Testing of Composite Pipe Repair Systems

CRUG 2013 Quarterly Meeting

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GTI at a Glance…

- Not-for-profit research, with 65+ year history
- Facilities
  - 18 acre campus near Chicago
  - 200,000 ft^2,
  - 28 specialized labs
- $60+ million in revenue
- Staff of 250
- Commercial partners take technologies to market

Flex-Fuel Test Facility

Energy & Environmental Technology Center

Objective

To establish procedures and evaluate the long-term performance of composite pipe repair methods and improve their selection, design, and application.

Testing Highlights

- Tests and Procedures for Mechanical Properties,
- Tests and Procedures for Performance under Hydrostatic and Cyclic Loading,
- Testing Procedure for Outside Loads,
- Evaluate Cathodic Disbondment of Composites,
- Determine the Likelihood of Degradation,
- Guidelines for Composites Design and Selection (Web-based Program).

Selection of Repair System

An assessment of the defect should be completed to identify the need for the repair, remaining strength of the defected pipe, and selection of the appropriate repair options.

Such assessment should be performed in accordance with relevant industry standards, including:

- Design and performance of oil and gas pipeline systems: ASME 31.4, ASME 31.8, and ASME B31G.
- Integrity management programs: ASME B31.8S, API 1160, and NACE SP0502,
- Fitness-for-Service practices such as API 579.

Selection of Repair System

Additionally, a risk assessment prior to any application should be performed to assess all the potential hazards such as surface preparation of a pressurized pipeline.

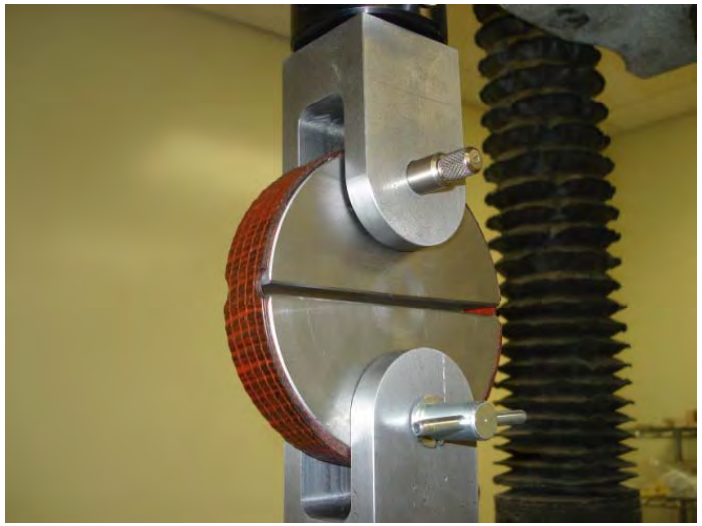
Other repair design considerations include the evaluation of the external loads, fatigue, fire, electrical conductivity, etc.

Composites Performance Properties

Property	Detail Properties	ASTM Test
Tensile Strength & Modulus (hoop and axial directions)	Tensile strength, modulus, strain to failure, and Poisson's ratio	ASTM D3039, *(ASTM D2290)*
Hardness	Barcol or Shore hardness data	ASTM D2583 ASTM D2240
Coefficient of thermal expansion,	In hoop and axial directions.	ASTM E831
Glass Transition Temp. (T_g), Heat distortion Temp. (HDT)	of polymer material,	ASTM E1640, ASTM E6604
Ply thickness		*(ASTM D5199)*
Adhesion Strength	Lap Shear Test	ASTM D3165 *(ASTM D2919 & D2294)*
Long-term strength	survival testing, Hydrostatic sustained load for 1,000 hr.	

(*) ASME PCC-2, Repair of Pressure Equipment and Piping, Article 4.1, Non-Metallic Composite Repair Systems- High Risk Applications, ASME, 2011.

