Automated Symmetry-Based Extraction of Microstructural Features:

Application to SX Ni-Based Superalloys

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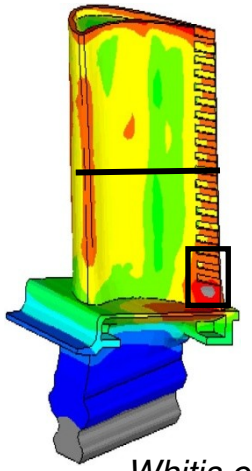
Outline

- Motivation
- Automated Extraction of Microstructural Features
  - Typical SX Ni-Based Serial Image
  - Automated Symmetry-based Technique
  - Application to Dendrites in SX Superalloy Images
  - Results
  - Continuity Rules – Slice-to-slice information
  - Potential improvements
- Conclusion

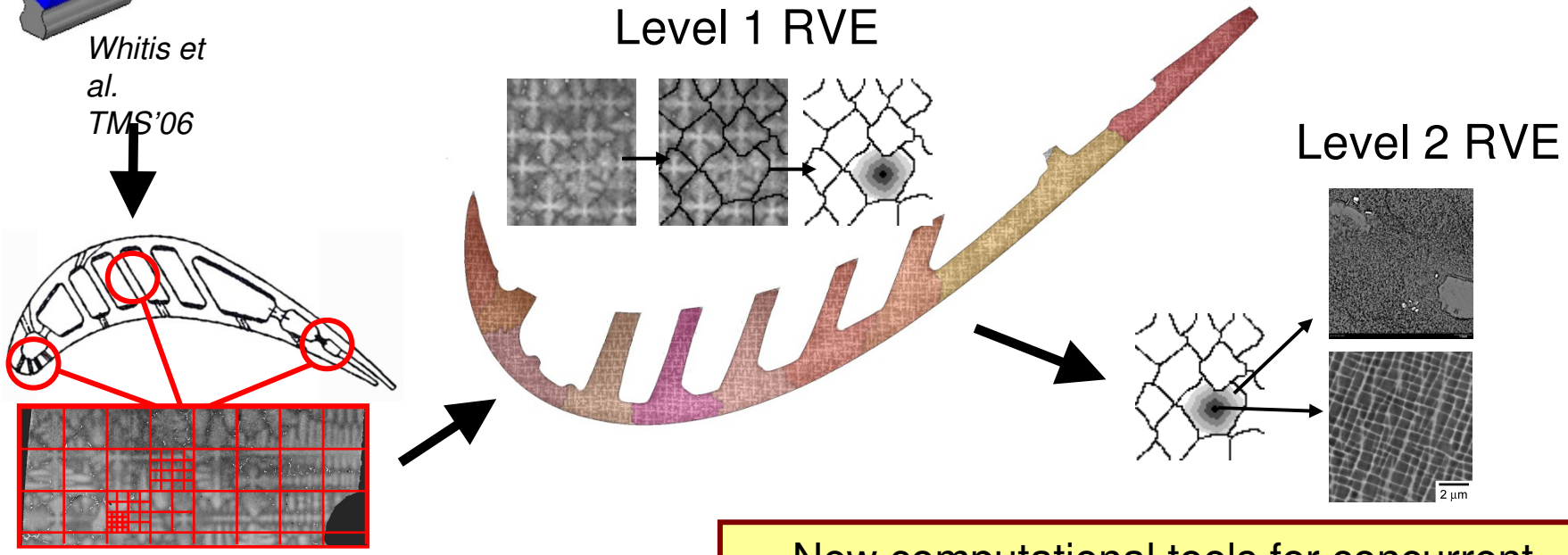
Vision: Systematic Multi-Scale Characterization + Modeling



Whitis et al. TMS'06

Multiscale, Feature-Specific Rep. Volume Elements (RVE)

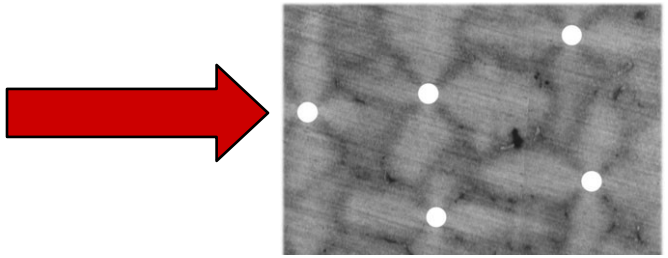
- Multiscale, multi-method characterization (Optical, FIB/SEM, OIM)
- Developing descriptor-based representation of microstructure
- Definition of inhomogeneous regions
- Rigorously-defined correlation lengths & "homogenization"
- Coupling to micromechanics "damage" models (Ghosh, OSU)

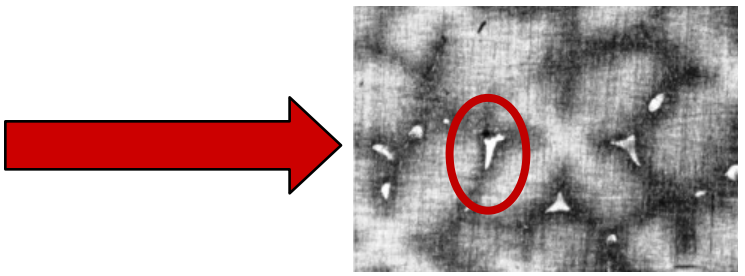


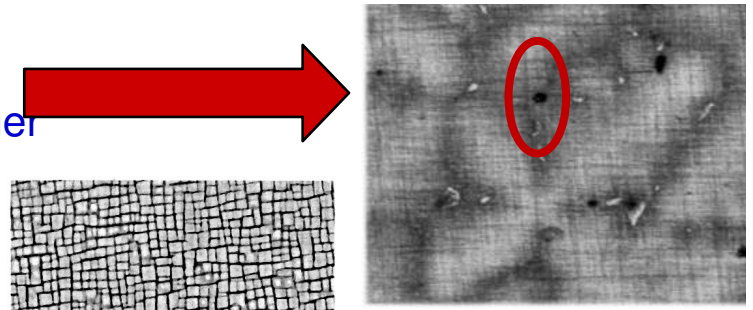
New computational tools for concurrent multi-scale FEM methods

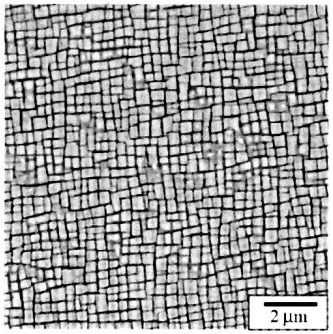
Approach: Multi-Scale Characterization

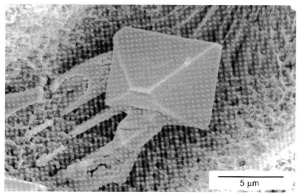
- Primary and Secondary Dendrites (L0-L1)
  - Arm Spacing from 3D & vertical sections
  - Spatial distribution of cores
  - Vf of dendrites & interdendritic region based on chemical analysis
- Eutectic particles (L1-L2)
  - Vf, size/shape distribution (3D)
  - Spatial distribution (#NN, correlate w/ other features)
- Pores/Voids (L0-L1-L2)
  - Vf, size/shape distribution (3D)
  - Spatial distribution (#nn, correlations w/ other features)
- ∀ γ' distribution (L2)
  - Homogeneity (core vs. interdendritic region across airfoil)
  - Stringers
- Carbides (L2)



