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Fatigue crack initiation and notch influence in austenitic stainless steels

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Exceptional service in the national interest

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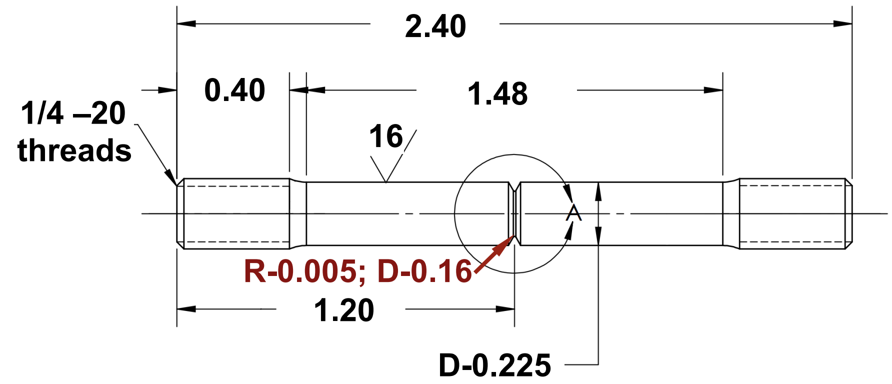
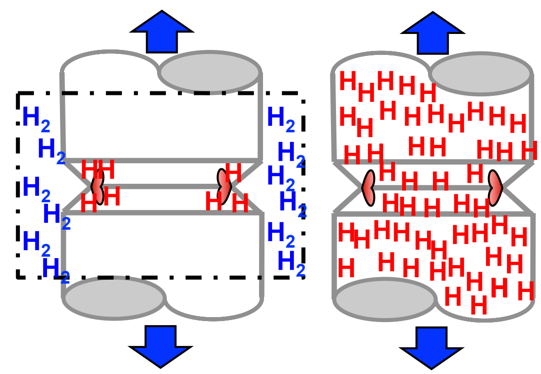
Hydrogen degradation of stainless steels: Fatigue-life Assessment

- Traditional fatigue relies on smooth specimens
  - *Measurement of axial fatigue-life largely represents material resistance to crack initiation*
- Many data sets in hydrogen developing around notched specimen testing
  - *Fatigue life includes both crack initiation/incubation AND crack growth*
- <u>Areas of current investigation/development</u>:
  - *Notched fatigue assessment, what do the data include?*
    - Separating crack 'initiation' from crack growth
  - *What is the effect of the notch on the measured fatigue environment?*

Notched Fatigue Testing

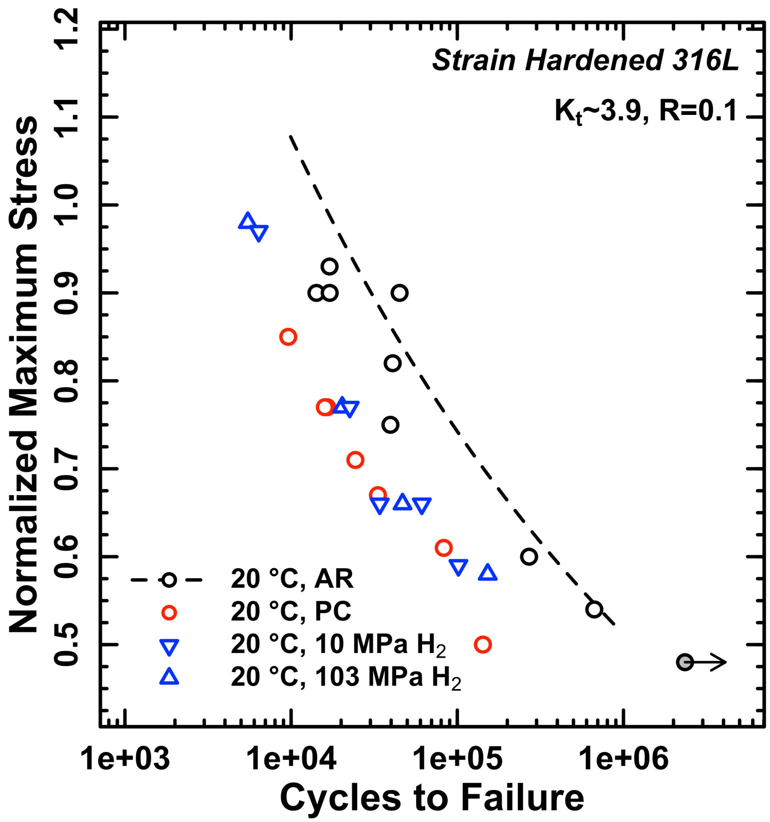
- R = 0.1 (tension-tension)
- Notched specimens (K_t~3.9)
- Limit to nominal stresses below yield stress
- Temperature, 20 and -50°C
- ***Hydrogen environment:***
  - *10 and 103 MPa external H_2*
  - *Saturated with internal H (PC)*

