Materials and Components Compatibility

Brian Somerday

Sandia National Laboratories

May 11, 2011

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

Project ID # SCS005

Overview

Timeline

- Project start date: Oct. 2003
- Project end date: Sept. 2015
- Percent complete: *70%*

Budget

- Total project funding
  - DOE share: $5.4M
- Funding received in FY10: $0.9M
- Funding for FY11: $0.7M

- Barriers & 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

- Interactions/collaborations
  - SAE, CSA, ASME, ISO
  - FIBA Technologies, Swagelok, Plug Power, Nuvera FC, Norris Cylinder
  - DOE Pipeline Working Group
  - HYDROGENIUS, I^{2}CNER (Kyushu University, Japan)

Objectives/Relevance

- Enable *market transformation* by providing data for standards and technology applied to H_2 components
  - Create materials reference guide (“Technical Reference”) and identify material property data gaps
  - Execute materials testing to meet immediate needs for data in standards and technology development
    - Examples: fatigue life test methods, measure weld properties
  - Improve efficiency and reliability of materials test methods in standards
    - Example: optimize frequency for fatigue crack growth testing in ASME Article KD-10 tank standard

- Participate directly in standards development
  - Design and safety qualification standards for components
    - SAE J2579, CSA HPIT1, ASME Article KD-10
  - Materials testing standards
    - CSA CHMC1

Program Approach

- Apply expertise and resources in materials compatibility to develop standards and technology for H_2 components
  - Sustain relationships with stakeholders (industry, SDOs) to identify needs in standards and technology development
  - Apply unique laboratory capability for conducting material tests in high-pressure (>100 MPa) hydrogen gas
    - Generate data to meet immediate needs for standards and technology development
    - Demonstrate improvements in materials test methods (e.g., fatigue crack growth test in ASME Article KD-10 tank standard)
  - Ensure data and technical perspectives are effectively communicated to stakeholders (industry, SDOs)
    - Materials guide ("Technical Reference") available on website
    - Reports with material data distributed directly to stakeholders
    - Sandia technical staff serve on standards development committees

Approach: Milestones

- Organize workshop on Hydrogen Compatible Materials
- Optimize load-cycle frequency in fatigue crack growth test method for ferritic steels in H_2 gas
- Establish method for evaluating effect of hydrogen on fatigue crack initiation
- Characterize fracture properties of hydrogen-exposed welds
  - Identified as high-priority technology gap
- Provide technical leadership in development of SAE J2579 and CSA CHMC1 standards
- Develop capability for variable-temperature testing in high-pressure H_2 gas
- Update content in “Technical Reference” with data from Sandia materials testing activities

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Accomplishment:

Convened Hydrogen Compatible Materials Workshop at SNL/CA

- Goal: coordinate and plan international R&D for hydrogen compatible materials and components

- Attendees: ~30 people from research labs, government, industry, and standards development organizations

- Output: identification of high-priority gaps in technology development, code development, and research
  - Influence of welds on H_2 compatibility of structures
  - Testing protocols for materials evaluation
  - Measurements of mechanical properties of structural metals in high-pressure H_2, in particular fatigue properties
  - Database for properties of structural materials in H_2 gas
  - High-strength, low-cost materials for long-life H_2 service

