

Fracture Toughness of Hydrogen Embrittled Welds and Heat Affected Zones in Stainless Steel

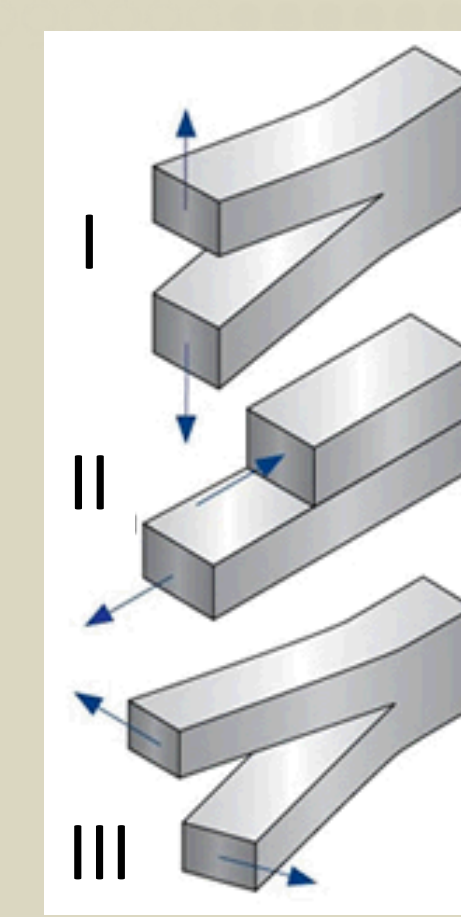
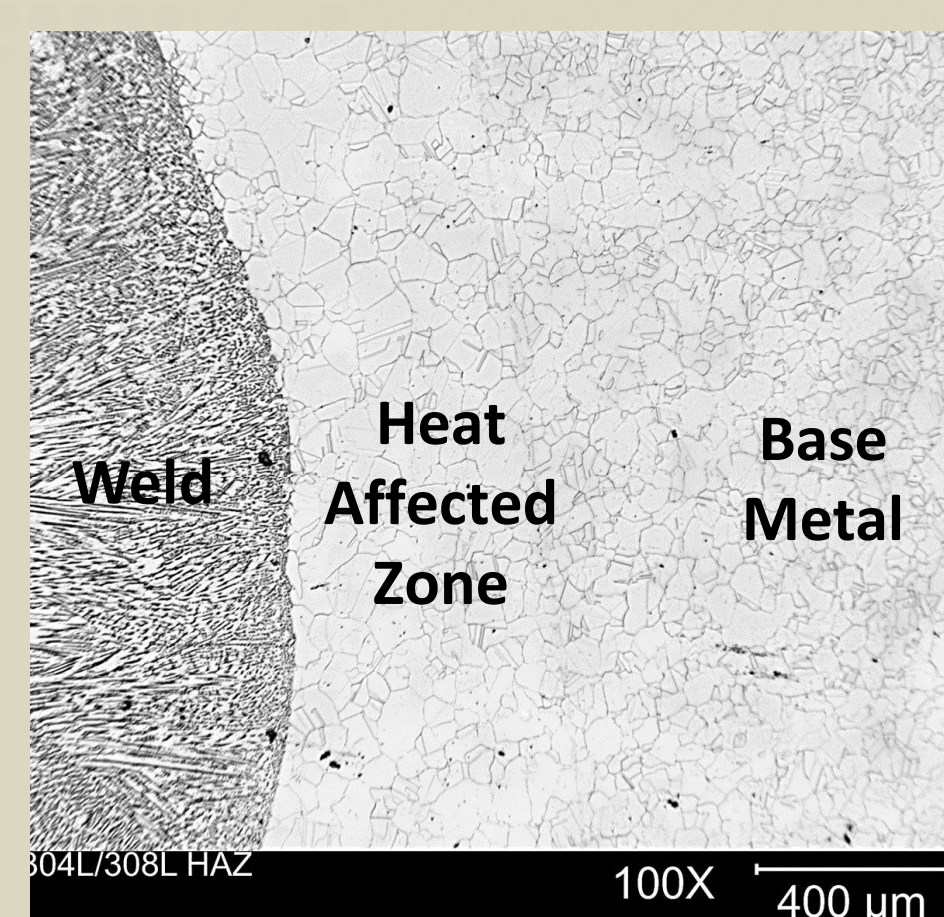