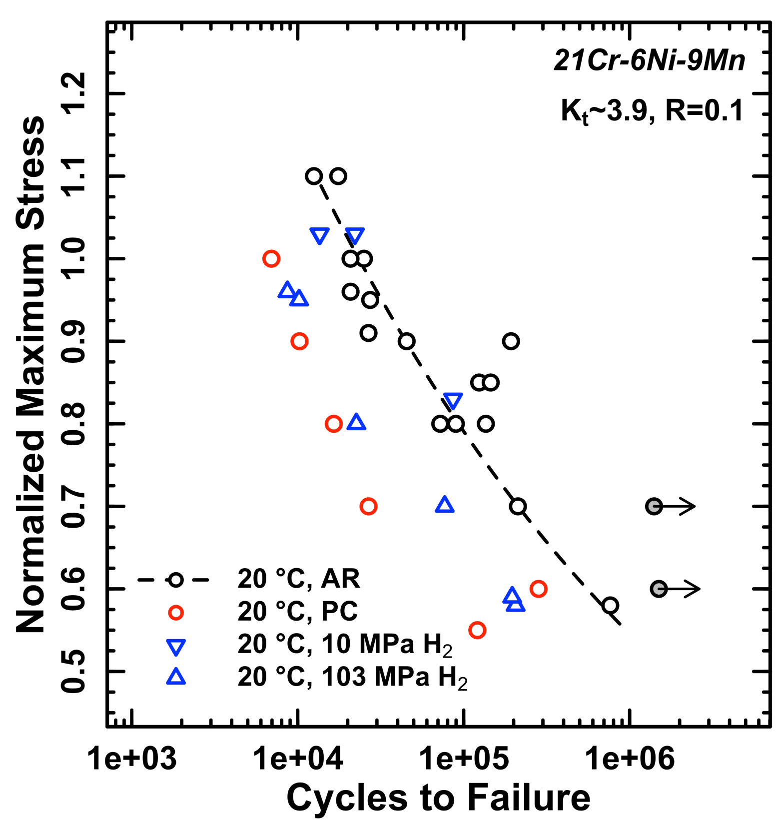




Notched Fatigue
Internal v. External Hydrogen

- ***Measure a fatigue life and offset due to hydrogen***
  - ***What about the contribution to initiation v. growth?***





Direct Current Potential Drop (DCPD)

