Materials Compatibility

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000

Overview

Timeline

- Project start date Oct. 2003
- Project end date Sept. 2015
- Percent complete 50%

Budget

- Total project funding (to date)
  - DOE share: $3.8M
- FY08 Funding: $1.1M
- FY09 Funding: $0.9M

(* R&D core, no IEA contracts)

Barriers & Targets

- Barriers and targets addressed
  - Materials reference guide for design and installation
  - Hydrogen storage tank standards for portable, stationary and vehicular use
  - Insufficient technical data to revise standards

Partners

- Interactions/Collaborations:
  - ASME, CSA, ISO
  - Swagelok, Fibatech
  - DOE Pipeline Working Group
  - HYDROGENIUS (AIST/Kyushu University, Japan)

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Objectives

- Enable development and implementation of codes and standards for H_2 containment components
  - Evaluate data on mechanical properties of materials in H_2 gas
    - "Technical Reference on Hydrogen Compatibility of Materials"
  - Generate new benchmark data on high-priority materials
    - Pressure vessel steels, stainless steels
  - Establish procedures for reliable materials testing
    - Sustained-load cracking, fatigue crack propagation
- Participate directly in standards development
  - Structural design standards
    - ASME Article KD-10
  - Materials testing standards
    - Automotive components

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Milestones

- Add/update chapters on stainless steels and precipitation-strengthened aluminum alloys in Technical Reference (FY08 Q4 and FY09 Q1; complete)
- Complete cracking threshold measurements on Ni-Cr-Mo pressure vessel steel (FY08 Q3; complete)
- Complete fatigue crack growth measurements on Ni-Cr-Mo vessel steel (FY08 Q4; in progress, expected FY09 Q3)
- Evaluate specimen designs for cracking threshold measurements of ferritic steels (FY09 Q2; complete)
- Compare fatigue crack growth data for stainless steels tested in H_2 gas *vs* H-precharged condition (FY09 Q2; in progress, expected FY09 Q4)
- Compare cracking threshold to fracture toughness measurements for vessel steels (FY09 Q3; complete)

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Approach

- Applied research
  - Conduct materials testing to address voids in data base
    - Emphasize high H_2 gas pressures (>100 MPa)
    - Apply test methods in ASME Article KD-10 (i.e., fracture mechanics)
    - Prioritize hydrogen-assisted fatigue crack growth
  - Critically review data to assess test methods
    - Ensure laboratory testing reveals material response for component
    - Evaluate variables that affect materials test methods

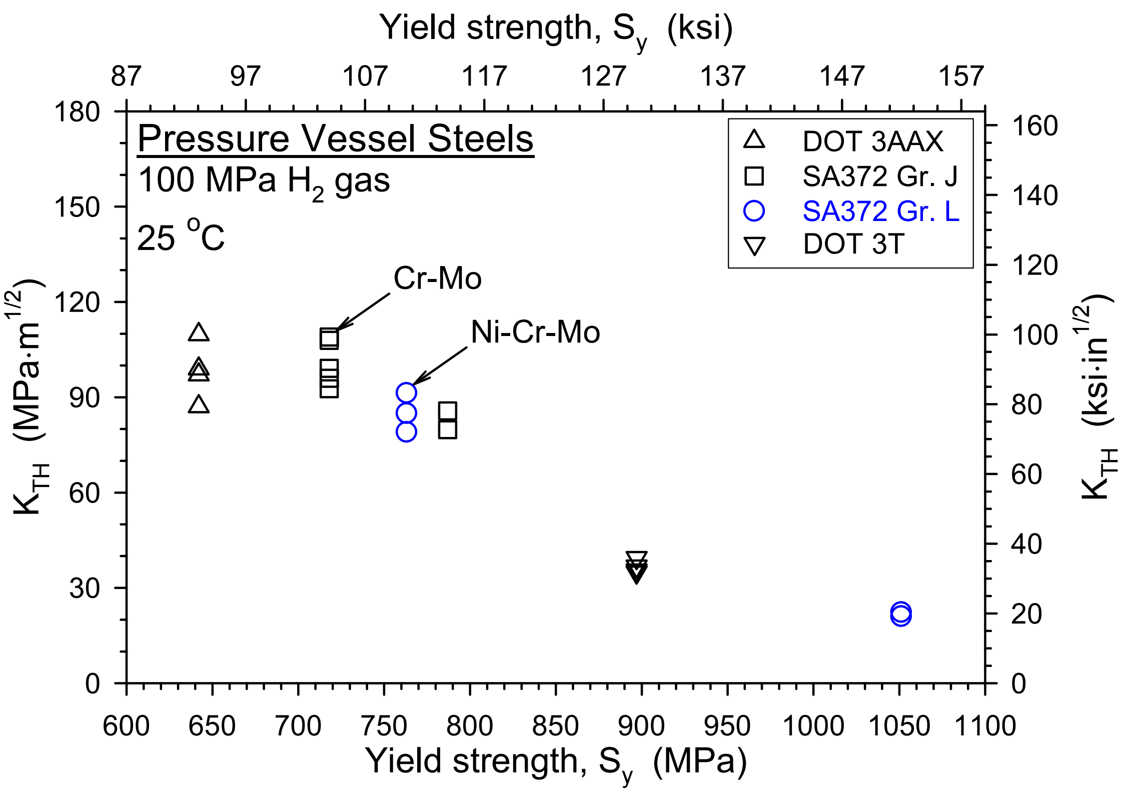
- Standards development activities
  - Provide feedback on ASME Article KD-10 based on results from materials testing
  - Develop ideas for materials testing standards applied to automotive components

