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Fiber Reinforced Composite Pipelines

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Savannah River National Laboratory

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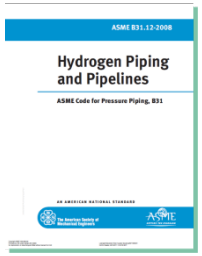


Project ID #: PD022

This presentation does not contain proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Project start date:10/2006
- Project end date:10/2017*

* The completion of this project is at the discretion of DOE based on program needs

Barriers

- High Capital Cost and Hydrogen Embrittlement of Pipelines ($490K/mile Transmission and $190K/mile Distribution Costs
- Safety, Codes and Standards, Permitting

Budget

- Funding for FY11
  - FRP Pipeline $150K
- Funding for FY12
  - FRP Pipeline $175K
  - Demo Project ($100K Pending)

Partners

- Commercial FRP Manufacturers
- ASME
- ORNL
- Aiken County (Demo Project)
- Gas Pipeline Co. (Demo Project Pending)

Relevance – 2010 DOE Technical Targets

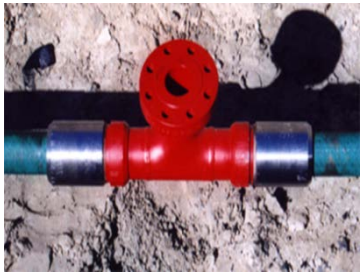
"Develop hydrogen fuel delivery technologies that enable the introduction and long long-term viability of hydrogen as an energy carrier for transportation and stationary power"

-DOE Hydrogen Delivery Goal

DOE Barriers	SRNL Goal
High Capital Cost and Hydrogen Embrittlement of Pipelines	Provide test data to support a technical basis to support fiber reinforced piping in hydrogen service. The specific details for implementation of FRP in Hydrogen service are addressed in an FRP Life Management Plan that SRNL developed in collaboration with ASME.
Safety, Codes and Standards, Permitting	Have FRP integrated into the ASME B31.12 Hydrogen Piping and Pipeline Code by 2015. The proposed SRNL Demonstration will facilitate codification, public acceptance and provide a test case for permitting.

FRP for H_2 Delivery

- **Impact:**
  - Composite pipeline technology has the potential to reduce installation costs and improve reliability for hydrogen pipelines.



- **Advantages to using FRP**:
  - Excellent burst and collapse pressure ratings
  - Large tensile and compression strengths
  - Superior chemical and corrosion resistance
  - Long lengths can be spooled for delivery
  - A few workers can install thousands of feet of pipeline per day

- **Existing Technology:**
  - FRP is an existing commercial technology currently employed in the oil & gas business—commercial product up to 6” diameter and 1500psig pressure rating

SRNL FRP FY 2012 Accomplishments

- **SRNL in collaboration with ASME has developed an FRP Life Management Plan**
  - Fatigue testing has been completed for both flawed and unflawed samples
- **FRP Codification into ASME B31.12**
  - Codification workshop with all stakeholders
  - Presented technical data on FRP to B31.12 Committee
- **Proposal to DOE for FRP Demonstration Project**
  - Working to develop project team and South Carolina support

FRP Life Management - Burst Testing

Evaluation of Third Party Damage

Multi - Layer Reinforcement

Baseline Flaw

Width 1”x 0.125”

40% Depth

- Reduction in Burst Pressure from unflawed condition to 40% through wall flaw of 28 % for short term burst and multiple layer reinforcement
- With the 40 % through wall flaw there is still a margin of approximately 3 above the rated pressure

Failure mode changes from global to local and then move back towards global as flaw depth increases

2 X Width 1”x 0.25”

40% Depth

2 X Length 2”x 0.125”

40% Depth

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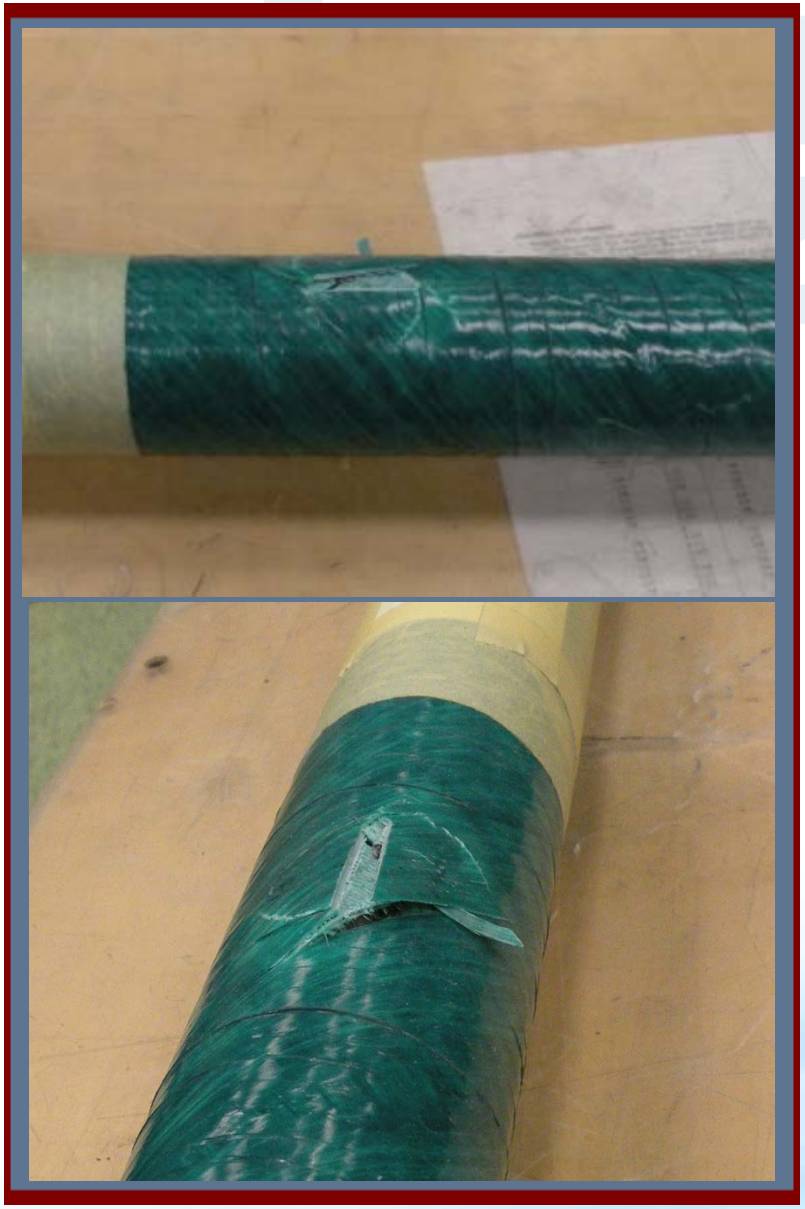
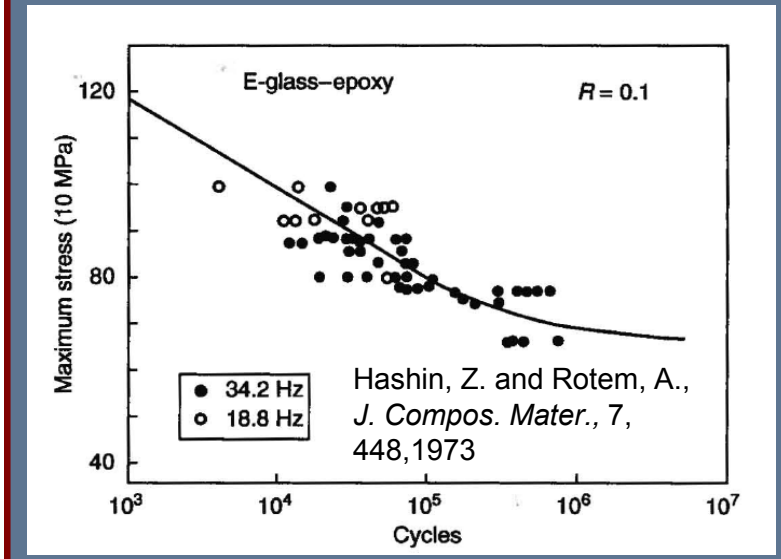
FRP Life Management – Structural Fatigue Testing

