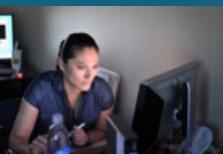




Enhanced predictive modelling of laser weld failure using 3D characterization of 304L



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Outline

- Motivation
- Weld Characterization
- Predictive Modelling
- Conclusion



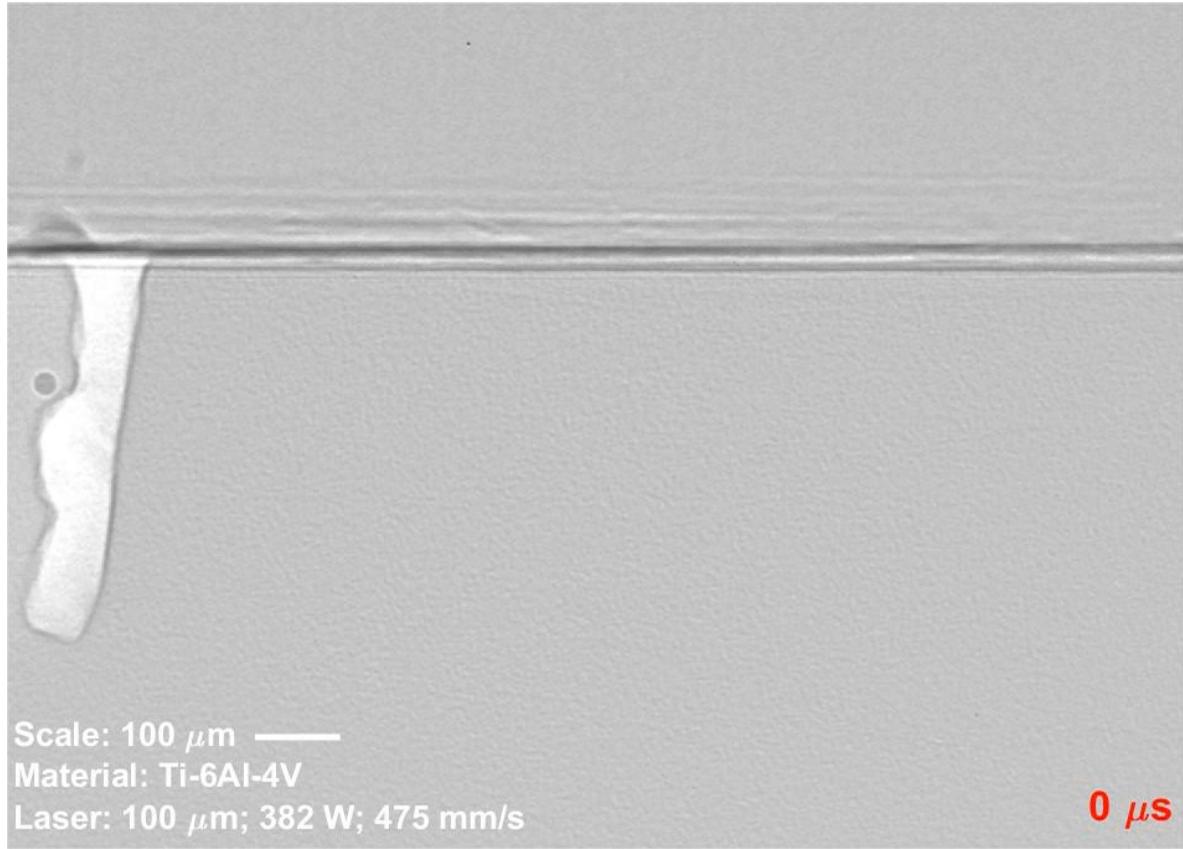
3 | Laser welds have diverse applications across multiple industries

Laser weld advantages

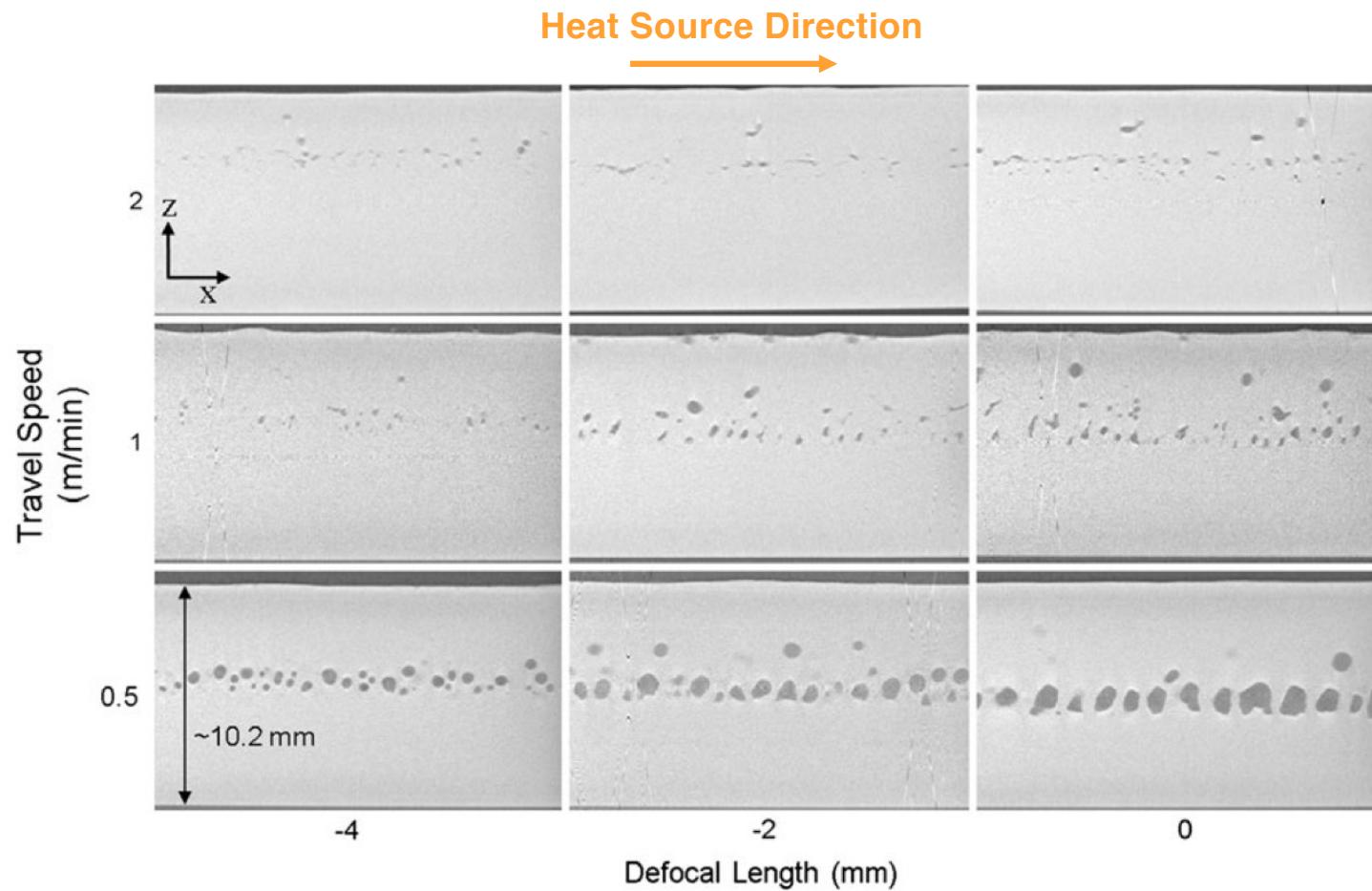
- Relatively low heat input
- Fast solidification rates
- Minimal distortion of parts

Laser weld challenges

- Porosity formation
- Hot cracking

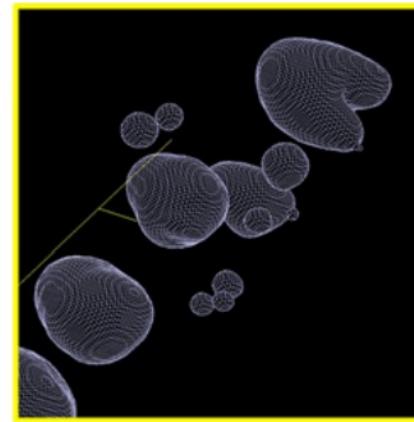


Weld porosity is highly sensitive to processing conditions



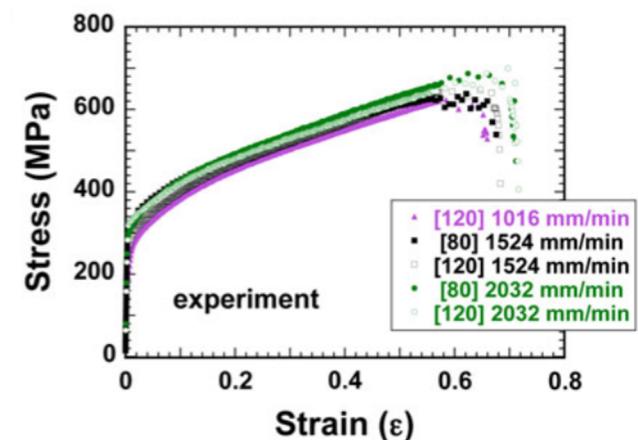
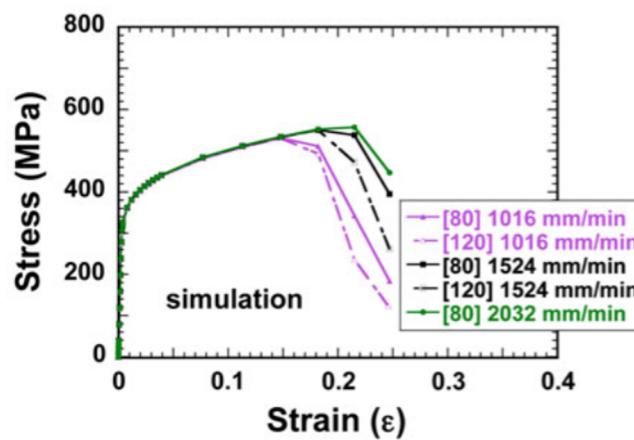
5 Mechanical effects of porosity can be simulated using FE modelling

