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School of Materials Engineering

Failure Analysis of Stainless-Steel Frying Basket Welds

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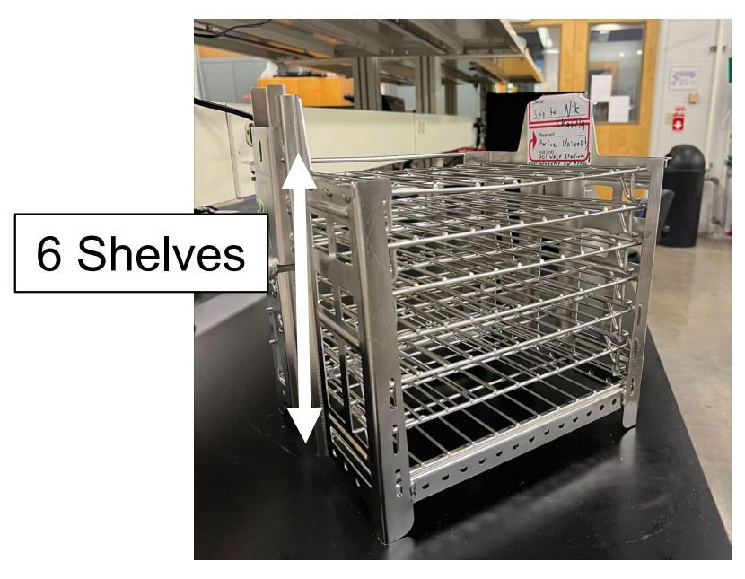
This study establishes a model for the failure of austenitic 300 series stainless steel frying basket welds resulting from internal weld defects. The root causes of weld failures were assessed through a combination of tensile testing, X-ray tomography, and fractography. Void size and shape were connected to weld integrity quantitatively, and failure and failure modes were qualitatively explained through post-fracture imaging. Ultimately, this model predicts the susceptibility of 300 series stainless steel welds to failure, enabling proactive maintenance and design improvements.

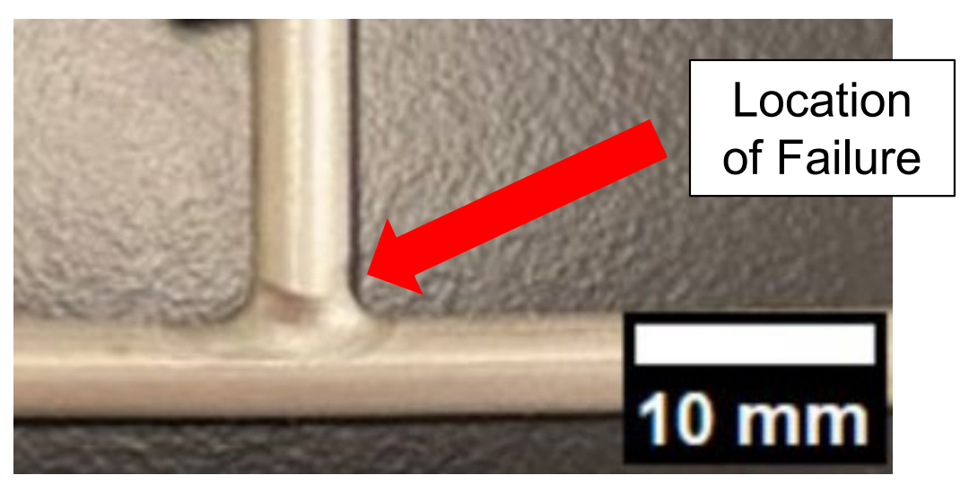
This work is sponsored by a Chicken Quick Service Restaurant

Background

- Baskets currently last 25-50% of their service life
- Wire shelves built using pressure welding and tungsten inert gas (TIG) welding
- TIG welds add strength and corrosion resistance to basket joints.
- Welds fail prematurely



