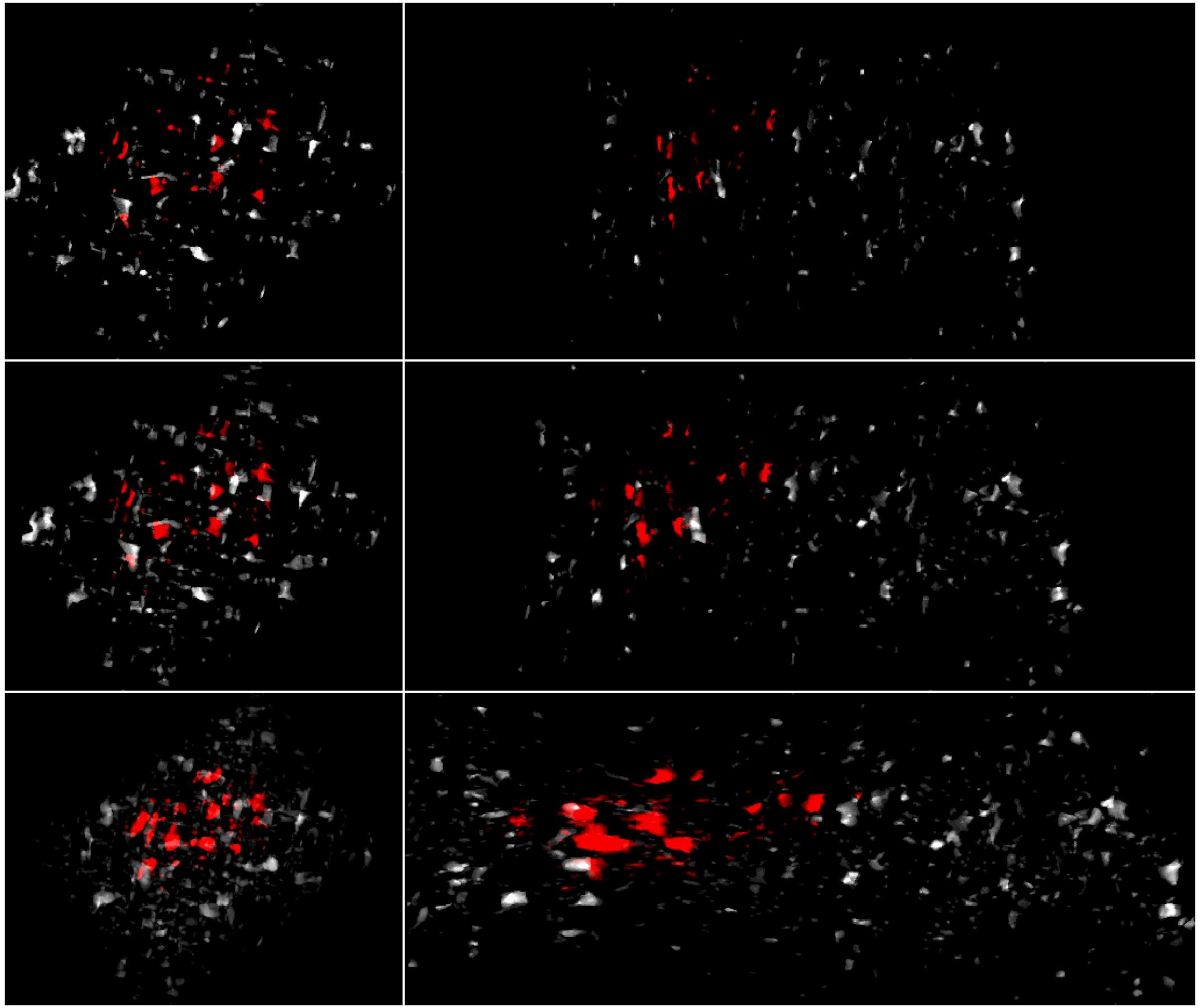


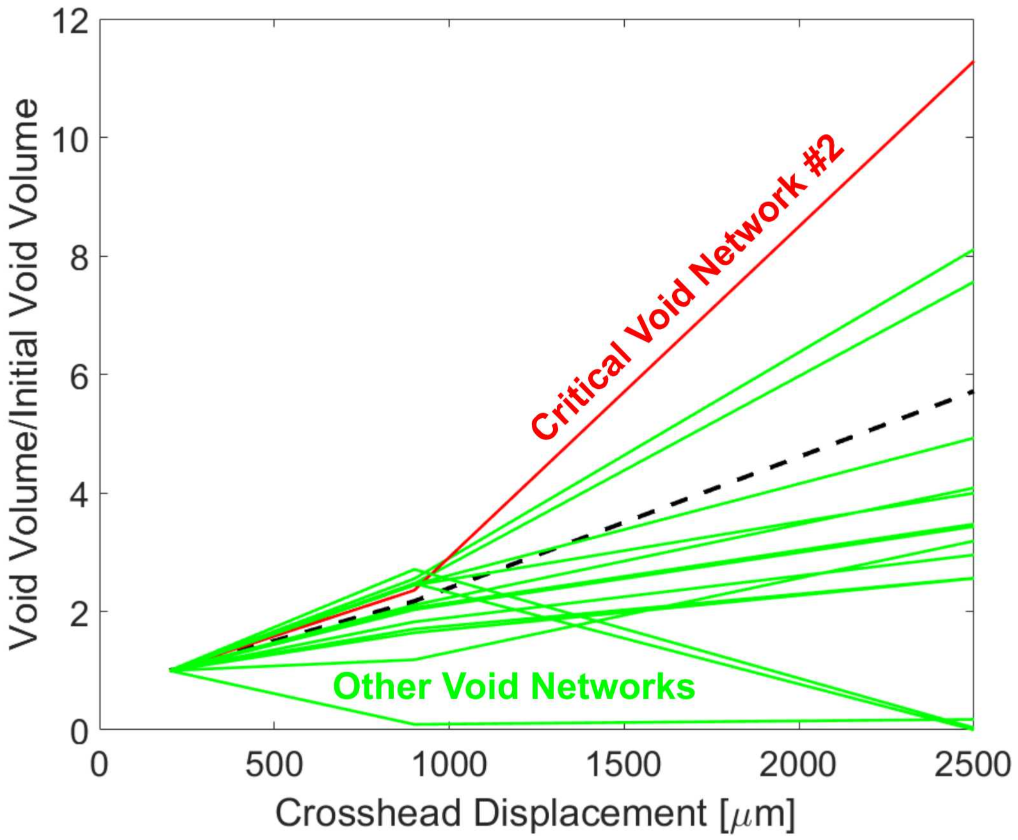


- Voids grow and coalesce in plastic regime
- Before fracture, voids absorb into free surface