Weld porosity meshed directly from μ CT
and instantiated into a bulk material volume



Simulation captures yielding and hardening,
but not failure behavior

- $\sim 1/3$ of observed strain to failure
- ~ 100 MPa lower peak stresses



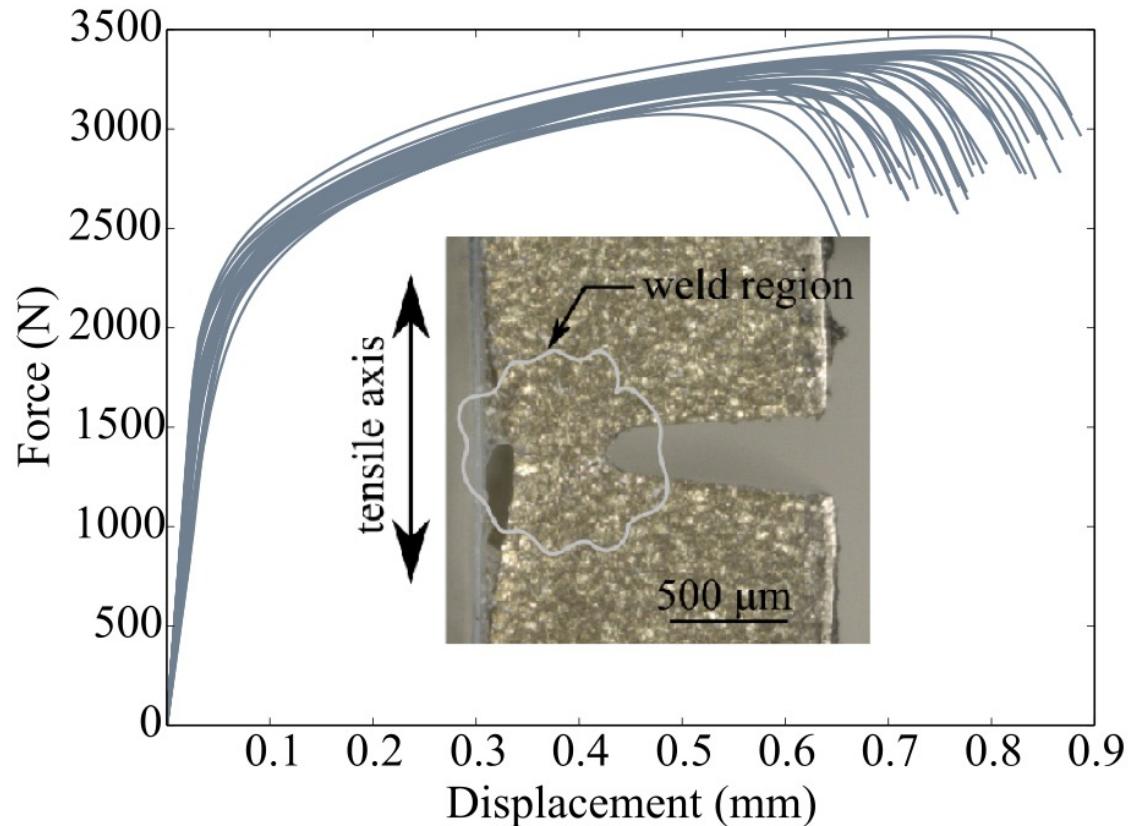
6 | Laser welds also exhibit variable mechanical properties

Nominally identical samples

- 13% variation in peak load
- 59% variation in strain at peak load

Potential factors influencing variability:

- Porosity
- Weld geometry
- Root roughness
- Complex necking behavior in ductile metals





Experimental Weld Characterization



8 | Investigated series of partial penetration butt welds



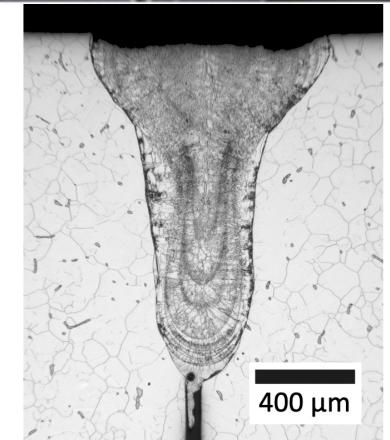
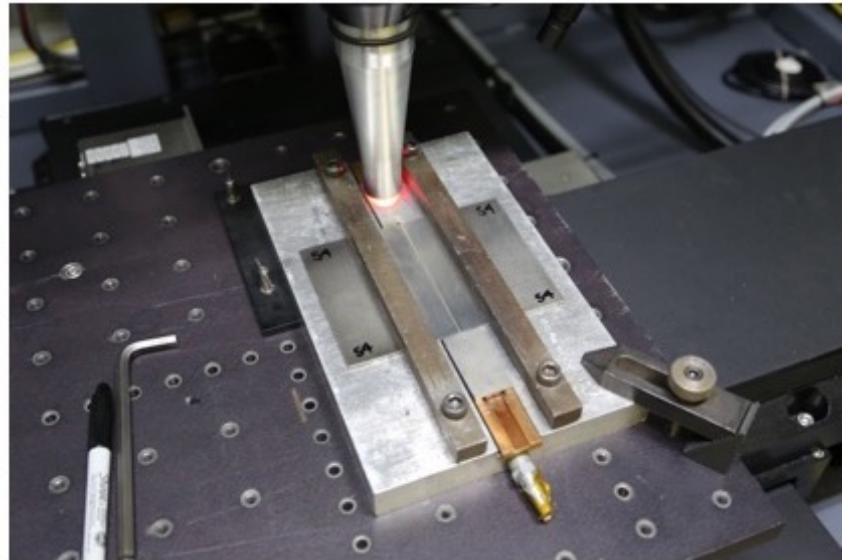
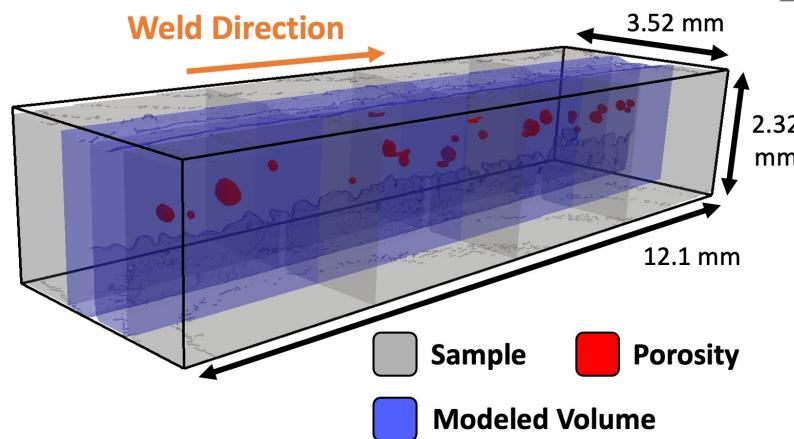
Two weld schedules (α and β)

3 different gap widths (0.10, 0.20, and 0.25 mm)

