DOE Hydrogen Program

Materials Compatibility

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Project ID # SCS2

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Overview

Timeline

- Project start date Oct. 2003
- Project end date Sept. 2015
- Percent complete 42%

Budget

- Total project funding (to date)
  - DOE share: $2.9M
- FY07 Funding: $0.9M
- FY08 Funding: $1.1M

(* 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

- Collaborators:
  - ASME, CSA
  - Swagelok, Fibatech
  - NIST
  - DOE Pipeline Working Group

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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
- Participate directly in standards development
  - Component design standards
    - ASME Article KD-10
  - Materials testing standards
    - Automotive components

Milestones

- Complete Technical Reference chapters on polymers and martensitic stainless steels (FY07 Q4 and FY08 Q2; complete)
- Complete crack growth threshold measurements of SA 372 Gr. J, DOT 3T, and DOT 3AAX pressure vessel steels (FY07 Q4; complete)
- Complete acquisition and installation of capability for measuring fatigue crack growth in high-pressure H_2 (FY07 Q3; in progress, expected FY08 Q3)
- Fatigue crack growth testing of 316 stainless steel in collaboration with industrial partner (FY08 Q2; in progress, expected FY08 Q4)

Approach

- Applied research
  - Measure fracture resistance of materials emphasizing:
    - Exposure to high hydrogen gas pressures (>100 MPa)
    - Fracture mechanics methods
    - Material fabrication and service variables (e.g., welds, temperature)
  - Critically review data to assess test methods
    - Ensure measurements reflect lower-bound fracture properties
    - Evaluate how data enable structural design

- 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 on Hydrogen Compatibility of Materials

- Created Sandia report consisting of first 14 chapters
  - Available on web site (www.ca.sandia.gov/matlsTechRef)
- New chapters in FY07-FY08
  - Martensitic stainless steels (e.g., 400 series)
  - Precipitation-hardening martensitic stainless steels (e.g., 17-4 PH)
  - Semi-austenitic stainless steels (e.g., 17-7 PH)
  - Polymers
- Future chapters
  - 310 and 321 stainless steels
  - Precipitation-hardening aluminum
  - Nickel alloys

Technical Reference report distributed to industrial gas, automotive, SDO stakeholders

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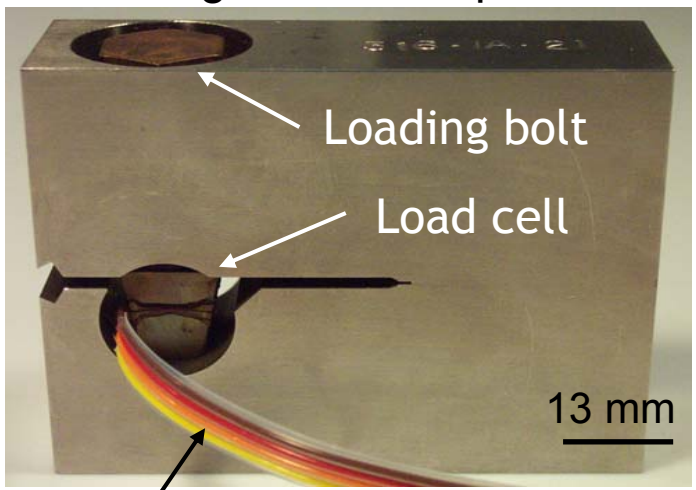
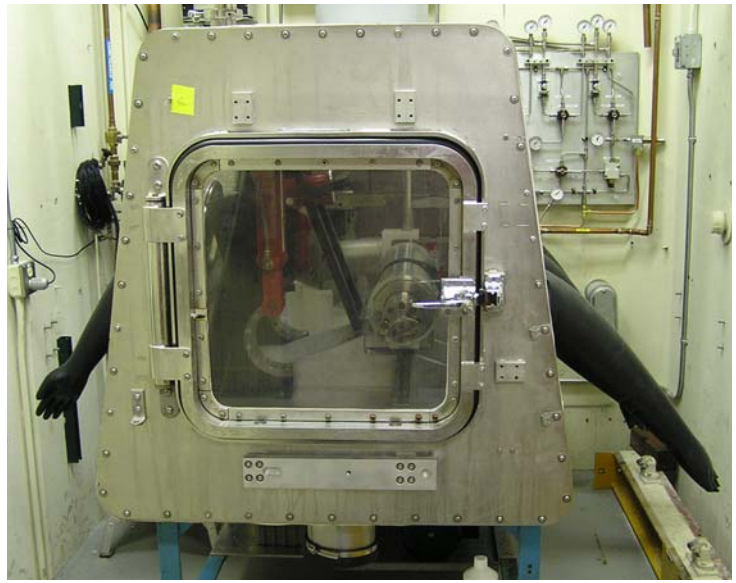
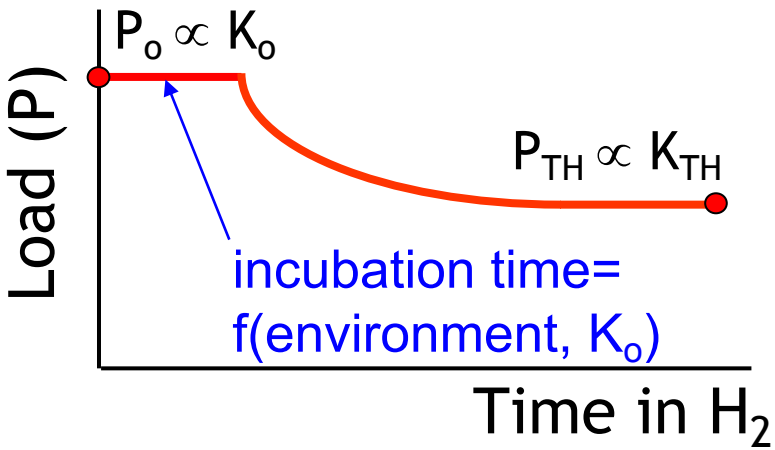
Measurement of sustained-load cracking thresholds in steels

