Sandia National Laboratories

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Fatigue Crack Initiation Across Materials and Specimen Geometries

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Hydrogen-Materials Study Group 8/6/20

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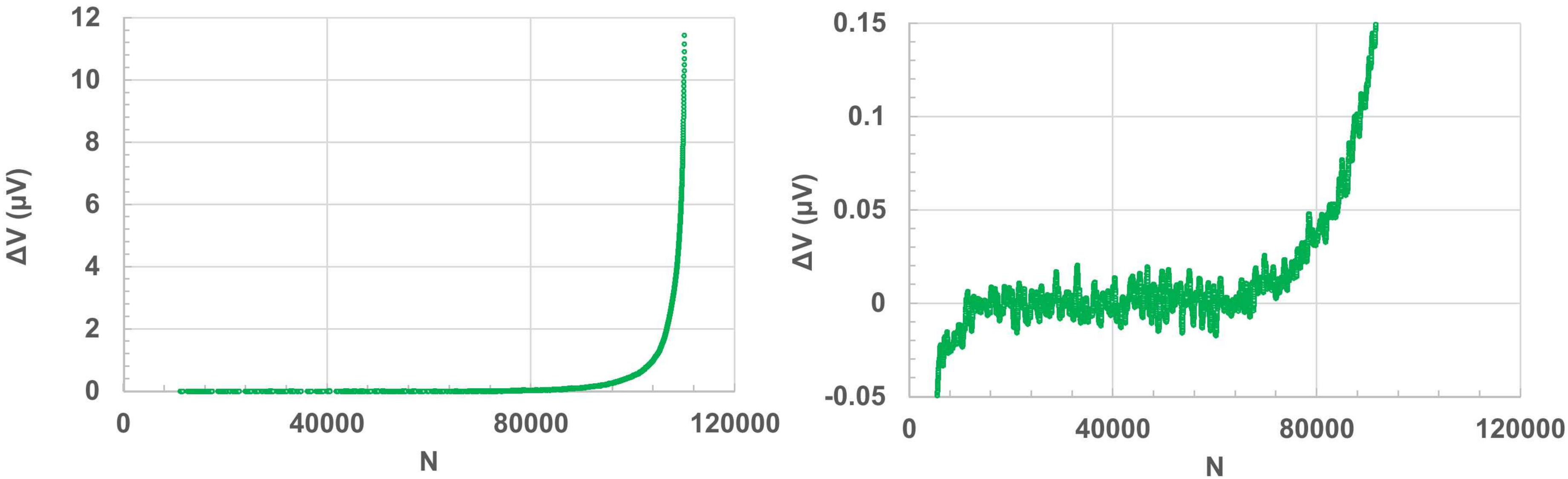
Motivation: Crack initiation accounts for a significant portion of fatigue life