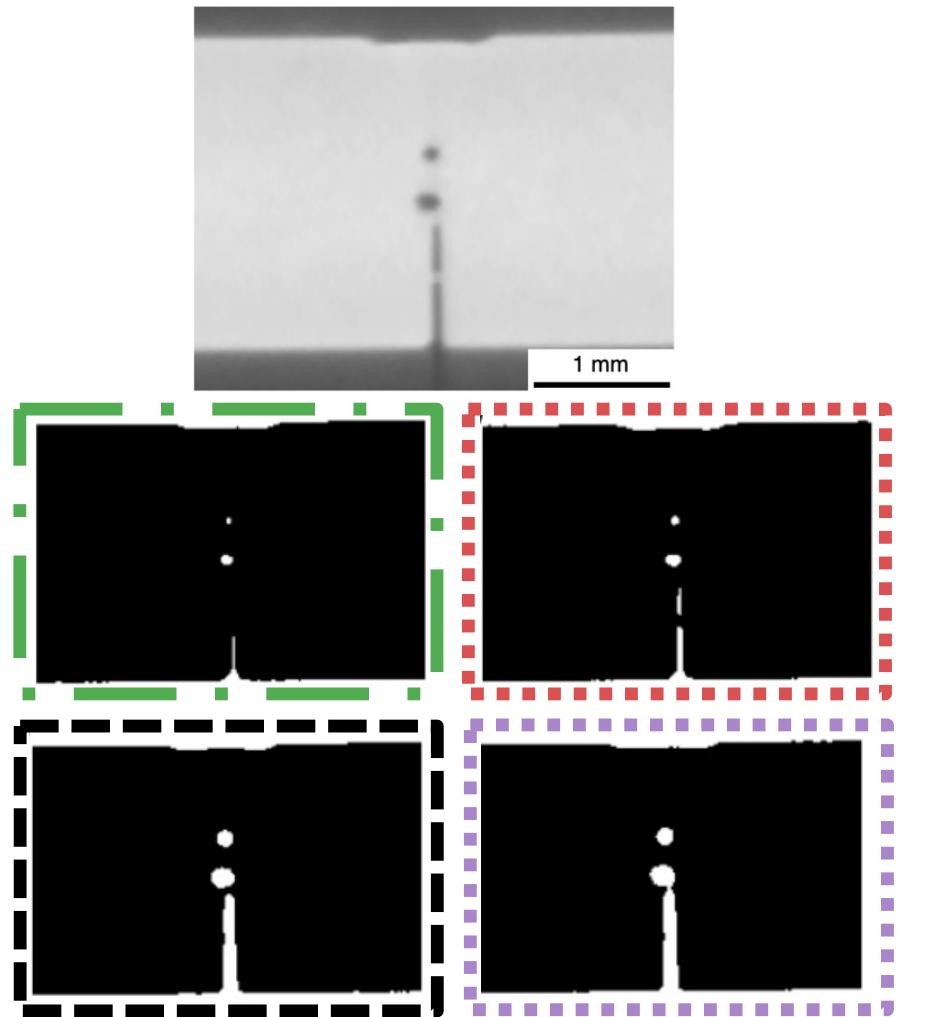
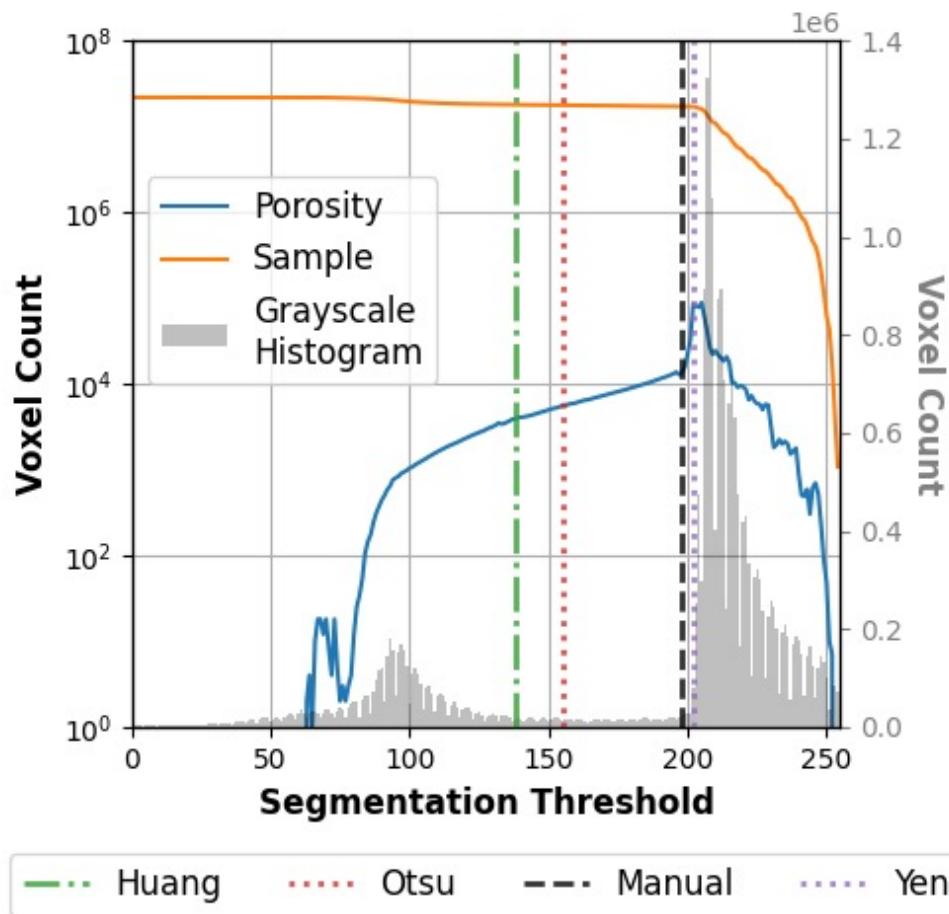
μ CT characterization via NorthStar X50 machine

- 17.6 μ m voxel resolution

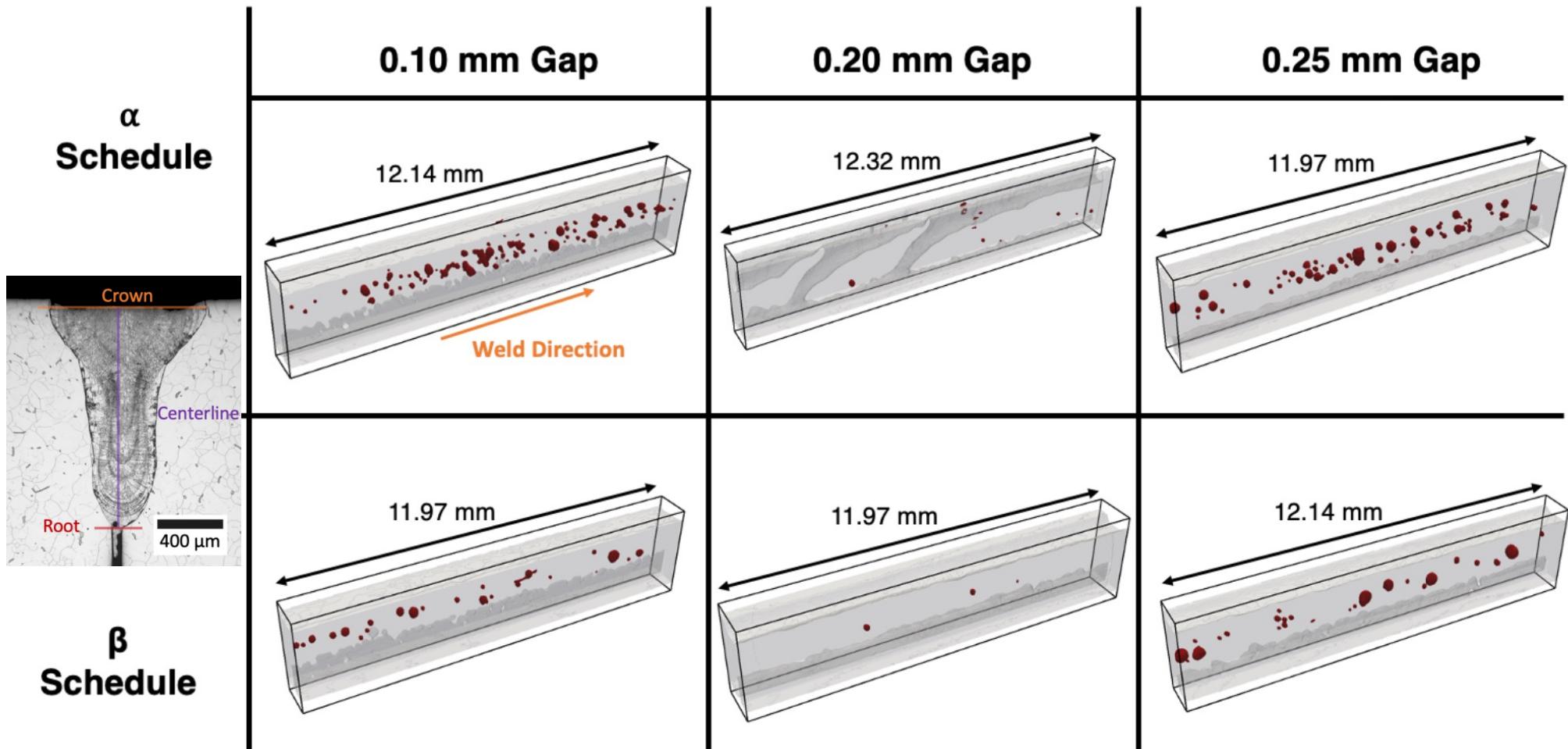
Tensile testing and simulated loading



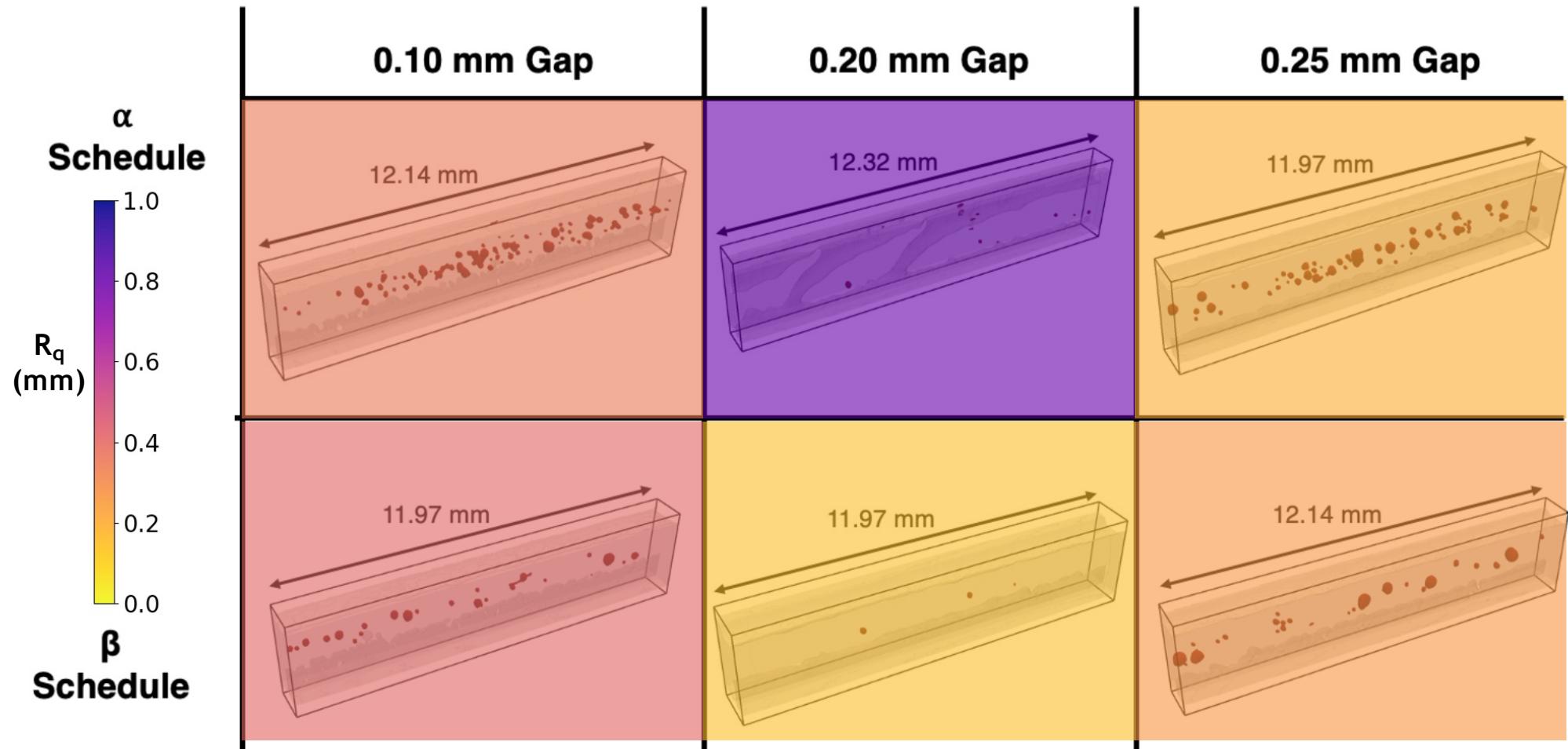
Segmentation decisions impact image analysis



