Sandia National Laboratories

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Understanding Hydrogen Effects on Metals for Fuel Cell Applications: Combined Experimental and Computational Approaches

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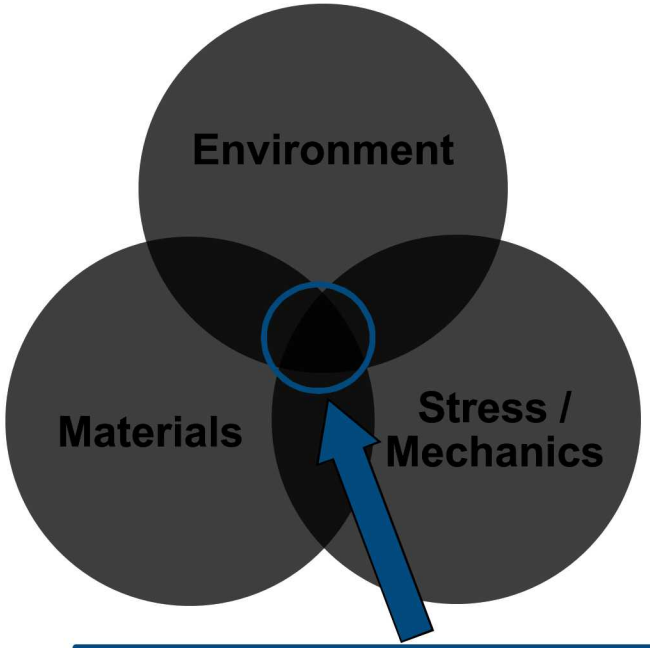
Motivation: Hydrogen reduces fatigue life and fracture resistance of metal components in fuel cell applications



*Hydrogen effects occur in **materials** under the influence of **stress** in hydrogen **environments***

Needs:

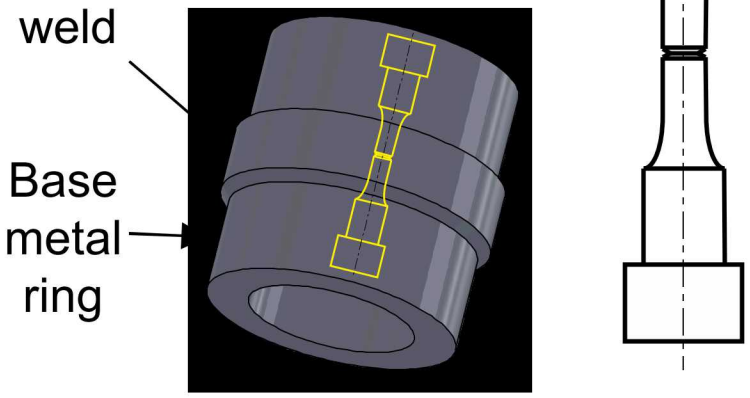
- Relevant methods to evaluate fatigue resistance of welded configurations in gaseous hydrogen
- Extended design lifetimes by accounting for fatigue crack nucleation
- Low-cost, light-weight alternatives to annealed 316L austenitic stainless steels for vehicle applications

Need method to evaluate fatigue of small welded components in gaseous hydrogen

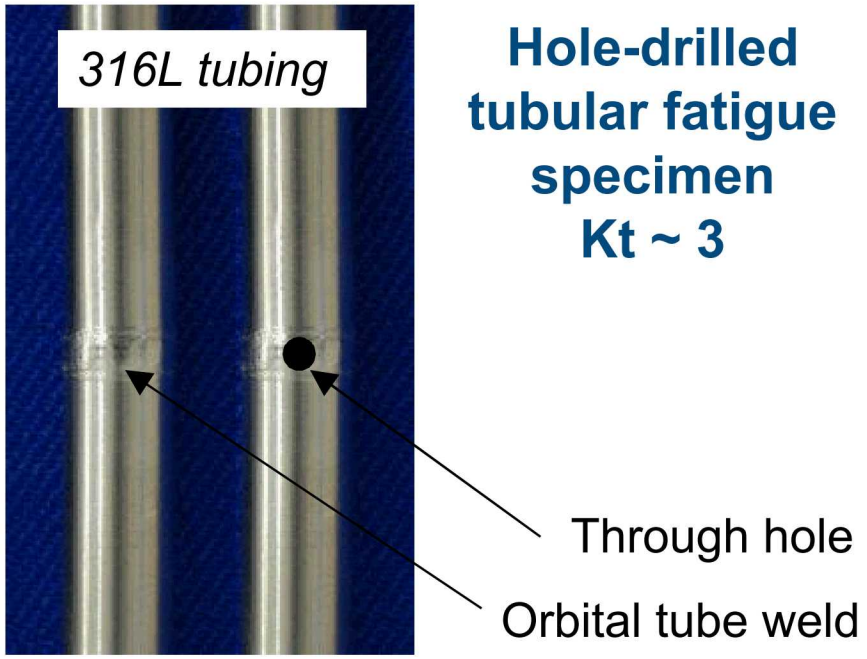
Notched bar is standardized and easily applied to large welds, such as GTA welds and EB welds

