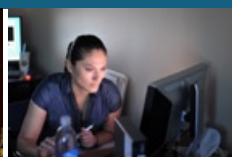
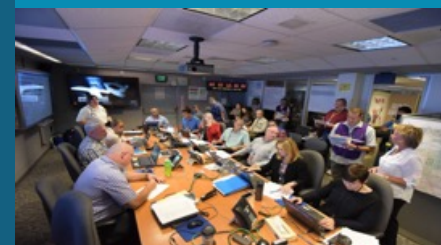




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# Enhanced predictive modelling of laser weld failure using 3D characterization of 304L



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Wednesday, March 2, 2022



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## Outline

- Motivation
- Weld Characterization
- Predictive Modelling
- Conclusion



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## Laser welds have diverse applications across multiple industries

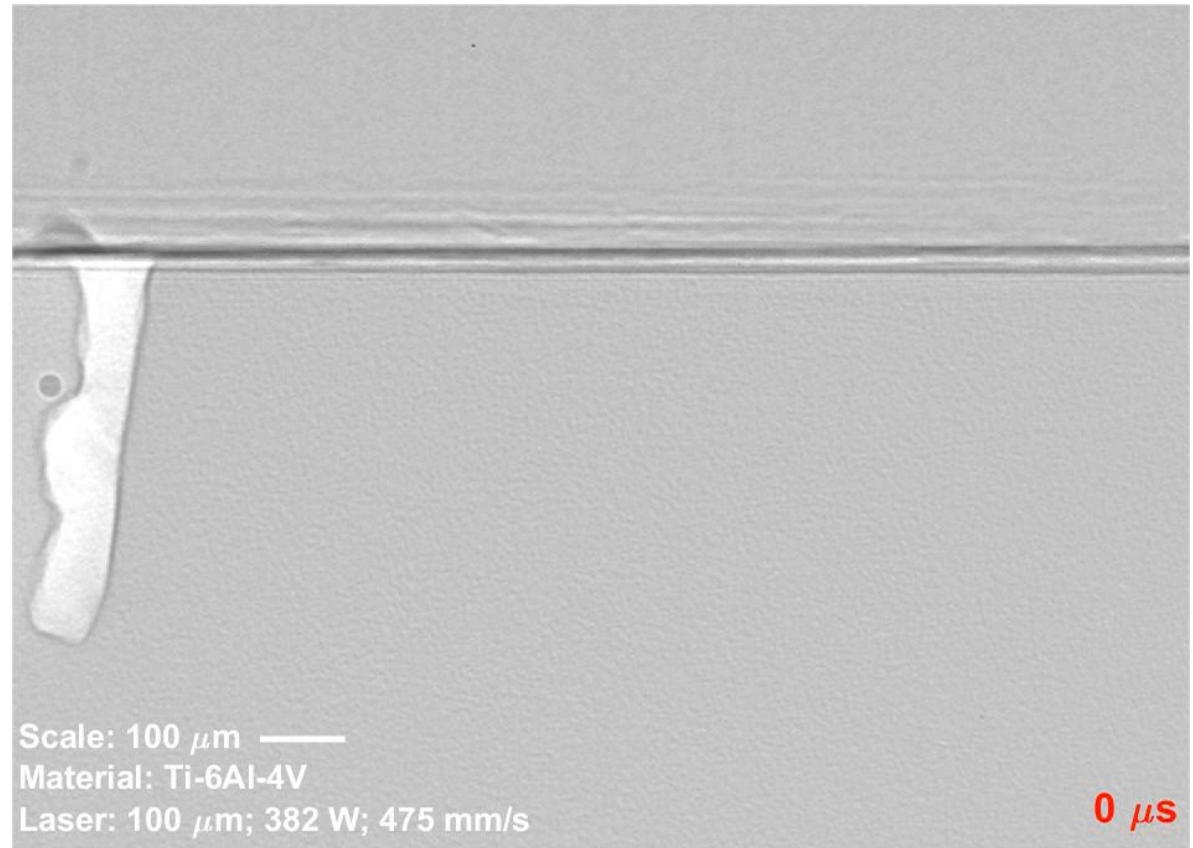


### Laser weld advantages

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

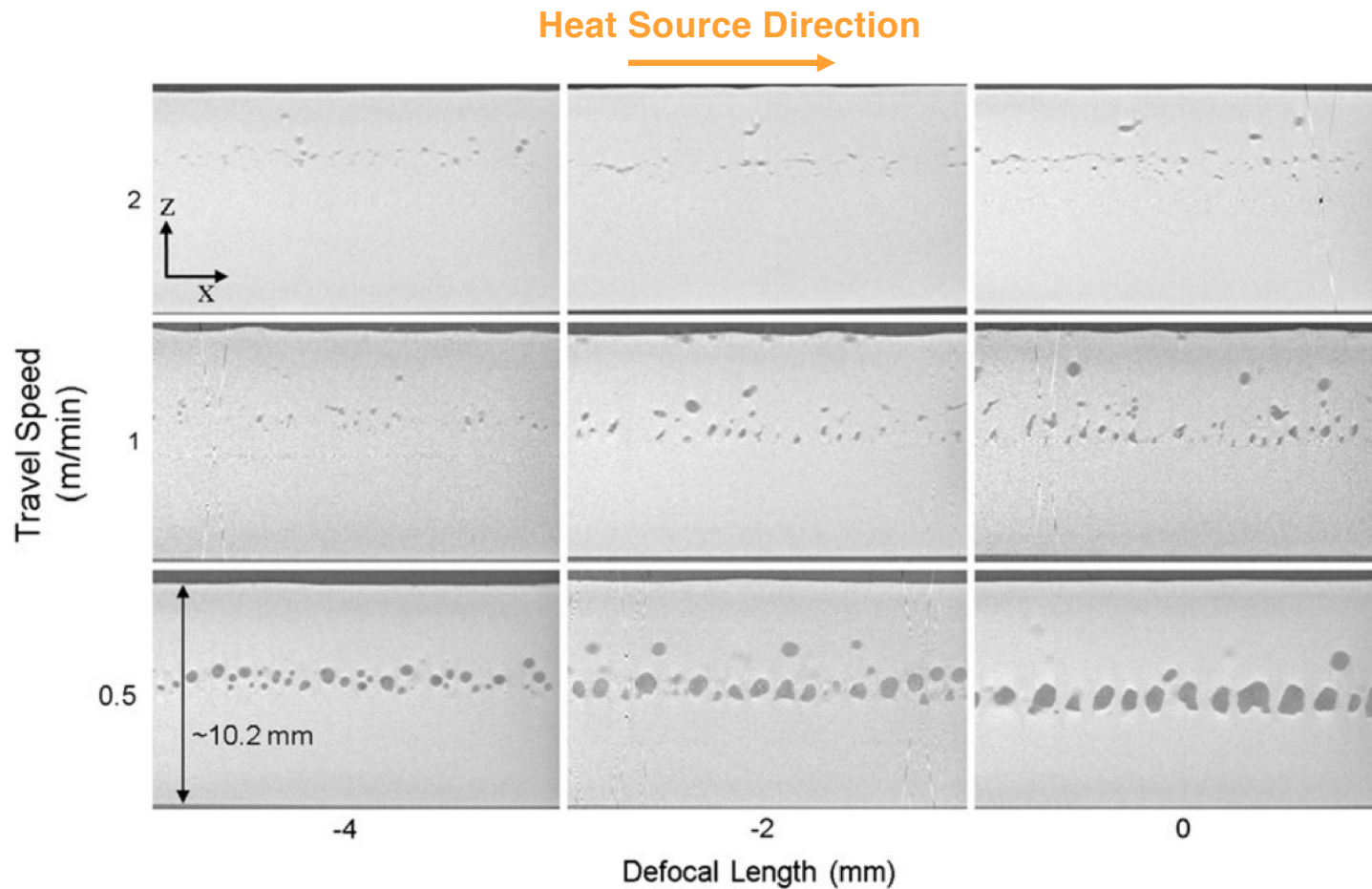
### Laser weld challenges

- Porosity formation
- Hot cracking



4

Weld porosity is highly sensitive to processing conditions



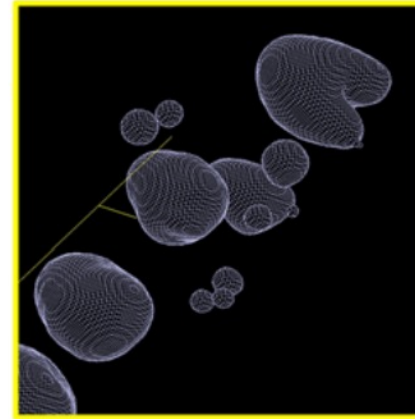


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## Mechanical effects of porosity can be simulated using FE modelling

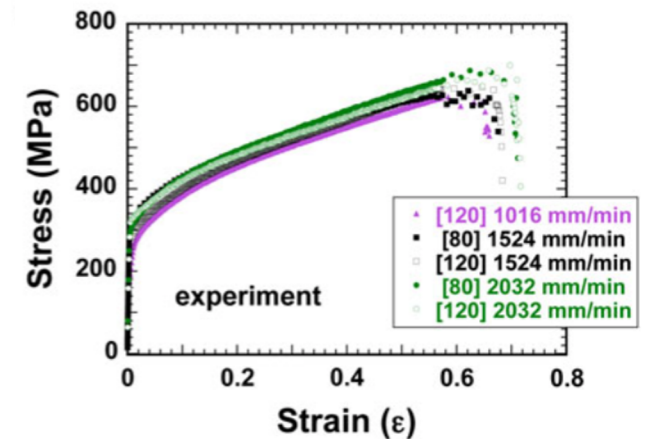
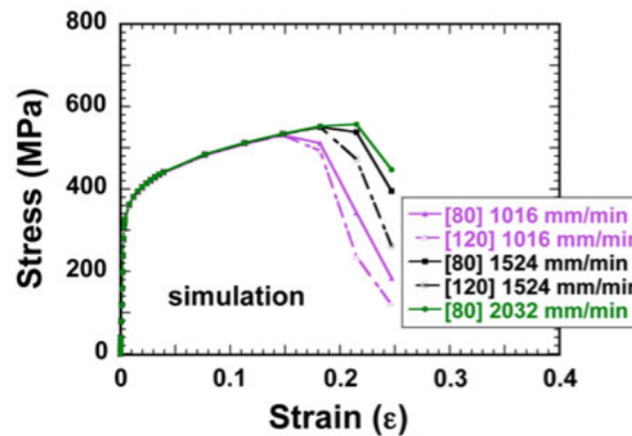


