# State of the Art of Composite Repair Systems (Past and Ongoing Research)

## Presentation to the PHMSA R&D Forum

Marriot Crystal City ● Wednesday, June 24, 2009

Presentation by Dr. Chris Alexander (Stress Engineering Services, Inc.)

Taking on your toughest technical problems

STRESS ENGINEERING SERVICES INC.

an employee-owned company

# Presentation Topics

- Assessment of composite repair technology
- Ongoing composite repair research programs
  - MATR-3-3/4 Long-term study (3 & 10 year programs)
    - Industry survey: Operator results
    - Research program specifics
  - MATR-3-5 Dent study
- Knowledge and technology gaps

# Technology Assessment

- Many players in the composite repair industry
- Minimal oversight, although ASME PCC-2 and ISO-24817 now providing industry standards
- Composite system generally over-designed
- Principal fiber materials of choice
  - E-glass
  - Carbon
  - Kevlar
- Performance criteria should be based on required service conditions
- Numerous success stories with few failures

# Survey Results

## (MATR-3-3)

# Project Web Site
## (www.compositerepairstudy.com)




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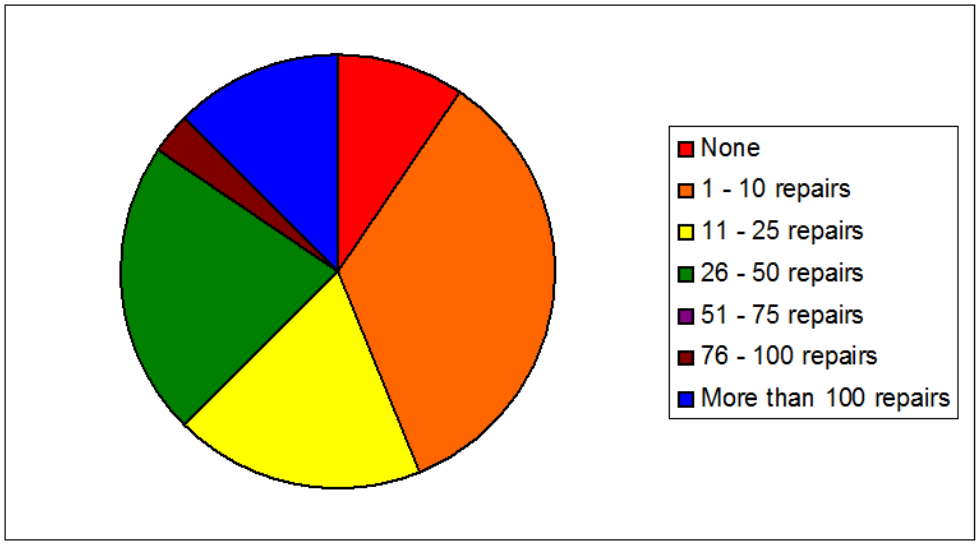
# Survey Participants

- Operators responding
  - 18 pipeline companies
  - 30 individual entries
- Manufacturers responding
  - Armor Plate, Inc.
  - Air Logistics Corporation
  - Clock Spring Company, LLC
  - Citadel Technologies
  - EMS Group
  - Pipe Wrap, LLC
  - T.D. Williamson, Inc.
  - Walker Technical Resources Ltd.
  - Wrap Master
  - Furmanite
  - Neptune

