2011 First Annual Composite Repair Users Group Workshop
Meeting held at Stress Engineering Services, Inc. (Houston, Texas)
Thursday, September 8, 2011

Presentation by Chris Alexander

Taking on your toughest technical problems
First Annual Workshop

• Welcome and introduction
• Housekeeping notes
  ▪ Facilities
  ▪ SES Staff
  ▪ Information packet (schedule, attendee list, and ballot)
• Meeting Schedule
• CRUG Mission Statement
• CRUG Board Members
• Presentations
Today’s Meeting Schedule

8:00 to 8:30  Meet, greet, and check-in (continental breakfast)
8:30 to 8:45  Introductions, welcome, and workshop overview – Chris Alexander
8:45 to 9:15  Overview: Ongoing research and lessons learned – Chris Alexander
9:15 to 9:45  Codes and Standards – Simon Frost (Walker Technical Resources)
9:45 to 10:00  Morning break and booth time
10:00 to 10:30  Comparison of composite repairs to other pipe repair technologies including economic assessments – Steve Siever (Armor Plate)
10:30 to 11:00  Composites 101: Understanding the fundamentals – Larry Cercone (Pipe Wrap, LLC)
11:00 to 11:30  Inspection of composite materials – Jerry Palomo
11:30 to 11:45  Voting for 2011-2012 Board Members (Ballot submission)
11:45 to 12:45  Lunch Break and booth time
12:45 to 2:00  Panel Discussion
Richard Sanders (PHMSA), Max Kieba (PHMSA), Christy Lan (BOEMRE), Randy Vaughn (Texas Railroad Commission), Franz Worth (Air Logistics), Simon Frost (Walker Technical Resources), and Matt Green (NRI)
2:00 to 2:30  How does an operator select a composite repair system, including any internal company requirements? Satish Kulkarni (El Paso)
2:30 to 3:00  Regulator Perspectives – Richard Sanders (PHMSA)
3:00 to 3:30  Afternoon break and booth time
3:30 to 4:00  Open forum discussion, board election results, and closing comments
Next Meeting: November 3, 2011 (to be held at Stress Engineering)
CRUG Mission Statement

The Composite Repair Users Group has been organized to promote the proper use of composite materials and provide education for industry on structurally repairing pipelines, piping, and other pressure containing equipment subject to industry accepted standards.
2010-2011 CRUG Board Members

• Chris Alexander, Chair
• Franz Worth, Vice-Chair
• Jim Souza, Secretary/Treasurer
• Tommy Precht, Public Relations
• Simon Frost, Compliance
• Shawn Laughlin, Board Member
• Dit Loyd, Board Member
Overview: Ongoing research and lessons learned
State of the Art

• Composite materials have been used to repair high pressure transmission pipelines for more than 20 years

• The key to integrating composite technology is properly designed and installed systems possessing adequate service life

• Performance testing has been an essential element in demonstrating the capacity of composite repair technology
Composite Repair Past Uses

- Corrosion
- Dents (Plain; dents in seam and girth welds)
- Mechanical damage (dents with gouges)
- Tees, elbows, bends, and branch connections
- Girth welds
- Seam weld defects
- Wrinkle bends
- Cracks
- Pipe spans
- Hydrotest leak repair
- Offshore pipelines and risers
PRCI Research Programs

- MATR-3-4 Long-term performance (10-year)
- 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

Future programs (potential)
- Re-rating pipelines
- Crack repair and reinforcement
- Elevated temperature testing
What are we learning?

• It is important that testing be conducted as a system and not just components in the system
• The key to understanding the capability of a composite repair is to take it to failure (limit state)
• Designs should be based on the service life for the pipeline system being repaired
• Quality installation work is essential
• Standards such as ASME PCC-2 are critical to ensure that composite repair systems are properly designed
Specific Insights

• Case Study #1
  - Defect: Corrosion
  - Loading: Cyclic pressures

• Case Study #2
  - Defect: Dents (plain, girth weld, seam weld)
  - Loading: Cyclic pressures

• Case Study #3: Inter-layer strains
  - Defect: Corrosion
  - Loading: Static pressure
Case Study #1
Repair of Corrosion
12.75-inch x 0.375-inch, Grade X42 pipe (8-feet long)

- 8 feet
- Center machined area on sample
- 8 inches long
- 0.75-inch radius (at least)
- 0.375 inches
- 75% corrosion: remaining wall of 0.093 inches
- Break corners (all around)
- Measure wall thickness at 9 locations in the machined area using a UT meter.

