History of Composite Repairs in the Pipeline Industry

2014 4th Annual Composite Repair Users Group Workshop

Meeting Date: September 11, 2014

Presented by: Dr. Chris Alexander, P.E.

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STRESS ENGINEERING SERVICES INC.
an employee-owned company

Presentation Overview

- Composite repair overview (State of the Art)
- Composite repair timeline
- Industry interest as reflected in PRCI studies
- Case study: Effects of pressure during installation
- Looking forward

State of the Art

- Composite systems have been used to repair high pressure pipelines for more than 20 years
- The key to integrating composite technology is properly <u>designing</u> and <u>installing</u> systems possessing adequate service life
- Performance testing has been an essential element in demonstrating the capacity of composite repair technology
- Continued "pushing of the envelope"

Composite Repair Timeline (1/3)

(Based on work done by Stress Engineering)

1994 Started testing Clock Spring with GRI

(primary interest reinforcing mechanical damage)

1997 Started testing Armor Plate® Pipe Wrap

(wide range of studies including load transfer, dents, cyclic, etc.)

2000 Started testing for NRI and WrapMaster

2004 Started working with Pipe Wrap

2005 Started testing Aquawrap

2006 Stress Engineering ASME PCC-2 involvement

Start of significant individual operator funding

(e.g. El Paso, TransCanada, Panhandle, Williams, CenterPoint, & Chevron)

Composite Repair Timeline (2/3)

(Based on work done by Stress Engineering)

2008 PRCI long-term buried project (13 mfgs) See below

Armor Plate, Inc. (10 years)
Air Logistics Corporation (3 years)
Clock Spring Company, LLC (3 years)
Citadel Technologies (10 years)
EMS Group (10 years)
Pipe Wrap, LLC (3 years)
T.D. Williamson, Inc. (10 years)
Walker Technical Resources Ltd. (3 years)
Wrap Master (3 years)
3X Engineering (3 years)
Furmanite (3 years)
Neptune (3 years)
Pipestream (10 years)

2009 First meeting of what would become CRUG

Started testing for Western Specialties

2010 Started testing for Pipestream (re-rate / cracks)

2012 Started testing for Fyfe Company

2013 Development of PRCI Comp. Guideline Doc.

Composite Repair Timeline (3/3)

(Based on work done by Stress Engineering)

2014 Elevated temperature testing

Reinforcement of fittings with combined loads

Optimizing composite repair designs using FEA

Validation testing for ASME PCC-2

Dent Validation Collaborative Industry Program

(DV-CIP participants: ROSEN, 5 operators, and 6 repair companies)

PRCI Research Programs

MATR-3-4	Long-term performance (10-year study)
MATR-3-5	Repair of dents
MATR-3-6	Repair of subsea pipelines/risers
MATR-3-7	Girth weld reinforcement
MATV-1-2	Wrinkle bend reinforcement
MATR-3-9	Re-rating to establish MAOP
NDE 2-3	NDE & Inspection Techniques
MATR-3-10	Composite Repair Guideline Document

- Composite Roadmap
- Future (potential) programs
  - Crack repair and reinforcement
  - Effects of pressure during installation
  - Elevated temperature testing

