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

STRESS ENGINEERING SERVICES INC.

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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) *DOOR PRIZE* give-away
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 <u>designed</u> and <u>installed</u> 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 <u>essential</u>
- Standards such as ASME PCC-2 are critical to ensure that composite repair systems are properly designed

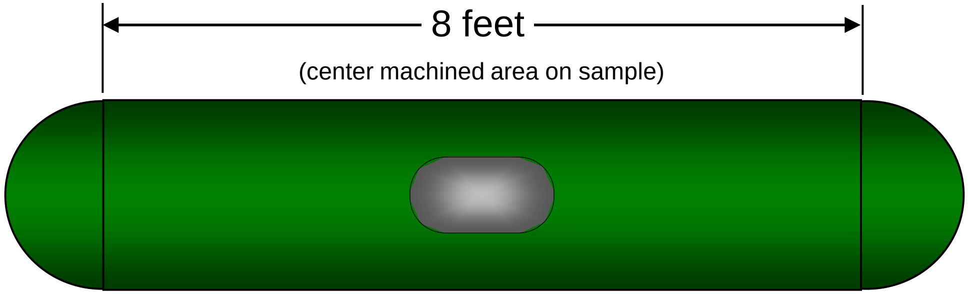
Specific Insights

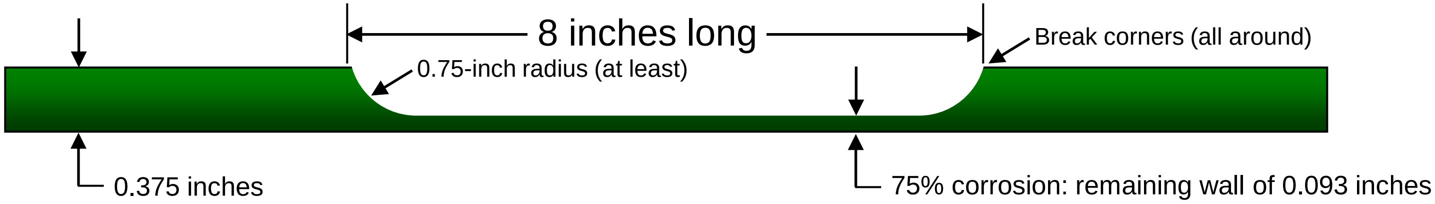
- Case Study #1
    - Defect: Corrosion
    - Loading: Cyclic pressures
- Case Study #2
    - Defect: Dents (plain, girth weld, seam weld)
    - Loading: Cyclic pressures
- Case Study #3: Inter-layer strains
    - Defect: Corrosion
    - Loading: Static pressure

Case Study #1

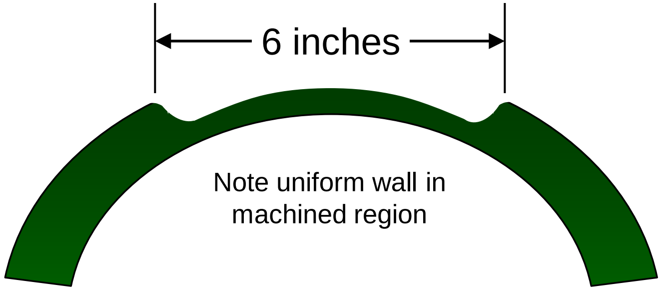
Repair of Corrosion

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





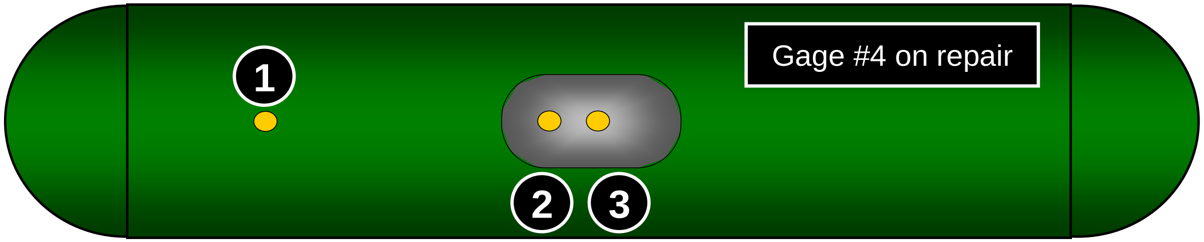
NOTE: Perform all machining 180 degrees from longitudinal ERW seam.