Weld porosity meshed directly from  $\mu$ CT  
and instantiated into a bulk material volume



Simulation captures yielding and hardening,  
but not failure behavior

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



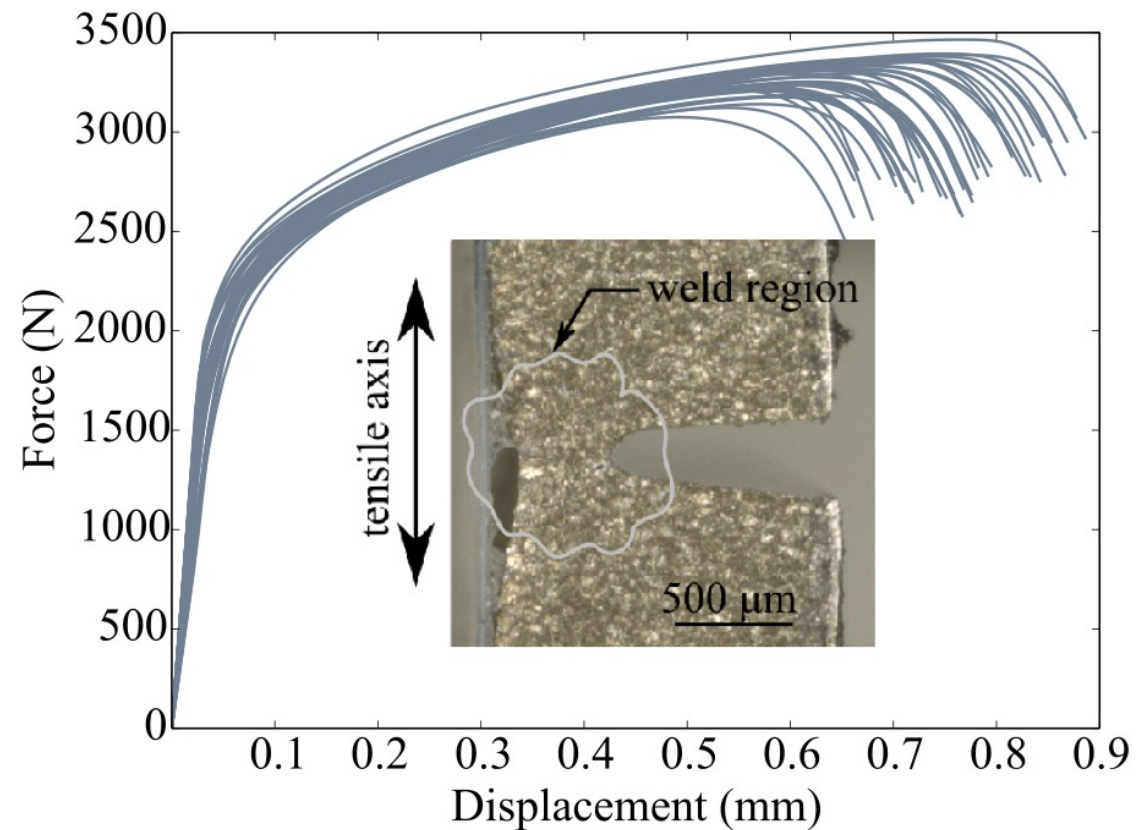
## 6 Laser welds also exhibit variable mechanical properties

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

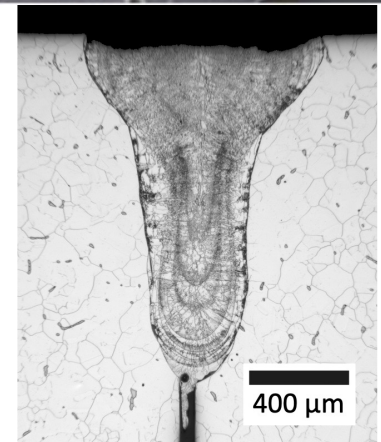
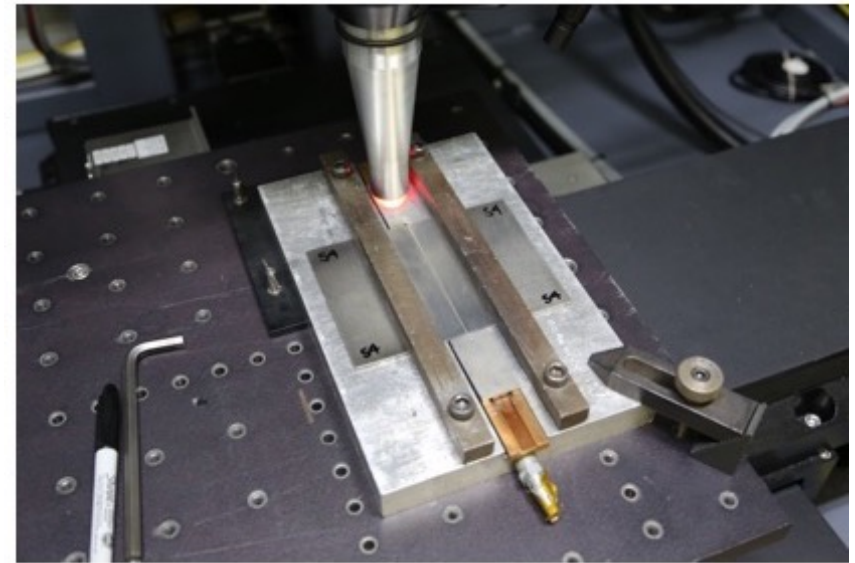
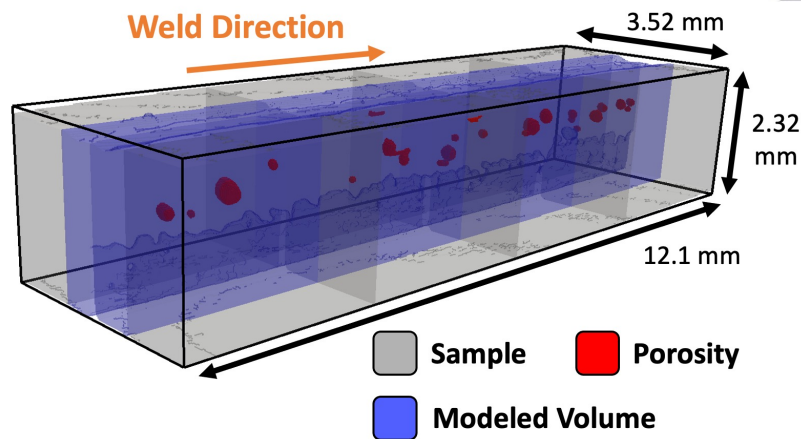
Two weld schedules ( $\alpha$  and  $\beta$ )

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

$\mu$ CT characterization via NorthStar X50 machine

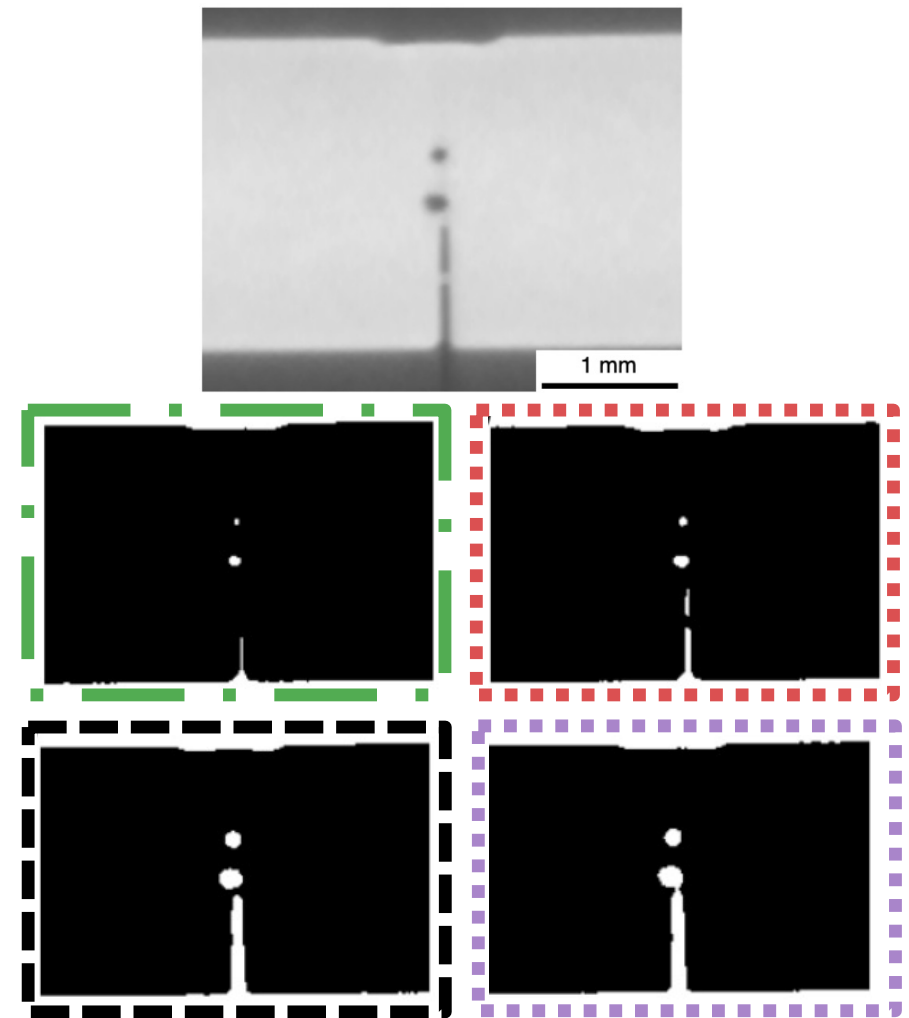
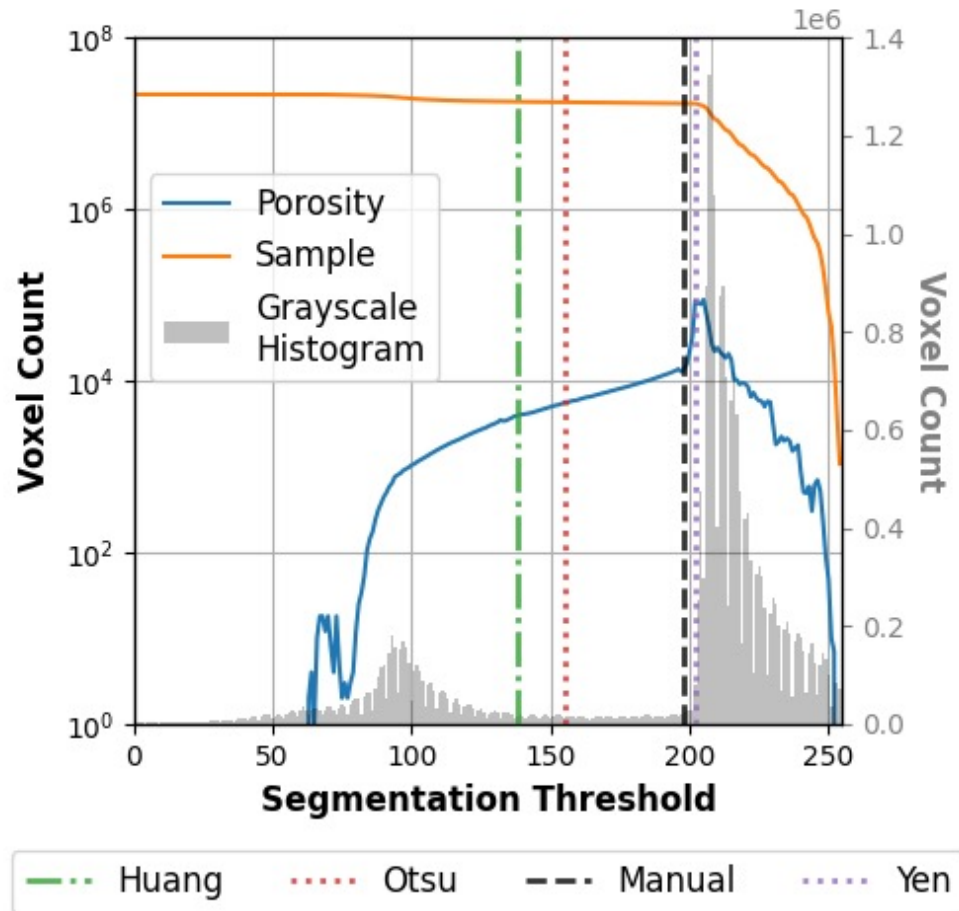
- 17.6  $\mu$ m voxel resolution

