Composite Repair Technology:
Innovation Meeting Industry Demands

6th Annual Composite Repair Users Group Workshop

Meeting Date: September 15, 2016
Presented by: Dr. Chris Alexander, P.E.

Taking on your toughest technical challenges.
Talking Points

• A little football story
• “Ode” to CRUG
• Timeline of composite repair history
• Industry interest as reflected in PRCI studies
• Case study: Crack Arrestors
• Looking to the future
an employee-owned company
“Ode” to CRUG

Since 2009, the Composite Repair Users Group has been an integral part of the culture associated with the composite repair industry.

At its core, composite repair technology represents innovation, design, and technology. Its acceptance has been based on the vision of industry leaders and a willingness of operators and regulators to adopt emerging technologies driven by manufacturer-innovation based on unending R&D efforts.
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, Columbia, Williams, Enable, Chevron, & Boardwalk)
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
       Dent Validation Collaborative Industry Program
          (DV-CIP participants: ROSEN, 5 operators, and 6 repair companies)

2015  Six (6) Joint Industry Programs (JIPs, next slide)
       BSEE / PHMSA study sponsorship
       Reinforcement of planar defects

2016  Completed 5 of 6 JIPs (offshore study still going)
2015-2016 JIPs

- Studies being conducted
  - Offshore Study (10,000-hr test in simulated seawater)
  - Onshore Study
  - Load Transfer Study
  - Wrinklebend Study
  - Crack Reinforcement Study
  - Crack Arrestor Study

- Participation composite manufacturers
  - Armor Plate
  - Air Logistics
  - Citadel
  - Furmanite
  - Milliken
  - NRI
  - Western Specialties
PRCI Research Programs (10 to date)

- 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
- MATR-3-11 Load transfer / pressure during installation
- MATR-3-12 Effects of delamination on performance
- Composite Roadmap (see next slide)
<table>
<thead>
<tr>
<th>Pipeline Anomaly, Technical Issue, or Feature</th>
<th>PRCI Research</th>
<th>Actual Field Installations</th>
<th>Guidance from Standards (ASME &amp; ISO)</th>
<th>Independent Research</th>
<th>Notes</th>
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<td>External corrosion</td>
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<td>Plain dents subjected to cyclic pressure</td>
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<td>Dents with corrosion subjected to static/cyclic pressure</td>
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<td>Dents in welds (seam and girth) subjected to cyclic pressure</td>
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<td>Dents with gouges</td>
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<td>Seam weld defects</td>
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<td>Vintage girth welds (pressure, tension, bending)</td>
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<td>Wrinkle bends</td>
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<td>Reinforced branch connections</td>
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<td>Elbows and bends</td>
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<td>Tees</td>
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<td>Subsea installations</td>
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<td>Internal corrosion (non-leaking)</td>
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<td>Stress corrosion cracking (SCC)</td>
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<td>Corrosion &gt; 80%</td>
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<td>Uprating (re-rating) pressure / Establishing MAOP</td>
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<td>Effects of pressure during installation</td>
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<td>Repair of leaks</td>
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<td>Effects of cyclic pressure on corrosion (fatigue design)</td>
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<td>Reinforcement of cracks</td>
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<td>Performance at elevated temperatures</td>
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<td>NEW Composite crack arrestors for high pressure gas pipelines</td>
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**Color Code**
- Green: Work performed in this area
- Yellow: Moderate/limited experience
- Red: Minimal to no experience
Case Study
The Composite Repair Evolution &
A Look at Composite Crack Arrestors
The Composite Repair Evolution

- Crack Arrestors
- Corrosion
- Plain Dents
- Mechanical Damage
- Wrinkle Bends
- Elbows and Bends
- Tees
- Offshore Structures
- Elevated Temperature Applications
- Reinforcement of Planar / Crack-Like Defects
Crack Arrestor Samples
Crack Arrestor Test Frame (1 of 2)

Perforated Shielding
Allows Pressure Wave to Escape
Crack Arrestor Test Frame (2 of 2)

Adjustable End Fixtures Apply Test Pre-Compression
Unreinforced Sample 1

Crack Propagated All the Way to the End Fixture

Self Arrest (Ring Out)

Burst Pressure of 3,065 psi
C-HALT Crack Arrestor

COMPOSITE WRAP

CL PIPELINE STEEL

an employee-owned company
C-HALT Crack Arrestor Post-Test
C-HALT Crack Arrestor Post-Test

Ring Out Example: Unreinforced Pipe
(Example of What to Avoid)
Looking to the Future

- In the future composite materials will continue to play a critical role in reinforcing pipelines, piping, and structures.
- Of particular interest at the present time is the reinforcement of planar flaws and crack-like defects using advanced reinforcing materials.
- One reason composite technologies have been successful is the willingness of operators, manufacturers, and regulators to work together and ask the tough questions.
Thank You!