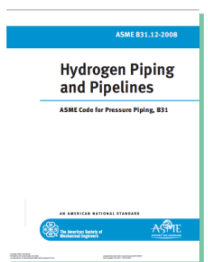
We Put Science To Work

Fiber Reinforced Composite Pipelines

George Rawls (PI)

Savannah River National Laboratory

June 10 2015



ASME B31.12 Code
- Scope
- Materials
- Design
- Fabrication
- Examination
- Testing
- Inspection

Project ID #: PD022

pd022_rawls_2015_o

Project Overview – FRP for H_2 Delivery

Timeline

- Project start date:10/2006
- Project end date:10/2015*

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

Budget

- Funding for FY14 $350K
- Funding for FY15 $250K
  - March FY15 60% Complete
- Total Project Funding $1.5M

Partners

- FRP Manufacturers
- ASME
- ORNL
- University of Hawaii

DOE Barriers

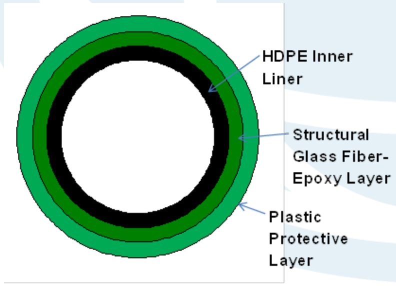
- High Capital Cost and Hydrogen Embrittlement of Steel Pipelines
- Safety, Codes and Standards, Permitting

Project Goals

- Provide data to support a technical basis for fiber reinforced piping in hydrogen service.
- Have FRP integrated into the ASME B31.12 Hydrogen Piping and Pipeline Code by 2015.

Relevance – FRP for H_2 Delivery

- **Impact**
  - Composite pipeline technology has the potential to reduce installation costs and improve reliability for hydrogen pipelines.
- **Existing Technology**
  - FRP is an existing commercial technology currently employed in the oil & gas industry.
  - Spoolable commercial products up to 8” diameter and 2500 psig pressure rating.
  - Site manufactured products are available up to 12” diameter and 1000 psig pressure rating.
- **Advantages to using FRP**
  - Half mile lengths can be spooled for delivery reducing installation cost.
  - Site manufactured lengths can be provided in 2 to 3 mile lengths.
  - FRP is not susceptible to hydrogen embrittlement.
  - Superior chemical and corrosion resistance.