6-tier frying basket

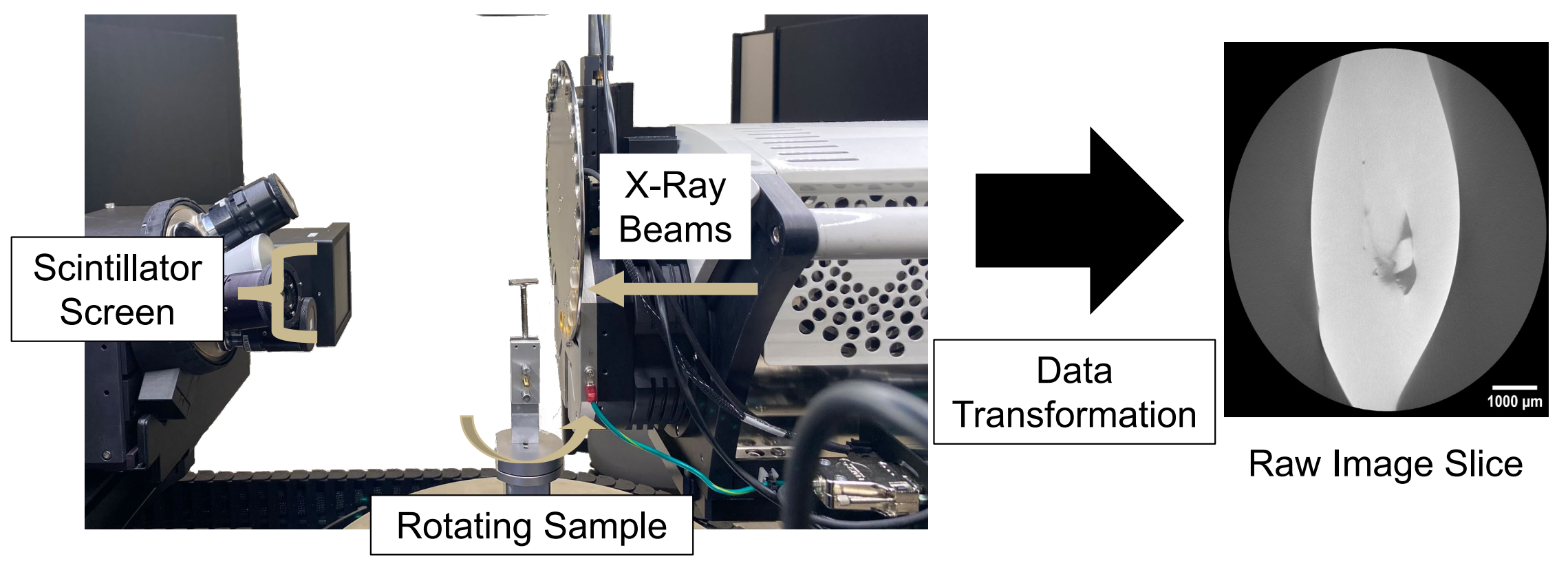


TIG Welded Joint

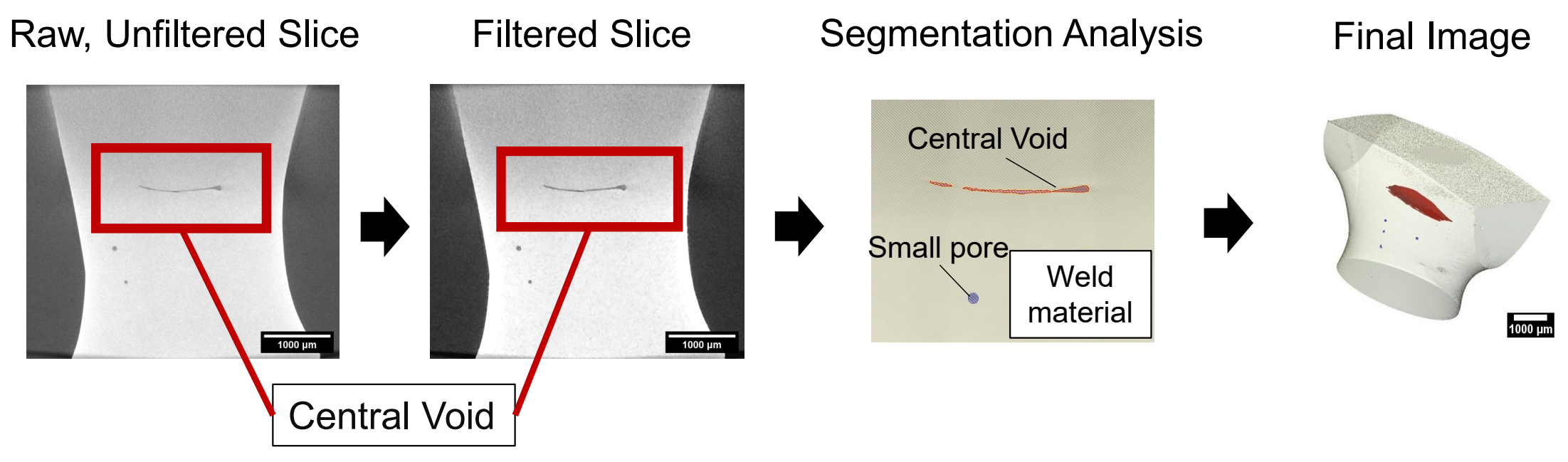
- Broken baskets decrease product output by 17-33% per shelf and cost several hundreds of dollars to replace
- Need to understand what is causing weld failures and how to prevent them from continuing in the future