Tensile testing and simulated loading



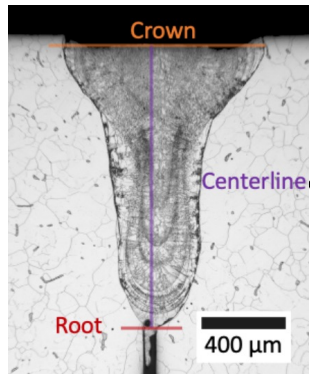


## Segmentation decisions impact image analysis

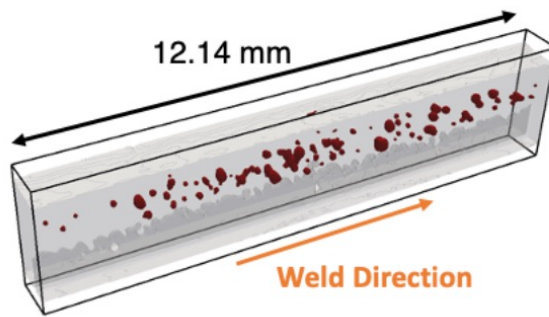




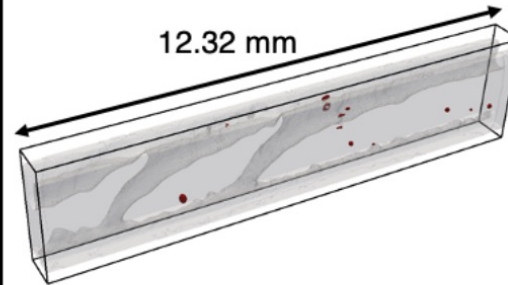
$\alpha$   
Schedule



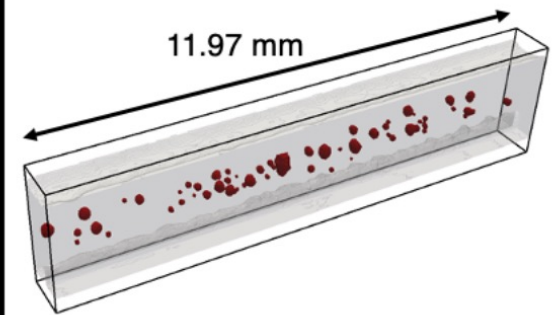
0.10 mm Gap



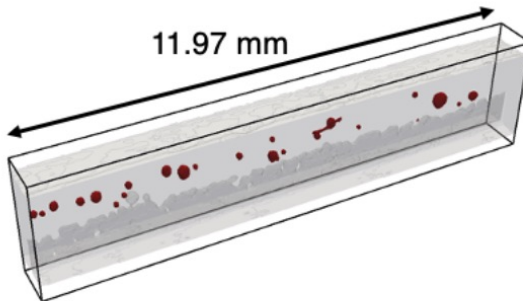
0.20 mm Gap



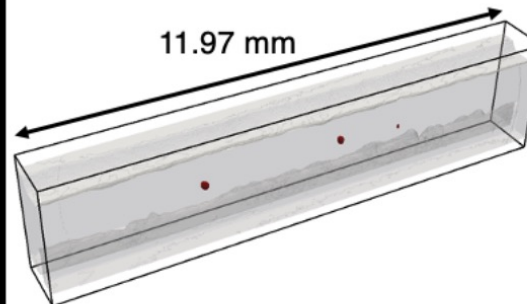
