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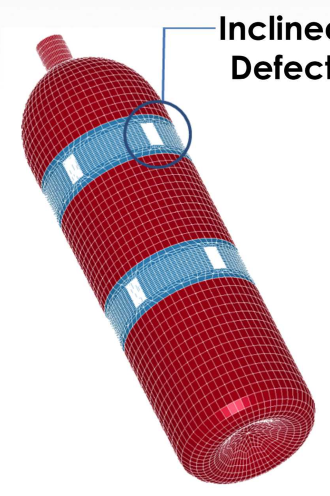
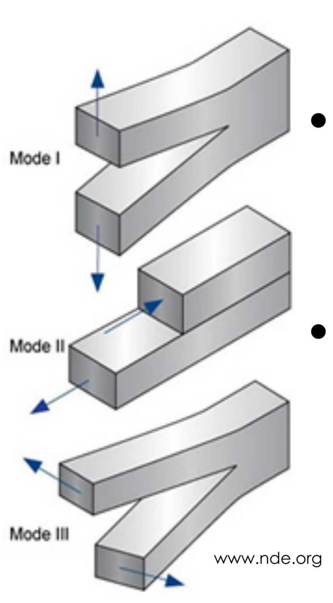
Mixed Mode Fracture Toughness Testing of Hydrogen-Charged 21Cr-6Ni-9Mn Stainless Steel

S.K. Lawrence[1], B.P. Somerday[2], G. Yee[3], D.K. Balch[1]
1. Sandia National Laboratories, Livermore, CA
2. Southwest Research Institute, San Antonio, TX
3. Carnegie Mellon University, Pittsburgh, PA

Mixed Mode Loading

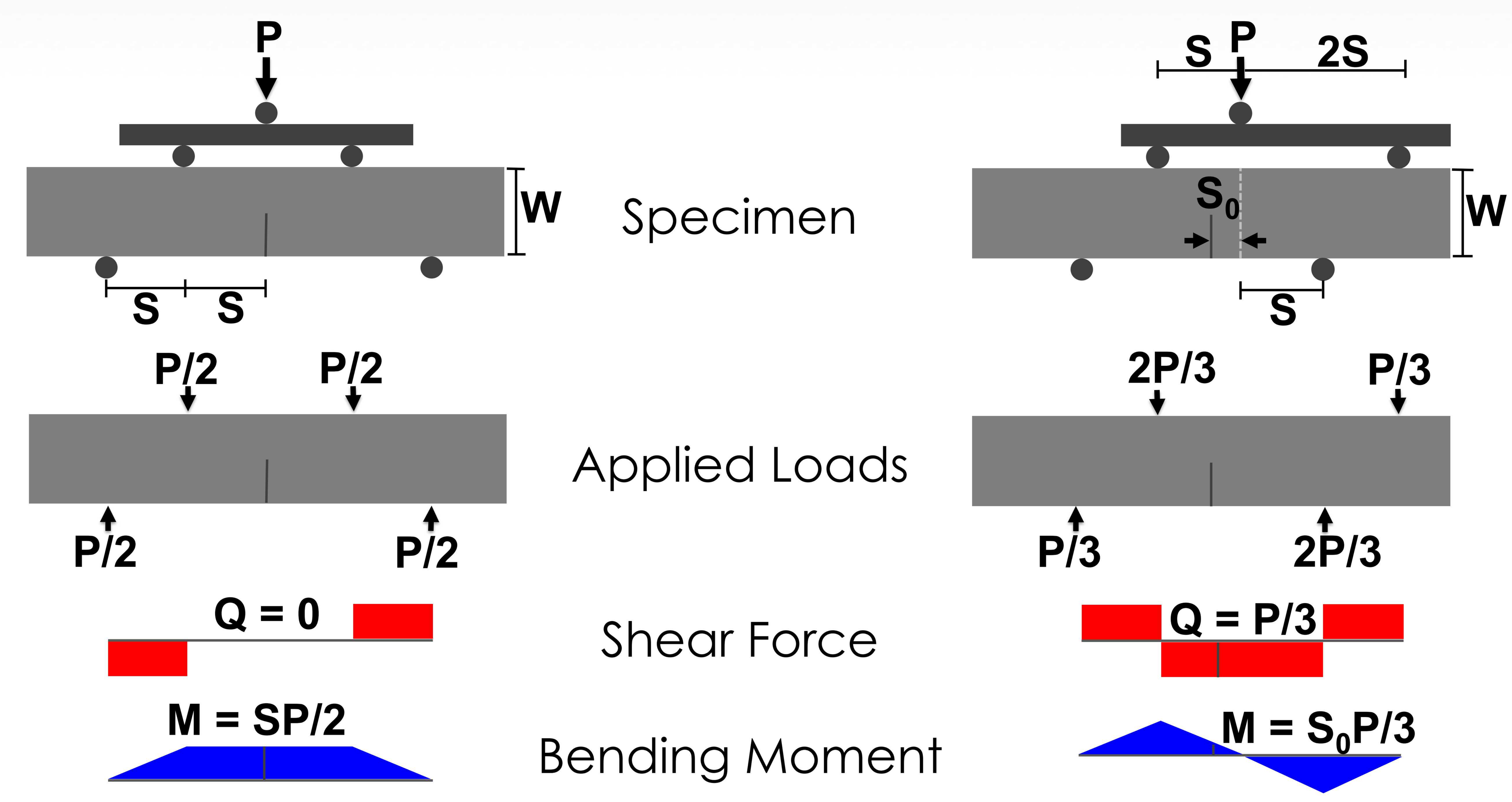
- Defect orientation dictates loading mode-mixity in hydrogen storage & distribution components.