DCPD signal from constant load test of hole-drilled tube



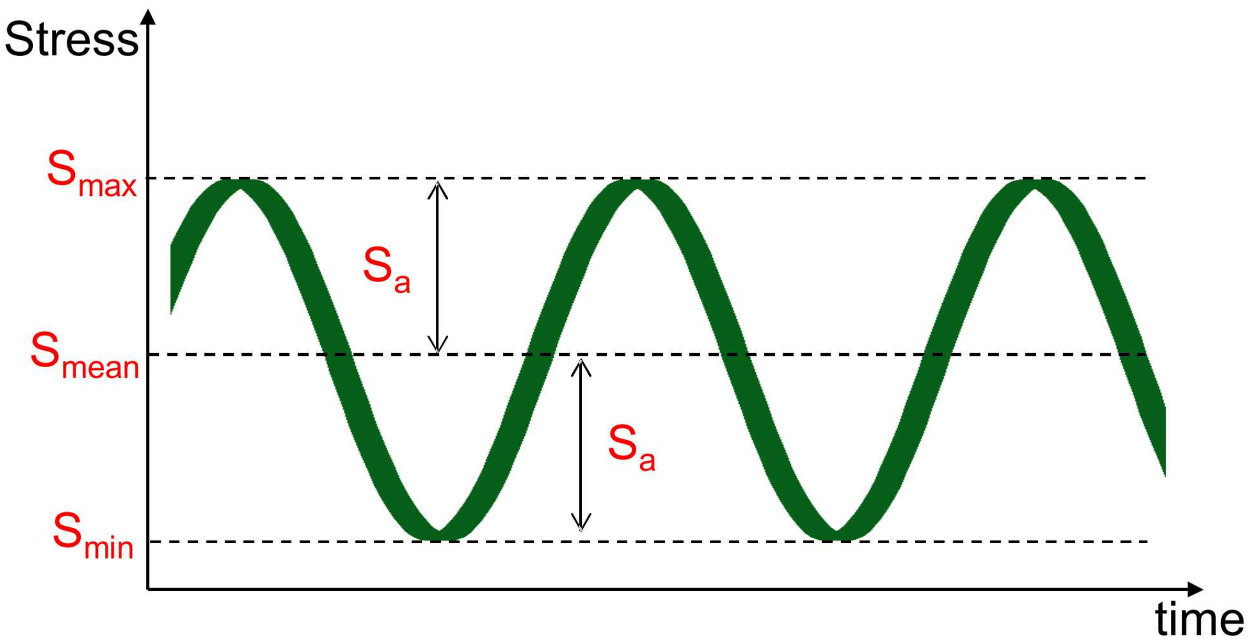
Cycles to crack initiation = 72,000
Cycles to failure = 110,000
Percent of cycles to initiation = 65%

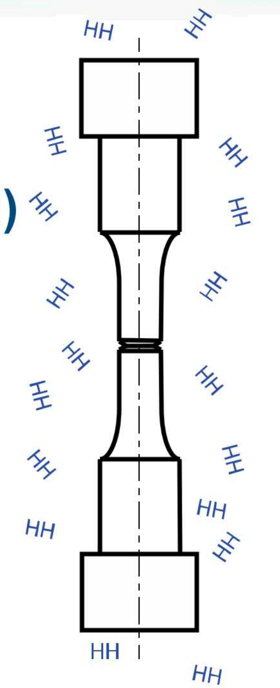
With greater understanding of the mechanisms of crack initiation, can a design and testing approach be developed to extend lifetimes?

Approach: fatigue life testing adapted to environment and engineering configurations

Hydrogen fatigue life testing

- **Circumferentially notched tensile (CNT) specimens: K_t ~ 3.9**
- **Tension-tension loading (R = 0.1)**
- **Constant load amplitude (constant stress until crack initiation)**
- **Crack monitoring with DCPD**
- ***In situ* in gaseous hydrogen or hydrogen-precharged**