Hole-drilled tube is ideal for evaluation of common weld configuration, such as orbital tube weld

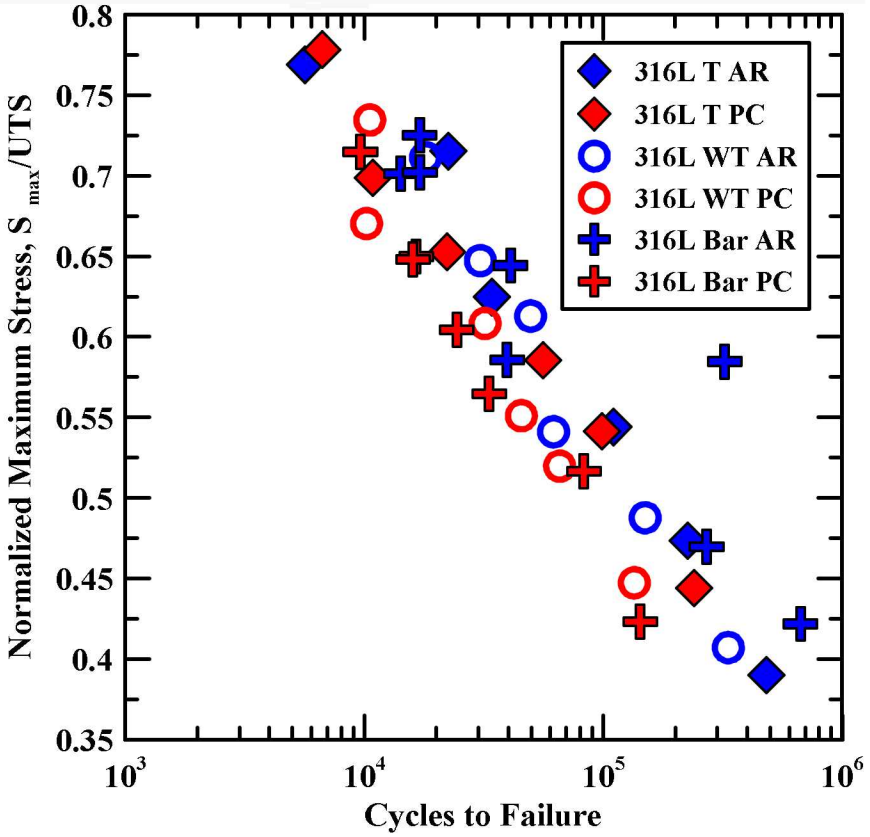
Notched fatigue specimen $K_t \sim 4$



Hole-drilled tubular fatigue specimen Kt ~ 3



Similitude in fatigue life for notched bar and hole-drilled tubes when stress is normalized