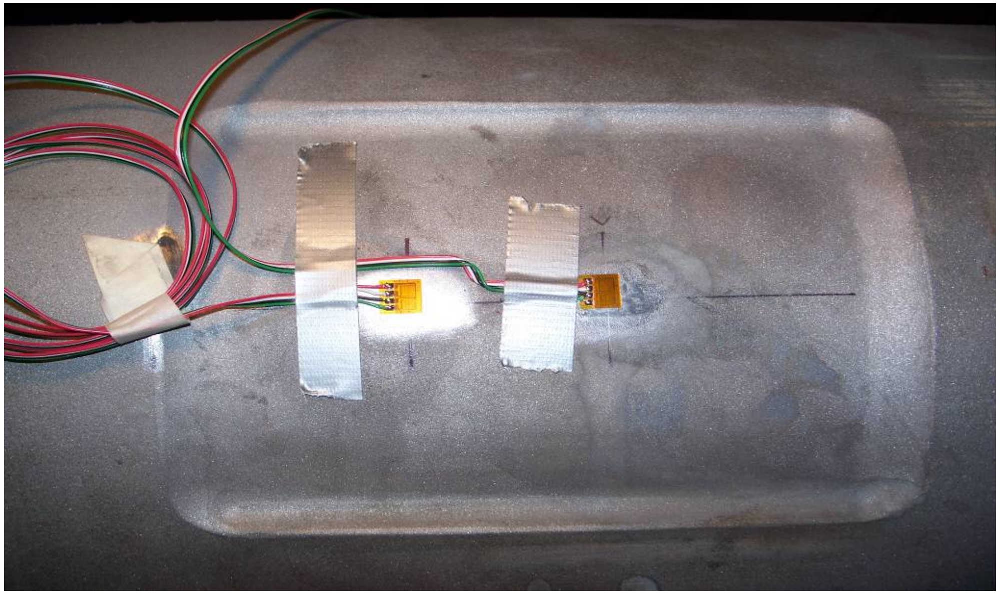
Measure wall thickness at 9 locations in the machined area using a UT meter.