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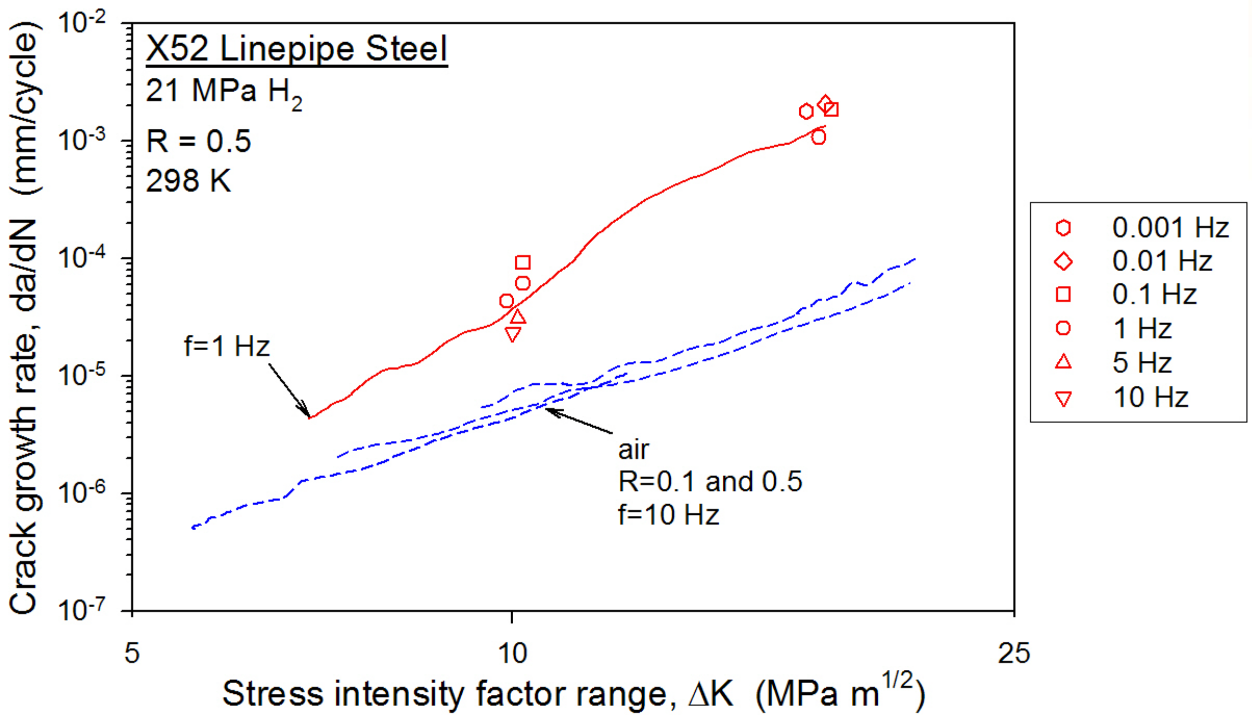
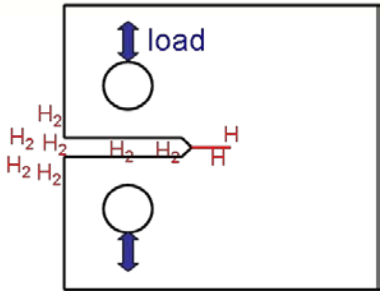
Accomplishment:

Measured effects of load-cycle frequency on fatigue crack growth rates in H_2

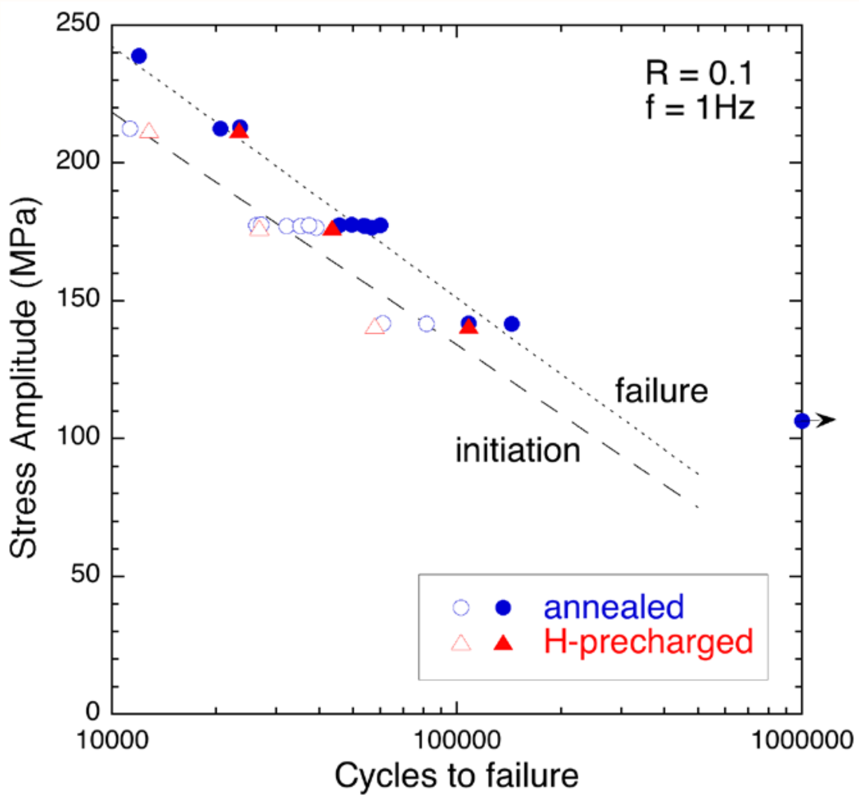




- Optimizing load-cycle frequency is essential for efficient and reliable testing
- Improved test methods impact ASME Article KD-10 and B31.12
- Leveraged effort with Hydrogen Delivery project