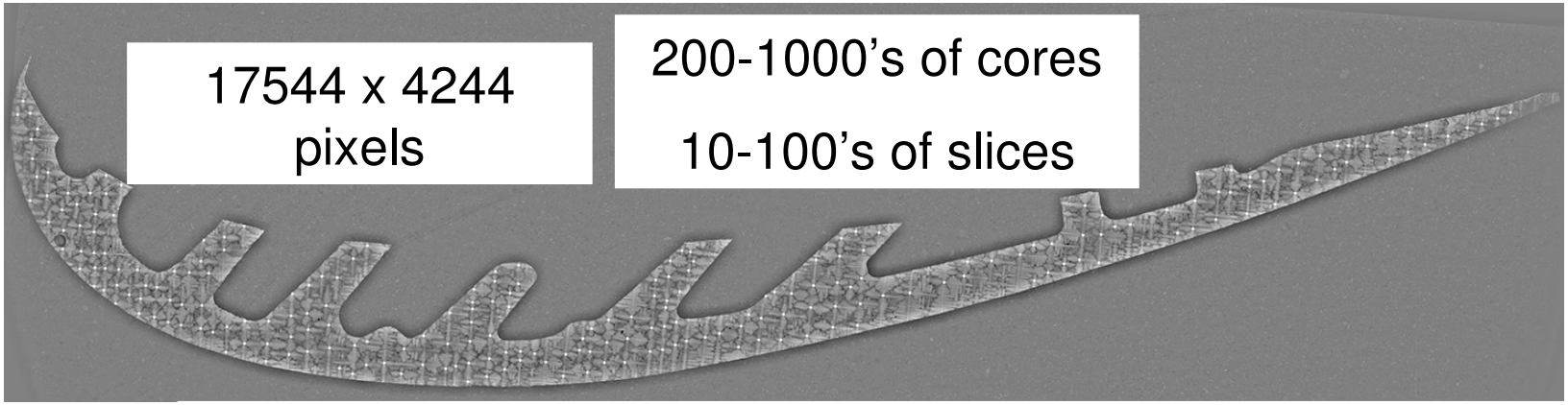






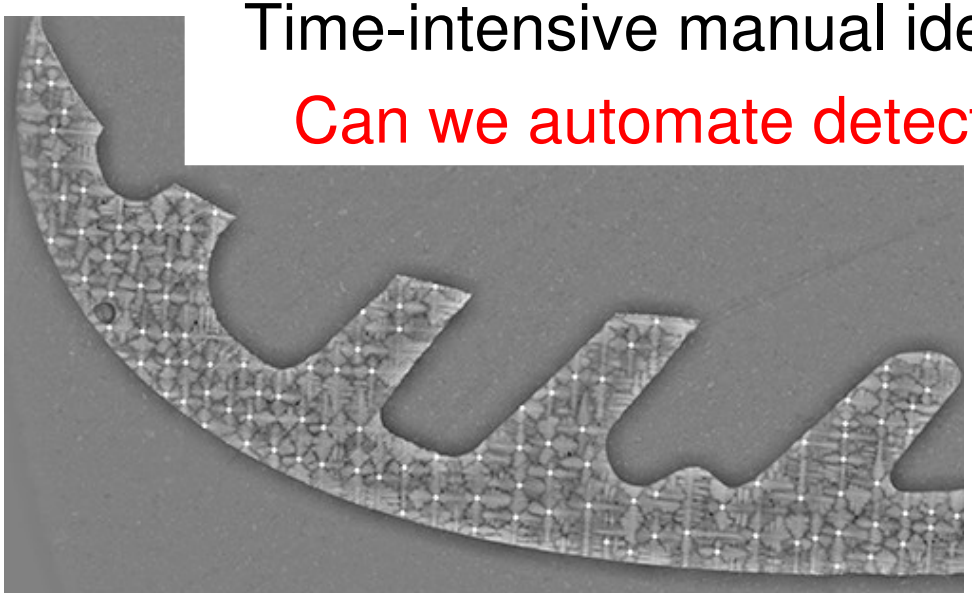


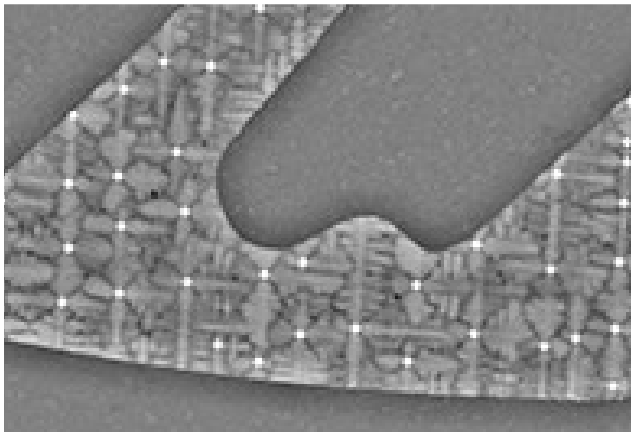
Motivation



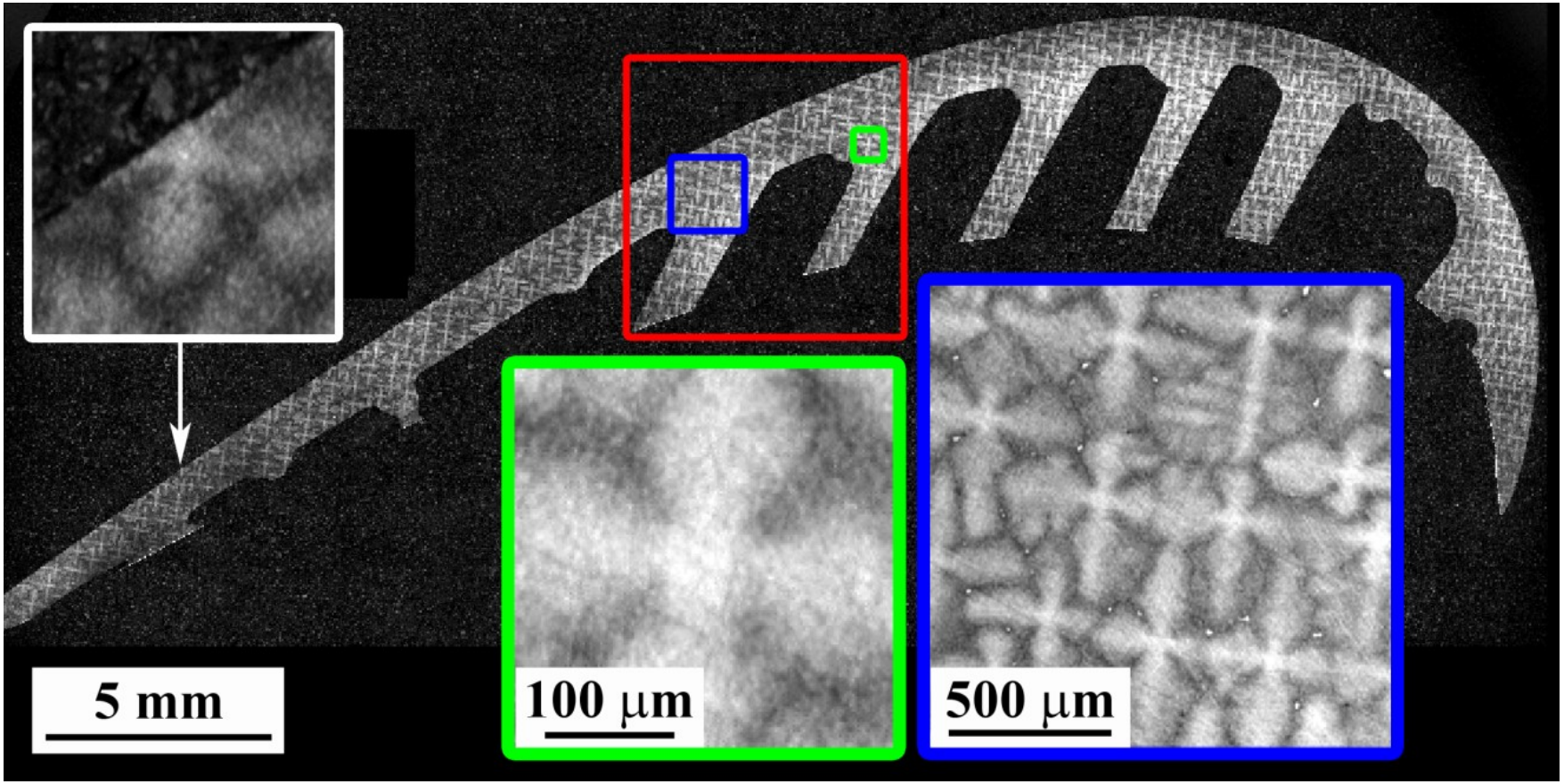
Time-intensive manual identification of features

