Hydrogen Embrittlement of Structural Steels

Brian Somerday

Sandia National Laboratories

June 9, 2010

Project ID # PD025

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Overview

Timeline

- Project start date Jan. 2007
- Project end date Sept. 2015
- Percent complete 40%

Budget

- Total project funding (to date)
  - DOE share: $700K
- FY09 Funding: $150K
- FY10 Funding: $150K

Barriers & Targets

- Pipeline Reliability/Integrity
- Safety, Codes and Standards, Permitting
- High Capital Cost and Hydrogen Embrittlement of Pipelines

Partners

- DOE Pipeline Working Group
  - Federal Labs: Sandia, Oak Ridge, Savannah River, NIST
  - Universities: Univ. of Illinois
  - Industry: Secat, industrial gas companies
  - Standards Development Organizations: ASME

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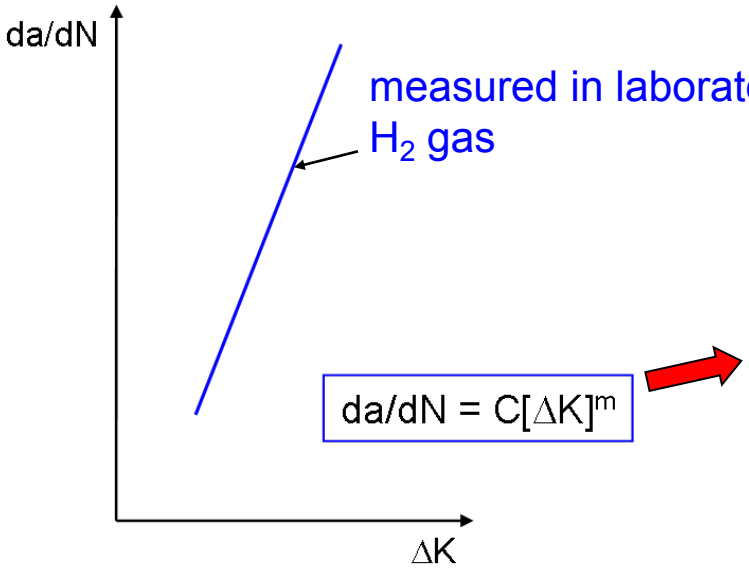
Objectives/Relevance

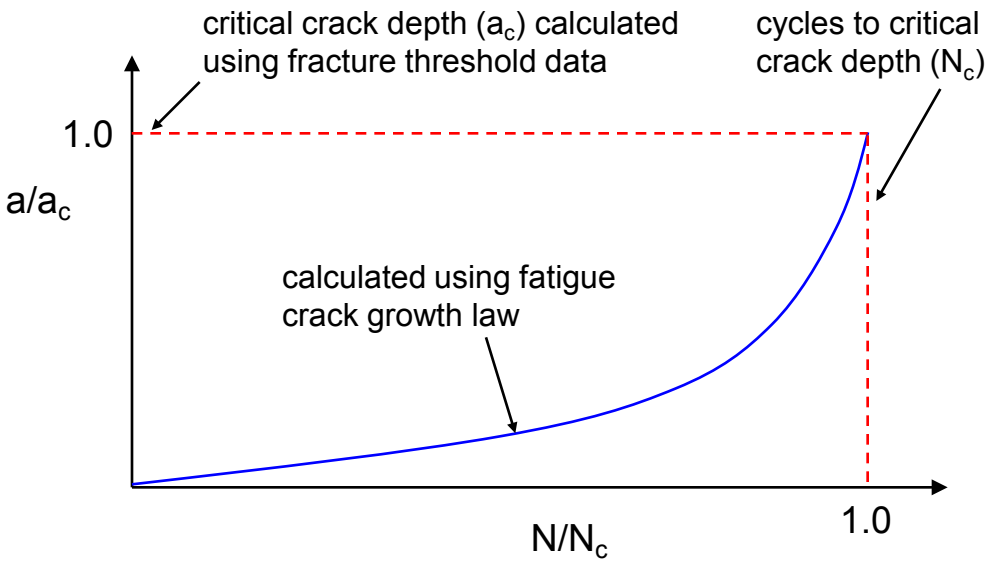
- Why steel hydrogen pipelines?
  - Safety of steel pipelines well established (e.g., third-party damage tolerance)
  - Hydrogen pipelines safely operated under *static pressure*
- Demonstrate reliability/integrity of steel hydrogen pipelines for *cyclic pressure*
  - Address potential fatigue crack growth aided by hydrogen embrittlement
- Enable pipeline design that accommodates hydrogen embrittlement
  - Apply and optimize H_2 pipeline design code ASME B31.12
    - Emphasis in FY09-FY10 on measuring fracture thresholds and fatigue crack growth laws for X52 steel in H_2 gas

