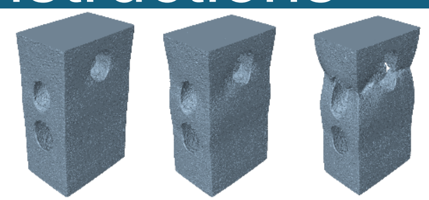
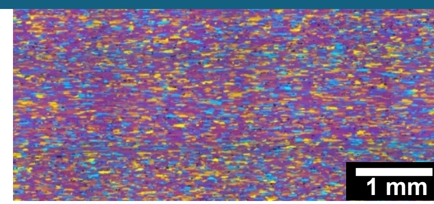
SAND2018-11709C

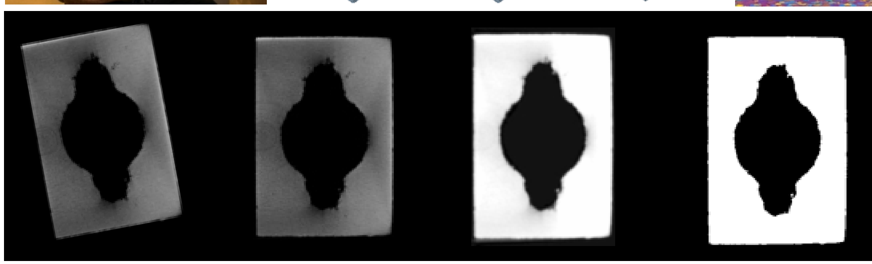
MS&T18 MATERIALS SCIENCE & TECHNOLOGY

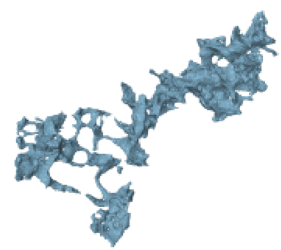
Sandia National Laboratories

Assessing the Impact of Image Acquisition/Processing Method on 3D Reconstructions









IMS International Metallographic Society
ASM INTERNATIONAL

MS&T 2018

Wednesday Oct. 17, 2018

PRESENTED BY

Thomas Ivanoff, Jonathan Madison, Josh Koepke, and Bradley Jared

U.S. DEPARTMENT OF ENERGY NNSA

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Outline

Why 3D Analysis?

3D Reconstructions and Assessment Metrics

- Common methods and measures

Image Processing Workflow

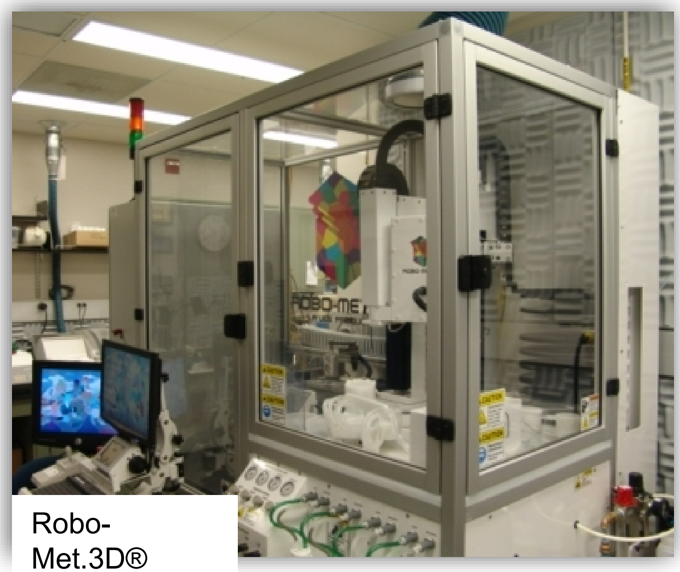
Impact of Image Processing

- Area of focus: segmentation

Impact of Acquisition Technique

- Microcomputed X-ray tomography
- Destructive serial sectioning Robo-Met.3D®

Summary



Robo-Met.3D® UES, Inc.

Why Study Microstructure/Structure in 3D?

2D characterization techniques are inadequate for characterization of certain 3D aspects of microstructure (e.g. morphology and topology)

3D shapes and distributions influence the mechanical and physical properties of materials

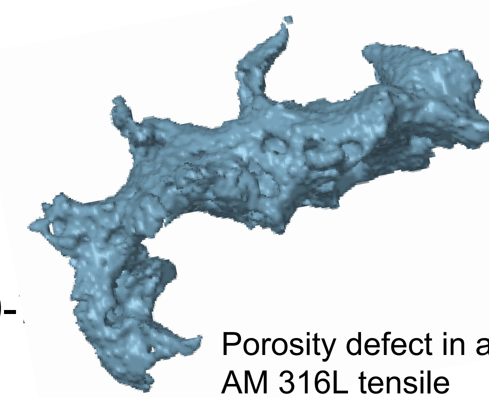
3D reconstructions used to develop and validate computational models

Powerful computer hardware is reasonably priced and commercial software packages are available for 3D reconstruction, visualization, and analysis

- DREAM.3D, Matlab, Paraview, IDL, Mimics, 3Matic, etc

Importance of 3D materials science is increasing:

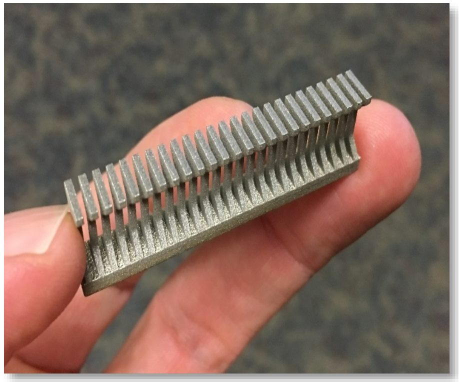
- *Materials Characterization*, 2017, vol. 124, pp. 241 – 249
- *Surface and Coatings Technology*, 2017, vol. 310, pp. 70-
- *JOM*, 2011, vol. 63, no. 3
- *MRS Bulletin*, 2008, vol. 33, no. 6
- *Scripta Materialia*, 2006, vol. 55, no. 1



Porosity defect in an AM 316L tensile dogbone

3D reconstruction

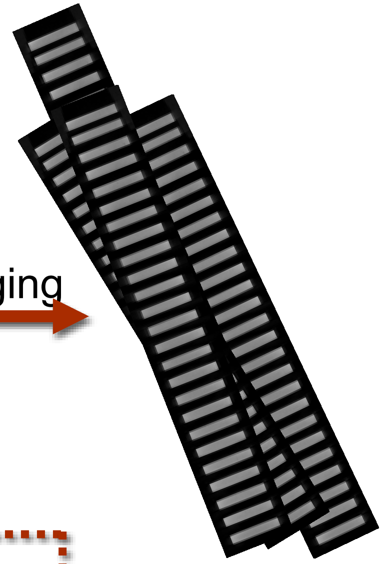
Part to be reconstructed



3D reconstruction

Part to be reconstructed

Imaging



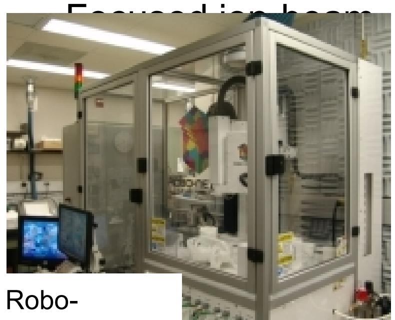
Non-destructive

- Micro-computed tomography
- Synchrotron

Nikon Avonix M2 225/450 kV Helical Scanner

Destructive

- Mechanical-serial-sectioning
- Tri-beam (SEM) serial sectioning
- Focused ion beam

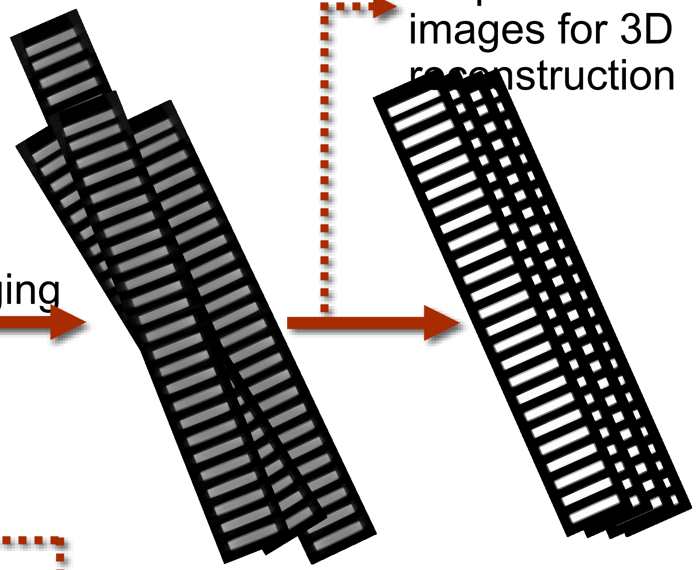


Robo-Met.3D UES, Inc.

3D reconstruction

Part to be reconstructed

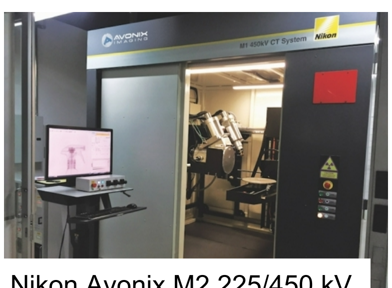
Imaging



Prepare 2D images for 3D reconstruction

Non-destructive

- Micro-computed tomography
- Synchrotron



Nikon Avonix M2 225/450 kV Helical Scanner

Destructive

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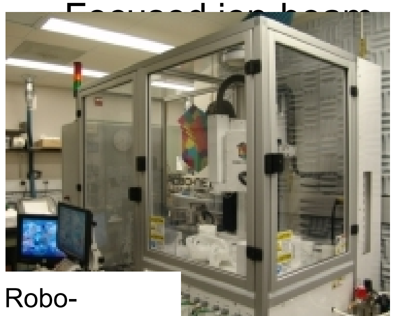
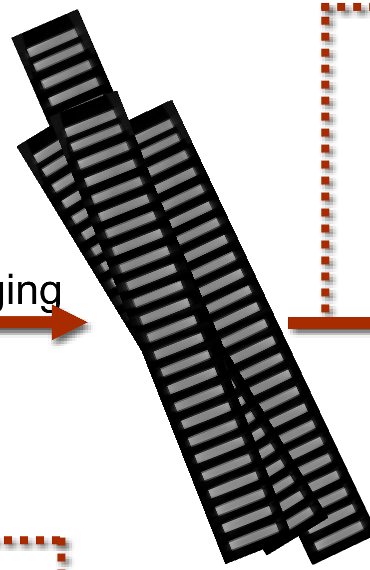


Robo-Met.3D UES, Inc.