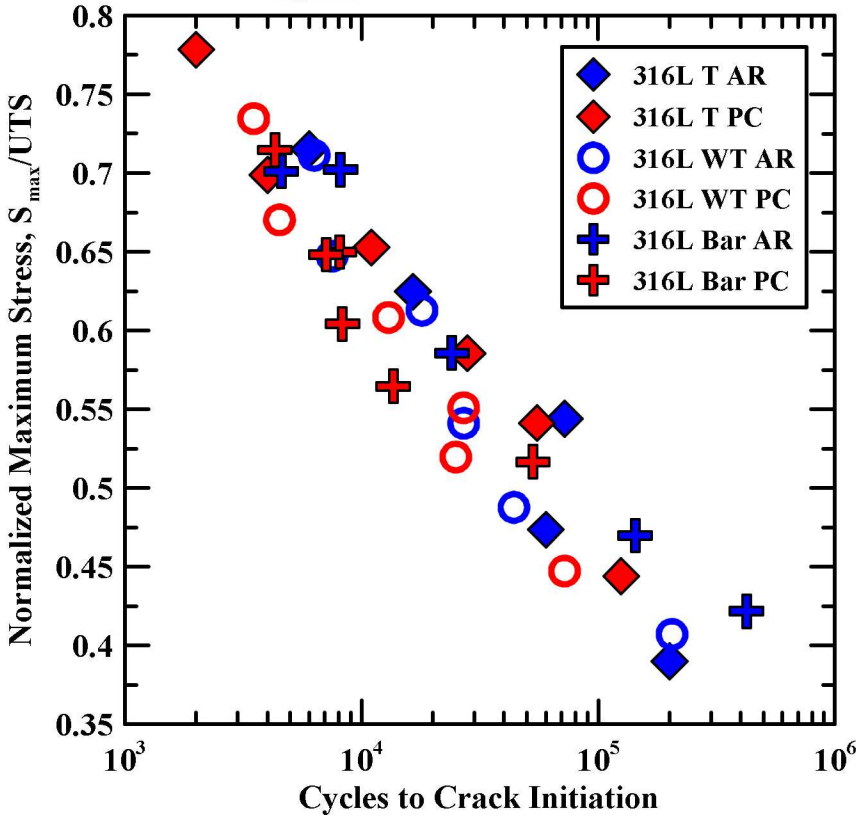
Compare fatigue life of welded tubes, non-welded tubes, and notched bars

Same effect of pre-charged hydrogen

Similitude despite difference in K_t (3 vs 4) and yield stress (~300 MPa vs ~600 MPa)

Does crack nucleation show the same similitude?

Same similitude between notched bar and hole-drilled tube for crack nucleation



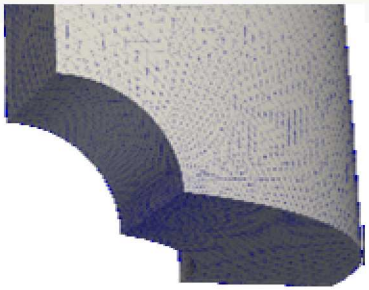
With and without hydrogen, cycles to crack nucleation is 45% of total life

Hole-drilled tube results are consistent with notched bar

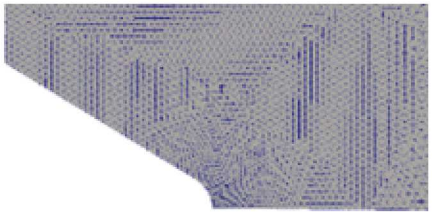
How do the mechanics of the specimens compare?

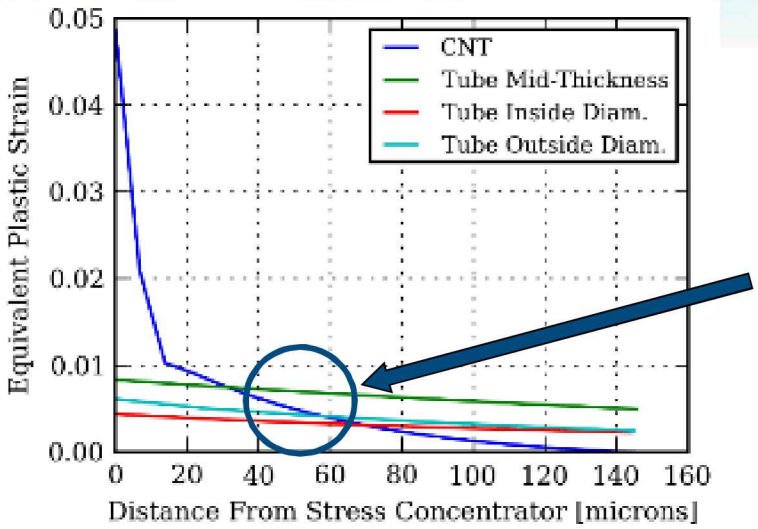
Stress and strain fields overlap 40-60 μm from stress concentration

Tube



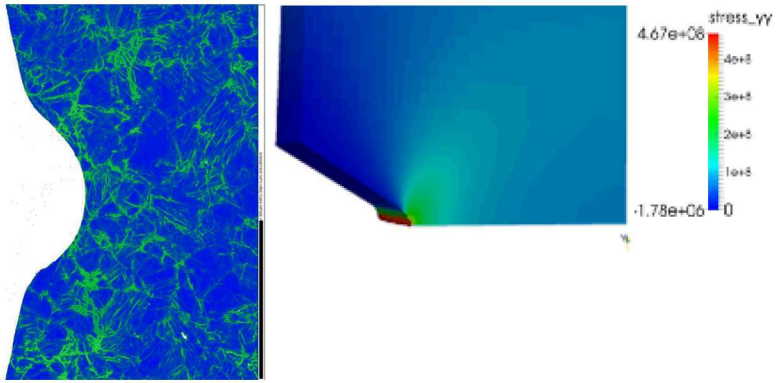
Notched Bar





Characteristic distance for microstructural feature, such as grain size?