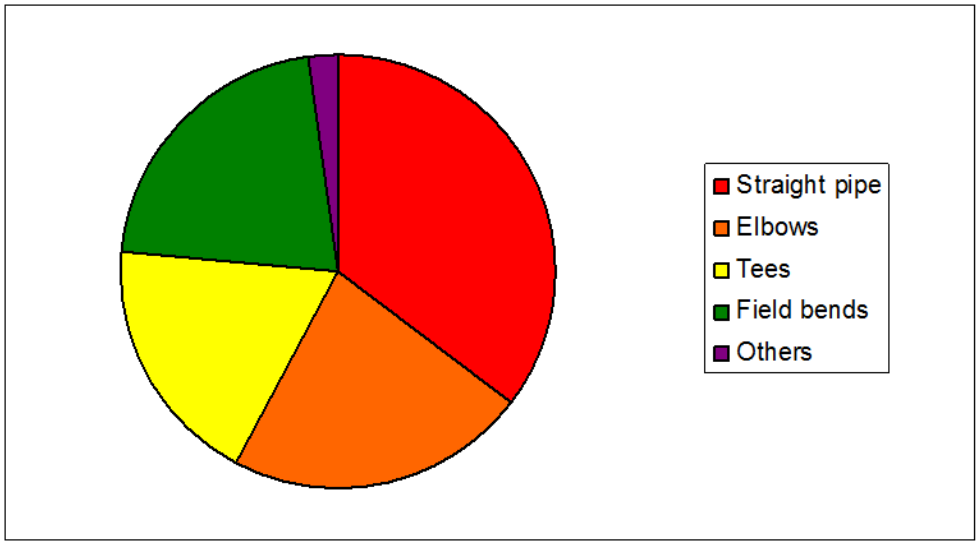
# Operator's Survey Data (1/5)

- Estimate the total number of composite repairs that will be used in the next 12 months?
  - None [3 votes]
  - 1 - 10 repairs [11 votes]
  - 11 - 25 repairs [6 votes]
  - 26 - 50 repairs [7 votes]
  - 51 - 75 repairs
  - 76 - 100 repairs [1 vote]
  - More than 100 repairs [4 votes]



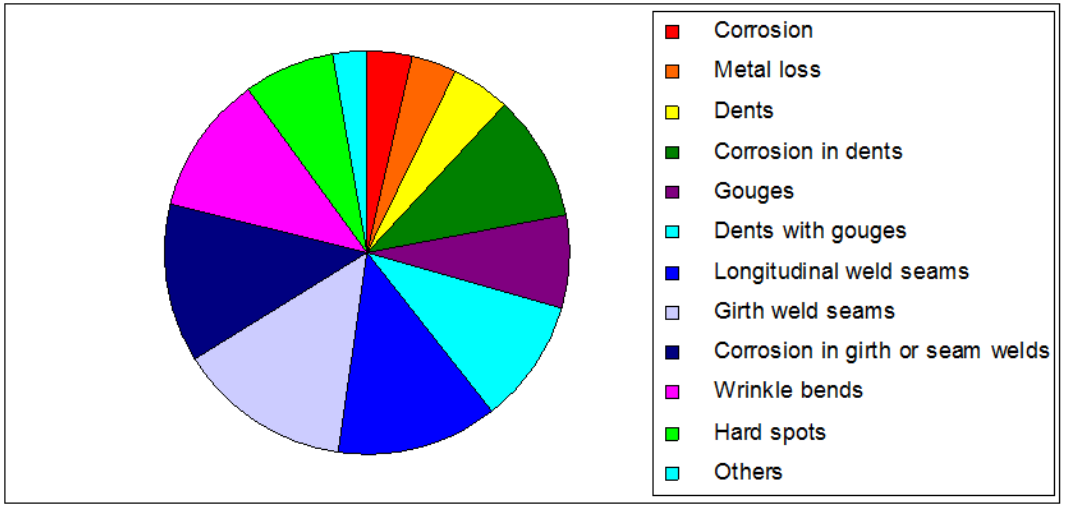
# Operator's Survey Data (2/5)

- Do your composite repair procedures allow for the repair of the following pipe geometries?
  - Straight pipe [30 votes]
  - Elbows [19 votes]
  - Tees [16 votes]
  - Field bends [18 votes]
  - Others [2 votes]