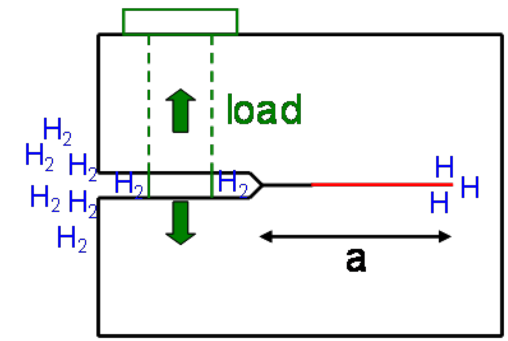
Technical Reference for Hydrogen Compatibility of Materials

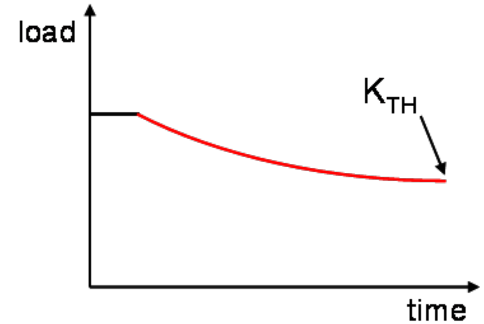
- Additional/updated chapters in FY08-FY09
  - “Stabilized” austenitic stainless steels (i.e., 321 and 347)
  - Duplex stainless steels (updated with Sandia data)
  - Precipitation-strengthened aluminum (2xxx and 7xxx)
- Future chapters
  - Nickel alloys
  - Update chapters on ferritic steels with Sandia data
- www.ca.sandia.gov/matlsTechRef

Stakeholders (industry, SDOs, etc.) provide input on priority materials and receive completed products

Measurement of thresholds (K_{TH}) for Ni-Cr-Mo steels completed







- K_{TH} measurements required in ASME Article KD-10
- Lower-strength variation of SA372 Gr. L may be attractive for thick-walled H_2 pressure vessels