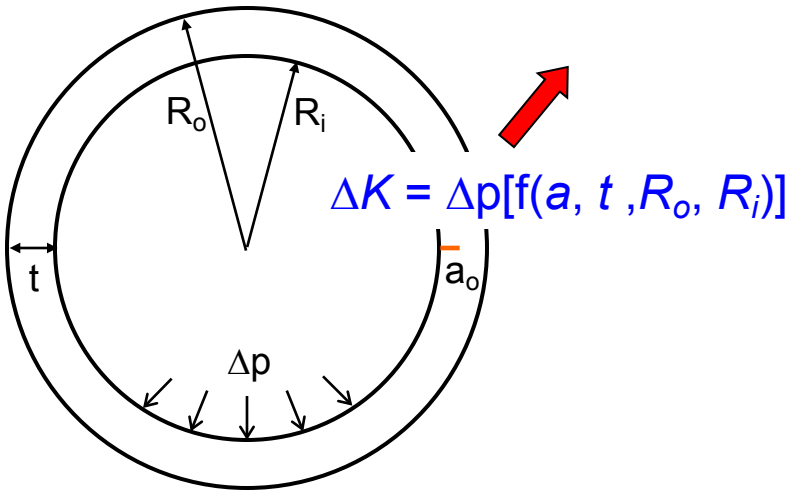
Approach

- Exploit unique capability for measuring fracture properties of steels in high-pressure H_2
  - Fracture properties serve as inputs into reliability/integrity assessment as specified in ASME B31.12 pipeline code
  - Milestone: Measure fatigue crack growth laws for X52 steel as function of loading frequency (75% complete)
  - Milestone: Measure fracture threshold for X52 steel as function of displacement rate (20% complete)
- Improve efficiency and reliability of test methods for steels in high-pressure H_2
  - Provide feedback to standards development organizations (e.g., ASME) through DOE Pipeline Working Group

Reliability/integrity assessment framework in ASME B31.12 requires fracture data in H_2







- Two fracture properties in H_2 needed
  - Fatigue crack growth law
  - Fracture threshold
- Reliability/assessment framework accommodates H_2 embrittlement

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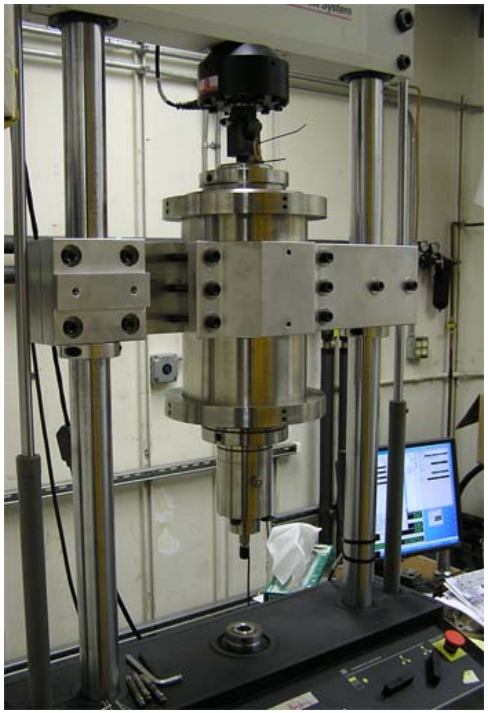
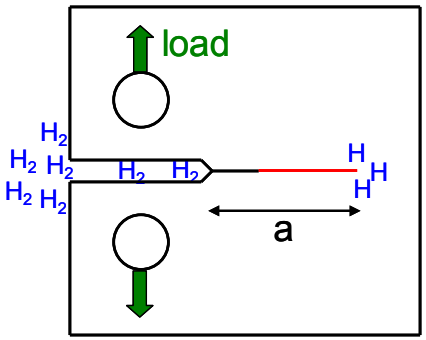
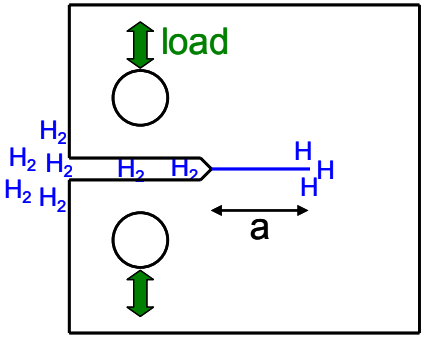
Fracture data in H_2 measured using specialized laboratory capability