0.25 mm Gap



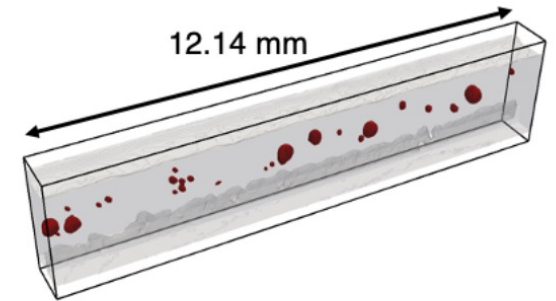
11.97 mm



11.97 mm



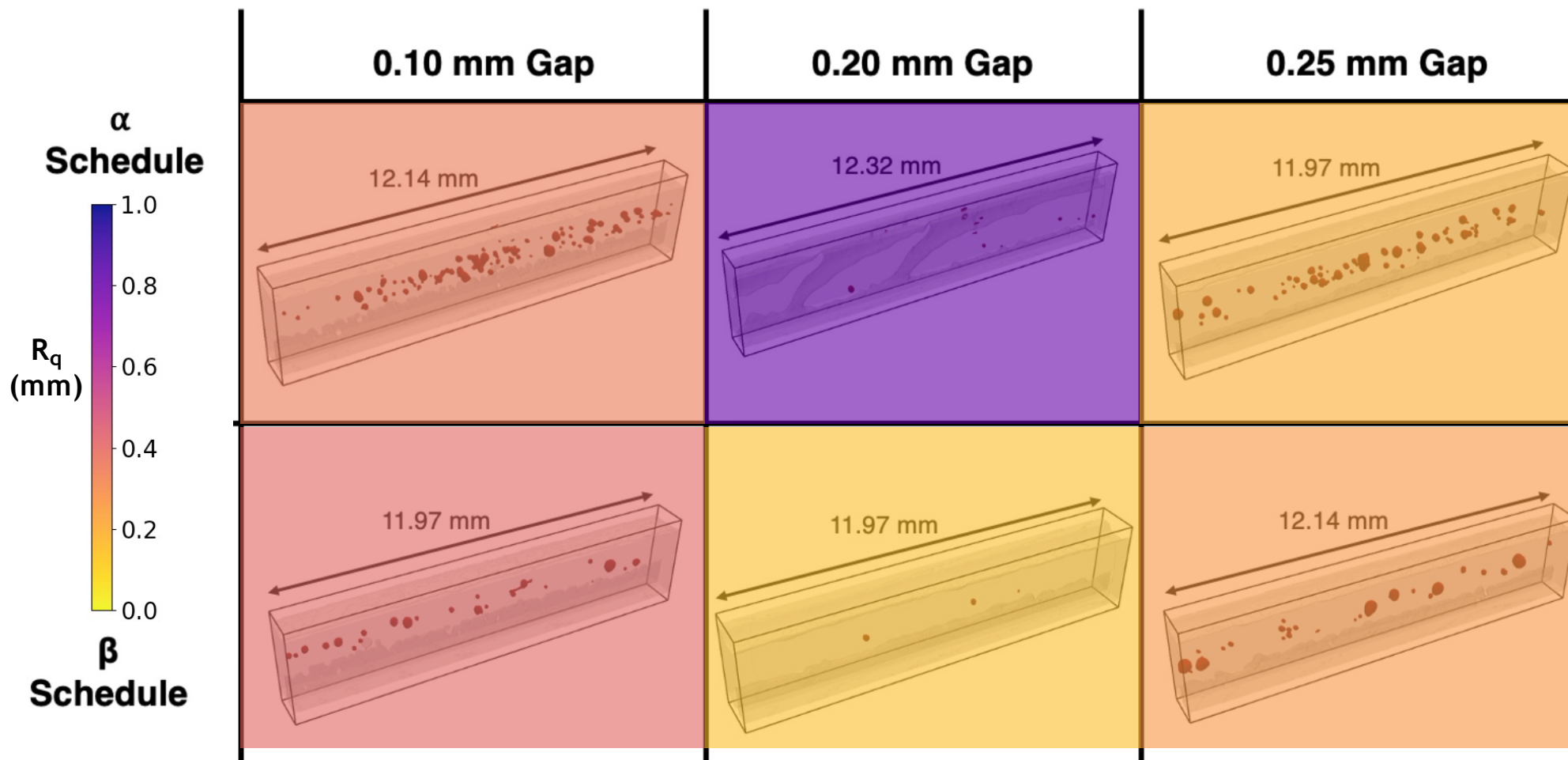
12.14 mm



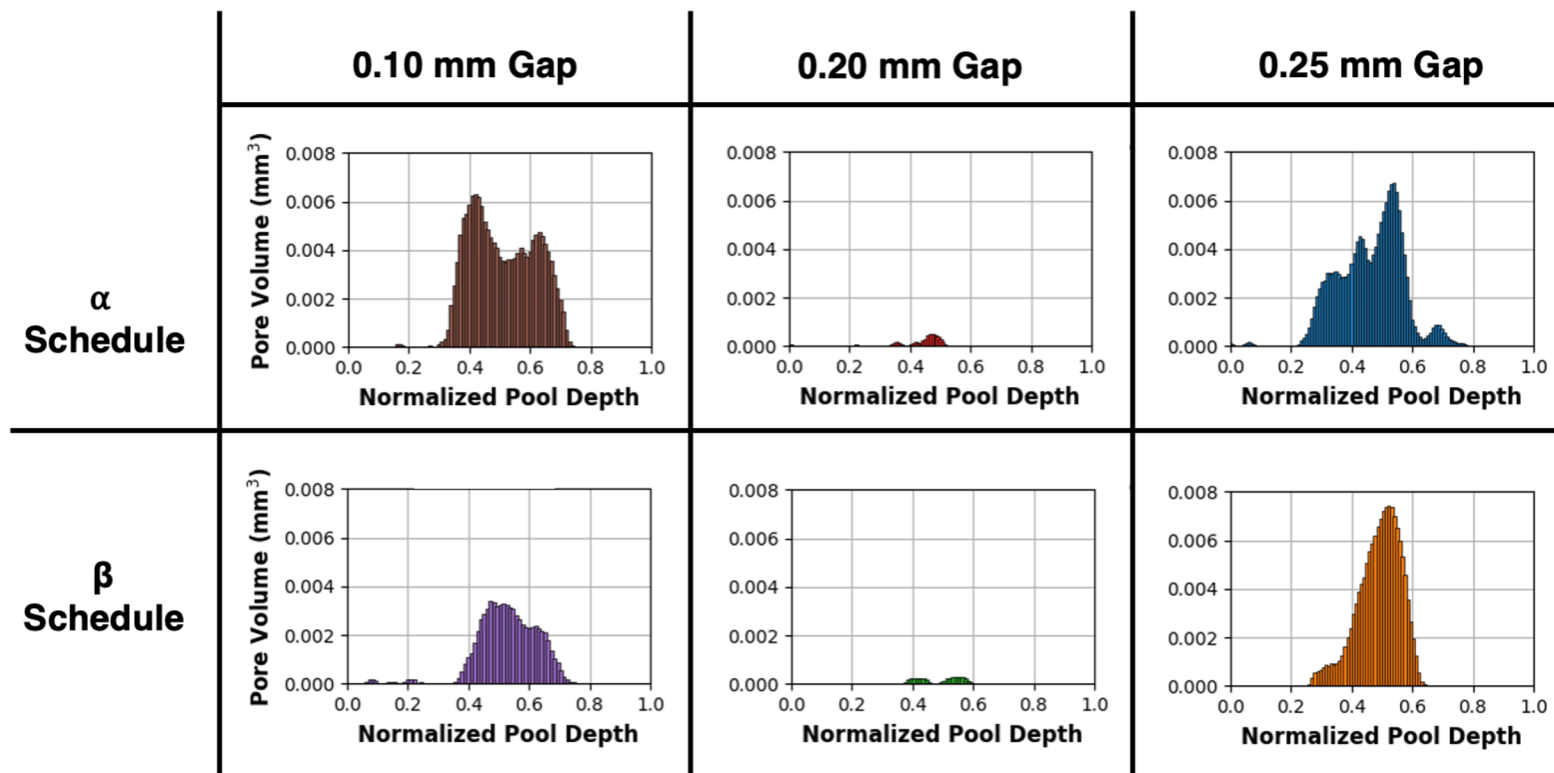
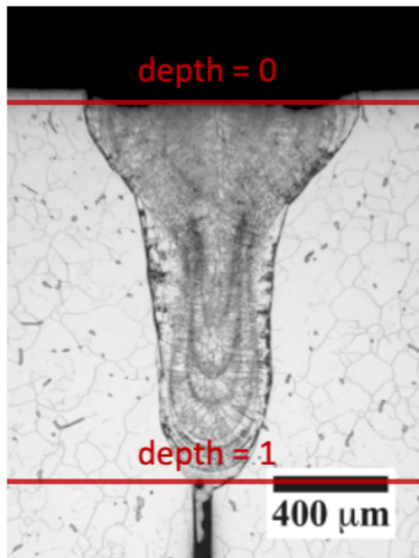
$\beta$   
Schedule



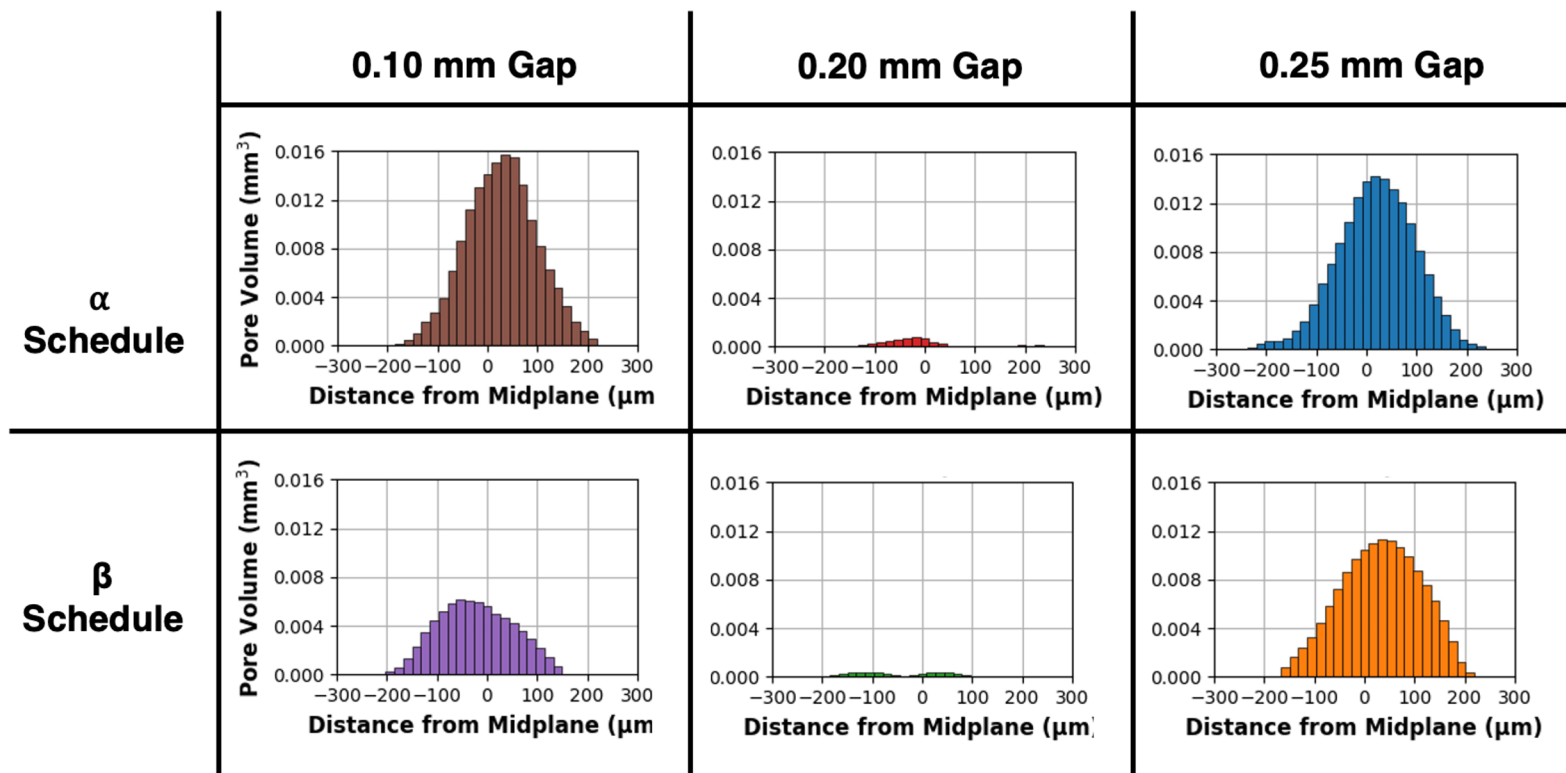
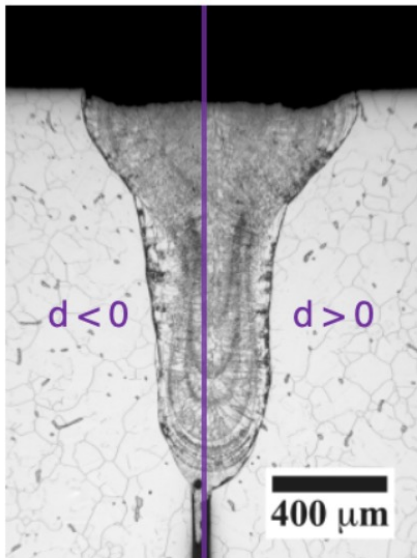
# Root mean squared roughness ( $R_q$ ) of weld root