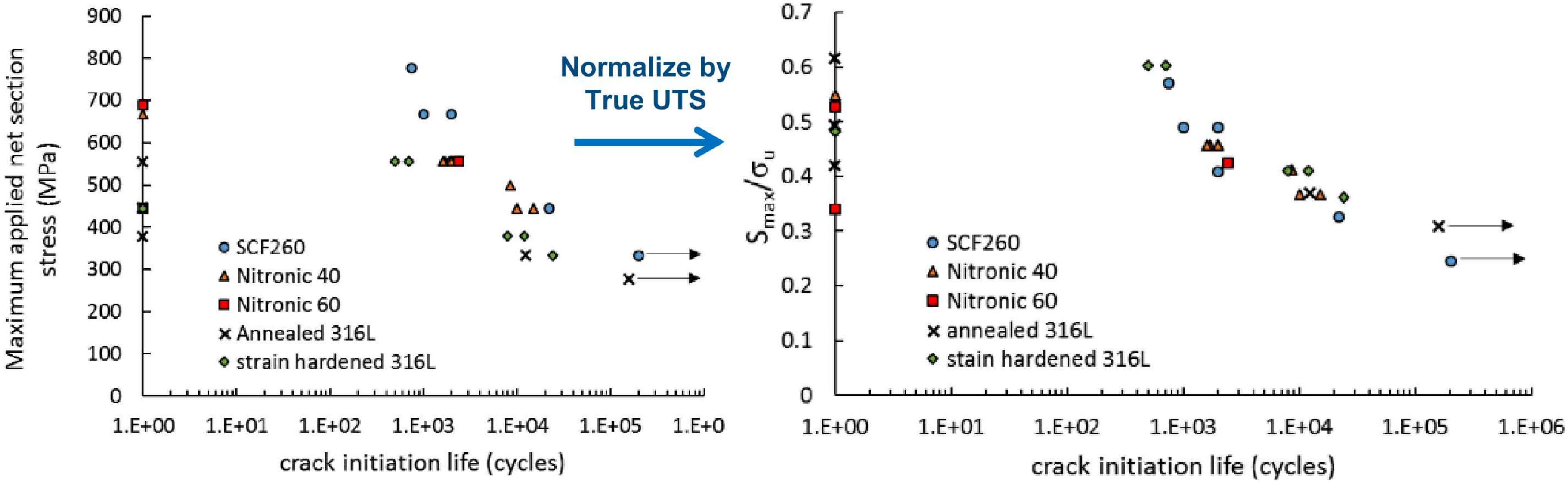




$R = S_{min} / S_{max}$

$S_{max} = 2S_a/(1-R)$

Similitude in crack initiation life for multiple materials when stress is normalized

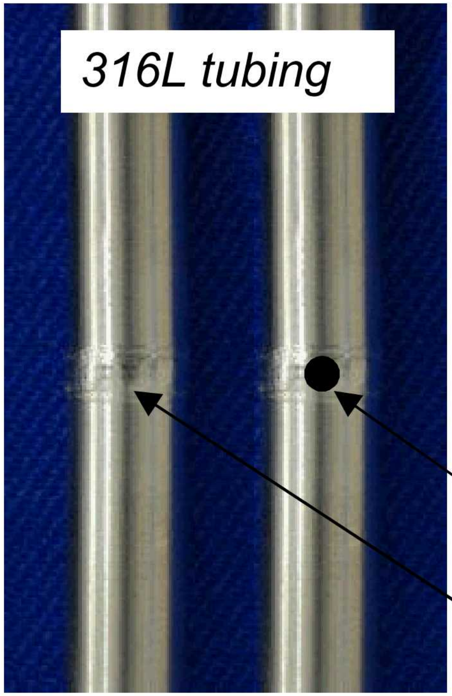


Nibur, et al. 2017

CNT specimens tested in 10 MPa H_2

What about other specimen geometries?

