III.4 Fiber Reinforced Composite Pipeline

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Overall Objectives

Successfully adapt spoolable fiber reinforced composite pipeline (FRP) currently used in the oil and natural gas industry for use in high-pressure hydrogen delivery systems and development of data needed for life management and codification fiber reinforced composite piping into the American Society of Mechanical Engineers (ASME) B31.12 Hydrogen Piping Code.

Fiscal Year (FY) 2013 Objectives

- Complete draft code section for FRP codification in ASME B31.12.
- Develop the fatigue design curve for unflawed FRP pipe over the range of design pressures from 750 psig to 3,000 psig.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(D) High As-Installed Cost of Pipelines

(J) Hydrogen Leakage and Sensors

(K) Safety, Codes and Standards, Permitting

Technical Targets

This project is focused on the evaluation of FRP for hydrogen service applications. Assessment of the structural integrity of FRP piping and the individual manufacturing components in hydrogen will be performed. Insights gained will support qualifications of these materials for hydrogen service including:

- Transmission pipeline reliability: acceptable for hydrogen as a major energy carrier
- Transmission pipeline total capital cost $735k per mile (2015)
- Transmission pipeline total capital cost $715k, per mile (2020)
- H_2 delivery cost <$0.90/gasoline gallon equivalent
- H_2 pipeline leakage: <780 kg/mi/y (2020)

FY 2013 Accomplishments

In FY 2013, the SRNL project has focused on development of the technical basis needed for codification of FRP material into the ASME B31.12 Hydrogen Piping Code. The material testing in FY 2013 focused on the development of a fatigue curve for unflawed FRP piping. The fatigue tests were performed over a range of pressure between 750 psi and 3,000 psi. The tests were performed on an FRP product with a rated pressure of 1,500 psi. The results from the fatigue testing provided insight into specific failure modes of the FRP mechanical joint. A technical report was completed in collaboration with Oak Ridge National Laboratory (ORNL) to compile all the data from the DOE FRP H_2 testing effort. The report will serve as the baseline technical document for FRP codification into ASME B31.2

- **FRP Materials Testing**
  The fatigue tests were performed over a range of pressure between 750 psi and 3,000 psi and a preliminary design fatigue curve was developed.
- **FRP Codification into ASME B31.12**
  Technical baseline report for FRP codification was completed.

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INTRODUCTION

The goal of the overall project is to successfully adapt spoolable FRP currently used in the oil industry for use in high-pressure hydrogen pipelines. The use of FRP materials for hydrogen service will rely on the demonstrated compatibility of these materials for pipeline service environments and operating conditions. The ability of the polymer piping to withstand degradation while in service, and development of the tools and data required for life management are imperative for successful implementation of these materials for hydrogen pipelines.

APPROACH

To achieve the objective an FRP life management plan was developed. The plan was a joint document developed by SRNL and the ASME to guide generation of a technical basis for safe use of FRP in delivery applications. The plan addresses the needed material evaluations and also focuses on the needed information for codification of FRP into the ASME B31 Code of Pressure Piping. The B31.12 Hydrogen Piping Code is the existing code that provides a consensus standard for the safe and reliable implementation of the piping in hydrogen service. This plan is designed to provide the needed information to support the codification of FRP. The B31.12 Code addresses the initial construction of piping systems. The plan also identifies the tasks needed for the post construction management of FRP to insure structural integrity through end of life. The plan calls for detailed investigation of the following areas:

- System Design and Applicable Codes and Standards
- Service Degradation of FRP
- Flaw Tolerance and Flaw Detection
- Integrity Management Plan
- Leak Detection and Operational Controls Evaluation
- Repair Evaluation

RESULTS

Fatigue Testing

Fatigue testing of FRP was initiated at SRNL in FY 2012 and continued through FY 2013. The material testing in FY 2013 focused on the development of a fatigue curve for unflawed FRP piping. The fatigue tests were performed over a range of pressure between 750 psi and 3,000 psi. The tests were performed on an FRP product with a rated pressure of 1,500 psi. The range of test pressure was selected to provide sufficient data to understand the general shape of the FRP fatigue curve. Figure 1 shows the fatigue test data and the preliminary design fatigue curve.

The first fatigue test was performed at the rated pressure of the FRP product of 1,500 psi. During the test a seal failure of the mechanical connection was observed at 14,424 cycles. The O-ring seals were replaced and the test continued. The 1,500 psi test sample has been cycled to 20,127 cycles where a structural failure of the pressure boundary occurred in the center span of the test sample. The second fatigue test at the 1,500 psi rated product pressure was cycled to failure. The second test failed at 16,233 cycles. The second test failed at the end of the pipe and the initial visual evaluation indicated issues with the end joint preparation may be a contributing factor. Additional failure analysis is being conducted.