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

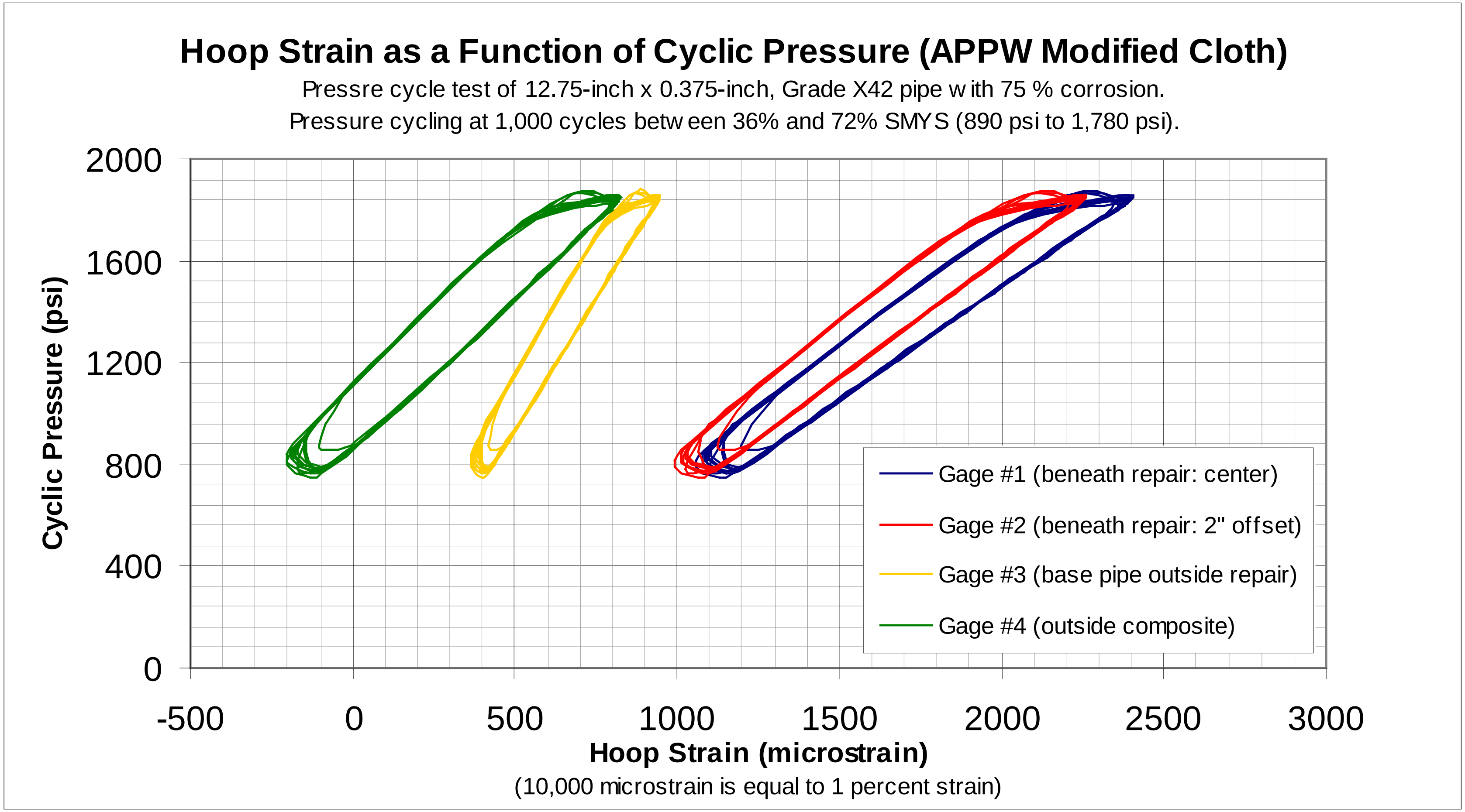


Photograph of strain gages installed in the machined corrosion region

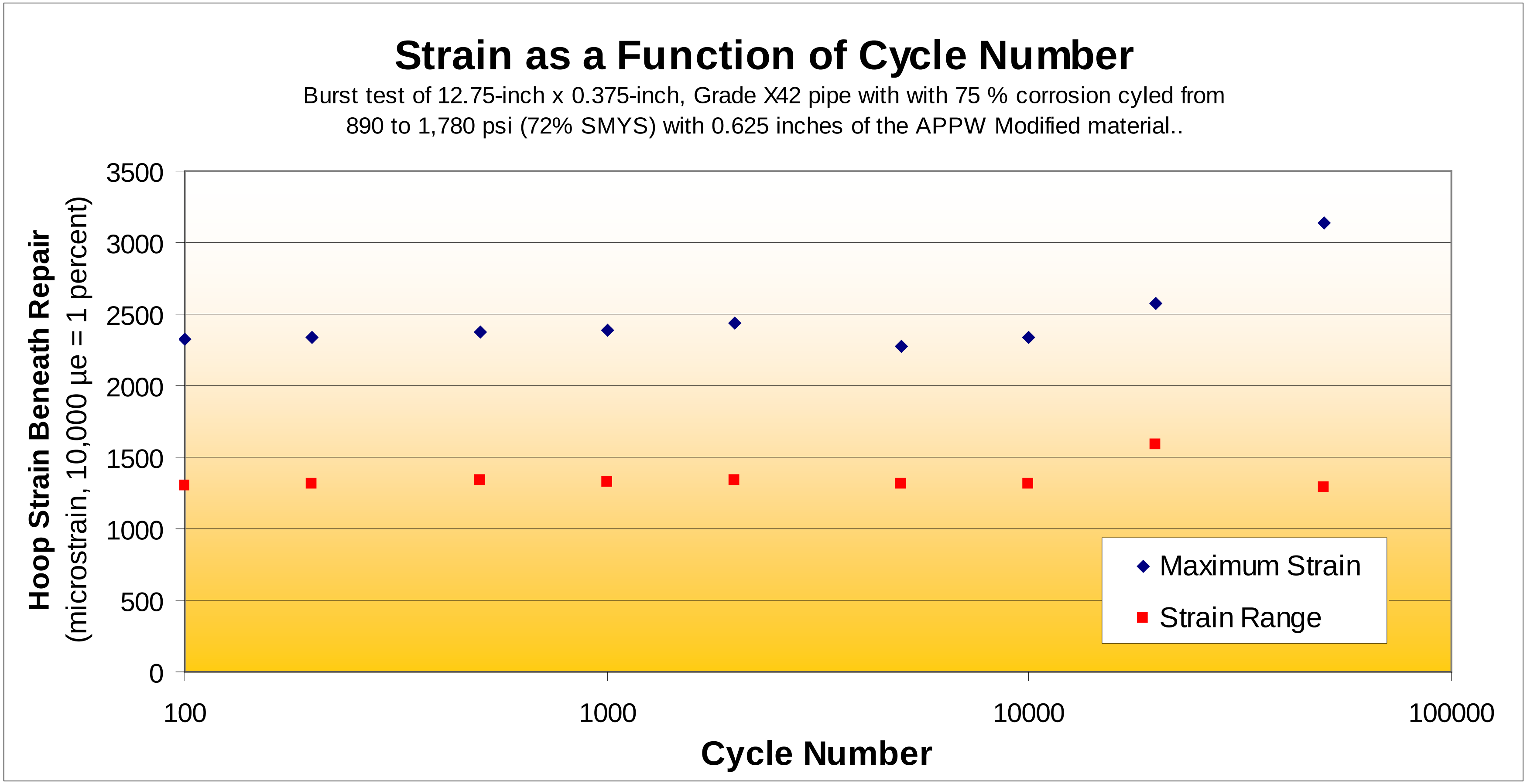
Pressure Cycle Test Results

- 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)

Pressure Cycle Strain Data (1/2)



Pressure Cycle Strain Data (2/2)