Evaluate fatigue of small welded components with hole-drilled tube specimen



Hole-drilled tubular fatigue specimen Kt ~ 3

Through hole

Orbital tube weld

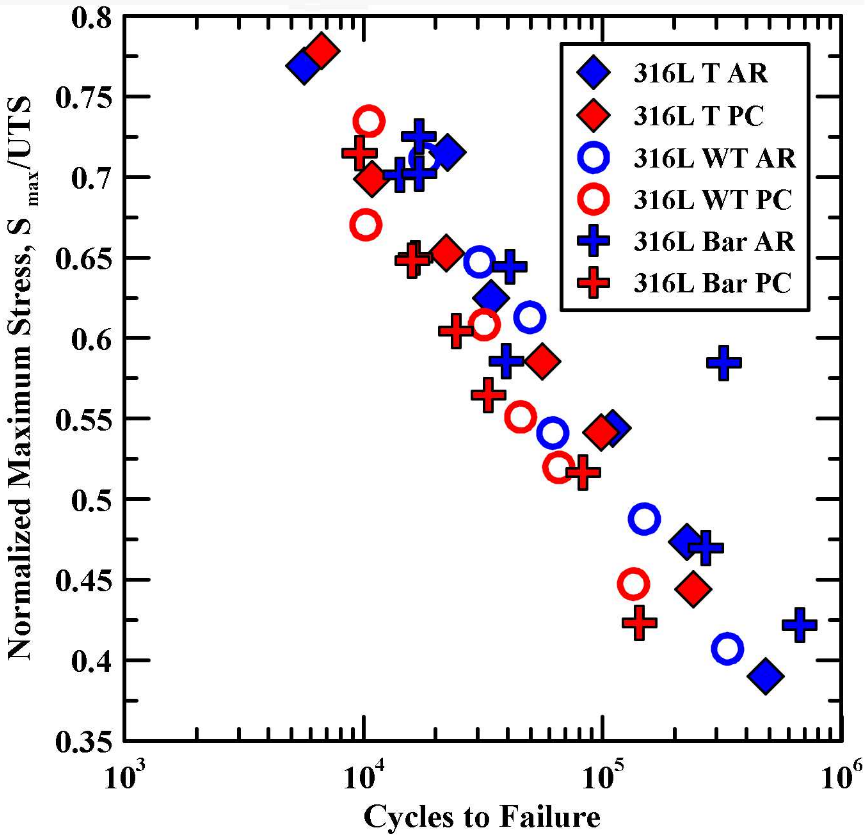
Hole-drilled tube is ideal for evaluation of common weld configuration, such as orbital tube weld

Test 316L welded tubes and non-welded tubes with and without pre-charged hydrogen

Compare to CNT results

DCPD to identify crack initiation

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



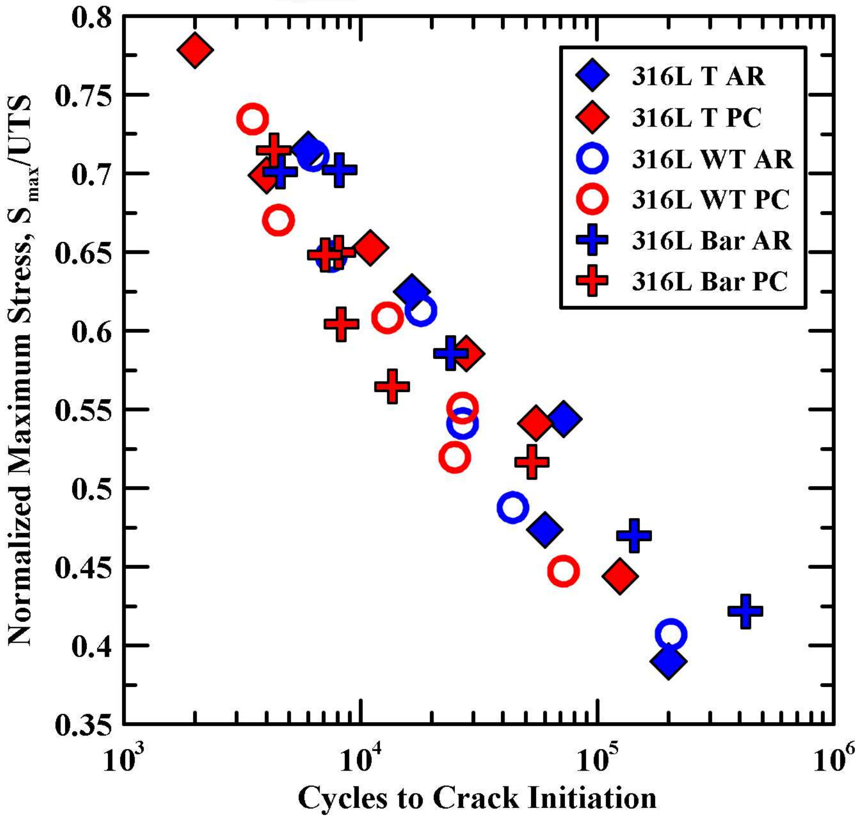
Compare fatigue life of welded tubes, non-welded tubes, and notched bars

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 initiation show the same similitude?