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Background

- Hydrogen embrittlement (HE) must be managed in gas transfer system (GTS) reservoirs, with special attention paid to welds and heat affected zones (HAZ) due to differences in microstructure.
- Performed 3 point bend (3PB) tests (pure mode I loading) on hydrogen charged stainless steel specimens.
- Direct current potential drop (DCPD) used to record crack initiation/extension, and J-integral used to quantify fracture toughness.
- Early stages of exploring effects of mixed modes I & II loading on fracture toughness in hydrogen charged stainless steels.



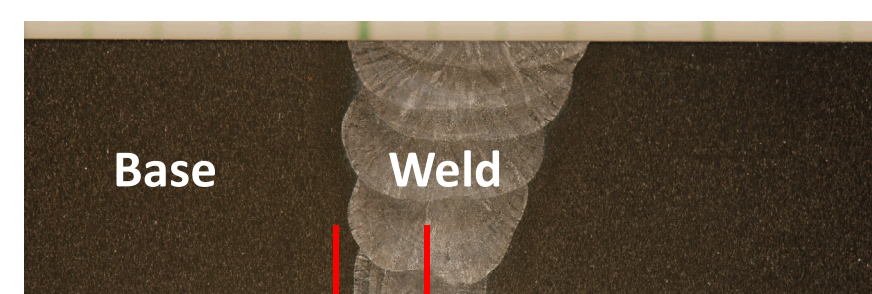
δ - ferrite visible in weld, and enlarged grains visible in HAZ

Loading modes (courtesy of www.nde-ed.org)