FRP Cross Section

Site Manufactured FRP

Spooled FRP Installation

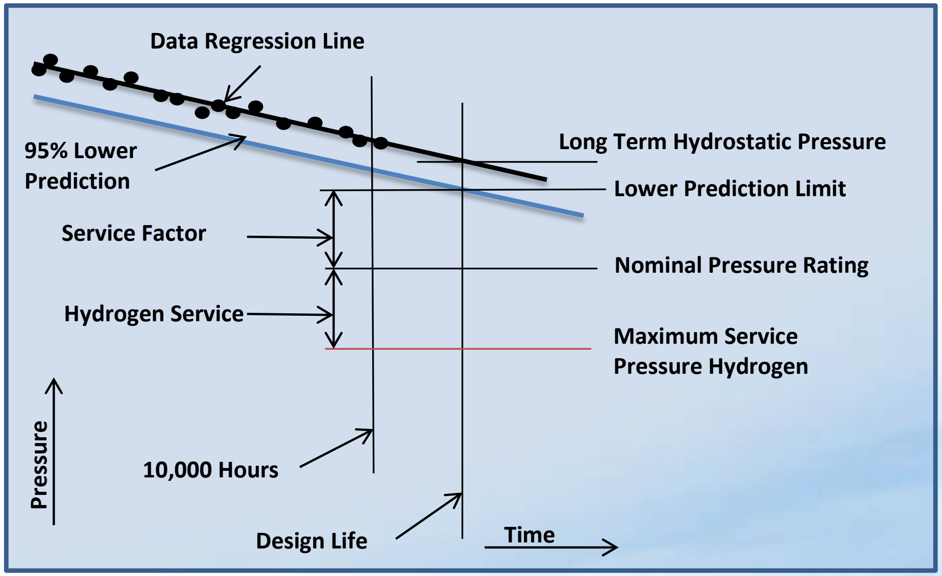
Approach – FRP for H_2 Delivery

- **The SRNL approach towards FRP for hydrogen delivery:**
  - Critically evaluate the current application of available FRP product standards through independent testing.
  - Define changes to the current FRP product standards to meet the ASME Code Methodology.
  - Build a body of data to support codification in the ASME B31.12 Hydrogen Piping Code.

FRP Delivery Program

ASME Methodology ⟷ **FRP Product Methodology**

ASME B31.12 Code
- Scope
- Materials
- Design
- Fabrication
- Examination
- Testing
- Inspection



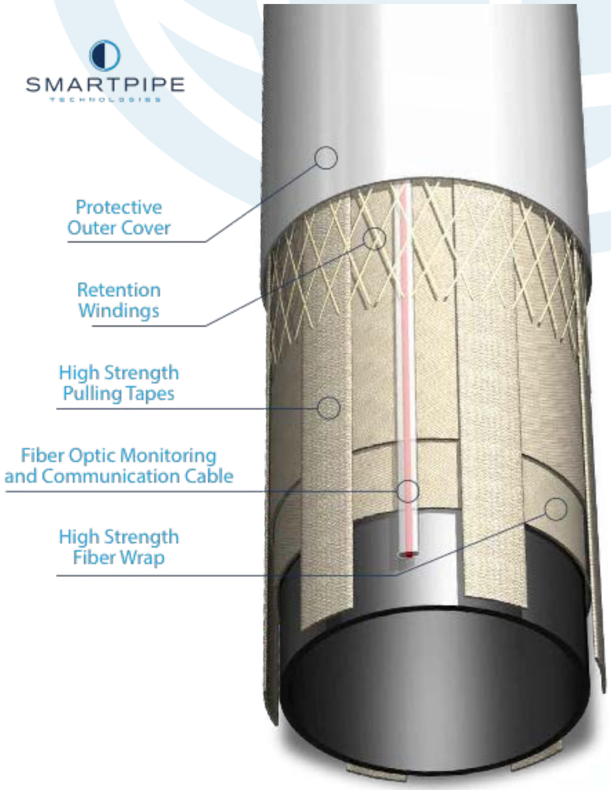
SRNL

SRNL FRP Accomplishments (Prior Years)

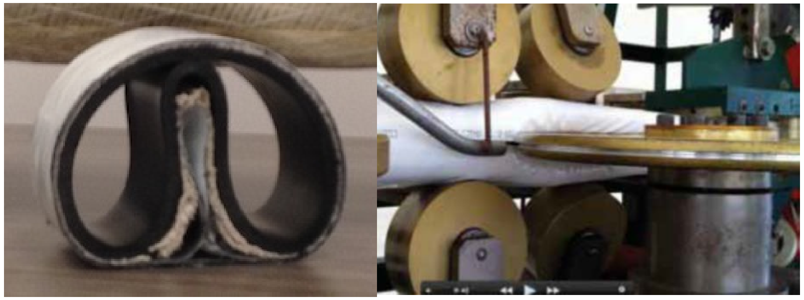
- **System Design and Applicable Codes and Standards**
  - Complete review of relevant FRP piping and pressure vessel standards.
- **Service Degradation of FRP**
  - Tested FRP following high and low PH exposure.
  - Evaluated joints for leak integrity.
- **Evaluated effect of flaws on burst strength and fatigue life.**
  - Burst tested flawed and unflawed piping to evaluate design margins.
- **Fatigue Testing**
  - Evaluated effect of flaws on fatigue life.
  - A primary design fatigue curve has been developed.
- **Evaluation for 50 Year Design Life**
  - Evaluate stress rupture effect and fatigue life to support a 50 Year design life to support hydrogen refueling stations.
- **Developed Concepts for Improved FRP Joint**
  - Robust joint designs without elastomer sealing elements.