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



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

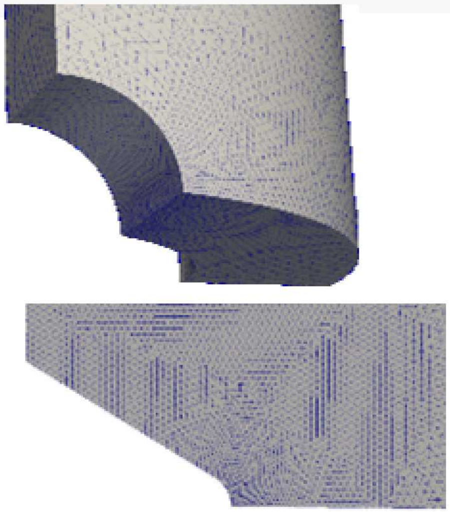
Hole-drilled tube results are consistent with notched bar

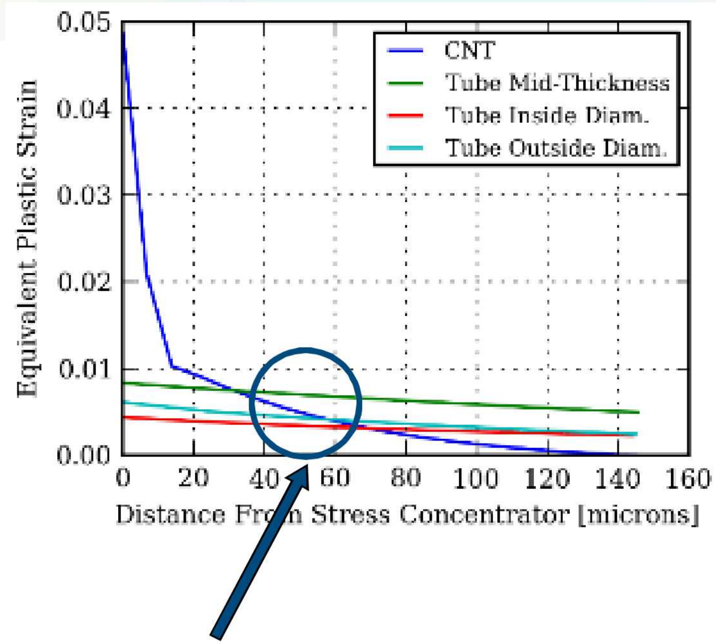
How do the mechanics of the specimens compare?

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

Tube

Notched Bar



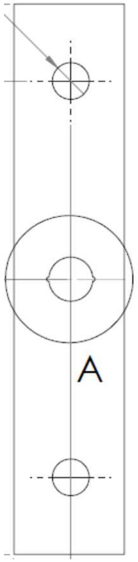


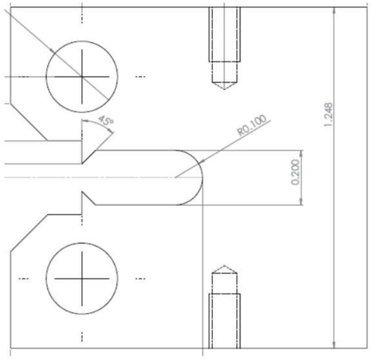
Crack initiation driven by full plastic zone and not just plastic strain directly at notch?
Characteristic distance for microstructural feature, such as grain size?