- Fatigue Tests have been performed on 2 flawed FRP samples.
- The samples were cycled with compressed nitrogen at 1500 psi which is the rated pressure of product.
- The baseline flaw (1” x 0.125”) a 40 % depth was tested.
- The pressure cycle interval was a minimum of 1 minute with a 30 second hold time at 1500 psi.
- The 2 flawed samples failed after 2830 and 4862 full design pressure cycles .



FRP Life Management - Structural Fatigue Testing

- An additional fatigue test was have performed on an unflawed FRP sample.
- The unflawed sample was cycled for 8077 full design pressure cycles.
- The unflawed sample was then burst tested and failed at 4935 psi which shows a 22% reduction over the burst tested sample without fatigue damage.
- The literature data supports the reduction in fiber tensile strength with fatigue cycles for glass fiber.



Hashin, Z. and Rotem, A., *J. Compos. Mater.*, 7, 448,1973

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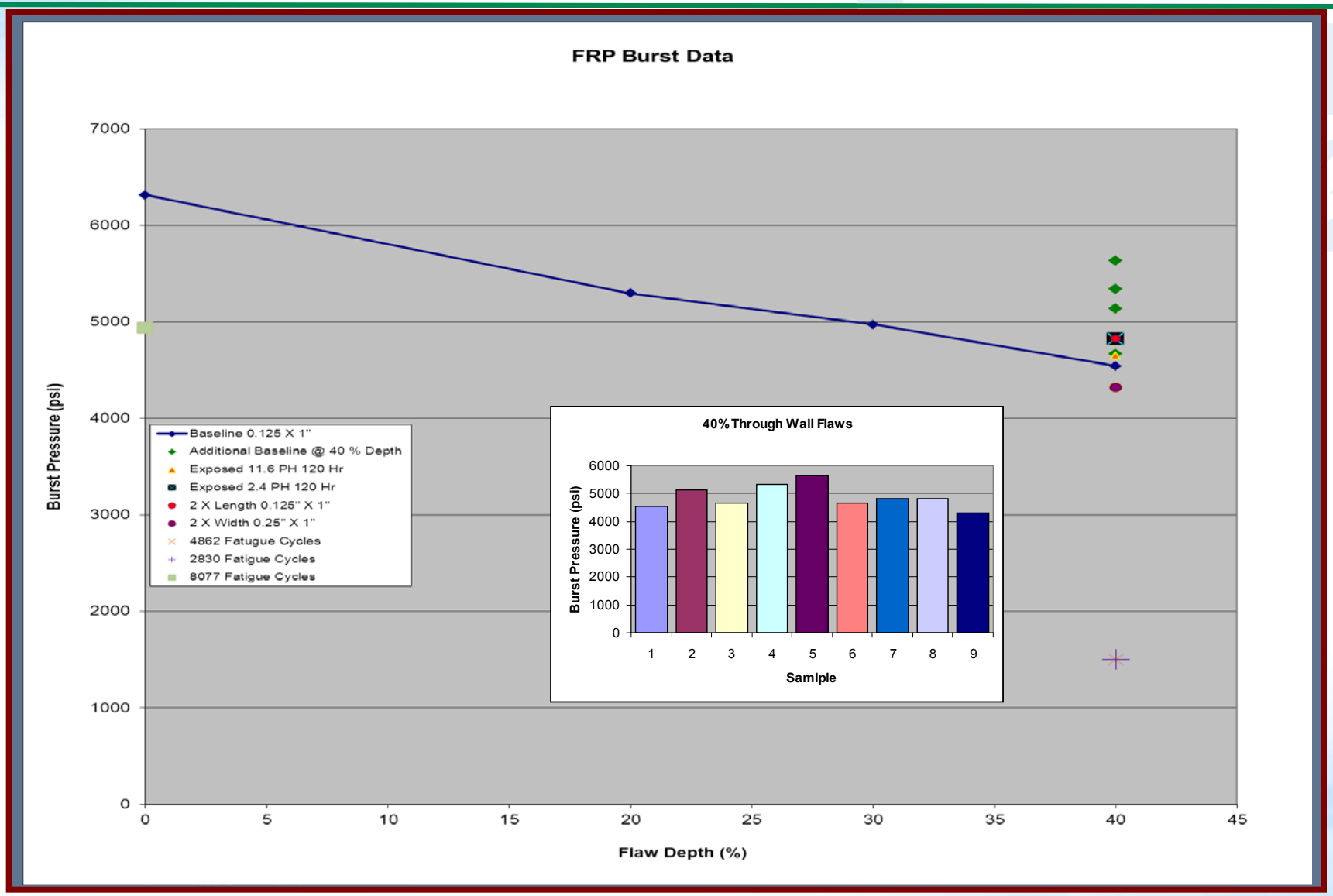
Fiber Reinforced Composite Pipeline Test Data