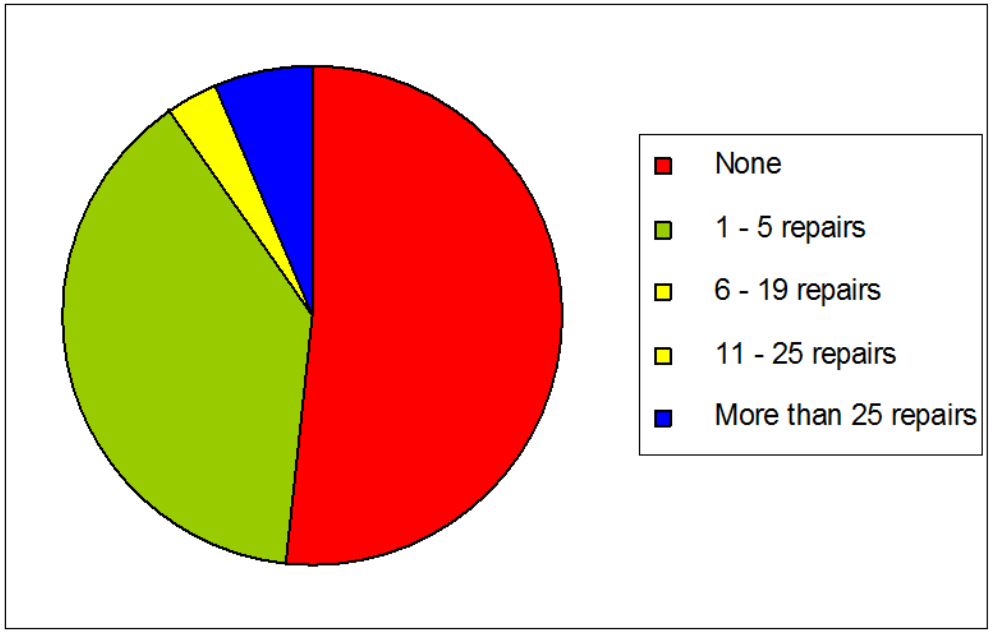
# Operator's Survey Data (3/5)

- Which of the following anomaly type repairs are <u>not permitted</u> by your company using composite materials?
  - Corrosion [4 votes]
  - Corrosion in girth or seam welds [14 votes]
  - Metal loss [4 votes]
  - Dents [5 votes]
  - Corrosion in dents [11 votes]
  - Gouges [8 votes]
  - Dents with gouges [11 votes]
  - Longitudinal weld seams [14 votes]
  - Girth weld seams [15 votes]
  - Wrinkle bends [12 votes]
  - Hard spots [8 votes]
  - Others [3 votes]



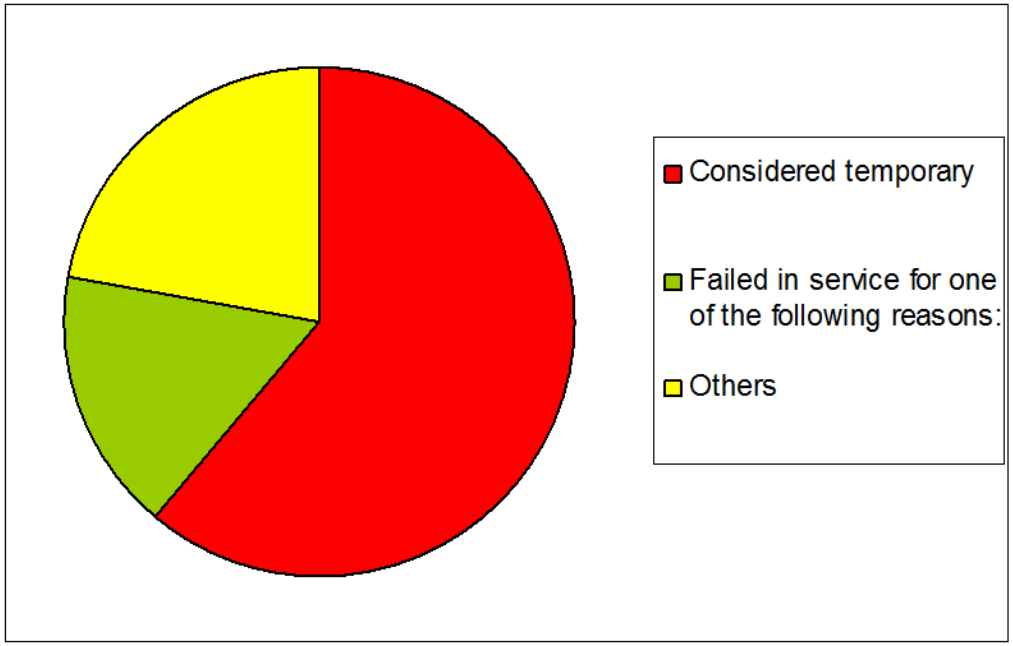
# Operator's Survey Data (4/5)

