SANDIA NATIONAL LABORATORIES
HYDROGEN PRODUCTION & DELIVERY PROGRAM

QUARTERLY PROGRESS REPORT FOR OCTOBER 1, 2010–DECEMBER 30, 2010

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RECIPIENT: SANDIA NATIONAL LABORATORIES

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Sandia National Laboratories

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Project Title: Enabling Hydrogen Embrittlement Modeling of Structural Steels

Project Period: October 1, 2010 to December 31, 2010
Date of Report: January 13, 2011

Principal Investigator: Brian Somerday, 925-294-3141, bpsomer@sandia.gov
Other Key National Lab Researchers: Chris San Marchi (SNL/CA), Heather Jackson (SNL/CA)

Sub-Contractors Funded through AOP Task: none

Industrial Partners: Secat, University of Illinois (Petros Sofronis), NIST (David McColskey)

DOE Managers: Sara Dillich, Hydrogen Production & Delivery Team Lead
Dan Sanchez, DOE Field Project Officer

Project Objective: The principal objective of this project is to provide an experimental component to the development of prognosis models for steel hydrogen gas pipelines. These models include both mechanism-based simulations of hydrogen embrittlement as well as structural integrity analyses to predict safety margins for pipelines. The aim of the experimental effort is to establish physical models of hydrogen embrittlement in steels and to generate material properties that serve as model inputs. The focus of the latter is on fracture mechanics properties such as crack propagation thresholds and fatigue crack growth relationships.

Background: Carbon-manganese steels are candidates for the structural materials in hydrogen gas pipelines; however, it is well known that these steels are susceptible to hydrogen embrittlement. While hydrogen embrittlement compromises the structural integrity of steel components, decades of research and industrial experience have allowed many salient variables that affect hydrogen embrittlement of steels to be identified. As a result, there are established paths for managing hydrogen embrittlement in steels and quantifying safety margins for steel hydrogen containment structures. For example, fatigue crack growth aided by hydrogen embrittlement is a potential failure mode for steel hydrogen containment structures subjected to pressure cycling. Applying appropriate structural integrity models coupled with measurement of relevant material properties allows quantification of safety margins against fatigue crack growth in hydrogen containment structures.

Status: The principal activity during FY11 Q1 was measuring the fatigue crack growth relationship for electric resistance welds (ERW) from X52 line pipe steel in hydrogen gas. The fatigue crack growth rate (da/dN) *vs* stress-intensity factor range (ΔK) relationship is a necessary material-property input into damage-tolerant life prediction models applied to steel hydrogen pipelines. One such design life methodology for steel hydrogen pipelines was recently published in the ASME B31.12 code. The measurements of crack propagation thresholds and fatigue crack growth relationships in this task support the objective of establishing the reliability/integrity of steel hydrogen pipelines.

The X52 line pipe steel was selected for this task because of its recognized technological relevance for hydrogen pipelines. The X52 steel from the round robin tensile property study (FY08) was tested for the following reasons: 1) some characterization of the material was already provided from the round robin study, 2) ample quantities of material were still available, and 3) the X52 steel was in the form of finished pipe, which is the most relevant product form and also allows samples to be extracted from the ERW seam weld.

The hydrogen-affected fatigue crack growth relationship (da/dN *vs* ΔK) for the structural steel is the basic element in pipeline life-prediction models. The ASME B31.12 code requires measurement of the fatigue crack growth relationship for pipeline steels at the hydrogen gas operating pressure. Initial measurements of the fatigue crack growth relationship for X52 steel base metal were conducted in 21 MPa hydrogen gas (the upper limit specified for hydrogen pipelines in the ASME B31.12 code) at a load-cycle frequency equal to 1 Hz and load ratio (R = minimum load/maximum load) equal to 0.1 (Figure 1). This load-cycle frequency was selected to balance test effectiveness and test efficiency since fatigue crack growth rates can be enhanced at lower test frequency, but the test duration can become prohibitively protracted. Two replicate measurements were conducted at R=0.1 and 1 Hz to evaluate data variability (Figure 1).