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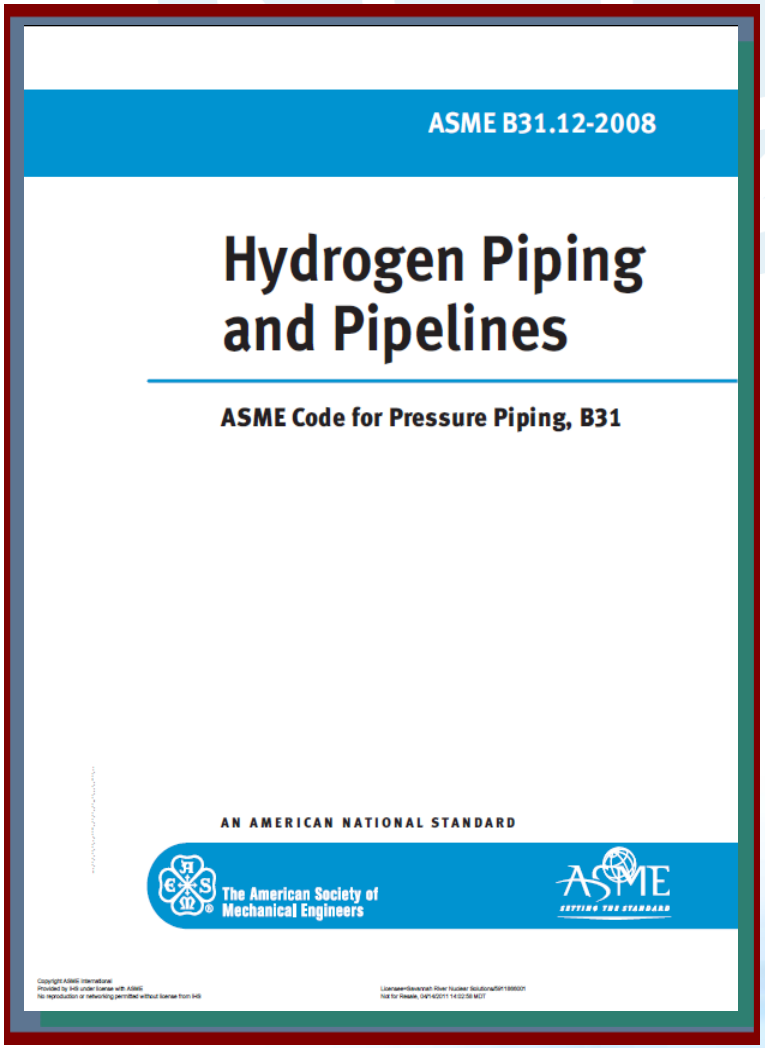
Fiber Reinforced Composite Pipeline - B31.12 Codification

- A workshop to discuss ASME B31.12 Codification of Fiber Reinforced Piping was held on August 16, 2011
- The workshop was attended by DOE, ASME, SRNL, ORNL, FRP Manufacturers, and Aiken County
- An outline of the proposed B31.12 Code section has been submitted to the B31.12 Code Committee
- The technical background for Codification of FRP was presented to the B31.12 Committee on March 15, 2012.
- A report summarizing the FRP testing by SRNL and ORNL will be prepared following feedback from the B31.12 Committee.


ASME B31.12-2008

Hydrogen Piping and Pipelines

ASME Code for Pressure Piping, B31

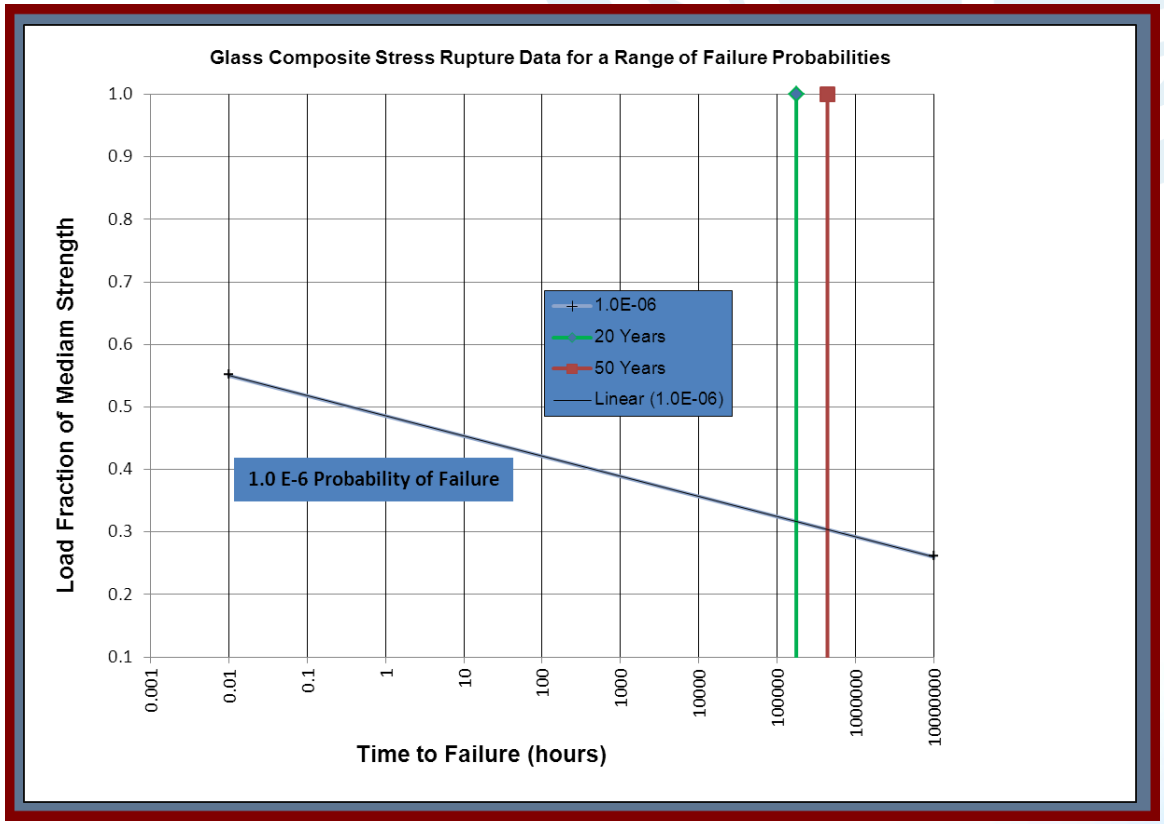
AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