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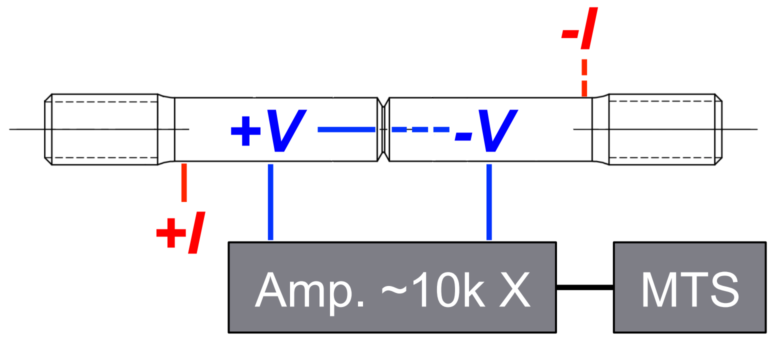
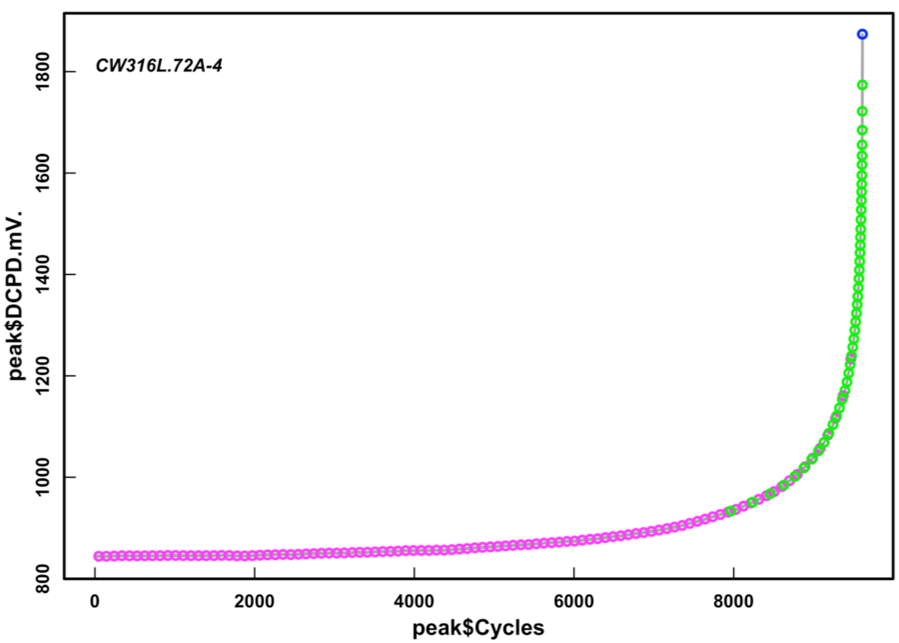
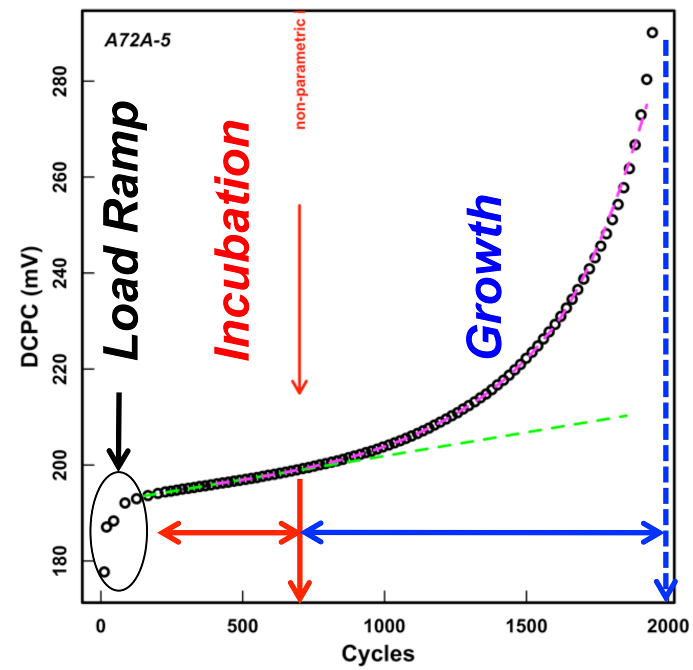
- **Continuously measure voltage across the notch during cycling**