3D reconstruction

Part to be reconstructed

Imaging



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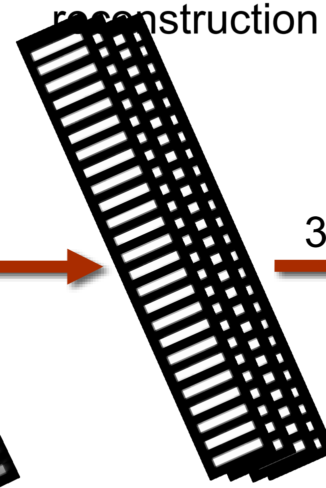
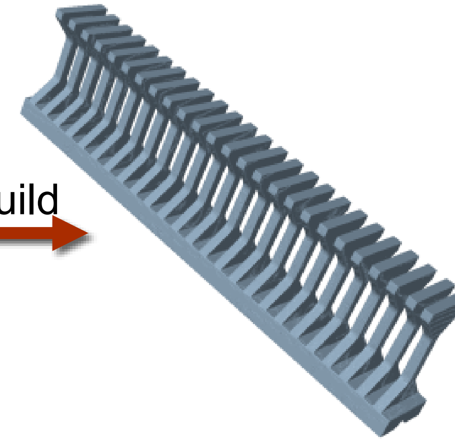


3D Rebuild



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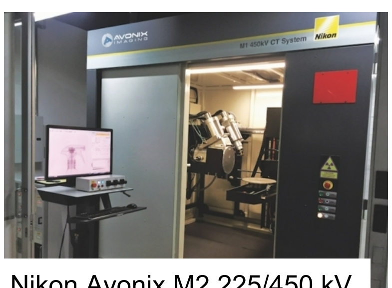

Nikon Avonix M2 225/450 kV Helical Scanner

Destructive

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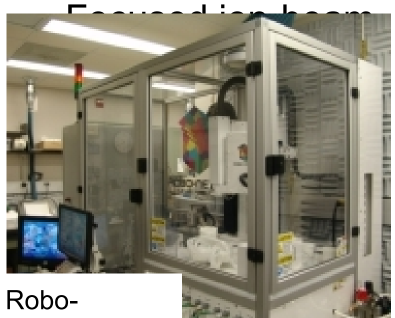

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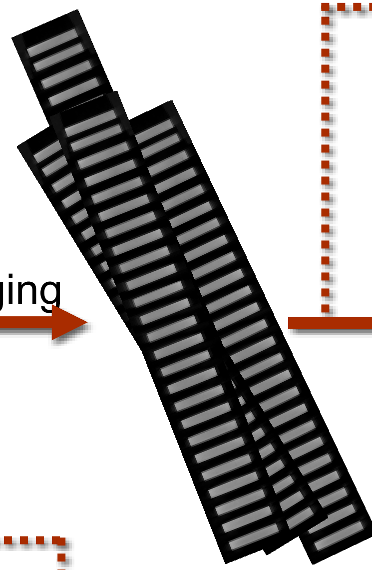
3D reconstruction

Part to be reconstructed

Imaging



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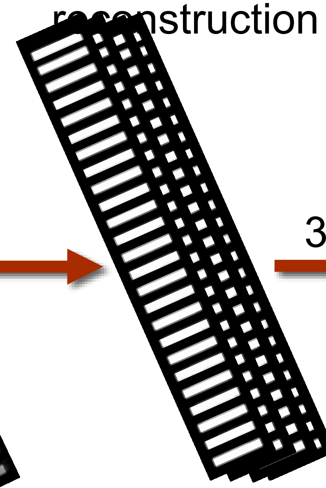
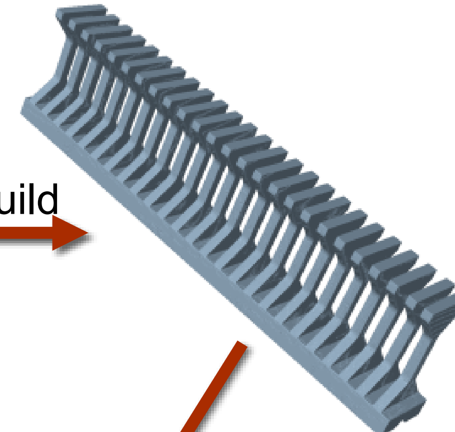
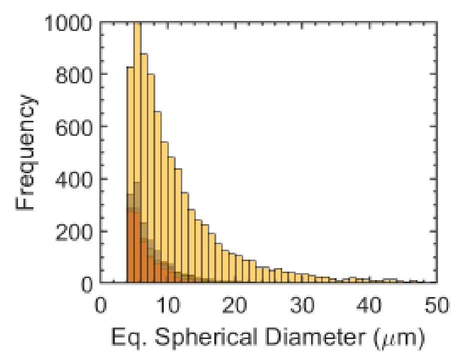
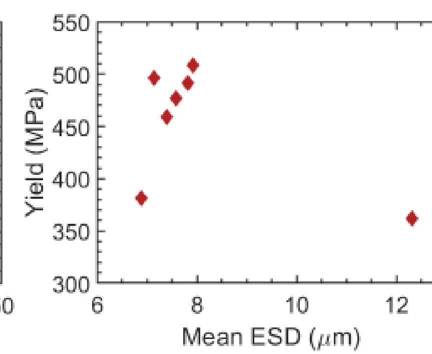


3D Rebuild



Quantitative Analysis





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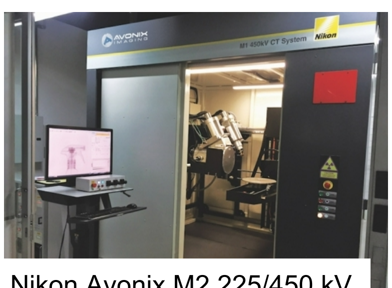

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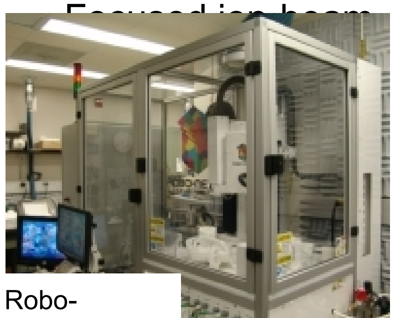

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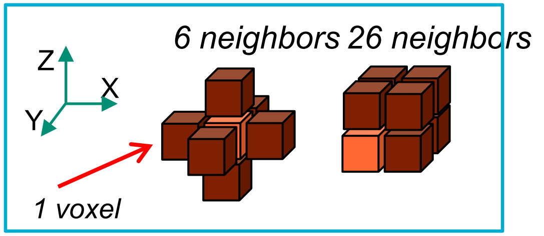
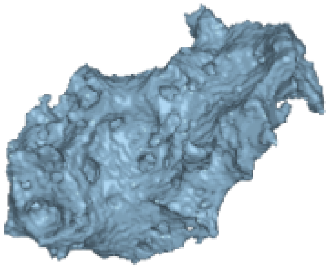
Assessment Metrics

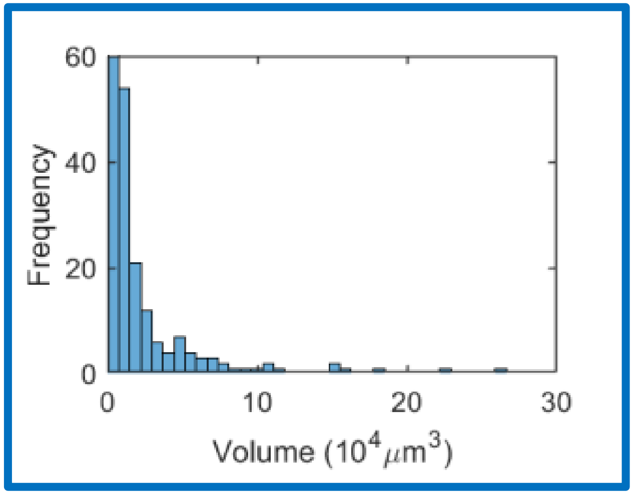
3D Voxels





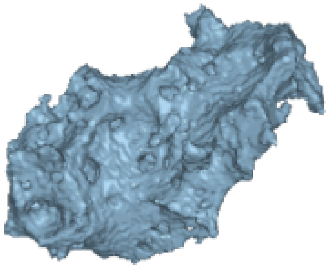
Assessment Metrics – **Scalar**

First order



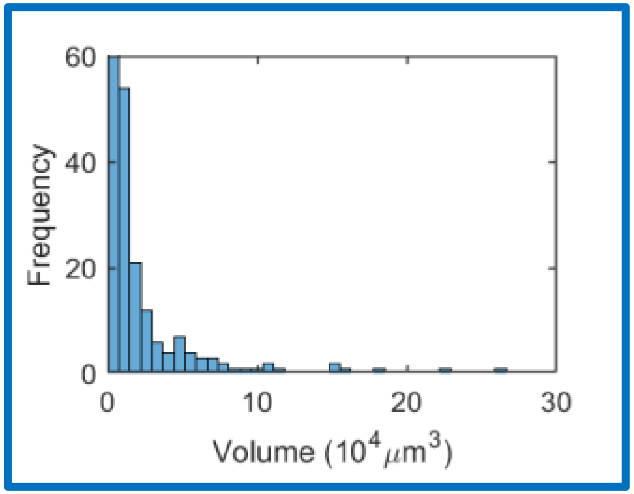
Characterize individual bodies:

- Measure volume by counting voxels
- Calculate equivalent spherical diameters

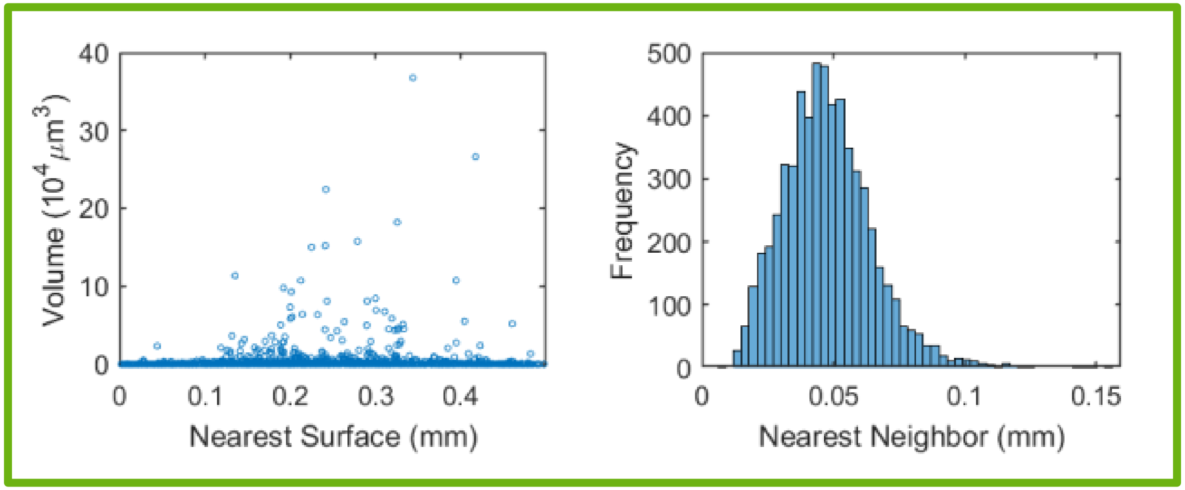


Assessment Metrics – **Relational**

First order

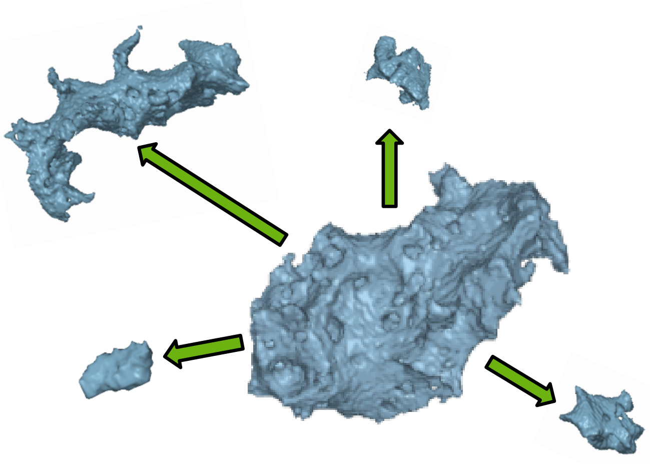


Second order



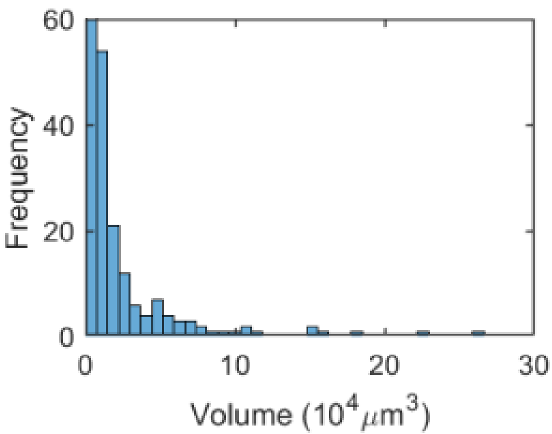
Analyze body networks:

- Determine void locations within the specimen
- Find nearest neighbor distances
- Relate spatial information to other void metrics