Two fatigue tests were performed at 3,000 psi which is twice the product rated pressure. Tests were performed above the rated product pressure to provide data and understanding of the available margins if overpressure events occur in-service. During the first 3,000 psi test, seal failures occurred at 447 cycles followed by a structural failure of the pressure boundary at 593 cycles. A second 3,000 psi fatigue test failed in the pressure boundary at 681 cycles. Inspection showed damage to the o-ring at completion of the second 3,000 psi fatigue test, but no seal failure occurred.

One fatigue test has been completed at 750 psi which is half the products rated pressure. The test sample has been cycled to 40,700 cycles without a structural failure where the test was terminated. Seal failure was observed at 23,071 cycles. The o-rings were replaced and the test was

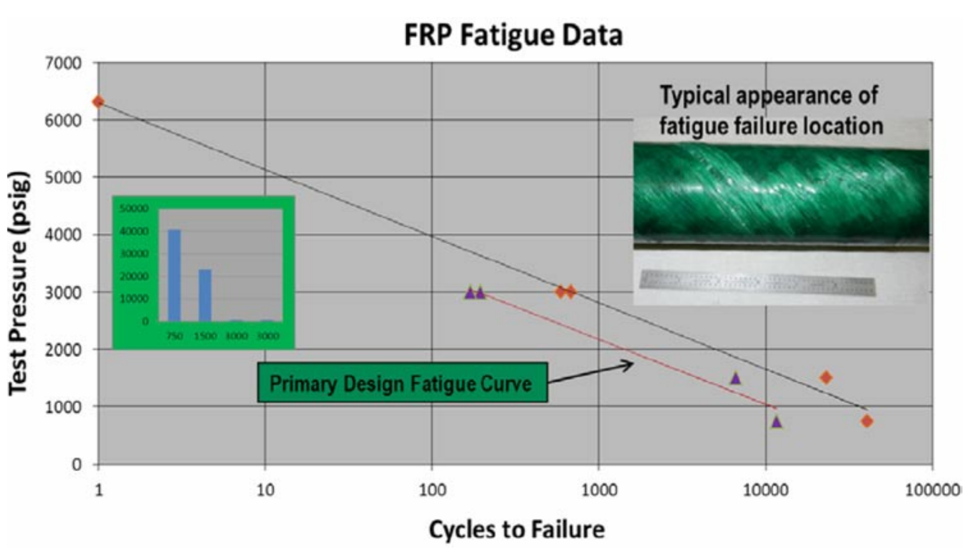

FIGURE 1. FRP Preliminary Fatigue Curve

completed. The o-ring damage was less severe than in the 1,500 and 3,000 psi tests.

The results from the fatigue testing provided insight into specific failure modes of the FRP mechanical joint as shown in Figure 2. The connectors are all metallic with elastomer o-ring seals. To form the connection the internal diameter of the polyethylene liner is machined to a specified diameter. The machined portion of the liner is where the o-rings in the metallic connector interface with the composite piping to form the fluid seal. The outer nut of the connector is tightened, mechanically compressing ferrules on the piping, resulting in compression of the seals.

O-ring failures occurred during the fatigue testing of the structural layer at all pressure levels. The o-ring failures show classic indication of extrusion from their retaining groove. The failure, shown in Figure 3, is a progressive distortion of the o-ring from the fatigue loading. The o-rings did not leak while testing with hydrogen or during burst testing.

Testing of the o-ring material showed that the material hardness (durometer level) was lower than the specified design value. Tested values showed that the rubber hardness was approximately 60 Durometer M. Values of 70 to 90 would be required based on literature data. Subsequent testing with high durometer o-rings (85 Durometer M) has resolved this issue. The o-ring data provides valuable insight into needed code examination.

ASME B31.12 Codification

A report summarizing the FRP testing by SRNL and ORNL has been completed. The report will become the basis for ASME Codification of FRP into the B31.12 Hydrogen Piping Code. Review comments from ASME, ORNL and Fiberspar (an FRP manufacturer) have been incorporated into the technical basis report. The report will be updated to include the 2013 fatigue testing data and the service experience data obtained from Fiberspar. The revised report will be provided to the ASME B31.12 Code Committee for peer review in September 2013.

