OPTIMIZATION AND SCALE-UP TESTING OF COMPOSITE REPAIR TECHNOLOGIES

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IDTEXPO

OVERVIEW

- Who We Are
- History
- Background
- Repair System and Tests
- Preliminary Testing (Coupon)
- Full-scale Testing (Burst and Cyclic)
- Conclusions

WHO WE ARE

- Manufacturer of composite materials designed to comply with ASME, ISO and ACI standards in addition to solutions for protecting directional drill piping
- State-of-the-art, ISO 9001-certified manufacturing and R&D facility in FL
- Solution driven products are backed by in-house R&D, engineering, training and site support departments. Also offer accredited continuing education courses

R&D

Manufacturing

Training

HISTORY

- China Airlines Flight 611 – Taiwan to Hong Kong
- February 7, 1980
  - Tail strike on landing
- May 25, 2002
  - Crash due to metal fatigue and improper repair killing all 225 on board

BACKGROUND

- Increased composite material usage leading to more testing programs and awareness
- Understanding small changes in composite make-up
- Many testing focused only on “burst testing”
- This testing was to focus on the effect of the fibers within the repair system on the defect to optimize the two as a system

Anomaly Type / Environment	Current Industry Validation Level of Composite Repair Systems
Corrosion	Well documented
Dents	Well documented
Wrinkle Bends	Documented
Cracks	Limited
High Temperature (up to 100°C / 212°F)	Limited

FABRIC AND TEST MATRIX

- Bi-directional E-glass (0/90, stitched) with 2-part epoxy
  - Varying additions of load transfer chopped strand mat
- Coupon-level
  - Tensile, Flexural, Interlaminar Shear Strength testing
    - Strength, Modulus, and Elongation/Displacement
- Full Scale
  - Burst test following two five minute pressure holds at MAOP (1,778 psi) and 100% SMYS (2,470 psi)
  - Cyclic tests ranging from 36-72% SMYS (890-1,780psi) at 6 cycles per minute with a target of 275,000 cycles

FABRIC AND TEST MATRIX

	Ratio of Fiber Hoop:Axial	Load Transfer CSM Addition (oz/yd^2)	Coupon Level Tests	Full Scale Tests	
Group 1	70:30	0, 4, 8, 12	Tensile	-	-
Group 2	80:20		Flexural	Burst	Cyclic
Group 3	90:10		ILSS	Burst	-

COUPON TESTING

- Composite design from industry standards and past testing results used for comparison purposes
- Tensile modulus and elongation to failure identified as critical elements from design perspective
  - Other elements met by the polymer alone (i.e. temperature limits, viscosity, etc.)
- This testing was to focus on the effect of the fibers within the repair system and to optimize that piece of the system