# Porosity tends to localize in center of weld

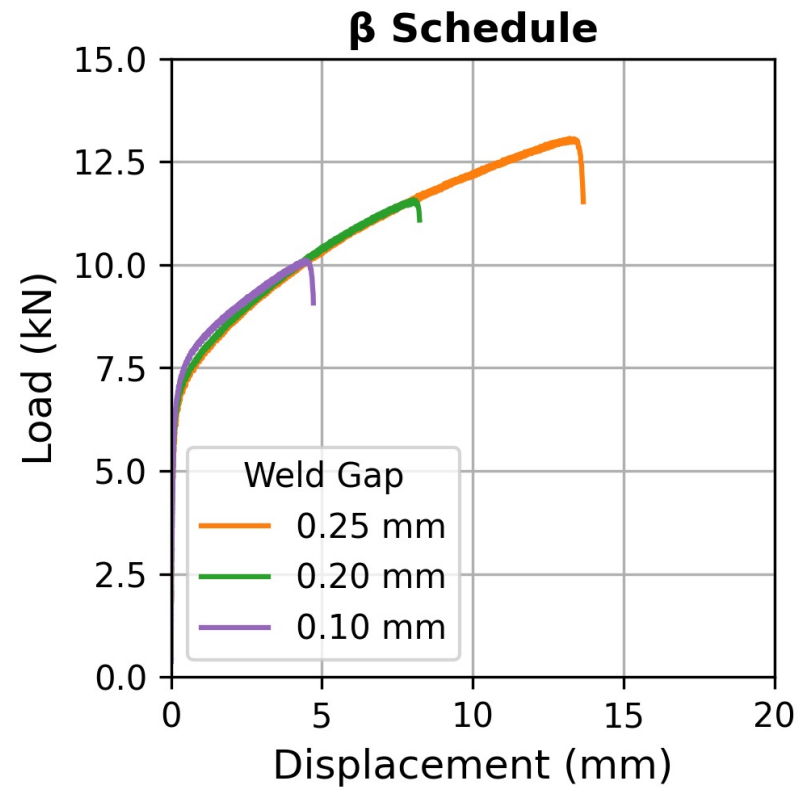
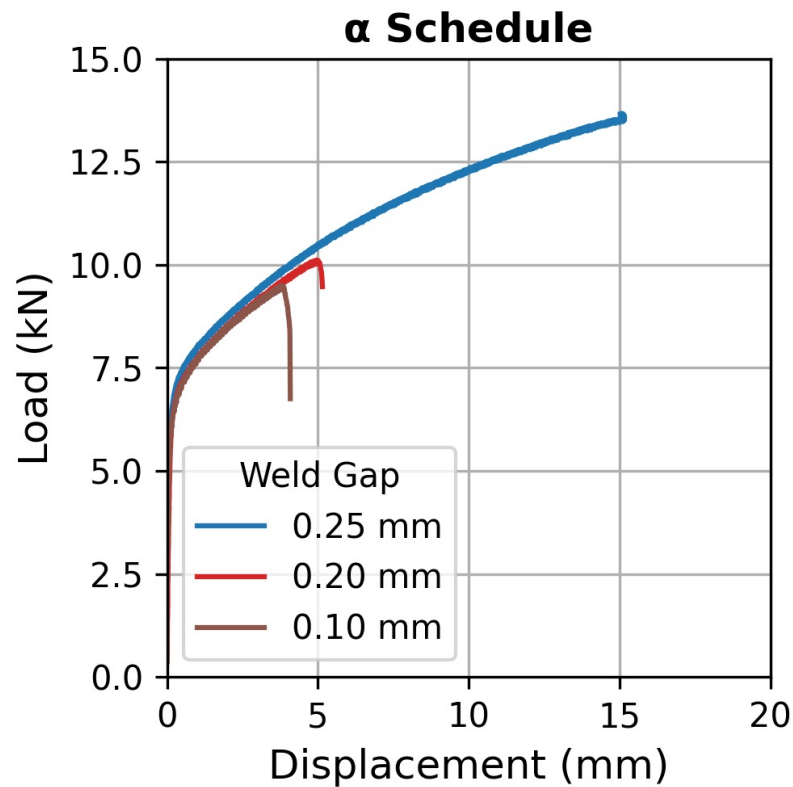


# Porosity tends to localize in center of weld



## Tensile testing of welds

Increasing strength with increasing gap due to complex stress states





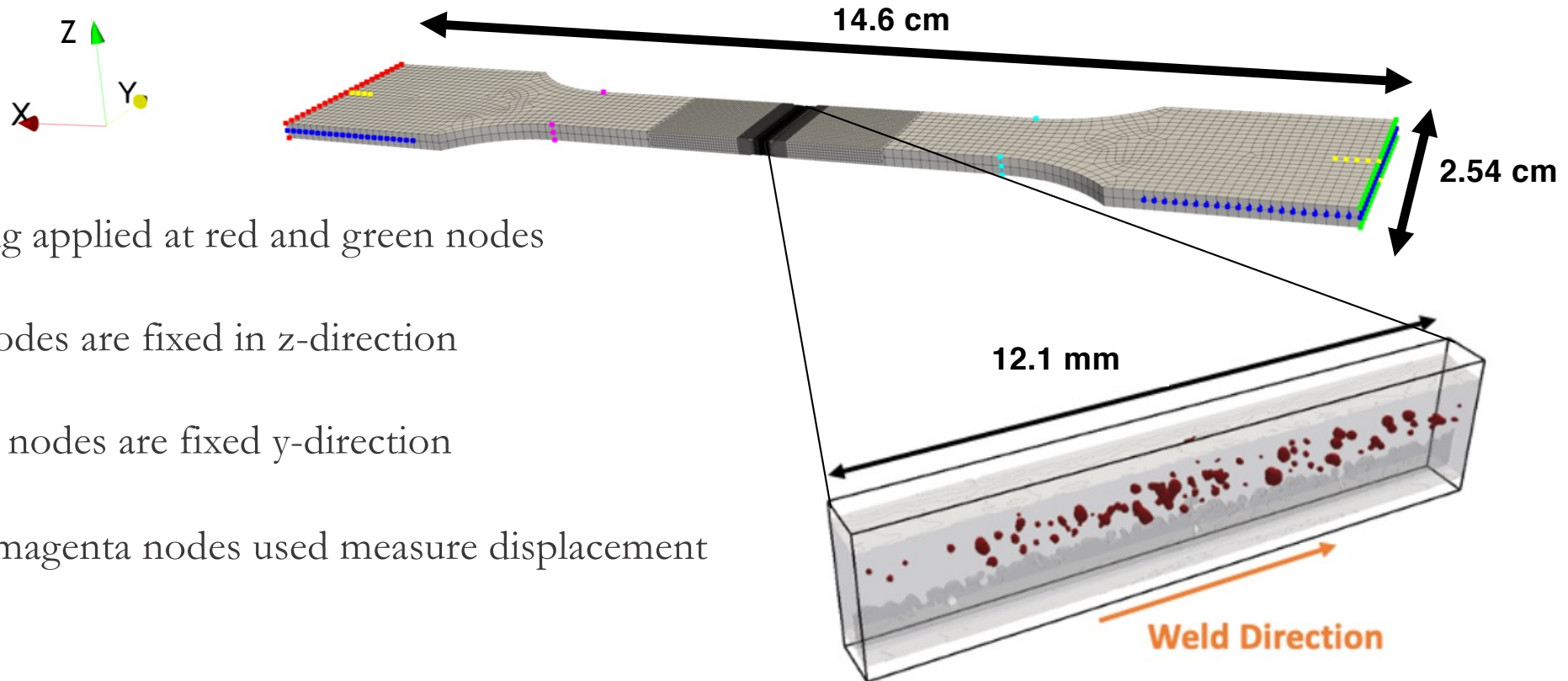
# Predictive Modelling



## Finite element mesh generated using 3D data

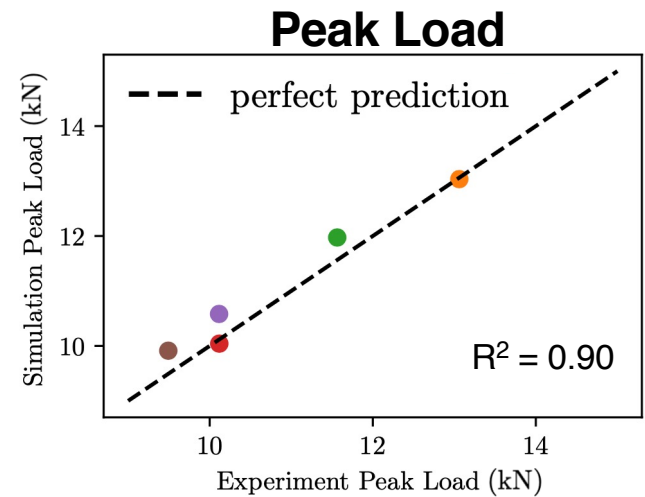
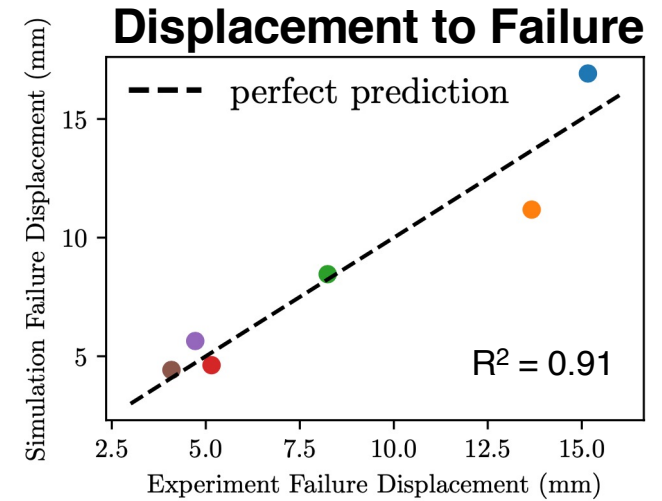
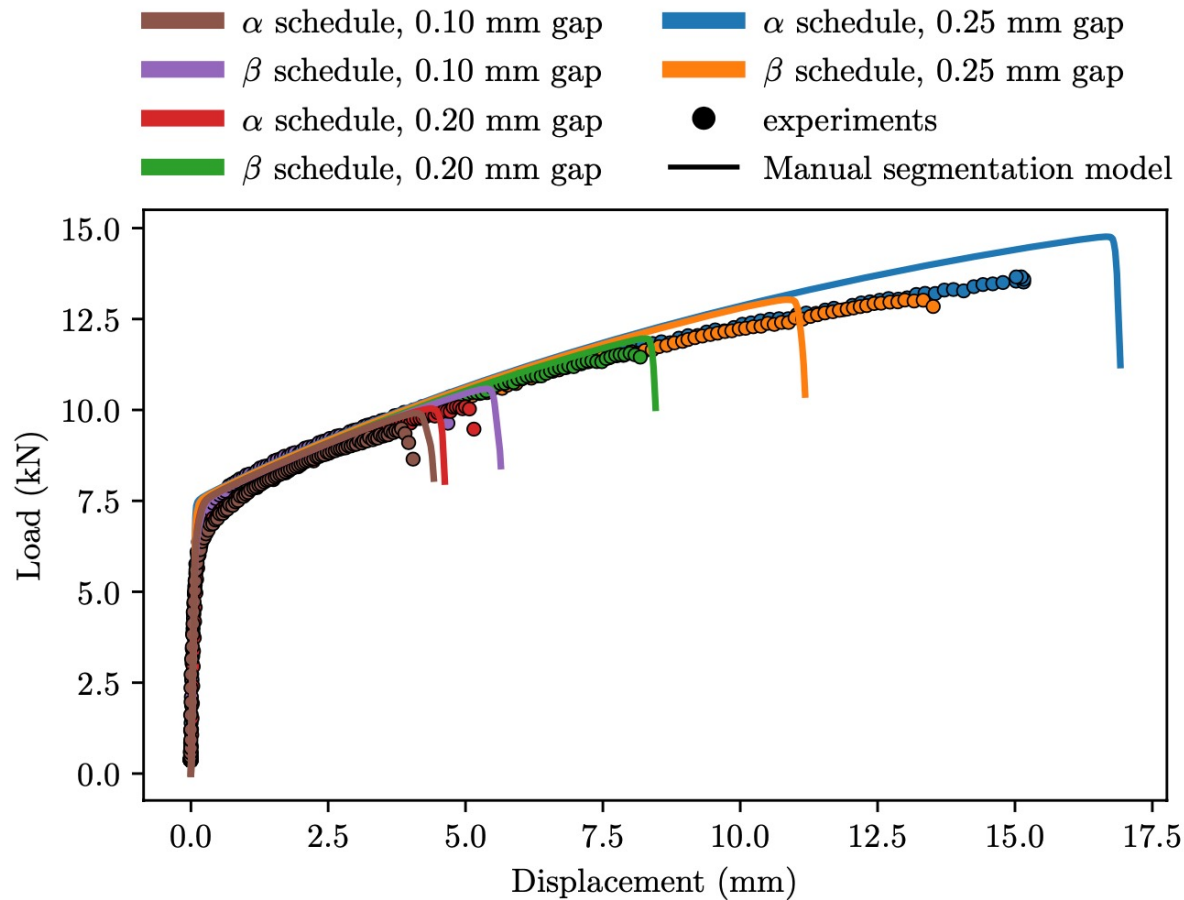