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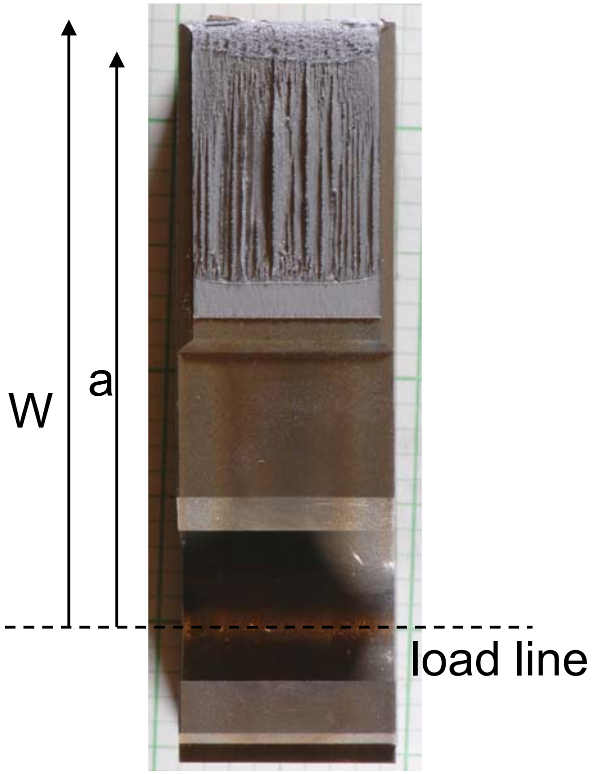
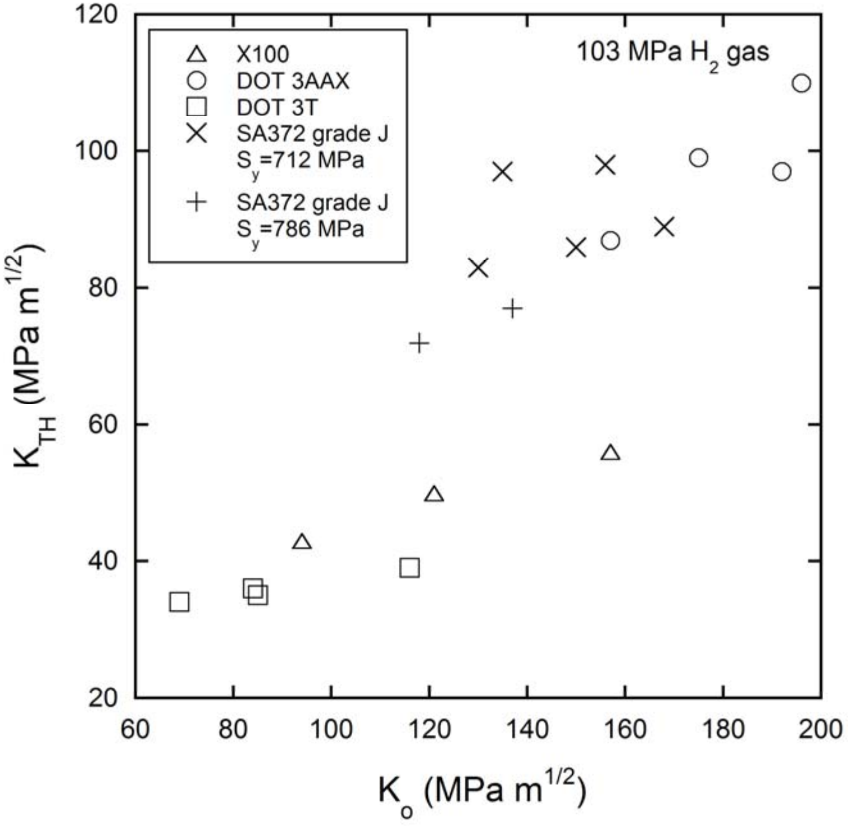
Unexpected K_{TH} trend may be influenced by specimen features

Long cracks (large a/W) result from high initial load (K_o)