Same data presented on previous slides (strain measured beneath repair)

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Case Study #2

Repair of Dents

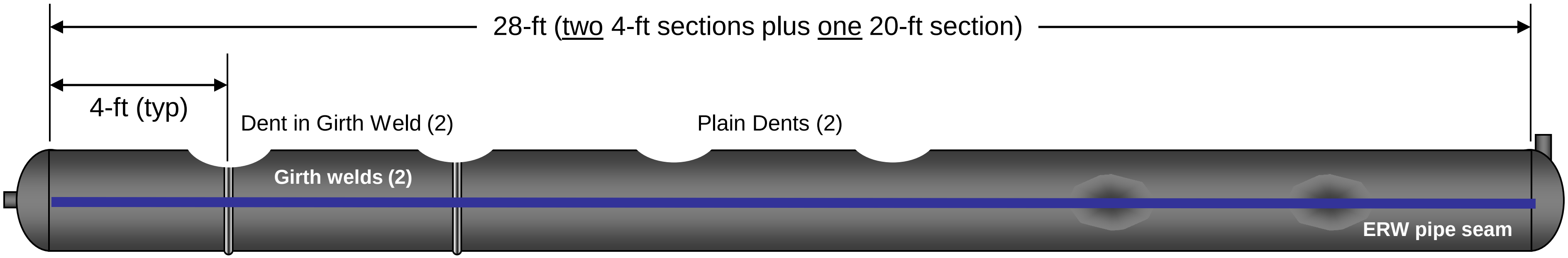
Test Sample Details

- 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 (ΔP=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



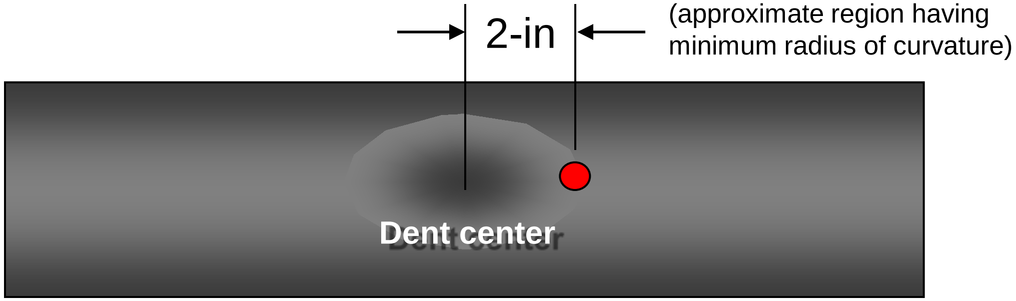
Side View of Pipe Sample (6 defects total)