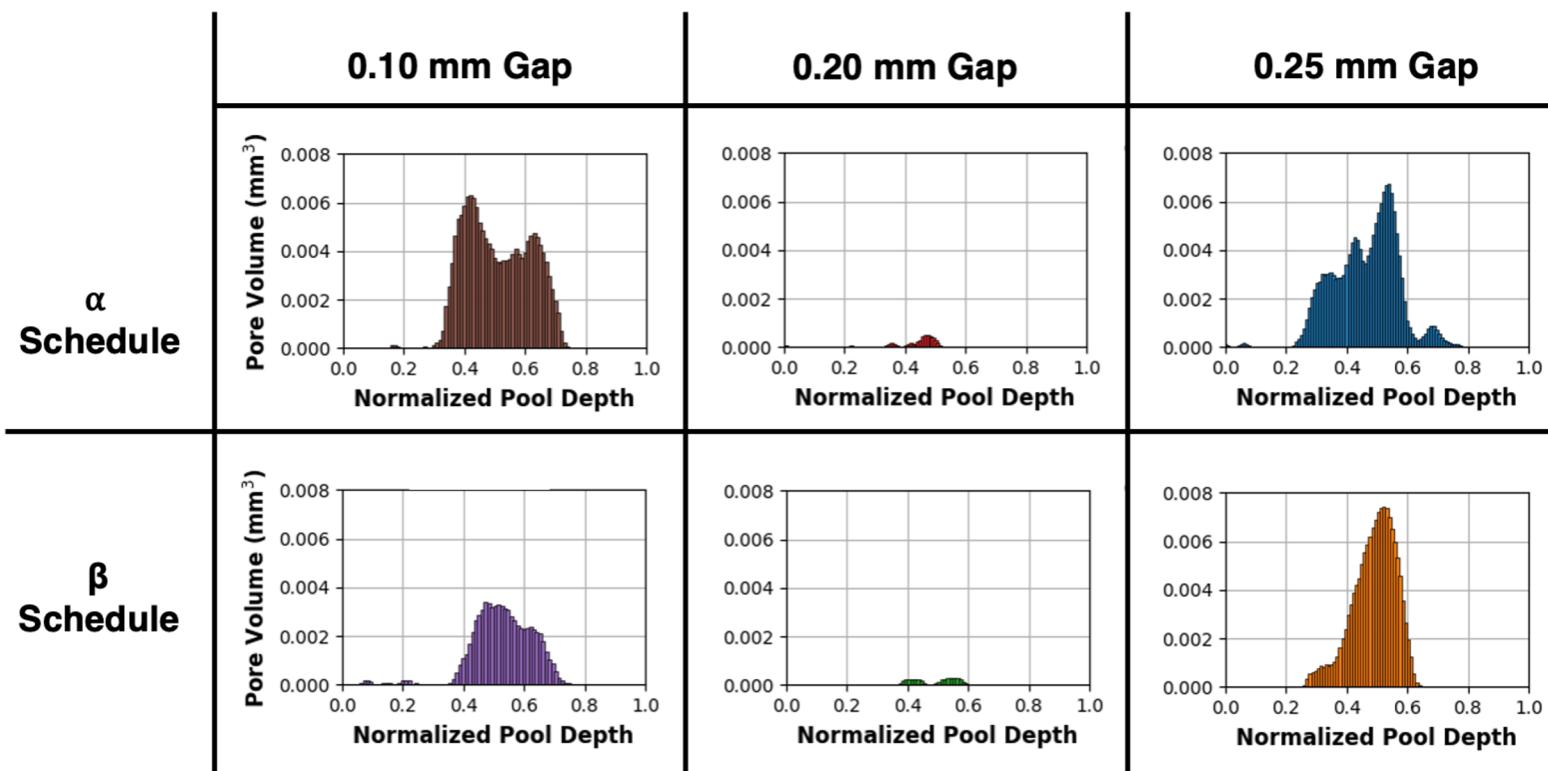
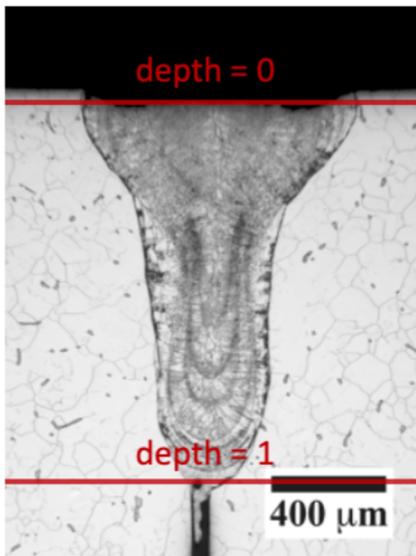
3D reconstructions



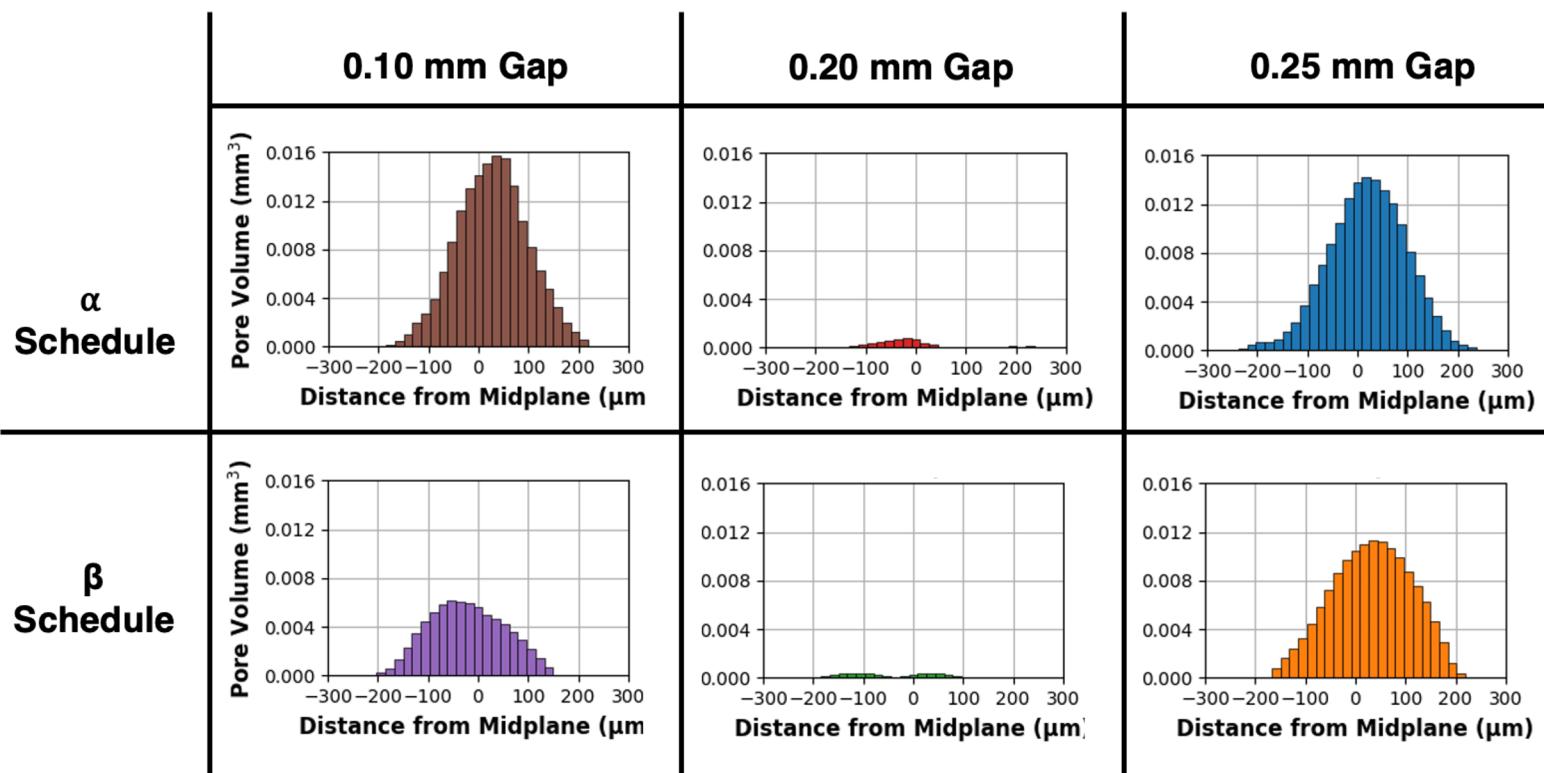
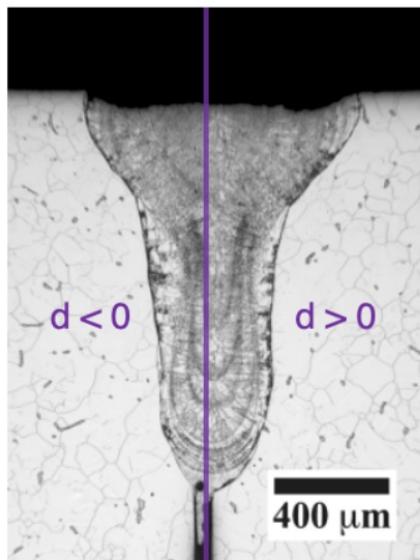
Root mean squared roughness (R_q) of weld root