Accomplishment:

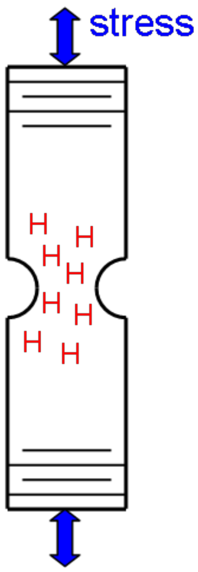
Developing test methods for measuring fatigue initiation life of H_2-exposed metals



21-6-9 stainless steel

S_y = 540 MPa

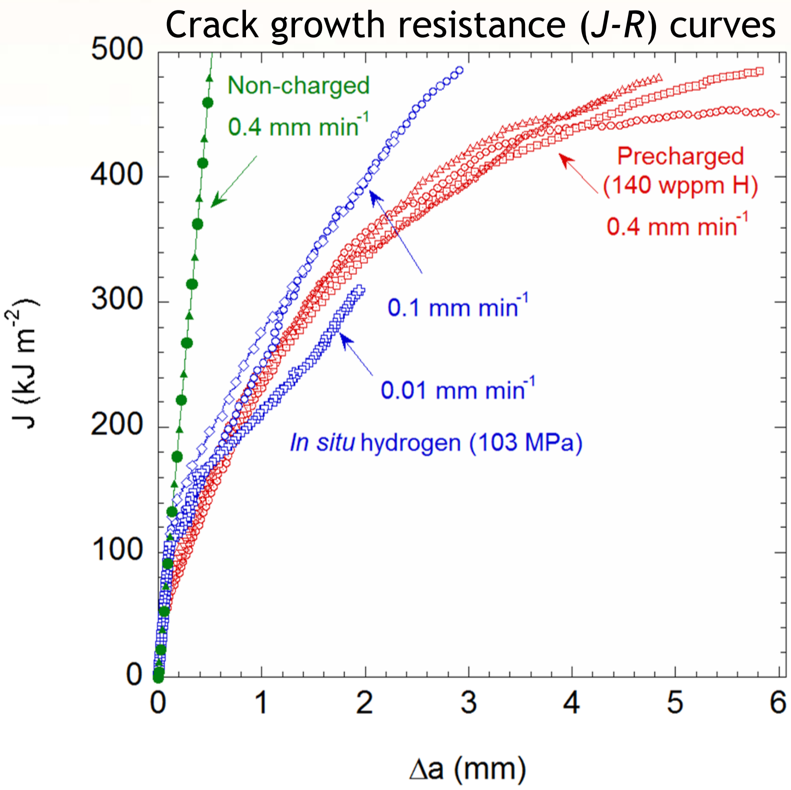
250 wppm H

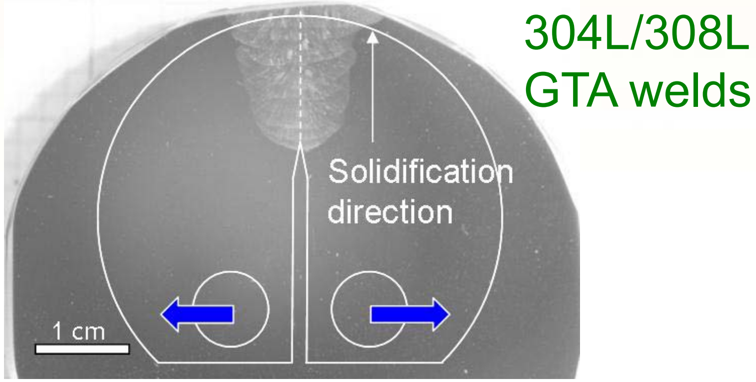


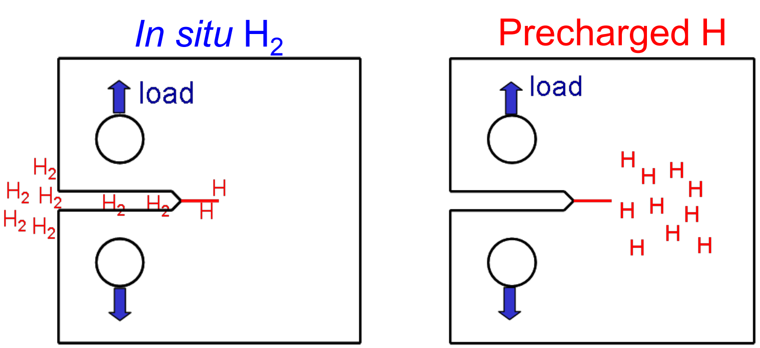
- Reliable fatigue initiation test methods needed for SAE J2579 and CSA CHMC1 standards