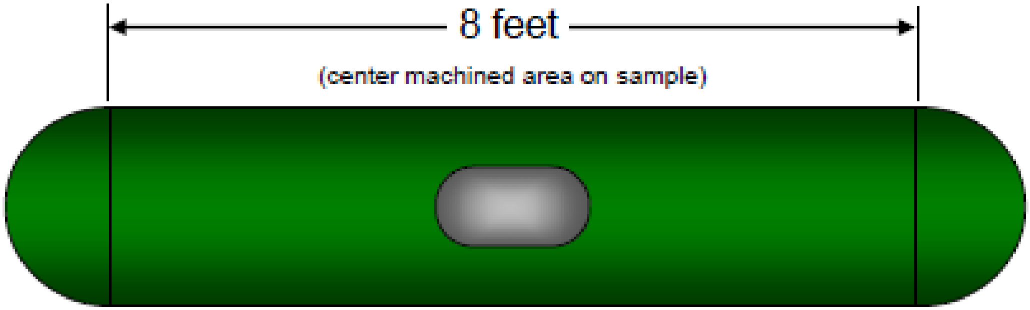
COUPON TEST DISCOVERIES

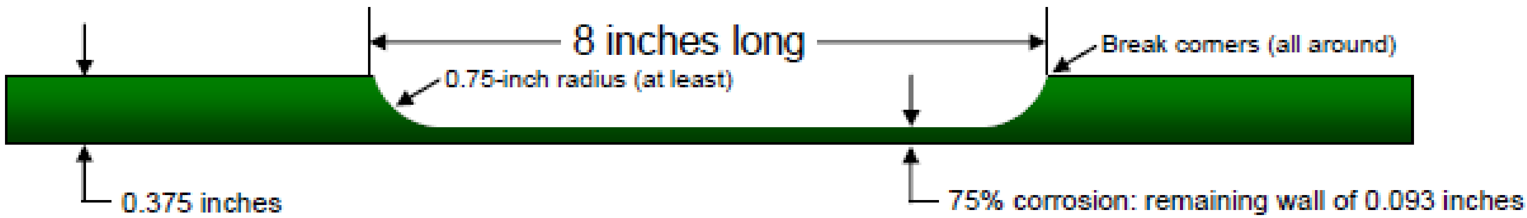
- Tensile Testing
  - Elongation to failure tended to increase with addition of chopped fiber (*preferable for long-term cyclic testing*)
- Flexural Testing
  - Failure mode of the 0 and 12 oz/yd^2 samples was primarily fiber breakage
  - Failure mode of the 4 and 8 oz/yd^2 samples was primarily delamination (*preferred method of failure*)
- ILSS Testing
  - Not a significant difference with different percentages of reinforcement

FULL-SCALE PRESSURE TEST

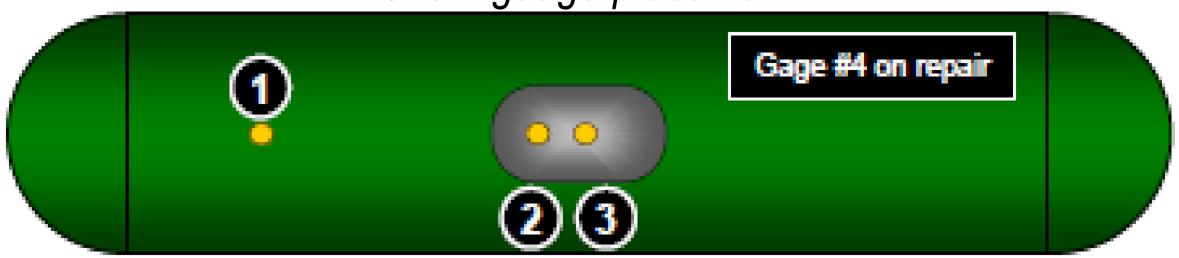
- Based on results and discoveries in coupon testing:
  - Test group #1 (70:30) was eliminated entirely
  - Test group #s 2.2, 2.3, 3.2, and 3.3 chosen to continue (80:20 and 90:10 with 4 and 8oz/yd^2 of CSM)
  - Test group #3.1 (90:10 with no CSM) was also chosen but only to serve as a baseline comparison for the other test groups
- Full-scale pressure test conducted on each sample and biaxial strain data collected
- Pipe sample and defect created according to drawing using a 12.75-inch x 0.375-in, Grade X52 pipe
- Strain gauges applied at marked areas