Porosity tends to localize in center of weld



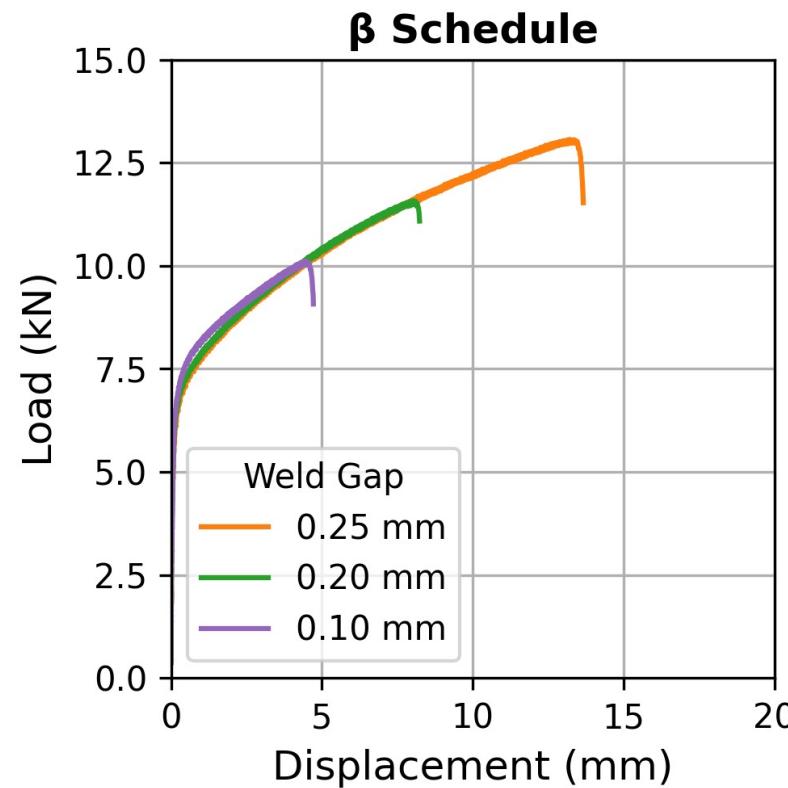
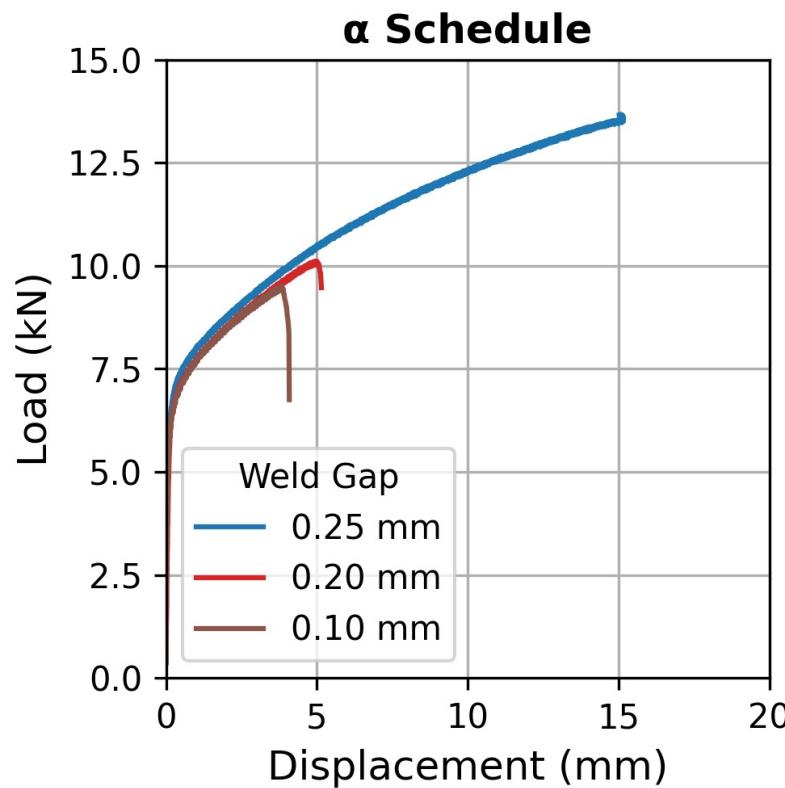
Porosity tends to localize in center of weld