Dry Wrap Thermoplastic Pipe

- **Dry Wrap Reinforced Thermoplastic Pipe Product Description**
  - The structural layer typically consists of an even number of helically wound tapes. There is no thermosetting resin within or between the various layers.
  - The dry wrap allows for forming the piping into a compact shape.
  - High strength axial pulling tapes are applied to enable long continuous manufacturing and installation lengths of several miles.



Dry Wrap Thermoplastic Piping



Forming of Compact C Shape

SRNL

Dry Wrap Thermoplastic Pipe Accomplishments

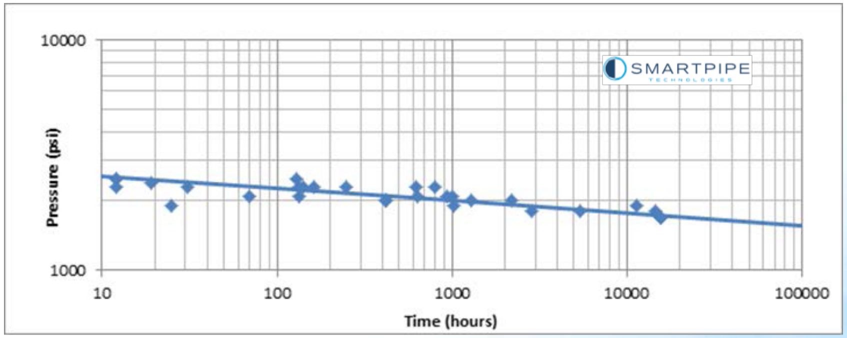
- **Burst Testing of Thermoplastic Pipe**
  - The pressure design basis follows the ASTM D2992 standard used for the thermosetting resin FRP.
  - Two burst tests were performed in the dry wrapped thermoplastic pipe samples.
  - The samples were formed into a compact C shape and re-rounded prior to testing.
  - Burst pressures were above the manufacturer's acceptance limit of 3538 psig though burst testing used lower pressurization rates than specified by ASTM D1599.

Burst Test Data

Test ID	Rated 50 Year Pressure (psig)	Burst Pressure (psig)
1	580	3670
2	580	3870

Rating includes a 0.67 hazardous gas service factor and is for 140 F service temperature