Ongoing: Evaluate damage evolution and crack nucleation for different materials and specimens to develop crack nucleation models → account for crack nucleation in design lifetime



Need to understand micro-mechanisms of hydrogen-microstructure interactions to inform microstructural design strategies

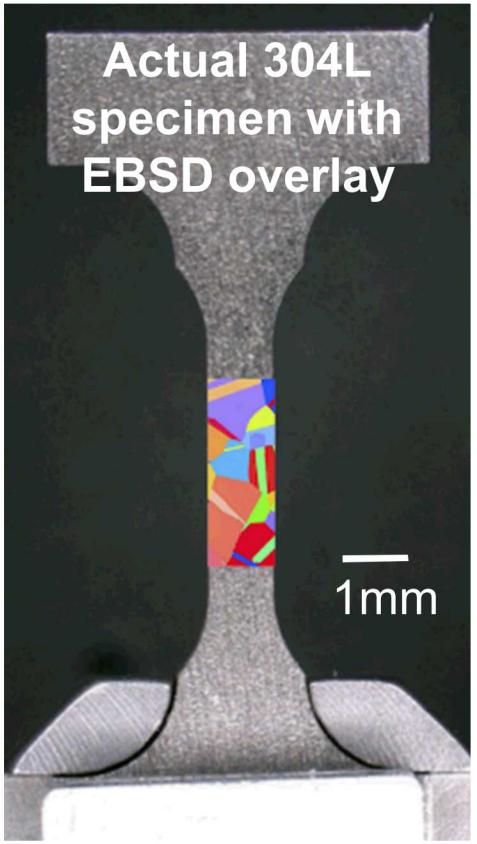
Probe the effects of hydrogen on deformation and damage accumulation in 316 and 304L

Experimental

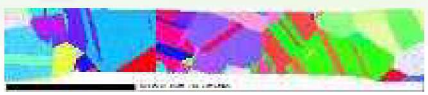
- Quantify localization of deformation in idealized system (oligocrystals)

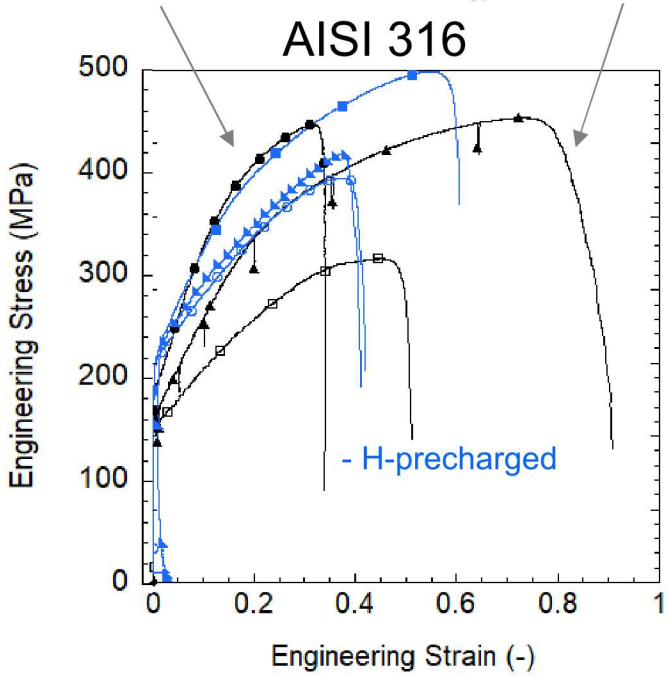
Computational

- Probe realistic digital representations of tested microstructures to develop crystal plasticity model