Tensile testing of welds



Increasing strength with increasing gap due to complex stress states





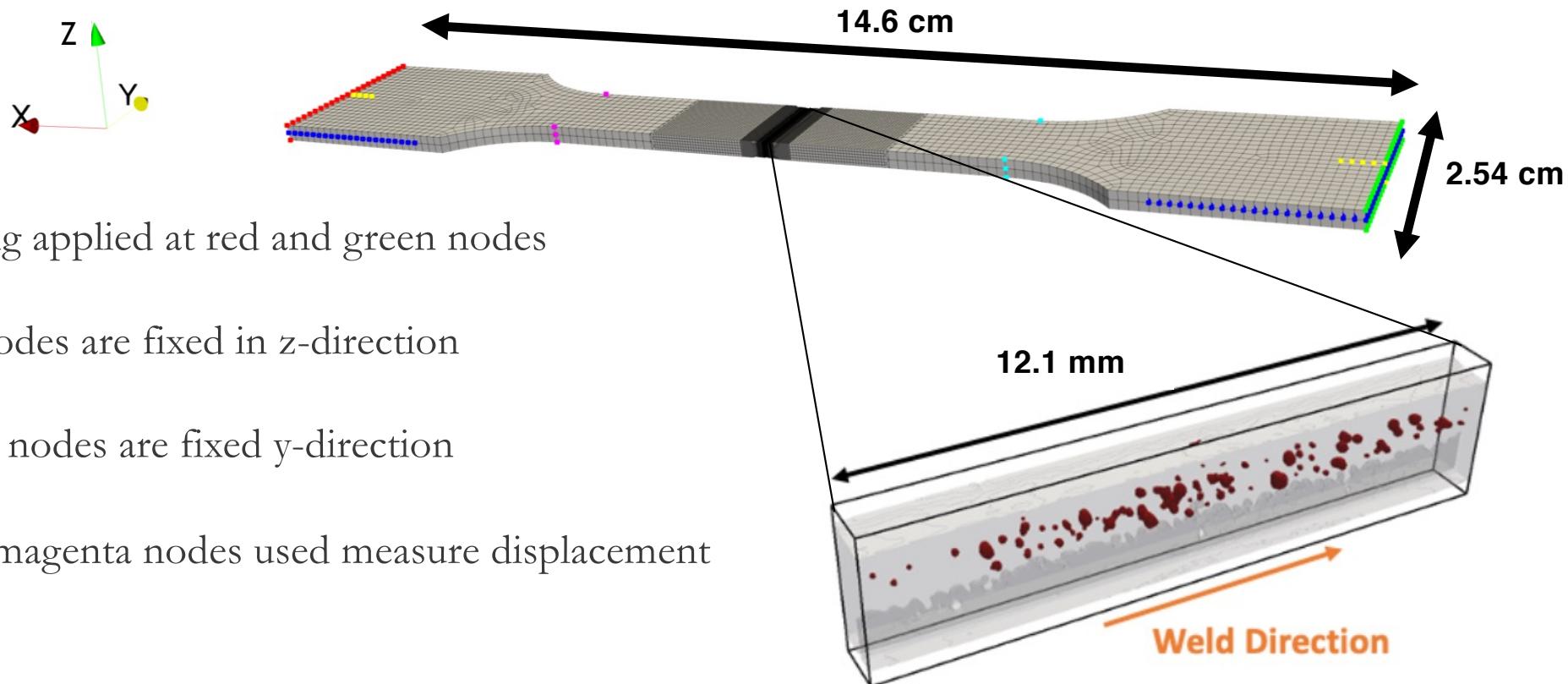
Predictive Modelling



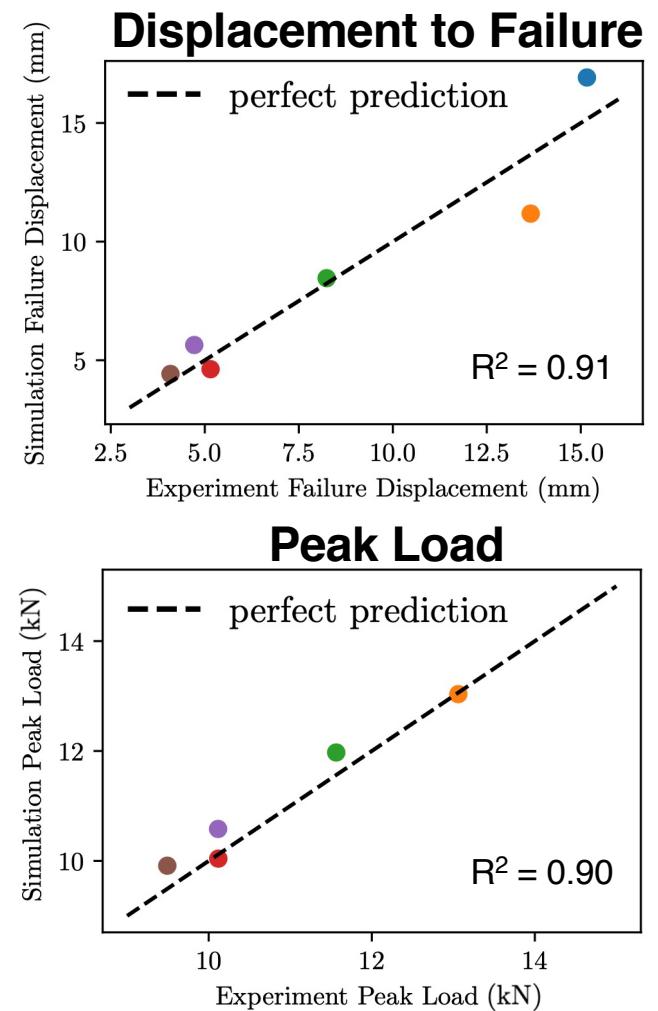
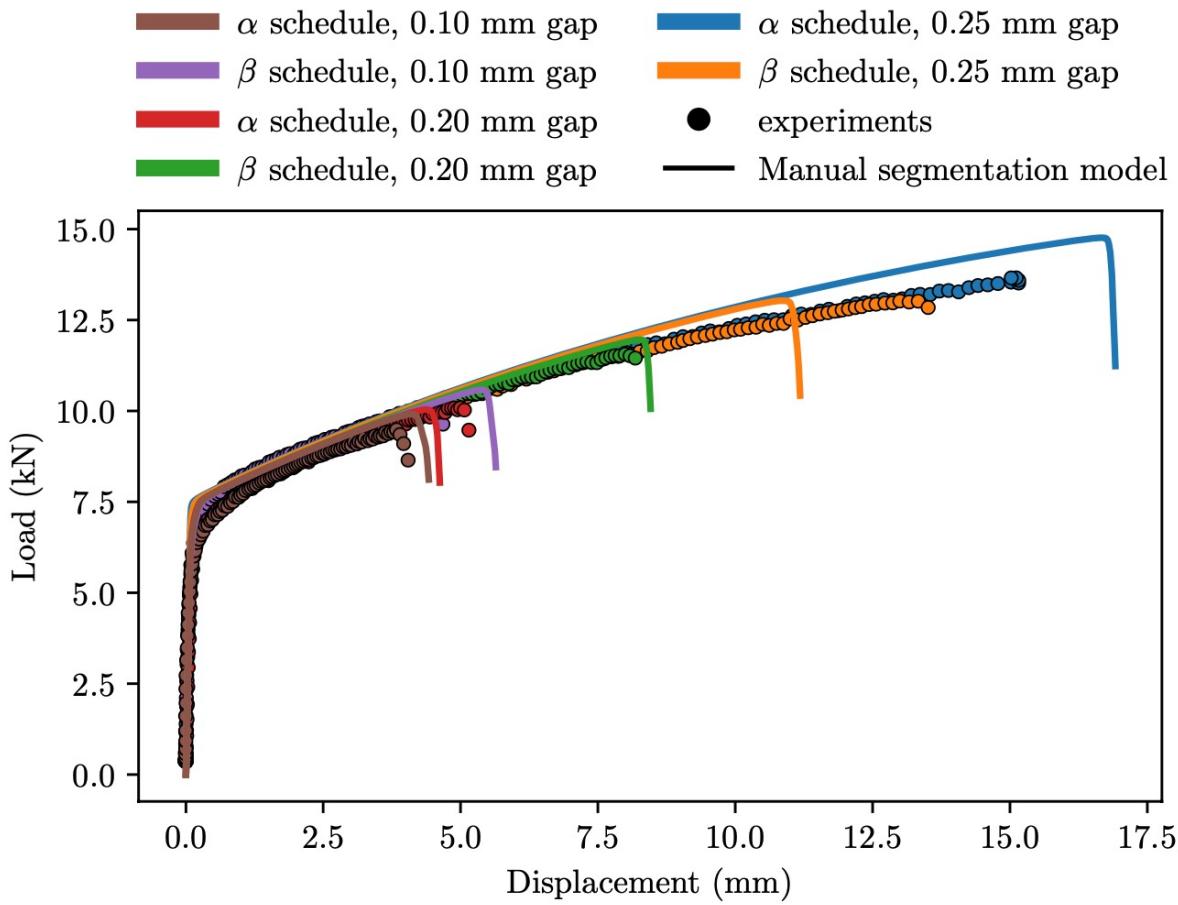
Finite element mesh generated using 3D data