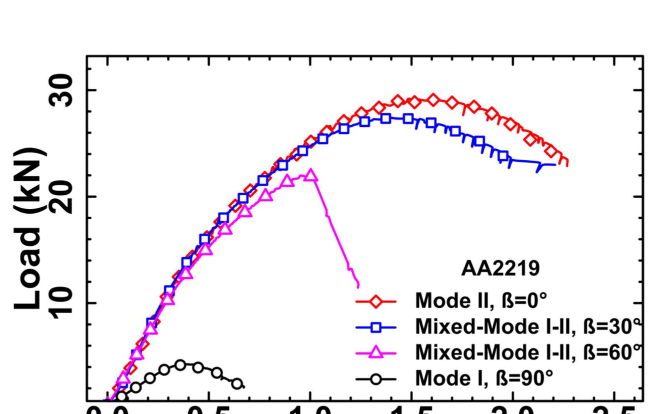


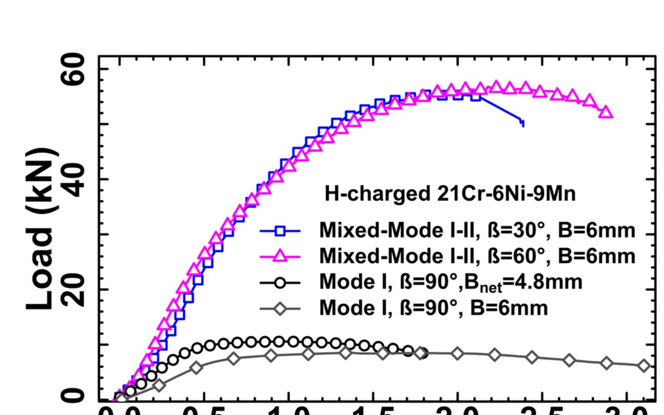
- Mixed Mode I/II is likely in pressure vessels.
- Is Mode I fracture toughness a conservative design metric?