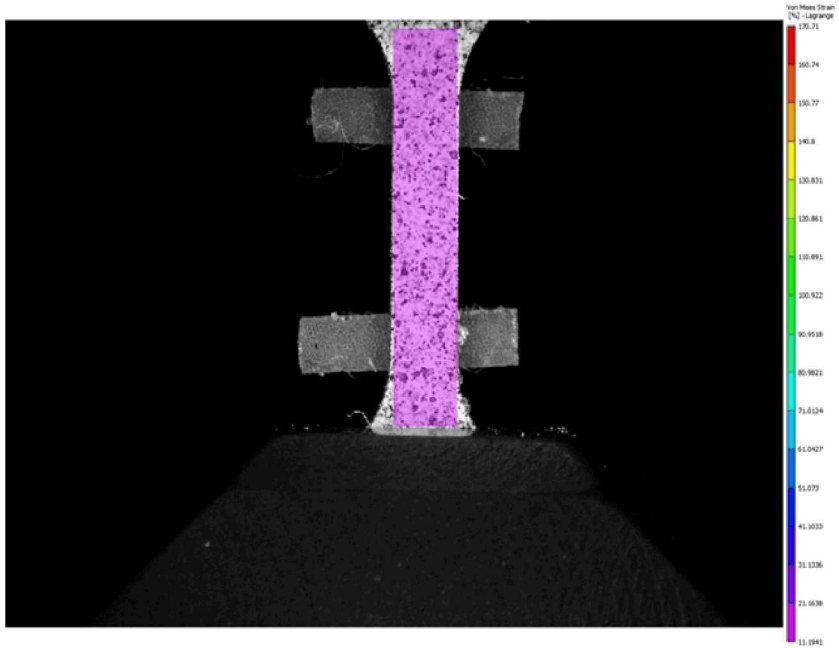


Crystallographic variation masks effects of hydrogen on flow properties





316 no Hydrogen

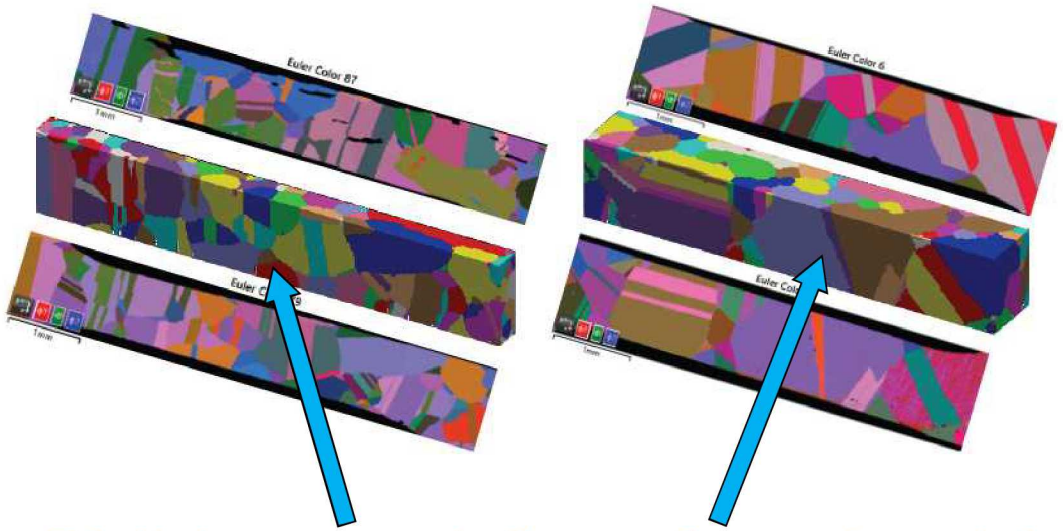


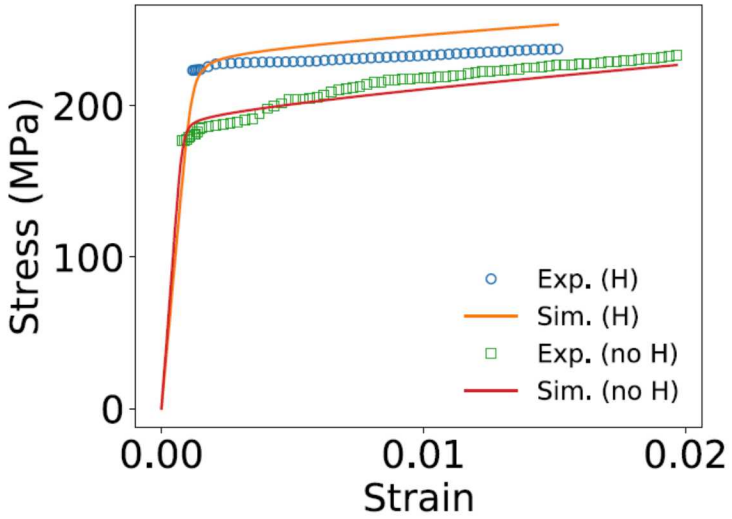
- Digital image correlation (DIC) reveals strain localization
- Crystal plasticity modeling can clarify the roles of crystallographic variation and hydrogen