Gage #1 (24 inches from end)

Top View of Pipe Sample

(notice position of dents relative to welds)

Notice orientation of bossets



(approximate region having minimum radius of curvature)

Close-up View of Dented Region

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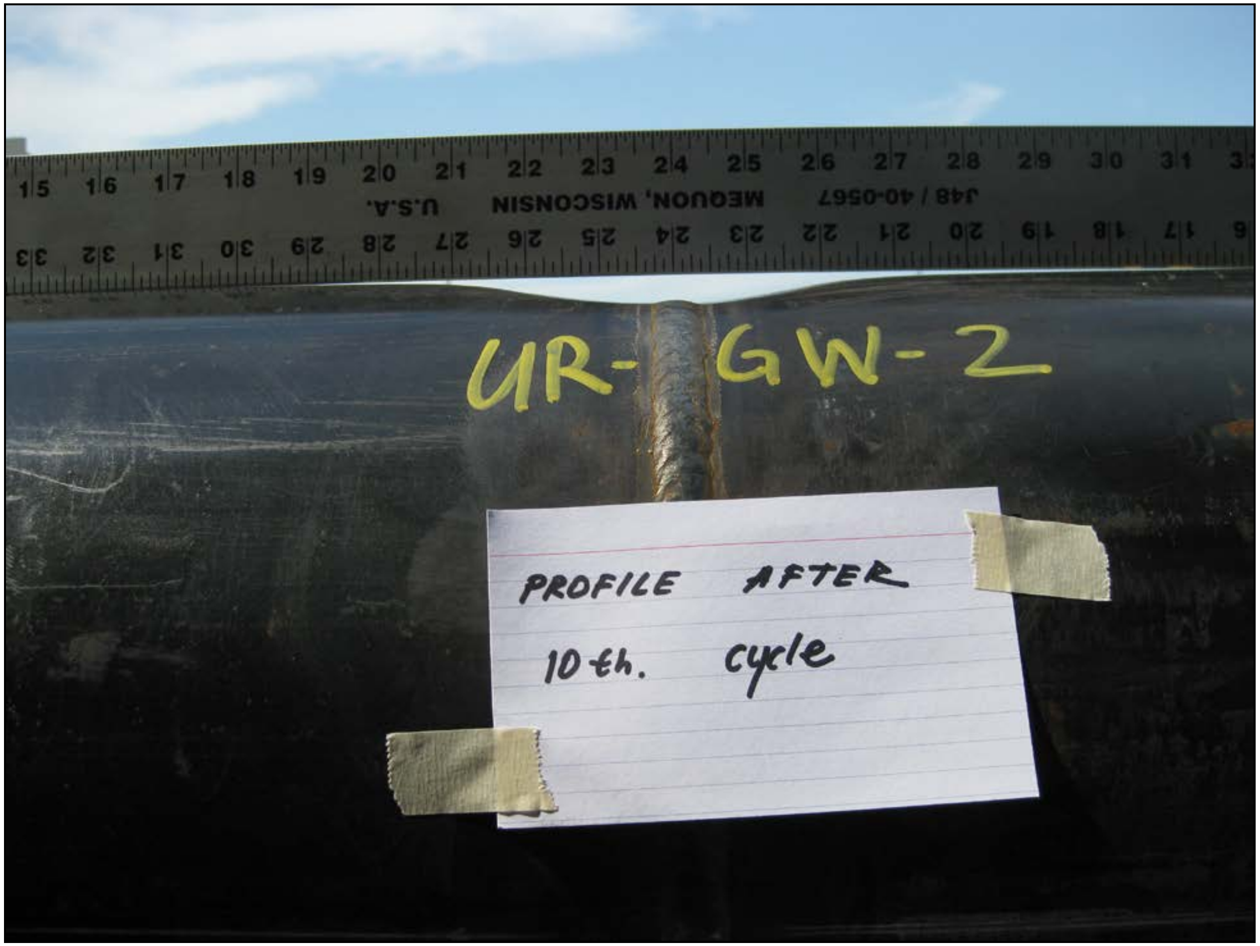
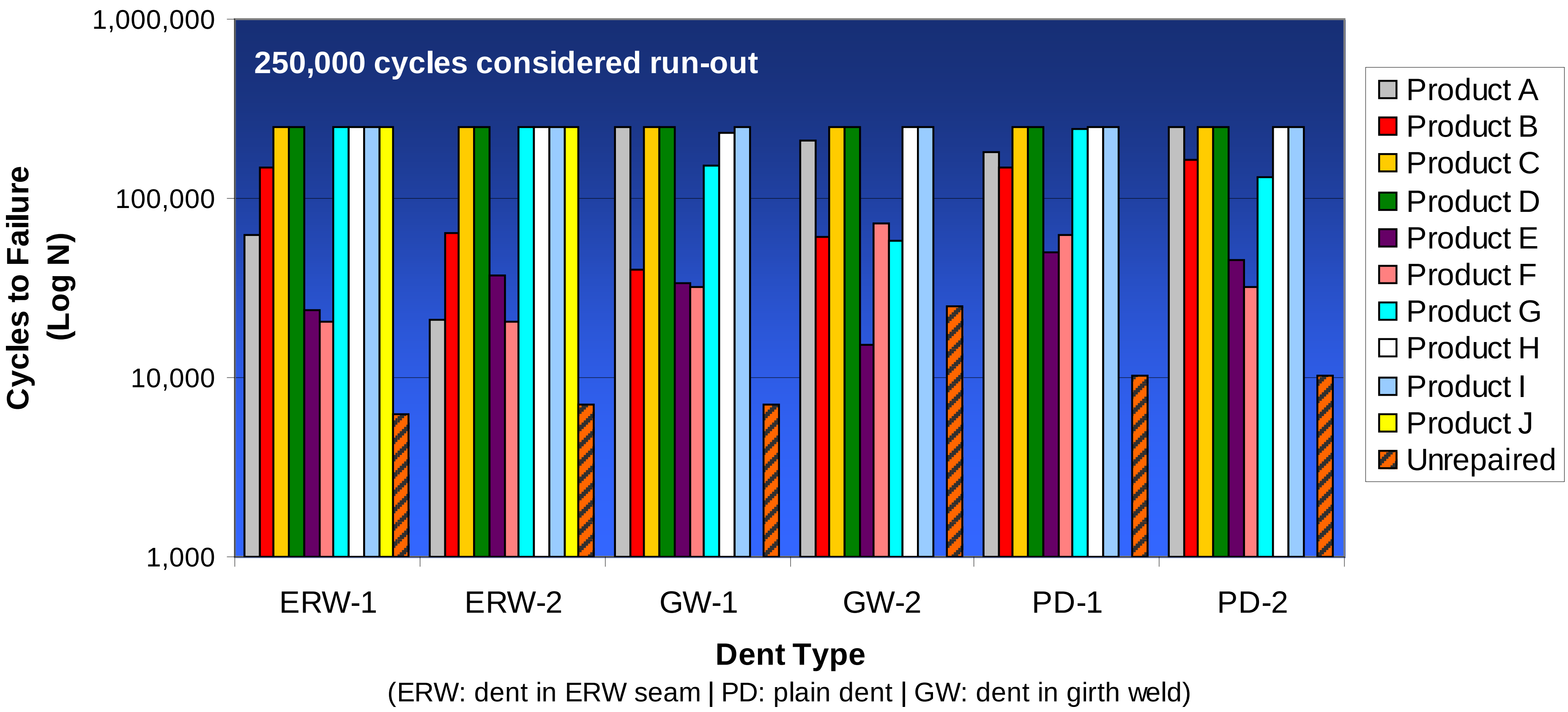
Generating Dent Photos (1/2)