X-Ray Tomography

- 3D imaging method based on differential X-ray absorption used to visualize and quantify voids in TIG voids



- Tomography data reconstructed from 2D radiographs to create volume renderings

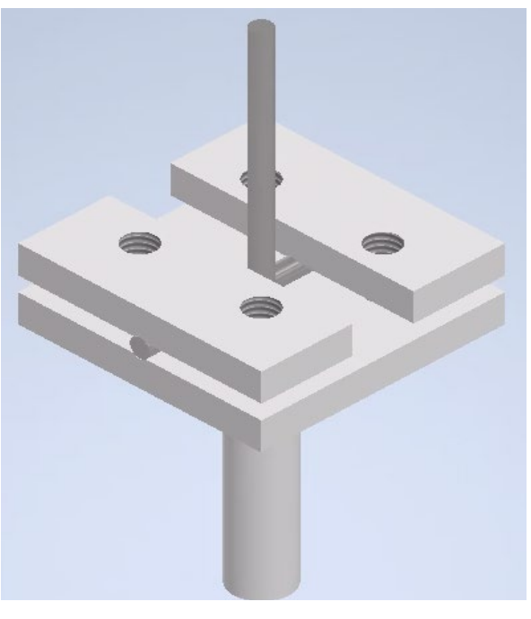


The segmentation analysis process for internal defect identification and quantification

- Welds measured before destructive testing

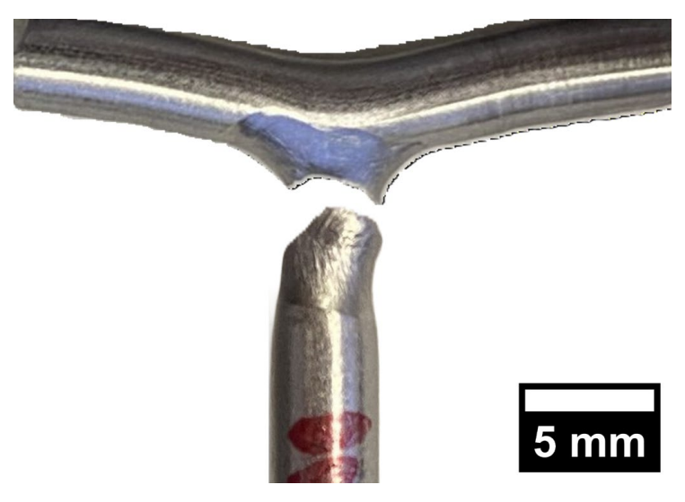
Tensile Testing

- Vise-like design to hold sample during testing
- Designed to be simple to manufacture, easy to load the sample, and concentrate tensile load on welded region to limit deformation in the wires