Several different mesh sizes as we move away from the joint



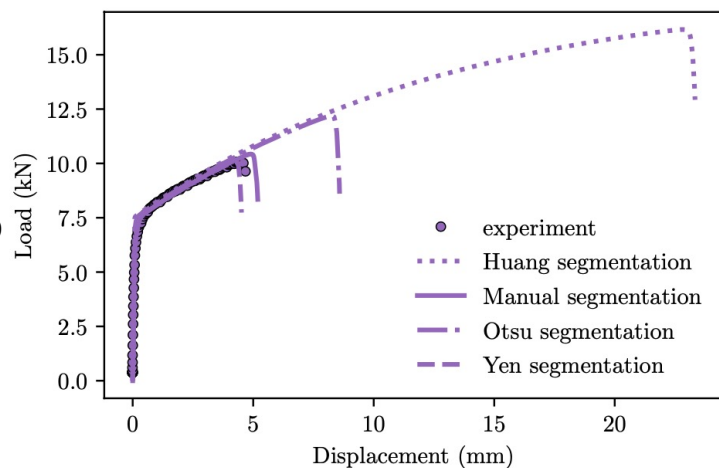


## Full fidelity simulation captures mechanical response

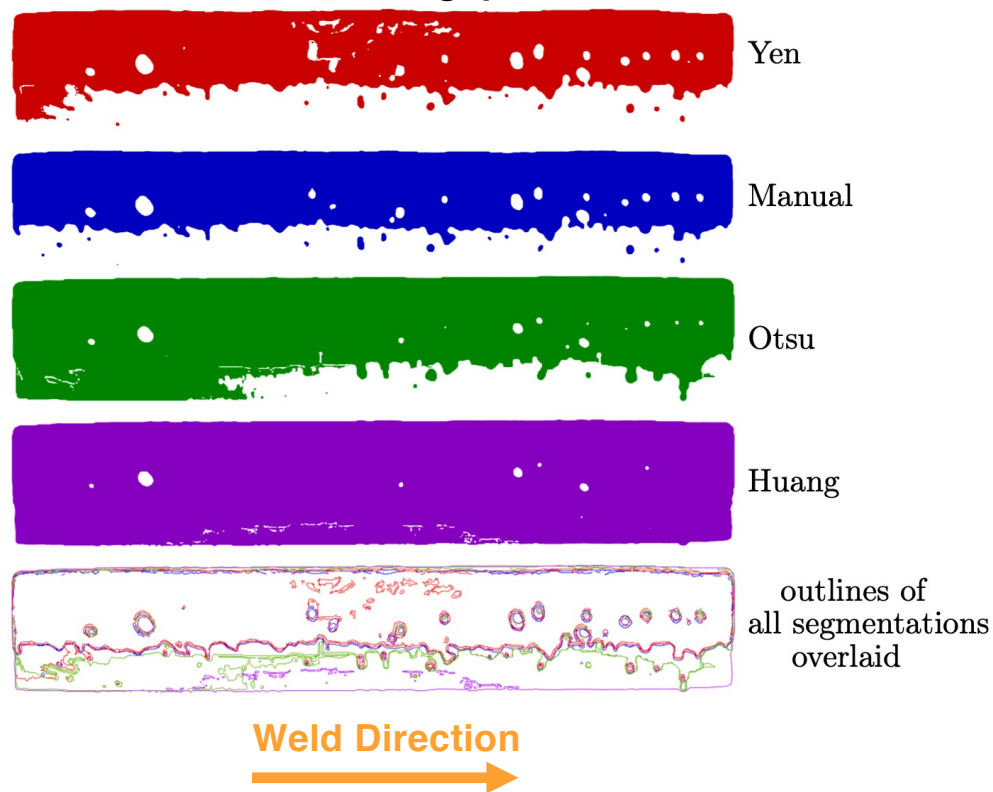


## Sensitivity to segmentation approaches also manifests in modelling

$\beta$  schedule  
0.10 mm gap



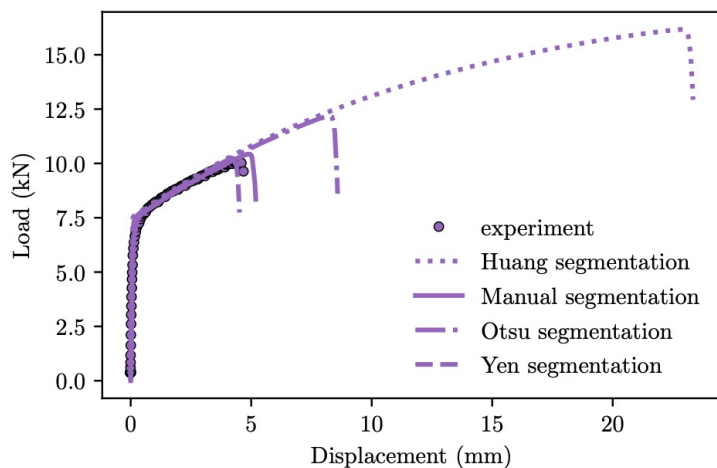
$\beta$  schedule  
0.10 mm gap



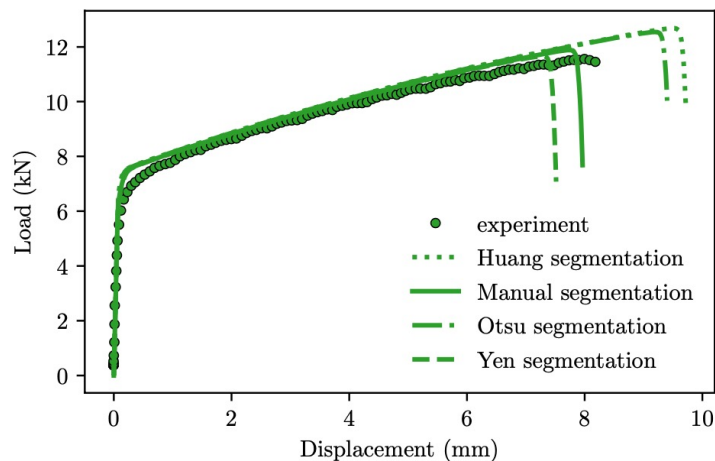
# Sensitivity to segmentation approaches also manifests in modelling



**$\beta$  schedule  
0.10 mm gap**



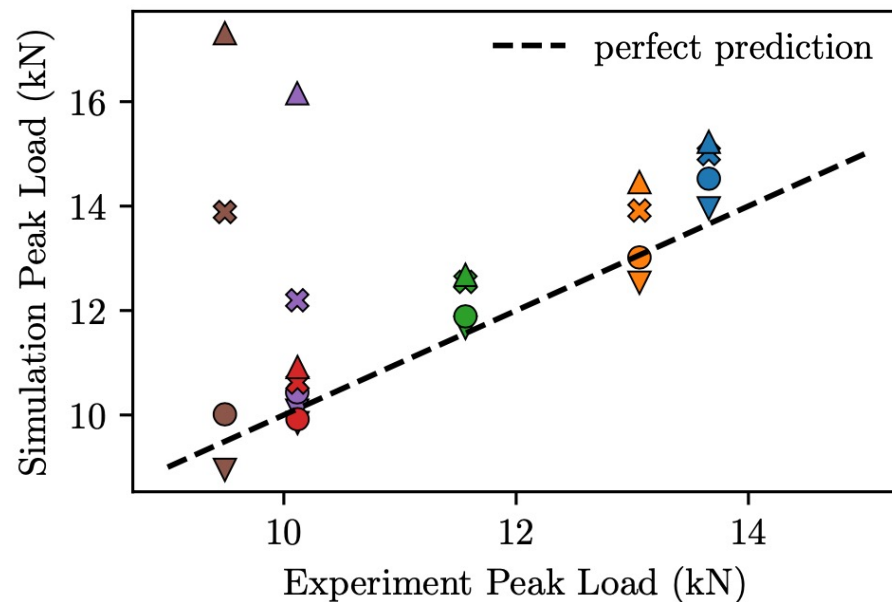
**$\beta$  schedule  
0.20 mm gap**



- $\alpha$ -Schedule, 0.10 mm gap
- $\beta$ -Schedule, 0.10 mm gap
- $\alpha$ -Schedule, 0.20 mm gap
- $\beta$ -Schedule, 0.20 mm gap
- $\alpha$ -Schedule, 0.25 mm gap
- $\beta$ -Schedule, 0.25 mm gap