Generating Dent Photos (2/2)



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 Δσ = 72% SMYS.



One system was pressure cycled to 358,470 cycles after which the ERW seam failed.

Measured Strain Gage Results

Product	Hoop Strain (microstrain)			Plain Dent Experimental $N_{average}$
	Plain Dent #1	Plain Dent #2	Average	
A	1,753	1,990	1,872	215,271
B	1,748	1,894	1,821	157,351
C	950	1,148	1,049	250,000
D	596	549	573	250,000
E	2,176	2,477	2,327	47,661
F	1,544	1,814	1,679	47,299
G	901	1,018	960	186,452
H	586	860	723	250,000
I	689	726	708	250,000
Unrepaired	4,396	4,678	4,537	10,249

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

12.75-inch x 0.188-inch, Grade X42
ΔP = 72% SMYS

Percent SMYS	**Very Aggressive**	**Aggressive**	**Moderate**	**Light**
72	20	4	1	0
65	40	8	2	0
55	100	25	10	0
45	500	125	50	25
35	1000	250	100	50
25	2000	500	200	100
Total	3660	912	363	175
Single equivalent number of cycles with DP as noted				
72%	276	67	25	10
36%	3,683	889	337	128

Kiefner J. F. et al, *Estimating Fatigue Life for Pipeline Integrity Management*, Paper No. IPC04-0167, Presented at the International Pipeline Conference, Calgary, Canada, October 4 – 8, 2008.

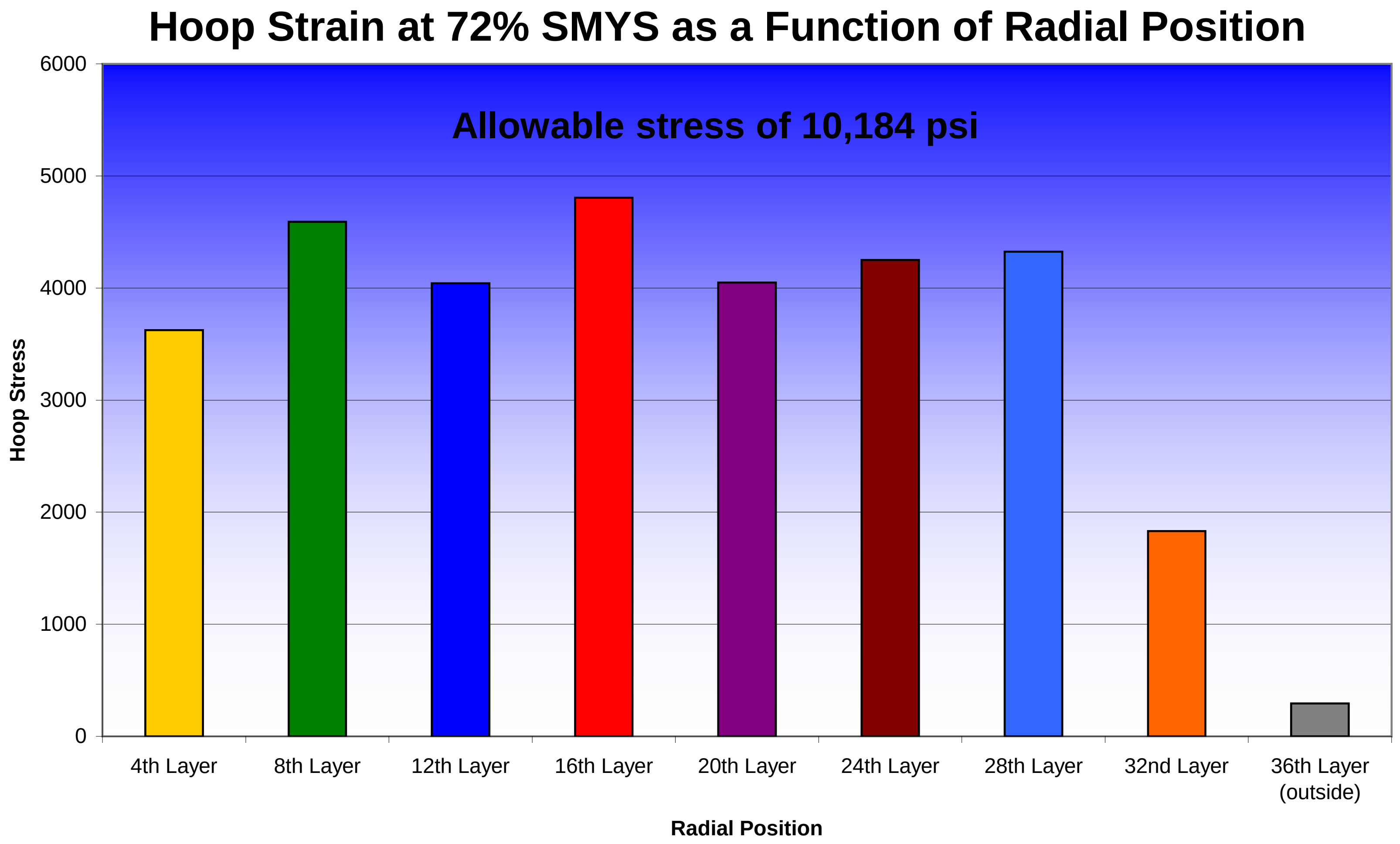
Case Study #3

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)