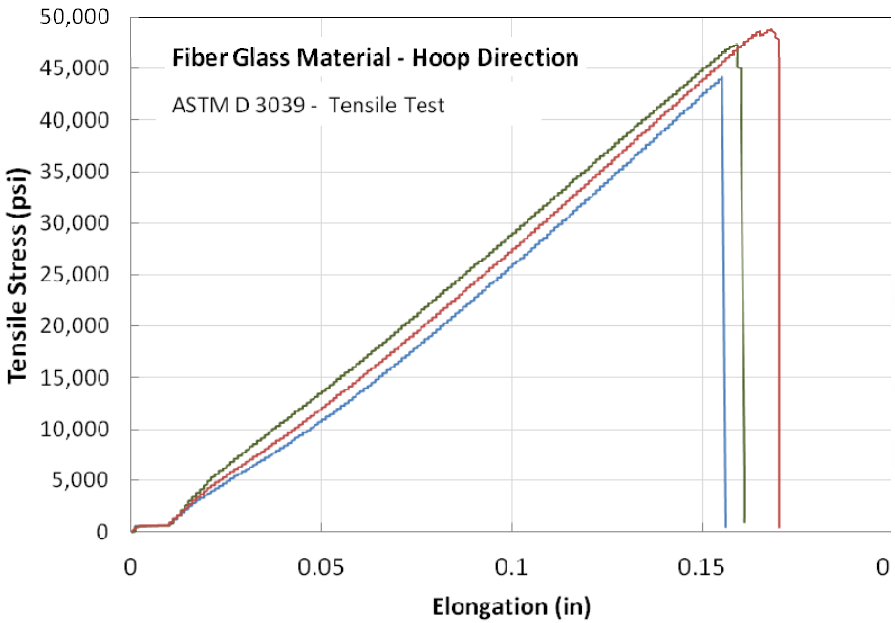
Composites Performance Properties



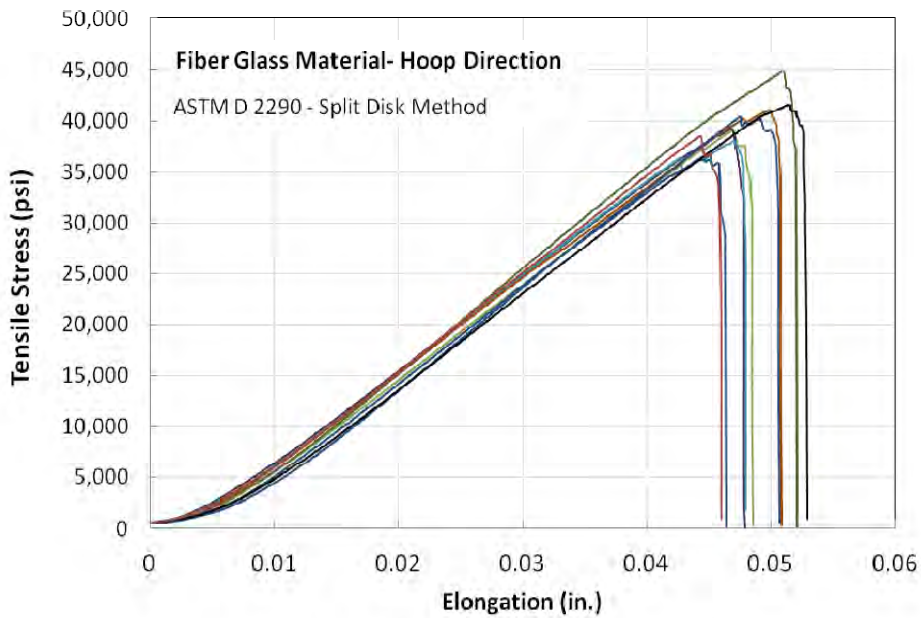
ASTM D3039: Test Method for Tensile Properties of Polymer Matrix Composite Materials. The test uses specimen sizes of 1 inch wide and 10 inches long.

ASTM D2290: Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk. The sample size is 2.5 inch diameter .

Composites Performance Properties



ASTM D3039

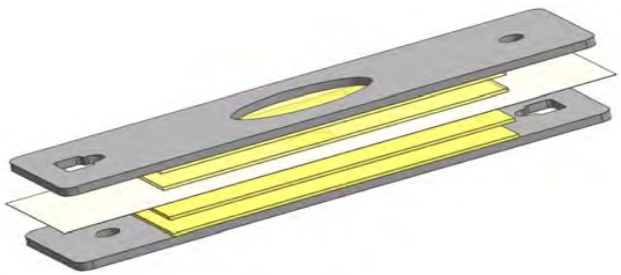


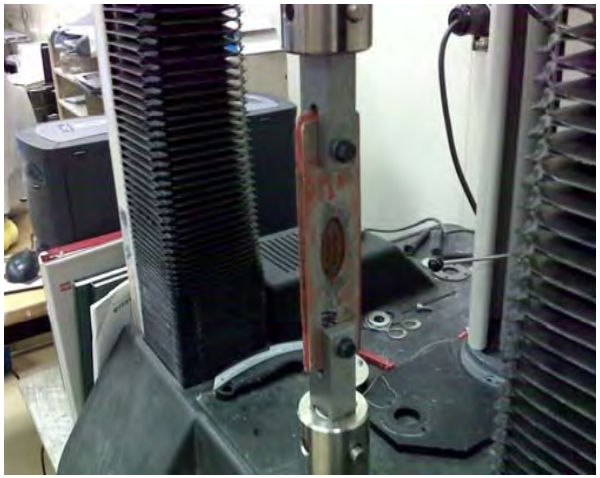
ASTM D2290

Typically, strength is 5-10% lower in Disk Method (D2290)