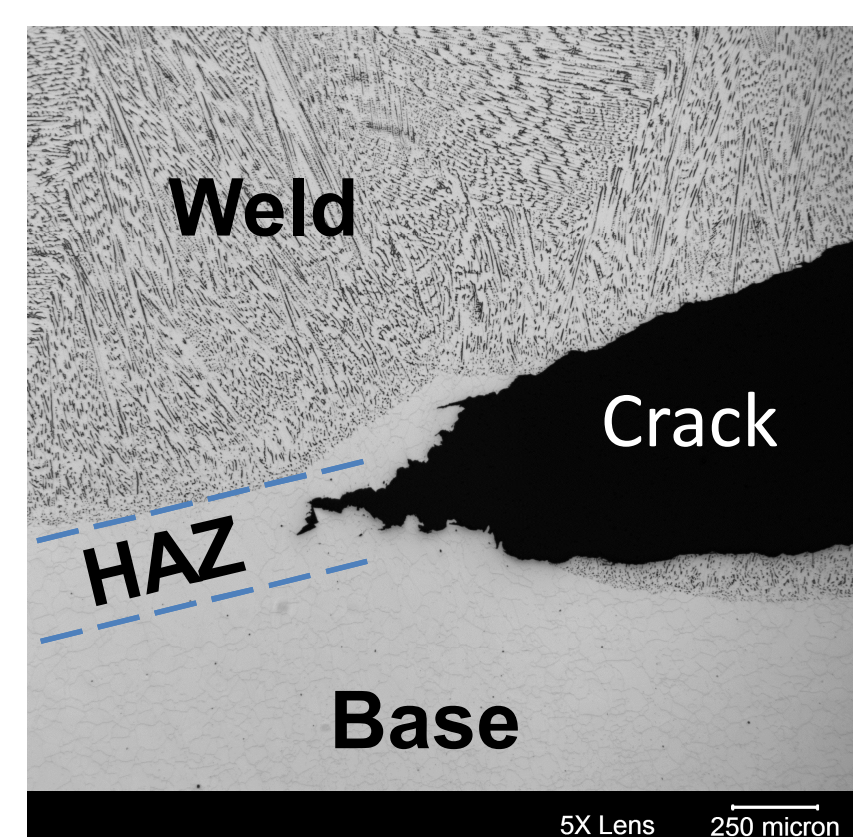


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Experimental Methods



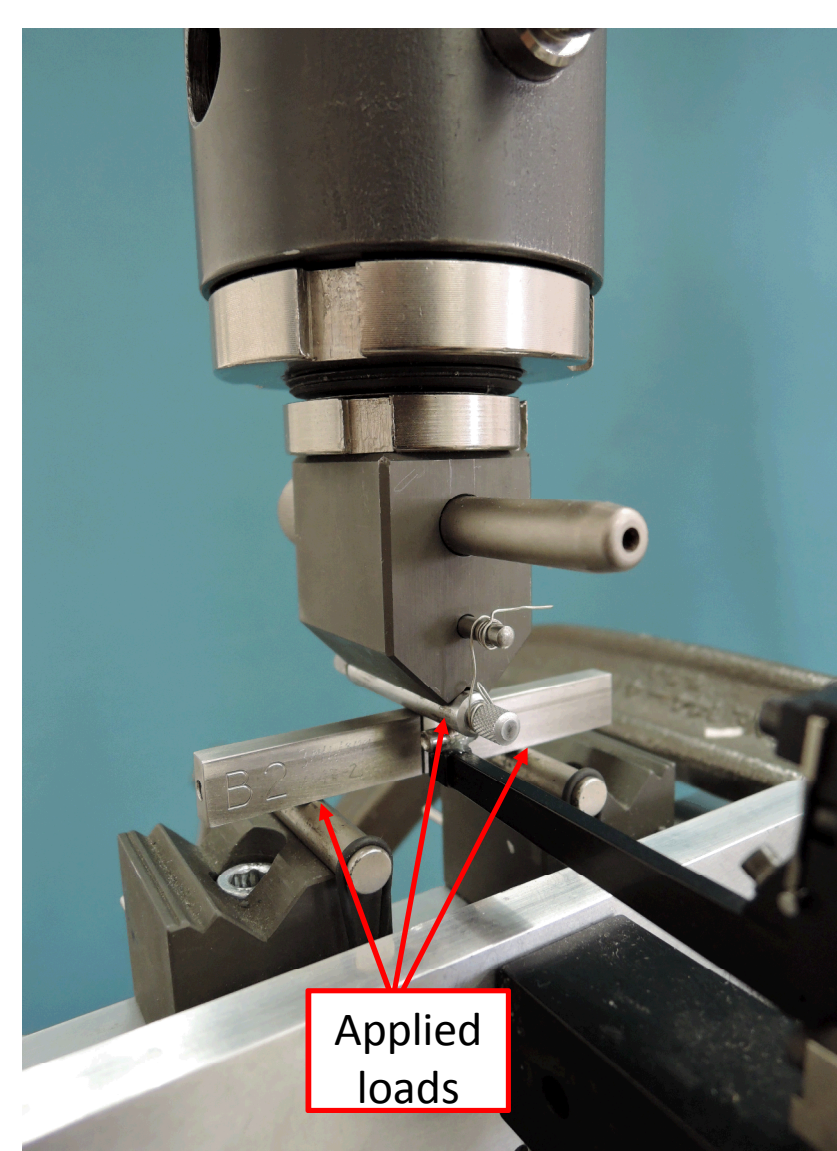
Placement of machined notches on 3PB specimen for HAZ (left) and weld (right) testing



Fatigue precrack and stable crack extension in HAZ



Hydrogen pre-charging: 300°C, 20,000psi, 16 days, resulting in a minimum of 0.8 at% H