wedge opening load (WOL) cracking threshold specimen







- Specimen loaded to $K_o > K_{TH}$ using bolt while contained in glove box
- Loaded specimen exposed to H_2, crack extends after incubation time
- Generate benchmark data for SA 372 Gr. J, DOT 3AAX, DOT3T

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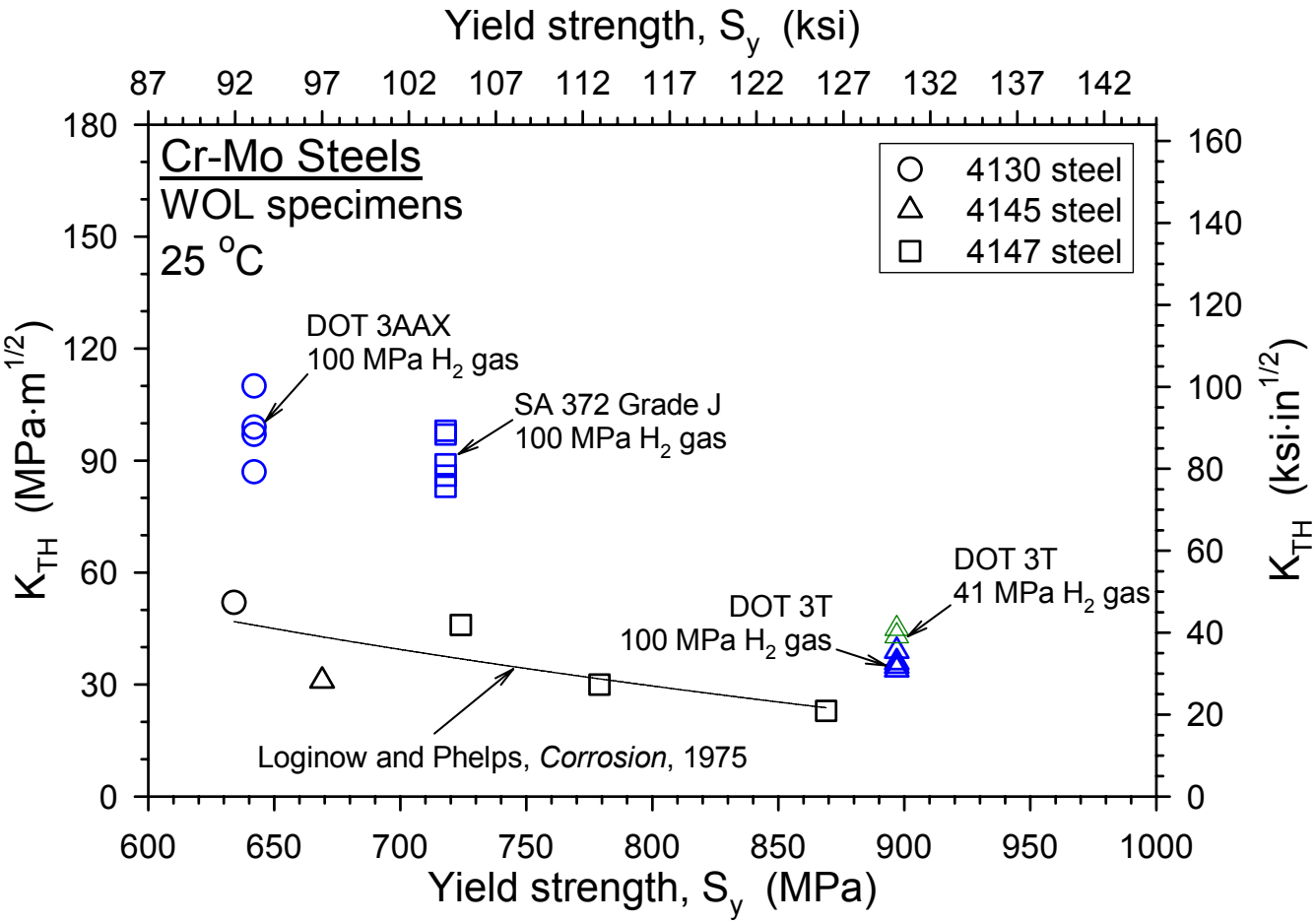
Measurement of thresholds (K_{TH}) for Cr-Mo steels completed