Can we automate detecting dendrite cores?



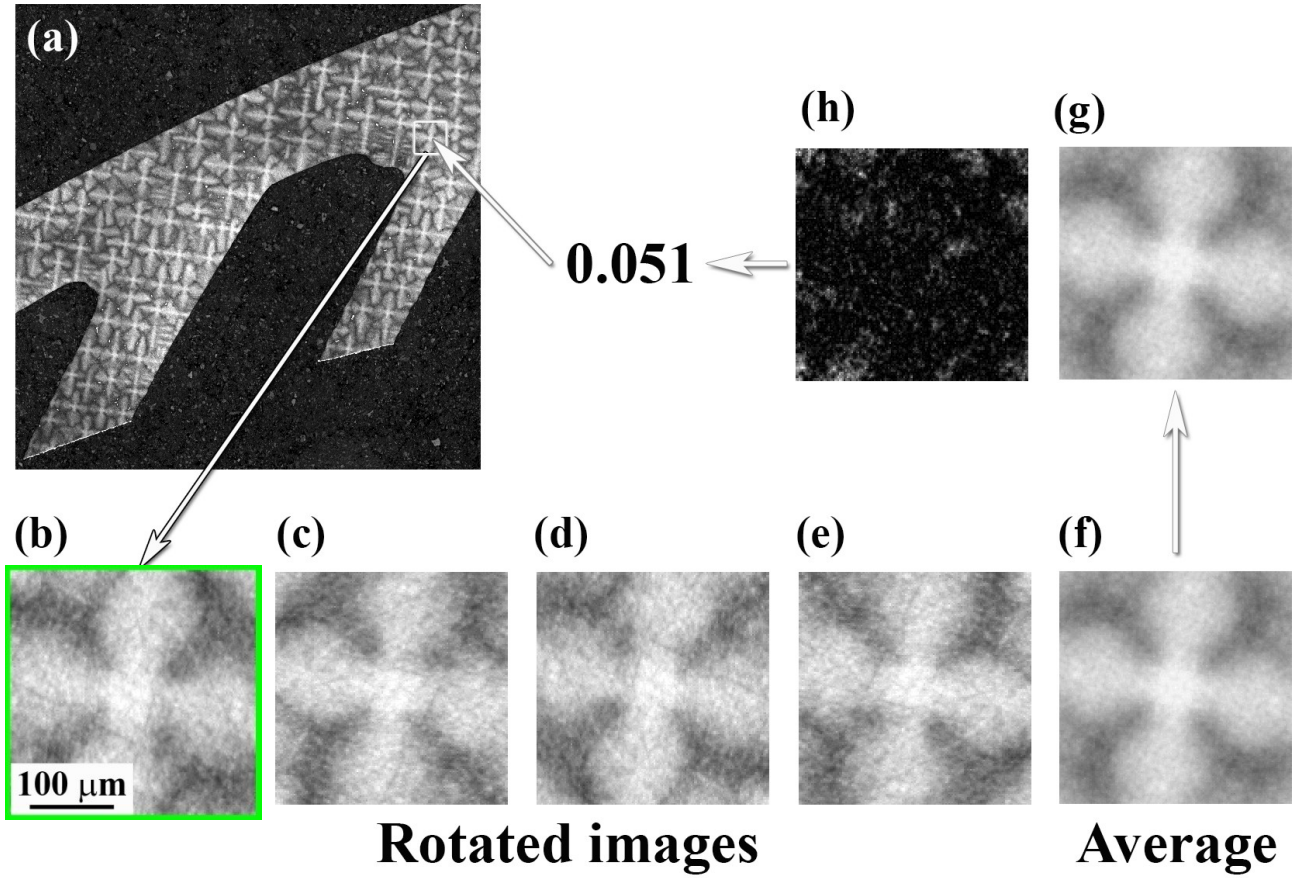


Typical Image



Tschopp, Groeber, Simmons, et al., Scripta Materialia (accepted).