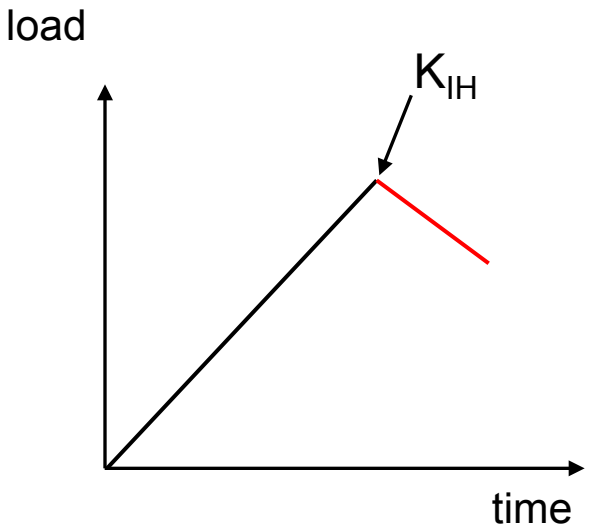


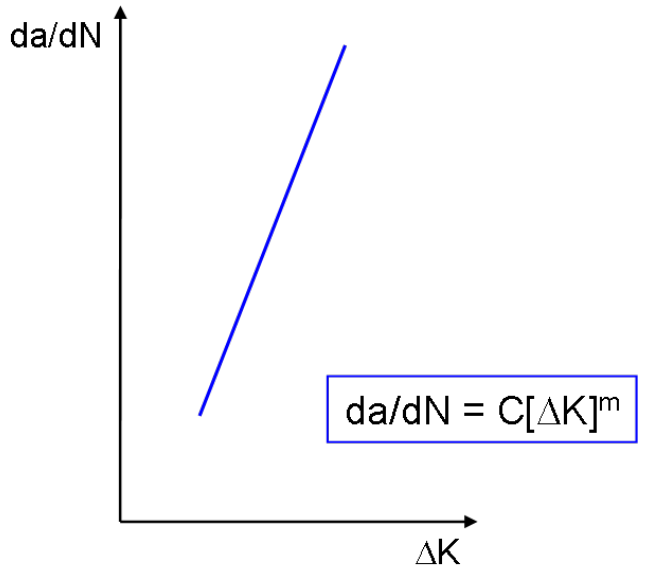
Fracture threshold



Fatigue crack growth







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