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.

Taking on your toughest technical challenges.
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 designing and installing 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

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
Case Study: Effects of pressure during installation

Sample Layout

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

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

<table>
<thead>
<tr>
<th>Sample</th>
<th>Installation Pressure (psi)</th>
<th>Pressure Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample #1 (Unrepaired Base Case)</td>
<td>0</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #2</td>
<td>0</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #3 (20% MAOP)</td>
<td>356</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #4 (40% MAOP)</td>
<td>712</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #5 (80% MAOP)</td>
<td>1,424</td>
<td>Burst</td>
</tr>
<tr>
<td>Sample #6 (80% MAOP)</td>
<td>1,424</td>
<td>Cycling</td>
</tr>
</tbody>
</table>

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

Burst Test Results

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Burst Pressure (psi)</th>
<th>Failure Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample #1</td>
<td>3,133</td>
<td>Base Pipe (No Repair)</td>
</tr>
<tr>
<td>Sample #2</td>
<td>4,199</td>
<td>Repair</td>
</tr>
<tr>
<td>Sample #3</td>
<td>4,190</td>
<td>Base Pipe</td>
</tr>
<tr>
<td>Sample #4</td>
<td>4,189</td>
<td>Base Pipe</td>
</tr>
<tr>
<td>Sample #5</td>
<td>4,161</td>
<td>Repair</td>
</tr>
</tbody>
</table>

Fatigue Test Results

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

Sample Configurations

<table>
<thead>
<tr>
<th>Sample</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample #1</td>
<td>Unrepaired</td>
</tr>
<tr>
<td>Sample #2</td>
<td>Repaired @ 0 psi</td>
</tr>
<tr>
<td>Sample #3</td>
<td>Repaired @ 20% MAOP</td>
</tr>
<tr>
<td>Sample #4</td>
<td>Repaired @ 40% MAOP</td>
</tr>
<tr>
<td>Sample #5</td>
<td>Repaired @ 80% MAOP</td>
</tr>
<tr>
<td>Sample #6</td>
<td>Repaired @ 80% MAOP (cyclic)</td>
</tr>
</tbody>
</table>

Hoop Strain Measurements

### Strain Readings at 1,780 psi (microstrain)

<table>
<thead>
<tr>
<th>Sample</th>
<th>1 Hoop</th>
<th>2 Hoop</th>
<th>3 Hoop</th>
<th>4 Hoop</th>
<th>5 Hoop</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>3,361</td>
<td>3,804</td>
<td>3,759</td>
<td>759</td>
<td>920</td>
</tr>
<tr>
<td>#2</td>
<td>1,369</td>
<td>1,410</td>
<td>1,408</td>
<td>783</td>
<td>924</td>
</tr>
<tr>
<td>#3</td>
<td>1,393</td>
<td>1,411</td>
<td>1,399</td>
<td>784</td>
<td>792</td>
</tr>
<tr>
<td>#4</td>
<td>1,678</td>
<td>1,753</td>
<td>1,642</td>
<td>762</td>
<td>778</td>
</tr>
<tr>
<td>#5</td>
<td>1,459</td>
<td>1,370</td>
<td>1,418</td>
<td>767</td>
<td>780</td>
</tr>
</tbody>
</table>

### Strain Readings at 2,470 psi (microstrain)

<table>
<thead>
<tr>
<th>Sample</th>
<th>1 Hoop</th>
<th>2 Hoop</th>
<th>3 Hoop</th>
<th>4 Hoop</th>
<th>5 Hoop</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>11,664</td>
<td>14,613</td>
<td>12,872</td>
<td>970</td>
<td>1,154</td>
</tr>
<tr>
<td>#2</td>
<td>2,837</td>
<td>3,232</td>
<td>3,255</td>
<td>1,132</td>
<td>1,268</td>
</tr>
<tr>
<td>#3</td>
<td>3,465</td>
<td>3,628</td>
<td>3,387</td>
<td>1,059</td>
<td>1,082</td>
</tr>
<tr>
<td>#4</td>
<td>3,862</td>
<td>4,231</td>
<td>3,862</td>
<td>1,032</td>
<td>1,056</td>
</tr>
<tr>
<td>#5</td>
<td>3,464</td>
<td>3,661</td>
<td>3,607</td>
<td>1,028</td>
<td>1,114</td>
</tr>
</tbody>
</table>

Gages under repair in corroded area

Case Study: Effects of pressure during installation

Fatigue Test Results

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