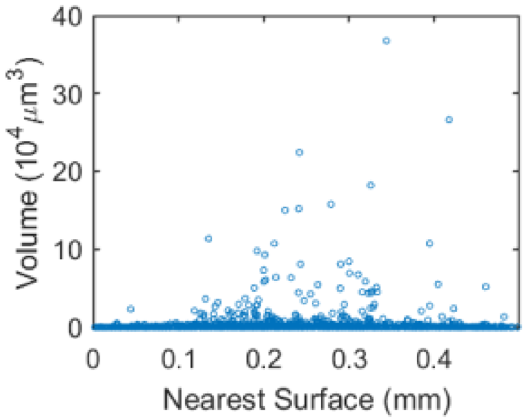


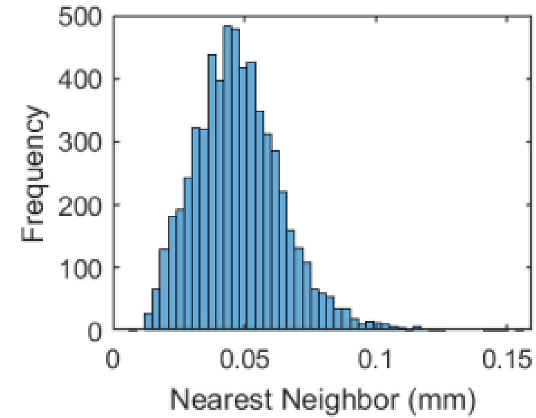
Assessment Metrics – **Contextual**

First order

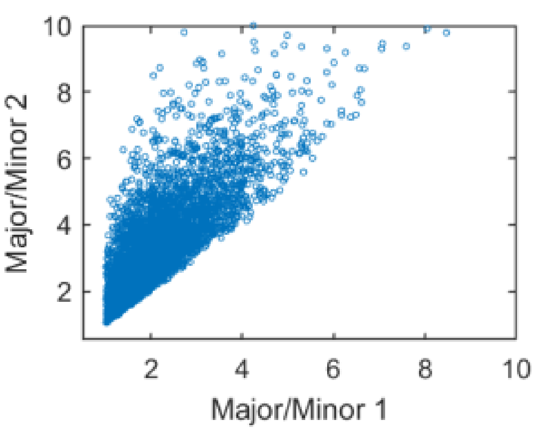


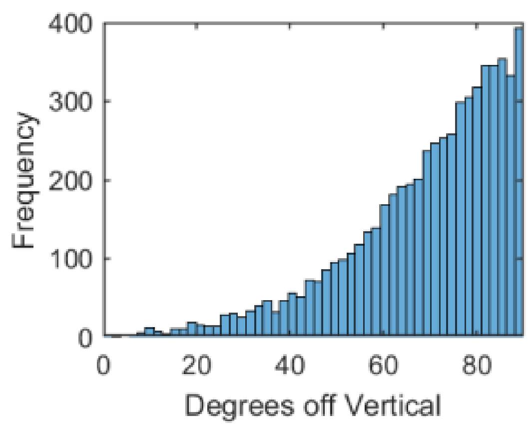
Second order





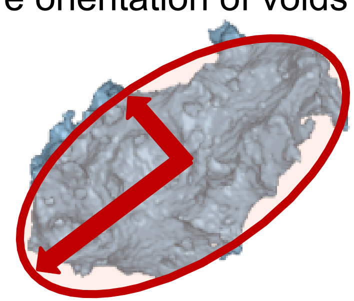
Third order





Characterize body shape, size and morphology:

- Fit shapes to voids. Find aspect ratios and shape parameters
- Measure orientation of voids



Ellipse fit

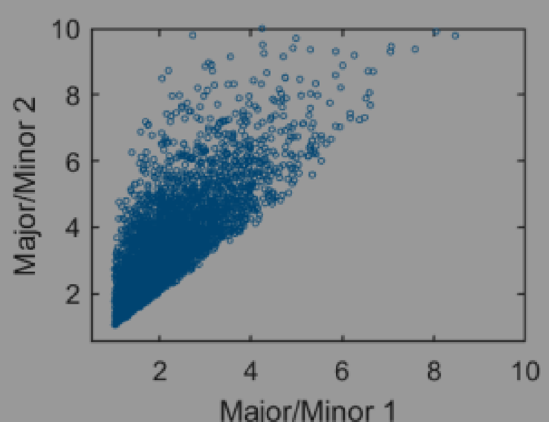
Assessment Metrics – Contextual

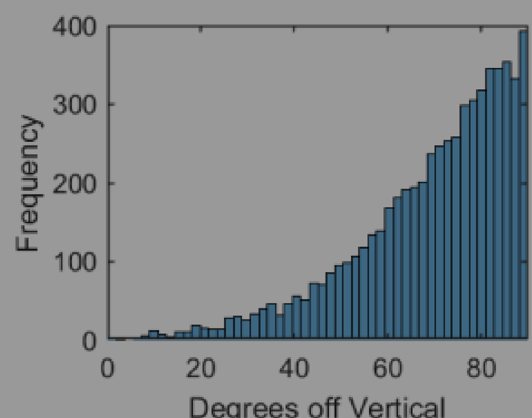
First order

Second order

1) How does image processing impact 3D assessment metrics?

2) How does imaging technique impact 3D assessment metrics?





- Fit shapes to voids. Find aspect ratios and shape parameters
- Measure orientation of voids

Ellipse fit

Image Processing

Images prepared for 3D reconstruction and porosity analysis by:

- Pre-processing to improve image quality, remove extraneous data and accentuate features of interest.
- Segmentation to create binary images. Individual voxels represent either material or voids.

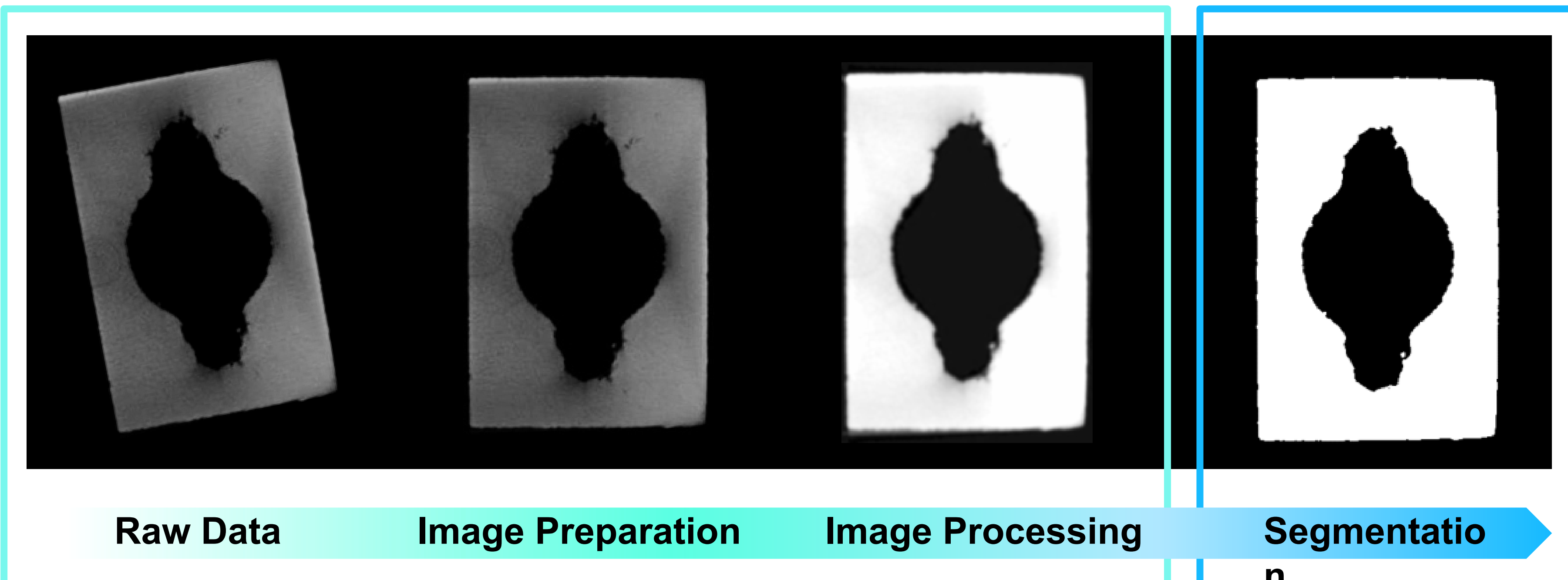


Image Processing Toolbox

Over 20 image processing and three-dimensional analysis scripts created. Each is fully customizable and adaptable for different data sets. These scripts allow automated, batch processing necessary for organization and analysis of big data.

Image preparation (6)

Automated image preparation scripts:

- Rotations
- Cropping
- Image selection and renaming
- Image alignment procedures
- Region of interest definition
- Image noise reduction

File organization:

- Creates uniform file locations.
- Reports meta-data

Matlab Dream3d

Fiji/ImageJ

Image Processing (5)

Normalizing image intensity:

- Bimodal histogram analysis. Normalizes image intensity throughout an image stack.

Image smoothing:

- Three dimensional smoothing filters with customizable options.

Advanced filtering:

- Removes uneven background intensity while preserving local image features

Matlab Dream3d

Segmentation (4)

Global threshold:

- Multiple threshold values can be selected and compared.
- Different segmentations can be combined.

Local threshold:

- Adapts to local image criteria. Accepts custom or established threshold methods.
- Full customization of local search areas and paths.
- Allows baseline filtering.

Matlab

3D Reconstruction (8)

Reconstruction:

- Interactive 3D visualizations.
- Create flythrough movies and rendered images.

Quantitative analysis:

- Individual features of interest and statistical distributions.
- Selectively analyze certain regions or features.
- Plotting and visualization of statistical measures.

Matlab IDL

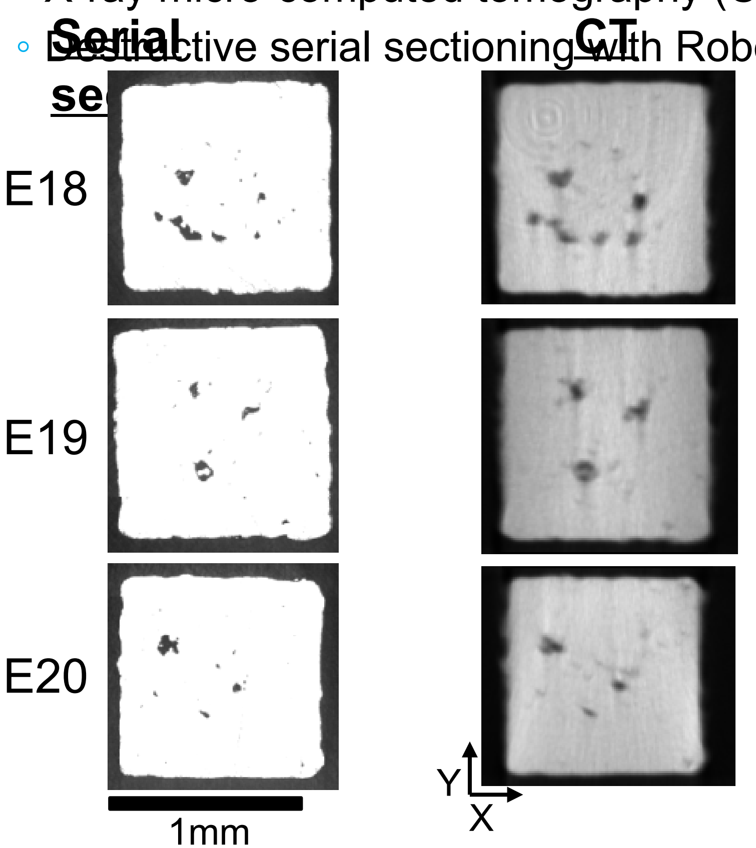
Case Study

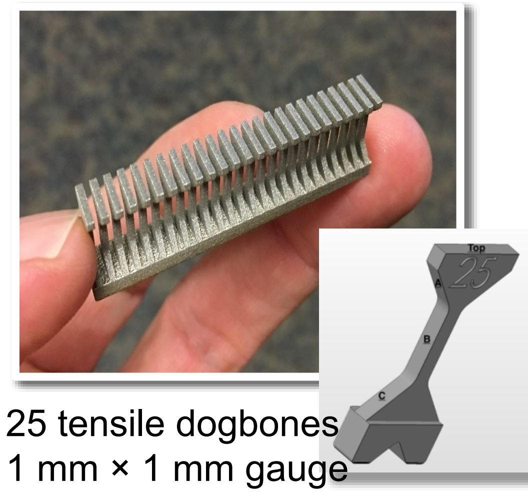
Characterizing porosity in AM 316L stainless steel