FULL-SCALE PRESSURE TEST

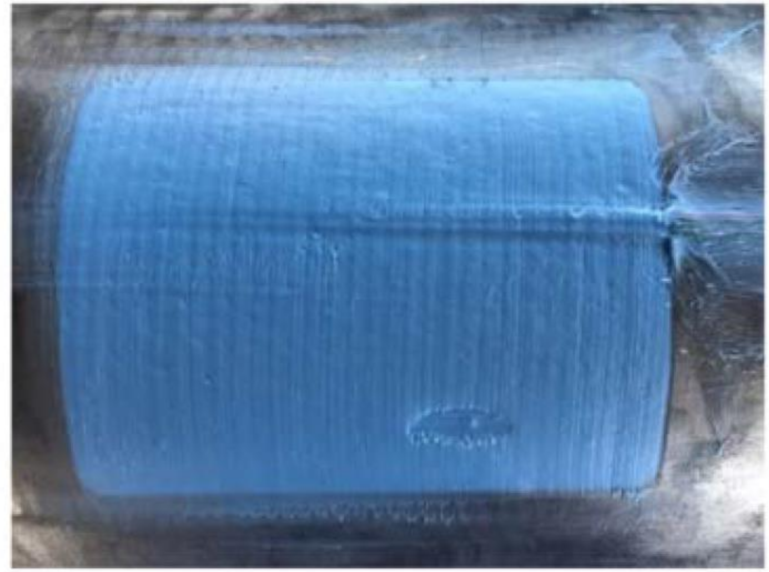


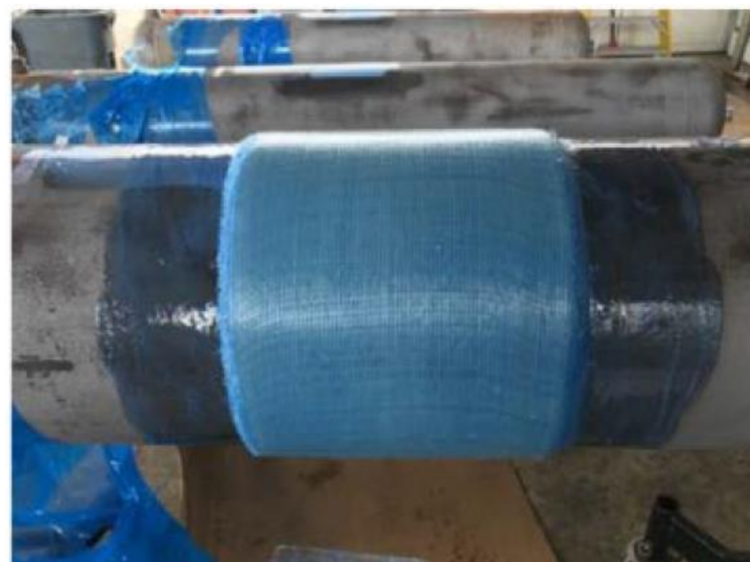


Strain gauge placement



REPAIR INSTALLATION





BURST TEST RESULTS

- Failure pressures noted were all similar in value (*within 4% of the average of all tests*)
- Nothing conclusive given by the burst pressure burst therefore emphasizing the importance of collecting strain data
- Determine and rank burst performance for each sample according to strain

BURST TEST RESULTS

- For strain data, benchmark targets set based on existing testing from PRCI
  - 3,200 microstrain at MAOP
  - 5,400 microstrain at SMYS
- Based on the strain readings, all repairs exceeded targets
- One sample clearly stood out and appears to be the ‘best’ overall performer