Bonding-Strength of the Composite

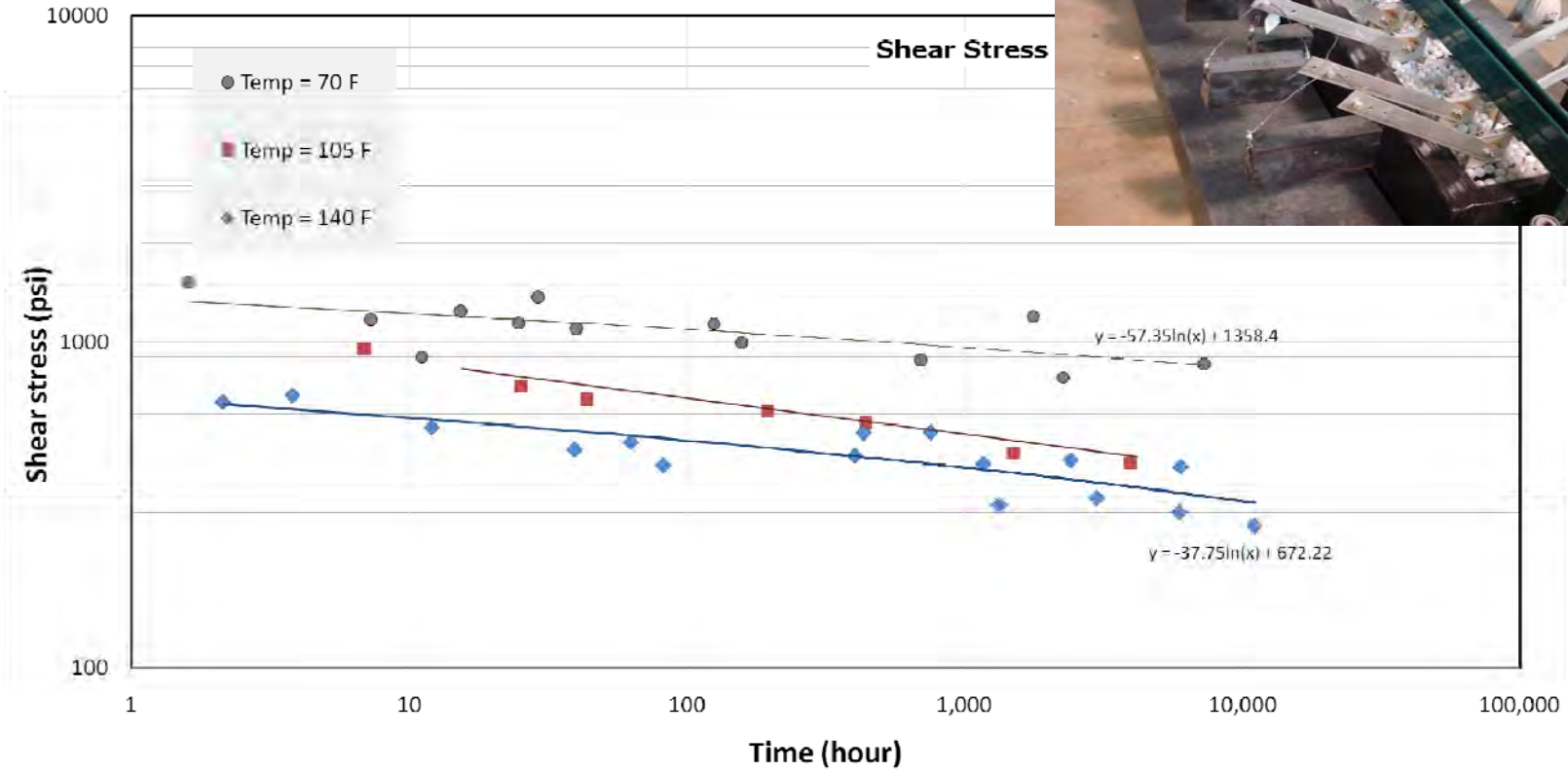
The durability of the inter-laminate adhesive bond is required to ensure adequate load transfer between the pipe and the composite layers over the predicted lifetime of the repair.





Bonding-Strength of the Composite

- ASTM D2919 and D2294 procedures
- 10,000-Hr shear tests at elevated temperatures



Long-Term Hydrostatic Pressure

Apply damage (dent & gouge)