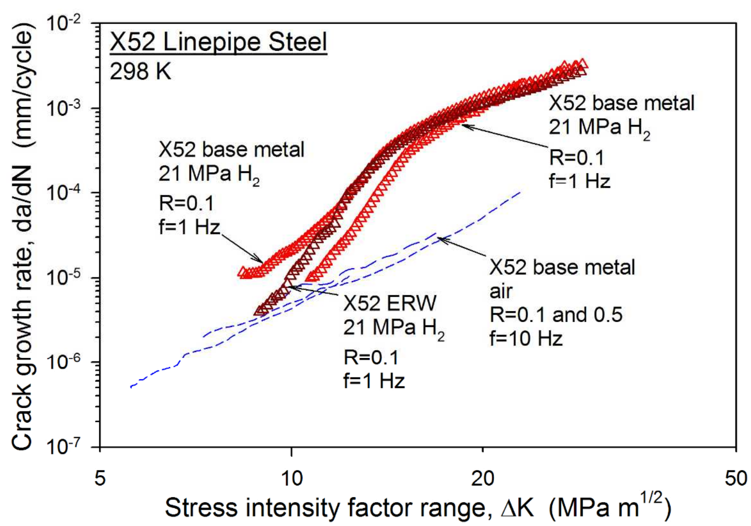

Figure 1. Fatigue crack growth rate (da/dN) *vs* stress-intensity factor range (ΔK) plots for X52 steel in hydrogen gas and air.

Compact-tension specimens for measuring the fatigue crack growth relationship of the ERW seam weld were successfully prepared. The specimen preparation process presented some challenges, as it was difficult to reveal the ERW with chemical etching.

It was important to clearly reveal the ERW so that the compact-tension specimens could be precisely located on either the weld bond line or in the weld heat-affected zone (HAZ). Once the ERW was convincingly revealed by chemical etching, compact tension specimens were machined from the weld with the precrack-starter notch located on the bond line. The bond line material was selected for evaluation since this region had the higher hardness compared to the neighboring heat affected zone.

The fatigue crack growth relationship for the X52 ERW was successfully measured in 21 MPa hydrogen gas. The test was conducted at R=0.1 and 1 Hz so that the fatigue crack growth relationship could be directly compared to results for the X52 base metal. Figure 1 shows that the da/dN *vs* ΔK relationship for the X52 ERW is similar to the relationships measured for the X52 base metal. These results indicate that the ERW seam weld is not more susceptible to hydrogen-assisted fatigue crack growth compared to the base metal.

Plans for Next Quarter and Key Issues: The focus for FY11 Q2 is measuring the fatigue crack growth relationship for X52 girth welds in hydrogen gas.

Patents: none

Publications / Presentations: none

Task/Milestone Schedule

Task Number	Project Milestones	Task Completion Date				Progress Notes
		Original Plan	Revised Planned	Actual	Percent Complete	
2.1	Measure fracture properties of X52 seam weld at constant H_2 gas pressure	12/31/10			35%	Completed initial fatigue testing
2.1	Measure the da/dN vs ΔK relationship for steel girth weld at constant H_2 gas pressure	03/31/10			0%	
2.2	SMART milestone: Determine the threshold level of oxygen impurity concentration required to mitigate accelerated fatigue crack growth of X52 steel in hydrogen at gas pressures up to 3000 psi.	09/30/10			0%	

Project Title: Geologic Storage of Hydrogen

Project Period: October 1, 2010 to December 31, 2010
Date of Report: January 11, 2011

Principal Investigator: Anna Snider Lord, 505-284-5588, acsnide@sandia.gov
Other Key National Lab Researchers: Peter H. Kobos, 505-845-7086, phkobos@sandia.gov , David J. Borns, 505-844-7333 djborns@sandia.gov

Sub-Contractors Funded through AOP Task: none

DOE Managers: Sara Dillich, DOE HQ Technology Manager,
Dan Sanchez, DOE Field Project Officer

Project Objective: This year's project consists of two objectives, (1) to develop geologic storage parameters for the Hydrogen Delivery Scenario Analysis model (HDSAM), and (2) to incorporate a GIS interactive map interface as part of the Hydrogen Energy and Demand Model.