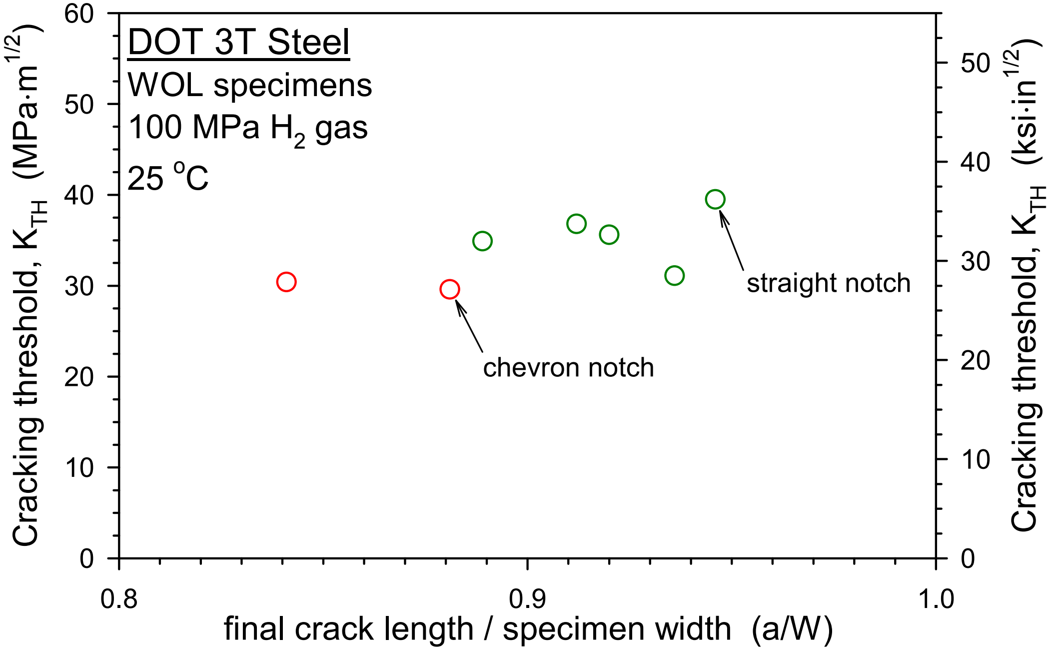


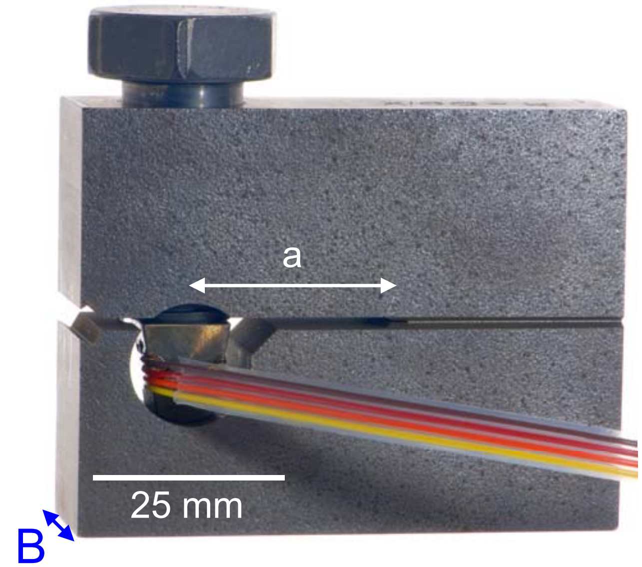
K_{TH} not independent of K_o

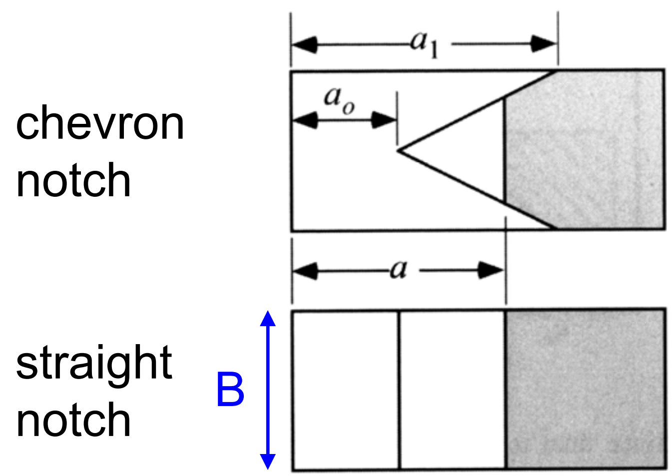


K_{TH} values must represent reliable lower bounds to ensure safe design of H_2 containment vessels

Modified specimen may yield lower K_{TH} values







Chevron notch allows shorter initial crack lengths (a_o), leading to crack arrest further from back face

From: Anderson, T.L. 2005, *Fracture Mechanics*, 3rd edition, Taylor and Francis p.379