ASME

Increased Design Life for FRP- ASME Comment

- The 20 year design life was questioned during the ASME review of the background data. One industrial gas supplier questioned the 20 year design life currently used in FRP Standards.
- Pipelines are a large capital investment for a 20 year design life.
- A draft ISO Standard 15399 is proposing a design life of up to 50 years.
- Review of the available stress rupture data indicates that only a small increase in design margin is required to support an increase to 50 years.



Robinson , Aerospace Corporation

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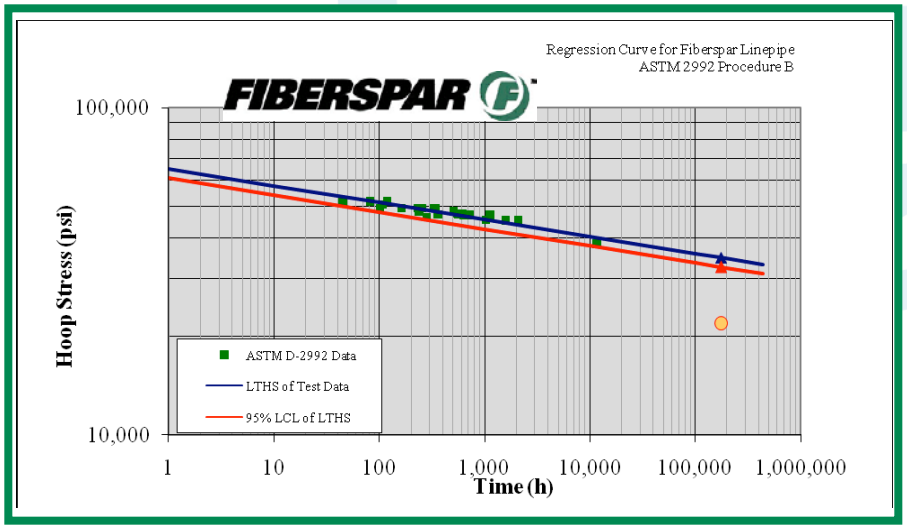
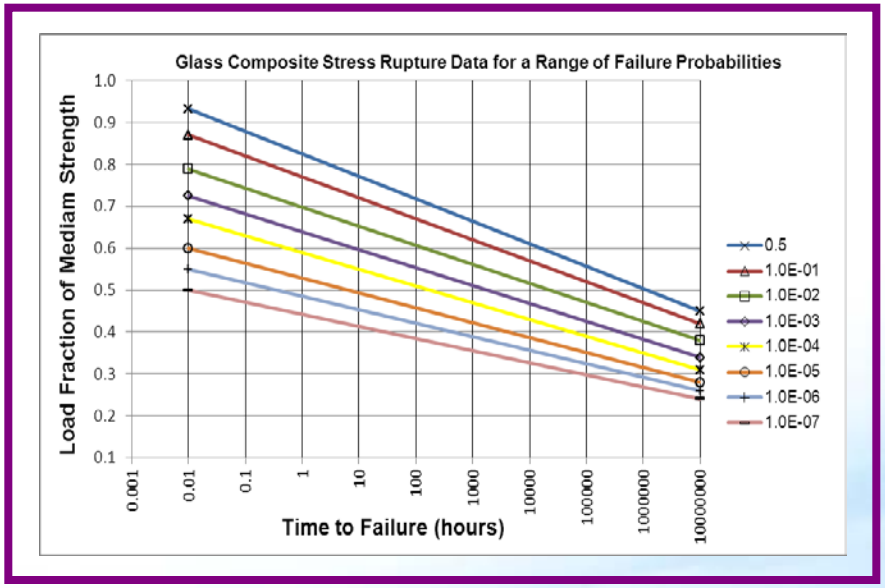
Design Margin for FRP

- Stress ratios are being set in newer standards to address reliability in regards to stress rupture as compared with the Hydrostatic Design Basis used in ASTM D2992.
- The date provided by Robinson, Aerospace Corporation has shown that a margin of 3.5 on the burst pressure (.28 Stress Ratio) will provide a creep rupture life of 25 years.
- Burst data for FRP Design to ASTM D2992 indicated that the margin on burst of 4.0 indicating that there is additional margin to address factors like third party damage, increased design life and environmental conditions.