Accomplishment:

Extensive testing of H_2-exposed stainless steel welds conducted at Sandia







- Leveraged effort between DOE FCT Program and NNSA
- Knowledge of weld behavior reflected in SAE J2579

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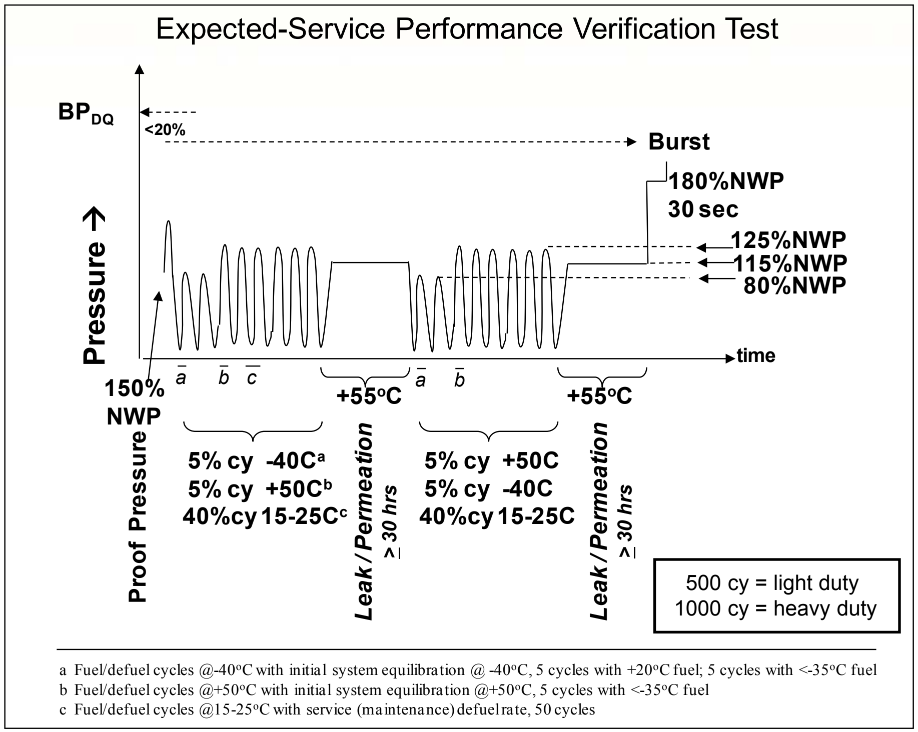
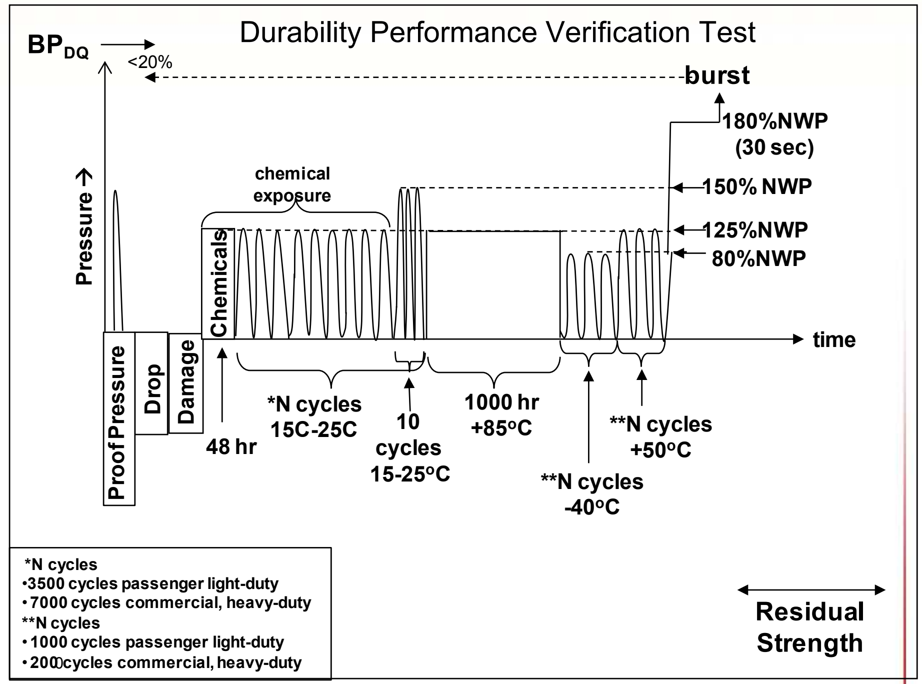
Accomplishment:

Updating FCV tank standard SAE J2579 to address hydrogen embrittlement

Pneumatic test (H_2)



Hydraulic test



- Current safety qualification performance tests do not evaluate “durability” under H_2 gas pressure cycling, i.e., hydrogen embrittlement

Accomplishment:

Three new sections in SAE J2579 enable hydrogen compatibility qualification

Metal tank components fabricated from 6061 Al or high-nickel 316 stainless steel? (Appendix B.1.2.3)

OR

Structural metals meet acceptance criteria from materials testing in H_2? (Appendix C.15)

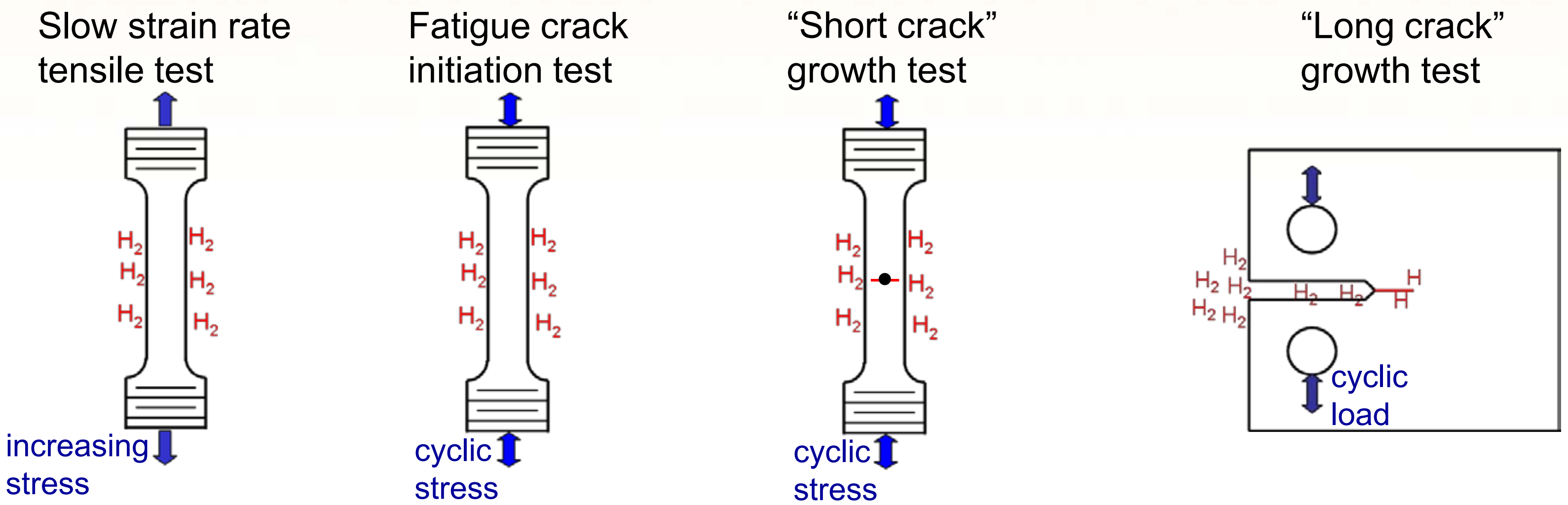
Y → Tank safety qualification using hydraulic pressure cycling only (Section 5.2.2.3)