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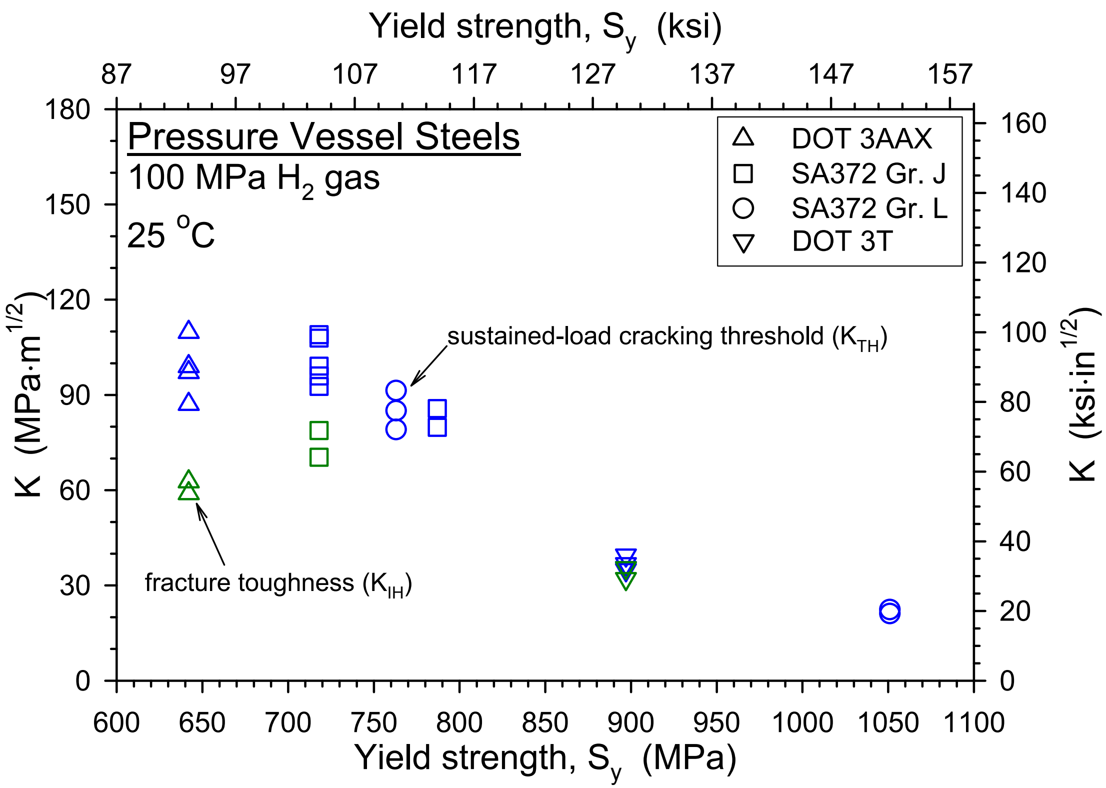
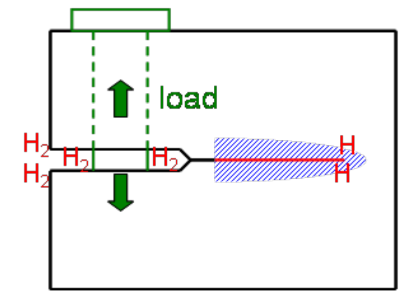
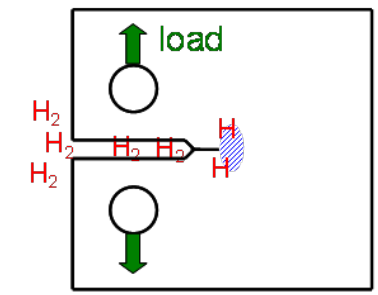
Two test methods compared: “crack arrest” *vs* “crack initiation”



Measures K_{TH} at crack arrest



Measures K_{IH} at crack initiation



- Materials testing prescribed in ASME Article KD-10 (i.e., K_{TH} measurements) appears non-conservative
- Results will be presented to ASME Project Team on Hydrogen Tanks