Fiber Reinforced Composite Pipeline - B31.12 Codification

- **Standards Reviewed**
  - **API 15HR, Specification for High Pressure Fiberglass Line Pipe**
  - **AWWA C950 Fiberglass Pressure Pipe**
  - **ASME Code Case N-155-2 Fiberglass Reinforced Thermosetting Resin Pipe**
  - **ASME B31.3 Process Piping**
  - **ASME B31.8 Gas Transmission and Distribution Piping**
  - **ISO 14692 Petroleum and Natural Gas Industries Glass-reinforced plastics (GRP) piping**
- **These documents used the ASTM D2992 (Hydrostatic Design Basis) to establish an allowable design margin to address creep rupture. A performance based standard is needed to address all the technical issues for hydrogen pipelines.**

B31.12 FRP Codification - Elements for Code Section

- **Tailor requirements for FRP in H2 service from existing fiber reinforced piping standards and the ASME composite pressure vessel requirements.**
  - **Scope – Establish the design limits for the product.**
    - Product Form
    - Design Pressure Limits
    - Design Temperature Limits
    - Design Life
  - **Material - Additional controls on resigns and fibers will be required.**
    - Fibers
    - Resign System
    - Liner Material
  - **Design - Design to ASTM D2992 for the pressure design basis**
    - Design Pressure Basis
    - Maximum and Minimum Design Temperature
    - Protective Layer

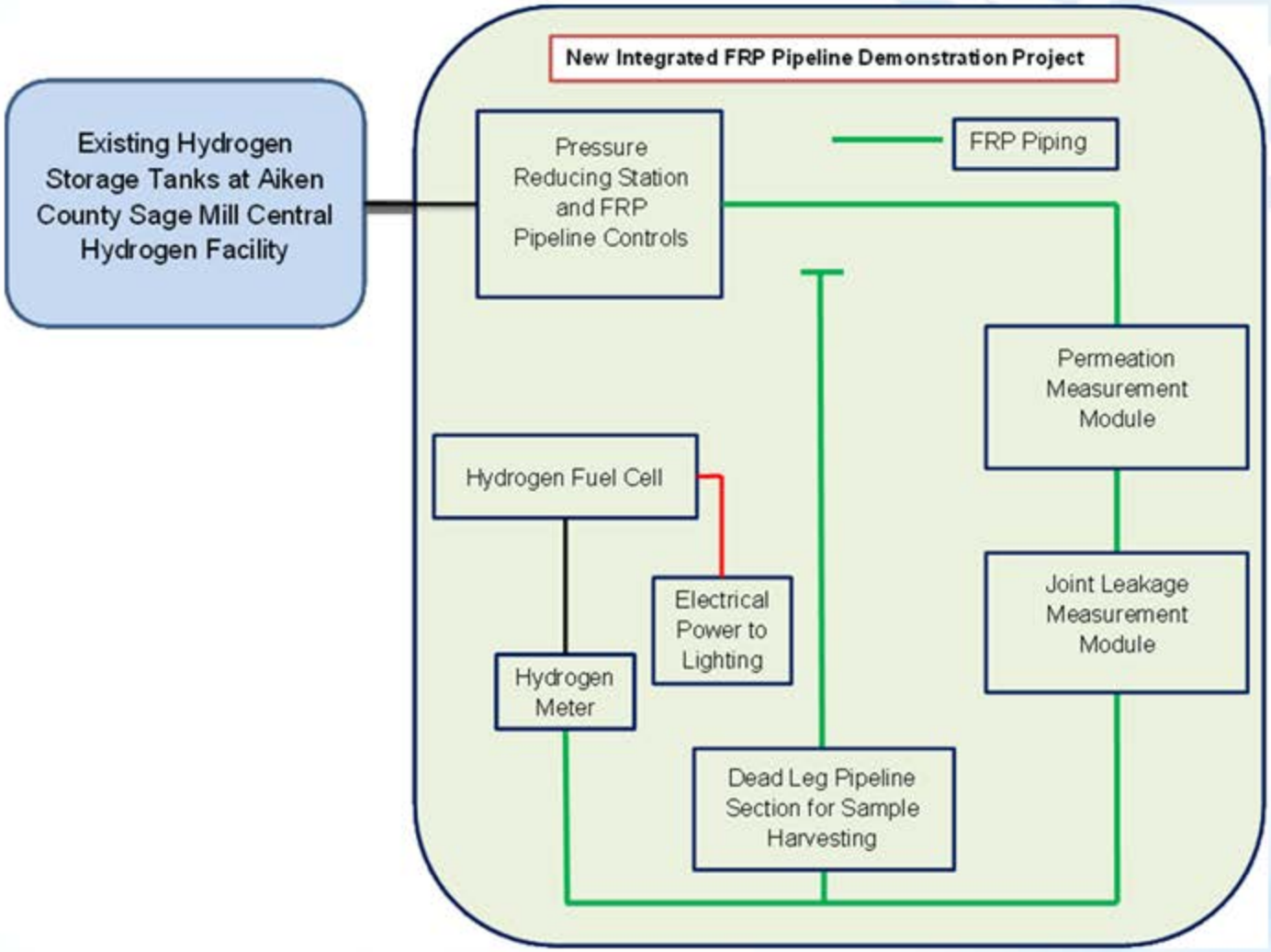
B31.12 FRP Codification

- **Elements for Code Section**
  - **Fabrication**
    - Manufacturing Specification to control resin and fiber
    - Supplementary Code Fabrication Requirements – (Mechanical Joint vs. Wrapped Joint)
  - **Examination**
    - Qualification of Nondestructive Testing Personnel
    - Manufacturing Examination Requirements
    - Supplementary Code Examination Requirements - Acceptable Flaw Size
  - **Testing**
    - Qualification Tests – Burst, Fatigue, Stress Rupture, Flaw Environmental, and Permeability
    - Production Tests - Quality Control burst tests on random production samples
  - **Inspection**
    - Supplementary Code Inspection Requirements

Hydrogen Pipeline Demonstration Project

- **Objective**
  - **Install a 1000' FRP pipeline operating in hydrogen service at a design pressure of 1500psi.**
  - **The pipeline would serve as a test and surveillance facility as a final proof of concept for FRP in Hydrogen Service.**
  - **The facility will have an integrated educational component for the public.**
- **Location**
  - **Savannah River National Laboratory with demonstration portions at the Sage Mill Central Hydrogen Facility located at Aiken County's Sage Mill Industrial Park.**
- **Partners**
  - **SRNL, Aiken County Economic Development Partnership, Center for Hydrogen Research, ORNL and ASME will partner with industry and government to provide an integrated hydrogen delivery demonstration project.**

Schematic of Hydrogen Pipeline Demonstration Facility



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Sage Mill Central Hydrogen Facility

•Partnership with Aiken County

•The Sage Mill Central Hydrogen Facility contains a 9000 gallon liquid hydrogen storage tank. Existing vaporizer and compressor stations transfer the liquid to a bank of tube storage vessels. The equipment is owned by Air Products and are placed on land owned by Aiken County

Clear Area Located at the Sage Mill Hydrogen Facility

Existing 9000 Gallon Liquid Hydrogen Storage Tank

Existing Gaseous Hydrogen Storage Vessels

Hydrogen Pipeline Demonstration Project Execution

Project Execution

- **Phase 1 - Conceptual Design (Possible Funding FY 12)**
  The project concept will be completely defined by the partners. Conceptual design will be developed . A detailed cost estimate will be prepared.