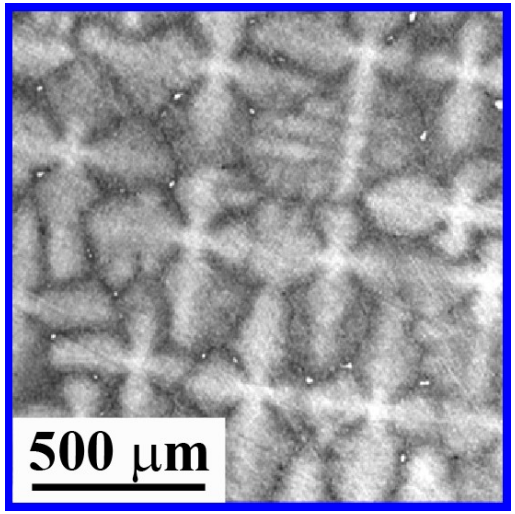
Symmetry-based Technique

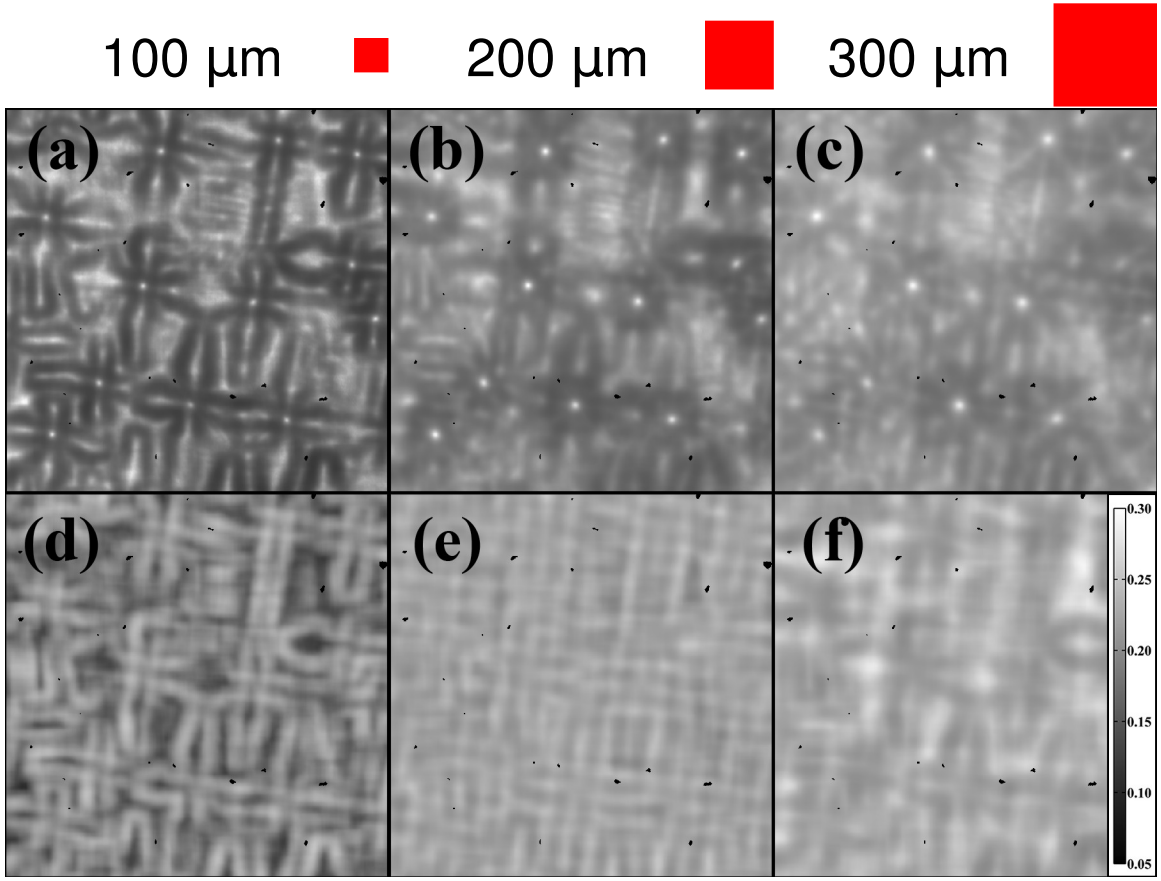


This schematic shows how the symmetry filter operates on a single pixel from a larger region.

Tschopp, Groeber, Simmons, et al., Scripta Materialia (accepted).

Four-fold Symmetry Results



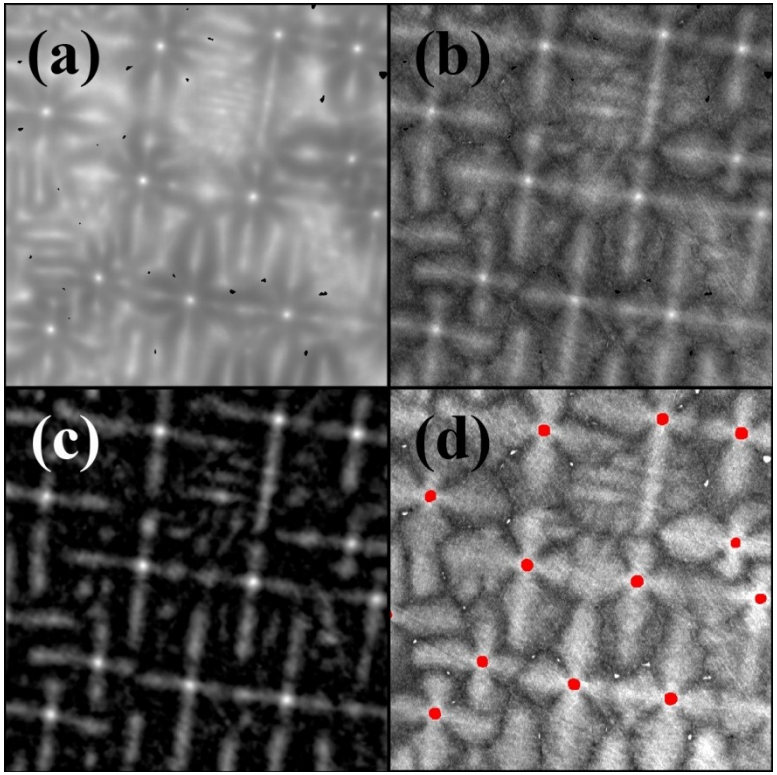


These images show the results of the fourfold symmetry filter and weighting factor applied to various neighborhood sizes.

Tschopp, Groeber, Simmons, et al., Scripta Materialia (accepted).

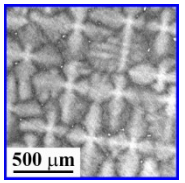
Four-fold Symmetry Results

Combine image information from multiple scales



Multiply original intensity image information

X



Apply Gaussian and morphological top hat image filters

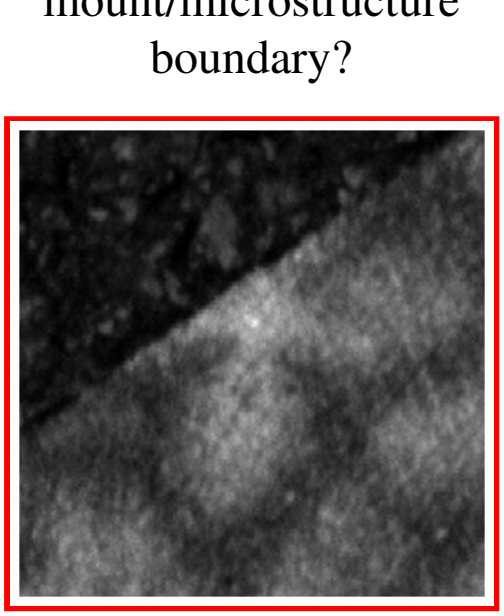
User-defined intensity threshold (142-202 for 8-bit image)