N → Tank safety qualification using hydraulic pressure cycling (Section 5.2.2.3) AND hydrogen gas cycling (Appendix C.14)

- New appendices in SAE J2579 are foundation for addressing H_2 compatibility in GTR

Accomplishment:

Materials testing procedures specified for design-unrestricted H_2 compatibility (C.15)

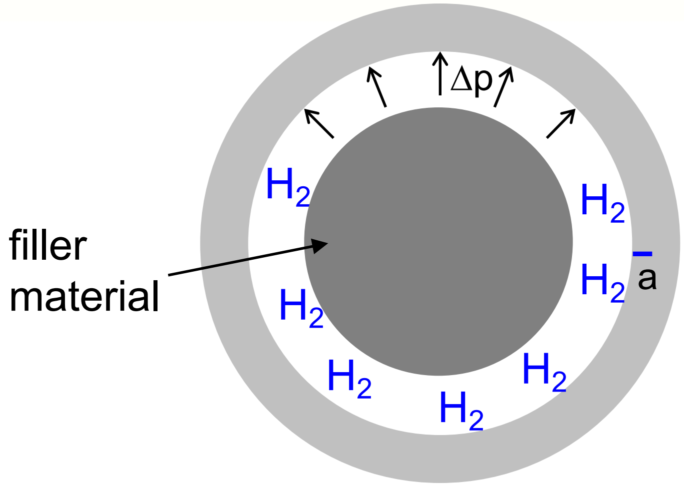


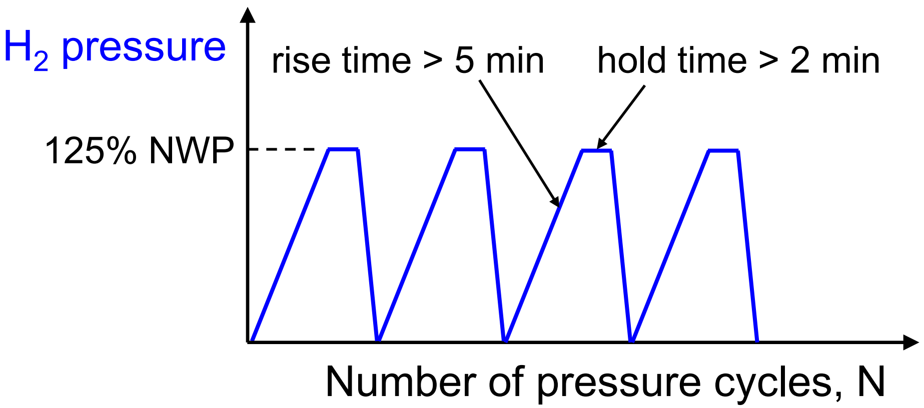
- Test details still need attention
  - Test temperature
  - Cyclic stress frequency

- Materials testing procedures in SAE J2579 developed through collaboration between U.S., Japan, and Europe

Accomplishment:

Performance testing procedures specified for design-restricted H_2 compatibility (C.14)





- Test procedures based on Sandia tank testing and CSA HPIT1 activities

Collaborations

- Standards Development Organizations (SDOs)
  - Examples: SAE, CSA, ASME, ISO
  - Sandia technical staff serve on committees
- Industry partners
  - Examples: FIBA Technologies, Swagelok
  - Provide technology-relevant materials for Sandia testing activities
- DOE Pipeline Working Group (PWG)
- HYDROGENIUS (AIST/Kyushu University, Japan)
- International Institute for Carbon-Neutral Energy Research (I^2CNER)
  - International research institute at Kyushu University with thematic area in Hydrogen Structural Materials funded by Japan MEXT
  - I^2CNER Director is Prof. Petros Sofronis (Univ. Illinois, DOE PWG)
  - Dr. Brian Somerday (Sandia) serving as Lead Principal Investigator for Hydrogen Structural Materials Division

Proposed Future Work

Remainder of FY11

- Establish optimized methods for measuring fatigue properties of H_2-exposed steels in component standards (e.g., Article KD-10, CSA CHMC1)
- Measure hydrogen-affected properties of representative stainless steel welds in gas distribution manifolds
- Complete drafts of SAE J2579 appendices and CSA CHMC1 standard
- Procure pressure vessel with variable-temperature feature for new fatigue testing capability

