SANDIA NATIONAL LABORATORIES
HYDROGEN PRODUCTION AND DELIVERY PROGRAM

QUARTERLY PROGRESS REPORT FOR OCTOBER 1, 2011–DECEMBER 31, 2011

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RECIPIENT: SANDIA NATIONAL LABORATORIES

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TASK 2: ENABLING HYDROGEN EMBRITTLEMENT MODELING OF STRUCTURAL STEELS

COVERING PERIOD: OCTOBER 1, 2011 THROUGH DECEMBER 31, 2011

DATE OF REPORT: JANUARY 30, 2012

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FY 2012 MILESTONES/DELIVERABLES

Task	Planned	Status
Task 2: Enabling Hydrogen Embrittlement Modeling of Structural Steels		
Subtask 2.1: Measurement of Fracture Properties of Structural Steels in High-Pressure H_2		
Measure the fatigue crack growth (da/dN *vs* ΔK) relationship at constant H_2 gas pressure in X65 pipeline girth weld supplied by industry partner	6/12	In progress
Subtask 2.2: Effect of Gas Impurities on Fracture Properties in H_2		
Quantify the relationship between H_2 pressure and the threshold level of oxygen impurity concentration required to mitigate hydrogen-accelerated fatigue crack growth of X52 steel.	9/12 This milestone is deferred at the lower funding target.	
Subtask 2.3: 2012 International Hydrogen Conference		
Organize and convene the 2012 International Hydrogen Conference at Jackson Lake Lodge, Grand Teton National Park, WY	9/12	In progress

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, established paths exist to manage hydrogen embrittlement in steels and to quantify 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 measuring relevant material properties in hydrogen gas allows quantification of safety margins against fatigue crack growth in hydrogen containment structures.

STATUS

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 life prediction 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. Previous results for pipeline and pressure vessel steels have demonstrated that gas species such as oxygen can favorably affect the fatigue crack growth relationship in hydrogen gas [1]. However, these studies have not systematically examined important variables such as the impurity partial pressure, hydrogen partial pressure, ΔK level, R ratio (K_{min}/K_{max}), and load-cycle frequency. Since the retarding effect of oxygen and other gas impurities on hydrogen-assisted fatigue crack growth may have technological benefits, the windows of variables that promote this positive effect need to be defined more quantitatively.

In FY11 Q4, the effects of oxygen on the fatigue crack growth relationship for X52 base metal in hydrogen gas were measured at a constant load ratio, R = 0.1. The X52 steel was tested in three hydrogen/oxygen gas mixtures: H_2/10 ppm O_2, H_2/100 ppm O_2, and H_2/1000 ppm O_2, in which the hydrogen gas partial pressure was approximately constant at 21 MPa. As shown in Figure 1, the concentration of oxygen has a profound effect on the da/dN vs ΔK relationship. The effect of oxygen in retarding hydrogen-accelerated fatigue crack growth is even more pronounced when the R ratio is increased to 0.5. For the hydrogen/oxygen gas mixture of H_2/1000 ppm O_2, fatigue crack growth rates were equal to growth rates in an inert environment (i.e., air) over the entire range of ΔK. In this case, hydrogen did not accelerate fatigue crack growth rates up to the maximum ΔK = 29 MPa $m^{1/2}$. The technological implication for this result is that oxygen is a more effective inhibitor when hydrogen gas containment components are operated at higher pressure ratios (p_{min}/p_{max}).

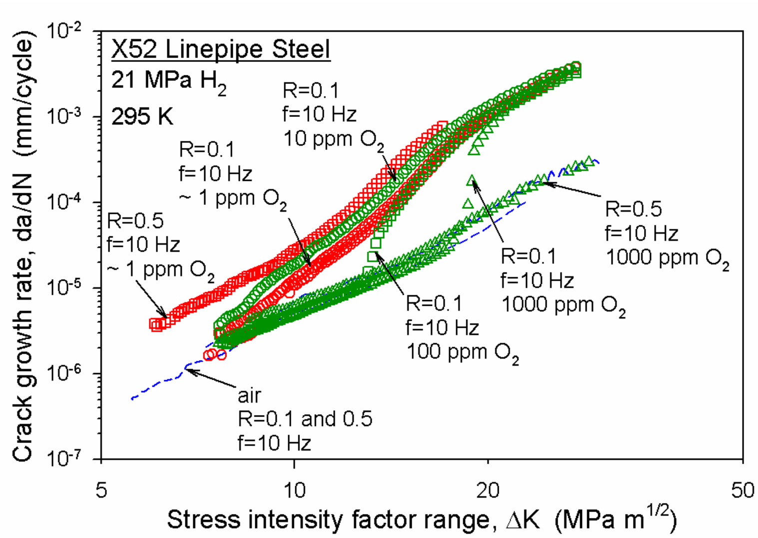

Figure 1. Fatigue crack growth rate (da/dN) vs stress-intensity factor range (ΔK) plots for X52 steel in hydrogen/oxygen gas mixtures, high-purity hydrogen, and air.

REFERENCES

1. C. San Marchi and B.P. Somerday, *Technical Reference on Hydrogen Compatibility of Materials*, SAND2008-1163, Sandia National Laboratories, Livermore, CA, 2008.

PLANS FOR NEXT QUARTER AND KEY ISSUES

The primary objective for FY12 Q2 is to prepare fatigue crack growth test specimens from girth welds in pipeline steels. ExxonMobil has supplied a generous quantity of girth weld in an X65 steel pipe (Figure 2). Test specimens will be prepared from this X65 girth weld.

Figure 2. X65 steel girth weld supplied by ExxonMobil.

PUBLICATIONS / PRESENTATIONS

- "Gaseous Hydrogen-Assisted Fatigue Crack Growth in X52 Linepipe Steel", B. Somerday, C. San Marchi, and K. Nibur, MS&T 2011, Columbus OH, October 2011.