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

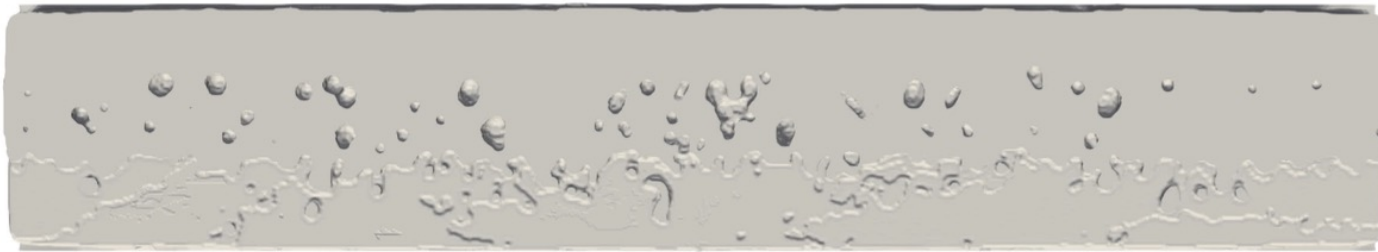
## Peak Load



Some form of idealization is needed for a scalable solution



### Full Fidelity Model



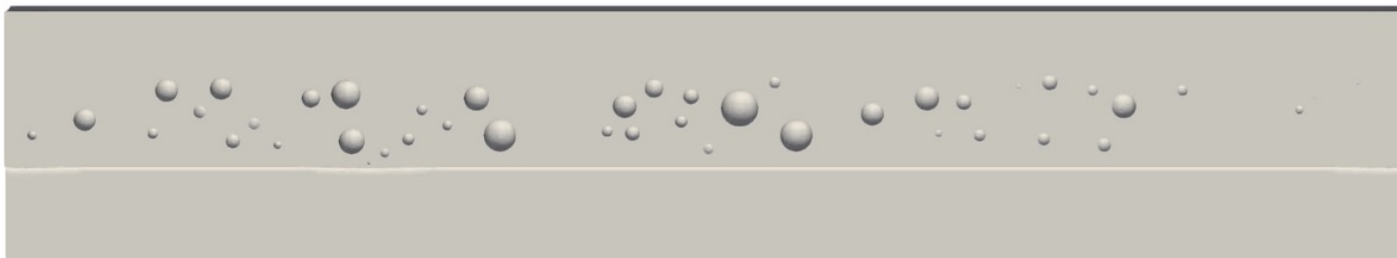
Weld Direction



Weld Direction



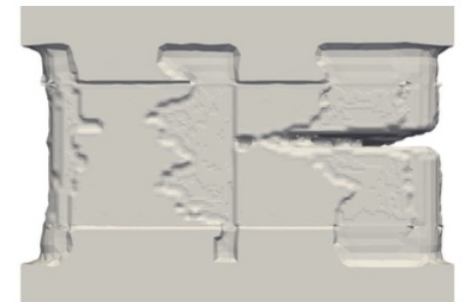
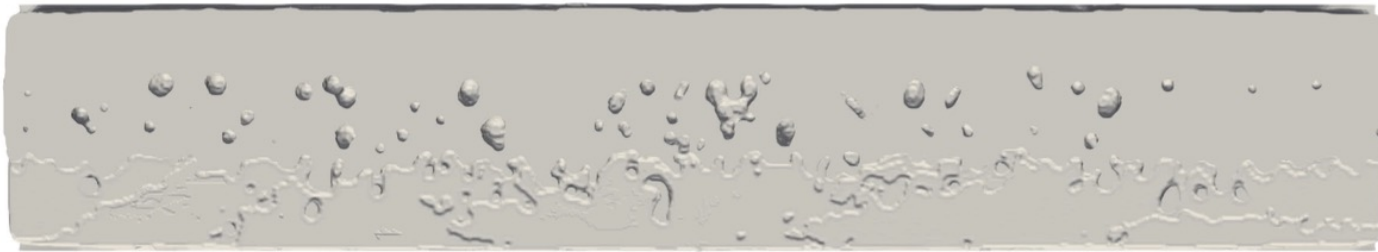
### Fully Idealized Model



Some form of idealization is needed for a scalable solution



### Full Fidelity Model



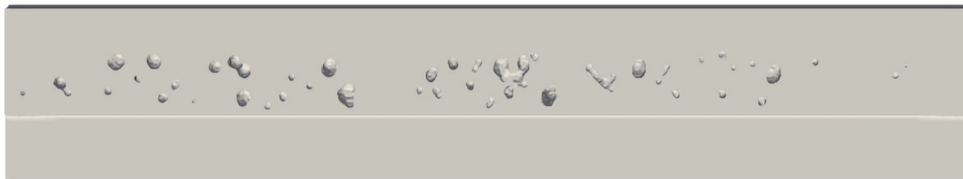
Weld Direction



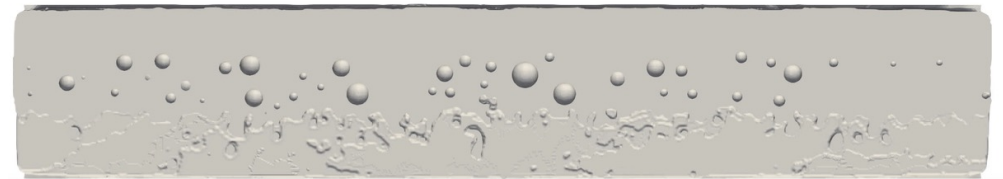
Weld Direction



### Idealized Root Model



### Idealized Porosity Model



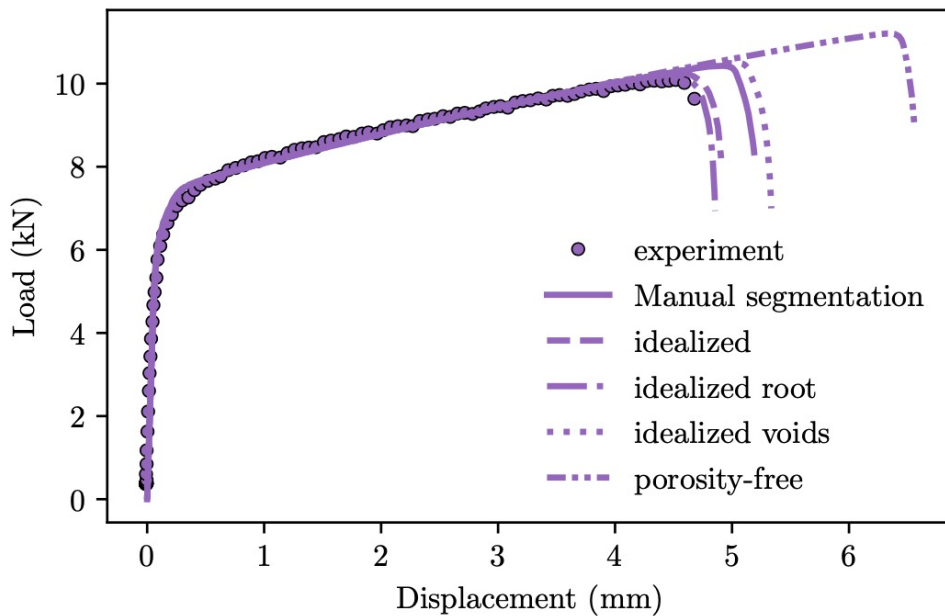
Weld Direction



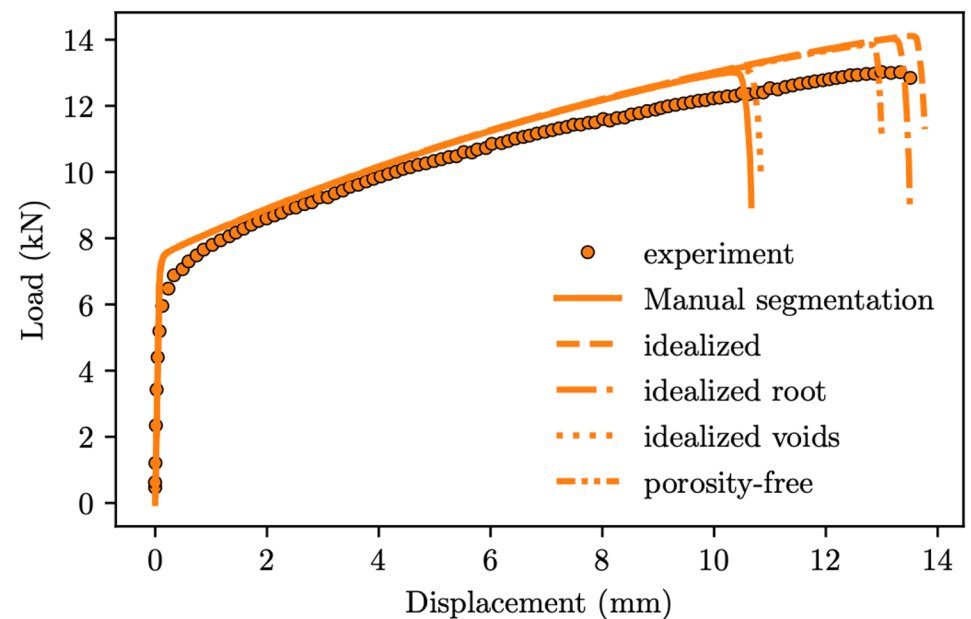
## Idealization predictions do not follow an obvious trend