Several different mesh sizes as we move away from the joint

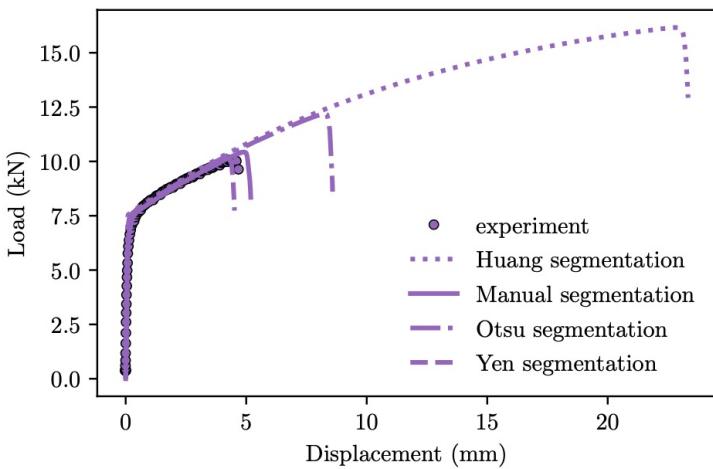


Full fidelity simulation captures mechanical response

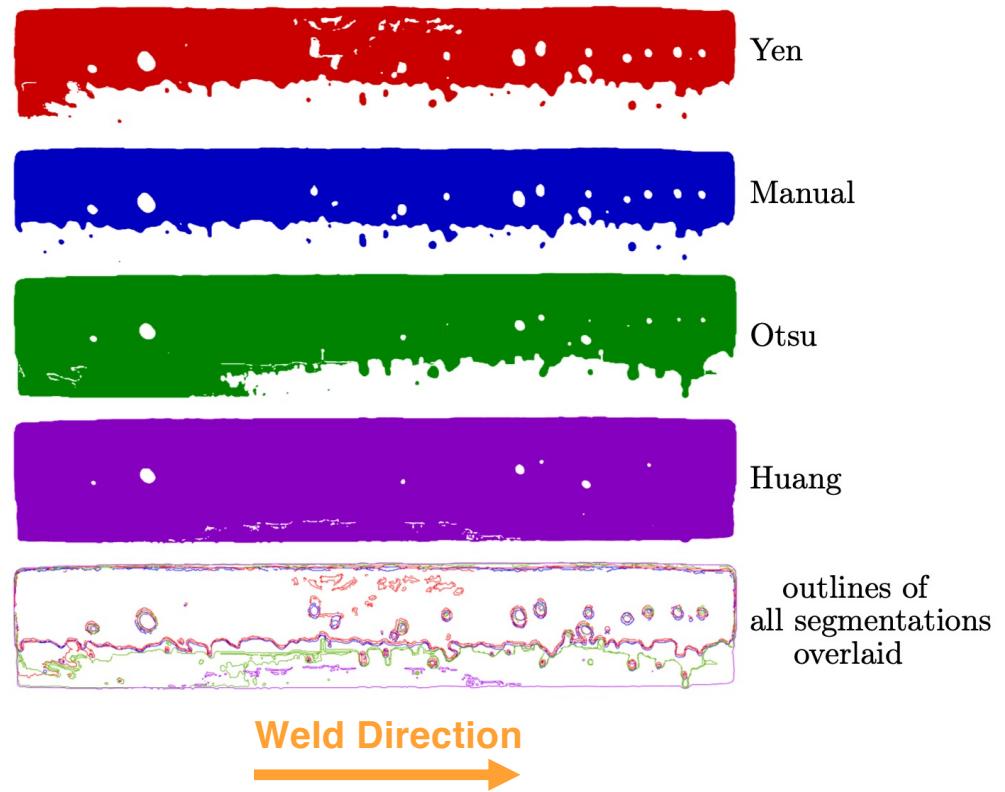


Sensitivity to segmentation approaches also manifests in modelling

**β schedule
0.10 mm gap**

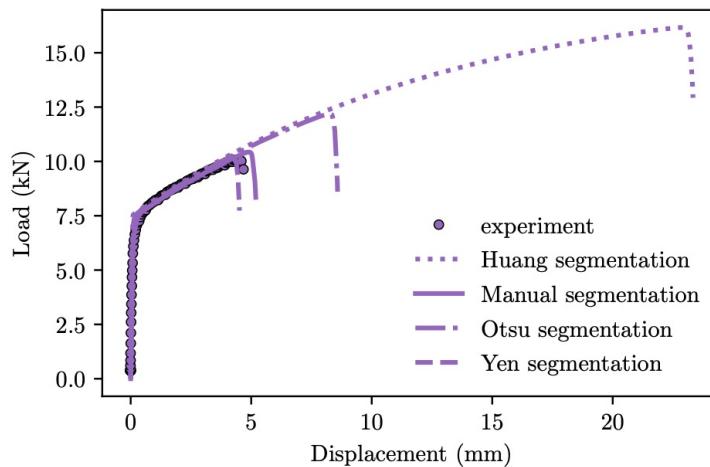


**β schedule
0.10 mm gap**

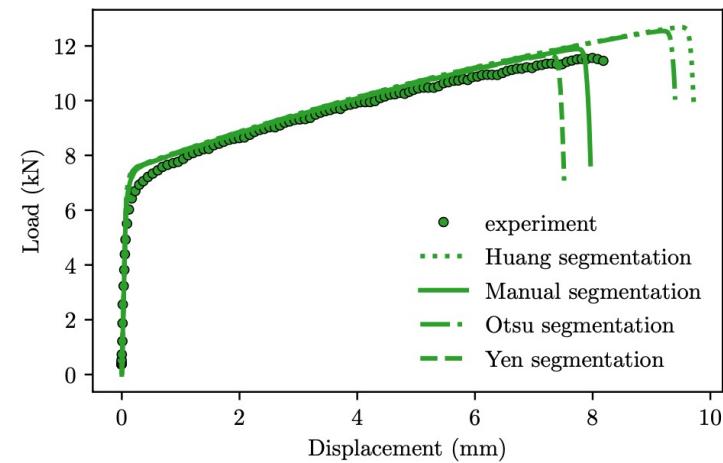


Sensitivity to segmentation approaches also manifests in modelling

**β schedule
0.10 mm gap**



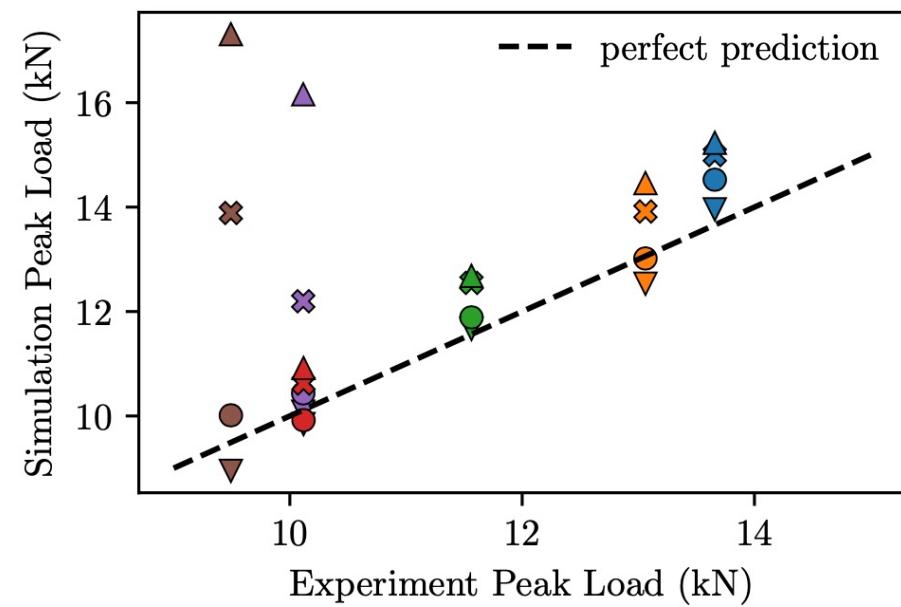
**β schedule
0.20 mm gap**



- α -Schedule, 0.10 mm gap
- β -Schedule, 0.10 mm gap
- α -Schedule, 0.20 mm gap
- β -Schedule, 0.20 mm gap
- α -Schedule, 0.25 mm gap
- β -Schedule, 0.25 mm gap

- ▼ Yen segmentation
- Manual segmentation
- ✖ Otsu segmentation
- ▲ Huang segmentation

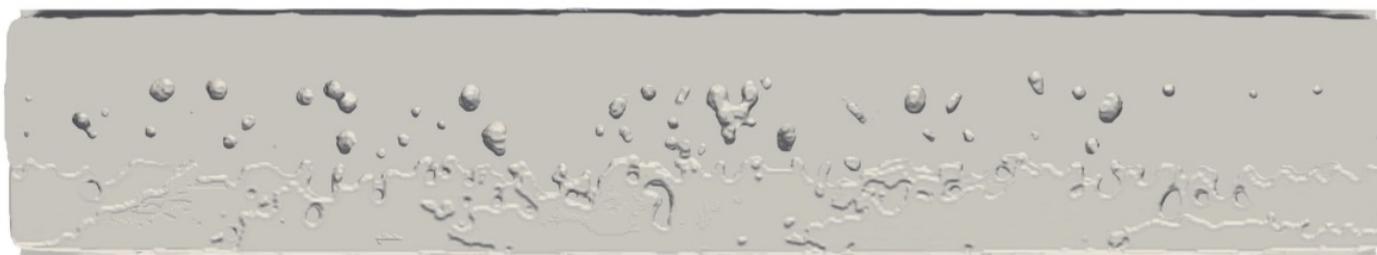
Peak Load



Some form of idealization is needed for a scalable solution

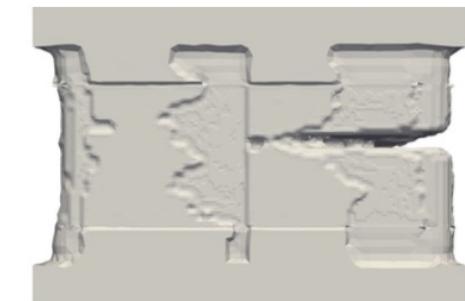
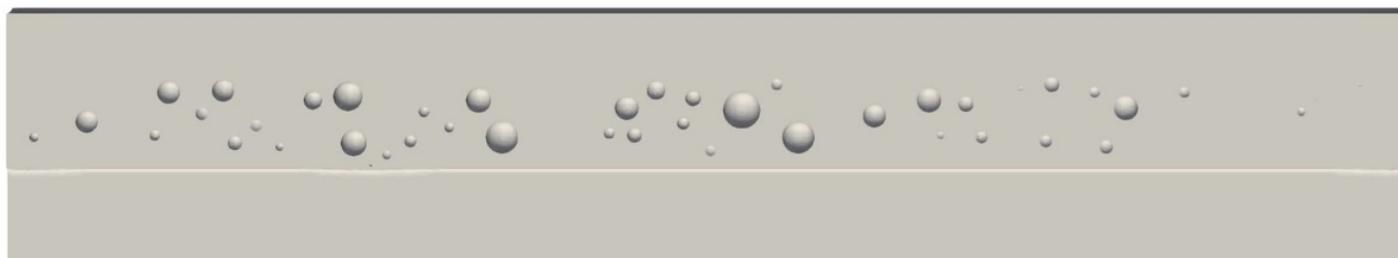


Full Fidelity Model



Weld Direction
→

Fully Idealized Model

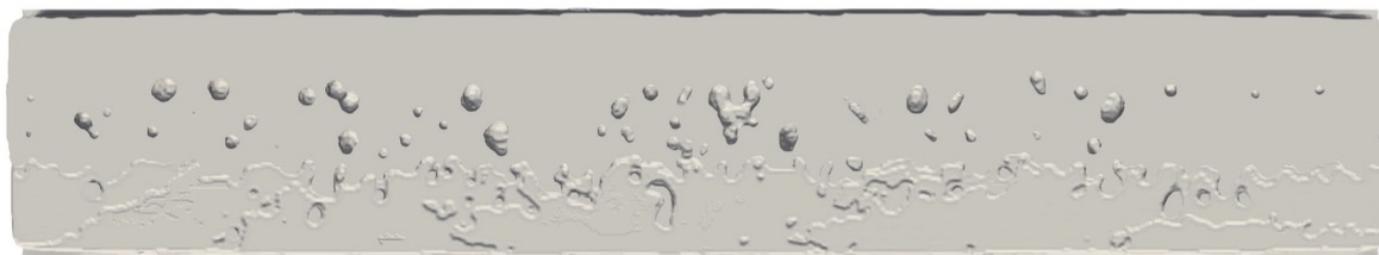


Weld Direction
X

Some form of idealization is needed for a scalable solution



Full Fidelity Model

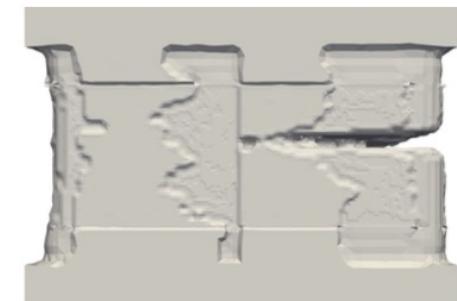


Weld Direction
→

Idealized Root Model



Weld Direction
→

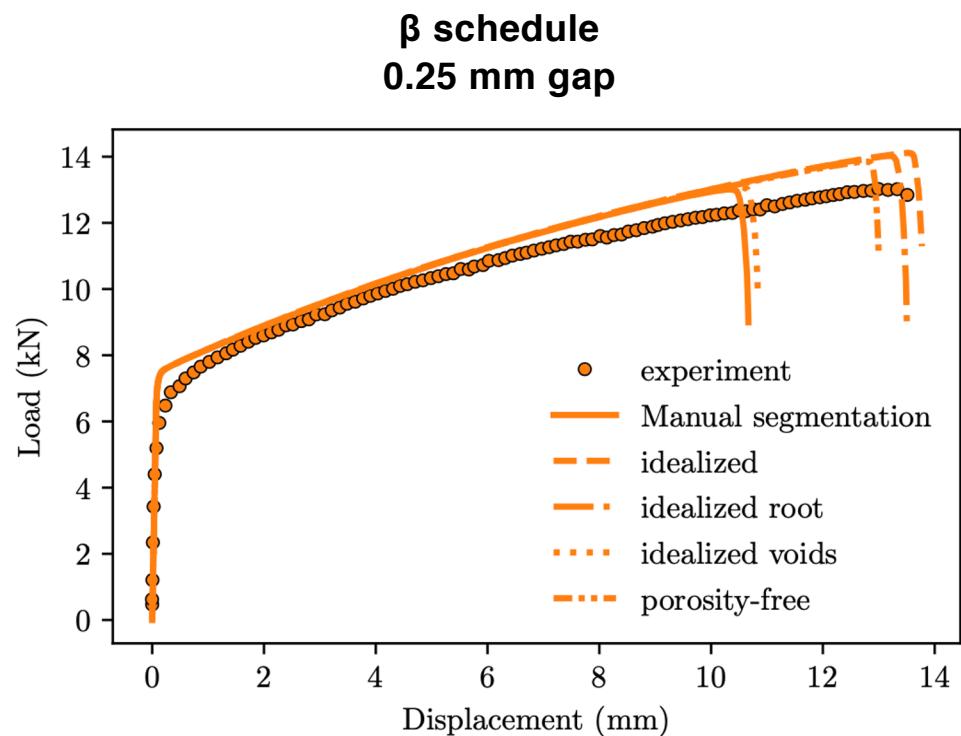
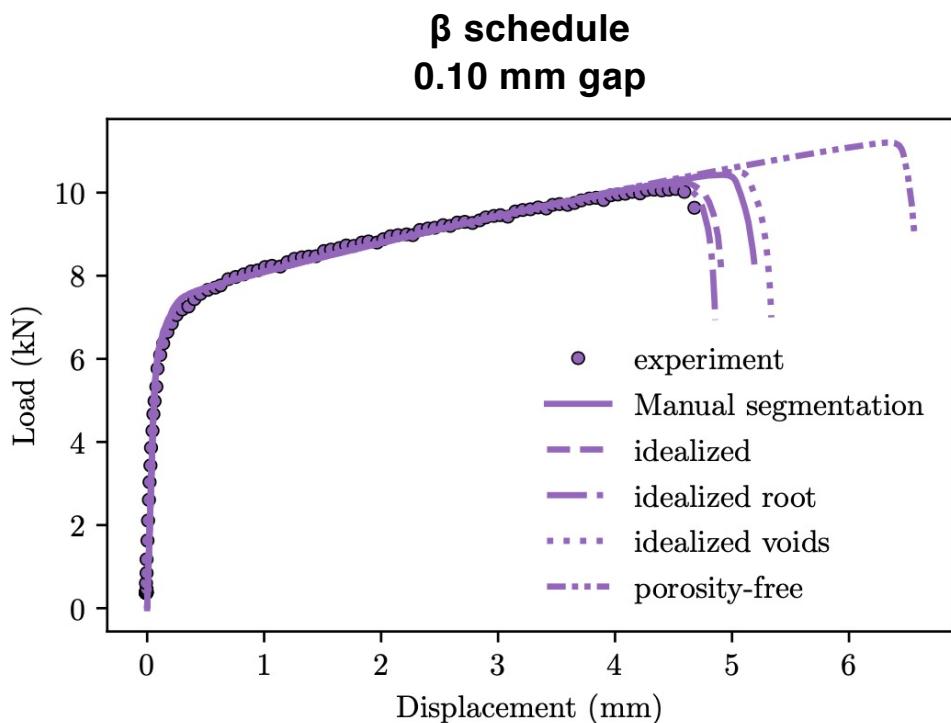