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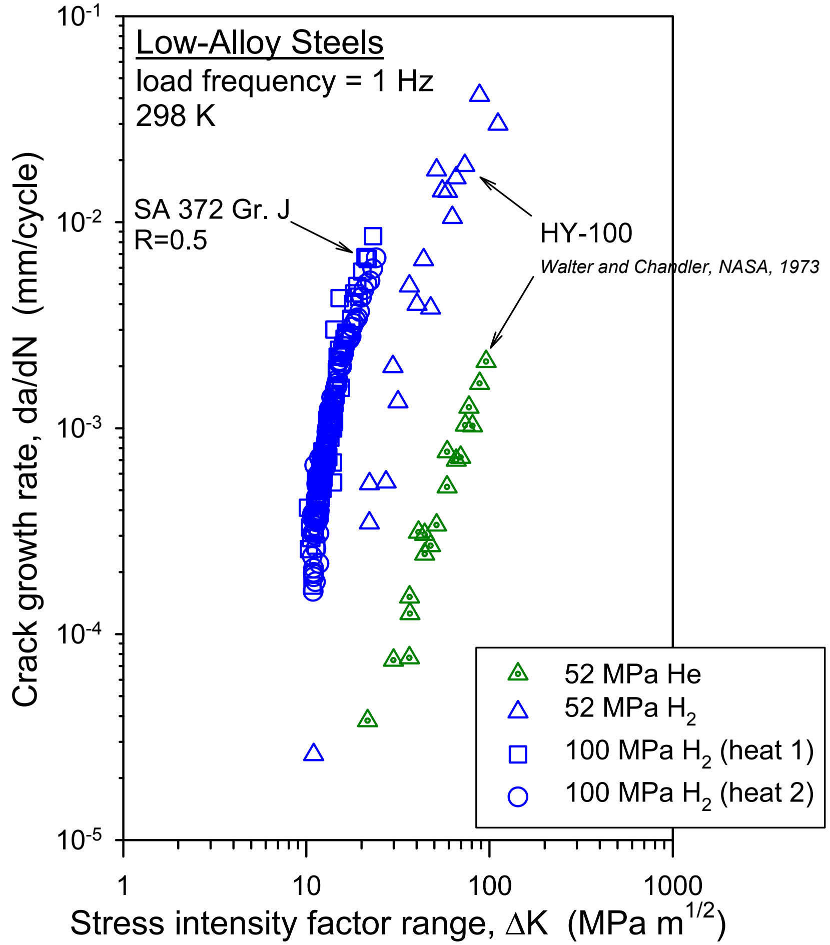
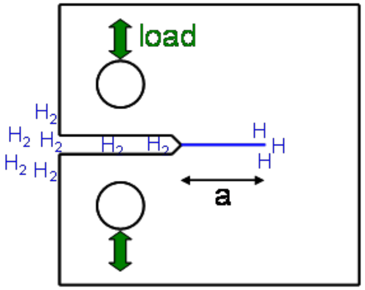
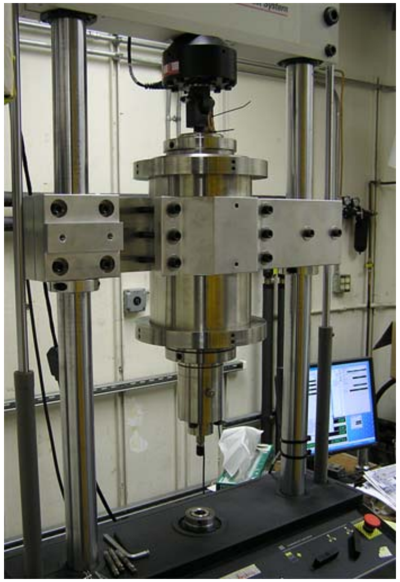
Fatigue crack growth measurements on vessel steel