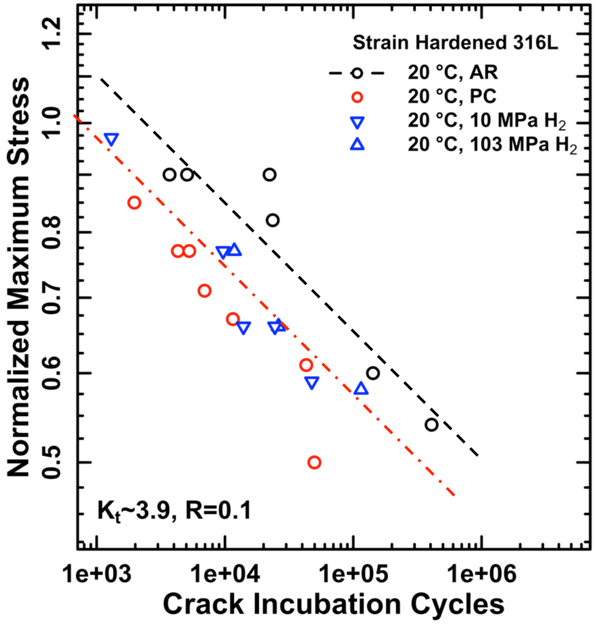


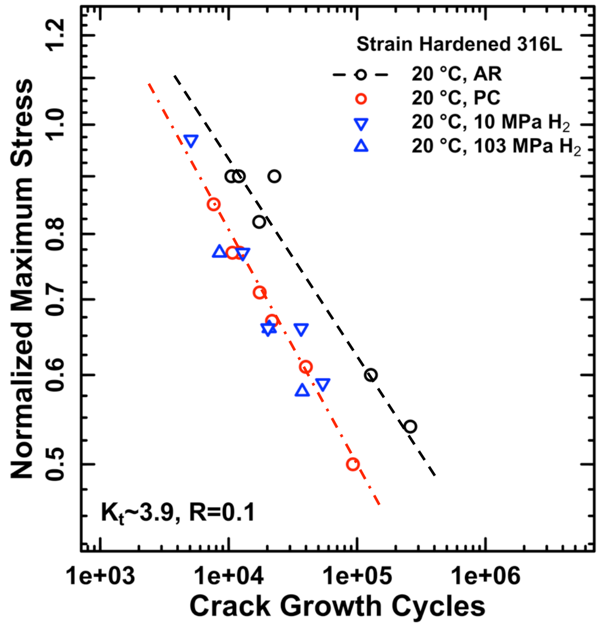


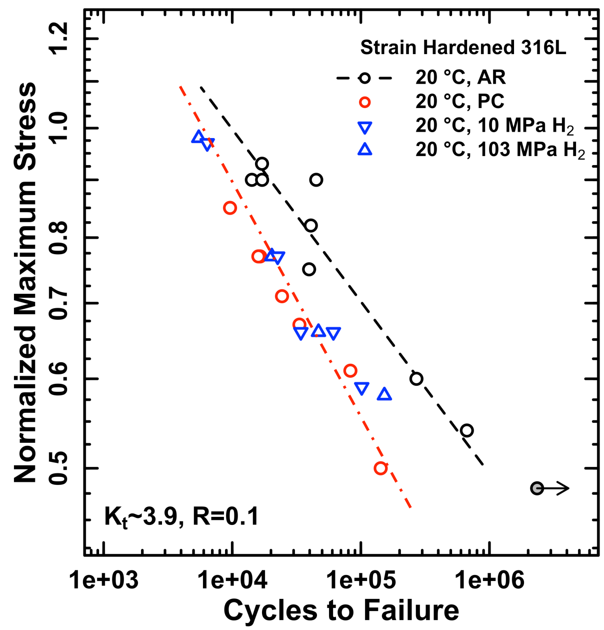


High Strength Stainless Steel: Strain-Hardened 316L

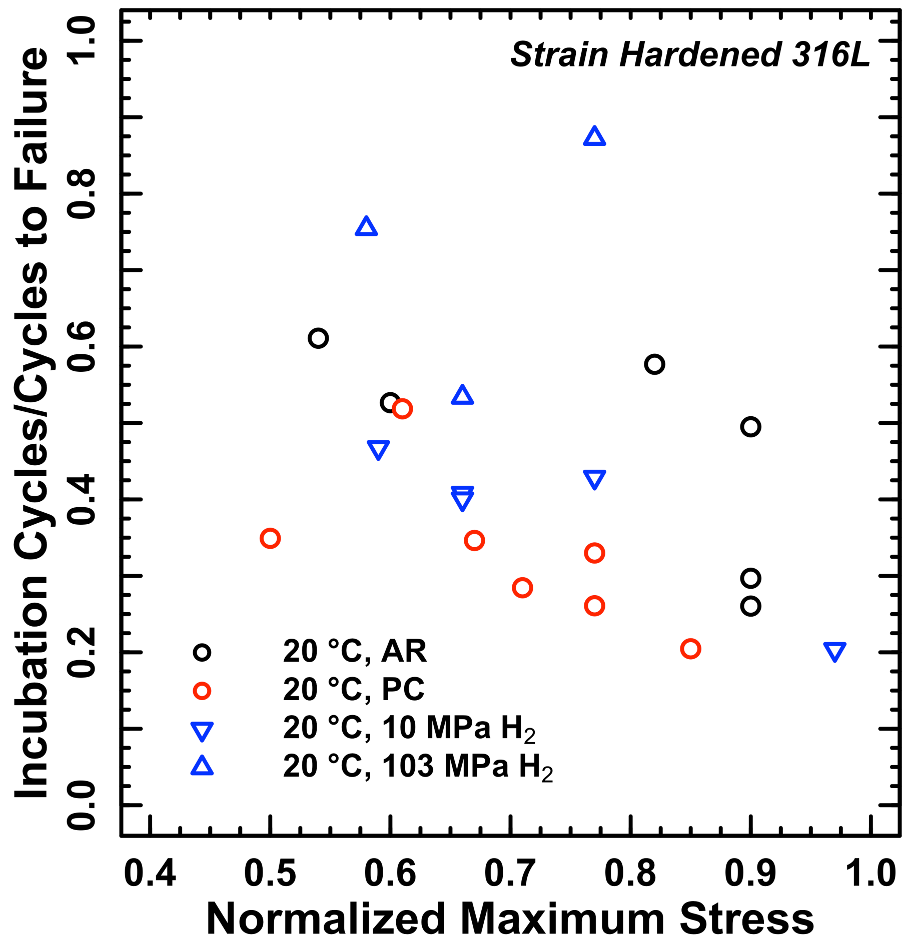
Regression line fit to only strain-hardened 316L
All plots in log-log space