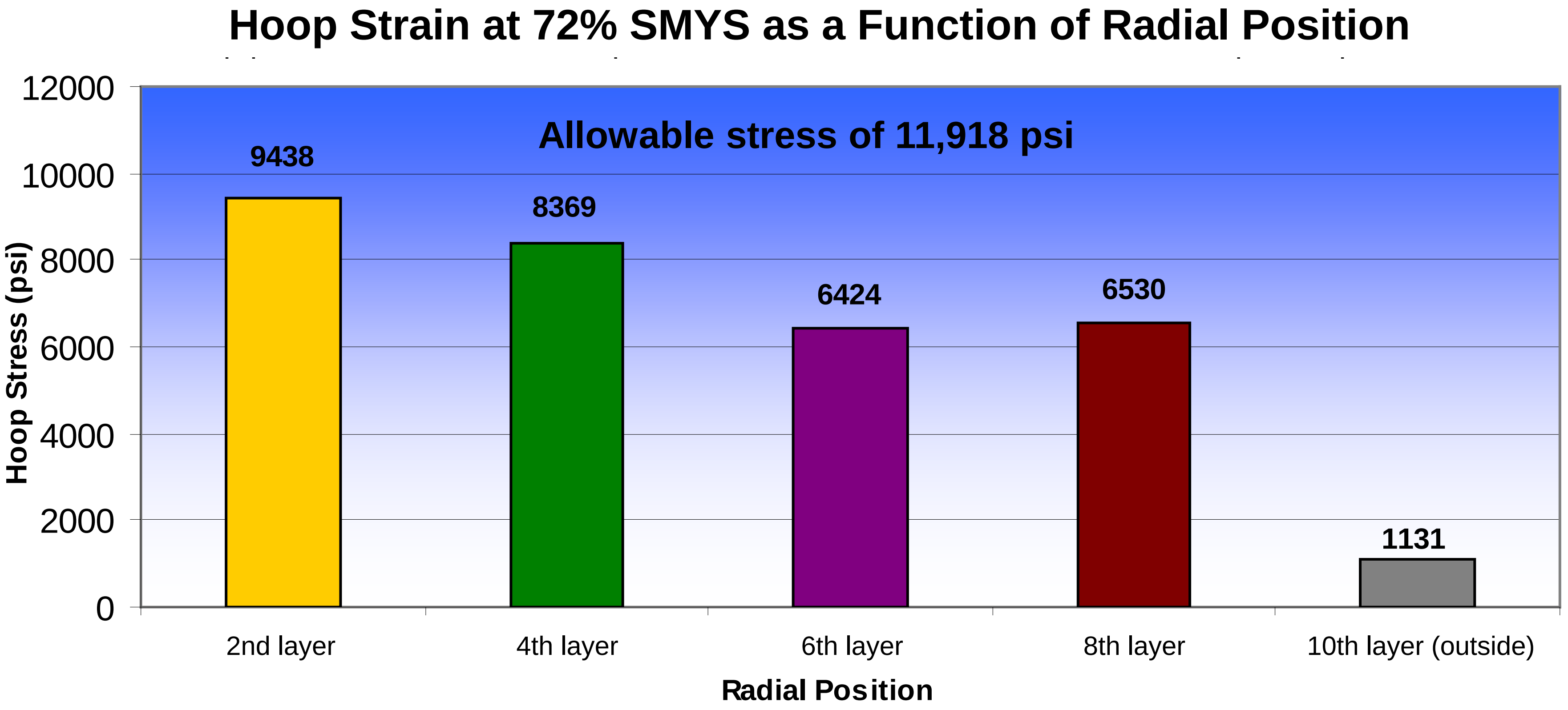
The average and maximum stresses measured in the composite material us the 72% SMYS design pressure (1,780 psi) were 3,940 psi and 4,806 psi, respectively.

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)



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?

Dr. Chris Alexander, P.E., Principal
chris.alexander@stress.com
(281) 897-6504 (direct)