Composite Repair of Transmission Pipelines Workshop

2020 PRCI Research Exchange
Presented by Dr. Chris Alexander, PE | ADV Integrity, Inc.
Tuesday, March 3, 2020 | 1:00 to 2:30 PM PST
Presentation Overview

- **Part 1:** The critical role of full-scale testing in evaluating composite repair technologies

- **Part 2:** Background on previous research and case studies

- **Part 3:** The future and advancing the state-of-the-art
High Level Composite Repair Concepts

- Composite repairs systems include:
  - E-glass or carbon fibers
  - Matrix (e.g., epoxy and urethane resins)
  - Filler (putty) materials
- First use dates back to early 1990s
- Minimal debate regarding their use for corrosion and dent features
- Inspection of repairs is a gap
- Advanced applications include leak repairs and reinforcement of cracks
Part 1: The critical role of full-scale testing in evaluating composite repair technologies
Why is testing important?

- Managing pipelines can be very difficult
- Integrity engineers are required to make complex decisions with limited information
- Numerical modeling can be effective in predicting behavior, but oftentimes has limitations due to unknowns with material properties and defect geometries
- In some regards, full-scale testing is “insurance” to help us better understand potential pipe behavior
Testing Program Key Elements

- Ronald Reagan’s “Trust, but verify” concept is the essence of every testing program.
- Full-scale testing allows us to simulate real-world pipeline conditions and establish a true limit state condition.
- The ideal scenario is one that involves both full-scale testing and numerical modeling.
- Testing can be extremely difficult and requires engineers and technicians with significant experience.
Key Aspects (Equipment, 1/3)

Pressure test chamber
Key Aspects (Equipment, 2/3)

Dent installation test rig

EDM notch installation

Electrode
Key Aspects (Equipment, 3/3)

3 million ft-lb bending frame
Cold Temperature Burst Box
(-51°F / -46°C)

Have also tested up to 140°F (60°C)
Case Studies (1/3)
Pressure cycle fatigue testing dents

In the test lab, dents can be simulated to achieve any geometry and also include interactions with seam welds, girth welds, and corrosion (to name a few).
Case Studies (2/3)
Seam weld cracking and technology validation
Case Studies (3/3)
Seam weld cracking and technology validation

Computed tomography (CT) results inspection results of crack-like features in 12-inch NPS pipe material.

Validation program funded by Inspection Associates, Inc.
Technology Readiness Levels

- TRL 7: System Operation
  - In service with review of monitored data
- TRL 6: System Installation
  - Full loading in field with monitoring
- TRL 5: System Integration Testing
  - Field deployment with limited functional loading
- TRL 4: Prototype Validation
  - Full-scale testing to simulate service loading
- TRL 3: Prototype Development
  - Reliability testing to achieve confidence
- TRL 2: Demonstration by Testing
  - Functionality testing via lab "mock ups"
- TRL 1: Proof of Concept
  - Paper study and low level analysis
- TRL 0: Basic Unproven Concept
  - Design based on fundamental first principles
Closing Comments on Testing

- A well-designed and executed testing program can help operators manage pipeline threats
- Testing takes much of the “guesswork” out of determining what impact defects have on pipeline performance
- There is no substitute in using full-scale testing to validate new and existing technologies
- Test results are usually clear and concise, allowing engineers to communicate to the public, upper management, and regulators what’s important
Part 2: Background on previous PRCI research and case studies
Typical Aims of Pipeline Repair Methods

- Restore strength to damaged pipes
- Reduce strain in damaged areas of pipe
- Seal corroded area of pipe from further development of corrosion
Target Applications of Repairs

- Gas and Liquid Pipelines
- Water Pipelines
- Small Utility Lines
- Chemical Plants
- Gas Plants and Refineries
- Offshore Facilities
Uses of Composite Materials
(repair and structural reinforcement)

- Metal wall loss (due to corrosion)
- Plain dents
- Mechanical damage (dents with a gouge)
- Re-rating pipeline system to achieve higher operating pressures
- Reinforcing sections like branch connections, bends, and elbows
Types of Composite Repairs
(used to repair pipeline systems)

- **Wet lay-up systems**
  - Monolithic
  - Can be applied to non-straight geometries
  - Versatility in range of resin technologies (e.g. underwater, high temperature, slow cure, etc.)

- **Layered systems (e.g. Clock Spring and PermaWrap)**
  - First widely-used composite repair technology
  - Layered repair system
  - Limited to repair of straight pipes

- **Hybrid systems: Steel and adhesives (e.g. Western Specialties’ ComposiSleeve)**
Composite Repair Overview (1/2)

- Composites widely accepted and used in repairing non-leaking transmission pipelines
- Plants use composite materials, including the repair of leaks
- Since 1994, more than 35 different composite repair systems have been evaluated experimentally
- Much of the early funding provided by manufacturers, although more recently operators are providing much of the funding
Manufacturer co-funding with PRCI has been an ideal means for comparing competing repair technologies.