Burst Test Failure

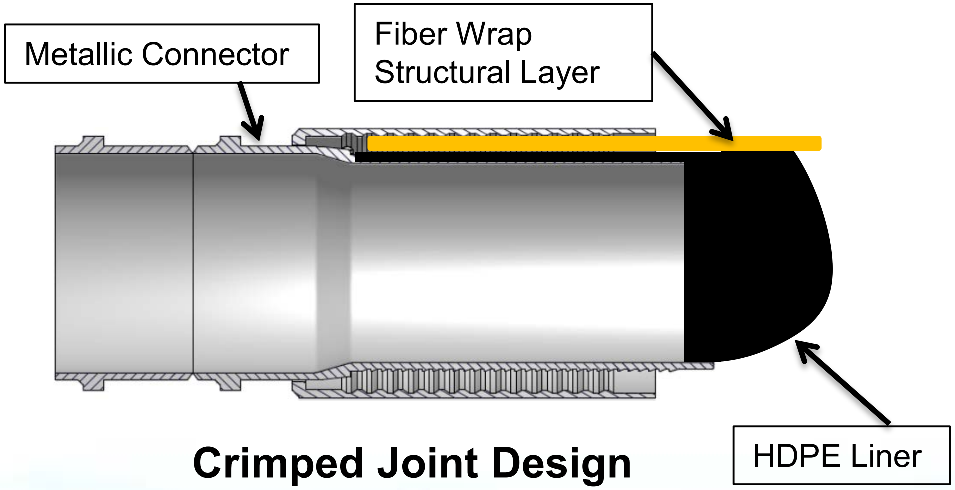


ASTM Long Term Pressure Testing

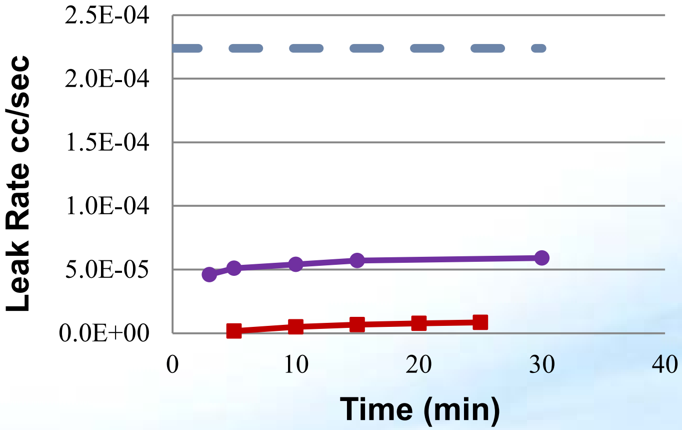
Dry Wrap Thermoplastic Pipe Accomplishments

- **Leak Testing of Thermoplastic Pipe**
  - Two leak tests were performed in the dry wrapped thermoplastic pipe samples.
  - The samples were formed into a compact C shape and re-rounded prior to testing.
  - Both tests were below the acceptable leak rate (blue dashed line in the plot) for a 25 minute test indicating no connector leakage. There were indications of permeation following the connector leak test.