- Structure-property relationships and qualifying AM components

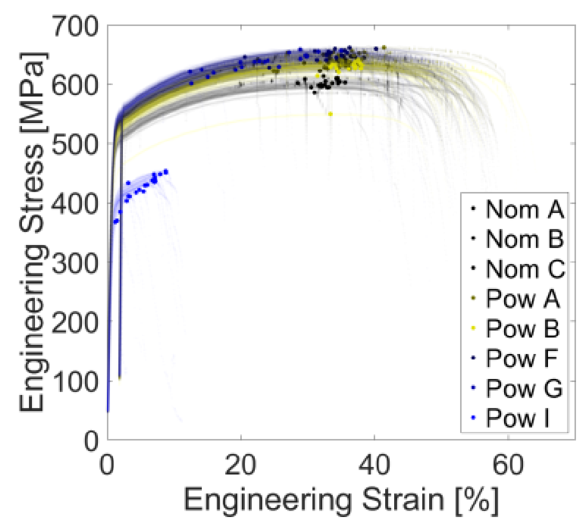
Characterized gauge region in 3 tensile dogbones using:

- X-ray micro-computed tomography (CT)
- Destructive serial sectioning with Robo-Met.3D®





25 tensile dogbones
1 mm × 1 mm gauge



High throughput mechanical test data from Nathan Heckman et al.

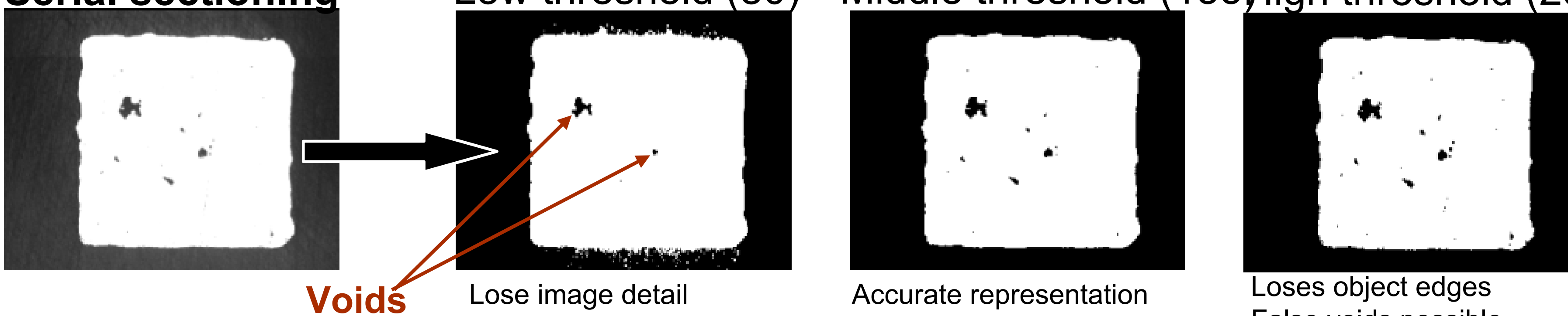
Image Processing: Segmentation

Global segmentation on 8-bit grayscale (voxel intensity between 0 – 255)

- Threshold values 10 – 45.
  - Voxel intensity value below threshold = black
  - Voxel intensity value above threshold = white

Quantify how threshold value impacts assessment metrics

Serial sectioning | Low threshold (80) | Middle threshold (155) | High threshold (230)



Low threshold (80): Lose image detail; Create image artifacts

Middle threshold (155): Accurate representation

High threshold (230): Loses object edges; False voids possible

Image Processing: Segmentation

Global segmentation on 8-bit grayscale (voxel intensity between 0 – 255)

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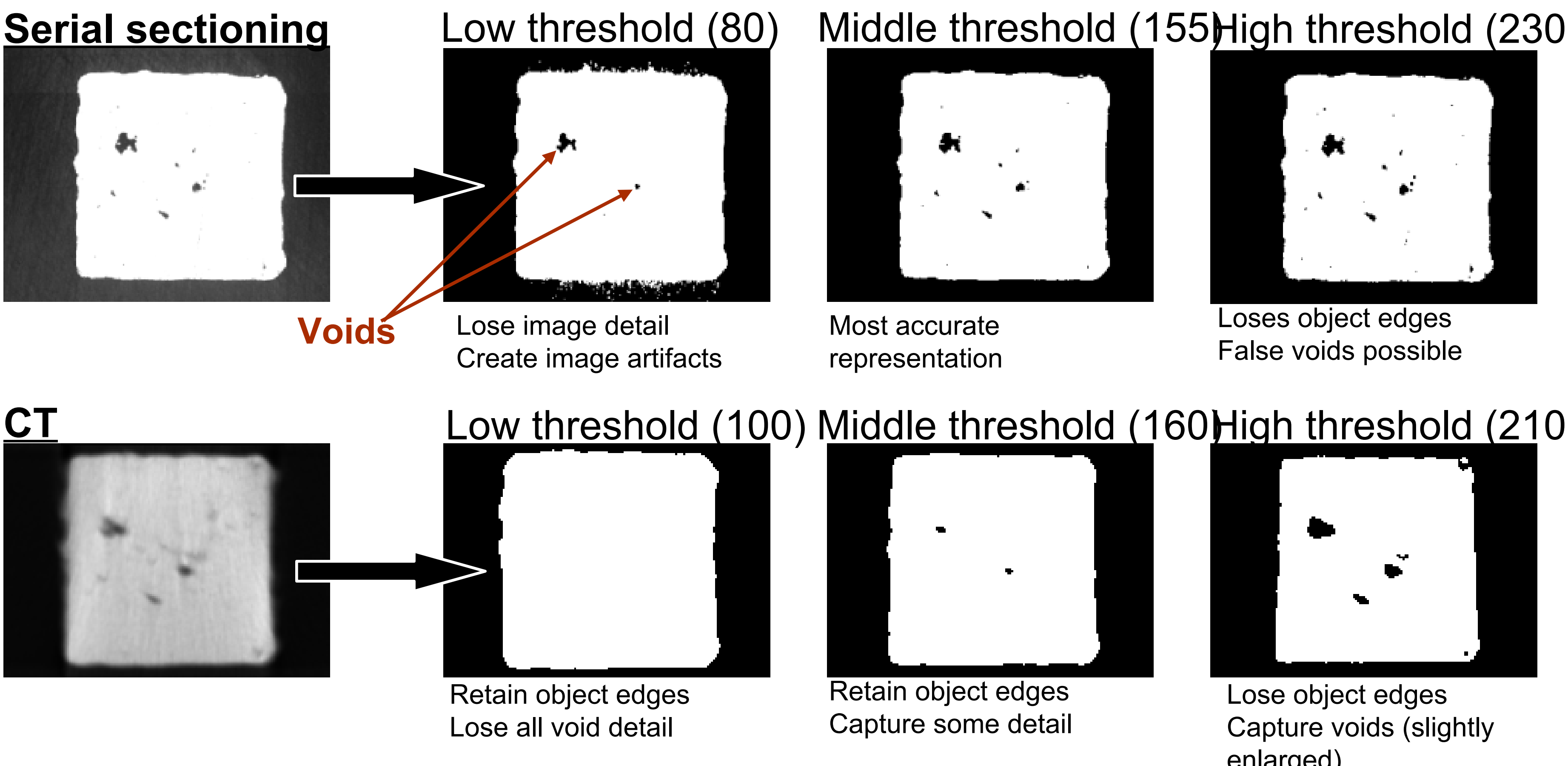
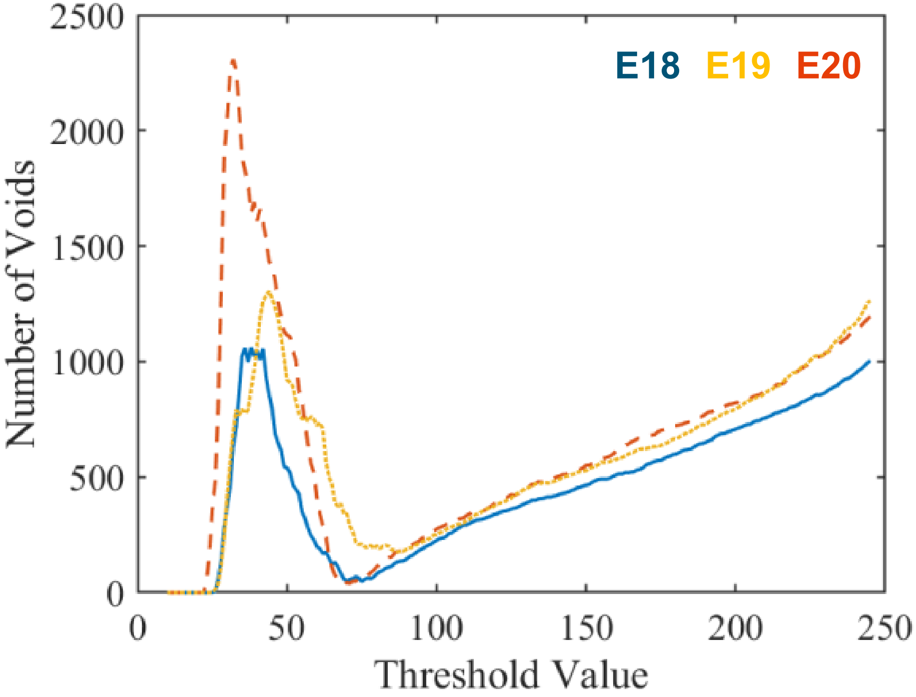


Impact of Segmentation: **Serial Sectioning**

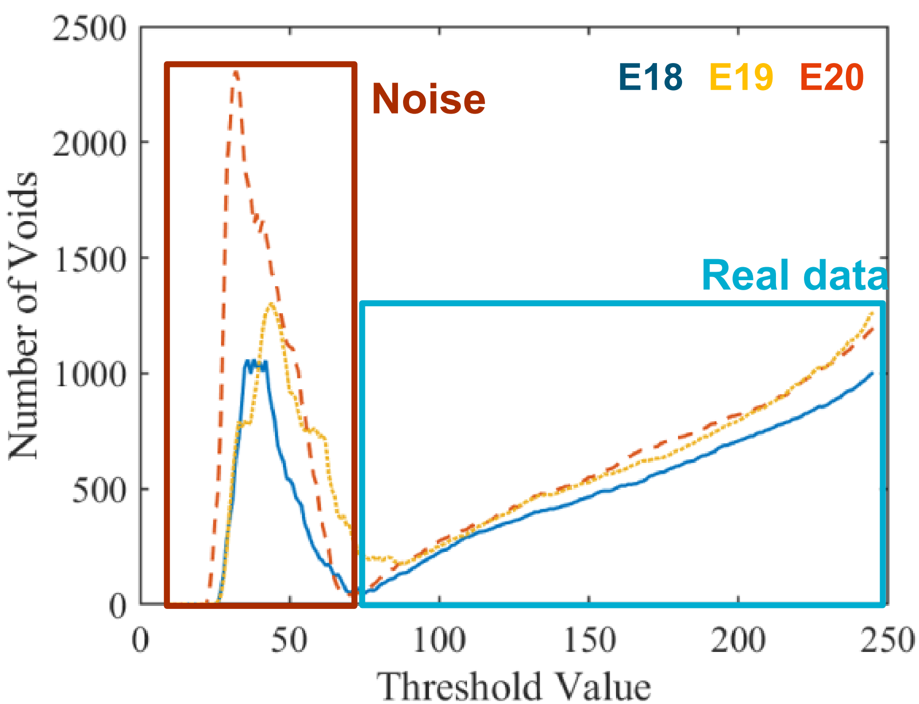
Number of Voids - **Scalar**



What is a 'good' threshold value?