K_{TH} values serve as benchmark data for implementing design standards such as ASME Article KD-10

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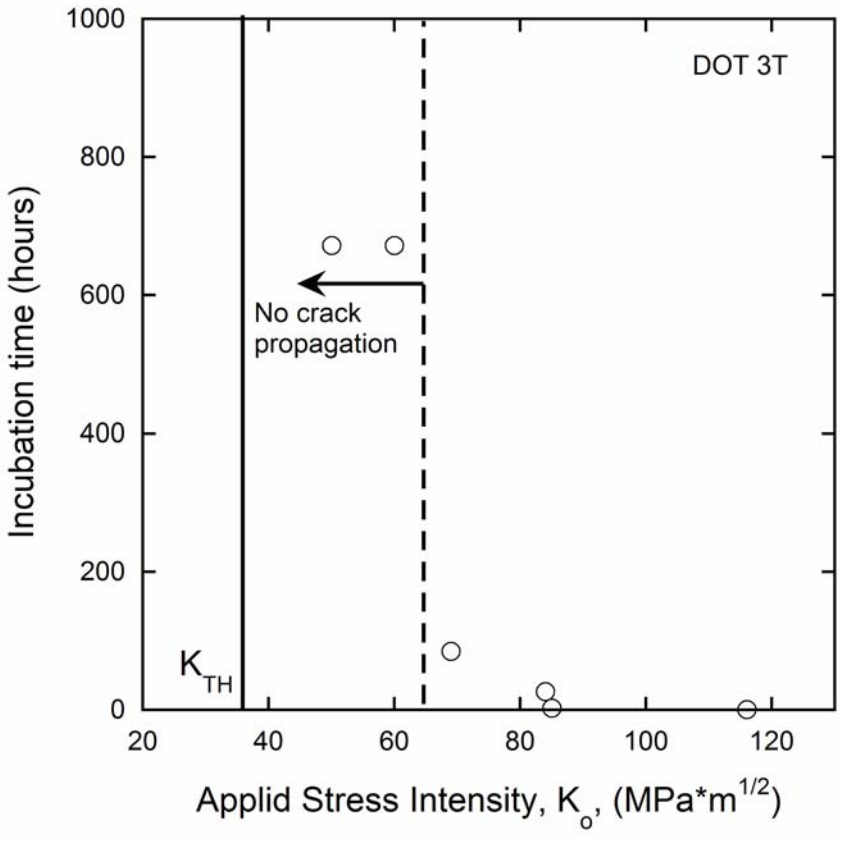
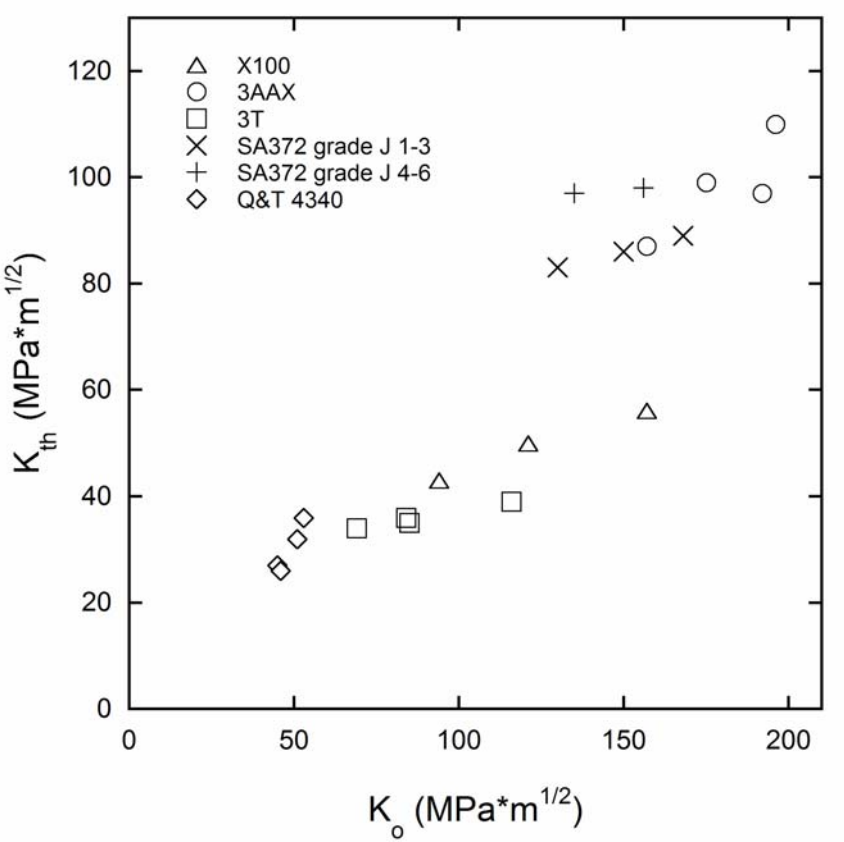
Data trends indicate procedures require further examination