- How many total composite repairs have been removed by your company?
  - None [16 votes]
  - 1 - 5 repairs [12 votes]
  - 6 - 19 repairs
  - 11 - 25 repairs [1 vote]
  - More than 25 repairs [2 votes]



# Operator's Survey Data (5/5)

- Why were the composite repair materials removed?
  - Considered temporary [11 votes]
  - Failed in service due to disbonding of composite material [3 votes]
  - Others [4 votes]



# Long-Term Study

## (MATR-3-4)

# LT Research Program Overview

- PRCI-sponsored program with co-funding from manufacturers
- Twelve (12) companies participating in study
  - Four 10-year study participants (21 samples each)
  - Eight 3-year study participants (12 samples each)
- 180 total 8-ft samples
- Test samples buried and removed at designated periods of time for burst testing
- Program objective is to validate composite materials for long-term service

# Participants

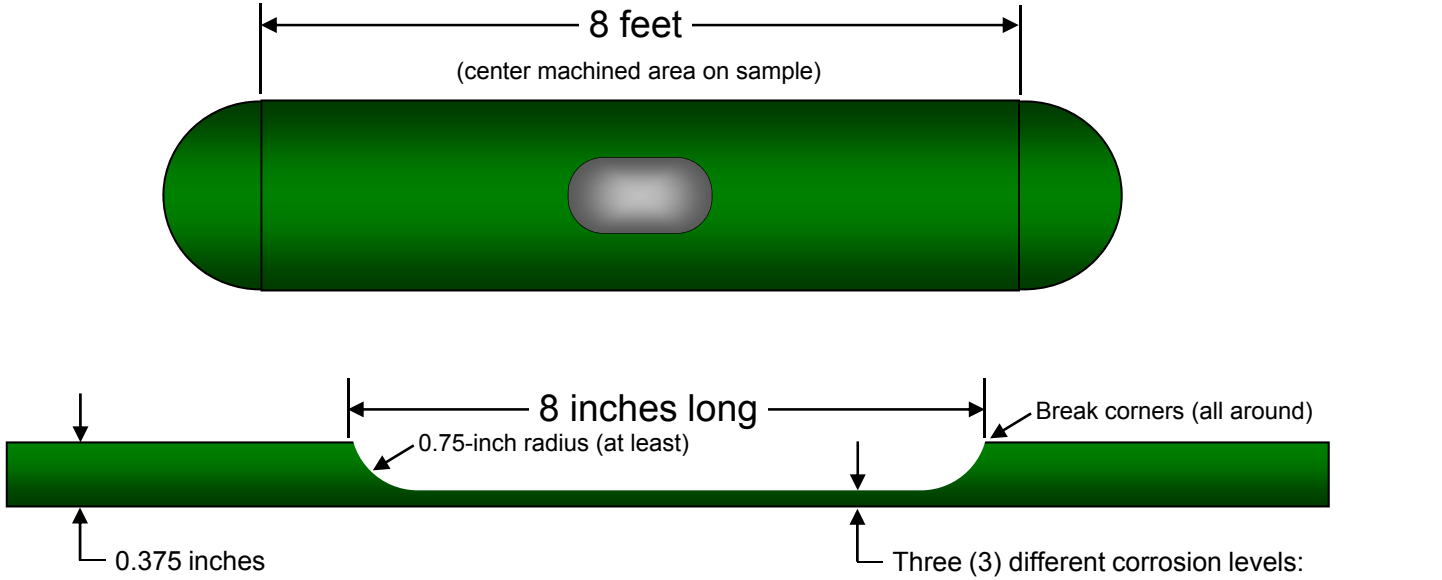
- Armor Plate, Inc. (10 years)
- Air Logistics Corporation (3 years)
- Clock Spring Company, LLC (3 years)
- Citadel Technologies (10 years)
- EMS Group (10 years)
- Pipe Wrap, LLC (3 years)
- T.D. Williamson, Inc. (10 years)
- Walker Technical Resources Ltd. (3 years)
- Wrap Master  (3 years)
- 3X Engineering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

