DOE Hydrogen Program

Hydrogen Embrittlement of Structural Steels

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Overview

Timeline

- Project start date Jan. 2007
- Project end date Sept. 2015
- Percent complete 30%

Budget

- Total project funding (through FY09)
  - DOE share: $384K
- FY08 Funding: $200K
- FY09 Funding: $0K

Barriers & Targets

- Target addressed: Reliability/Integrity
- Barrier addressed: 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: CTC, Secat, industrial gas companies
  - Standards Development Organizations: ASME

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Objectives/Relevance

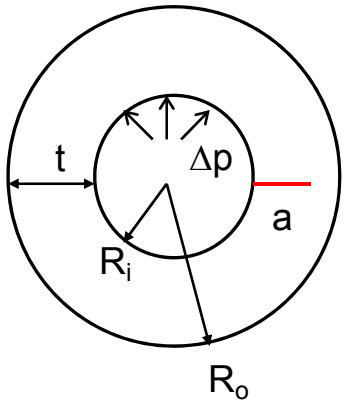
- Demonstrate reliability/integrity of steel H_2 pipelines
  - Address potential failure modes associated with pressure cycling, i.e., fatigue crack growth
- Enable pipeline design methods that accommodate hydrogen embrittlement
  - Generate material property data for steels as specified in pipeline design code ASME B31.12
  - Assess reliability of materials testing methods and material property data

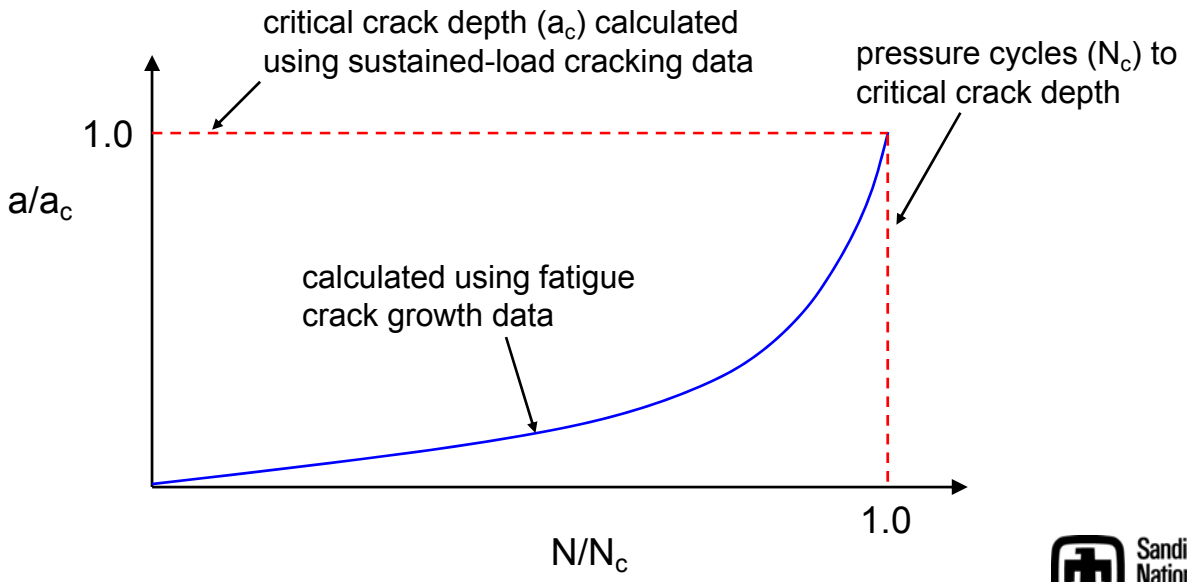
Approach

- Measure properties of pipeline steels in high-pressure H_2 using fracture mechanics methods
  - Emphasize measurements of fatigue crack growth rates
  - Milestone: Measure fatigue crack growth rates of X100 steel in H_2 over range of gas pressures (30% complete)
- Demonstrate reliability of data for steels tested in H_2
  - Participate in round robin test program coordinated through DOE Pipeline Working Group
  - Milestone: Complete tensile testing of X52 and X100 steels in H_2, He, and air (70% complete)

Materials testing motivated by design method

- Design methods in ASME B31.12 address two hydrogen-assisted failure modes
  - Fatigue crack growth induced by pressure cycling
  - Sustained-load cracking
- Design methods require measurement of material properties in H_2 using fracture mechanics methods