Issue: crack branching?



Issue: long cracks?



Must demonstrate that procedures allow measurement of lower-bound properties

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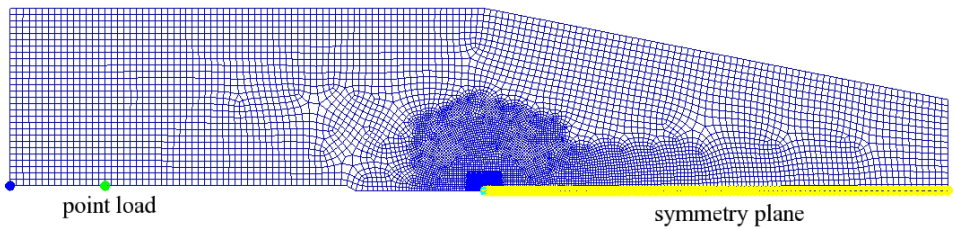
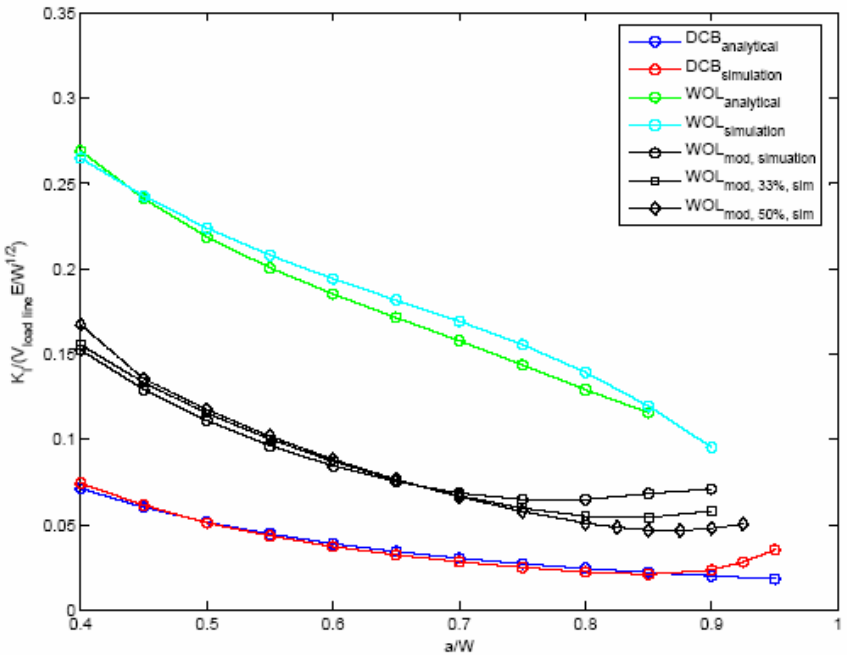
New specimen designed to validate K_{TH} measurements