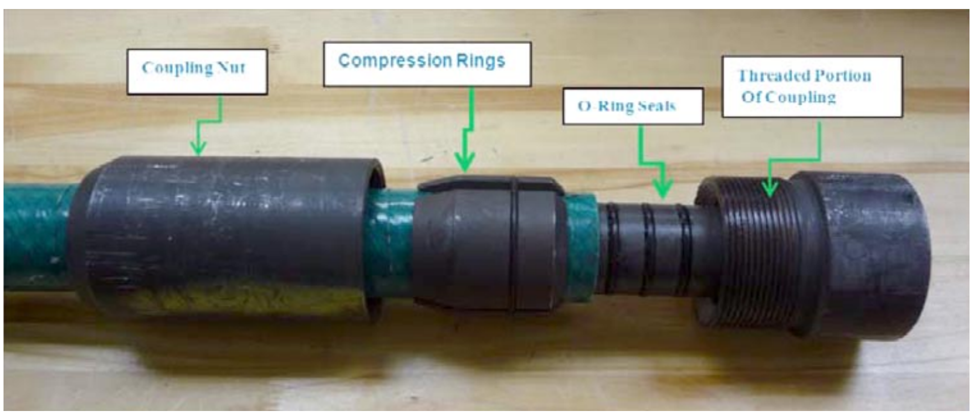

FIGURE 2. Components of FRP Compression Connector

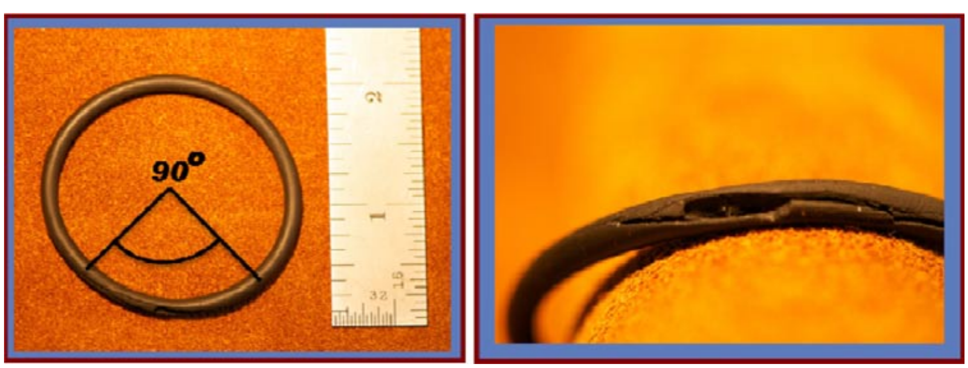

FIGURE 3. O-Ring Damage 3,000 psig Fatigue Test

CONCLUSIONS AND FUTURE DIRECTIONS

Conclusions

- FRP is an attractive technology with potential to support the DOE goal to reduce overall pipeline installation cost.
- Fatigue testing over the range of 750 psig to 3,000 psig has been completed. The data provide an initial indication on the fatigue life of FRP. The variability in the data still needs additional investigation. A preliminary design fatigue curve has been proposed based the current test data with a design margin applied based on literature review to estimate the variability.
- Fatigue testing of flaw FRP has been conducted. These tests have shown that a flaw will affect the fatigue life of FRP. These flawed fatigue test provide valuable information for installation and inspection requirements.
- The o-ring failures are a not structural failure of the pressure boundary, but still provide valuable data for the FRP codification process. The results of the o-ring failure analysis will be applied to specify attributes of the connector for examination, and types of examinations that need to be performed during fabrication and installation of the mechanical joint for the FRP pipeline.
- A report summarizing the FRP testing by SRNL and ORNL has been completed. The report will become the basis for ASME Codification of FRP. Review comments from ASME, ORNL and Fiberspar have been incorporated.

Future Work

- Perform additional fatigue testing in collaboration with Fiberspar to determine the variability in the fatigue data.
- Collect and document available service history data for FRP from literature and FRP manufacturers.
- Perform a long-term stress rupture test for flawed FRP samples.
- Evaluate non-mechanical joints for FRP application.
- Development inspection criteria for FRP joint based on conclusion from o-ring fatigue failures.
- Complete FRP Codification into ASME B31.12.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. Gaseous Hydrogen Embrittlement of Materials in Energy Technologies, Chapter 1, Hydrogen Production and Containment, Woodhead Publishing, 2012.

2. SRNL FRP Piping Project, Presentation to Hydrogen Delivery Technology Team, Washington, DC, August 2012.

3. DOE Polymer and Composite Materials for Hydrogen Service Meeting, Washington, DC, October 2012.

4. Fiber Reinforced Composite Pipelines, Presentation to ASME B31.12 Committee Chairman, Phoenix, AZ, November 2012.