Dry Wrap Thermoplastic Pipe Sample



Crimped Joint Design



Fiber Reinforced Composite Pipeline – Codification

- **ASME B31.12 Codification**
  - **Approval Process**

B31.12 Code Committee

↓ Passed

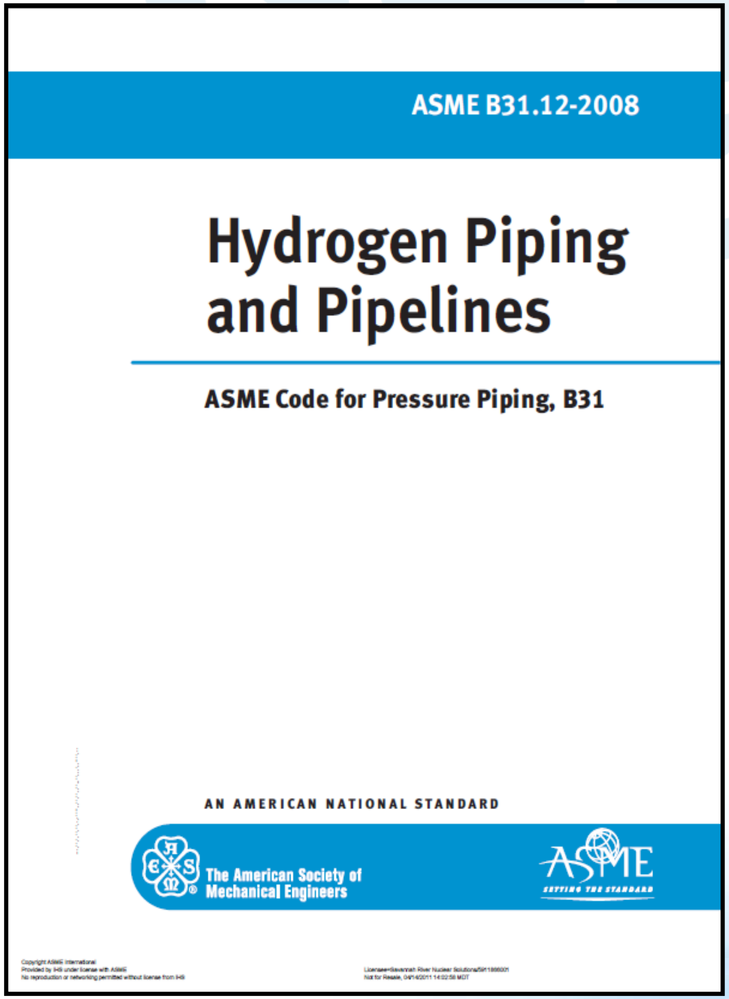
B31Standards Committee

↓

Board on Pressure Technology

↓

Public Review


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

SETTING THE STANDARD

Fiber Reinforced Composite Pipeline – Codification

Code Case Outline Composite Piping for Hydrogen Service

ASME B31.12 Hydrogen Piping

1. Scope
1.1. Product Form
1.2. Service Limitations

2. Code and Standards Referenced

3. Materials
3.1. Material Identification
3.2. Reinforcement
3.3. Resin System
3.4. Liner material
3.5. Metallic Parts

4. Design
4.1. *Design Basis*
4.2. Maximum Temperature
4.3. Minimum Temperature
4.4. Structural Layer

5. Fabrication
5.1. Manufacturing Specification
5.2. Fusion Joints
5.3. Installation Requirements

6. Examination
6.1. Manufacturing Examination Requirements
6.2. Qualification of Nondestructive Testing Personnel
6.3. Visual Examination
6.4. Design Dimensions Examination
6.5. Degree of Cure
6.6. Fusion Joints
6.7. Installation Examination Requirements
6.8. End Fitting and Coupling Components
6.9. Final Visual Examination

7. Testing
7.1. Installation Leak Test
7.2. Pipe Qualification Test Requirements
7.3. Fatigue Testing
7.3 Leak Test
7.4 Production Test requirements

8 Inspection

9 Operation and Maintenance

Items in red text were directly effected by the Hydrogen Production and Delivery Program

SRNL

Summary

- The Code Case for inclusion of fiber reinforced plastic piping has been drafted and reviewed by FRP manufacturers.
- The Code Case has been approved by the B31.12 Hydrogen Piping Committee.
- Two burst tests were completed on dry wrapped thermoplastic piping. The results of the burst test showed acceptable design margins.
- Two leakage tests were completed on a crimped connector design used on thermoplastic piping. The results indicated that the connectors were met the acceptance criteria. There were indications for high permeation rates from the leak testing.

Proposed Future Work – SRNL Scope for FRP

- Complete the FRP Codification into ASME B31.12.
- Collect and document available service history data for FRP from literature and FRP manufacturers.
- Continue the evaluation of non-mechanical joints for FRP application.
- Development an in-service inspection criteria for FRP.
- Continue to support the development of an FRP demonstration project.

Technical Back-Up Slides

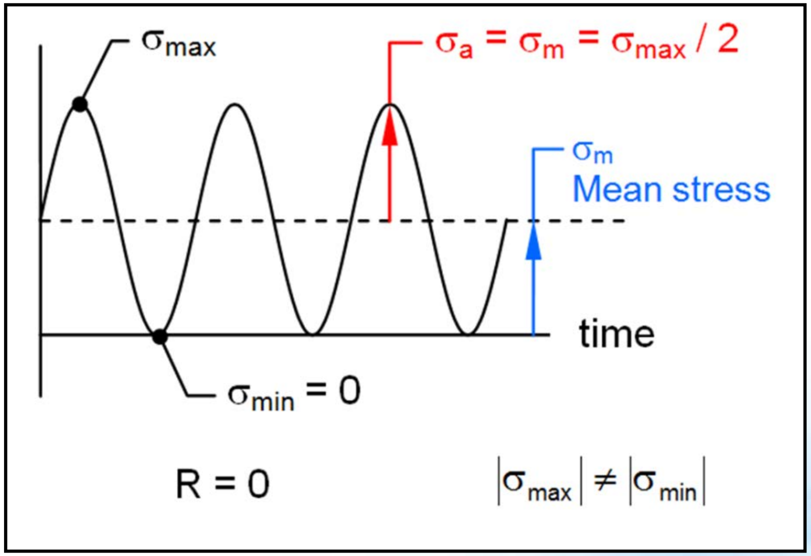
Fiber Reinforced Composite Pipeline - 50 Year Design Life