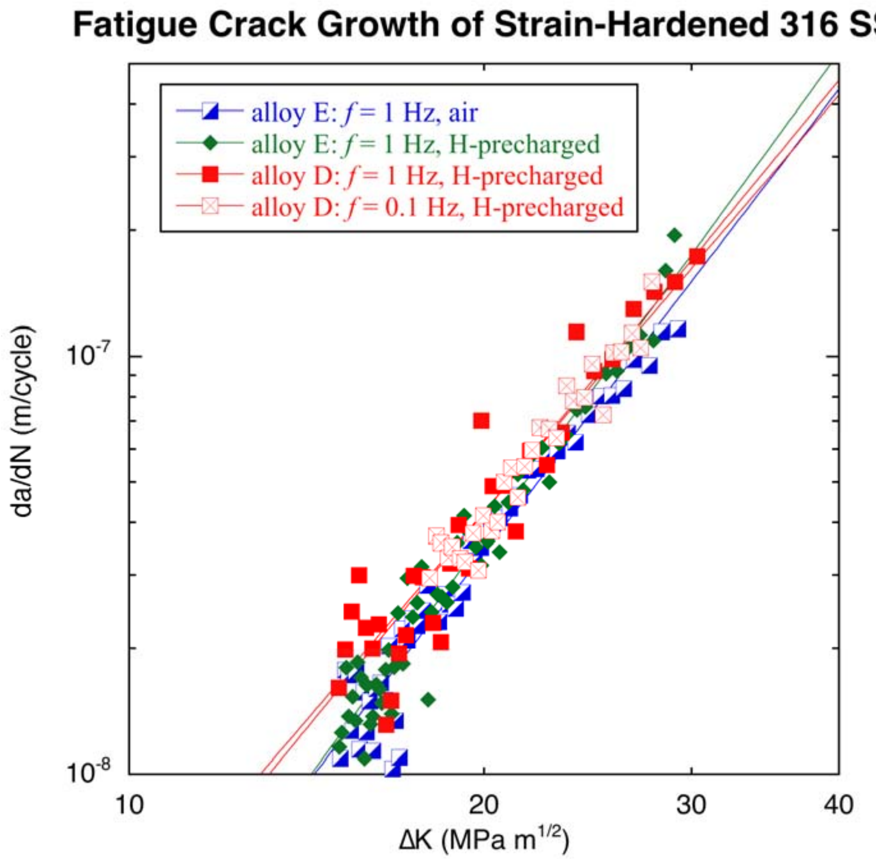




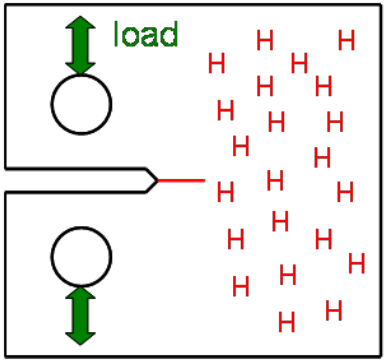


Industry partner using fatigue data to design H_2 pressure vessel according to ASME Article KD-10

Fatigue crack growth measurements on stainless steel



Alloy D: 12% Ni
Alloy E: 13% Ni



~140 wppm hydrogen

Materials testing standards must address effect of load cycle frequency on fatigue cracking rates

Future Work

Remainder of FY09

- Add/update Technical Reference chapters on nickel-based alloys and ferritic steels (Q3 and Q4 milestones)
- Evaluate the effects of load cycle frequency on fatigue crack growth rate of ferritic steels in H_2 gas (Q3 milestone)
- Compare fatigue crack growth data for stainless steels tested in H_2 gas *vs* H-precharged condition (Q2 milestone in progress)
- Develop reliable methods for measuring fracture response of aluminum alloys in H_2 gas (Q4 milestone)
- Engage domestic and international stakeholders to develop standards for pressure manifold components (i.e., fittings, regulators, etc.)

FY10

- Update Technical Reference chapters with Sandia data
- Evaluate effects of load cycle wave form on fatigue testing in H_2 gas
- Develop high- and low-cycle fatigue test methods for manifold component materials in H_2 gas

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Summary

- Completed measurement of cracking thresholds (K_{TH}) for Ni-Cr-Mo pressure vessel steels in high-pressure H_2 gas
  - K_{TH} measurements required in ASME Article KD-10
- “Crack arrest” test methods appear to yield non-conservative results compared to “crack initiation” test methods
  - Proposal to insert “crack initiation” test methods in Article KD-10 will be presented to ASME Project Team on Hydrogen Tanks
  - “Crack initiation” methods require test apparatus designed for dynamic loading of specimens in H_2 gas
- Demonstrated ability to measure fatigue crack growth of pressure vessel steels in high-pressure H_2 gas
  - Fatigue crack growth data in H_2 required in ASME Article KD-10
  - Test apparatus is one of few in U.S. or abroad for measuring fatigue crack growth in >100 MPa H_2 gas

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