Modified specimen designed using finite-element modeling



Normalized stress-intensity factor (K) *vs* crack length (a) relationship for modified specimen



Results from testing modified specimen will provide feedback on procedures in ASME Article KD-10

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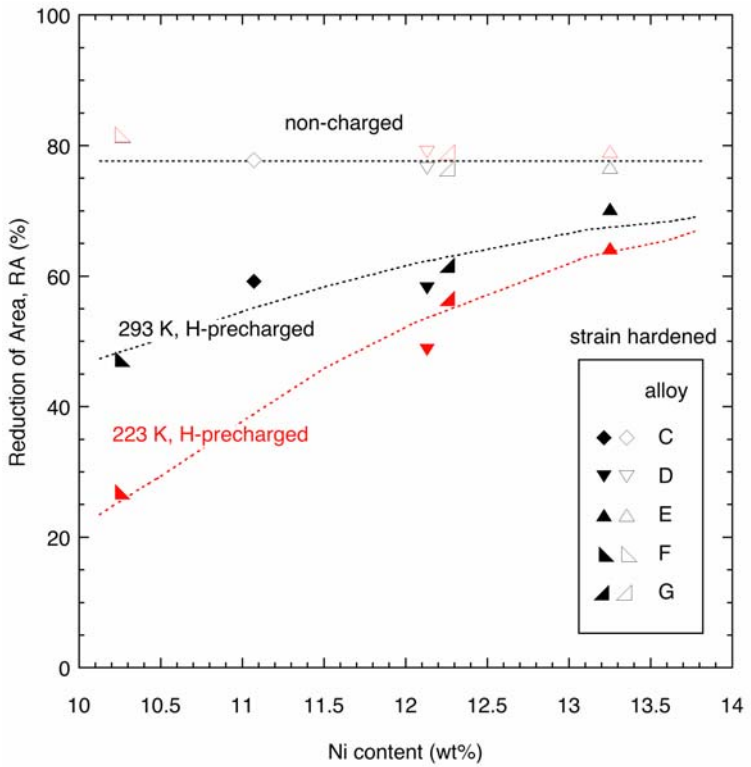
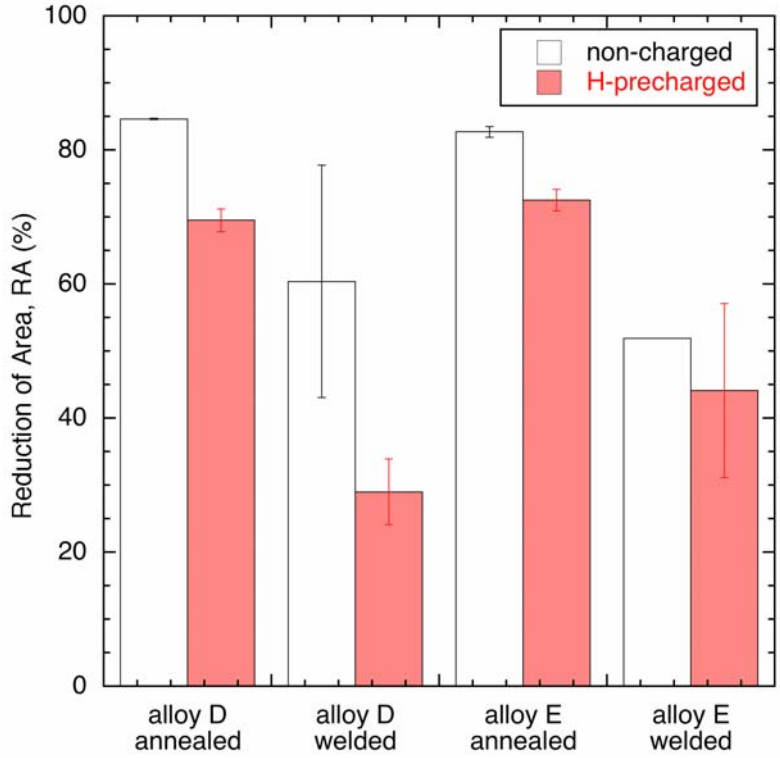
Evaluation of fabrication and service variables for 316 SS