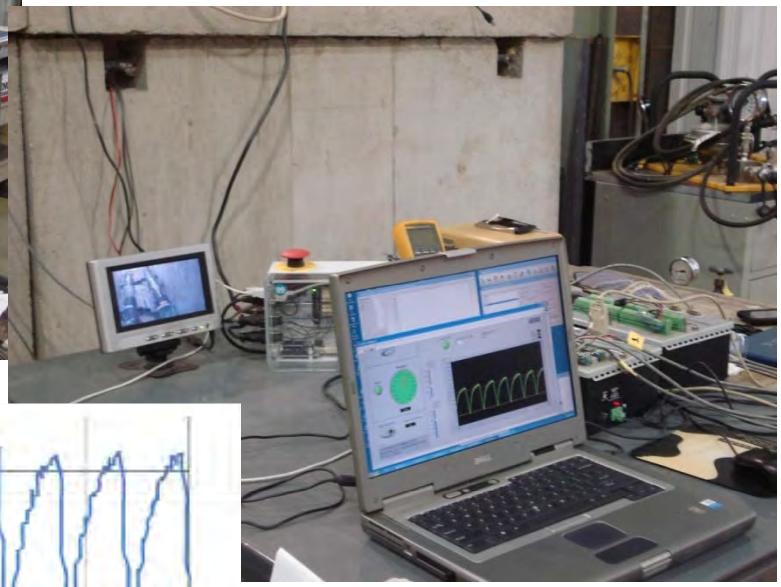
Prepare surface

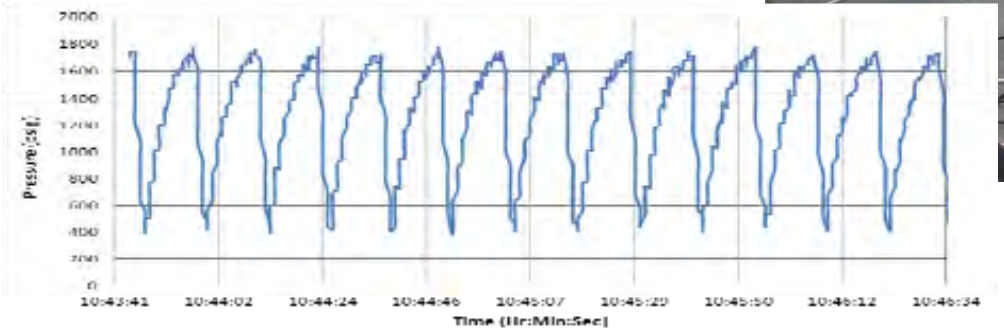
Apply Repair

Long-Term Hydrostatic Pressure

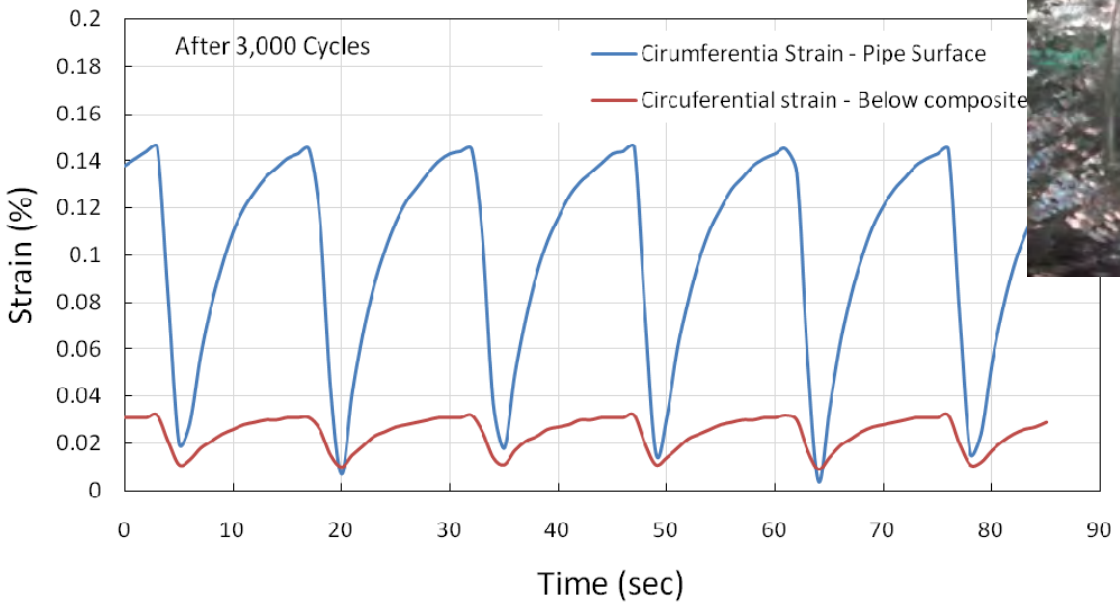
1,000-Hour Long-term hydrostatic pressure test [pressure at 100% SMYS]