**NOTE:** Perform all machining 180 degrees from longitudinal ERW seam.

**Details on machining**
(machined area is 8 inches long by 6 inches wide)
Strain Gage Installation

Location of strain gages installed on the test sample

Photograph of strain gages installed in the machined corrosion region
Pressure Cycle Test Results

- 12.75-inch x 0.375-inch, Grade X42 pipe pressure cycled at 36% SMYS with 75% deep corrosion
- Results for 8 different systems
  - E-glass system: 19,411 cycles to failure (MIN)
  - 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 (Pipe #1): 212,888 cycles to failure
  - Carbon system (Pipe #2): 256,344 cycles to failure
  - Carbon system (Pipe #3): 202,903 cycles to failure
  - E-glass system: 259,537 cycles to failure
  - Carbon system (Pipe #4): 532,776 cycles (run out, no failure)
  - Hybrid steel-E-glass: 767,816 cycles to failure (MAX)
Hoop Strain as a Function of Cyclic Pressure (APPW Modified Cloth)

Pressure cycle test of 12.75-inch x 0.375-inch, Grade X42 pipe with 75 % corrosion.
Pressure cycling at 1,000 cycles between 36% and 72% SMYS (890 psi to 1,780 psi).

Hoop Strain (microstrain)
(10,000 microstrain is equal to 1 percent strain)
Pressure Cycle Strain Data (2/2)

Strain as a Function of Cycle Number

Burst test of 12.75-inch x 0.375-inch, Grade X42 pipe with 75% corrosion cycled from 890 to 1,780 psi (72% SMYS) with 0.625 inches of the APPW Modified material.

Same data presented on previous slides (strain measured beneath repair)
Case Study #2
Repair of Dents
Test Sample Details

- Program test matrix (cycles sampled to failure)
  - Plain dent (unrepaired)
  - Dent interacting with girth weld (unrepaired)
  - Dent interacting with ERW seam weld (unrepaired)
  - Plain dent (repaired)
  - Dent interacting with girth weld (repaired)
  - Dent interacting with ERW seam weld (repaired)
- Pipe: 12.75-inch x 0.188-inch, Grade X42
- Measure strain using strain gages
- Cycle samples to failure ($\Delta P=72\%$ SMYS)
- 9 products: Air Logistics (2), Armor Plate (2), Citadel, Pipe Wrap A+, Furmanite, WrapMaster, and Pipestream

Note: Companies denoted with (2) tested two different systems in this program.
Dented Pipeline Samples – Strain Gage Locations

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

28-ft (two 4-ft sections plus one 20-ft section)

4-ft (typ)

Dent in Girth Weld (2)

Plain Dents (2)

Girth welds (2)

ERW pipe seam

Side View of Pipe Sample (6 defects total)

Gage #1 (24 inches from end)

Gage #2

Gage #3

Gage #4

Gage #5

Gage #6

Gage #7

Top View of Pipe Sample
(notice position of dents relative to welds)

28-ft (two 4-ft sections plus one 20-ft section)

Top View of Pipe Sample
(notice position of dents relative to welds)

(28-ft (two 4-ft sections plus one 20-ft section)

(28-ft (two 4-ft sections plus one 20-ft section)

Dent in Seam Weld (2)

Notice orientation of bossets

Dent center

Close-up View of Dented Region

(approximate region having minimum radius of curvature)
Generating Dent Photos (1/2)
Generating Dent Photos (2/2)

UR-GW-2

PROFILE AFTER
10-th. cycle
Cycles to Failure of 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 $\Delta \sigma = 72\% \text{ SMYS}$.

One system was pressure cycled to 358,470 cycles after which the ERW seam failed.
# Measured Strain Gage Results