Impact of Segmentation: **Serial Sectioning**

Number of Voids - **Scalar**



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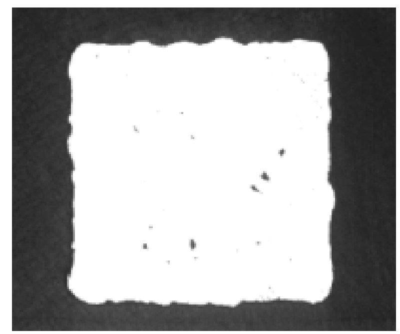

Original


Threshold 50

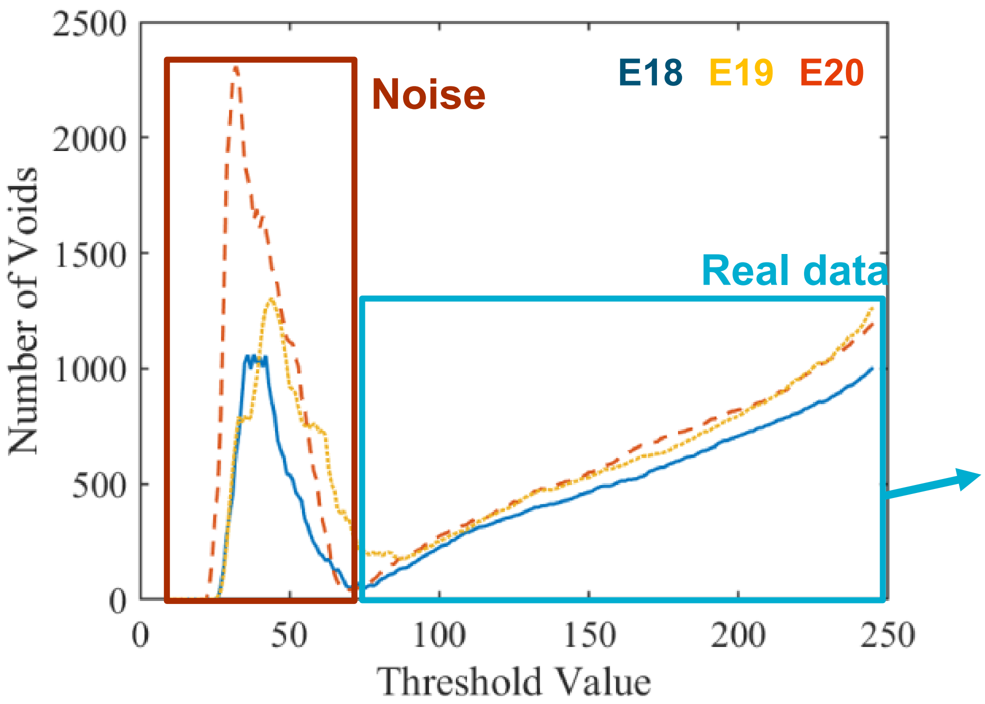

Threshold 150

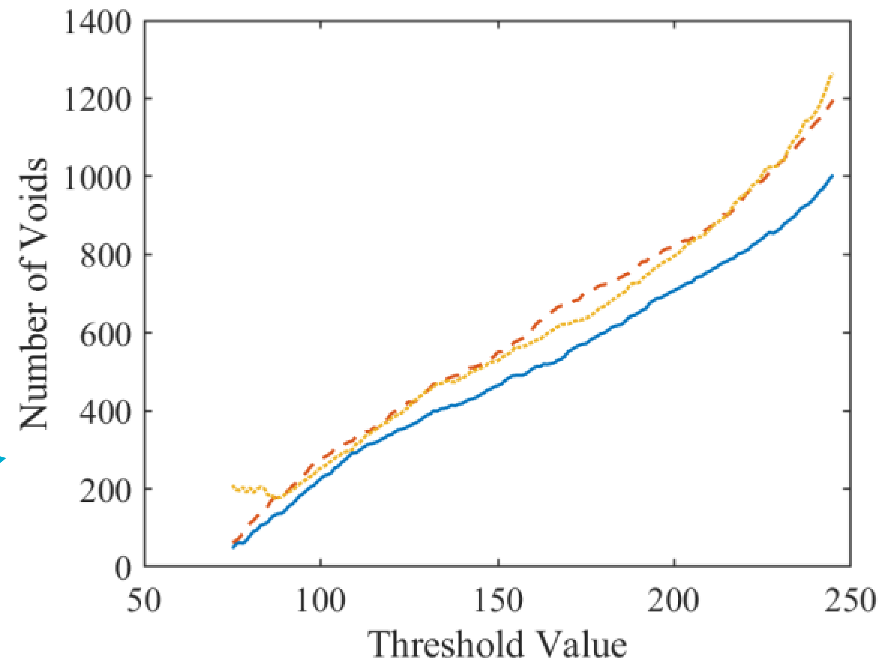

Threshold 200

E18

Impact of Segmentation: **Serial Sectioning**

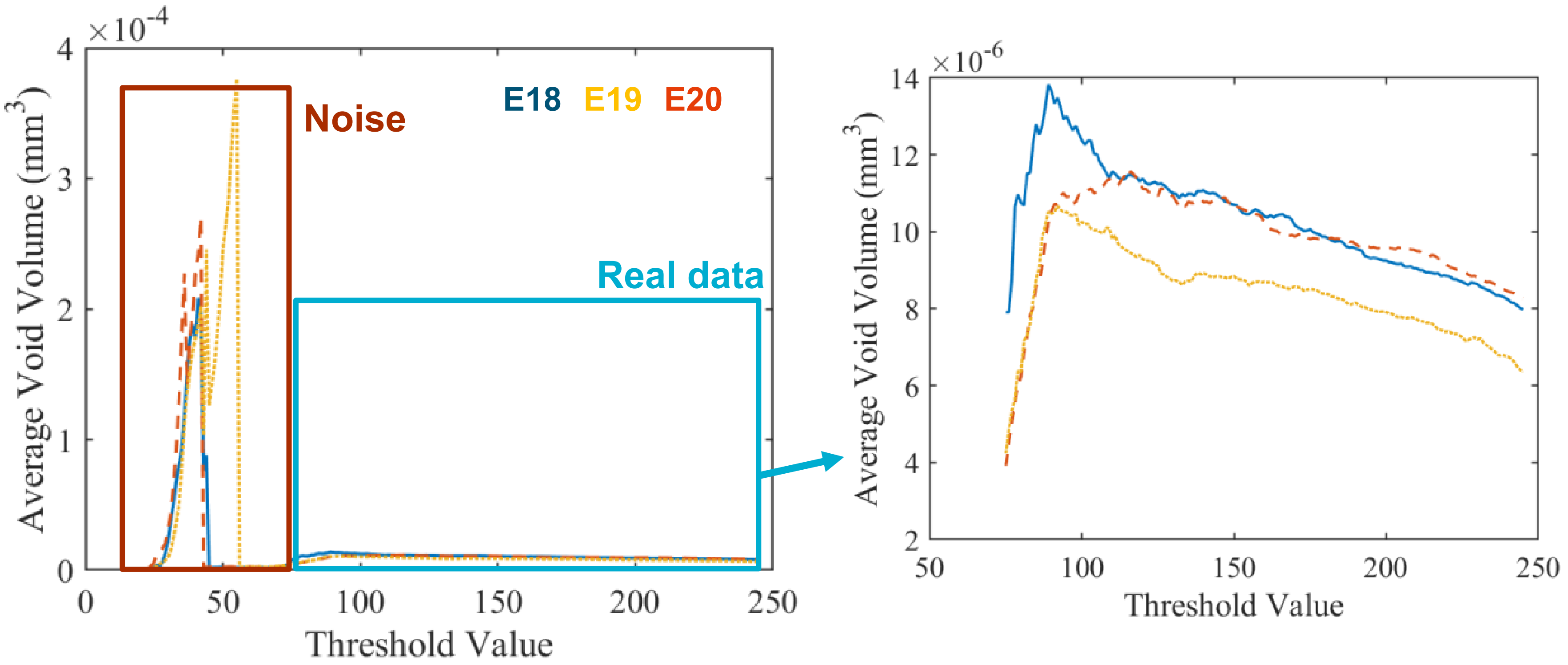
Number of Voids - **Scalar**





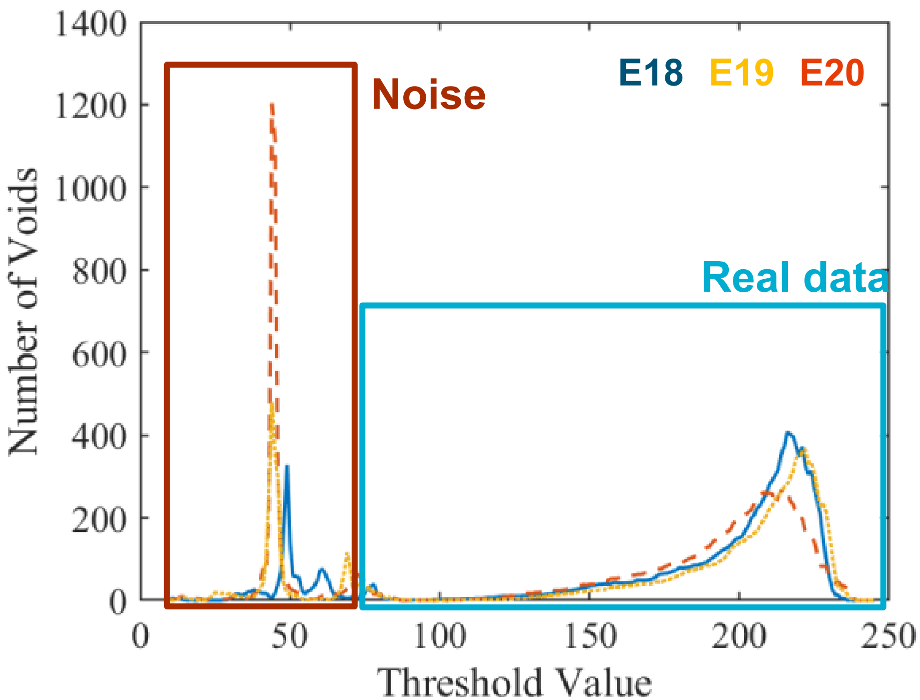
Impact of Segmentation: **Serial Sectioning**