# Program Specific Details

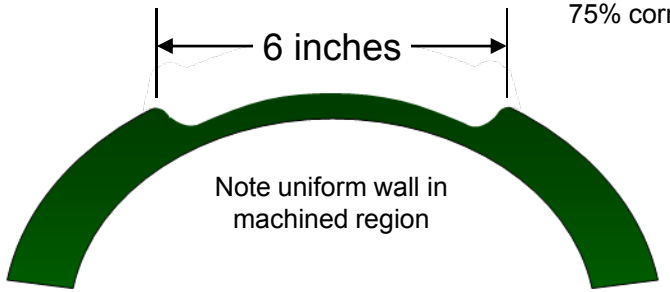
- Depths of corrosion in test samples
  - 40 percent
  - 60 percent
  - 75 percent
- Strain gage installation
  - Strain beneath the repair relates directly to the level of reinforcement
  - Performance-based information is provided
- Samples buried for designated time periods
- Burst tests at 1, 2, 3, 5, 7.5, and 10 years (see Note)

Note: Burst tests at 5, 7.5, and 0 years only applicable for participating manufacturers.

# 12.75-inch x 0.375-inch, Grade X42 pipe (8-feet long)

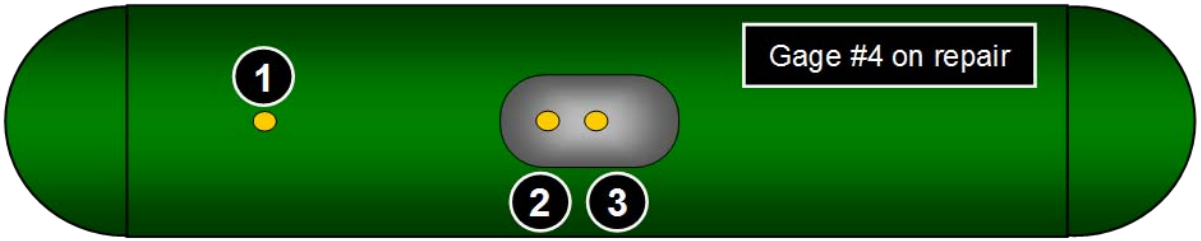


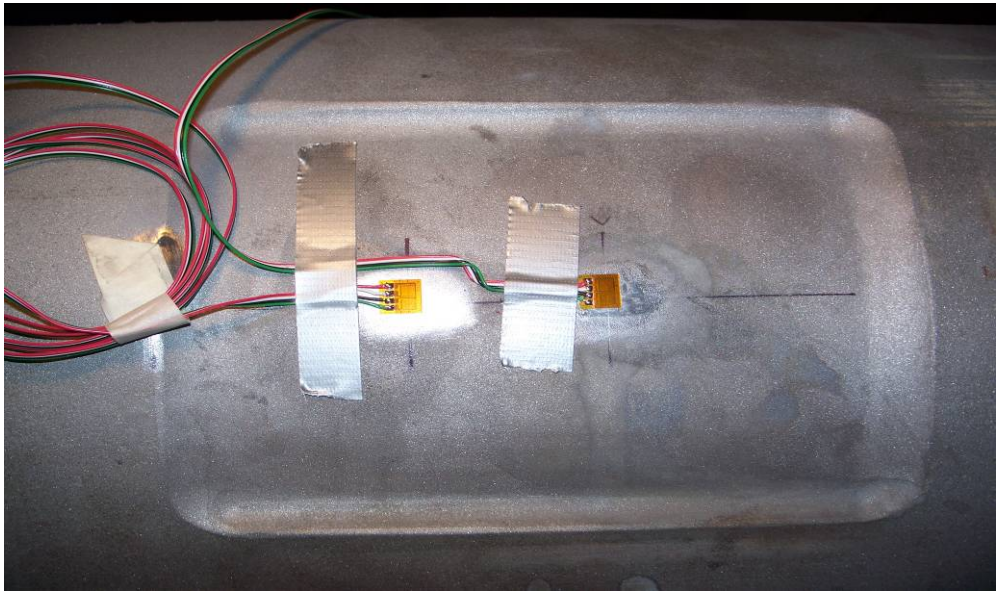

**NOTE:** Perform all machining 180 degrees from longitudinal ERW seam.



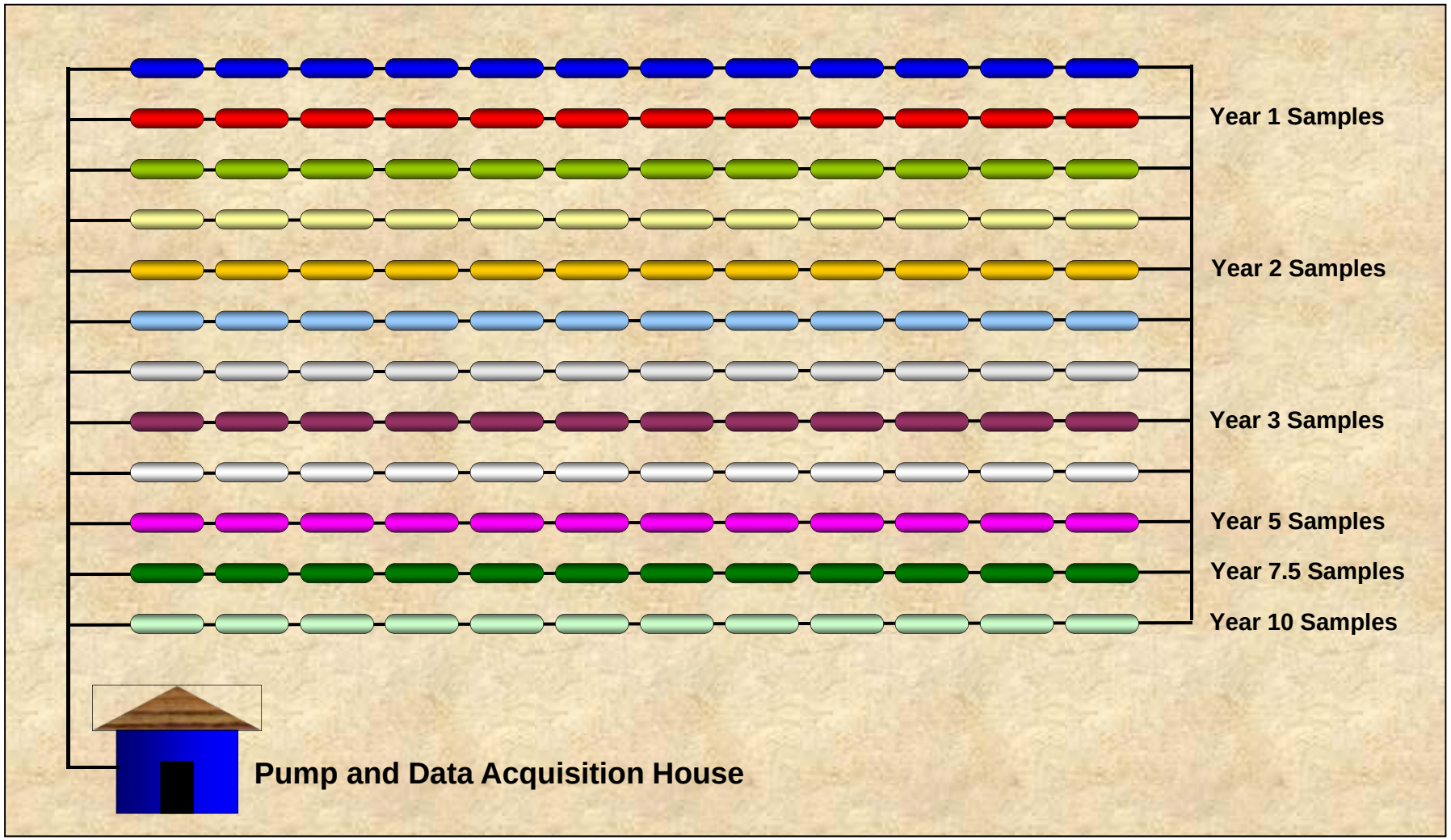

Details on machining
(machined area is 8 inches long by 6 inches wide)