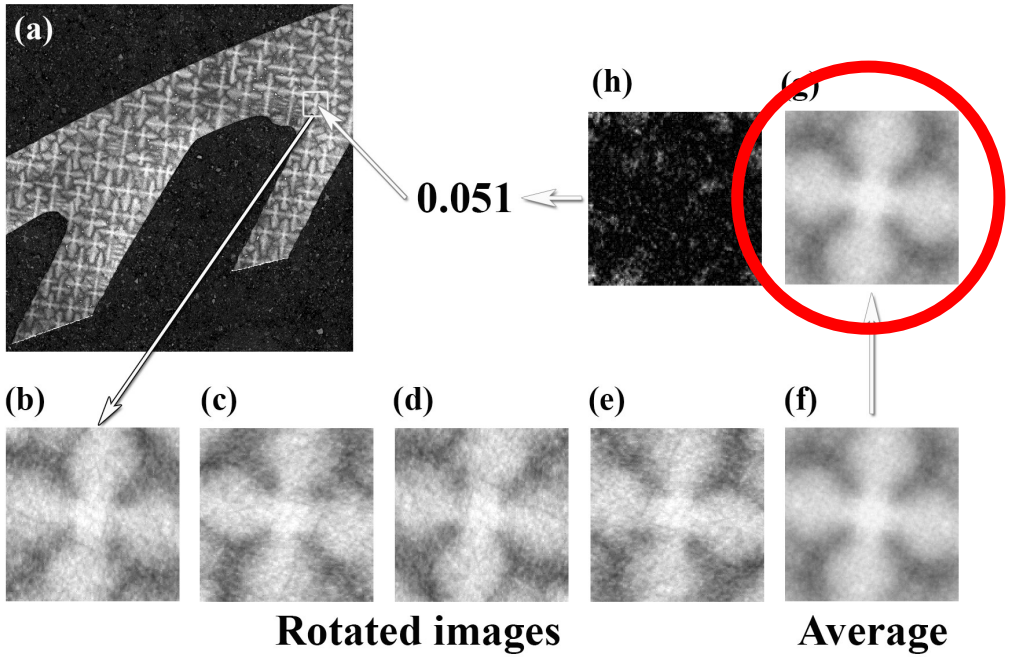
These images show the subsequent multi-scale processing to extract the four-fold symmetry (dendrite core) locations.

Tschopp, Groeber, Simmons, et al., Scripta Materialia (accepted).

Symmetry-based Technique

What about dendrites at the mount/microstructure boundary?



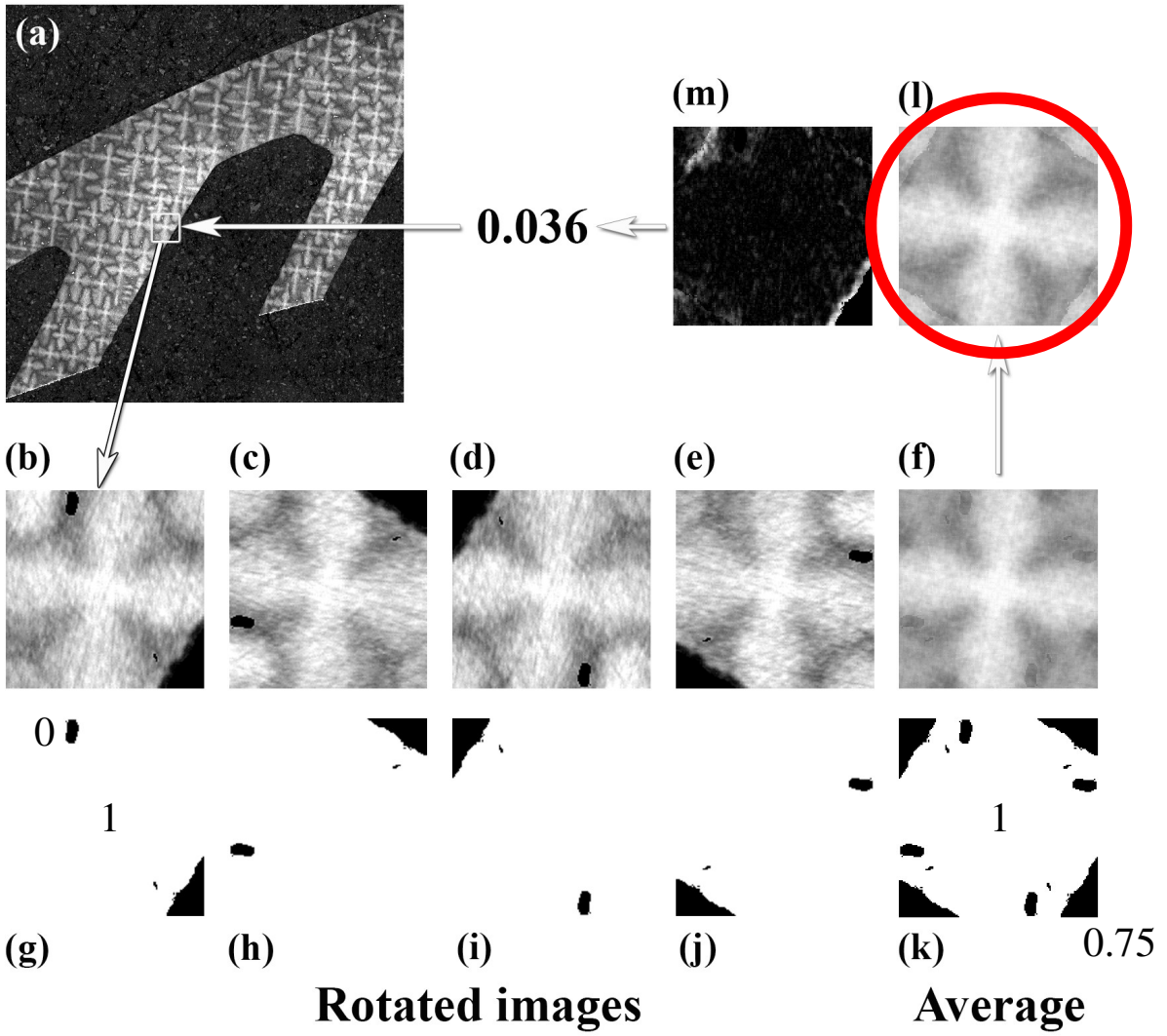


How do you account for four-fold symmetry at the mount/microstructure boundary? What about eutectic particles?

Tschopp, Groeber, Simmons, et al., Scripta Materialia (accepted).