<table>
<thead>
<tr>
<th>Product</th>
<th>Hoop Strain (microstrain)</th>
<th>Plain Dent Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plain Dent #1</td>
<td>Plain Dent #2</td>
</tr>
<tr>
<td>A</td>
<td>1,753</td>
<td>1,990</td>
</tr>
<tr>
<td>B</td>
<td>1,748</td>
<td>1,894</td>
</tr>
<tr>
<td>C</td>
<td>950</td>
<td>1,148</td>
</tr>
<tr>
<td>D</td>
<td>596</td>
<td>549</td>
</tr>
<tr>
<td>E</td>
<td>2,176</td>
<td>2,477</td>
</tr>
<tr>
<td>F</td>
<td>1,544</td>
<td>1,814</td>
</tr>
<tr>
<td>G</td>
<td>901</td>
<td>1,018</td>
</tr>
<tr>
<td>H</td>
<td>586</td>
<td>860</td>
</tr>
<tr>
<td>I</td>
<td>689</td>
<td>726</td>
</tr>
<tr>
<td>Unrepaired</td>
<td>4,396</td>
<td>4,678</td>
</tr>
</tbody>
</table>

Notes:

1. 10,000 microstrain (µε) equals 1% strain.
2. At 72% SMYS, strain range in base pipe is 1,008 µε (0.72 * 42,000 psi / 30 Msi).
3. Conclusion: Those system that reduce strain have the greatest fatigue life.
Estimated Years of Service
(Using three plain dent configurations)

- Plain unrepaired dent
  - 10,249 cycles
  - 512 design cycles (10,249 / 20)
  - Estimated years of service
    - Moderate: 20 years
    - Very aggressive: 1 year

- Product H plain dent (run-out+)
  - 358,470 cycles
  - 17,923 design cycles (358,470 / 20)
  - Estimated years of service
    - Moderate: 716 years
    - Very aggressive: 64 years

- Product E plain dent
  - 47,661 cycles
  - 2,383 design cycles (47,661 / 20)
  - Estimated years of service
    - Moderate: 95 years
    - Very aggressive: 8 years

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12.75-inch x 0.188-inch, Grade X42
\( \Delta P = 72\% \text{ SMYS} \)

<table>
<thead>
<tr>
<th>Percent SMYS</th>
<th>Very Aggressive</th>
<th>Aggressive</th>
<th>Moderate</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>72%</td>
<td>276</td>
<td>67</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>36%</td>
<td>3,683</td>
<td>889</td>
<td>337</td>
<td>128</td>
</tr>
</tbody>
</table>

Single equivalent number of cycles with DP as noted

Case Study #3
Inter-layer Strains
Inter-lay Strain Study

- During installation strain gages installed between layers
- Strain gages monitored during pressurization
- Ideal means for comparing PCC-2 design stresses to values that actually exist (verification of design theory)
Inter-Layer Strains (System #1)

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

The average and maximum stresses measured in the composite material at 72% SMYS design pressure (1,780 psi) were 3,940 psi and 4,806 psi, respectively.
Design Margins (System #1)

- Mean tensile stress of 51,700 psi (A)
- Long-term design stress of 20,369 psi (B)
- Allowable stress (0.5 x B) of 10,184 psi (C)
- Maximum measured stress of 4,806 psi (D)
- Maximum measured strain in steel: 2,976 με

Resulting design margins

- Allowable stress: 5.1 (A/C)
- Measured stress: 10.8 (A/D)
- Usage factor: 0.47 (D/C) – using 47% of the allowable

Data collected at 72% MAOP (design pressure), t_{repair} = 0.76 inches
Inter-Layer Strains (System #2)

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

Hoop Stress (psi) as a Function of Radial Position:
- 2nd layer: 9438 psi
- 4th layer: 8369 psi
- 6th layer: 6424 psi
- 8th layer: 6530 psi
- 10th layer (outside): 1131 psi

Allowable stress of 11,918 psi
Design Margins (System #2)

- Mean tensile stress of 72,088 psi (A)
- Long-term design stress of 23,836 psi (B)
- Allowable stress (0.5 x B) of 11,918 psi (C)
- Maximum measured stress of 9,438 psi (D)
- Maximum measured strain in steel: 3,125 με
- Resulting design margins
  - Allowable stress: 6.0 (A/C)
  - Measured stress: 7.6 (A/D)
  - Usage factor: 0.79 (D/C) – using 79% of the allowable

Data collected at 72% MAOP (design pressure), $t_{repair} = 0.63$ inches
Closing Comments
Implication of Results and Findings

• Not all composite repair systems perform equally
• Standards such as ASME PCC-2 are essential to ensuring that adequate designs exist
• Composite stiffness is extremely important in fatigue and to reinforce damaged pipe sections (product of Modulus and Thickness)
• When in doubt, conduct tests (especially when testing new applications)
• The intent in testing work is to improve confidence in the performance of composite repair systems
• Quality installation work is essential
Questions?

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