Symmetric Four-Point Bending (S4PB) / Anti-Symmetric Four-Point Bending (AS4PB)



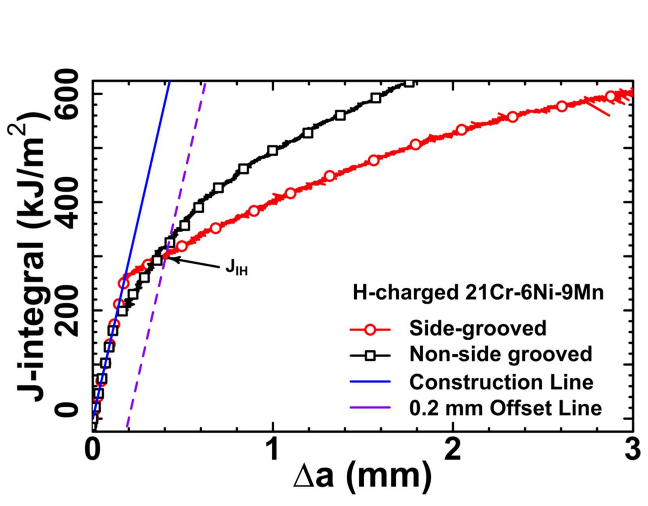
Applied Loads Increase with Mode II/I Ratio





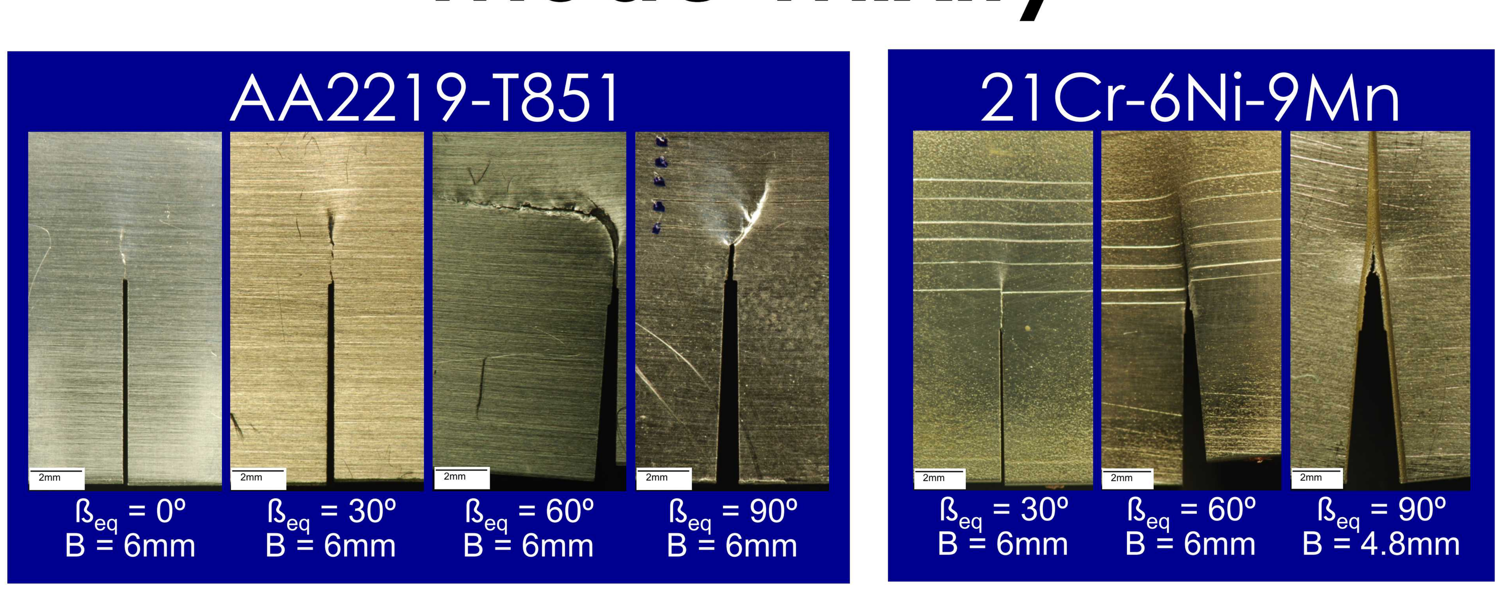
- AA2219-T851 used for test method development
- 5x increase from mode I to 60°; 7x increase to mode II
- Mode II not successful
  - Load limited
- 5x increase from mode I to 60° mixed mode I/II