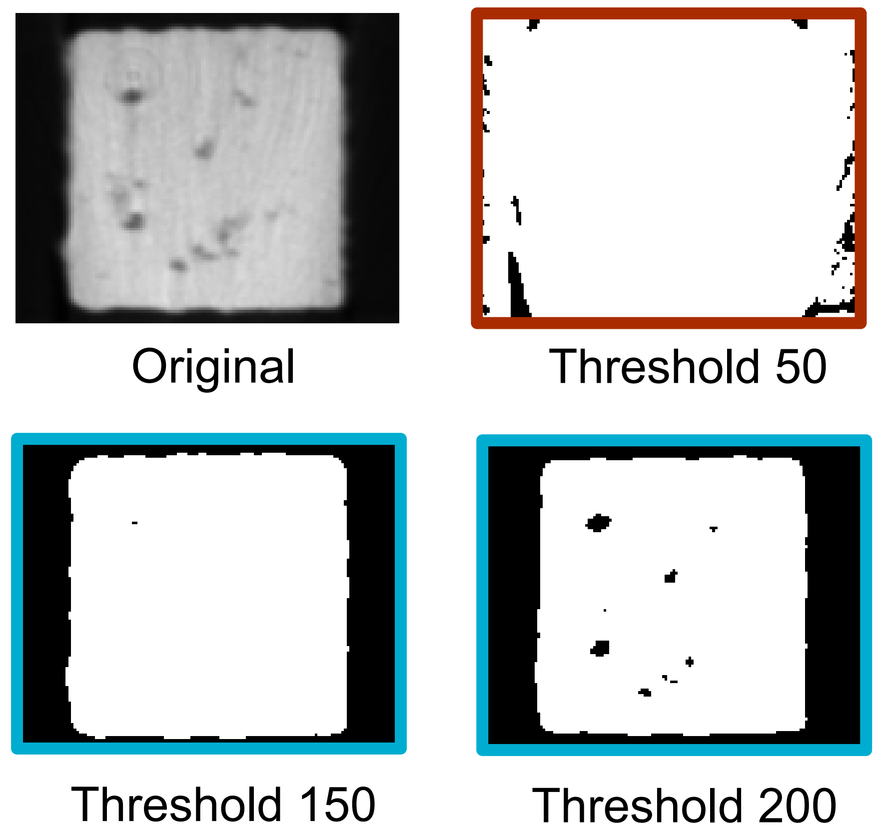
Average Void Volume - **Scalar**



Impact of Segmentation: **CT**

Number of Voids - **Scalar**

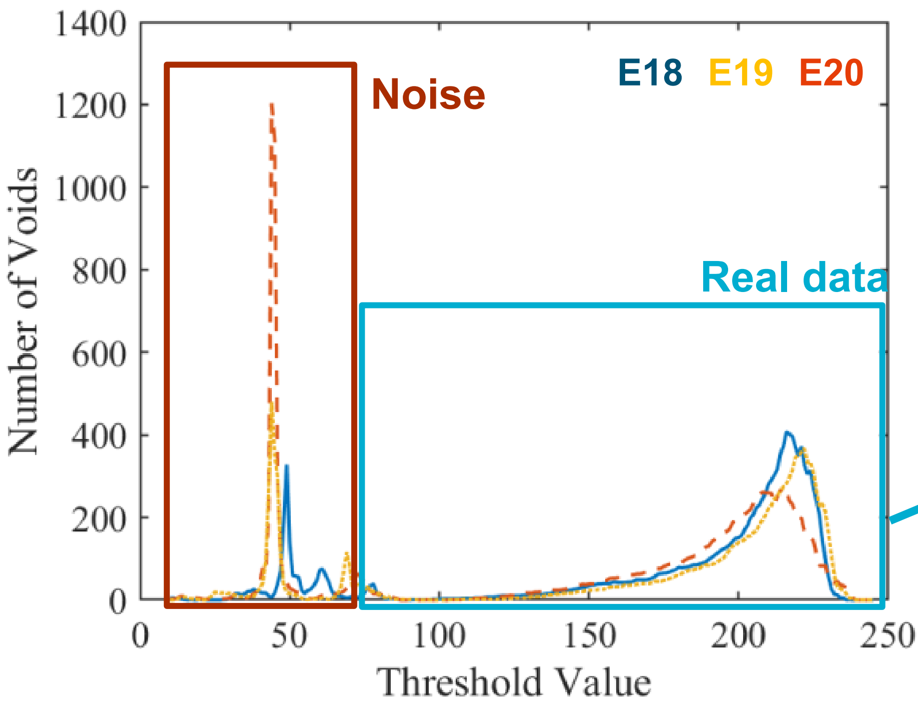


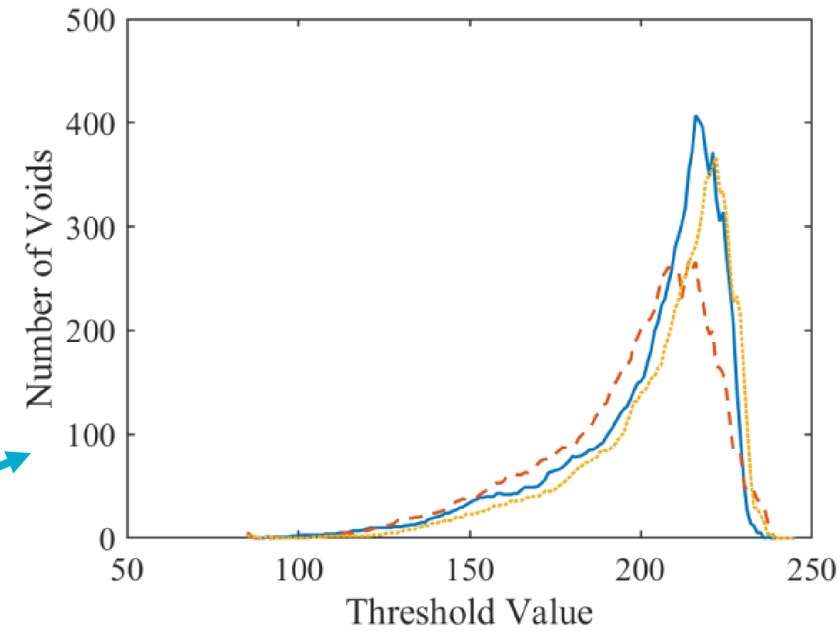


E18

Impact of Segmentation: **CT**

Number of Voids - **Scalar**





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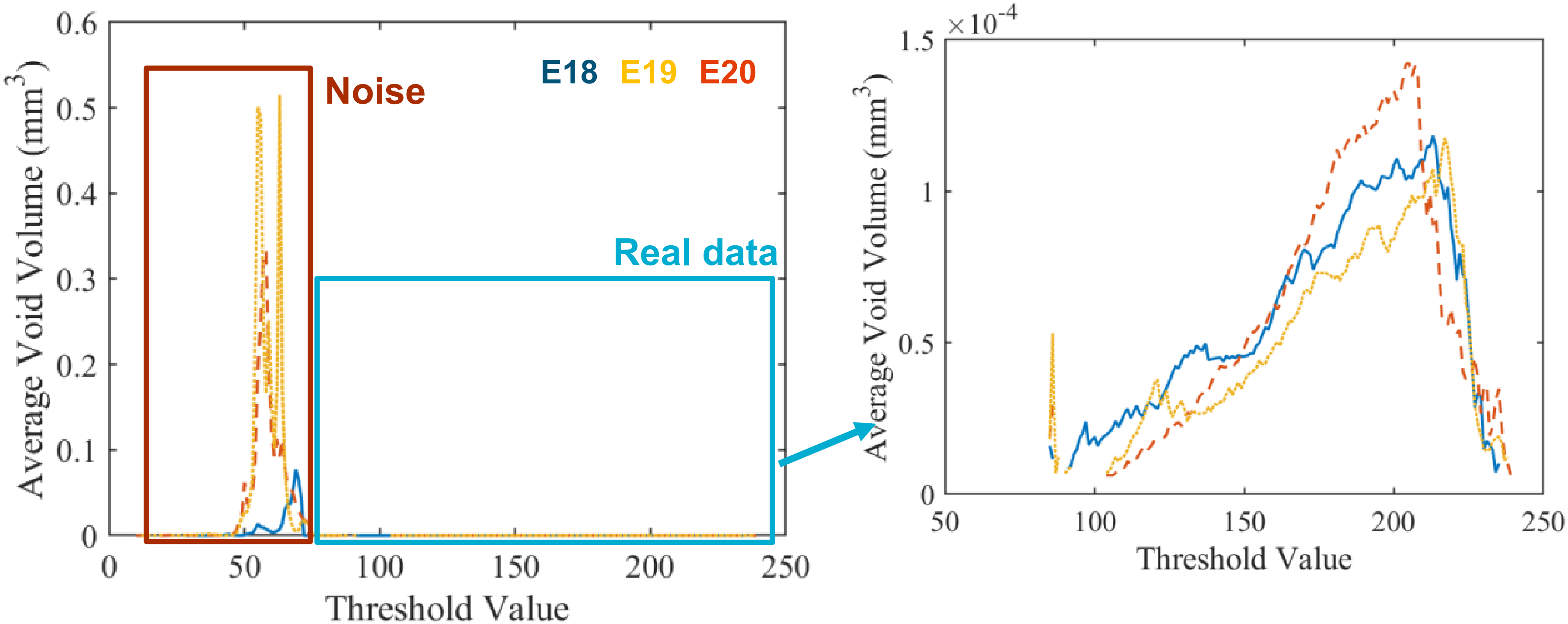


Impact of Acquisition Technique

Approximately equal minimum void volume

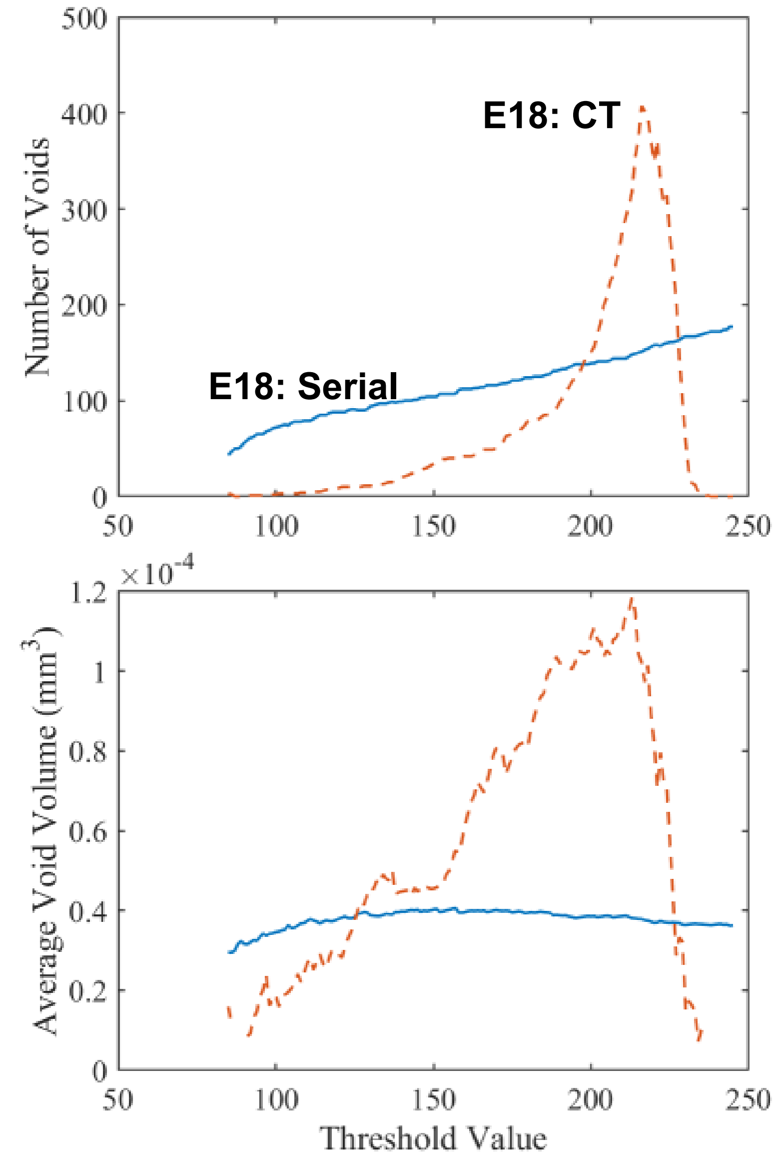
- Serial Sectioning: 64 voxels ~ 6144 μm^3
- Micro-CT: 8 voxels ~ 5832 μm^3

3D measurements from serial sectioning and CT data are different

- More variability noted in CT data

Potential causes for differences?