FY12

- Address research and technology gaps identified from Hydrogen Compatible Materials Workshop
  - Database for properties of structural materials in H_2 gas
  - Measurements of mechanical properties of structural metals in high-pressure H_2, in particular fatigue properties
  - High-strength, low-cost materials for long-life H_2 service

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Summary

- Hydrogen Compatible Materials Workshop identified important technology gaps
  - Workshop output expected to guide R&D activities at Sandia
- Materials testing motivated by standards development and technology needs
  - Improving fatigue testing methods impacts SAE J2579, CSA CHMC1, and ASME Article KD-10 and enables technology deployment
  - Measuring properties of welds addresses high-priority technology gap
- Concrete progress in developing methods for qualifying hydrogen compatibility of components in two standards
  - SAE J2579 FCV tank standard
  - CSA Compressed Hydrogen Materials Compatibility (CHMC1)
- Enhanced international collaborations established through SAE J2579 and I^2CNER activities

Technical Back-Up Slides

Accomplishment:

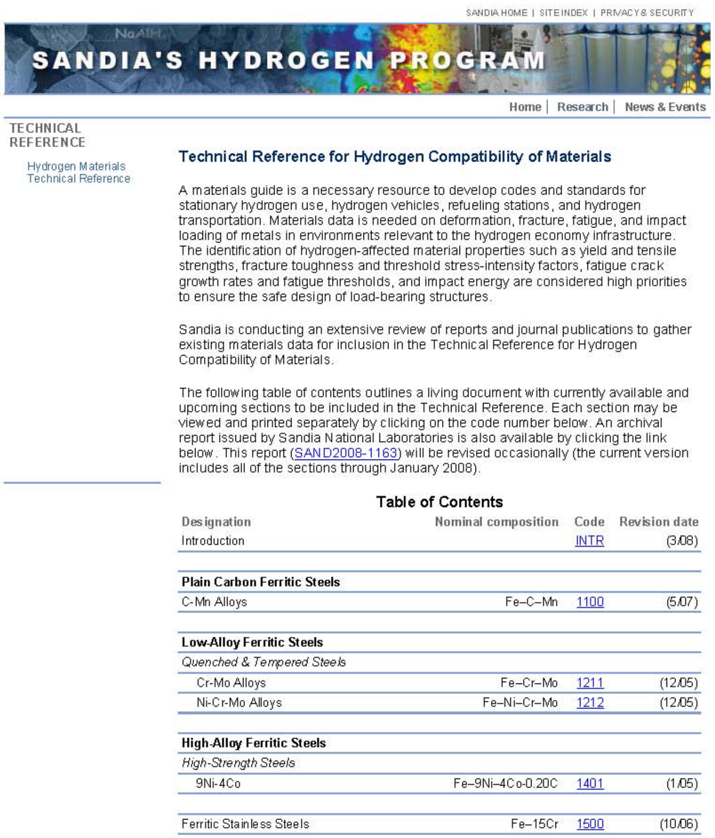
New efforts in developing standards and laboratory testing capabilities

- Sandia is leading CSA Technical Advisory Group on Compressed Hydrogen Materials Compatibility (CHMC1)
  - Standard specifies procedures for testing materials in H_2
  - Expect that standard will be referenced by other H_2 containment component standards
- Sandia is establishing new capability for conducting fatigue testing of materials in H_2 at low temperature
  - Hydrogen embrittlement can be enhanced at low temperature in certain metals (e.g., stainless steels)
  - Low temperatures can be attained in H_2 containment components (e.g., tanks, dispensers)

Accomplishment:

Updated "Technical Reference for Hydrogen Compatibility of Materials"

- Included new data from Sandia materials testing activities
  - Fatigue crack growth data for C-Mn steels in H_2 gas
- www.ca.sandia.gov/matlsTechRef



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TECHNICAL REFERENCE

Hydrogen Materials Technical Reference

Technical Reference for Hydrogen Compatibility of Materials

A materials guide is a necessary resource to develop codes and standards for stationary hydrogen use, hydrogen vehicles, refueling stations, and hydrogen transportation. Materials data is needed on deformation, fracture, fatigue, and impact loading of metals in environments relevant to the hydrogen economy infrastructure. The identification of hydrogen-affected material properties such as yield and tensile strengths, fracture toughness and threshold stress-intensity factors, fatigue crack growth rates and fatigue thresholds, and impact energy are considered high priorities to ensure the safe design of load-bearing structures.