High Strength Stainless Steel: Strain-Hardened 316L



Notched Fatigue Summary

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Benefits:

- **Notched fatigue simulates many of the environmental factors that a component will see in hydrogen service**
- **Results serve as a *qualitative* metric of performance**

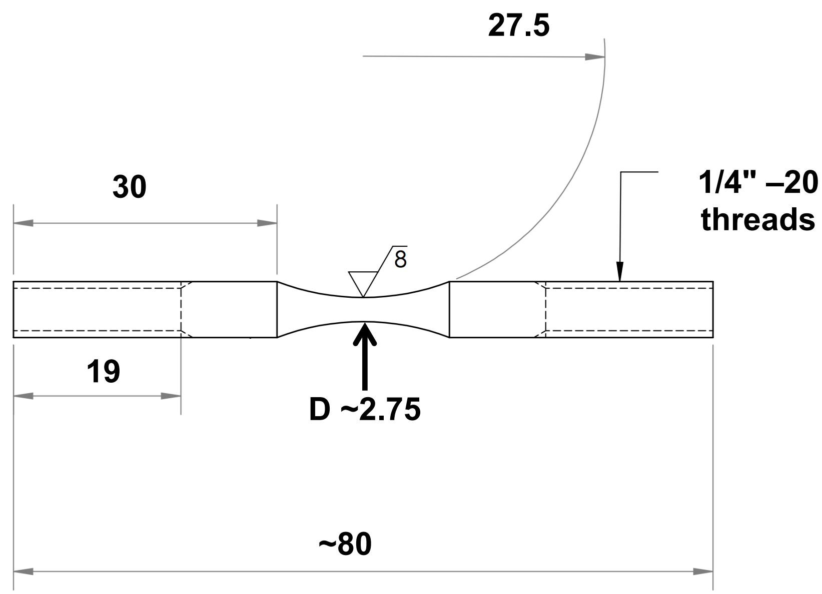
Challenges:

- **Non-general results**
  - ***Fatigue crack growth life depends on specimen size***
    - **20-40% of life this becomes significant**
  - ***Limited ability to extract contributions to life***
- **Possibly non-conservative, rely on crack propagation in component**
- **Difficult to assess mechanisms of degradation**

Smooth Fatigue Testing

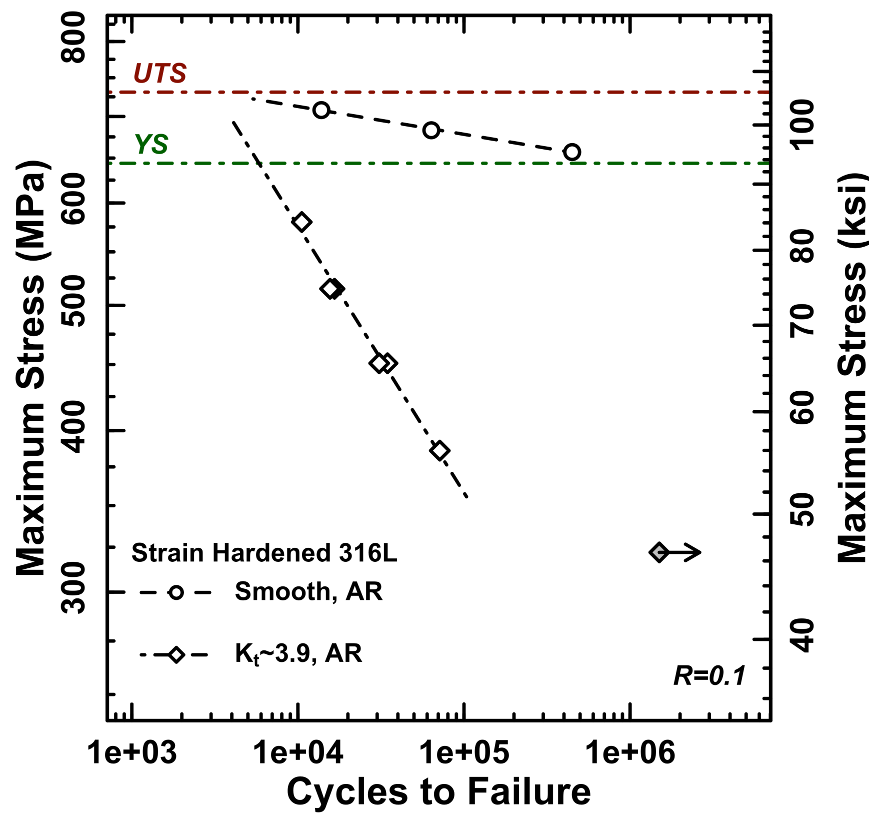
- R = 0.1 (tension-tension)
- Smooth specimens
- Temperature, 20
- *Hydrogen environment:*
  - *Saturated with internal H (PC)*