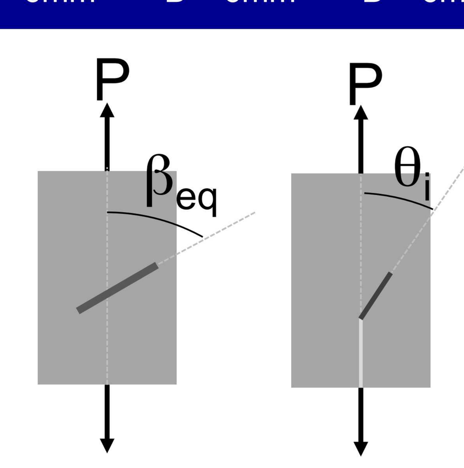
High Mode I Fracture Toughness after Hydrogen Exposure

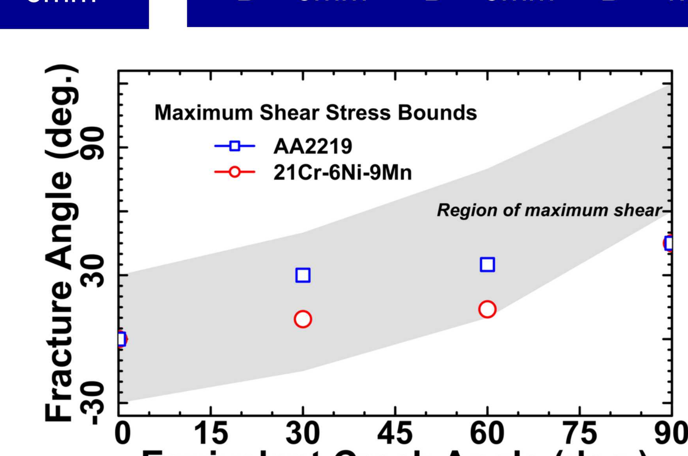


- Thermal charging (138 MPa, 573 K) leads to uniform H concentration, ~200 wt. ppm
- J_{IH} varies from ~295-310 kJ/m², with or without side grooves
- Consistent with values from CT tests in K.A. Nibur et al. *Acta Mater 57 (2009)*

Fracture Angle and Crack Displacements Depend on Mode-Mixity





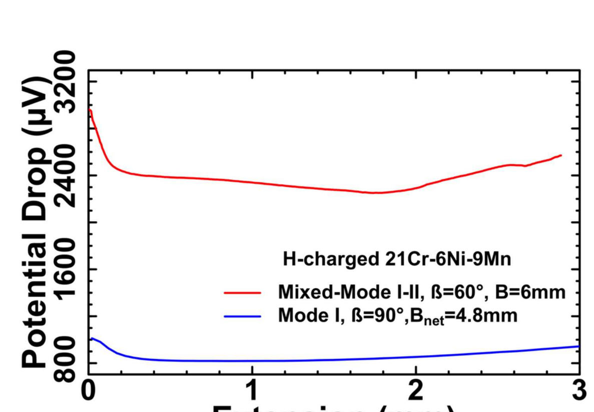


		AA2219-T851			21Cr-6Ni-9Mn		
Location	β_{eq}	δ_I	δ_{II}	θ_i	δ_I	δ_{II}	θ_i
Notch Root	0°	unmeasureable		0°	Not tested		
	30°	0.135	0.085	30°	0.051	0.113	9°
	60°	0.288	0.841	35°	0.414	0.856	14°
	90°	0.281	N/A	45°	1.067	N/A	0° or 45°*

*Non-side grooved specimens form shear lips; side grooves constrain crack front

Challenges

- Bend fixture alignment
- Specimen alignment with respect to fixtures
- Specimen positioning laterally on rollers
- Friction
- Excessive deformation at load points
- Relating crack extension to loading using DCPD



Final Thoughts

- J_{IH} of H-charged 21-6-9 is remarkably high compared with other H-compatible steels.
- Addition of mode II substantially increases load required to extend crack.
- To first order, mode I fracture toughness is a conservative design metric.

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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