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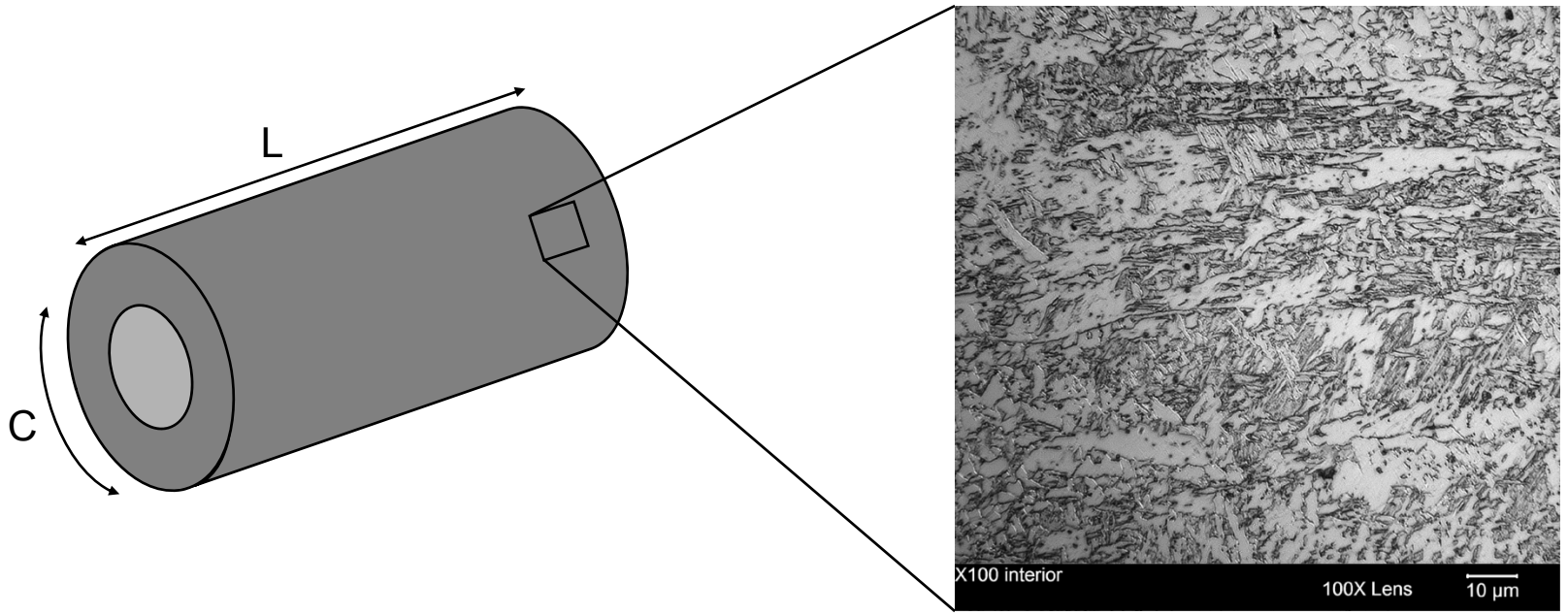
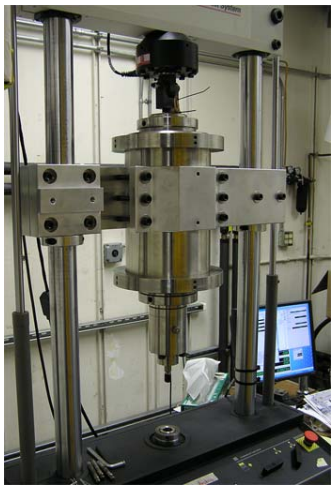
Testing of X100 line pipe steel

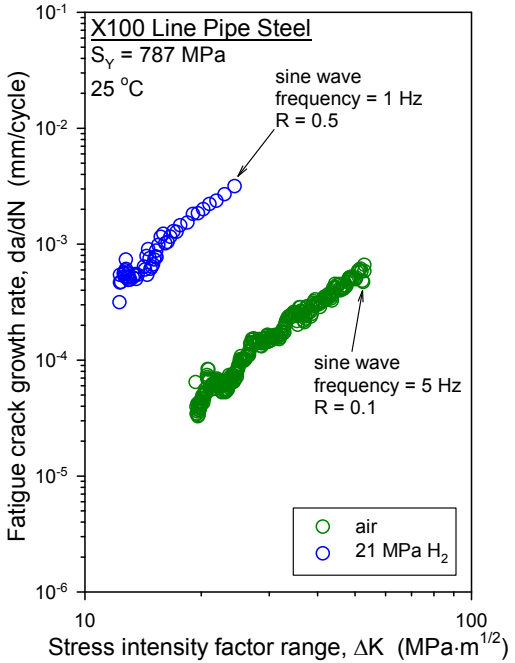
- Yield strength
  - 96 ksi (662 MPa) in longitudinal (L) orientation
  - 114 ksi (787 MPa) in circumferential (C) orientation