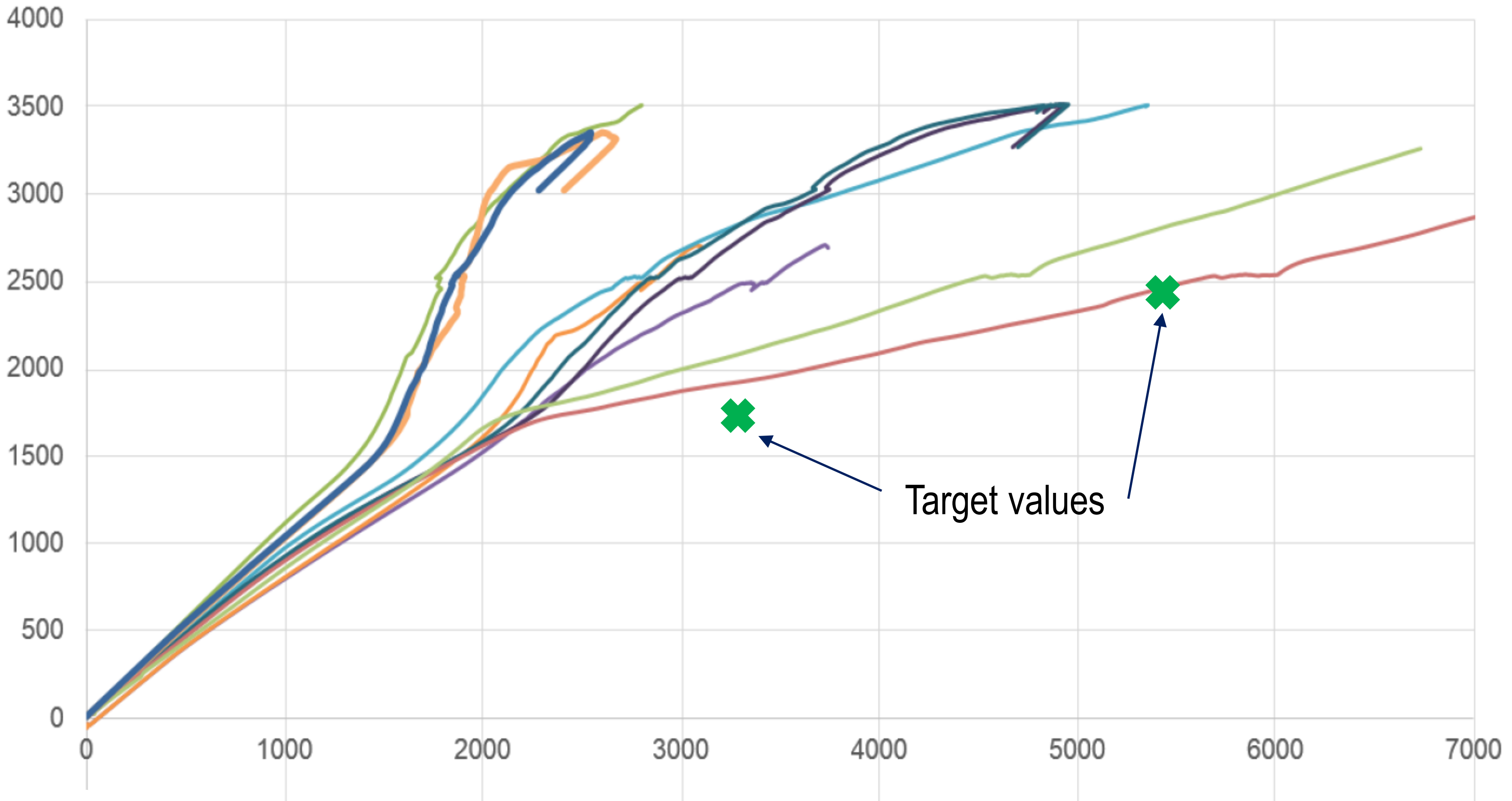
COUPON AND BURST TESTS

	Tensile Results (average)		
	Strength (ksi)	Modulus (Msi)	Elongation to Failure (%)
Group 1 (70:30)	**61.8**	**3.4**	**2.2**
Group 2 (80:20)	**74.7**	**3.7**	**2.1**
Group 3 (90:10)	**66.2**	**3.6**	**2.0**
	Flexural Results (average)		
	Failure Stress (ksi)	Modulus (Msi)	Displacement (in)
Group 1 (70:30)	**78.6**	**3.1**	**0.228**
Group 2 (80:20)	**77.3**	**3.5**	**0.193**
Group 3 (90:10)	**91.0**	**3.7**	**0.252**
	ILSS Results (average)		
	Failure Stress (ksi)	Modulus (Msi)	Displacement (in)
Group 1 (70:30)	**4.7**	**3.5**	**0.0380**
Group 2 (80:20)	**4.7**	**3.5**	**0.0390**
Group 3 (90:10)	**4.8**	**3.9**	**0.0365**

Burst Results
Pressure (average)
-
4510
4631

Defect yield expected at 765.

PRESSURE TEST RESULTS



CYCLIC PRESSURE TEST

- Based on pressure test results, test group #2.3 (80:20 ratio with 8oz CSM) chosen to undergo cyclic pressure testing
- Strain measurements taken to identify maximums, minimums, and strain range ($\Delta\varepsilon$) to identify long-term effects on repair system
- Target a strain range below 1500$\mu\varepsilon$. Past programs indicate the composite will not degrade significantly due to pressure cyclic fatigue below this range.