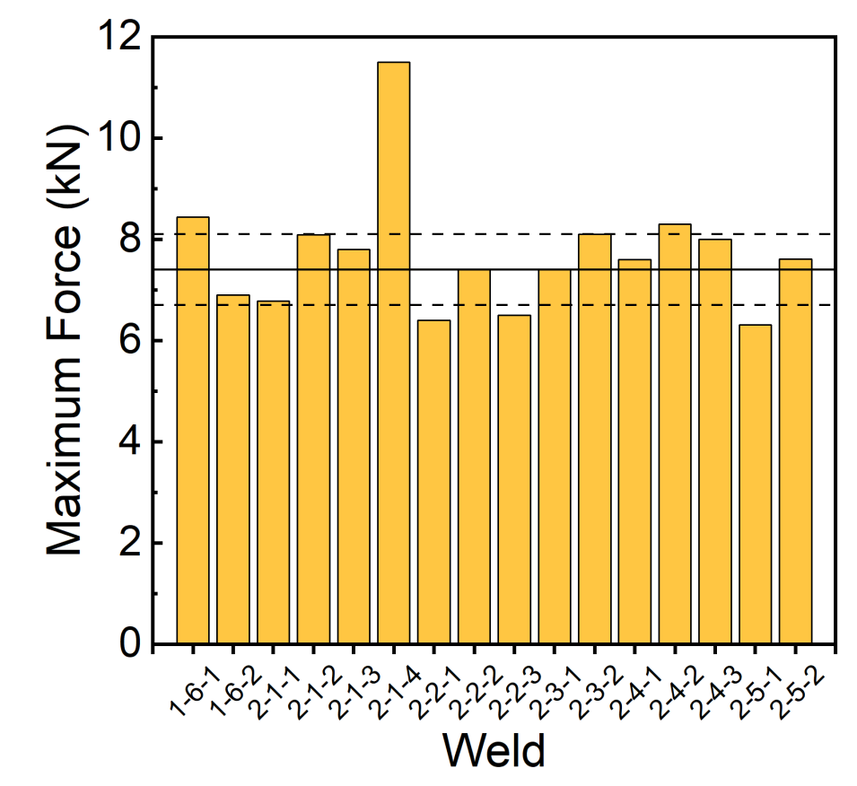


Tensile fixture CAD model

Tensile fixture loaded in MTS Landmark tensile testing machine



Sample post-failure



The maximum tensile force for each weld tested

- Average ultimate tensile load of 7.5 ± 0.7 kN
- Maximum force of 11.5 kN
- Minimum force of 6.3 kN
- What causes this variation?

Void – Strength Correlation

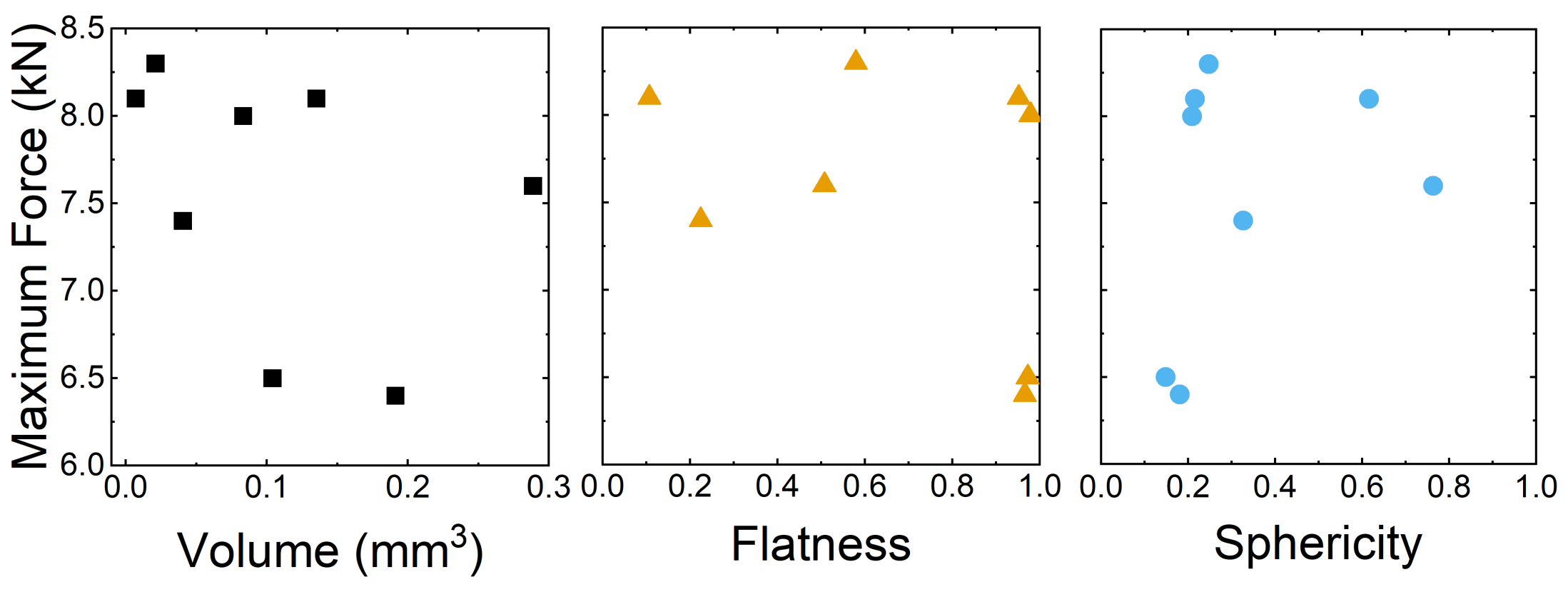
- The void shape can be described using 3D shape factors:
- **Flatness:** "plate-like" dimensions of void based on axis length comparisons, calculated using equation (1)
- **Sphericity:** similarity to spherical shape based on ratio of surface areas of void and encapsulating sphere, calculated using equation (2)