- Largest growth in plastic regime observed for this void network
- So does that mean it dictates fracture?



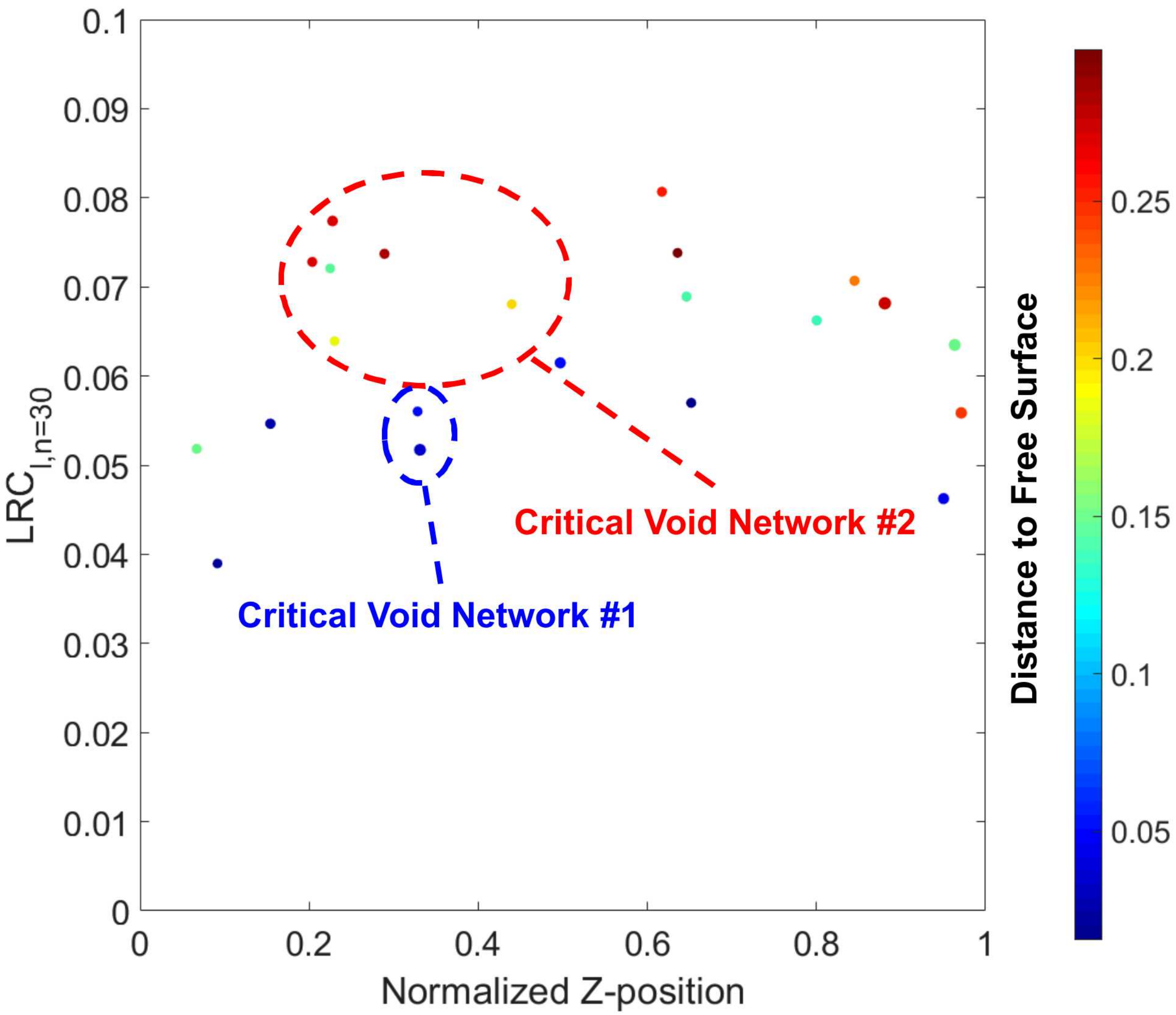
Critical Void Network #2:



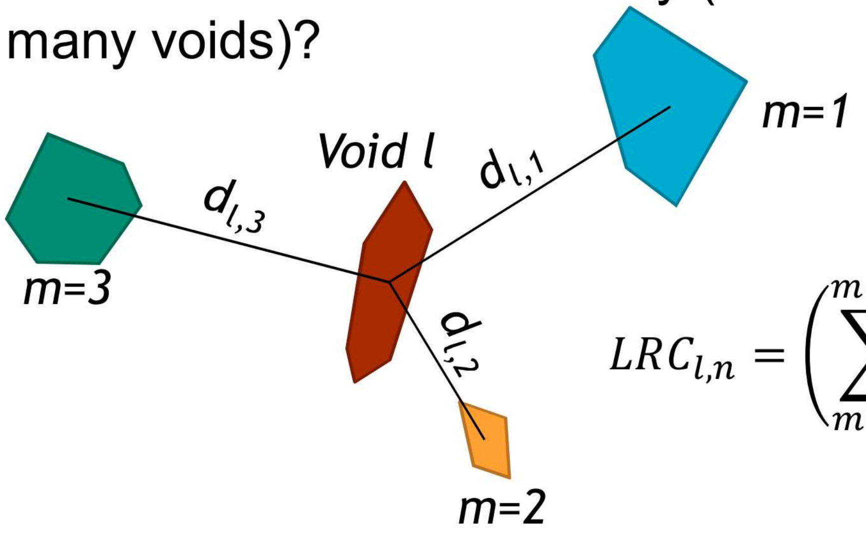


- What is critical about these voids that cause the higher void emergence/growth to occur for this void network?