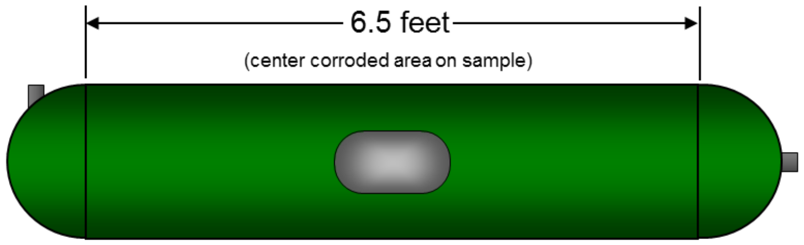
Case Study

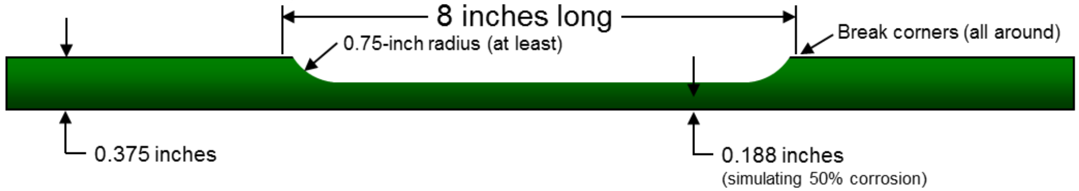
Effects of pressure during installation

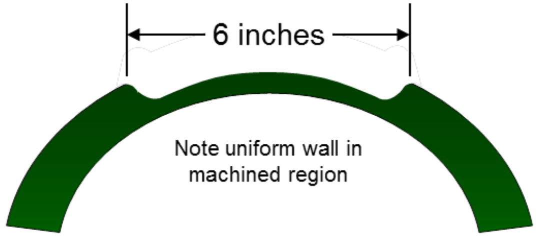
Project Overview

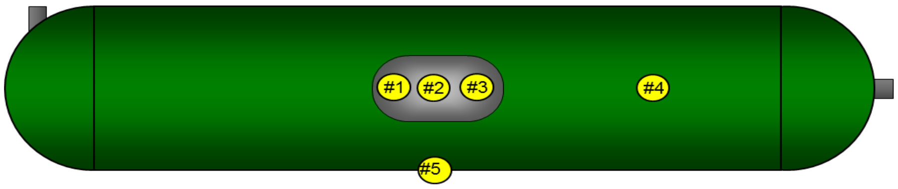
- For years industry has been concerned regarding the effects of pressure during installation
- A testing program evaluated the effects of reinforcement as a function of installation pressure
- Primary conclusion is that for the tested system the effects were not significant in terms
  - Strain reduction
  - Burst strength
- Conclusions may be product-specific; aggressive cycling should receive additional consideration

Sample Layout









Strain gage locations
(Gages #1-#3 under repair)

12.75-inch x 0.375-inch, Grade X42 pipe with 50% corrosion

Test Matrix

	Installation Pressure (psi)	Pressure Test
Sample #1 (Unrepaired Base Case)	0	Burst
Sample #2	0	Burst
Sample #3 (20% MAOP)	356	Burst
Sample #4 (40% MAOP)	712	Burst
Sample #5 (80% MAOP)	1,424	Burst
Sample #6 (80% MAOP)	1,424	Cycling

Note: MAOP is 1,780 psi, or 72% SMYS.

Test Results

Burst Test Results

	Burst Pressure (psi)	Failure Location
Sample #1	3,133	Base Pipe (No Repair)
Sample #2	4,199	Repair
Sample #3	4,190	Base Pipe
Sample #4	4,189	Base Pipe
Sample #5	4,161	Repair

Fatigue Test Results

Sample #6 failed at **506,473 cycles**
(ΔP = 890 psi to 1,780 psi, 36% SMYS)

Sample Configurations

Sample #1 Unrepaired
Sample #2 Repaired @ 0 psi
Sample #3 Repaired @ 20% MAOP
Sample #4 Repaired @ 40% MAOP
Sample #5 Repaired @ 80% MAOP
Sample #6 Repaired @ 80% MAOP (cyclic)

Hoop Strain Measurements

Strain Readings at 1,780 psi (microstrain)					
Sample	**1 Hoop**	**2 Hoop**	**3 Hoop**	**4 Hoop**	**5 Hoop**
#1	3,361	3,804	3,759	759	920
#2	1,369	1,410	1,408	783	924
#3	1,393	1,411	1,399	784	792
#4	1,678	1,753	1,642	762	778
#5	1,459	1,370	1,418	767	780

Strain Readings at 2,470 psi (microstrain)					
Sample	**1 Hoop**	**2 Hoop**	**3 Hoop**	**4 Hoop**	**5 Hoop**
#1	11,664	14,613	12,872	970	1,154
#2	2,837	3,232	3,255	1,132	1,268
#3	3,465	3,628	3,387	1,059	1,082
#4	3,862	4,231	3,862	1,032	1,056
#5	3,464	3,661	3,607	1,028	1,114

Gages under repair in corroded area (1 Hoop – 3 Hoop)

Summary of Results

- There appears to be no discernible impact on the burst pressure of the repaired samples.
- The effects of pressure during installation are likely proportional to the stiffness of the system.
- The 506,473 cycles represents more than 100 and 1,000 years for typical liquid and gas pipelines, respectively. An unreinforced sample would have likely failed around 50,000 cycles.

Looking Forward

- Reinforcement of cracks using composite materials
- Finite element modeling to optimize repairs for critical applications
- Moving beyond corrosion and dents; providing reinforcement for bends, tees, and other features
- Need to better understand elevated temperature performance (i.e. loss of strength)
- Joint industry studies a huge plus for the industry
- Continued work with PRCI

Thank You!