$\beta$  schedule  
0.10 mm gap



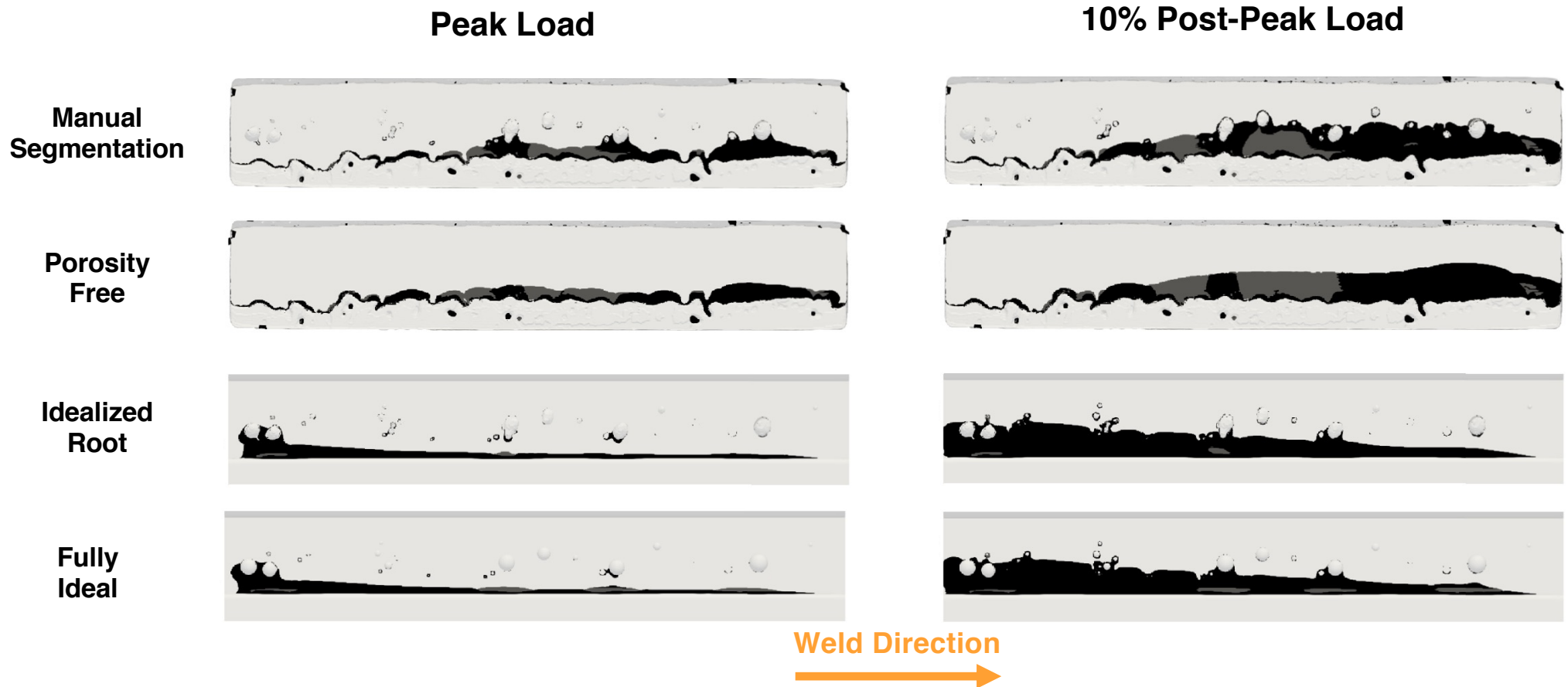
$\beta$  schedule  
0.25 mm gap



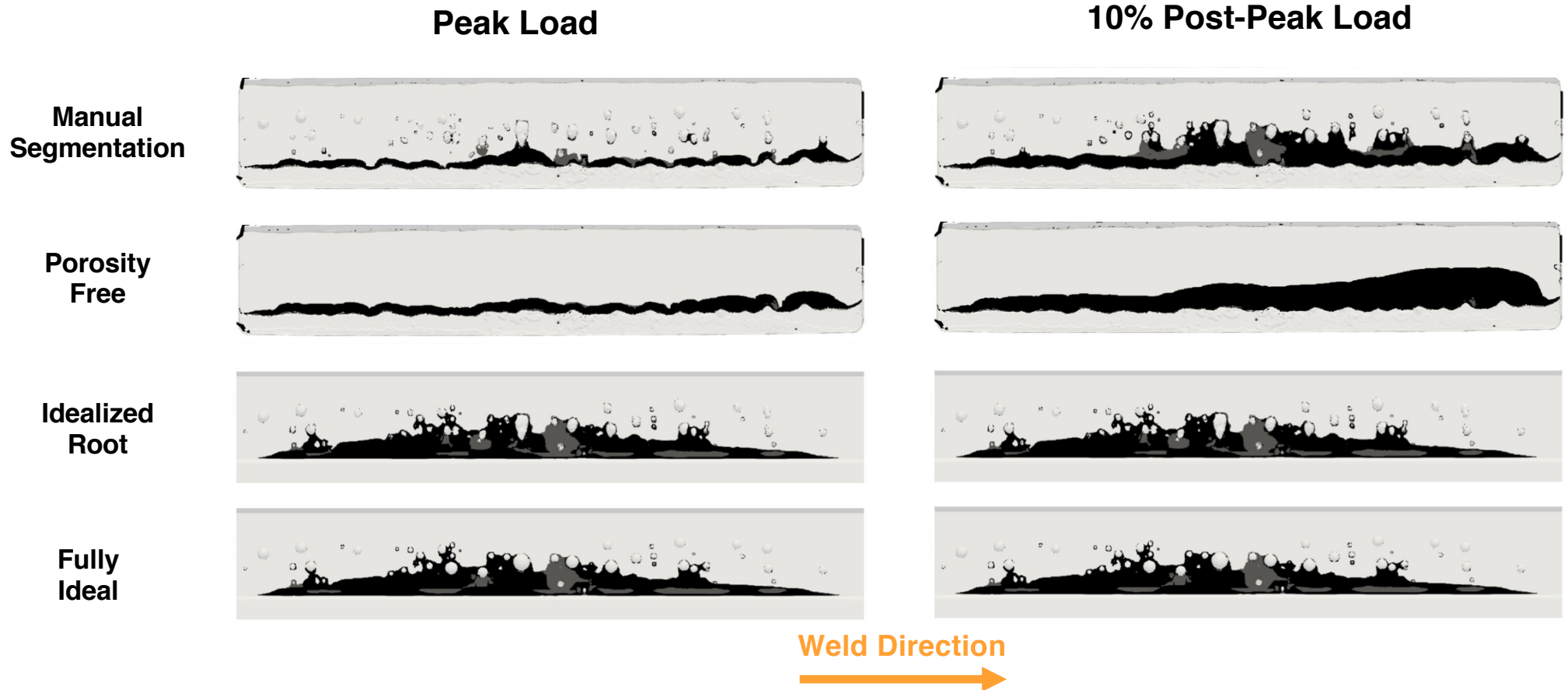




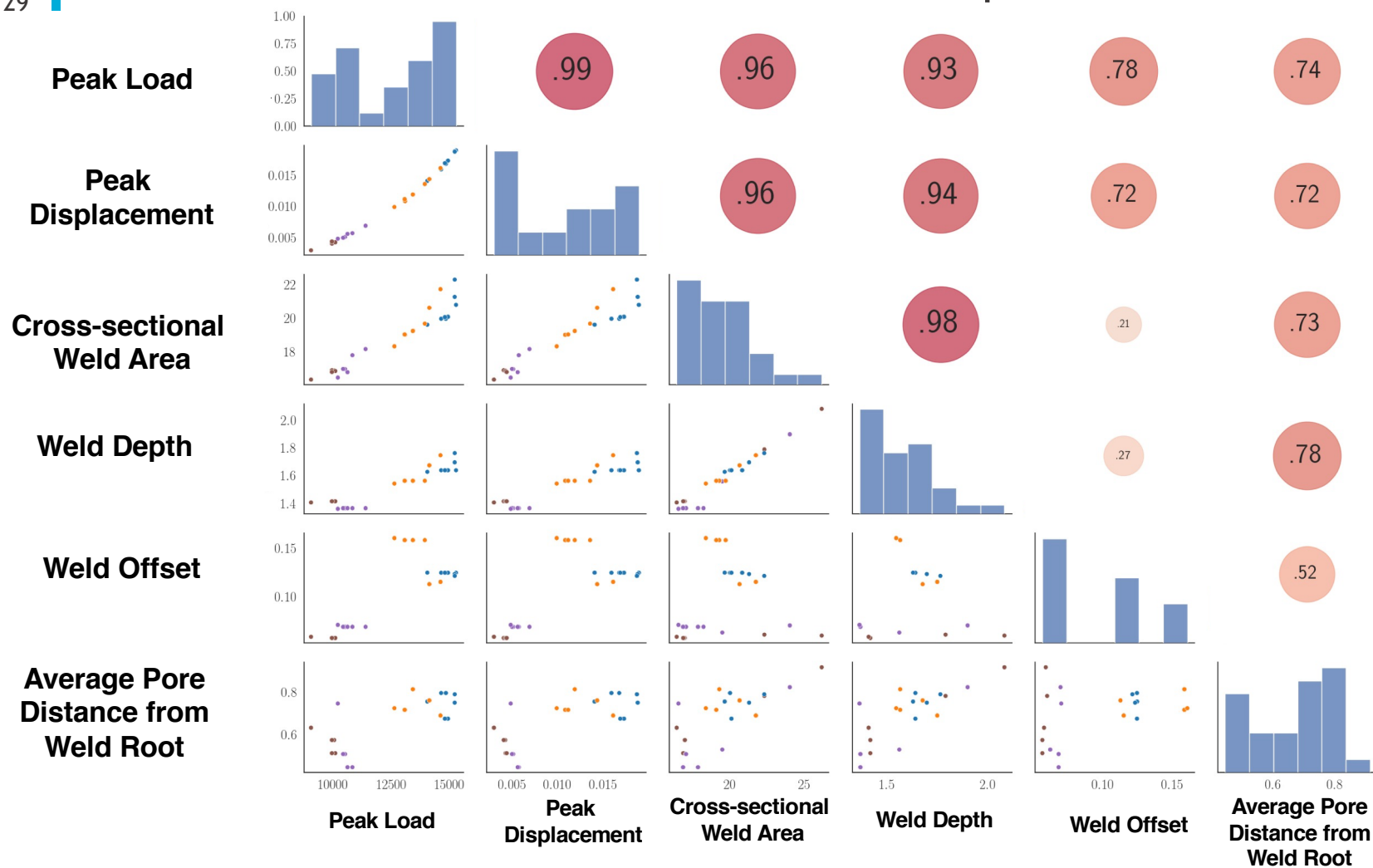
## $\beta$ schedule, 0.25 mm gap



$\alpha$  schedule, 0.25 mm gap

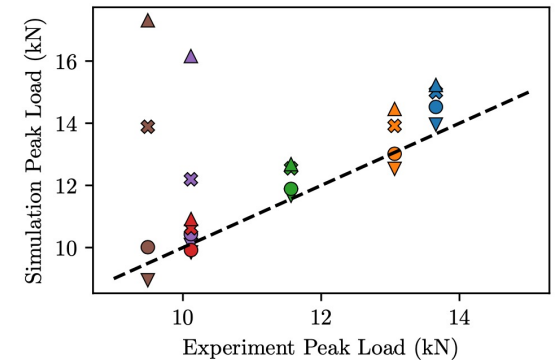
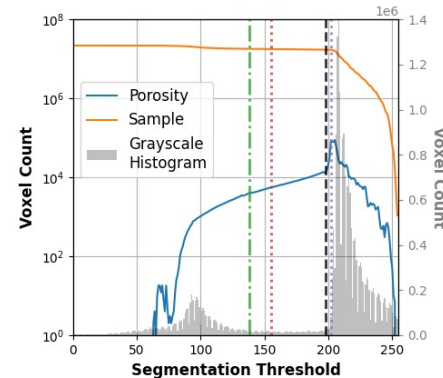
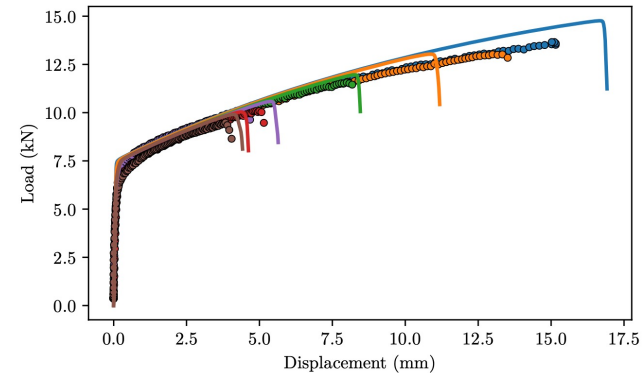


# Geometric correlations with mechanical performance



## Conclusions

- Mechanical response of welds can be better understood using 3D characterization
- Using full-fidelity  $\mu$ 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!