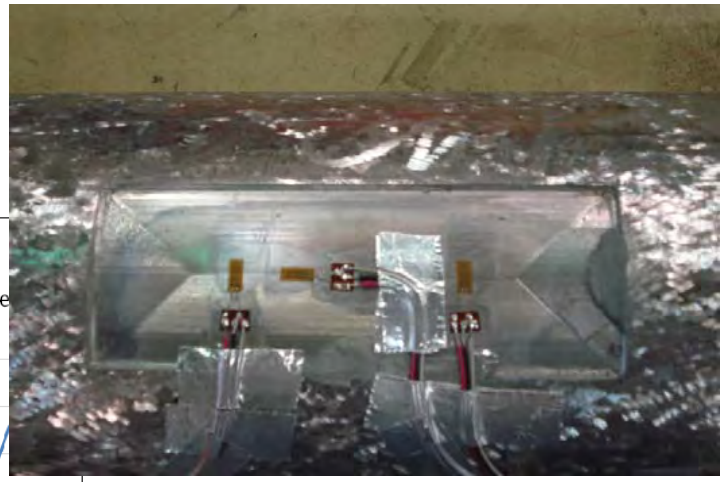
Cyclic Pressure Tests





Cyclic Pressure Tests





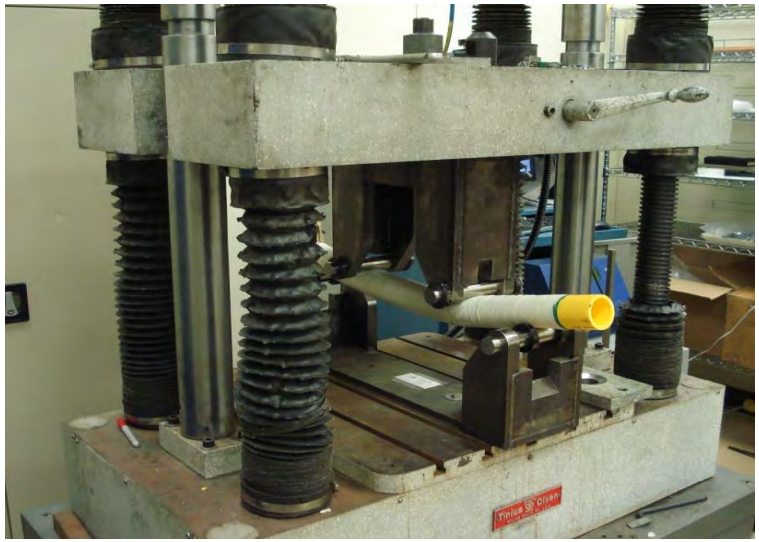
Strain measurements with & without repair

Note: Strains increase with the increase in the Number of cycles

Bending Tests on the Composites

- Standard practices for composite pipes require that the manufacturer should specify the maximum external pressure which a pipe should be exposed.
- Several ASTM standards are used for determining the flexural resistance to outside loads; including ASTM D790, ASTM D6272, and ASTM D7264.

4-Point Bending Test (ASTM D6272)



Bending Tests on the Composites

- To resist this external pressure, the minimum repair thickness, t_{min}, is given by [ASME PCC-2]:

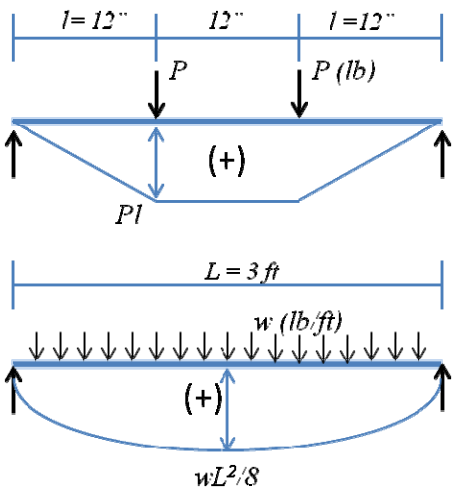
$$t_{\min} = D\left[\frac{3(1-\upsilon^2)P_e}{2E_c}\right]^{1/3}$$

D Pipe diameter,

P_e Applied external pressure on the composite (psi)

E_c Composite tensile modulus (circumferential) (psi)

v^2 is defined as $(v_{ca}^2 \times E_a / E_c)$.

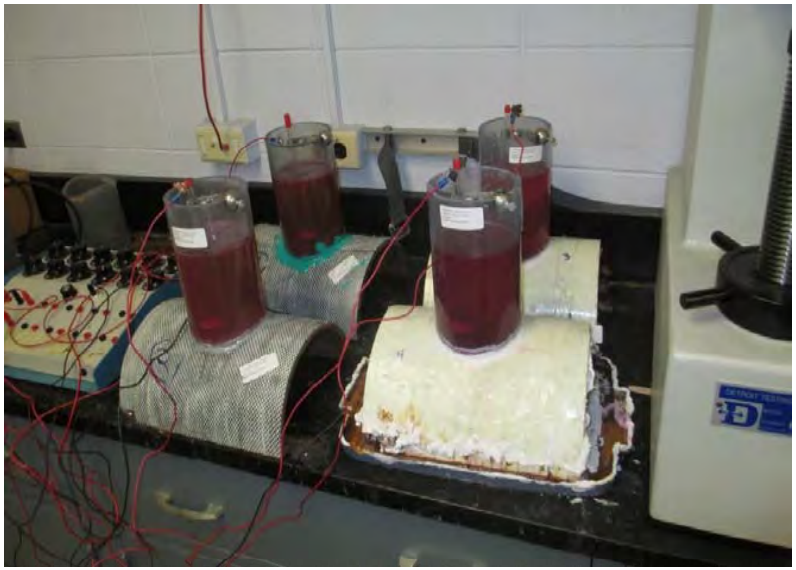


- Get ($P_{composite}$) from bending test (= $P_{total} - P_{pipe}$),
- Get equivalent distributed load (w) which causes the same moment,
- Use in equation after dividing by the appropriate safety factor.

Cathodic Disbondment

- The ASTM G8 test method covers procedures for determining the characteristics of the coating systems. However, it requires the test specimen to be submerged in electrolyte solution during the test.

- The ASTM G95 test method is more applicable to composite repairs since it is intended to facilitate testing when it is impractical to submerge the specimen.