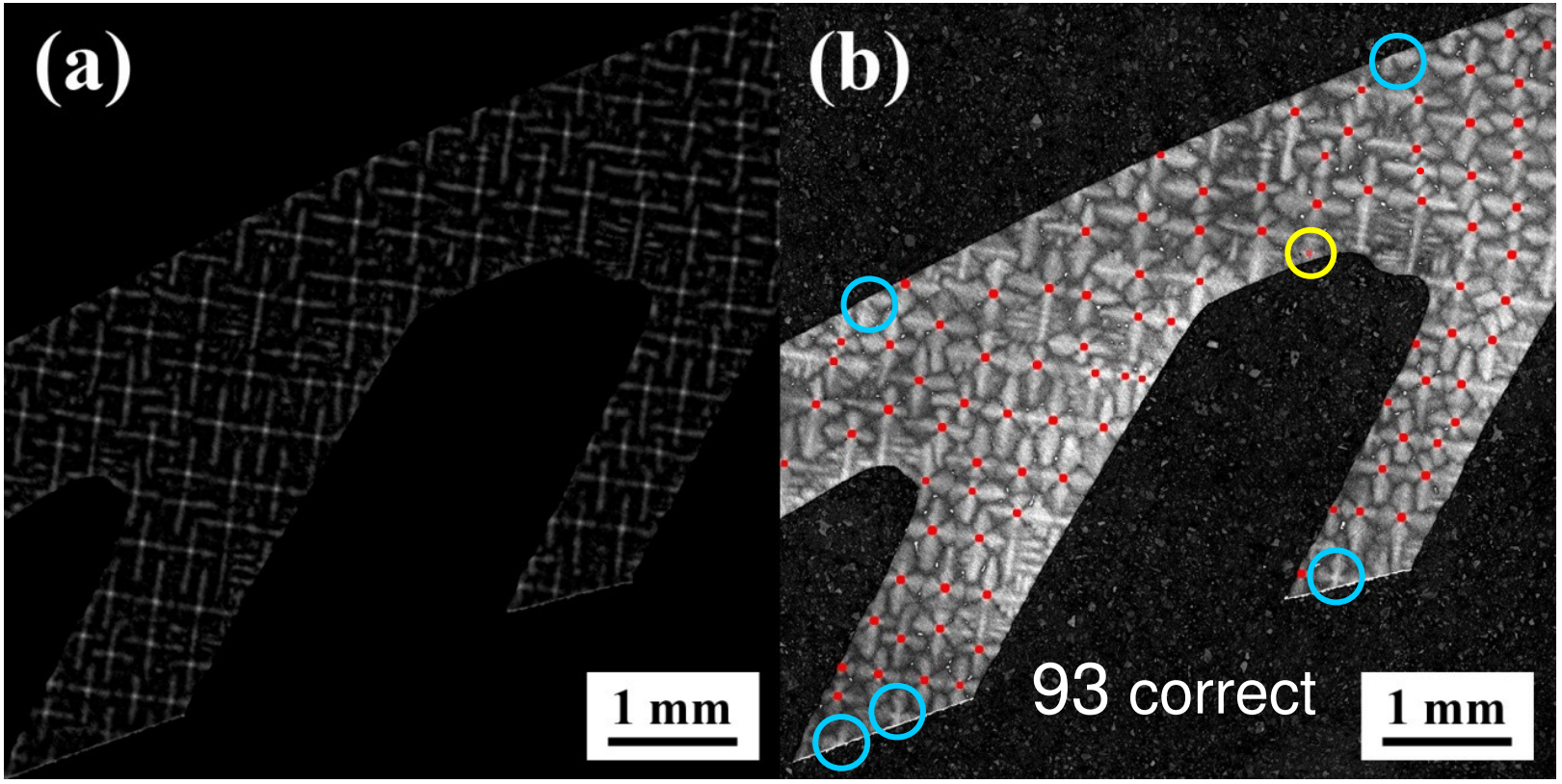
Symmetry-based Technique

This schematic shows how the symmetry filter operates on a single pixel with mount material & eutectic particles.



Tschopp, Groeber, Simmons, et al., in preparation.

Four-fold Symmetry Results

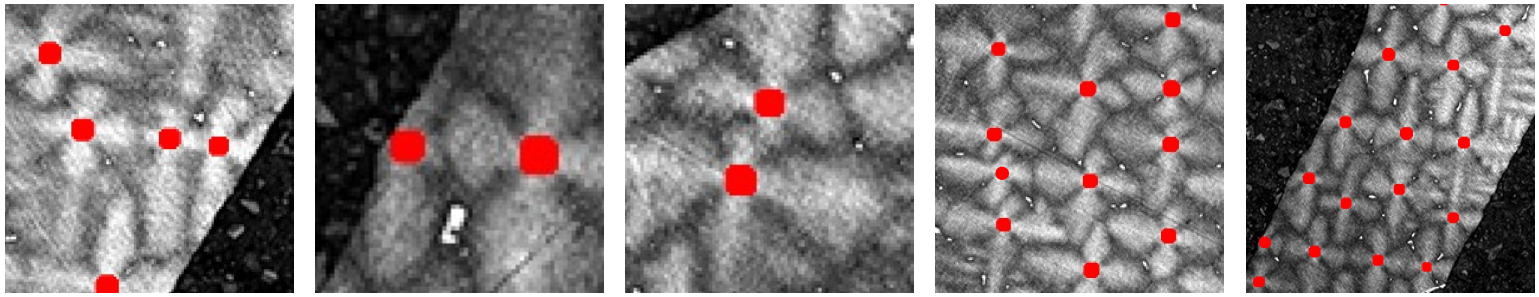


An example of the four-fold symmetry filtered image (a) and the results after applying a user-defined threshold (b).

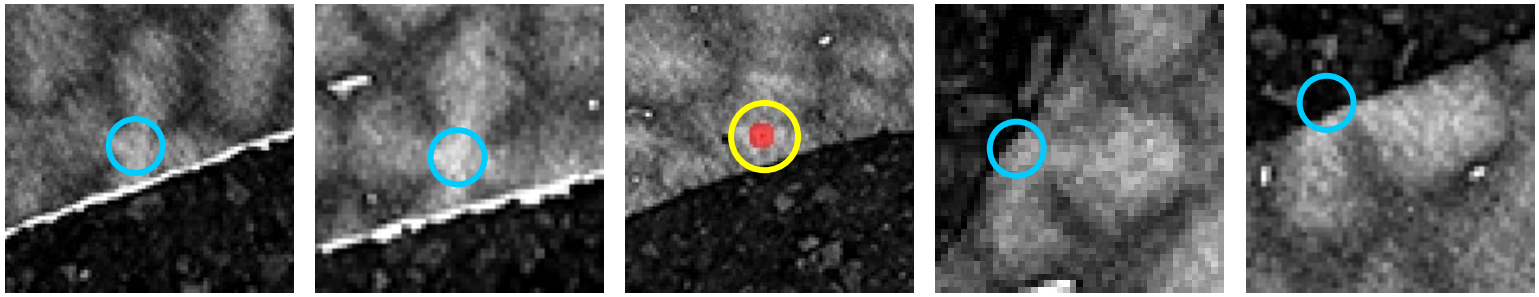
Tschopp, Groeber, Simmons, et al., Scripta Materialia (accepted).

Four-fold Symmetry Results

CORRECT



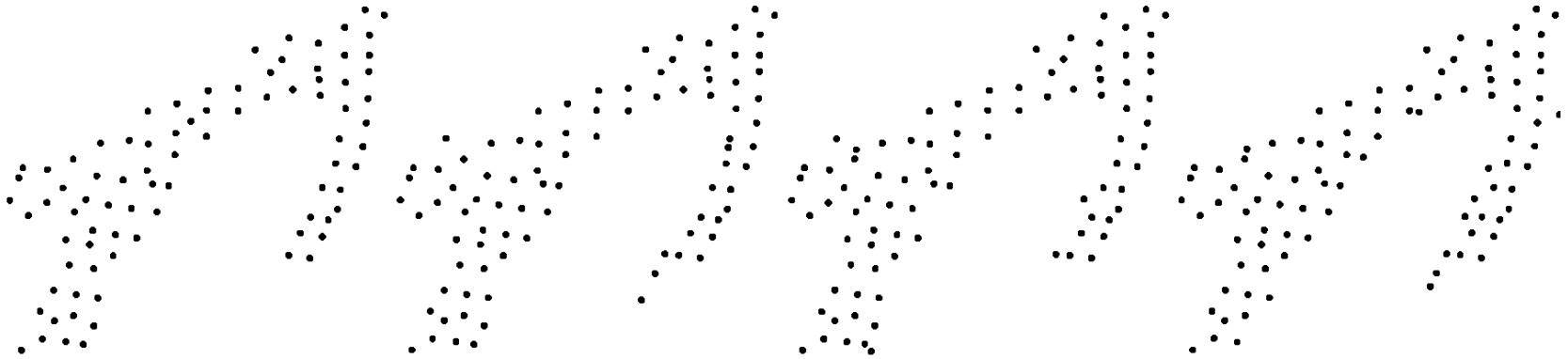
NOT CORRECT?