- **Phase 2 - Final Design and Permitting**
  Final design will be developed and permitting through the State will begin. South Carolina has state-wide permitting through the State Fire Marshall which will help expedite the project.

- **Phase 3 - Construction**
  The integrated demonstration will be constructed at the Sage Mill Industrial Park.

- **Phase 4 - System Start-Up and Operation**
  The pipeline will be filled with hydrogen and operation and monitoring of FRP performance will begin.

Summary

- FRP is an Attractive Technology with Potential to support the DOE Goal to Reduce Overall Pipeline Installation Cost.
- Flaw tolerance tests show that for flaws up to 40% through-reinforcement and up to 2 " length and 0.25" width a factor of 3X margin is maintained on rated pressure.
- Fatigue testing of both flaw and unflawed piping sections have been conducted. These tests have shown that fatigue cycles will effect the life of FRP. Additional fatigue testing is needed.
- SRNL has started working directly with the ASME B31.12 Committee to draft Code requirements for FRP.
- A proposal for an FRP pipeline demonstration project has been presented to DOE. SRNL will partner with ASME, ORNL and Aiken County to provide a demonstration project to support codification and life management of FRP.

Proposed Future Work – SRNL Scope for FRP

- Perform additional fatigue testing for FRP piping up to the full cyclic design life for pipelines.
- Perform long term stress rupture test for flawed FRP samples.
- Evaluate non-mechanical joints for pipeline application.
- Develop draft sections for ASME B31.12 Code for Hydrogen Piping and Pipeline and submit to Code Committee for review.
- Develop conceptual design for FRP demo project for implementation in FY 13.

Technical Back-Up Slides

FRP Life Management

- SRNL in collaboration with ASME has developed an FRP Life Management Plan

- Detail investigation is needed in 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

Experimental Testing

- Flaw Tolerance Testing
  - 40% Through Wall
  - 1-2” length
  - 0.125-0.25” width

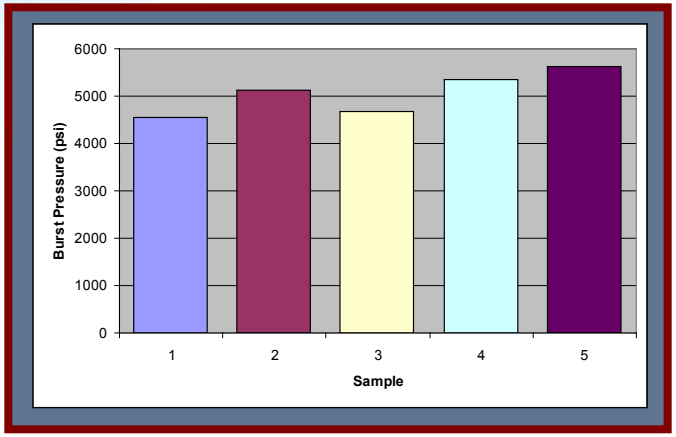
- Environmental Exposure Flaw Testing
  - 40% Through Wall
  - 1” length
  - 0.125” width
  - Exposure to pH 2.4 and 11.6@ 120 hrs

- Sustained Pressure Dimensional Stability
  - 1500psig (max rated pipe pressure)

- Joint Leakage
  - Bending Moment
  - Cyclic Load

Fiber Reinforced Composite Pipeline

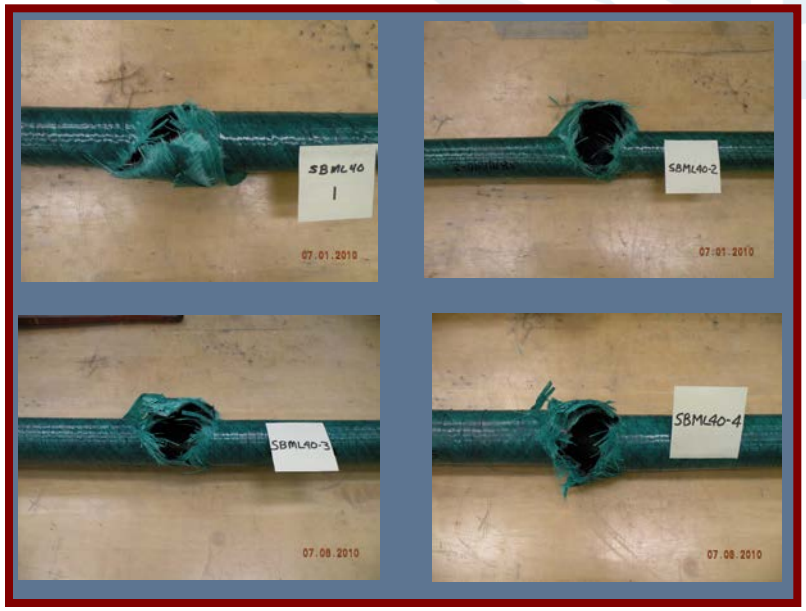
Evaluation of Third Party Damage Multi - Layer Reinforcement



Additional Baseline Flaw

1”x 0.125”

