III.6 Fiber Reinforced Composite Pipeline

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Fiscal Year (FY) 2011 Objectives

Fiber Reinforced Composite Pipeline (FRP)

- Focused evaluation of FRP for hydrogen service applications.
- Development of data needed for life management and codification FRP technical barriers.

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

(D) High Capital Cost and Hydrogen Embrittlement of Pipelines
(I) 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 the fiber reinforced piping and joining components needed for hydrogen delivery are addressed. Insights gained will support qualifications of these materials for hydrogen service including the DOE 2012 delivery targets:

- Pipeline Transmission and Distribution Cost: \$0.6 M/mile and 0.27 M/mile, respectively.
- Hydrogen Leakage: to be determined, <0.5% by 2017.

FY 2011 Accomplishments

- Multiple burst tests of FRP samples were completed to evaluate the design margins for flawed fiber piping to evaluate the consequence of third party damage to pipelines.
- Chemical exposure test of flaw samples were completed to evaluate address the influence of soil pH on FRP design margins.
- Completed initial literature review of flaw detection methodologies for FRP.

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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 pipeline.

In FY 2009 a FRP life management plan was developed by SRNL and the American Society of Mechanical Engineers (ASME) to focus the direction for the research and testing needed to have FRP codified in the ASME B31.12 Hydrogen Piping Code. The plan also provided 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

Approach

SRNL has completed the first areas of the Life Management Plan. Codes and standards for the high-pressure piping, process, and transport pressure vessels were reviewed and design margins and qualification techniques evaluated.

SRNL and Oak Ridge National Laboratory (ORNL) have collaborated on evaluating the service degradation of FRP in high-pressure hydrogen. Initial laboratory testing indicated that there is not a degradation mechanism connected with the use of hydrogen in FRP. The codes and standard development organizations would like additional long-term data on this question to ensure the long-term life management of FRP.

SRNL has begun investigation to determine the flaw tolerance of FRP products. Creep data on glass fiber was also reviewed to evaluate the effect of creep life on the glass fiber. The results indicate that a deign margin of at least 3.5 is required to address long-term creep effects for a 20+ year design life. The use of the fiberglass creep data has been effective in evaluating the effect of flaw tolerance using a short-term burst test. Multiple tests have been completed to evaluate the effect of flaw tolerance on FRP samples for FRP designed to a recognized national consensus standard were used in the evaluation. Flaws for various depths were machined into the samples and burst tests have been performed.

Tests have also been performed to evaluate the effect of chemical environment on the FRP. The purpose of the chemical exposure tests are used to determine a measure of soil pH on the FRP materials. The first series of tests measured the chemical resistance of S- and E-type fiberglass strands that are typical of those that are used to fabricate the load-bearing overwrap used for the composite pipeline segments. Type S and E glass fiberglass strands were exposed to aggressive chemical environments in order to determine bounds on the base mechanical properties of tensile strength and chemical resistance. These bounds were comparable to technical literature on the subject [1] which have not been chemically exposed. These samples were subjected to solutions of pH 2.4, 7 and 10.6 for periods of either 24 hours or 120 hours (5 days) and then subjected to tensile strength testing using an Istron 4507 Electromechanical System with a strain rate of 200 µm/sec per ASTM 1557-03. Additionally, two flawed pipe sections were exposed to the same pH levels for 120 hours and burst tested.

Results

To address third party damage the sensitivity of FRP to flaws must be established. The flaw testing was performed over a range of flaw sizes to determine the flaw tolerance of the FRP. FRP with single layer reinforcement and multi-layer reinforcement were evaluated.

The results of the single layer FRP tests are shown in Figure 1. A reduction in burst pressure from unflawed condition to a 2-inch long flaw cutting the reinforcing layer of 75% was observed. With the 2-inch long flaw cutting the reinforcing layer the burst pressure drops below the rated pressure for the single-layer product The single layer reinforced piping does not provide sufficient redundancy to tolerate third party damage. Following a review of the results from the piping with the single layer reinforcement, it was determined that this type of fiber-reinforced piping was not an acceptable option for hydrogen piping.