Influence of Void Properties: Long Range Connectivity



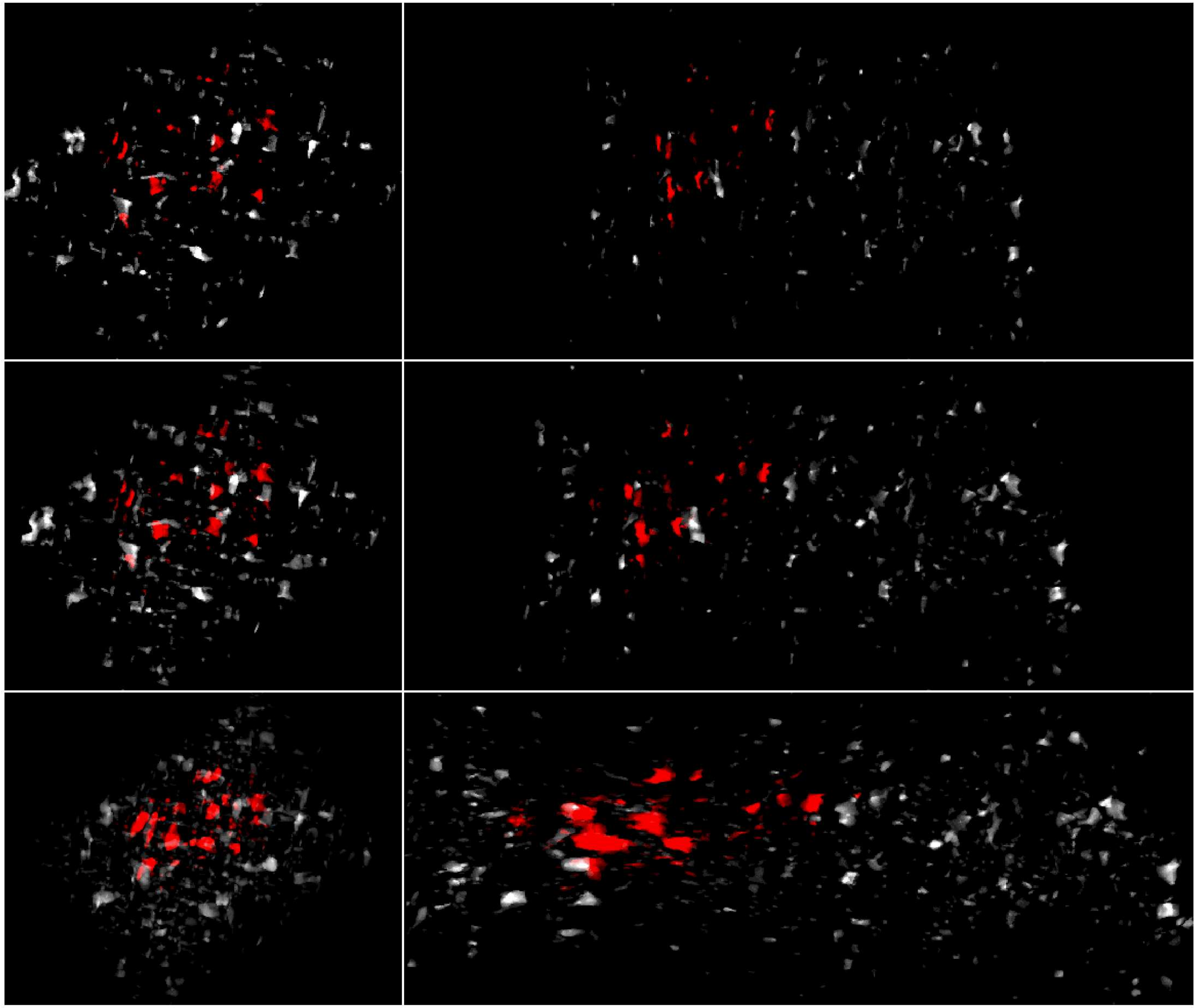
- Using same metrics used to find Critical Void Network 1, there are no clear explanations as to why void emergence and growth is most dominant at these voids
- What about void connectivity (relationship to many voids)?



$$LRC_{l,n} = \left(\sum_{m=1}^{m=n} \frac{d_{l,m}}{ESD_m}\right)^{-1}$$

- Critical Void Network 2 shows relatively high LRC (indicating these voids are close to many large voids)

Summary: Sample Deformation



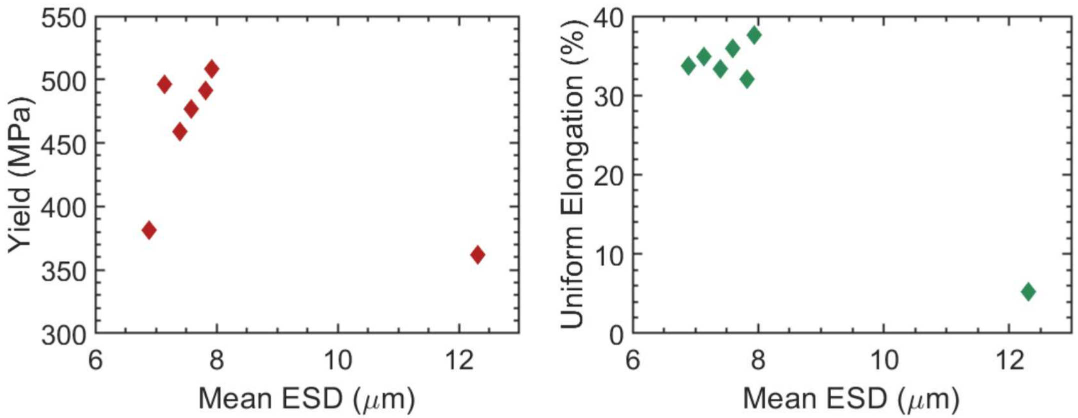
- Initial deformation localization highest for Critical Void Network 1 with the following features:
  - Contains several large voids
  - These voids are close to other large voids
  - These voids are close to the free surface
- Highest void growth/emergence and necking observed in Critical Void Network 2
  - Deformation localization from Critical Void Network 1
  - Higher connectivity to other voids for this void network

Conclusions

- Localized (not global) void parameters appear to dictate the deformation behavior
- In plastic deformation, parameters including void size, neighbor relationship, and void location seem to contribute the most to deformation
- Necking and ultimate material fracture appear to depend on a combination of deformation localization under plasticity and void network connectivity in high deformation regimes

Future Work

- Return to high throughput data: can criterion identified in this work better predict properties of AM metals?
  - There are other systems where treating the parameters in a similar fashion may be beneficial, e.g. Process Study:



Previous talk by Thomas Ivanoff

- Further analyze this data: how does the evolution of all void networks correspond to the void parameters?