How do notched and smooth data compare at R=0.1



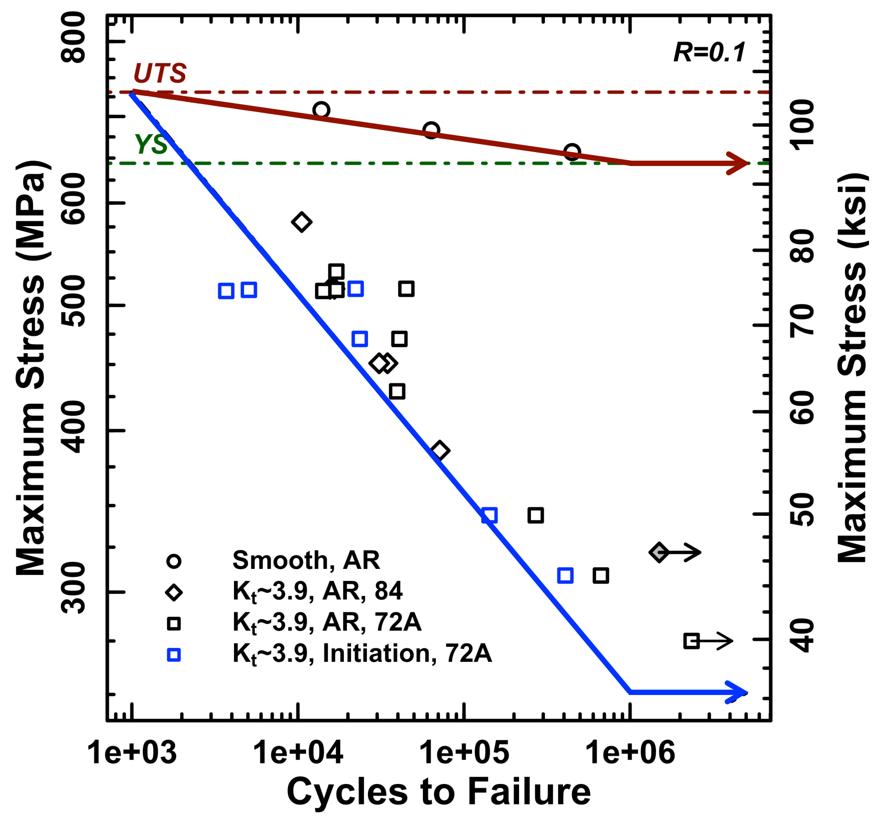
Smooth Fatigue
Internal v. External Hydrogen

- ***Measure a fatigue life dominated by initiation (smooth)***
- ***Compare to notched fatigue life***
- ***Extrapolations converge at high stress amplitudes (tensile rupture dominated)***
  - ***Testing of PC pending…***



Smooth Fatigue
Internal v. External Hydrogen

- ***Model for smooth fatigue:***
  - *LCF ~10^3 cycles S_{max}~UTS*
  - *HCF~10^6 cycles, S_{max}~YS*
- ***Methods to go from smooth -> notch***
  - *Peterson's calculations for K_f from K_t based on elastic-plastic behavior*
  - *Conservative estimate of life*
  - *Comparison to DCPD Initiation reasonable*
- **Reversing the analysis non-conservative**



Smooth Fatigue Summary

Results still extremely preliminary

Benefits:

- Life measurements appear to be dominated by initiation
- Sensitive to hardening/softening if make strain measurements
- Simple deformation

Challenges:

- Tests can be more challenging to execute consistently
  - *Surface preparation key*
- Limited data at positive R-ratio
- Lose the interaction between hydrogen and a local stress field