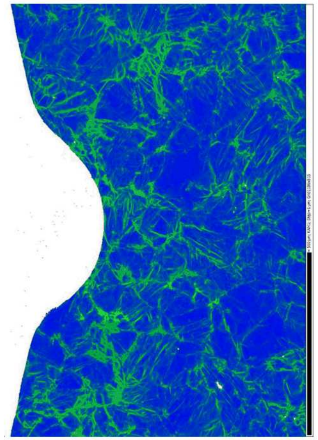
Ongoing: Assess relationship between crack initiation and damage evolution across materials and stress states

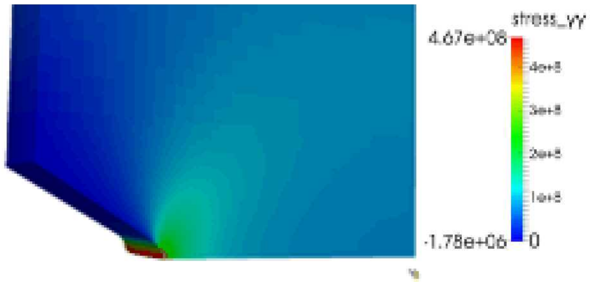
Materials:
Stainless steels
Cr-Mo Steels

Specimen Geometries:
Middle tension
Blunt notch compact tension
CNT
Arc
Smooth









Develop crack initiation models based on damage evolution, stress state, and material properties

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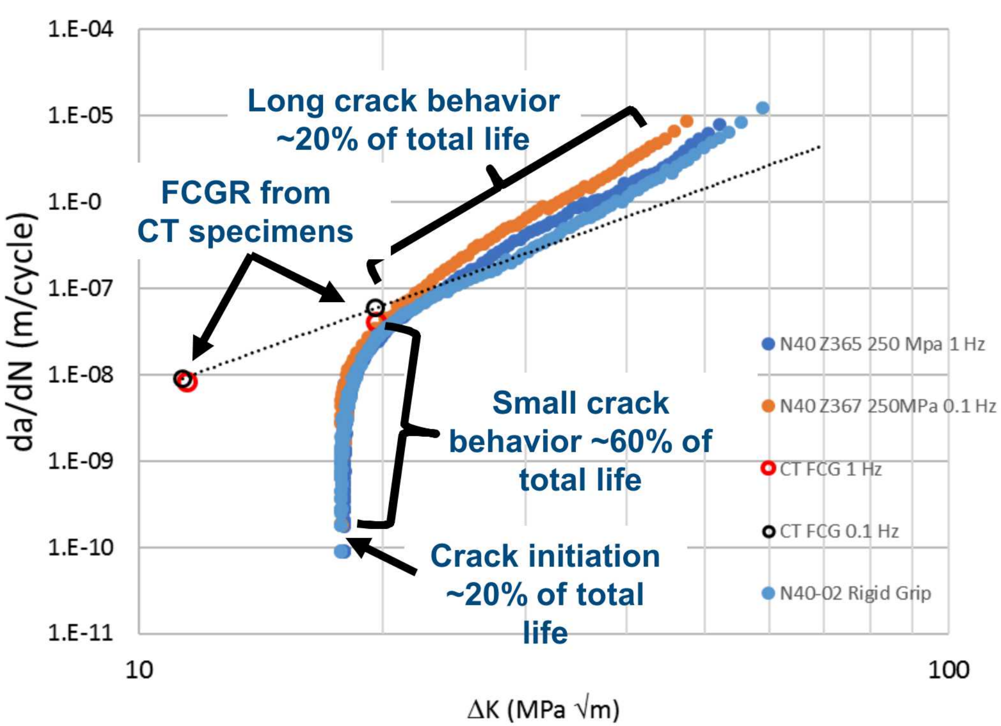
Design Considerations: Couple safe-life approach for crack initiation and fracture mechanics for long crack growth



S-N curves for crack initiation show same consistency as S-N for failure

Can lifetimes be extended by using S-N for crack initiation and fracture mechanics for long crack growth?

Questions:

- **What about small crack growth?**
- **NDE requirements?**
- **Effects of hydrogen?**

Summary and Outlook

- Crack initiation accounts for a significant portion of fatigue life
- Similitude in crack initiation life observed for different materials and specimen geometries
- Ongoing effort to understand crack initiation by relating damage evolution, stress state, and material properties
- Greater understanding of crack initiation could allow for innovative design strategies to extend design lifetimes

Thank you. Questions?