- The stress rupture data for both the ASTM D2992 data and the Robinson glass fiber stress rupture data support a 50 year design life with a less than 10% reduction in fiber stress.
- The results for the fatigue testing to date shows that for the current FRP product tested, the fiber stress level will have to be reduced if pipeline operation at full pressure cycles (low R ratio) is required.
- Piping systems that can be operated at a higher R ratio can be constructed with the current FRP products available today, with reduction in fiber stress of the same order of magnitude as required for the stress rupture life. It is noted that hydrogen pipelines are operated today with approximately constant operating pressure with very few fatigue cycles.
- The current data supports an increase in design life to 50 year for FRP with a 5% decrease in fiber stress and a limit on fatigue life of 28500 cycles at an R ratio of 0.5.

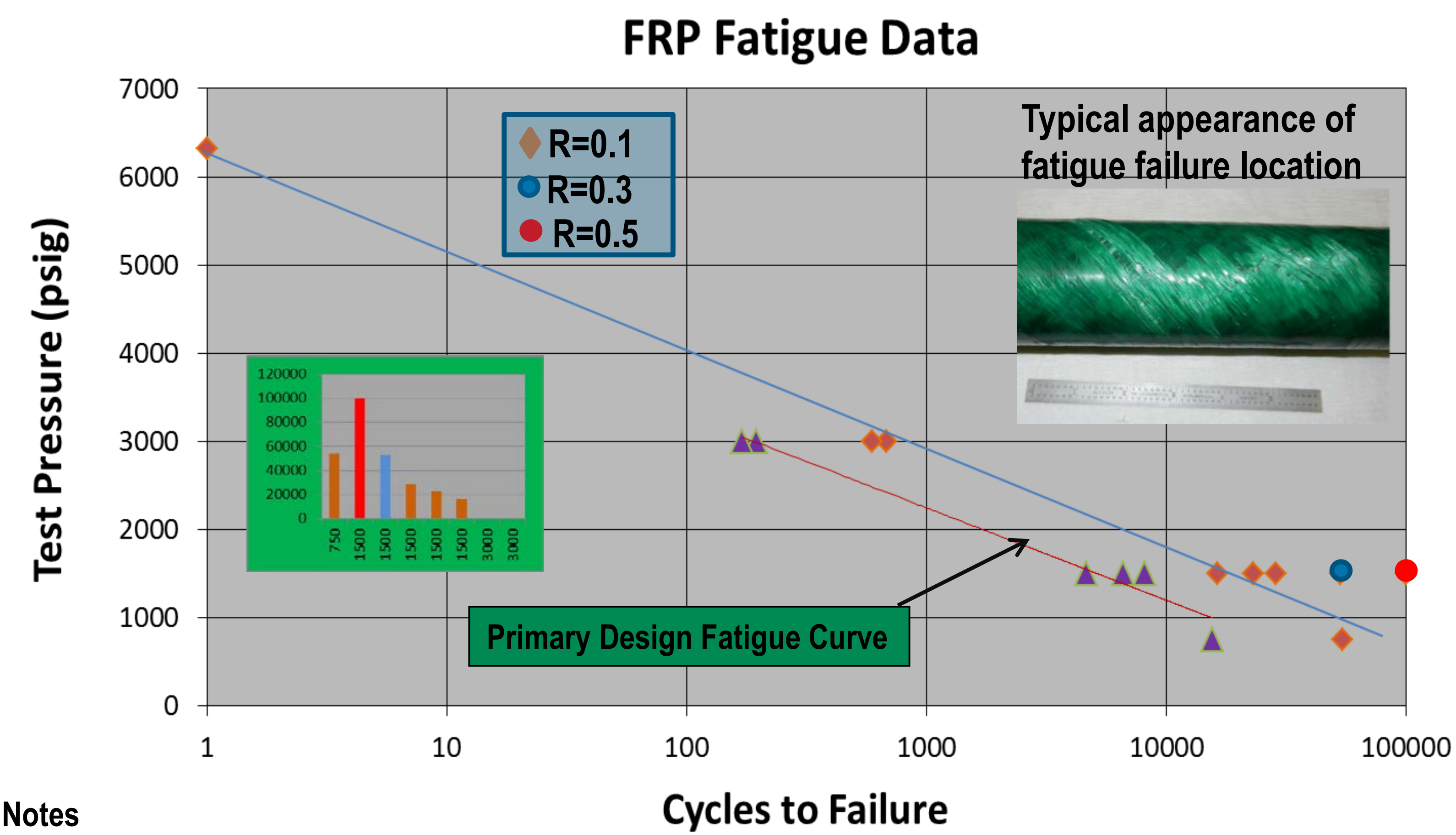
Years	Equipment Maintenance Demand		Refueling Station Demand	
	Fatigue Life (@1 Cycle per Month)	Fatigue Life (@2 Cycle per Month)	Fatigue Life (@1 Cycles per Day)	Fatigue Life (@2 Cycles per Day)
1	12	24	365	730
20	240	480	7,300	14,600
50	600	1200	18,250	36,500