$$fl = \frac{b^2}{a \cdot c + b^2} - \frac{c}{a + c} \quad (1)$$

$$\psi = \frac{\pi^{1/3}(6V_p)^{2/3}}{A_p} \quad (2)$$

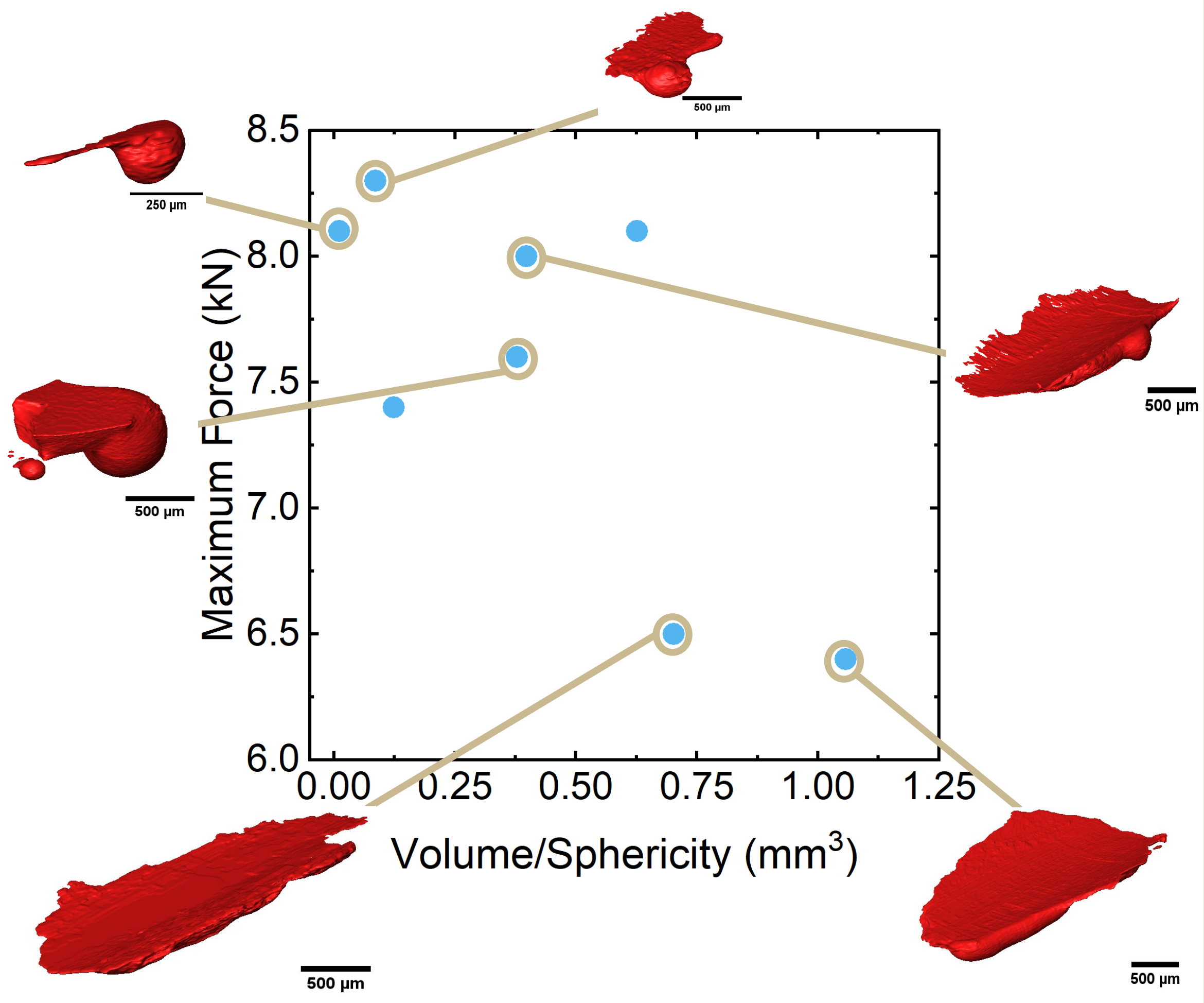
fl = flatness ratio
a = maximum axis length
b = median axis length
c = minimum axis length

ψ = sphericity ratio
V_p = particle (void) volume
A_p = particle (void) surface area