Closeup images of correctly detected dendrite cores along with false positives (yellow) and missed dendrite cores (blue).

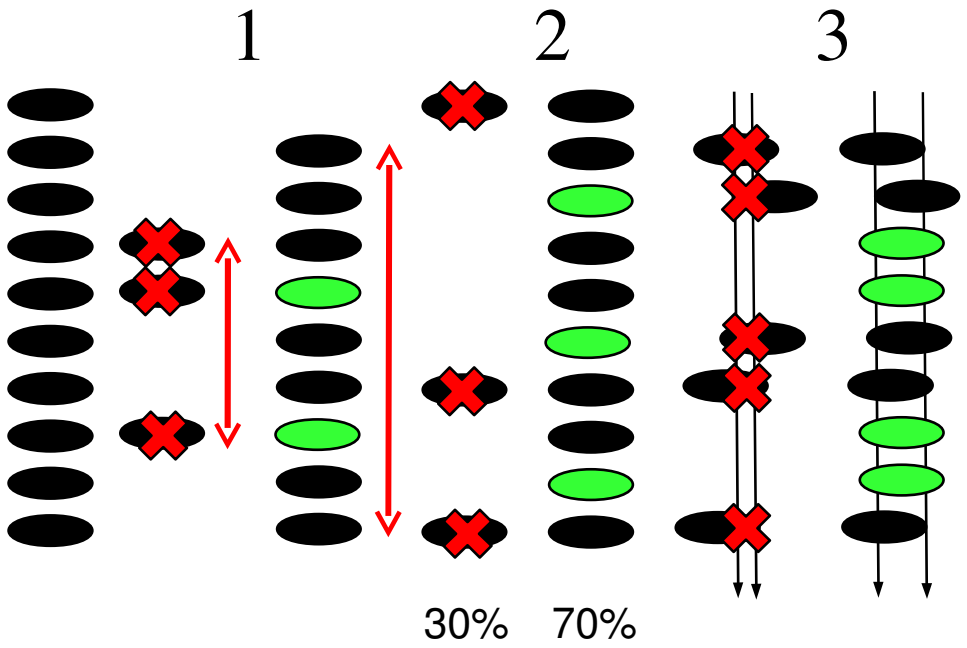
Tschopp, Groeber, Simmons, et al., Scripta Materialia (accepted).

Continuity Rules



Continuity rules are then applied to refine the extraction of dendrite cores.

1. Minimum Dendrite Length
2. Minimum Slice Occurrence
3. Minimum Size Threshold



Tschopp, Groeber, Simmons, et al., in preparation.

Continuity Rules

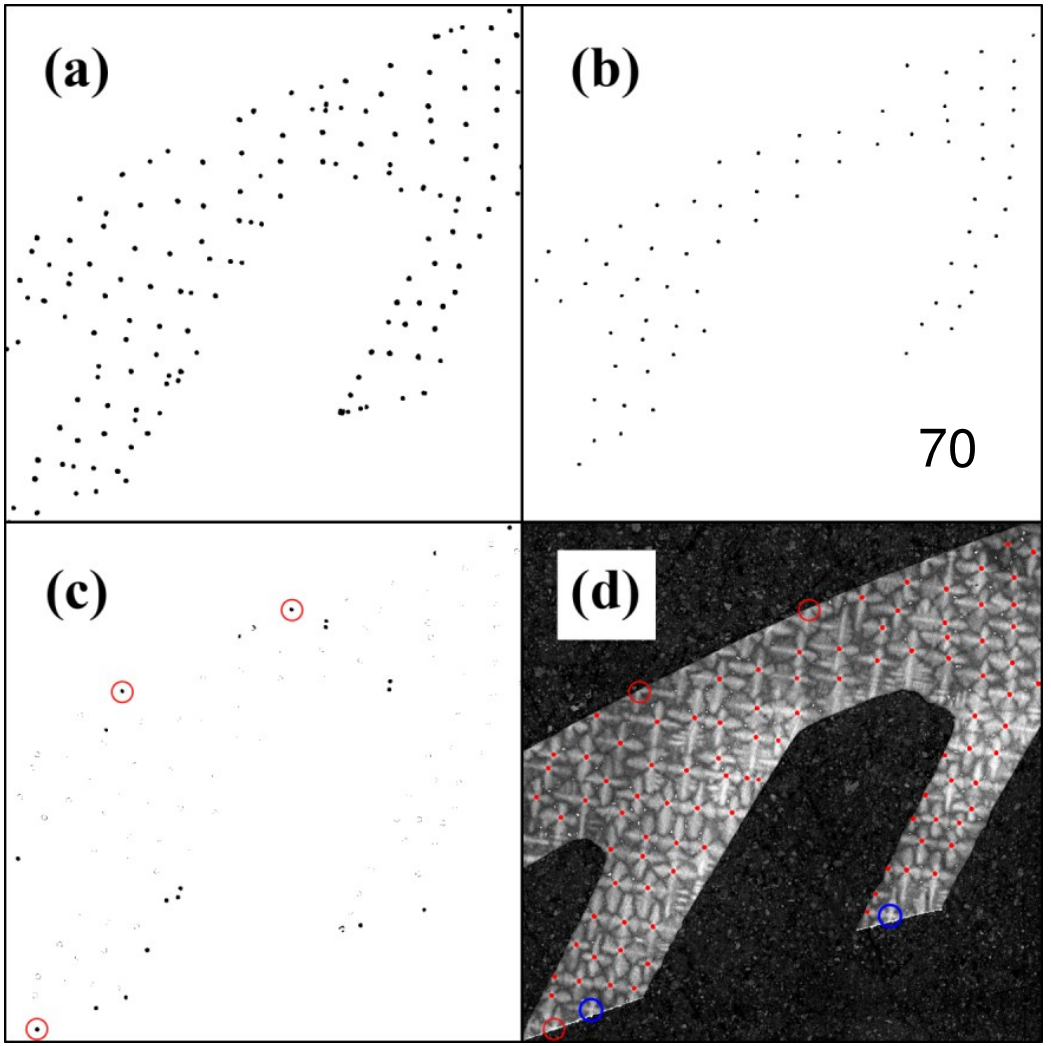
These images show the results of these continuity rules on the 16-image stack