Environmental Durability

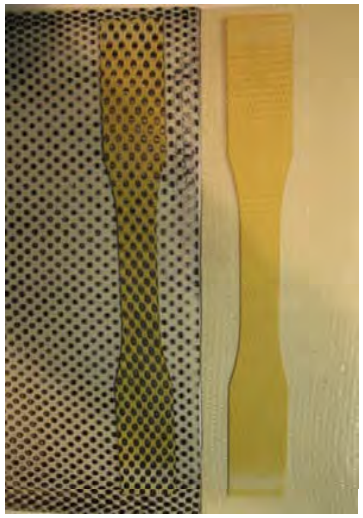
- The repair system shall be protected from UV, water, and damaging chemicals, either as an inherent characteristic or by the application of coating or barrier.
- In general, thermoset polymers are compatible with a wide range of environments but consideration needs to be given when it is strongly acidic (pH < 3.5), strongly alkaline (pH > 11), or is a strong solvent.
- When testing is required, use ASTM D543, ASTM C581, ASTM D3681, or equivalent.

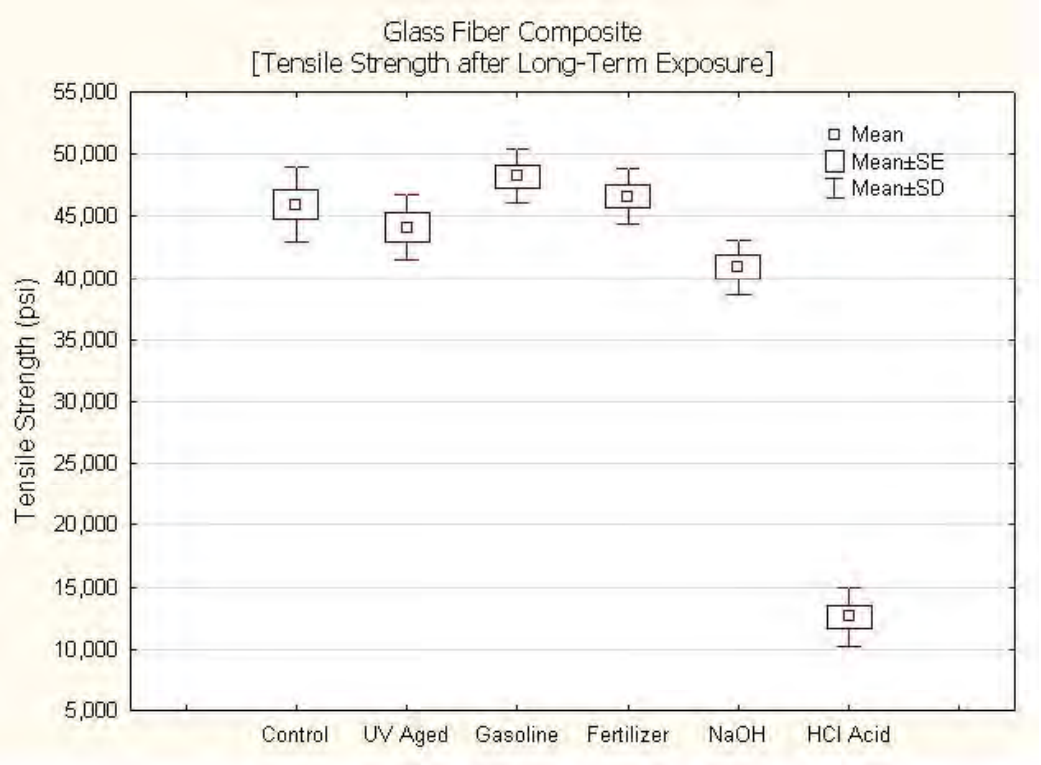
(*) ASME PCC-2, Repair of Pressure Equipment and Piping, Article 4.1, Non-Metallic Composite Repair Systems- High Risk Applications, ASME, 2011.

Environmental Durability

ASTM D543, 1,000-Hour exposure. The chemical tests used 10% solutions of the following:

- Gasoline,
- Fertilizer grade 10-10-10,
- Sodium Hydroxide NaOH
- Hydrochloric acid HCI.