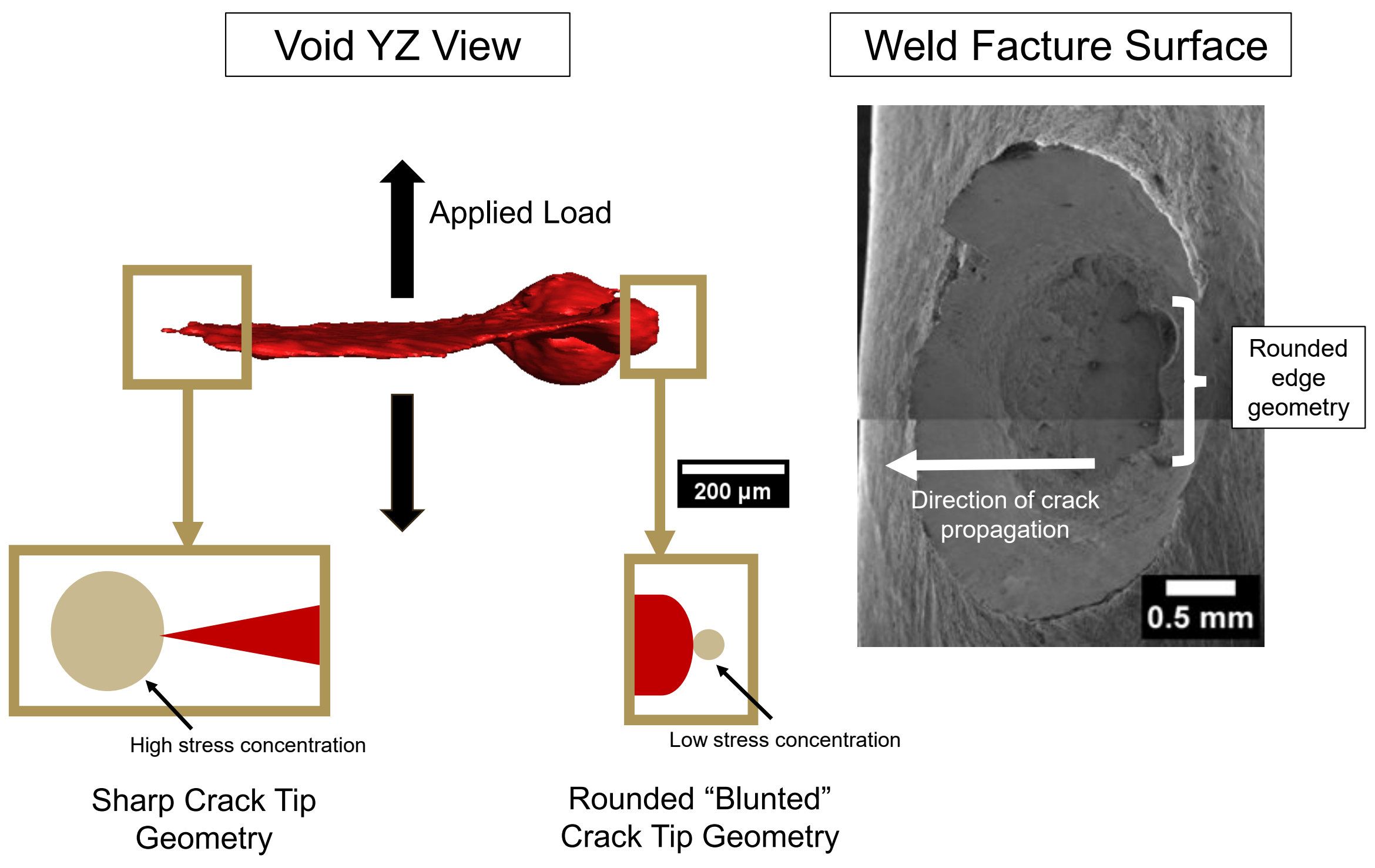
Volume, flatness, and sphericity relationships with maximum force as individual quantities.

- Flatness and sphericity alone do not show a strong relationship with maximum force
- Relationship between void volume and maximum force does not account for variation in shape between voids



Void volume and sphericity versus maximum force, segmented void shapes from different welds highlighted.

- Void volume was modified by sphericity to consider size and shape simultaneously
- Smaller voids with spherical features yield higher maximum force compared to larger voids with flat features