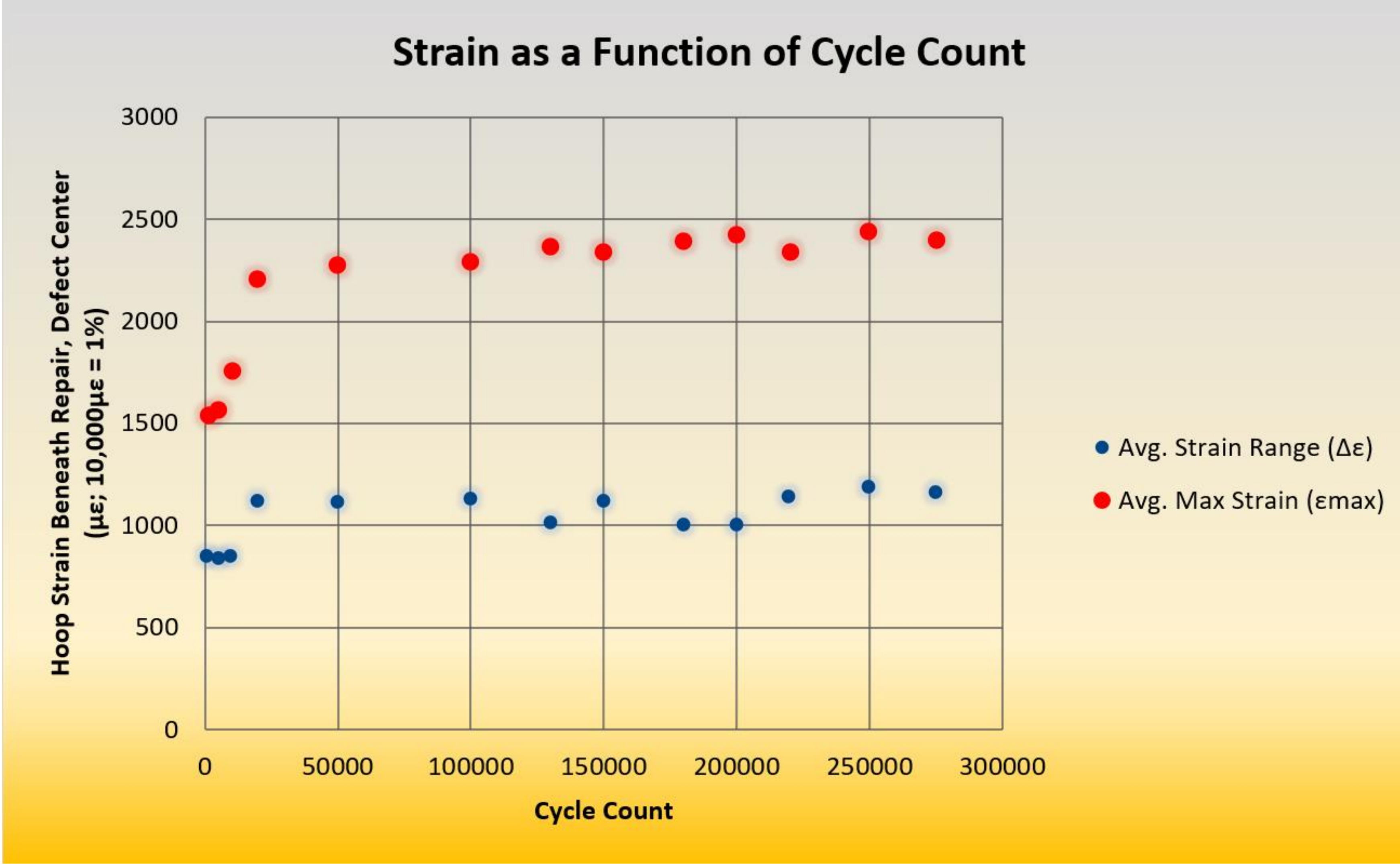
CYCLIC TEST RESULTS

- All pipe samples completed full "run-out" of 275,000 cycles with no failure or visual damage/wear identified.
- Relatively constant strain range over long-term usage.
- Identified early changes, considered "break-in" period of the system while reaching equilibrium of load distribution.
- Optimized system achieved an average strain range of 1000με (30% below industry findings) indicating long-term performance will be successful.
  - Target was 1500με or less.

CYCLIC TEST RESULTS

Cycle Count	Gauge Location	Hoop Strain Measurements (με) and Strain Range (Δε)								
		Pipe #14			Pipe #15			Pipe #16		
		Min	Max	Δε	Min	Max	Δε	Min	Max	Δε
100K	Defect center	1424	2404	**975**	1076	1992	**916**	1345	2476	**1131**
	2" off center	2041	3058	**1015**	1135	1995	**860**	1416	2391	**975**
190K	Defect center	1549	2524	**980**	1148	2053	**905**	1528	2660	**1132**
	2" off center	2293	3308	**1017**	1155	2053	**898**	1491	2456	**965**
250K	Defect center	2789	3789	**1000**	1186	2101	**915**	1651	2784	**1133**
	2" off center	3279	4316	**1037**	1199	2075	**876**	1548	2524	**976**
275K	Defect center	*Note*[1]	*Note*	**1051**	1150	2046	**896**	1628	2730	**1102**
	2" off center	*Note*	*Note*	**1089**	1169	2042	**873**	1514	2471	**957**