Sandia is conducting an extensive review of reports and journal publications to gather existing materials data for inclusion in the Technical Reference for Hydrogen Compatibility of Materials.

The following table of contents outlines a living document with currently available and upcoming sections to be included in the Technical Reference. Each section may be viewed and printed separately by clicking on the code number below. An archival report issued by Sandia National Laboratories is also available by clicking the link below. This report (SAND2008-1163) will be revised occasionally (the current version includes all of the sections through January 2008).

Table of Contents

Designation	Nominal composition	Code	Revision date
Introduction		INTR	(3/08)
Plain Carbon Ferritic Steels			
C-Mn Alloys	Fe–C–Mn	1100	(5/07)
Low-Alloy Ferritic Steels			
Quenched & Tempered Steels			
Cr-Mo Alloys	Fe–Cr–Mo	1211	(12/05)
Ni-Cr-Mo Alloys	Fe–Ni–Cr–Mo	1212	(12/05)
High-Alloy Ferritic Steels			
High-Strength Steels			
9Ni-4Co	Fe–9Ni–4Co-0.20C	1401	(1/05)
Ferritic Stainless Steels	Fe–15Cr	1500	(10/06)

Data used for materials selection in technology design and for standards development

Collaborations:

Sandia will have leadership role in the new I^2CNER international institute

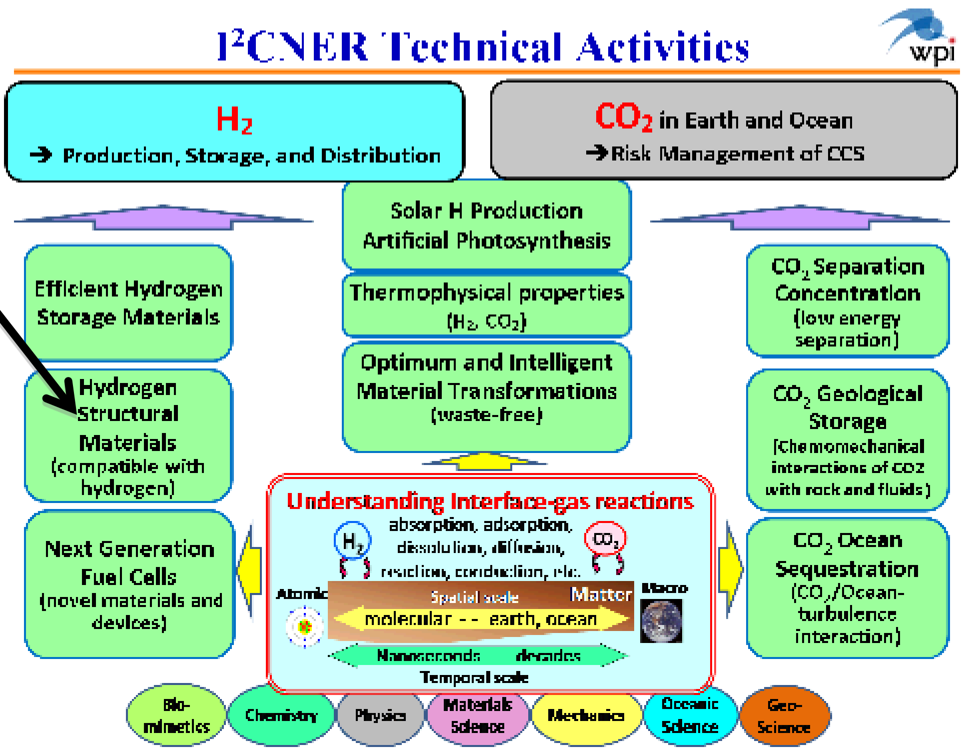
International Institute for Carbon-Neutral Energy Research

$10M/year Director P. Sofronis

KYUSHU UNIVERSITY ILLINOIS

LVOC-H_2 objective: connect international community of H_2-energy stakeholders (research, industry, code development)

B. Somerday



- **Leverage 40+ years in H_2 effects on structural materials at SNL**
- **Existing collaborations demonstrate productive role for SNL**
  - **SNL/Illinois collaborations since 2002**
- **DOE encouraging collaborations with Japan**
  - **Near-Pacific collaborative facilities**

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