# Strain Gage Installation



# Test Field Layout



# Field Work Photos (1/3)

# Field Work Photos (2/3)

# Field Work Photos (3/3)

# Burst Test Results

- 36 burst tests completed for 12 different manufacturers (plus 3 unrepaired test samples)
- Strain gage readings provided insight on level of reinforcement provided by composite materials
- Several burst failures occurred in the repaired region at pressures below 4,000 psi
- SES measured the thickness of composite repairs and wall thicknesses of machined regions

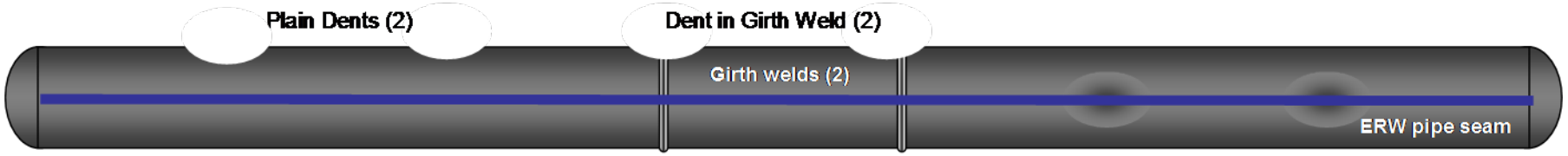
# Dent Repair Study

## (MATR-3-5)

# Composite Repair of Dented Pipes

- Program test matrix (cycle samples to failure)
  - Plain dent (unrepaired)
  - Dent interacting with girth weld (unrepaired)
  - Dent interacting with ERW seam weld (unrepaired)
  - Plain dent (repaired – 7 systems)
  - Dent interacting with girth weld (repaired – 7 systems)
  - Dent interacting with ERW seam weld (repaired – 7 systems)
- Pipe Material: 12.75-inch x 0.188-inch, Grade X42
- Measure strain using strain gages
- Cycle samples to failure ($\Delta P$=72% SMYS)
- Participants: Air Logistics, Armor Plate, Citadel, Pipe Wrap A+, Furmanite, and WrapMaster

# Test Sample Details




Side View of Pipe Sample (5 defects total)