a)All detected objects

b)Detected on all slices

c)Deleted from slices

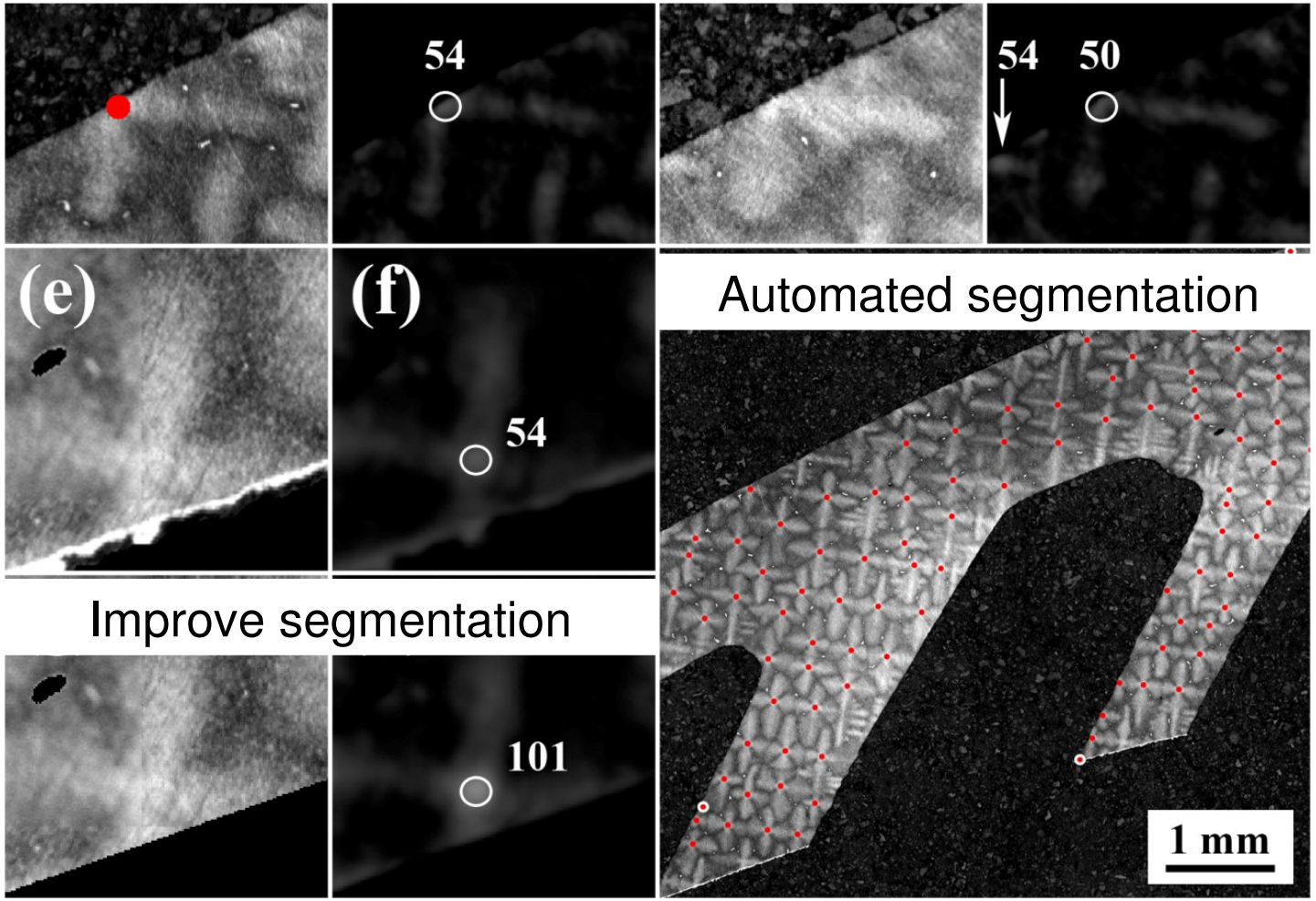
d)Refined segmentation



Tschopp, Groeber, Simmons, et al., in preparation.

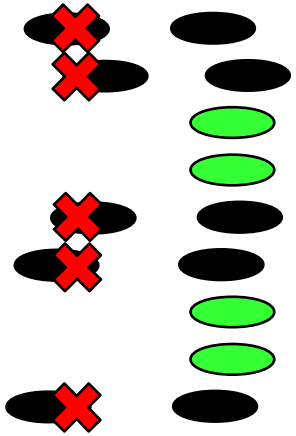
Potential Improvements

What is the best way to handle dendrites at the border?



Tschopp, Groeber, Simmons, et al., in preparation.

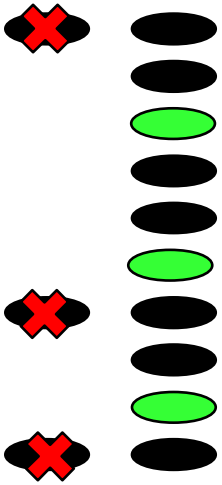
Summary

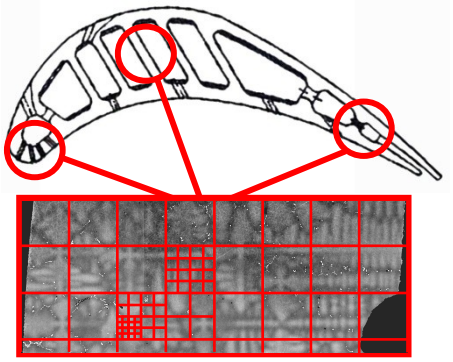


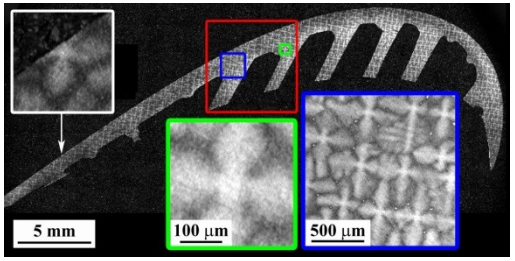
An automated technique for extraction of symmetric microstructural features is presented and applied to serial slices of a single crystal Ni-based superalloy.

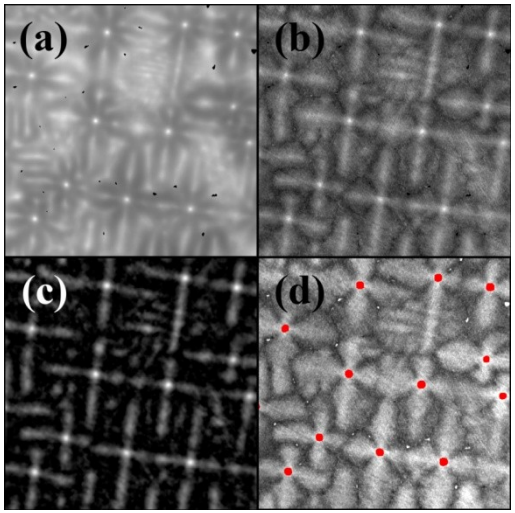
- The segmented dendrite core locations are detected with this technique.

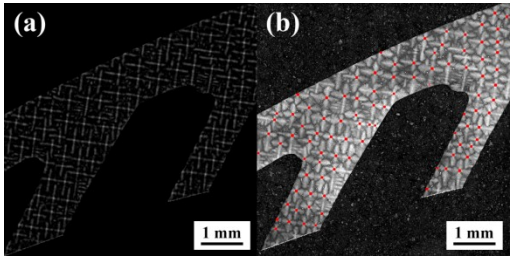
- Additional continuity rules help to exclude segmentation artifacts and improve dendrite core segmentation.











Thank you!

Questions?