The results of the multi-layer FRP tests are provided in Figure 2. Tests were conducted for increasing flaw depths up to 40% through wall. A 28% reduction in burst pressure from the unflawed condition to a 40% through wall flaw was observed. With the 40% through wall flaw there is still a margin of approximately 3x above the rated pressure of the FRP multi-layered product. The margin on burst of 3 provides an acceptable remaining product life to detect and repair flaws in FRP systems. Additional burst tests were conducted in on FRP samples with 40% through wall flaws to determine the variability between different samples. The results of the additional tests show that the variability between the tests is low and that all tests provide an acceptable design margin. The results for increasing the flaw length and width are also shown in Figure 1. The flaw with increased length showed no additional loss in design margin above the base flaw length. The flaw with increased width showed a small additional loss in design margin above the base flaw width. Two FRP samples were exposed to the high and low pH solutions and burst tested. The results are shown in Figure 2. The failure pressure for the chemically exposed samples fell within the variability of the unexposed data.

From the flawed samples, it was observed that as the flaw depth increased the failure mode changed from a local failure to a more global failure mode. The series of photos shown in Figure 3 illustrates these failure modes. The first photo from the left shows the failure of the unflawed sample indicating a global failure of the pipe. The next three photos illustrate how the failure mode changed as the flaw depth increased. The last photo on the right shows the 40% through wall flaw. In the 40% through wall photo, the failure encompasses most of the pipe circumference. Based on this data it was determined that the 40% through flaw was a reasonable upper limit to set for flaw detection.

The test results for glass fiber strands exposed to high and low pH solutions are shown in Figure 4. The red and blue curves in Figure 4 show the results for the untreated E- and S-type samples. As can be seen, mechanical failure typically occurred for the untreated samples below the 3% strain threshold, with the both samples showing