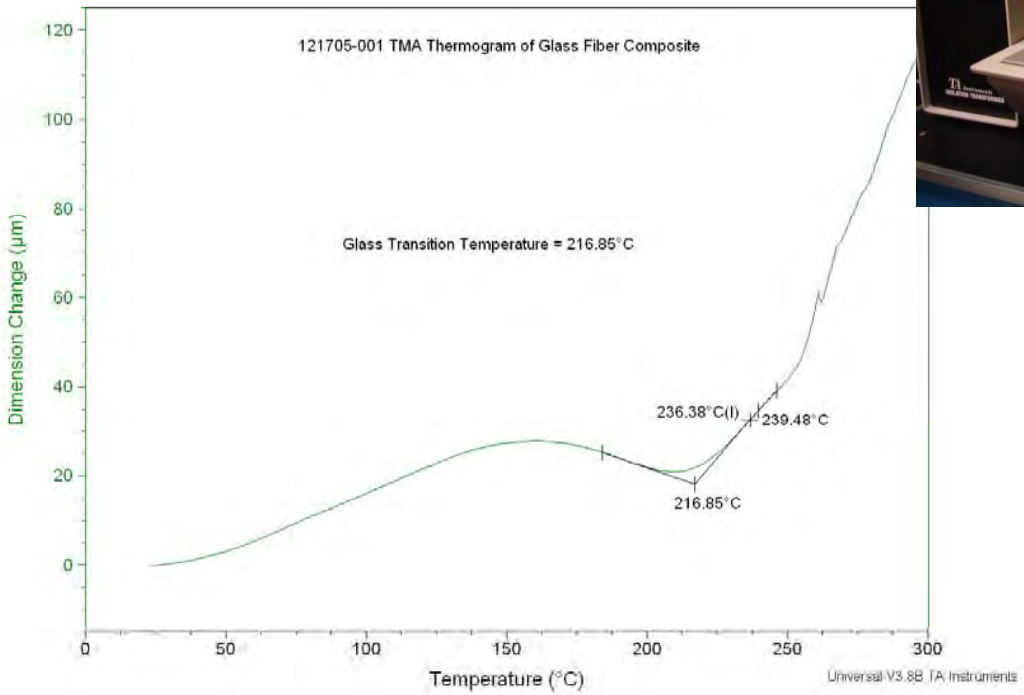




Environmental Durability

Temperature Stability

TMA-2940 thermo-mechanical analyzer for the glass transition temperature of the composite polymer



Selection of Composite Repair Systems

The web program utilizes the ASME PCC-2 Article 4.1 equations for the following design cases:

- Type A Design Case: The original pipe (substrate) is not leaking,
- The remaining strength of the substrate is included in the design. The pipe may or may not be yielding,
- The remaining strength of the original pipe in not included in the design and the repair is assumed to carry all the loads,
- The design is based on long-term performance data of the repair system.

Selection of Composite Repair Systems

Home
New Data Entry

Composite Pipe Repair Options

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Program Background References Disclaimer About

This program provides information about composite repair methods which can be used in the repair of pipelines with types of defects as per ASME-PCC2 Article 4.1: Non-Metallic Composite Repair Systems- High Risk Applications, 2011. These defects include:
(a) External corrosion where structural integrity is compromised,
(b) External damage, such as dents and gouges,
(c) Manufacturing or fabrication defects.

The program lists several composite repair methods which were tested in full-scale hydrostatic tests at GTI. The calculations of the thickness of the repair is based on the following:
- The pipeline is originally designed in accordance with ASME B31.4, B31.8, and ISO standards,
- Repair thickness is calculated for the circumferrential stresss of pipe due to hydrostatic pressure,
- For other stress conditions, refer to ASM-PCC2 or other appropriate standards.
- Repair calculations are limited to metal loss Type-A (Non-leaking Pipe) with a loss of wall thickness less than 80% of the original pipe wall thickness.

The design equations presented in the program are according to the following sections of the standard:
(a) 3.4.3 Component Pipe Allowable Stress: The design method in this section includes the contribution of the pipe in the calculation for load carrying capability and assumes the substrata yields.
(b) 3.4.4 Repair Laminate Allowable Strains: The design method in this section ignores the contribution of the original pipe for load carrying capability and uses short-term material properties.
(c) 3.4.5 Repair Laminate Allowable Stresses Determined by Performance Testing: The design methods uses performance data based on long-term failure test results.

Note: Please Click on 'Data Entry Page' to Enter Data

Selection of Composite Repair Systems

gti

Gas Technology Institute

Composite Pipe Repair Options

Home
New Data Entry

Select Composite Repair Method:
[Data entry should be complete for composites selection.]

A+ Wrap
Woven fiber-glass composite,
[Pipe Wrap, LLC.]

Aquawrap G-03
Woven fiber-glass composite,
[Air Logistics Corp.]

Black Diamond
Carbon fiber composite,
[Citadel Technologies]

Contour
Glass fiber composite,
[Clock Spring Co.]

ResQ
Carbon Fiber Composite,
[TD Williamson, Inc.]

Syntho-Glass XT
Glass fiber composite,
[NRI, Inc.]

Technowrap PRS
Glass fiber composite,
[Walker Technical Resources]

Viper-Skin
Hyprid glass-carbon fiber,
[NRI, Inc.]

Data Entry Page

Data entry for the calculation of thickness of composite repair material.

- Calculations are based on ASME-PCC2 Article 4.1: Non-Metallic Composite Repair Systems- High Risk Applications.
- Composite layers are calculated for circumferential stress due to internal pressure and for type-A (Non-leaking) pipes.
- For other stress conditions, refer to ASM-PCC2 or other appropriate standards.

Original Component Pipe Data:

- External Pipe Wall Diameter (inch):	16
- Wall Thickness of Original Pipe (inch):	0.25
- SMYS of Pipe Material (psi):	42,000
- Tensile Modulus of pipe material (psi):	30000000.
- Coeff. of Thermal Expansion of Steel (1/°F):	.0000065
- Design Temperature of the System (°F):	104

Pipe Pressure Data:

- Internal Pressure During Repair (psi):	0
- MAWP of pipe with the defect (psi):	640

[Determined from ASME FFS-1, ASME B31G, or equiv.]