3PB test set-up on MTS load frame

Primary GTS Materials

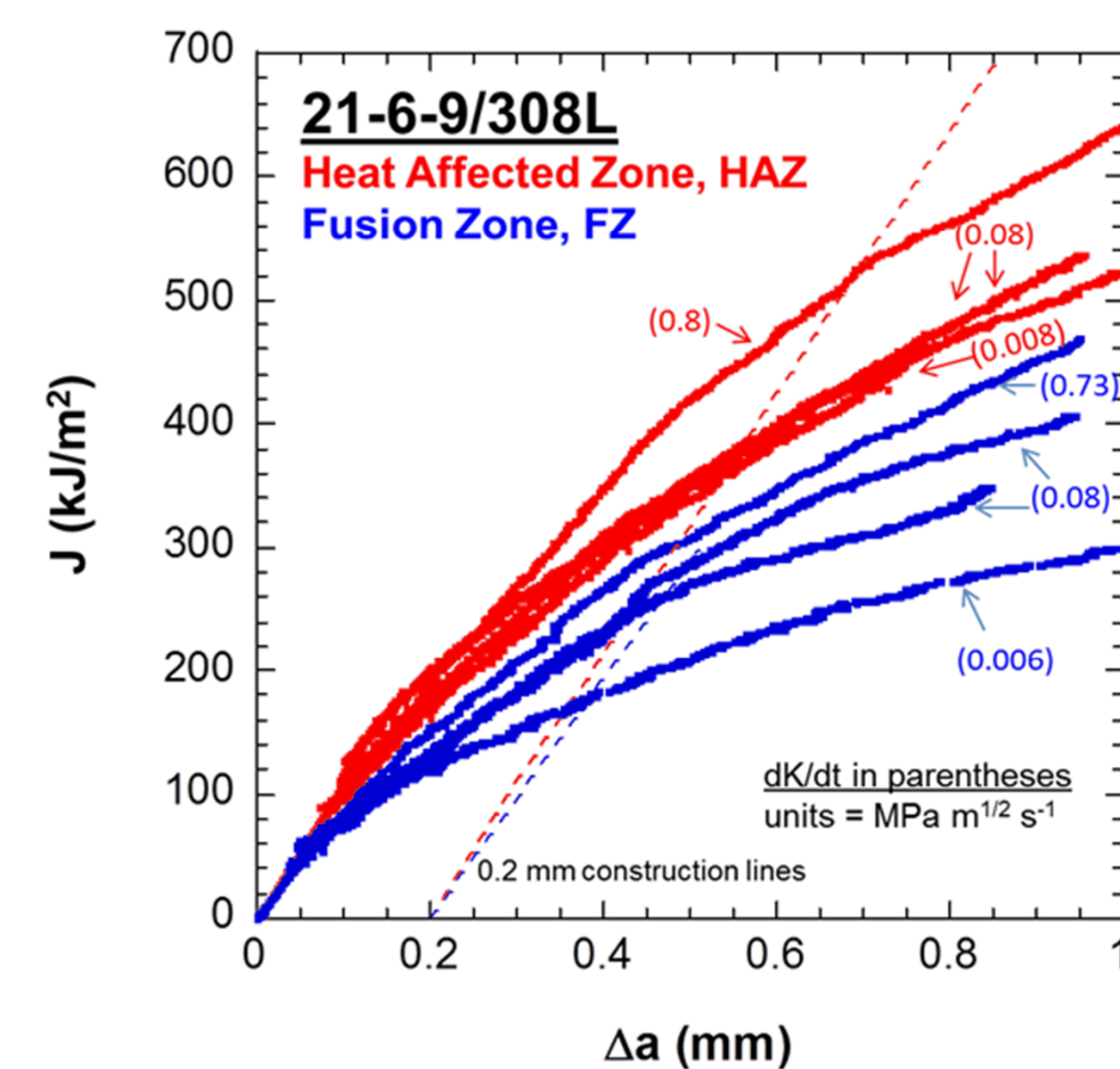
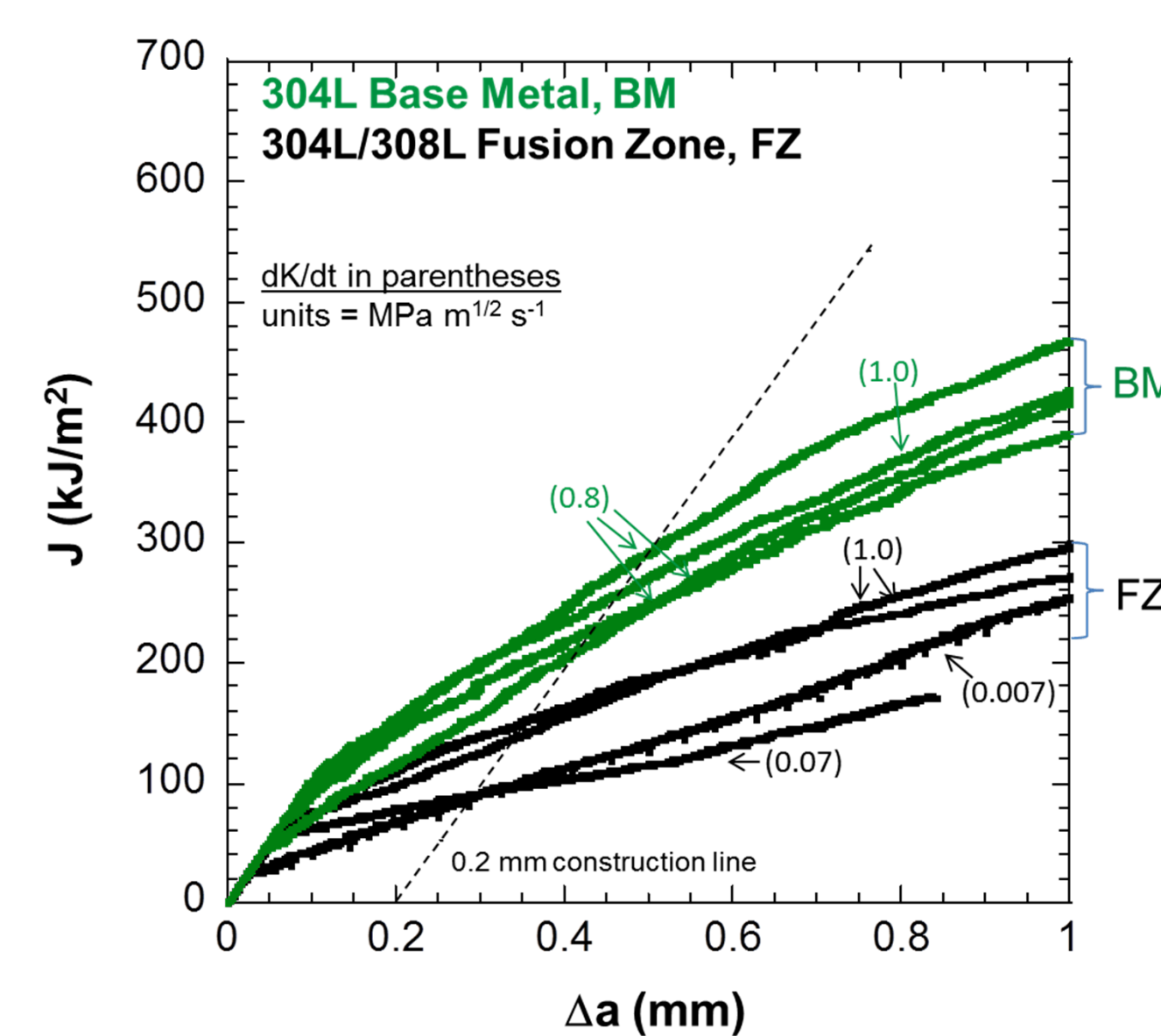
Type	Material	Composition %
Base Metal	21-6-9	21Cr - 6Ni - 9Mn
Base Metal	304L	19Cr - 10Ni - 2Mn
Base Metal	316L	17Cr - 12Ni - 2Mn
Weld	308L	20Cr - 9Ni - 1.5Mn

Results

Evaluation of crack growth resistance:

Weld (fusion zone) exhibits lower fracture toughness and crack growth resistance than base metal.