40% Depth

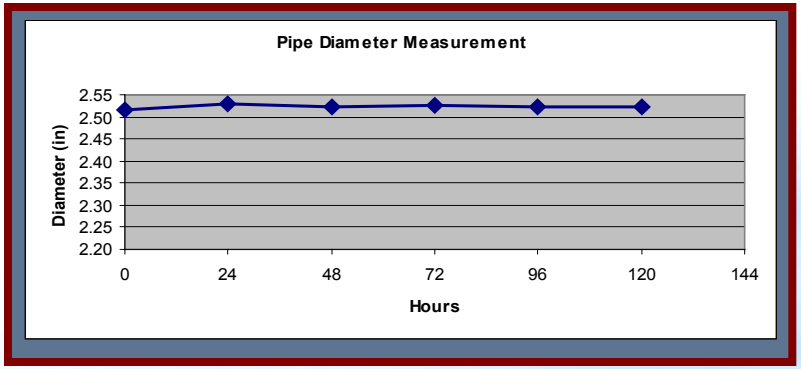


Baseline Flaw

1”x 0.125”

40% Depth

No Evidence of Bulging Under Sustained Pressure



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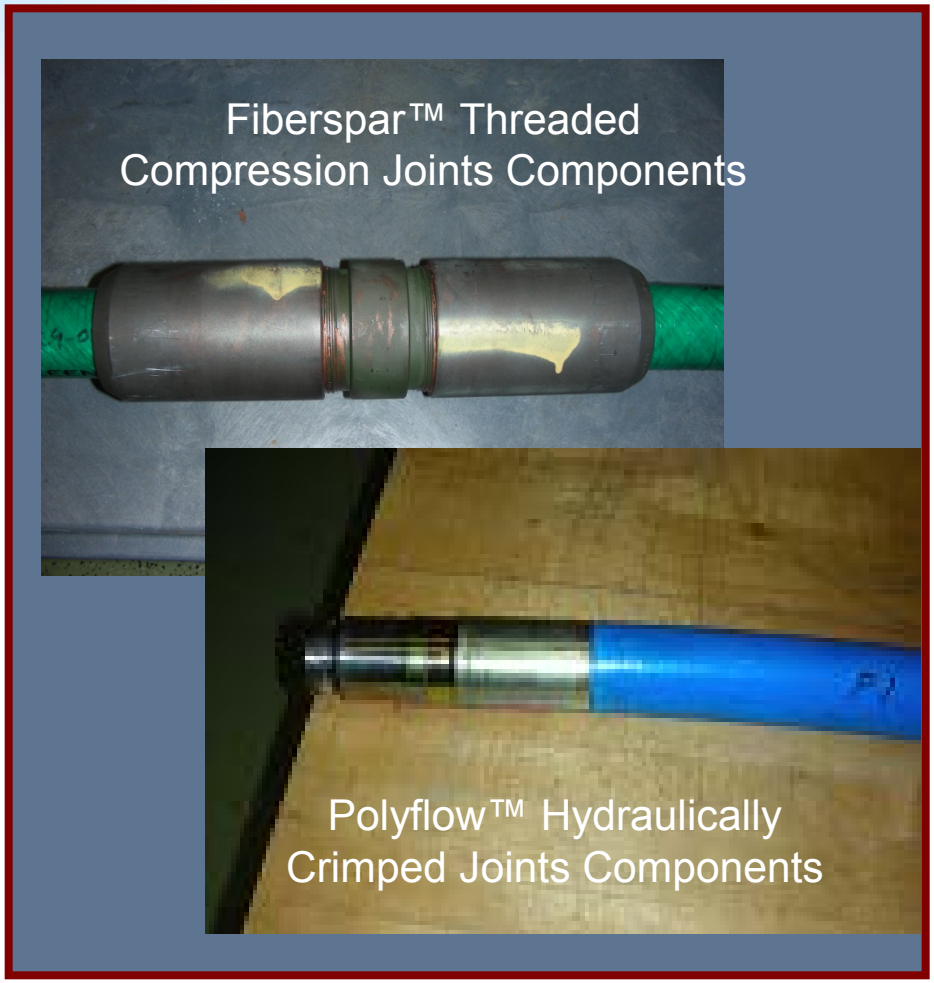
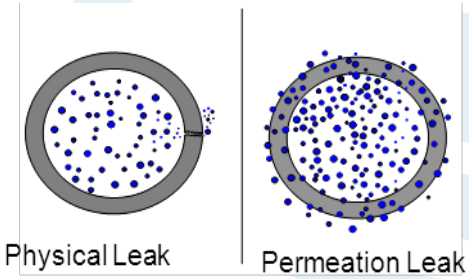
Fiber Reinforced Composite Pipeline Leak Testing