The ASME PCC-2 Standard has provided a common basis for evaluating composite technology.

Composite repair systems can be designed for unique applications.

Since 2005, more than $20 million has been invested in composite repair research.
On January 13, 2000, **Pipeline Safety: Gas and Hazardous Liquid Pipeline Repair**, was issued by the RSPA of the Department of Transportation, went into effect.

According to this document, the requirement for repairing corroded and dents in pipelines is as follows,

...repaired by a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe.
Industry Standards

- ASME PCC-2 (and ISO 24817)
- Part 4 – Nonmetallic and Bonded Repairs
- Committee is active and standard is developing to meet industries’ needs
- Key benefit to industry is uniformity and establishing minimum design requirements
PRCI Composite Project List

- MATR-3-3  *State of the Art report*
- MATR-3-4  Long-term buried pipe corrosion study
- MATR-3-5  Repair of dents (ERW and GW)
- MATR-3-6  Subsea study
- MATR-3-7  Girth weld study
- MATR-3-9  Re-rate study (est. MAOP)
- MATR-3-10 Composite Guideline Document
- MATR-3-11 Load transfer
- MATR-3-12 Delamination assessment
- MATR-3-13 Effects of pressure during installation
- MATV-1-2 Reinforcing wrinkle bends
MATR-3-4 Long-term Study

- The original program objective was to validate composite materials for long-term service
- Thirteen (13) companies participating in study
  - Five 10-year study participants (21 samples each)
  - Eight 3-year study participants (12 samples each)
- Final burst testing completed
- In general, results have been good
Original Participants

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

* Currently operating as CS-NRI
** No longer in the composite repair business
Pipe Test Samples
12.75-inch x 0.375-inch, Grade X42 pipe (8-feet long)

- 8 inches long
- 0.75-inch radius (at least)
- 0.375 inches

Three (3) different corrosion levels:
- 40% corrosion: remaining wall of 0.225 inches
- 60% corrosion: remaining wall of 0.150 inches
- 75% corrosion: remaining wall of 0.093 inches

Break corners (all around)

Details on machining
(machined area is 8 inches long by 6 inches wide)

Note uniform wall in machined region

Courtesy of Stress Engineering Services, Inc.
Test Field Layout

Courtesy of Stress Engineering Services, Inc.
Burst Test Effort

Courtesy of Stress Engineering Services, Inc.
Inter-Layer Stresses

Hoop Stress at 72% SMYS as a Function of Radial Position

Composite Thickness of 0.720 inches

Safety Factor of 10.8 on short-term tensile strength

Key for Long-term Performance

Courtesy of Stress Engineering Services, Inc.
Pressure Cycle Test Results

- 12.75-inch x 0.375-inch, Grade X42 pipe samples with \( \Delta P = 36\% \) to 72\% SMYS (75\% corrosion)

- Results for different repair systems:
  - E-glass system: 19,411 cycles to failure
  - E-glass system: 32,848 cycles to failure
  - E-glass system: 129,406 cycles to failure
  - E-glass system: 140,164 cycles to failure
  - E-glass system: 165,127 cycles to failure
  - Carbon system: 212,888 cycles to failure
  - Carbon system: 256,344 cycles to failure
  - Carbon system: 202,903 cycles to failure
  - E-glass system: 259,537 cycles to failure
  - Carbon system: 532,776 cycles (run out, no failure)
  - Hybrid steel/Epoxy system: 655,749 cycles to failure
  - Hybrid steel/E-glass system: 767,816 cycles to failure

Courtesy of Stress Engineering Services, Inc.
MATR-3-5 Dent Study Overview

- Program objective is to validate composite materials for repairing dents; comparison with existing technology
- Eleven (11) repair systems participating in study
  - 2 rigid coil Systems (one E-glass & one steel)
  - 4 carbon Systems
  - 4 E-glass Systems
  - 1 Steel Sleeve System
- One unrepaired test sample to serve as baseline
- Pipe: 12.75-inch x 0.188-inch, Grade X42 ($\Delta P = 72\%$ SMYS)
- Measured strain using strain gages beneath repairs
- Samples cycled to failure with 68 total dents in study
  - 62 completed evaluating composite materials
  - 6 dents repaired using Dresser steel sleeves
Strain Gage Locations

Samples fabricated using 12.75-inch x 0.188-inch, Grade X42 pipe material

Courtesy of Stress Engineering Services, Inc.
Pressure Cycle Fatigue Data

Cycles to Failure for Composite Repaired Dents

Dents initially 15% of OD installed on a 12.75-inch x 0.188-inch, Grade X42 pipe using a 4-inch end cap. Dents installed with 72%SMYS pressure in pipe and cycled to failure at $\Delta \sigma = 72\%$ SMYS.