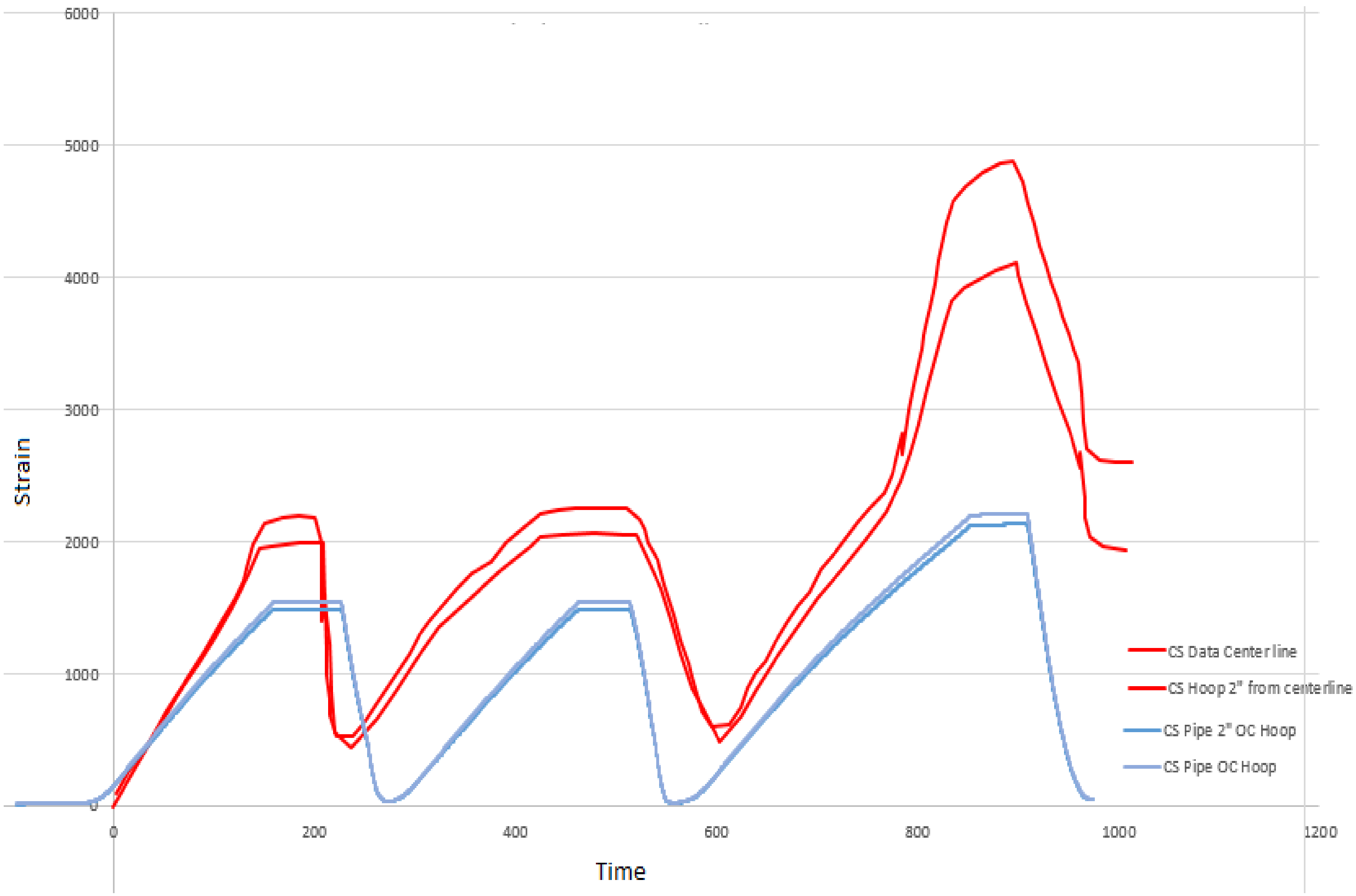
CYCLIC TEST RESULTS



FULL-SCALE TEST RESULTS

- Comparing to identical test on a product by GTI in the 1990's:
- In burst testing, reduced strain in the defect region by 50% at pressures up to 2000 psi and as pressure increased this reduced strain by over 70%.
- Also, when the pressure was returned to zero the strain went back to zero showing no permeant yielding in the defect zone.
- In cyclic testing, reduced max strain in defect region by 50%.
  - Relatively constant strain range over long-term usage

CYCLIC TEST RESULTS



CONCLUSIONS

- Progression from coupon level to full scale testing to optimize a fiber architecture that reduces the strain in severe corrosion defects considering aggressive loading conditions
- Indications show slight variations can have great impact on the repair system performances
- Historical data, ASME and ISO standards give baseline requirements but further development is needed to verify applicability of the solution

WHAT DOES GOOD LOOK LIKE IN 10 YEARS?

- Solution driven products optimized to address an ever expanding set of deficiencies
- Legacy, ‘work horse’ composite repair systems will see reduced roles, some retired
- Industry wide procedures and protocols developed beyond ASME/ISO
  - Regulators
  - Installers
- Continued collaboration between manufacturers along with operators and manufacturers

THANK YOU FOR YOUR TIME!

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