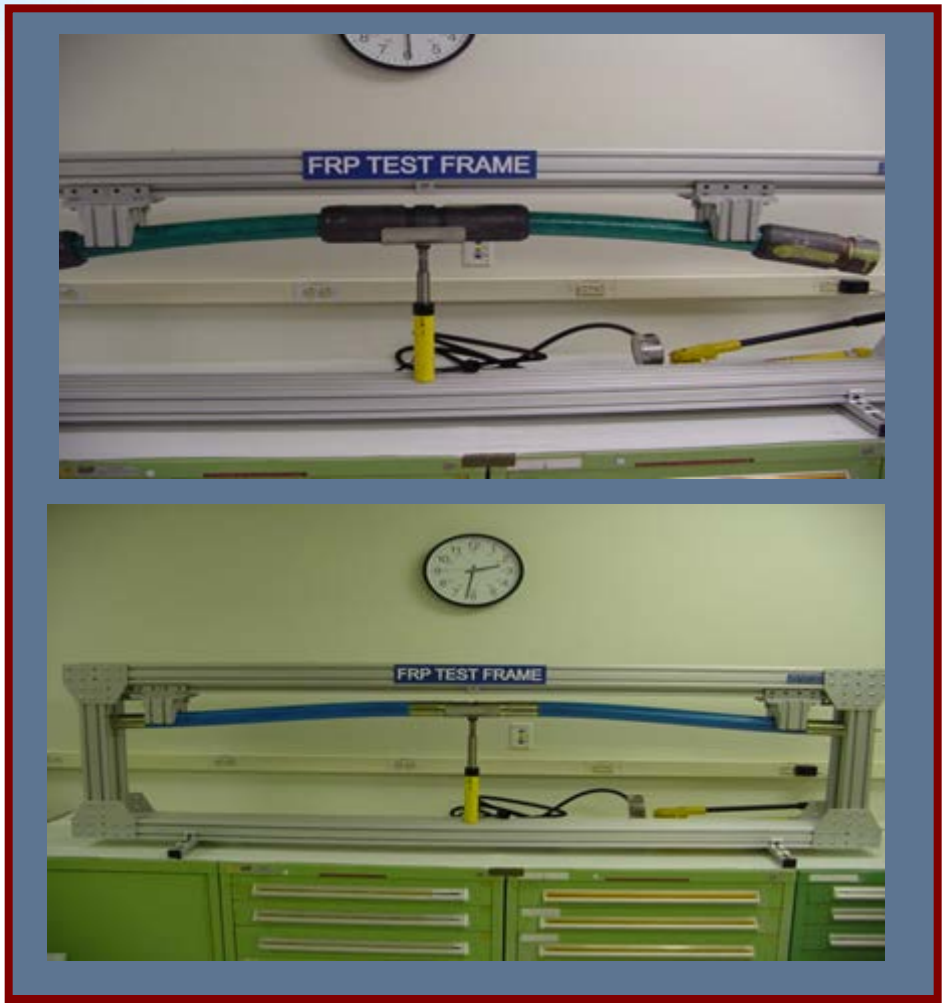


- **NASA Report NSS- 1740.16 Pressure boundary rupture only make up 14 percent of the hydrogen accidents. Accidents due to leakage and improper handling of hydrogen make up a greater percentage of the accidents.**

Sample	Leak Rate STD CC H_2/Sec
Fiber 1	9.8×10^{-5}
Poly 1	9.5×10^{-3}
Poly 1+	5.0×10^{-2}

Standard Code Leak Testing Evaluates Leak Rates on the Order of 10^{-2}-10^{-4}cc/sec of the fluid

Fiber Reinforced Composite Pipeline Test Under Applied Bending Load



- **DOT Gap Analysis Report Identifies 4 Major Needs for Composite FRP Piping**
  - Lack of Design Specifications
  - **Qualified Joints/Joining**
  - Permeation
  - Robustness to External Damage

- **Performed Hydrogen Leak Testing Measurements Using H_2 @ 1000 Psi Sensitivity of 10^{-5}-10^{-6} cc/sec**
- **Loaded in 3 Point Bending--2 Inch Displacement**

Sample	Leak Rate STD CC H_2/Sec
Fiber 1	1.4×10^{-4}
Poly 1 Cycled	8.9×10^{-4}
Poly 1+	8.1×10^{-4}

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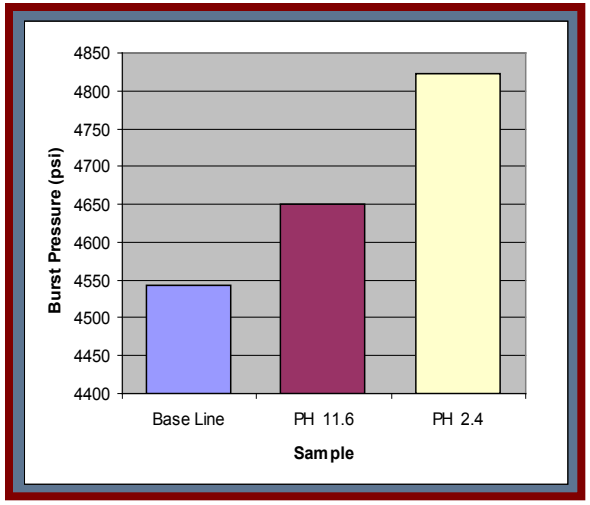
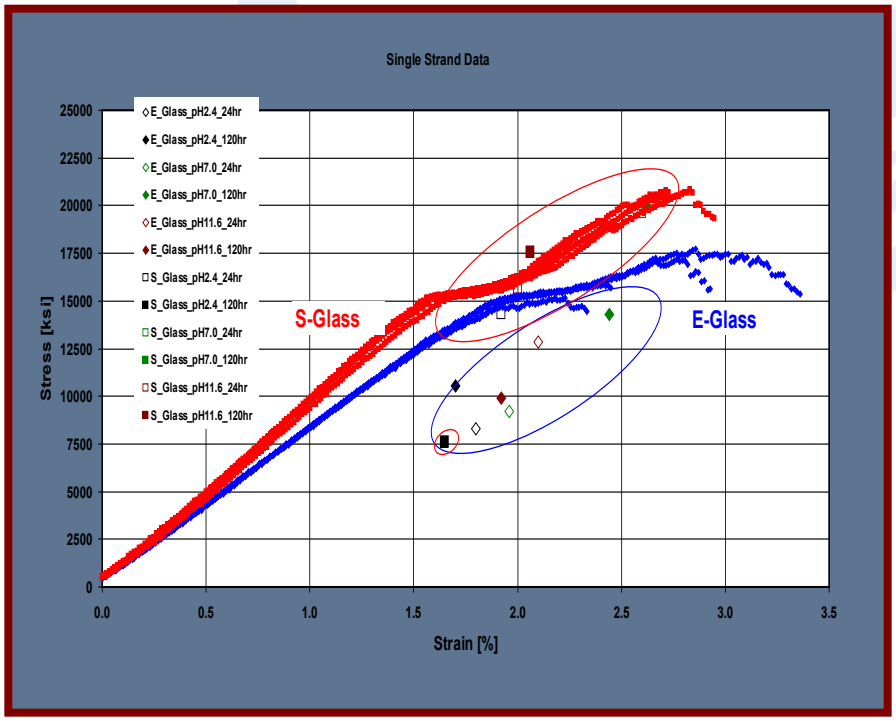
Chemical Exposure Tensile Strength Results

- The API 15HR Specification for High Pressure Fiberglass Line Pipe indicates the need to address an environmental service factor. But does not provide a methodology.
- A performance test as applied in pressure vessel standards may be a better option.





1”x 0.25”

40% Depth

PH 11.6 120 Hr

1”x 0.25”

40% Depth

PH 2.4 120 Hr

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