- Lower resolution of CT compared to serial sectioning
- Alignment differences (serial data is slightly tilted)
- Imaging technique (imaging characteristics)



Impact of Acquisition Technique

Approximately equal minimum void volume

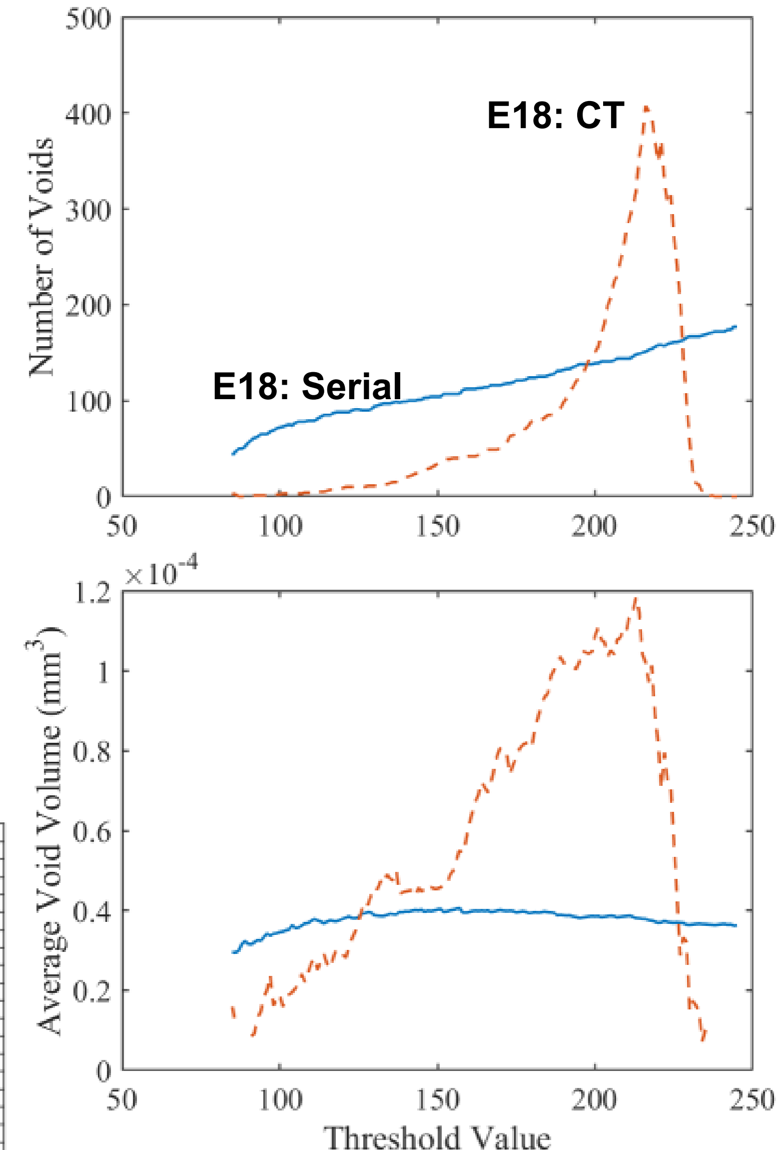
- Serial Sectioning: 64 voxels ~ 6144 μm^3
- Micro-CT: 8 voxels ~ 5832 μm^3

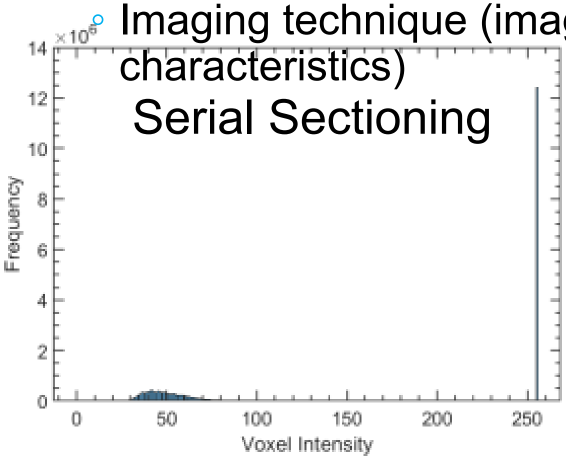
3D measurements from serial sectioning and CT data are different

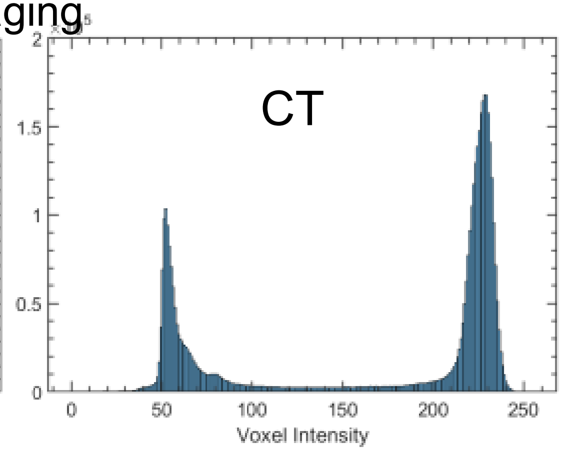
- More variability noted in CT data

Potential causes for differences?

- Lower resolution of CT compared to serial sectioning
- Alignment differences (serial data is slightly tilted)
- Imaging technique (imaging characteristics)







Summary

Image Processing

Segmentation value can significantly impact assessment metrics
- Sensitivity to segmentation value varies with assessment metric

First-order assessment metrics can change considerably with the image acquisition technique
- CT exhibited more variability than serial sectioning

Quantification of the impact of image processing decisions on assessment metrics are needed to:
1) Understand uncertainty in assessment metrics
2) Optimize imaging characteristics for particular assessment metrics
3) Move toward automated image processing

Recommendations

Imaging characteristics should be optimized for feature identification and for a specific assessment metric of interest

It is worthwhile to determine uncertainties associated with different assessment metrics

Qualification/inspection criteria should be based upon an optimized imaging procedure and selected assessment metrics with acceptable variability

Image Straightening

Images were initially tilted in the YZ and XZ planes

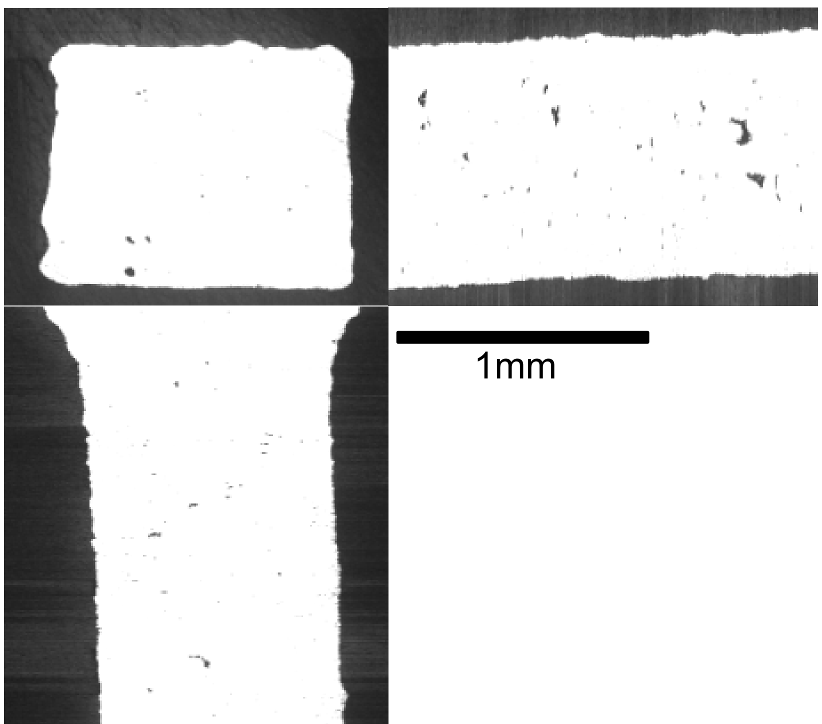
- Tilting is from their alignment in the metallography puck

Each specimen was straightened in these planes

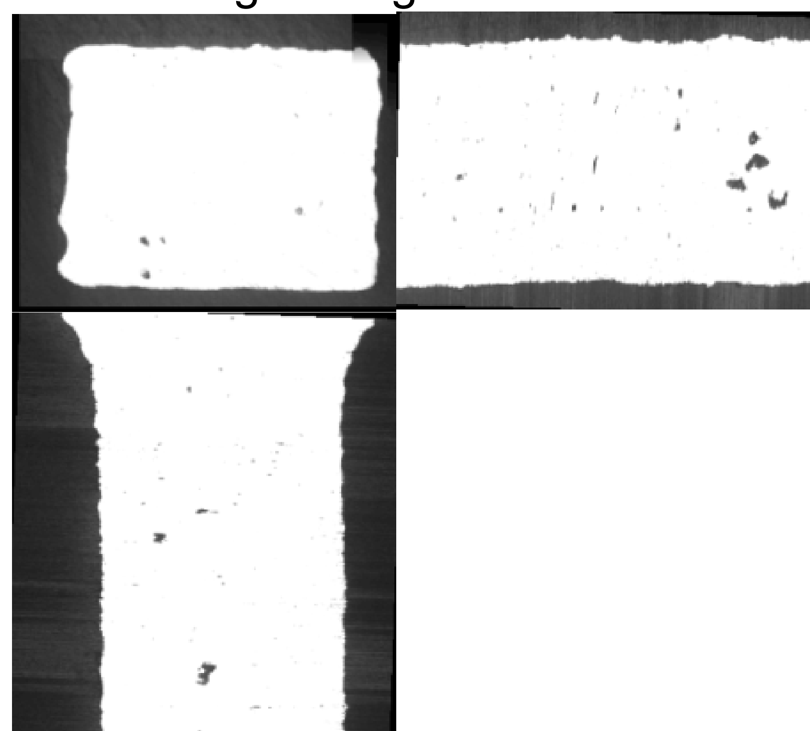
- Demonstrated on E20

Specimens were analyzed before and after straightening

Before straightening



After straightening

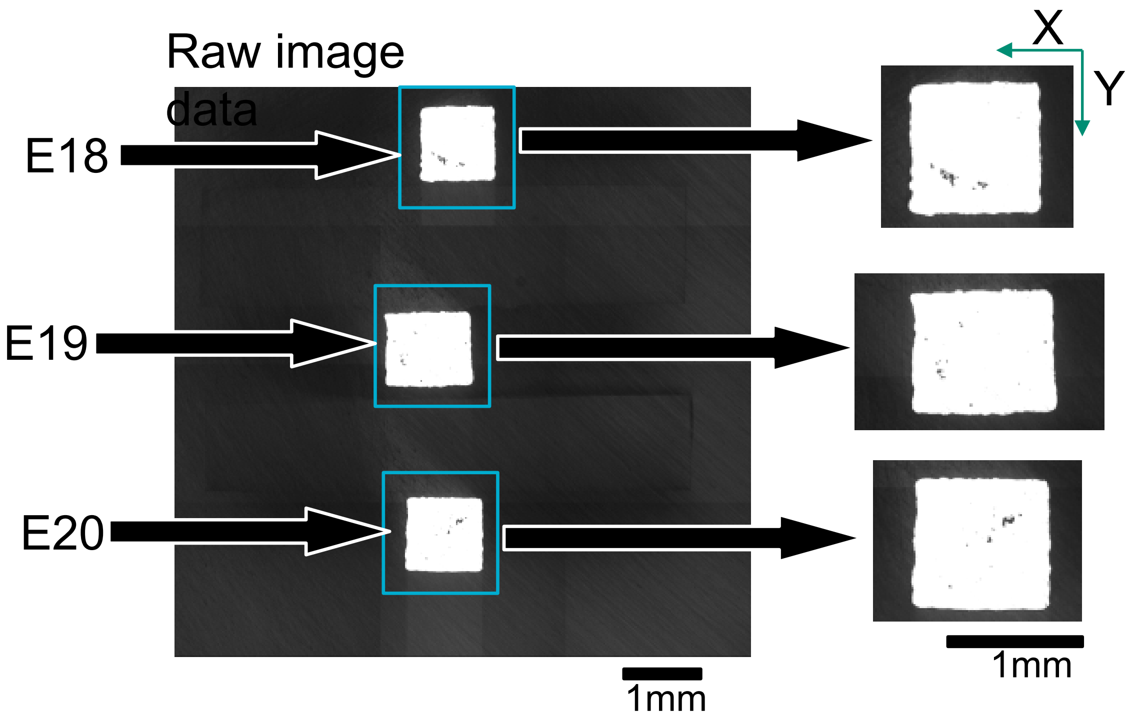


Mechanical Serial Sectioning Data

Specimens were simultaneously imaged in the same metallography puck

Specimens were characterized individually by cropping each from the original image stack