SRNL FRP - Fatigue Testing

- Fatigue testing of FRP was started at SRNL during FY 2012 and is continuing during FY 2014. The fatigue test data directly support both FRP codification and the evaluation of a 50 FRP design life.
- During FY 2013 six fatigue tests were completed at pressure levels ranging from 750 psi to 3000 psi. The pressure levels ranges from half to twice the rated pressure of the FRP product test samples. All these tests were performed at a stress of R- ratio of 0.1.
- The Stress Ratio R = $\sigma_{min}/\sigma_{max}$
- During FY 2014 two additional samples were tested. The maximum pressure for each test was 1500 psi, the rated FRP sample pressure. These tests were performed at a stress ratio or R-ratio values of 0.3 and 0.5. The FY 2014 fatigue tests show that the FRP product is sensitive to R-ratio.



Fiber Reinforced Composite Pipeline - Fatigue Testing

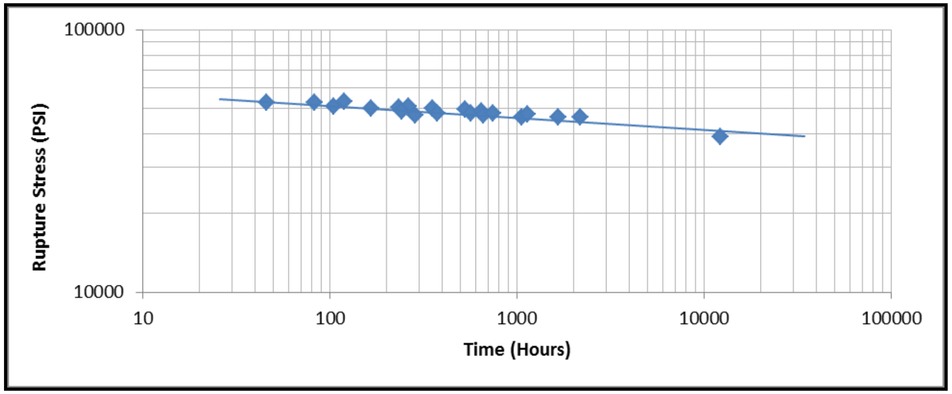


Notes
1 Single cycle test represents burst test data
2 750 psig fatigue test was terminated at 54160 cycles without a structural failure
3 The fatigue tests for R = 0.3 failed at 53020 cycles. The fatigue tests for R = 0.5 has not failed

Fiber Reinforced Composite Pipeline - 50 Year Design Life

- A data set from a ASTM D2992 (Hydrostatic Design Basis) test was used to calculate the reduction in design stress to support 50 a year design life.
- The failure data as a function of time illustrates the regression line used to determine the hydrostatic design stress.