Pipe Damage Data:

- Maximum Dent Depth of Pipe Section (inch):	1.2
- Maximum Depth of Gouge/Metal Loss (inch):	0.1
- Longitudinal Extent of Damaged Area (inch):	12

Please note that all data entries are required to proceed with selection of repair method.

Run Example Clear Data

gti

Selection of Composite Repair Systems

Home
New Data Entry

gti Composite Pipe Repair Options

ResQ

Manufacturer Home Page [TD Williamson, Inc.]
Product Information

Composite Repair Properties:

[Note: Data are in wrap (pipe circumferential) direction]

Tensile Modulus of Composite Laminate (psi):	8440000
Poisson's Ratio for Composite Laminate:	0.16
Allowable Repair Laminate Strain (%):	0.004
Long-Term Tensile Strength (95% Lower Confidence Limit), psi:	N/A
Long-term Service Factor:	0.75
Glass Transition Temperature (F):	171
Heat Distortion Temperature, HDT (F):	N/A
Upper Service Temperature of Repair (F):	135
Thermal Expansion Coefficient (1/F):	2.1E-06
Layer Thickness of Composite (inch):	0.0338

Repair Thickness as per ASME PCC-2 Articles 3.4.1 - 3.4.5:

- Repair thickness (with pipe contribution, pipe material does not yield), inch:	0.46
- Repair thickness (with pipe contribution, pipe material yields), inch:	0.14
- Repair thickness (pipe contribution is ignored), inch:	0.36

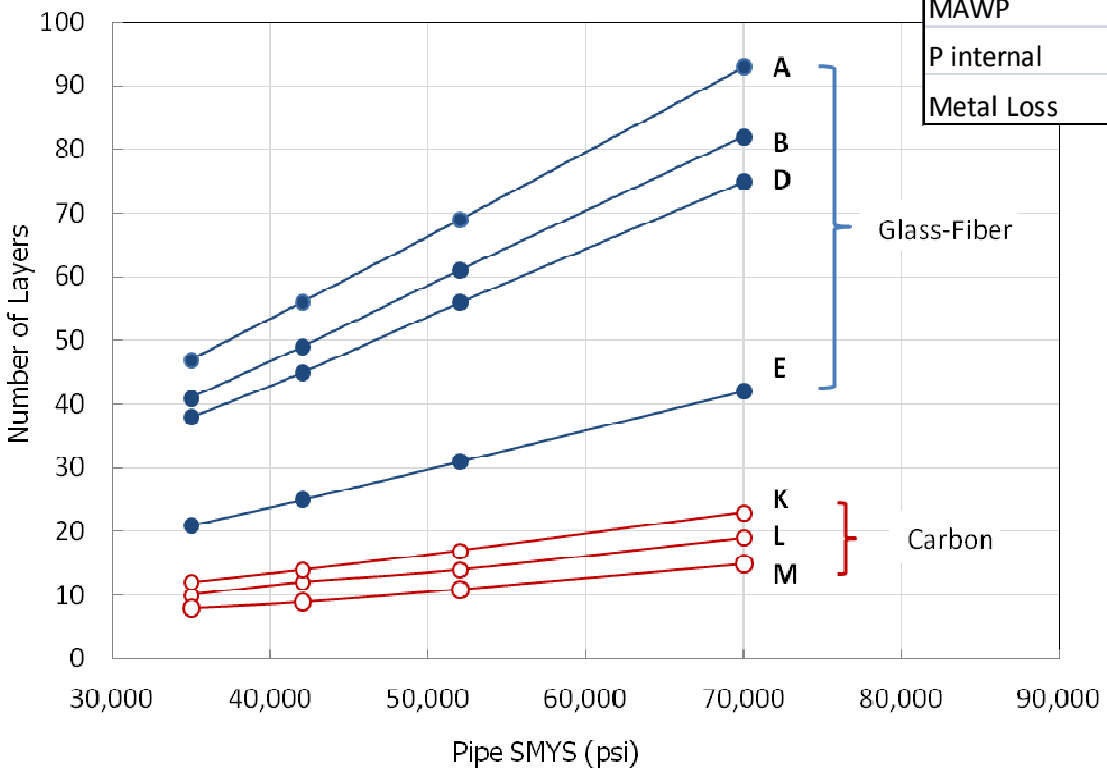
Minimum Number of Repair Layers: 5

Required Length of Repair (inch): 22

Notes:
- Dent depth (1.8 inch) > 10% pipe diameter, check design & operation requirements.

Selection of Composite Repair Systems

Diameter	12	12	12	12
Thickness	0.25	0.25	0.25	0.25
SMYS	**35,000**	**42,000**	**52,000**	**70,000**
Design Temp	104	104	104	104
MAWP	1,050	1,260	1,560	2,100
P internal	0	0	0	0
Metal Loss	0.2	0.2	0.2	0.2



Questions ...

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