III.9 Fiber Reinforced Composite Pipelines

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Project End Date: October 1, 2012

Objectives

Fiber Reinforced Composite (FRC) Pipeline

- Focused evaluation of FRC piping for hydrogen service applications.
- Development of structural integrity life management methodology.
- Evaluation of structural integrity – environmental effects and flaw tolerance.

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 FRC piping for hydrogen service applications. Assessment of the structural integrity of the FRC piping and the individual manufacturing components in hydrogen will be performed. Insights gained will support qualifications of these materials for hydrogen service including the DOE 2012 delivery targets:

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

Accomplishments

- Completed plan for life management methodology of FRC.
- Completed review of existing FRC design specifications/standards.
- Initiated FRC environmental effects testing.
- Initiated FRC flaw tolerance testing.

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Introduction

The use of FRC piping 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, the fiber strength wrapping to resist hydrogen attack, and the fiber-resin interface to remain intact are all critical to the successful implementation of these materials for hydrogen pipeline. The goal of the overall project is to successfully adapt spoolable FRC from oil and natural gas use to high-pressure hydrogen use. In Fiscal Year (FY) 2010 an FRC life management plan was developed by SRNL and ASME to focus the direction for the research and testing needed to have FRC codified in the ASME B31.12 Hydrogen Piping Code. The plan also provided the tasks needed for the post construction management of FRC 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 FRC
- Flaw tolerance and flaw detection
- Integrity management plan
- Leak detection and operational controls evaluation
- Repair evaluation

Approach

SRNL has begun investigation into the first three areas of the Life Management Plan. Codes and standards for the high-pressure FRC and process and transport pressure vessels were reviewed. Creep data on glass fiber was also reviewed to evaluate the effect of creep life on the glass fiber. The results indicate that a design margin of at least 3.5 is required to address long-term creep effects.

The effect of flaw tolerance has also been evaluated in the current FY 2010 funding. Samples for FRC design 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.

Additional test have been performed to evaluate the effect of chemical environment on the FRC. The purpose of the chemical exposure tests are used to determine a measure of soil pH on the FRC materials. The first series of tests measured the chemical resistance of S- and E-type fiberglass strands typical of those which are used to fabricate the load-bearing overwrap used for the composite pipeline segments.

Results

S and E glass fiberglass strands were exposed to aggressive chemical environments in order to determine reasonable bounds on the base mechanical properties of tensile strength and chemical resistance. These bounds were adopted by consultation with technical literature on the subject [1] as representative of the range where reasonable differences might be observed relative to samples which have not seen chemical exposure. 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). These samples were then subjected to tensile strength testing using an Istron 4507 Electromechanical System with a strain rate of 200 µm/sec per ASTM 1557-03.

Results typical of these tests are shown in Figures 1 and 2. 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. As can be seen, mechanical failure typically occurred for the untreated samples below the 3% strain threshold, with the both samples showing impressive reproducibility in the strain point of the initial point of failure.

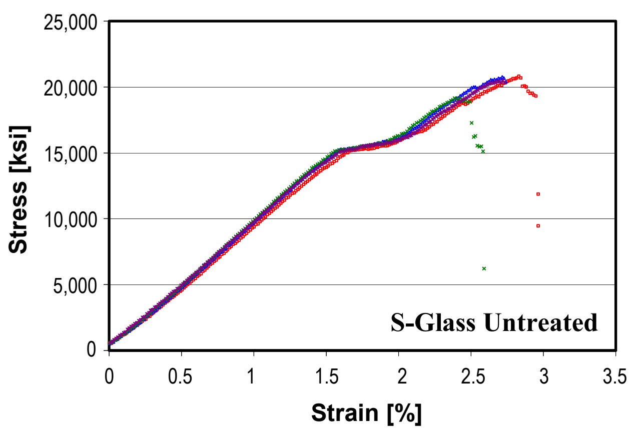

FIGURE 1. Tensile Strength for Untreated S-Glass Fiberglass as a Function of Applied Strain

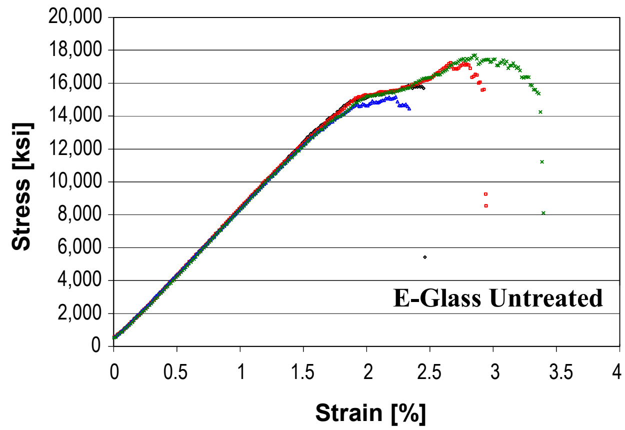

FIGURE 2. Tensile Strength for Untreated E-Glass Fiberglass as a Function of Applied Strain

A series of tests have been performed to evaluate the burst capacity for FRC containing flaws.