Image slices were then aligned in the XY plane



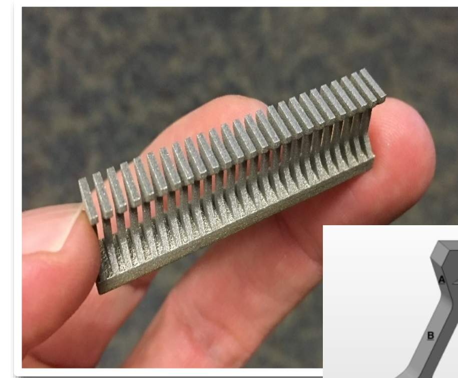
Case Study

Characterizing porosity in AM 316L stainless steel

- Structure-property relationships and qualifying AM components

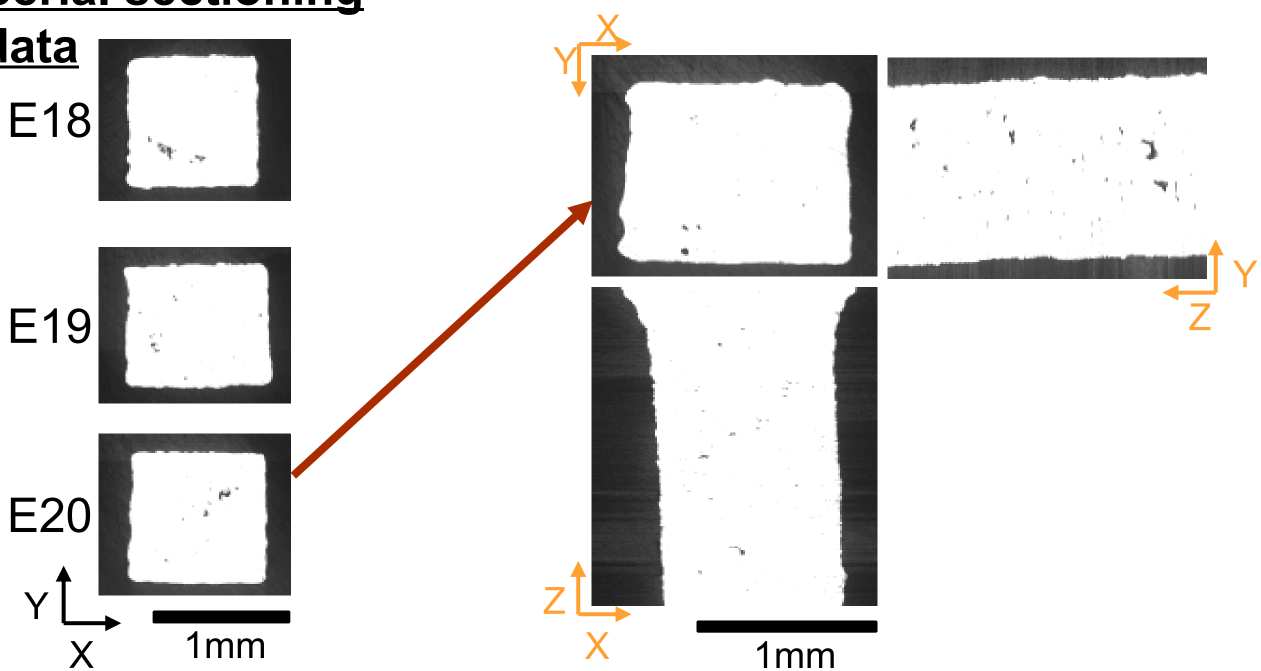
Characterized gauge region in 3 tensile dogbones using:

- X-ray micro-computed tomography (CT)
- Destructive serial sectioning with Robo-Met.3D®



25 tensile dogbones
1 mm × 1 mm gauge

<u>Serial sectioning data</u>



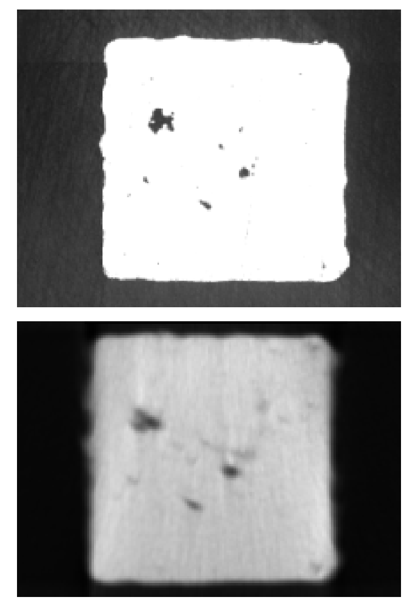
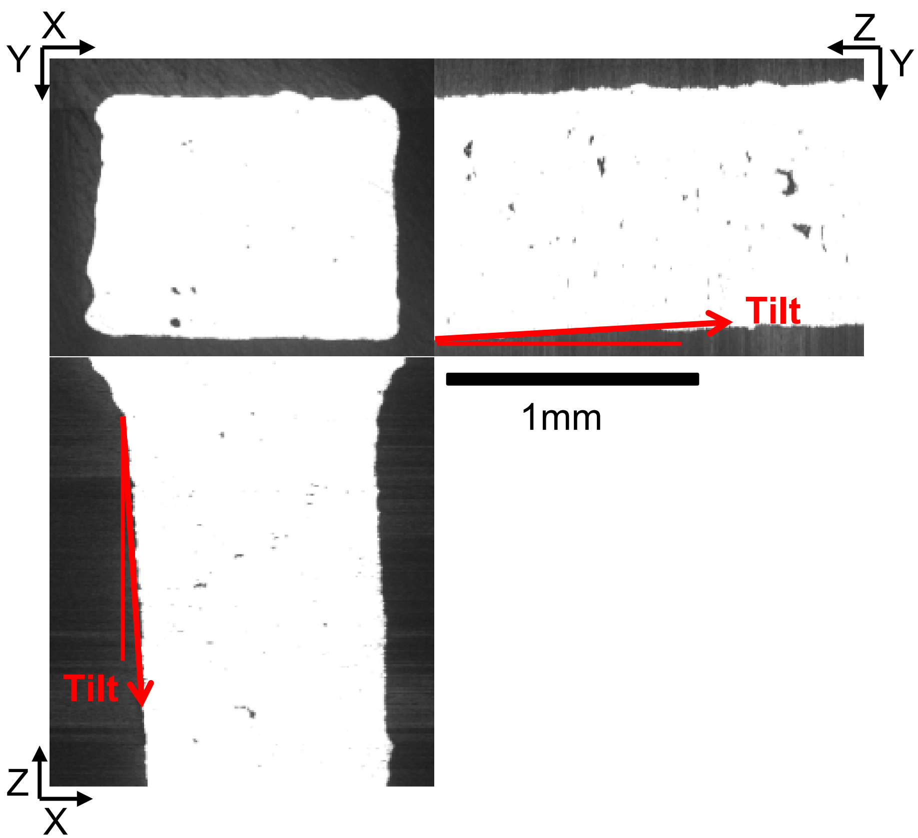


Image Preparation: Serial Sectioning

Align images and perform tilt corrections

- Tilt corrected using a bilinear rotation algorithm

Specimens were analyzed before and after straightening



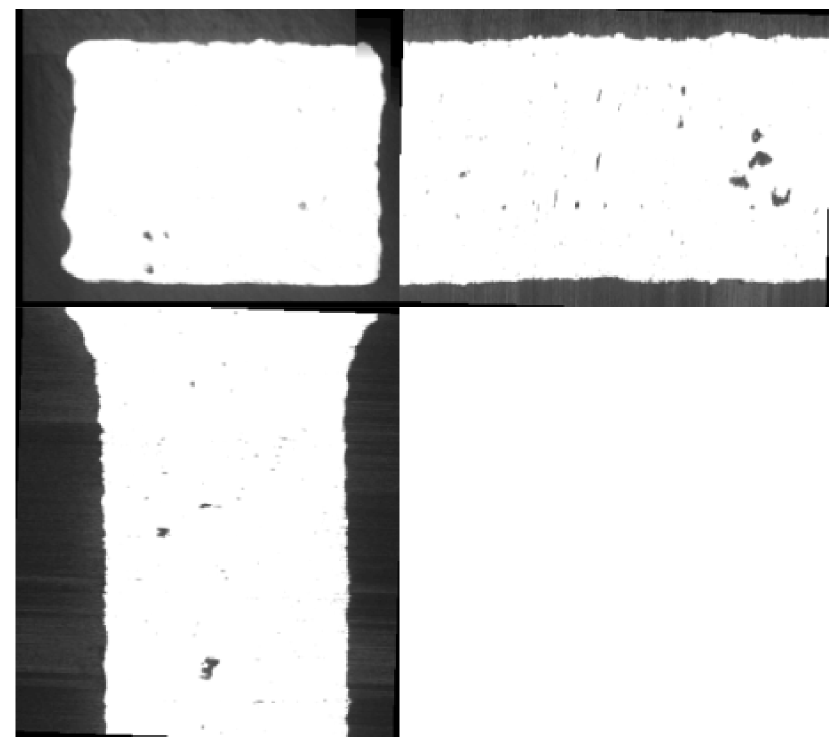


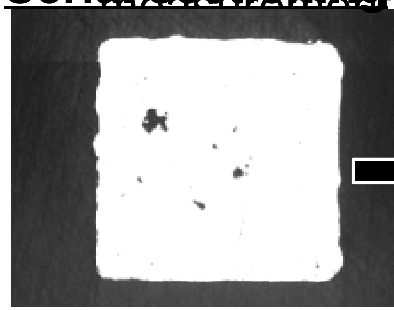
Image Processing: Segmentation

Global segmentation on 8-bit grayscale scale (voxel intensity between 0 – 255)

- Threshold values 10 – 45.
  - Voxel intensity value below threshold = black
  - Voxel intensity value above threshold = white
- Voids are black. Material is white

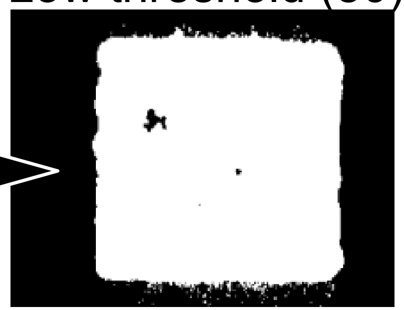
Need to quantify how changing the threshold value effects 3D measurements

Serial sectioning



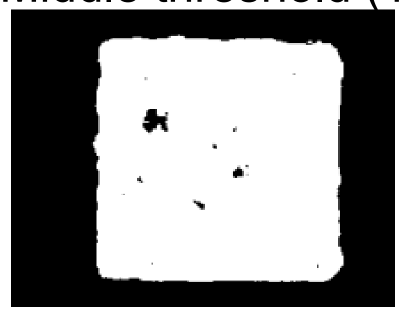
E20 image 143; Serial sectioning

Low threshold (80)



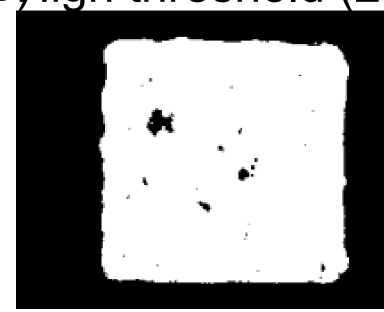
Loses image detail and creates image artifacts

Middle threshold (155)



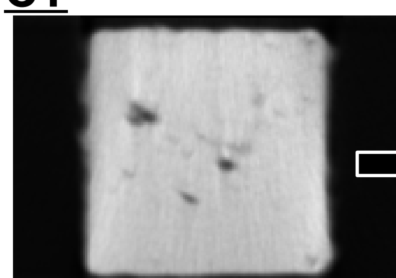
Most accurate representation

High threshold (230)



Loses detail around the object edges and creates false voids

CT

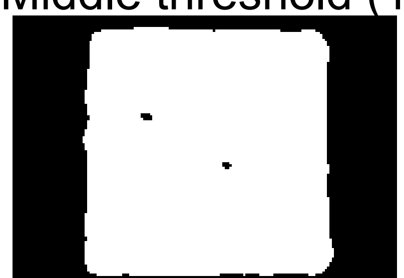


E20 image 117; Micro-CT

Low threshold (100)

Loses all void detail but retains object edges

Middle threshold (160)



Retains object edges and catches some detail

High threshold (210)

Catches all voids (slightly enlarges their sizes) and loses detail around object