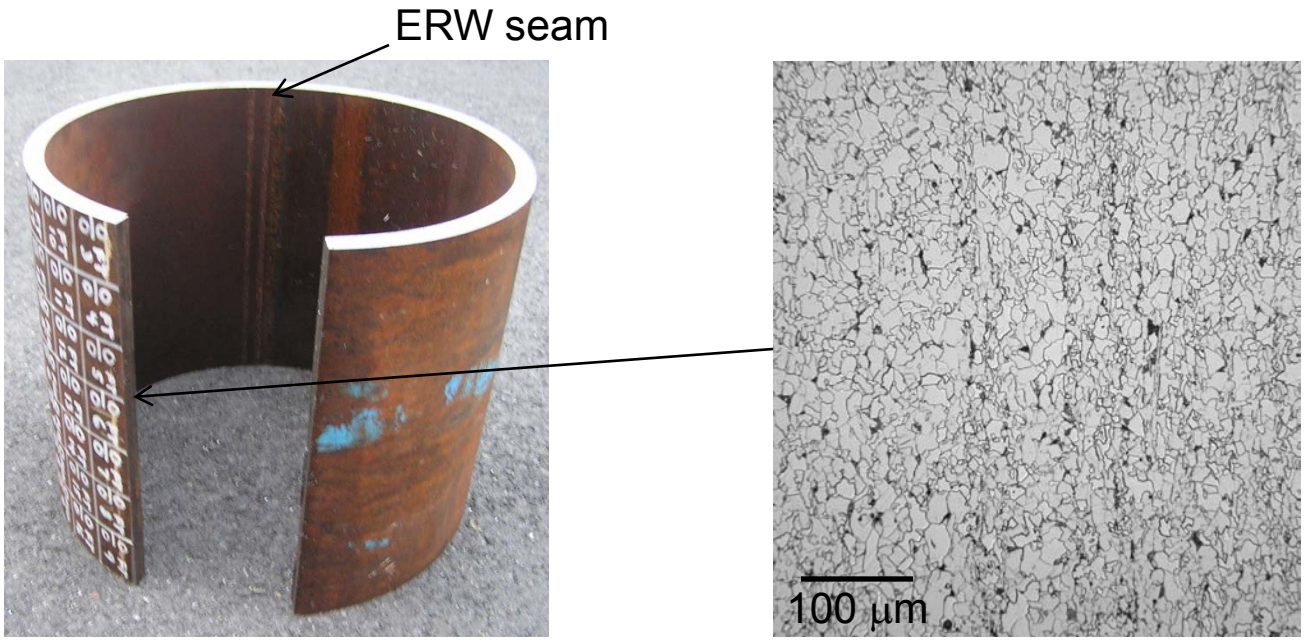
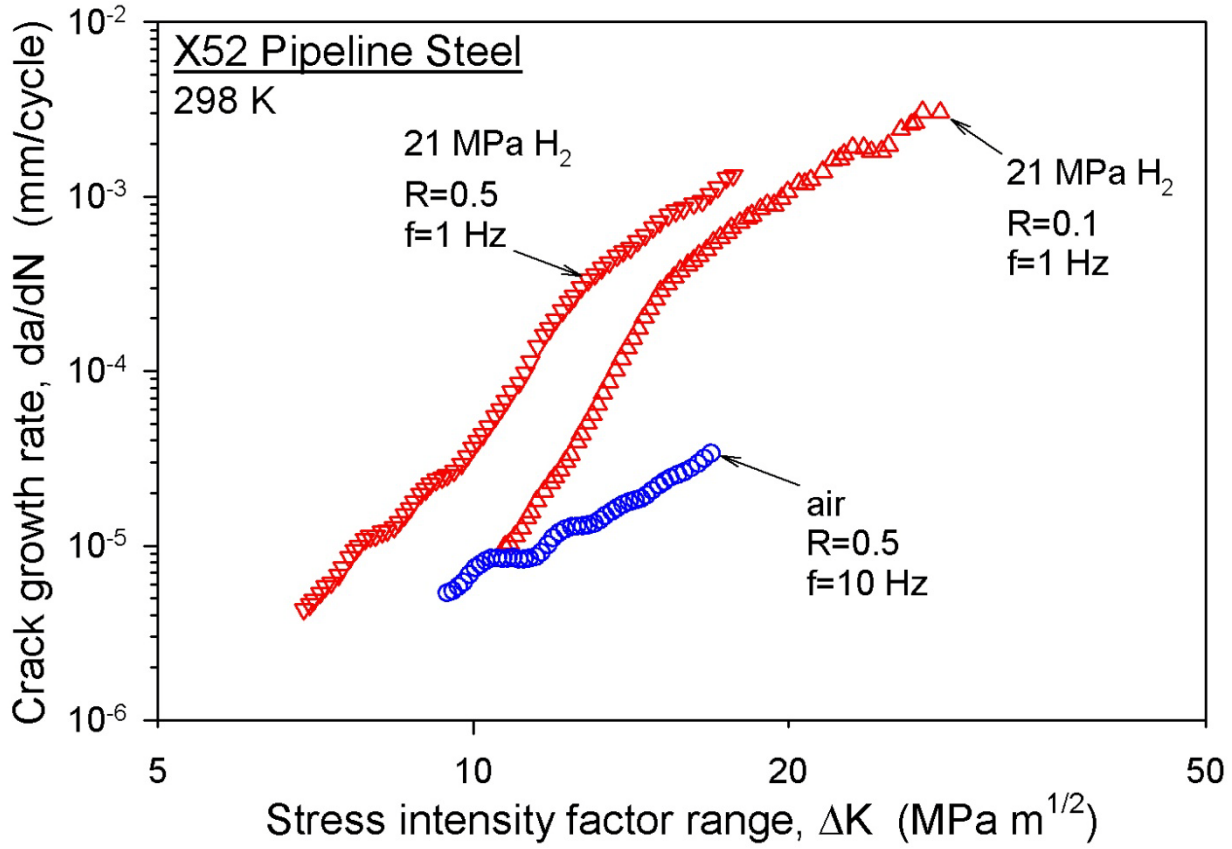
Measured fracture properties of technologically relevant steel: API 5L X52