Samples were taken from the same lot of fiberglass and were subjected to the chemical environments described above. These results are summarized in Table 1. S-Glass samples are, in most cases, the stronger of the two fiberglass make-ups, which is consistent with technical literature available on the subject. It can be seen that the aggressive chemical environments that the samples are subjected to have a deleterious effect on their mechanical properties, as is expected. These results confirm that preconditioning of the component fiberglass materials in harsh chemical environments can have an effect on the overall mechanical durability of the composite pipeline materials, and thus is an area that warrants continued scrutiny in the development of the

TABLE 1. Summary of Tensile Strength Testing for Fiberglass Samples Exposed to Solutions of Varied pH. All Results Given in Units of ksi.

Untreated Fiberglass Samples		
All Units ksi	S-Glass	E-Glass
--	19,971	16,486
Treated S-Glass Samples		
pH\Time of Exposure	24 hours	120 hours
2.4	14,325	7,611
7	19,629	19,941
11.6	15,667	17,552
Treated E-Glass Samples		
pH\Time of Exposure	24 hours	120 hours
2.4	13,432	10,528
7	9,227	14,270
11.6	12,831	9,928

high-density polyethylene pipelines for hydrogen service. It should also be noted, however, that the test conditions to which these glass samples were exposed are very aggressive and do not necessarily represent actual field conditions; these test conditions were selected to demonstrate the potential for an environmental effect and to highlight the need for further work and consideration of this potential effect.

To address third party damage issues 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 FRC piping. FRC piping with single-layer reinforcement and multi-layer reinforcement was evaluated. The results of the single-layer tests are shown in Figure 3. 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. The results of the multi-layer tests are provided in Figure 4; reduction in burst pressure from the

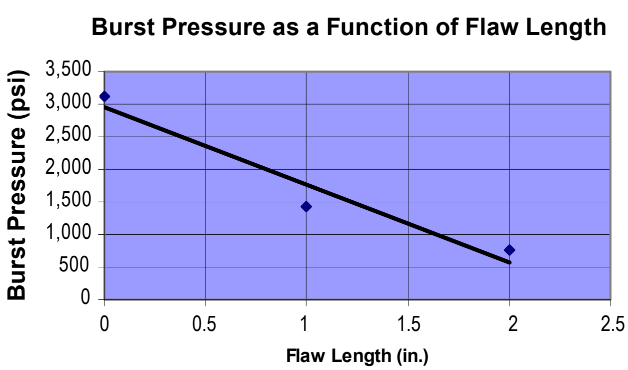

FIGURE 3. Single-Layer FRC Piping Flaw Tests

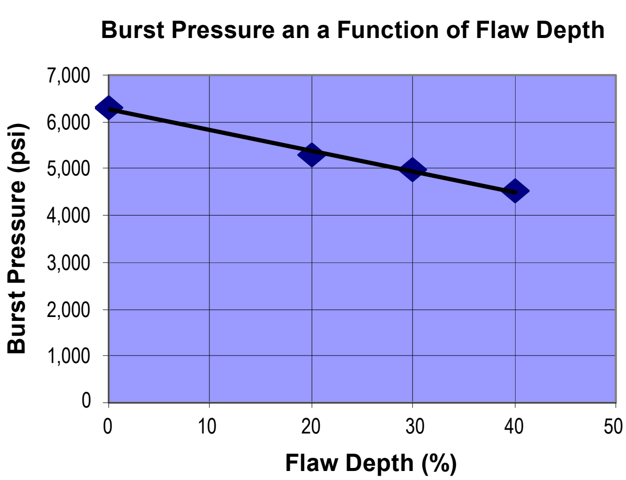

FIGURE 4. Multi-Layer FRC Piping Flaw Tests

unflawed condition to a 40% through wall flaw of 28% were observed. With the 40% through wall flaw there is still a margin of 3 above the rated pressure of the FRC multi-layered piping product. Larger flaws and creep effects still need to be reviewed for the multi-layered FRC product.

Conclusions and Future Directions

Conclusions

- FRC Pipe Fabricated API 15HR is the most relevant standard reviewed to date for the fabrication of FRC line pipe for hydrogen service. This standard can be tailored to address the need for hydrogen pipelines
- Scoping tests show that the burst pressure obtained using the ASTM D2992 (Hydrostatic Design Basis) provides additional design margin above what is needed for stress rupture when compared to the Lawrence Livermore National Laboratory long-term tests. This additional margin provides needed excess capacity to address third party damage and environmental effects.
- The initial environmental test indicate that a service factor for will need to be evaluated for all installations. Acceptable performance tests need to be developed to address the field environmental effects and flaw tolerance.

Future Work

- Initiate FRC life management methodology development.
- Initiate flaw tolerance/third party damage testing for FRC piping.
- Evaluation of environmental degradation of FRC piping.

FY 2010 Publications/Presentations

1. SRNL FRP Piping Project, Presentation to Hydrogen Delivery Pipeline Working Group, NIST Boulder, CO, August, 2009.