250,000 cycles considered run-out

Cycles to Failure (Log N)

Dent Type
(ERW: dent in ERW seam | PD: plain dent | GW: dent in girth weld)

Courtesy of Stress Engineering Services, Inc.
MATR-3-6 Subsea Study Overview

- Test sample repair configurations (5 repair systems)
  - Burst sample
  - Pressure cycle fatigue sample
  - Tension-pressure sample (pre-blast / underwater blast)
  - Bending-tension-pressure sample
- Test period of 10,000 hours
- All installation and testing work done underwater (simulated seawater conditions)
MATR-3-6 Photos (1/4)

Courtesy of Stress Engineering Services, Inc.
MATR-3-6 Photos (2/4)

Courtesy of Stress Engineering Services, Inc.
MATR-3-6 Photos (3/4)

Courtesy of Stress Engineering Services, Inc.
MATR-3-6 Photos (4/4)

Courtesy of Stress Engineering Services, Inc.
12.75-inch x 0.188-inch, Gr. X42

Sample preparation
- Deflective girth welds fabricated (lack of penetration)
- Material testing
- Surface sandblast (NACE 2)
- Strain gages installed

Five (5) repair systems tested

Tension and bending tests

Courtesy of Stress Engineering Services, Inc.
Tension to Failure Results

![Graph showing tension to failure results for various materials.](image)

- Armor Plate
- Pipe Wrap
- Air Logistics
- Citadel

Key points:
- AYS = 51.5 ksi
- SMYS = 42 ksi

Courtesy of Stress Engineering Services, Inc.
Unrepaired Test Failures

Courtesy of Stress Engineering Services, Inc.
Repaired Test Failures

Sample prior to testing in tension

Failure in tension sample

Courtesy of Stress Engineering Services, Inc.
MATR-3-13 Study

- Dented pipe samples 12.75-inch OD x 0.188-inch WT, Grade X42
- Pressure cycled until first failure
  - Failed dent is cutout, endcap re-welded, surviving dent is cycled to failure
- One (1) Unreinforced sample
- Six (6) Repair installations made under pressure (64% SMYS)
NRI Steel Wrap
NRI-D02-64|Dent 2 leaked after 30,814 cycles
WrapMaster
WM-D03-64|Dent 2 Leaked after 24,721 cycles
Western Specialties ComposiSleeve

WSCS-D04-64|Dent 1 leaked after 59,927 cycles
Recent Advances

- Optimized technologies, including the ability to weave specific fabrics for particular applications
- “Smart” sleeves involving the embedding of sensors and fiber optic technologies
- Remote monitoring with the ability to assess repairs and pipelines
- Deepwater composite repairs, including ROV-assisted installations (work with NRI)
Overall Observations

- For more than 25 years, the pipeline industry has been using composite repair systems
- A significant body of research exists addressing a variety of repair types
- We continue to learn more, which improves our confidence with composites
- Validating long-term performance is a critical effort in ongoing and future efforts
- Installation and quality control are probably today’s hottest topic in composite repairs
Part 3: The Future and Advancing the State-of-the-art
Where do we go from here?

- Number of repairs will likely increase as ILI tools are improving their “sizing” capabilities

- Knowledge gaps exist in terms of:
  - Elevated temperature performance
  - Reinforcement of cracks
  - Repair of leaking defects
  - Inspection technologies and assessment criteria

- Current Research Ideas (TC Energy and ADV):
  - Composite Technology Leak Repair Research Idea (June 13, 2019)
  - Reinforcement of Crack-like Features Using Composite Materials (July 7, 2019)
Recent TC Energy Work

A two-year study was conducted to evaluate the ability of composite repair systems to repair leaking corrosion features (Upcoming Paper No. IPC2020-9757)
Recent Leak Repair Study (1/3)

- Stage I testing started in February 2018 and originally involved four (4) companies
- Stage II started in 2019 and involving Milliken and Western Specialties
Recent Leak Repair Study (2/3)

- **Major testing categories / elements:**
  - Severe corrosion (85%) with thru-wall defects in extremely thin-wall 6-inch x 0.157-inch pipe
  - Buried pipe samples with nitrogen gas (90 days)
  - Elevated temperature up to 60°C (140°F)
  - Cyclic pressure up to 80% SMYS, including elevated temperatures
  - Reduced surface preparation (flash rust)
  - Some repairs made with shop air

- **Qualification based on burst and cyclic pressure results**
Recent Leak Repair Study (3/3)
Wrapping it all up…
Points of Discussion

- New “applications” of composite repairs require careful consideration.
- It’s important to understand the anomalies’ behavior and response to loading.
- The required level of reinforcement dictates design of the composite.
- Once designed, the composite repair should be validated via full-scale testing.
- PHMSA advocates design by performance and supports validation using full-scale testing.
Presentation Closing Comments

- Thank you for not falling asleep!
- There is a wealth of research completed to date involving more than 1,000 tests over the past 20 years
- We keep learning more about reinforcing defects, but there is more work to be done
- Quality control in relation to installation methods and design optimization are the two biggest factors facing us in the pipeline industry