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

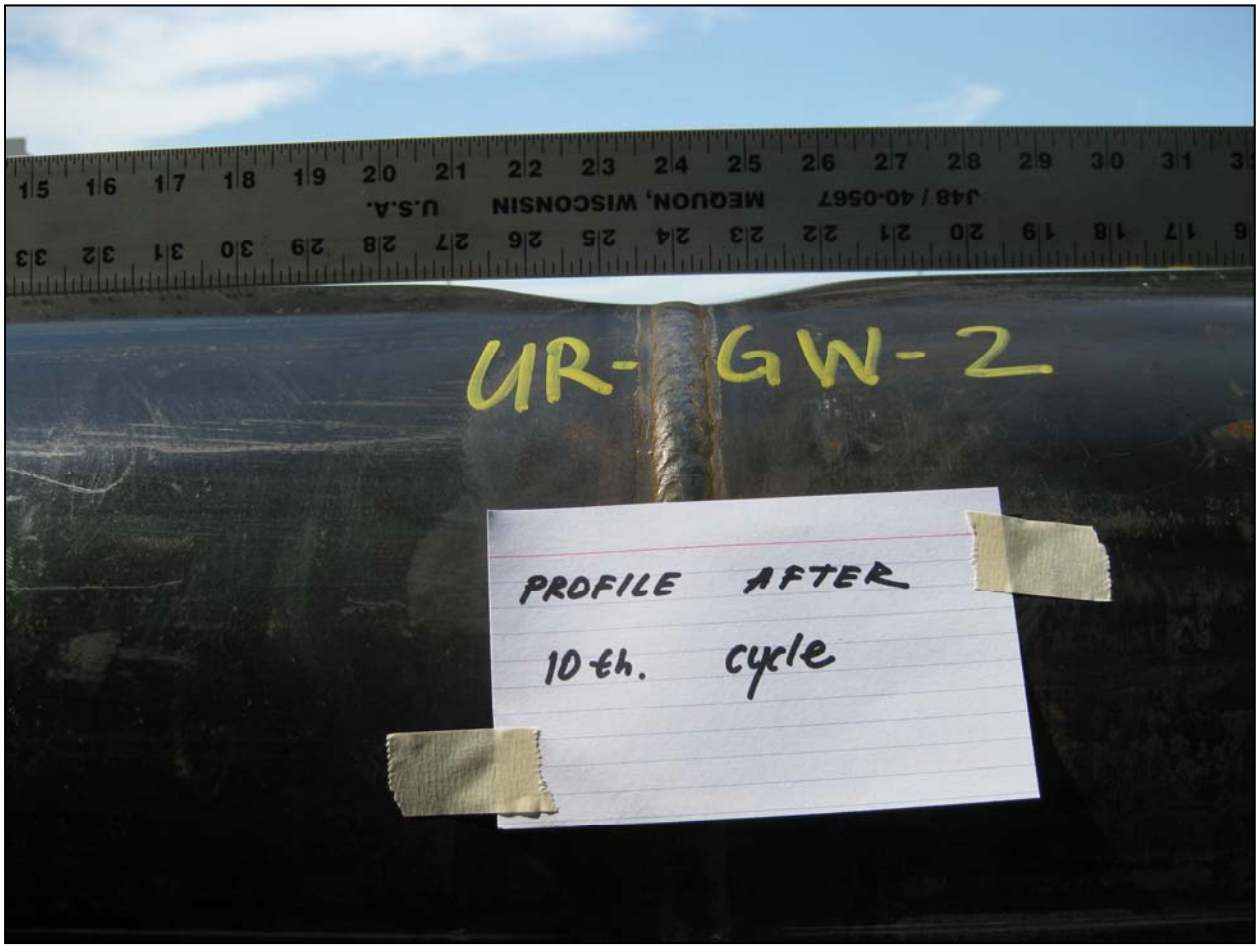
Notes:

1. Six dent defects per sample (2 of each type of defect).
2. One unrepaired pipe sample will be prepared and tested (will serve as the reference data set).
3. All six defects will be repaired by each manufacturer using their system.
4. Strain gages to be installed beneath repairs (key performance indicator of the composite reinforcement level).
5. Samples will be cycled to failure – the performance of the composite repair will be based on its ability to increase fatigue life over the unrepaired samples.

# Generating Dent Photos (1/3)

# Generating Dent Photos (2/3)

# Generating Dent Photos (3/3)



# Fatigue Test Results to Date
## (all unrepaired test samples)

- Unrepaired plain dent samples
  - UR-PD-1: 10,163 cycles
  - UR-PD-2: 10,334 cycles
- Unrepaired dent in seam weld samples
  - UR-ERW-1: 6,205 cycles
  - UR-ERW-2: 7,018 cycles
- Unrepaired dent in girth weld samples
  - UR-GW-1: 7,023 cycles (failure in girth weld itself)
  - UR-GW-2: 24,996 cycles

# Knowledge and Technology Gaps

- Repair of atypical conditions including wrinkle bends, bends/elbows, and girth welds
- Effects of bending and axial tension loads on composite performance
- Reinforcement of severe corrosion (e.g. 80%) over an extended time period with cyclic loading
- Repair of offshore piping, pipelines, and risers
- Moving towards a strain-based design as opposed to a traditional stress-based approach
- Standardization in pipeline codes (e.g. PCC-2)