Weld Direction
X

Idealized Porosity Model



Idealization predictions do not follow an obvious trend

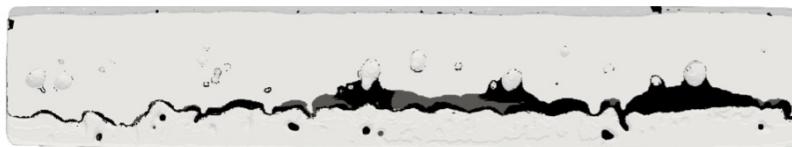




β schedule, 0.25 mm gap

Peak Load

Manual
Segmentation



Porosity
Free



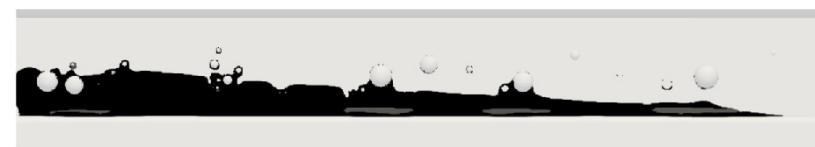
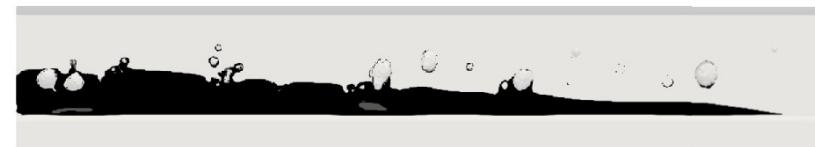
Idealized
Root



Fully
Ideal



10% Post-Peak Load



Weld Direction



Crack propagation behavior



α schedule, 0.25 mm gap

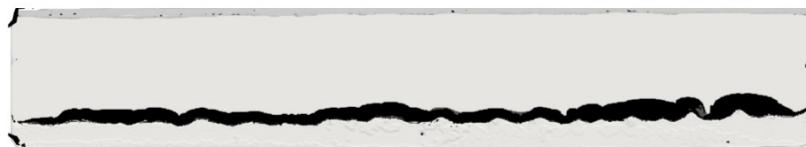
Peak Load

10% Post-Peak Load

Manual
Segmentation



Porosity
Free



Idealized
Root



Fully
Ideal



Weld Direction

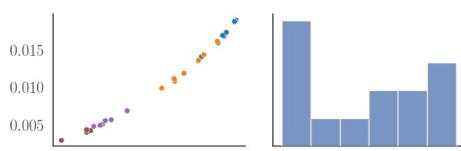


Geometric correlations with mechanical performance

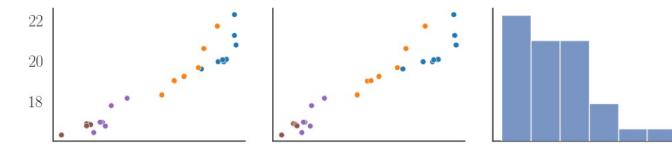
Peak Load



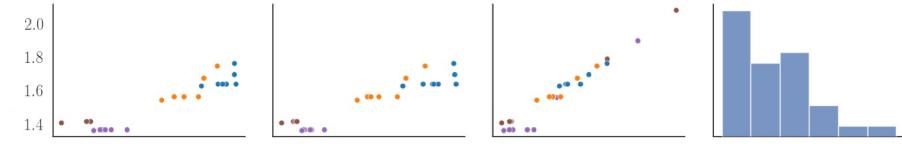
Peak Displacement



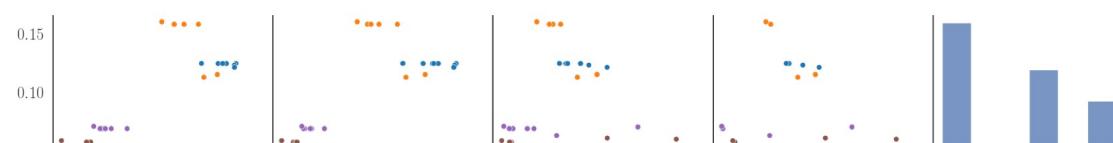
Cross-sectional Weld Area



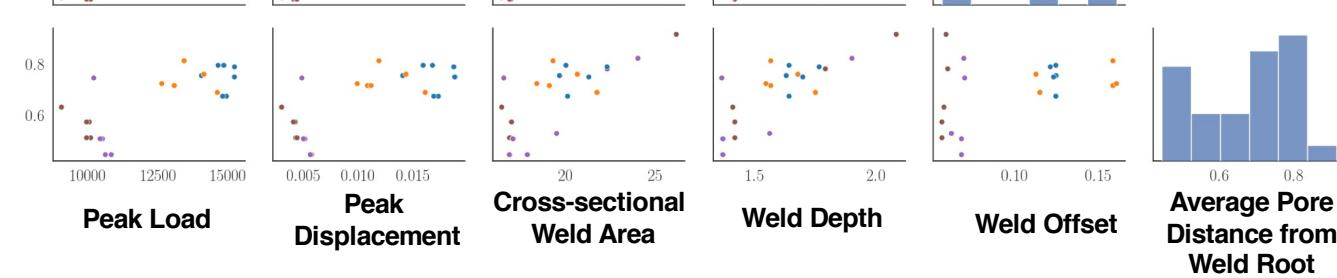
Weld Depth



Weld Offset

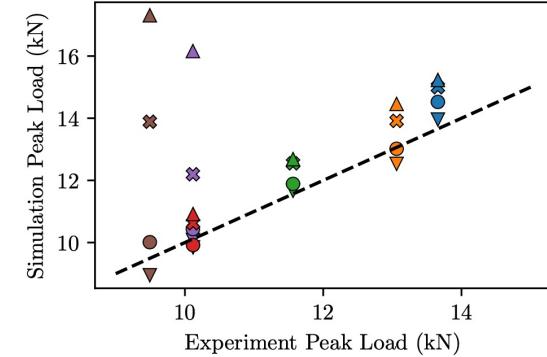
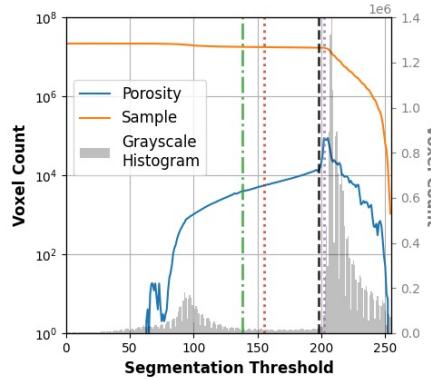
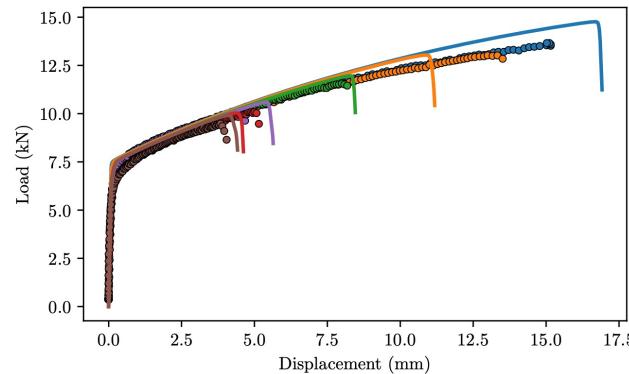


Average Pore Distance from Weld Root



Conclusions

- Mechanical response of welds can be better understood using 3D characterization
- Using full-fidelity μ CT data, mechanical response of welds can be accurately modelled
- Segmentation decisions play an important role in 3D data analysis
- Evolving interactions between porosity and the weld root during plasticity must be considered
- Cross-sectional area and weld offset are key factors in controlling weld performance



Manual Segmentation



Idealized Root





Thanks!