316 stainless steels with ~140 wppm hydrogen





Issue: defects in welds

Benchmark data motivated by needs of stakeholders (e.g., ASME, industrial gas, automotive)

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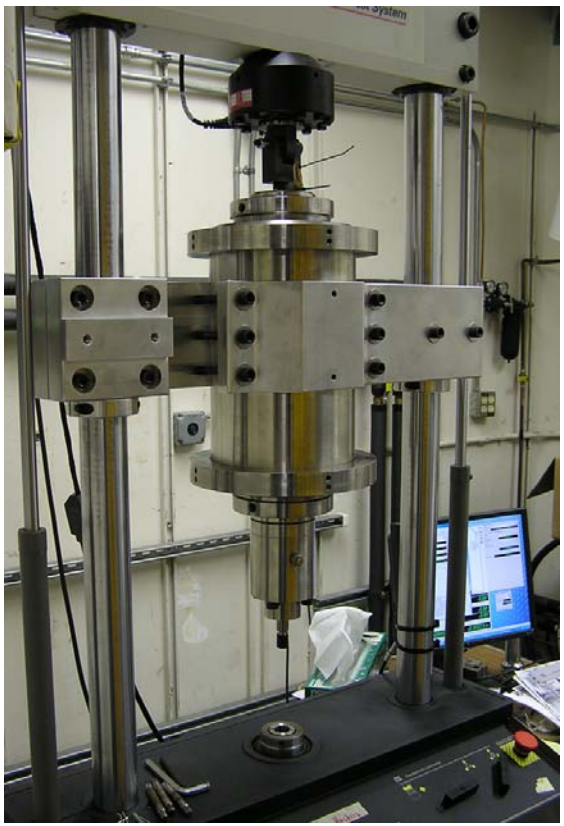
Design of system for fatigue crack growth tests in high-pressure H_2

vessel on mechanical test frame



- Pressure vessel designed to contain H_2 gas up to 20 kpsi (138 MPa)
  - Only two other known similar systems: Japan and UK
- Challenges in testing and system design
  - Leak rates at dynamic seals
  - Accurate load measurement
  - Effect of high-pressure H_2 gas on instrumentation
- Materials data serve as inputs for design method in ASME Article KD-10

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Future Work

Remainder of FY08

- Compose Technical Reference chapters on 310 and 321 stainless steels
- Measure cracking thresholds of Ni-Cr-Mo pressure vessel steel in 100 MPa H_2 gas
- Measure fatigue crack growth rates of 316 stainless steels containing thermally precharged hydrogen
- Measure fatigue crack growth rates of Cr-Mo and Ni-Cr-Mo pressure vessel steels in 100 MPa H_2 gas

FY09

- Compose Technical Reference chapters on precipitation-hardening aluminum and nickel alloys
- Emphasize fatigue crack growth rate testing
- Include aluminum alloys in materials testing

Summary

- Completed measurements of cracking thresholds for SA 372 Gr. J, DOT 3T, and DOT 3AAX steels in high-pressure H_2
  - K_{TH} values serve as benchmark data for implementing design standards such as ASME Article KD-10
- Unexpected dependence of K_{TH} on initial stress level (i.e., K_o) prompted review of testing procedures
  - Must demonstrate that testing procedures allow measurement of lower-bound properties
  - Designed modified specimen to validate measurements
- Evaluated effects of fabrication and service variables on hydrogen-assisted fracture in 316 stainless steel
  - Benchmark data for welds motivated by needs of stakeholders