- A curve fit to the data results in the following model for rupture stress as a function of time.
- $\sigma_{\text{Rupture Stress}} = 10^{4.814 - 0.0481 \text{Log}_{10} t}$
- A decrease in the fiber stress level by 4.3% will provide the required increase in design life.
- The required decrease in fiber stress of 6% was calculated using the Robinson strand data.



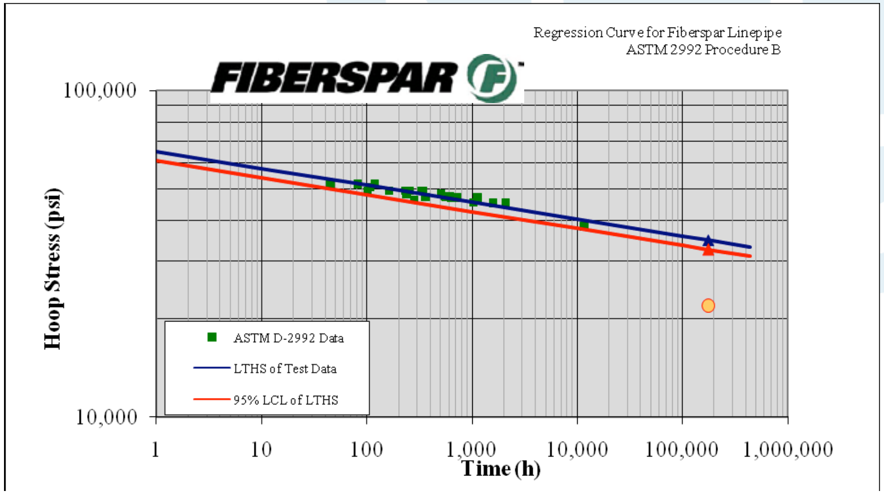
ASTM D2992 Data set for FRP

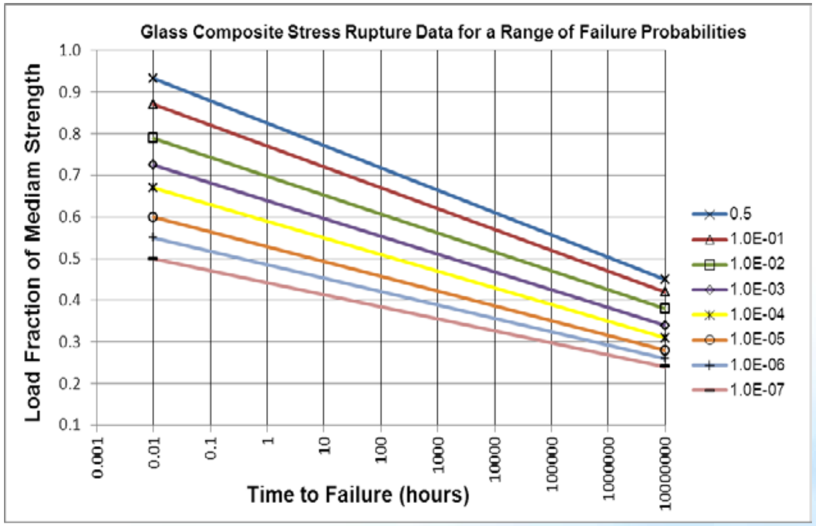
Years	Time (hours)	Rupture Stress (psi)
1	8,760	42113
20	175,200	36465
50	438,000	34894

Stress Levels vs. Time

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.





Robinson, Aerospace Corporation

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