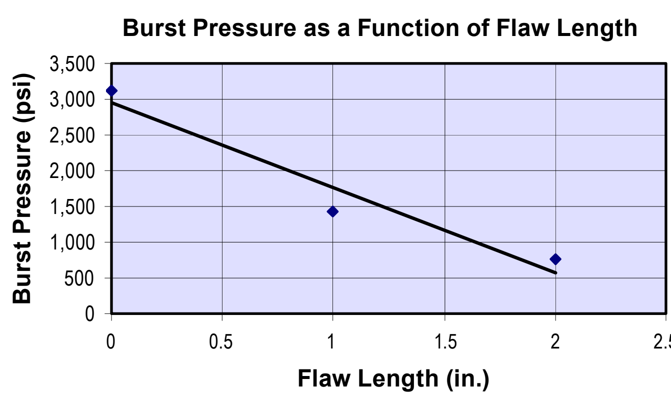

FIGURE 1. Single-Layer FRP Burst Test

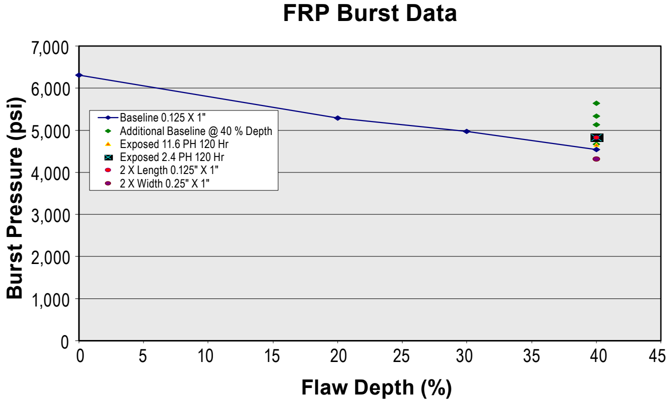

FIGURE 2. Multi-Layer FRP Flaw Tests

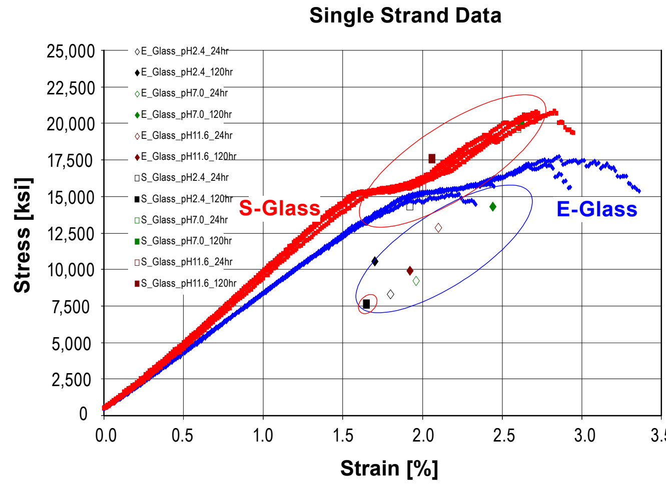

FIGURE 4. Test Results for Glass Fiber Strands

FIGURE 3. Photo Illustrating Failure Mode of FRP

reproducibility in the strain point of the initial point of failure. These tests were performed using thread grips and the samples were inspected after testing to ensure that failure occurred in a position not associated with applied stress or pinching at the grip surfaces.

Samples were taken from the same lot of fiberglass and were subjected to the chemical environments described above. The data in the blue circle provides the failure strain for the chemically exposed samples. It can be seen from a review of the chemically exposed data that the aggressive chemical environments can have a deleterious effect on their mechanical properties of the uncoated glass samples. Additional testing on chemically exposed uncoated glass sample indicated the effect of the chemical environment had resulted in corrosion of glass. Because the glass fibers are epoxy coated in the actual FRP product form, chemical exposure tests were conducted on flawed FRP samples. Two FRP samples were exposed to the high and low pH solutions and burst tested. The results are shown in Figure 2. The failure pressure for the chemically exposed samples fell within the variability of the unexposed data.

To establish a life management program the ability to detect external flaws in FRP by applying internal examination or smart pipe technology is needed for controlling failures and maintaining acceptable safety margins. The laser profilometry method is one technique to be investigated for inner diameter examination of FRP. In FY 2011 SRNL began work on flaw detection. A literature review was begun to investigate the potential for flaw detection using the laser profilometry method. In addition, to determine the effect of small flaws on FRP geometry, a flawed sample of FRP was pressurized to the rated design pressure and the sample was monitored for swelling. The initial result indicate that for the small flaw sizes the geometry changes for the sample will be negligible. The initial review for flaw detection data points to the need for smart pipe technology or an external flaw detection scheme.

Conclusions and Future Directions

Conclusions

- FRP is an attractive technology with potential to reduce overall pipeline installation cost.
- Field case studies indicate 20-60% reduced cost over steel pipeline.
- American Petroleum Institute standard 15HR is the most relevant standard reviewed to date for the fabrication of FRP line pipe for hydrogen service. This standard can be tailored to address the need for hydrogen pipelines.

- Flaw tolerance tests show that for flaws up 40% through reinforcement and up to 2 inch length and 0.25 inch width a factor of 3X margin is maintained on rated pressure.
- The current recommendation is to develop a performance-based design specification to be included in ASME B31.12.
- Workshop to discuss next steps toward ASME codification to be held in FY 2011.

Future Work

- Perform long-term stress rupture test for flawed FRP samples.
- Performed additional burst testing of flawed FRP samples on aged samples.
- Recommend performance qualification tests for FRP in hydrogen service to the ASME B31.12 committee.
- Evaluate B31.8S (Managing System Integrity of Gas Pipelines) for changes needed to address FRP in hydrogen service.
- Develop FRP hydrogen demonstration loop project among DOE, State of South Carolina, Aiken County, SRNL, ORNL, and ASME.

FY 2011 Presentations

1. SRNL FRP Piping Project, Presentation to Hydrogen Delivery Tech Team, Detroit MI, December, 2010.

2. SRNL FRP Piping Project, Presentation to Hydrogen Delivery Pipeline Working Group, Boulder, CO, April 2011.