HAZ exhibits higher fracture toughness and crack growth resistance than base metal.



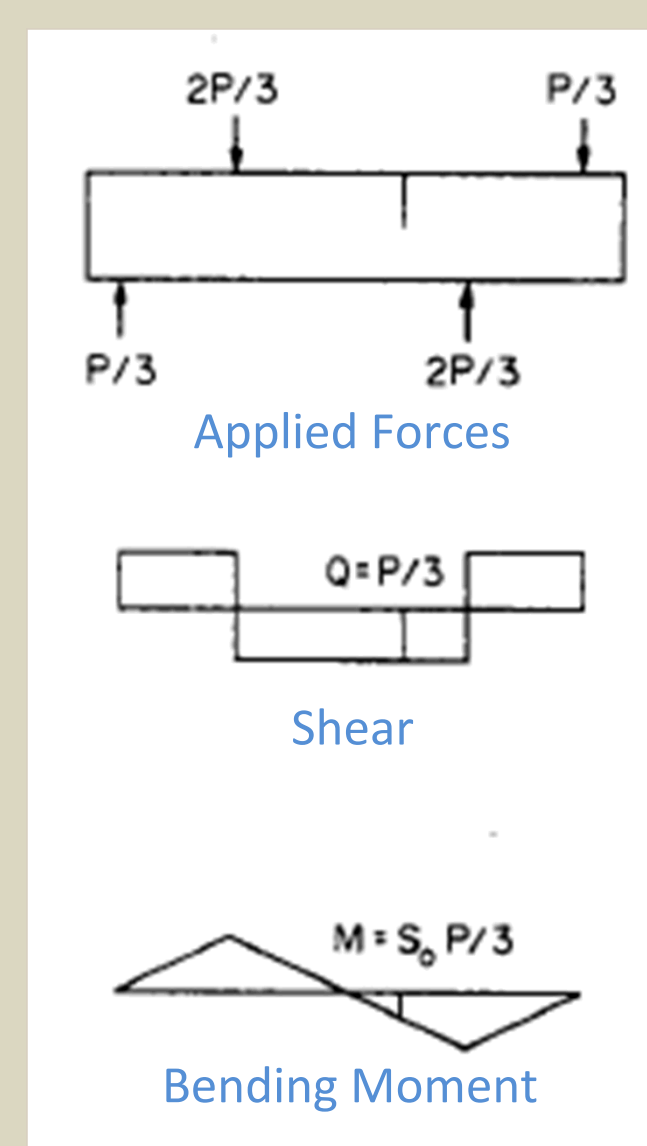
Conclusions to Date

- In H₂ environments, welds exhibit a higher susceptibility to HE, as quantified by lower fracture toughness than both the base metal and the HAZ.
- H-charged HAZ exhibit a higher fracture toughness than the base metal, likely due to the relatively annealed state.
- Determining fracture toughness of metal components is essential to accommodating HE and quantifying safety margins in GTS.

Acknowledgments

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Future Work: Mixed Mode Loading



Asymmetric 4-pt bend schematic (courtesy of Maccagno et al.)

Mixed mode loading simulates the stresses applied to defects in certain GTS, but there is little information on the specific effects of this type of loading on hydrogen embrittled steels.

We hypothesize:

- Lower mode I fracture toughness with increasing mode II loading.
- Exacerbated fracture mechanisms (e.g. increased shearing, less uniform crack front).