Sandia will work with Argonne National Laboratory and National Renewable Energy Laboratory to help update the HDSAM with the latest hydrogen underground geologic storage parameters and cost estimates. The initial step will concentrate on providing NREL with realistic geologic storage costs estimates for a specific storage scenario they provided to Sandia.

The GIS interface will allow for map data to be extracted that will allow for the user to conceptualize geographically the geologic underground storage options available in the region of interest.

Background: Geologic storage is used extensively in the oil, natural gas, and compressed air energy industries. To understand the scale of this utilization, 800 million barrels of oil and 100's of billion cubic feet of natural gas are stored geologically in the US. The basic drive for geological storage is that the cost per volume-stored is 3 to 5 times less than surface storage. With this relatively inexpensive way to store large volumes, storage can be situated to buffer seasonal demands, provide continuity in case of disruption in the supply chain, and control congestion in the pipeline system. For example, industry analysis estimates that the current natural gas storage in the US reduces the need for pipelines by 50%.

Geologic cavern storage of hydrogen for industrial use already exists at several locations in Texas. In addition, an evolving hydrogen economy and infrastructure raises similar needs as the natural gas and oil infrastructures. Analyses of the hydrogen infrastructure (Ogden, Williams, Simbeck and Chang, Lord) indicate that there may be an important role for geologic storage. This need, similar to fossil energy stocks, is to buffer seasonal demands, provide continuity in case of disruption in the supply chain, and control congestion in the pipeline system.

To date a white paper has been written describing the various types of underground geologic storage options available for the storage of natural gas. The report includes four location maps showing the available underground storage sites in the U.S. The three most likely geologic candidates for the underground storage of hydrogen are 1) salt caverns, 2) depleted oil/gas reservoirs, and 3) aquifers. The report was published as a documentable internal report (i.e. SAND report).

In addition a model has been developed that characterizes the costs entailed in developing and operating three types of hydrogen underground storage facilities; 1) salt caverns, 2) depleted oil/gas reservoirs, and 3) aquifers. The work was presented at the 28th USAEE/IAEE North American Conference in New Orleans, December 2008. A summary report was completed as a documentable internal SAND report, which will allow for public distribution.

Status: The funding for the current task was received July, 2010.

Sub-Task 3.1: This quarter the Hydrogen Energy and Demand model continued to be refined and updated to specifically address the fourth storage option and to incorporate the effects of storage life and cyclicity on cost.

Sub-Task 3.2: A draft version of the GIS interface has been developed. The interface is being tested by staff.

Plans for Next Quarter and Key Issues: Next quarter Sandia will work with Argonne National Laboratories to incorporate underground geologic storage parameters into HDSAM. In addition, incorporate the GIS interface with the Hydrogen and Energy Demand model.

Patents: none

Publications / Presentations:

Lord, A.S., P.H. Kobos, and D.J. Borns, A Life Cycle Cost Analysis Model Framework for Geologic Storage of Hydrogen, SAND2010-3677C, Sandia National Laboratories, Albuquerque, NM, 2010.

Lord, A.S., P.H. Kobos, and D.J. Borns, A Life Cycle Cost Analysis Framework for Geologic Storage for Hydrogen: A Scenario Analysis, SAND2010-6939, Sandia National Laboratories, Albuquerque, NM, 2010

Lord, A.S., Investigating the Potential for Hydrogen Geostorage with Igneous and Metamorphic Rocks: A Status Report, SAND2010-6938, Sandia National Laboratories, Albuquerque, NM, 2010.

Task/Milestone Schedule

Task Number	Project Milestones	Task Completion Date				Progress Notes
		Original Plan	Revised Planned	Actual	Percent Complete	
3.1	Letter report: Status report	10/2010		10/11/2010	100%	Funding received 4/2010
3.1	SAND report: Summary report of tasks to date	12/2010	7/2010		50%	Included in White Paper.
3.2	GIS Map Interface: Letter report	9/2011			70%	Included in White Paper.