Sharp Crack Tip Geometry

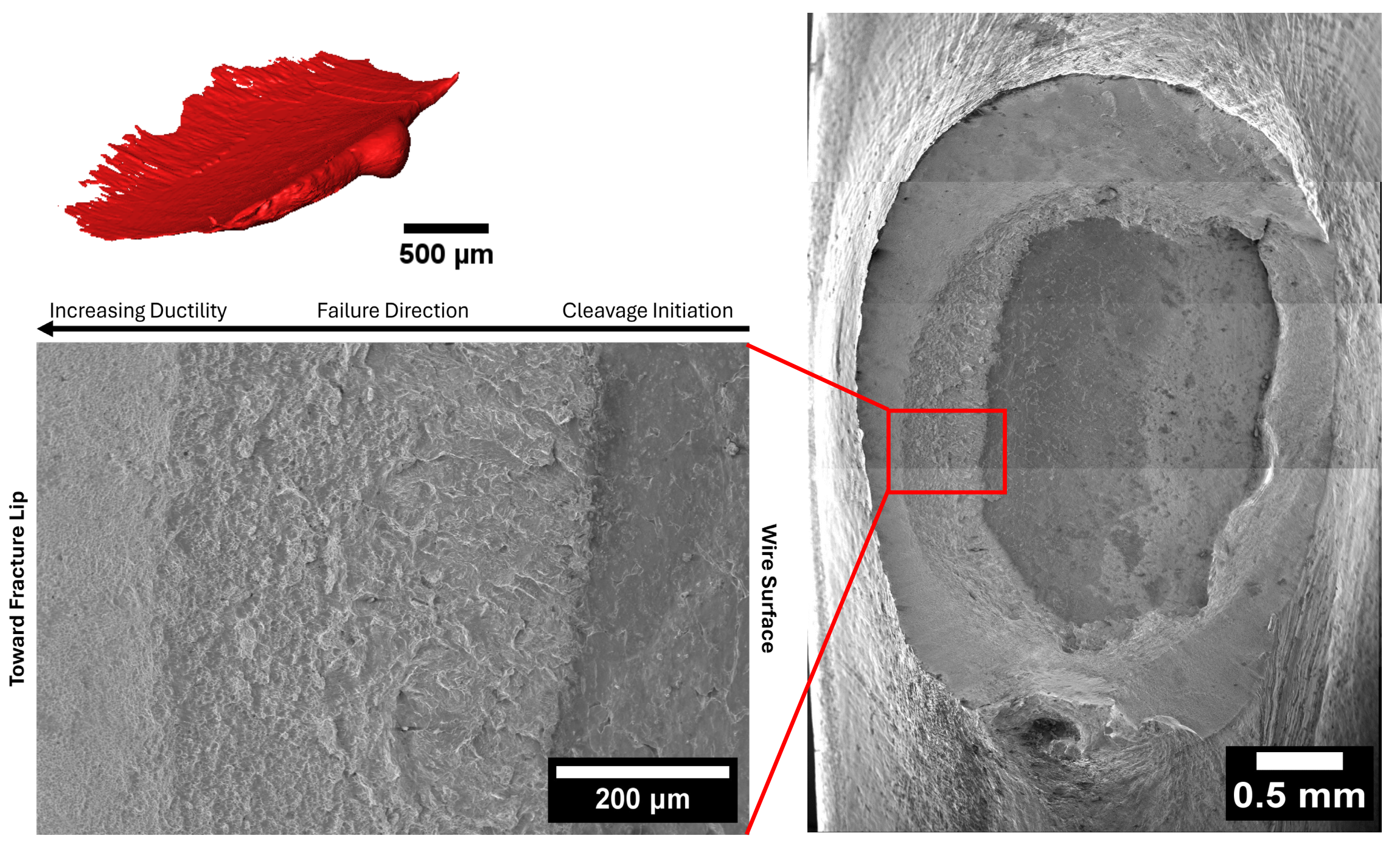
Rounded "Blunted" Crack Tip Geometry

- Narrow voids concentrate deformation at their edges
- Rounded edges inhibit deformation at their edges
- As tensile load is applied, narrow void edges will form and propagate cracks into material until failure

Fractography

Void-Induced Fracture

Fractography validated a relationship between void shape and fracture mechanisms.