- Tested same X52 steel from DOE Pipeline Working Group tensile property round robin
  - Stakeholders (e.g., ASME) expressed interest in X52 steel
- Tensile properties
  - Yield strength: 62 ksi (428 MPa)
  - Ultimate tensile strength: 70 ksi (483 MPa)



Accomplishment:

Measured baseline fatigue crack growth law for X52 steel in 21 MPa H_2



- Results reveal transitions in da/dN *vs* ΔK trend that must be captured for measurements in H_2

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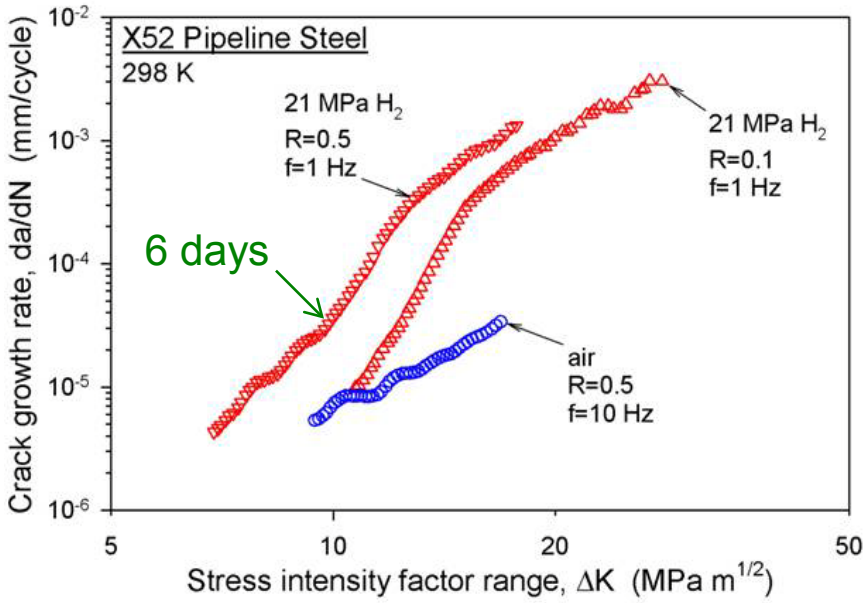
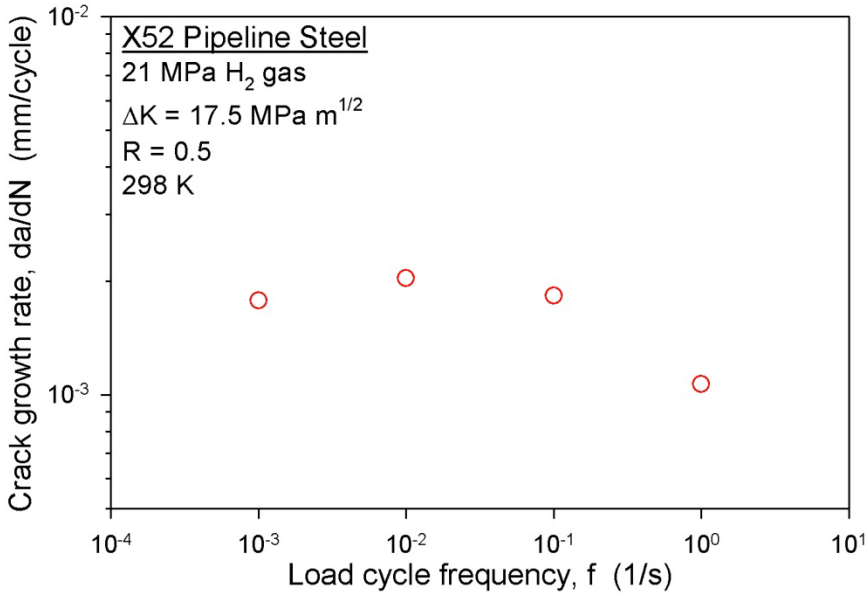
Accomplishment:

Measurement of fatigue crack growth laws must consider effects of frequency





- Tests at 1 Hz yield non-conservative data at high crack growth rates
- Frequency selected must balance test efficiency (i.e., duration) and data reliability
- Results can help optimize test methods referenced in H_2 pipeline standard ASME B31.12

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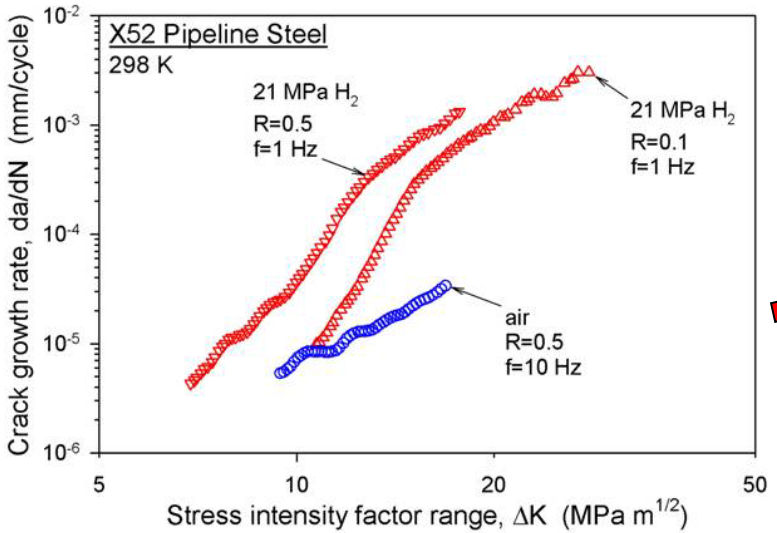
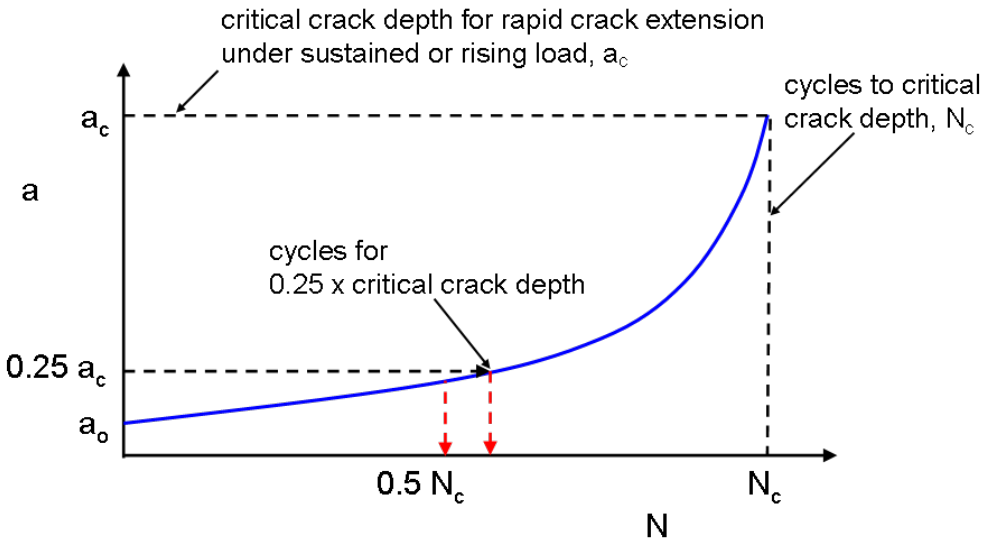
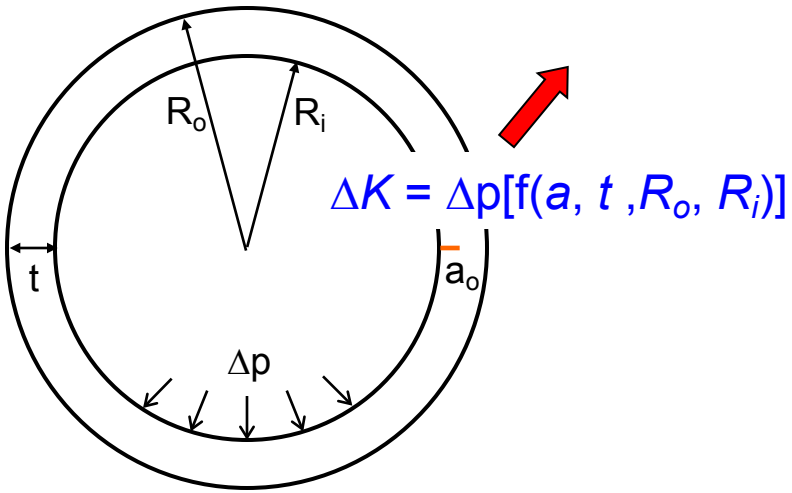
Fatigue crack growth laws can be used to evaluate reliability/integrity of X52 H_2 pipelines







- Life assessment framework in B31.12 allows limiting number of pressure cycles to be established

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Collaborations

- DOE Pipeline Working Group (PWG)
  - Participants funded by DOE H_2 Program
    - Federal Labs: Sandia, Oak Ridge, Savannah River
    - Universities: Univ. of Illinois
    - Industry: Secat
  - Participants not funded by DOE H_2 Program
    - Federal Labs: NIST
    - Industry: energy and industrial gas companies
    - Standards Development Organizations: ASME
  - PWG meets up to 2 times/year for participants to report results and receive feedback
  - Activities coordinated among PWG participants
    - Example: Sandia and NIST coordinating testing of X52 steel in H_2

Future Work

Remainder of FY10

- Complete measurements of da/dN vs frequency for X52 steel in H_2 at lower fatigue crack growth rates
- Measure fracture threshold (K_{IH}) for X52 steel in H_2 as a function of displacement rate
- Measure fatigue crack growth law for X52 steel seam weld in H_2

FY11

- Develop test methods for measuring the fracture properties of pipeline steel girth welds in H_2
- Measure the fatigue crack growth law for pipeline steel girth welds in H_2

Summary

- Measured fatigue crack growth laws allow evaluation of reliability/integrity of steel H_2 pipelines for cyclic pressure
  - Hydrogen embrittlement accommodated by measuring fracture properties in H_2 following ASME B31.12 pipeline design standard
- Measurements on X52 steel in H_2 show that fatigue crack growth rates depend on load-cycle frequency
  - Results can help optimize test methods in standards, i.e., enhancing test efficiency without compromising data reliability