Crystal plasticity modeling can clarify the roles of crystallographic variation and hydrogen

316 no H

316 with H

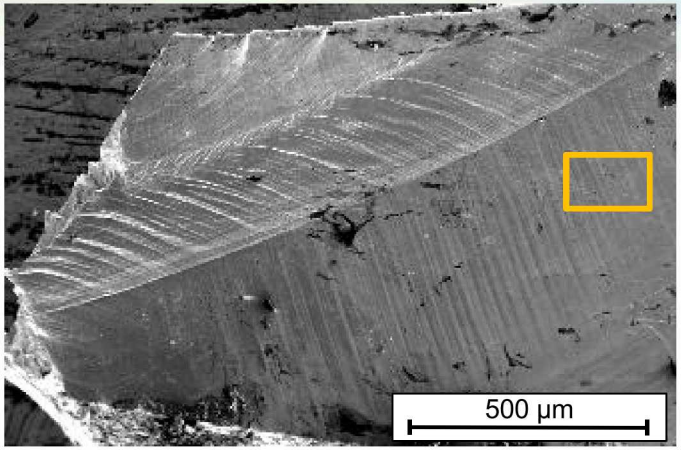




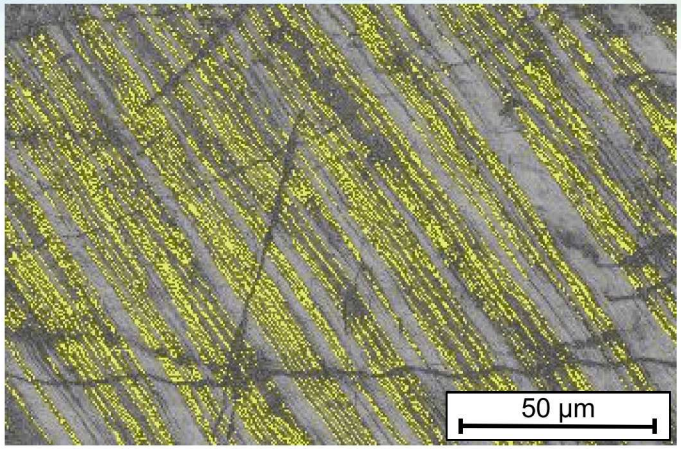
Digital representations of experimental microstructures created from EBSD images

Deformation modes can be identified on polished surfaces of deformed specimens

EBSD shows deformation localized in bands with mechanical twins

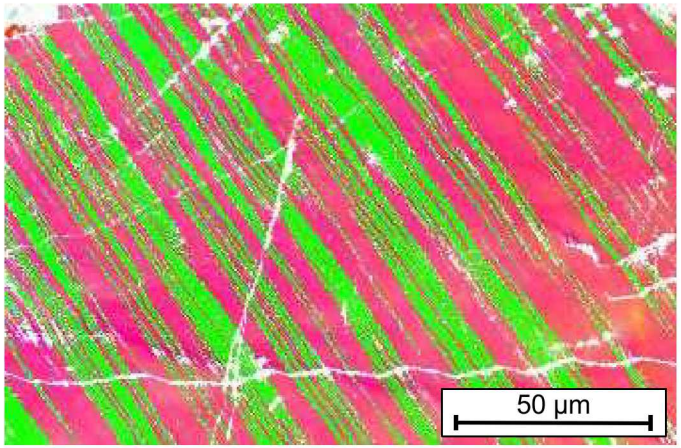


SEM



Band Contrast + Twins

304L with PC H after fracture



IPF Z

Ongoing: Quantitatively assess influence of microstructure (304L vs 316) and hydrogen on deformation modes (slip, twinning, martensite formation)

Summary and Outlook

- Hole-drilled tube specimen can be incorporated into standards to assess fatigue of small-welded components
- Design lifetimes could be significantly increased if models of fatigue crack nucleation can be derived from experimental results
- Investigation of hydrogen effects on deformation mechanisms of stainless steel will aid in the design of higher strength, lower cost microstructures for hydrogen environments

Thank you. Questions?