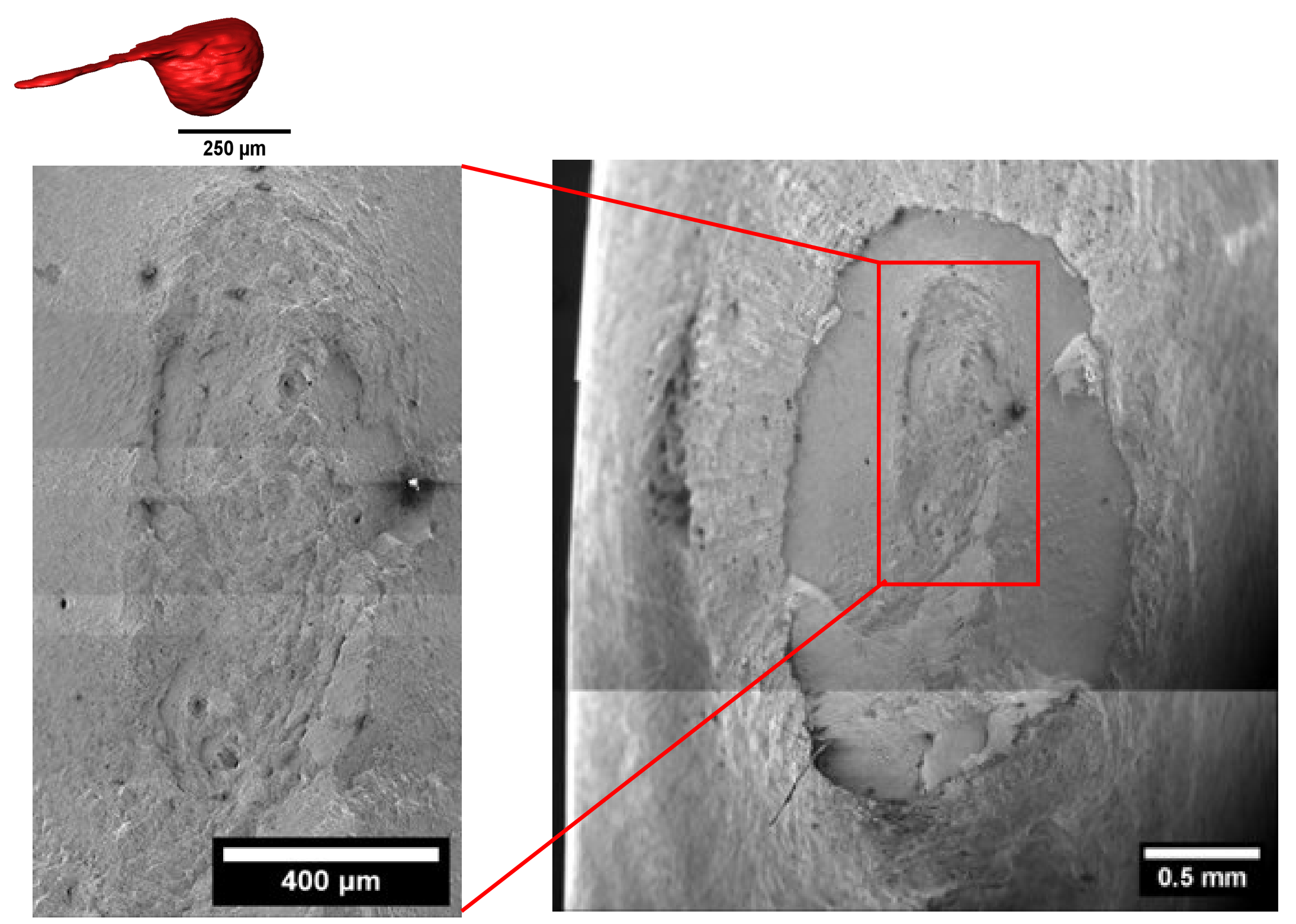


Transition from brittle cleavage (right) to ductile failure (left)

Surface of void-induced fractured weld

- Weld failure initiates at the surface of the void and causes brittle cleavage
- Fracture transitions to ductile failure near the surface
- Sharper edge of void has a more gradual transition to ductile failure

Small Volume – High Sphericity Void Fracture



Central defect of failed weld

Fractured surface of weld

- Weld did not fail at the weld-wire interface
- Fracture surface conforms to planar contour of top section within the internal void
- Reduced void volume and spherical configuration led to ultimate tensile force exceeding the average

Conclusions

- Crack geometries directly lead to variations in fracture, with large, flat defects concentrating stresses and initiating failure sooner
- Non-destructive testing (XRT) and 3D analysis can identify vulnerabilities in welds based on size and morphology
- During the welding process, void formation needs to be controlled to minimize size and ensure the geometry does not add vulnerabilities to weld failure

References

[1] V. Angelidakis, S. Nadimi, and S. Utili, "Elongation, flatness and compactness indices to characterise particle form," *Powder Technology*, vol. 396, pp. 689–695, Jan. 2022. doi:10.1016/j.powtec.2021.11.027
[2] P. Peltola, F. Alobaid, T. Tynjälä, and J. Ritvanen, "Overview of fluidized bed reactor modeling for chemical looping combustion: Status and Research Needs," *Energy & Fuels*, vol. 36, no. 17, pp. 50–51, Aug. 2022. doi:10.1021/acs.energyfuels.2c01680
[3] R. I. Stephens, A. Fatemi, R. R. Stephens, and H. O. Fuchs, "Fundamentals of LEFM and Applications to Fatigue Crack Growth," in Metal Fatigue in Engineering, 2nd ed., John Wiley & Sons, 2001, pp. 122–154.

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