Accomplishment:

Measured fatigue crack growth rates for X100 steel in H_2





- Capability for fatigue crack growth testing in H_2 successfully developed
- High fatigue crack growth rates in H_2 show effect of hydrogen embrittlement
- Material property data enable design calculations that establish reliability and integrity of H_2 pipelines

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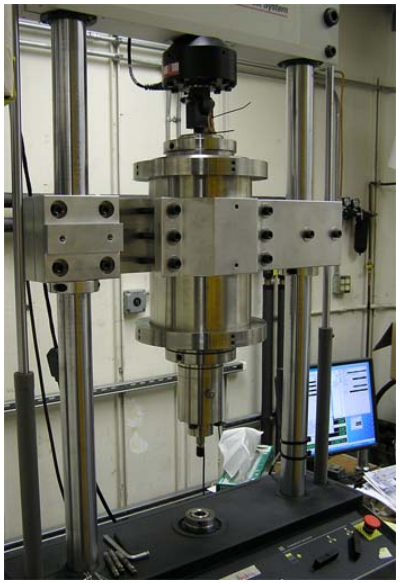
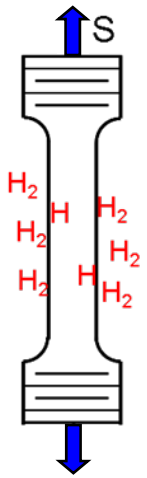
Reliability of test methods in H_2 assessed through round robin





- Coordinated through DOE Pipeline Working Group
- Scope: measure tensile properties of X52 and X100 steels in H_2, He, and air
- Common test methods followed by three labs: Sandia, Oak Ridge, NIST
- Testing logistics and data analysis facilitated by CTC

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Accomplishment:

Completed duplicate tests on X52 and X100 steels in H_2, He, and air

Steel	Test ID	Environment	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	RA (%)
X52	SNL02	air	429	481	31	79
X52	SNL03	air	431	488	29	80
X52	SNL04	helium	417	486	31	75
X52	SNL08	helium	423	481	30	76
X52	SNL01	hydrogen	430	495	24	49
X52	SNL05	hydrogen	423	486	24	60
X100	SNL14	air	769	919	20	74
X100	SNL18	air	725	856	21	78
X100	SNL15	helium	719	878	20	79
X100	SNL16	helium	787	882	21	77
X100	SNL13	hydrogen	755	914	13	38
X100	SNL17	hydrogen	791	897	13	38

- Data provided to CTC for analysis
- Expected effect of hydrogen embrittlement manifested in elongation and RA data
- Internal consistency of results is positive indication that test methods are reliable

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Collaborations

- DOE Pipeline Working Group
  - Participants funded by DOE H_2 Delivery Program
    - Federal Labs: Sandia, Oak Ridge, Savannah River
    - Universities: Univ. of Illinois
    - Industry: CTC, Secat
  - Participants not funded by DOE H_2 Delivery Program
    - Federal Labs: NIST
    - Industry: energy and industrial gas companies
    - Standards Development Organizations: ASME
- Round robin testing one example of coordinated activity in Pipeline Working Group
  - Materials testing: Sandia, Oak Ridge, NIST
  - Test logistics and data analysis: CTC

Future Work

Remainder of FY09

- No activities due to lack of funds

FY10

- Conduct materials testing to ensure reliability/integrity of H_2 pipelines fabricated from X42 and X52 steels
  - Measure fatigue crack growth rates and sustained-load cracking thresholds in H_2
  - Include both base metal and welds
  - Evaluate reliability of materials test methods

Summary

- Measured fatigue crack growth rates for X100 steel in H_2
- Completed duplicate tensile tests on X52 and X100 steels in H_2, He, and air for round robin
- Materials testing results represent progress toward assuring reliability/integrity of steel H_2 pipelines