

PIPELINE REPAIR OF CORROSION AND DENTS: A COMPARISON OF COMPOSITE REPAIRS AND STEEL SLEEVES

Chris Alexander

Stress Engineering Services, Inc.
Houston, Texas
chris.alexander@stress.com

Brent Vyvial

Stress Engineering Services, Inc.
Houston, Texas
brent.vyvial@stress.com

Fred Wilson

Armor Plate, Inc.
Pasadena, Texas
fwilson@armorplate.com

ABSTRACT

When pipeline repairs are made on high pressure onshore transmission pipelines, in modern times repairs typically involve steel sleeves or composite repair systems. A comprehensive testing program was conducted to evaluate the repair of severe corrosion and dents using composite materials, as well as Type A and B steel sleeves. Full-scale destructive testing was performed including cyclic pressure loading and burst testing. Along with testing to failure, strain gages installed beneath the repairs were used to quantify the level of reinforcement provided by the respective repair systems.

In this seminal body of work, operators are given information that provides a direct comparison between these competing repair technologies. The fundamental objective in testing was to determine the service life of the competing repair technologies, although of specific interest in this study was an effort to qualify the relative performance of the composite repairs and steel sleeves. The authors also utilized the test results to quantify the service lives of the repaired anomalies based on the operating conditions of actual pipeline systems.

INTRODUCTION

Composite materials are widely recognized as a viable means for repairing corrosion and dents in gas and liquid pipelines. Dating back to 1994, Stress Engineering Services Inc. (SES) has been evaluating the performance of composite repair systems for reinforcing features and defects in pipelines including corrosion, dents, mechanical damage, wrinkle bends, branch connections, defective girth welds, and fittings such as elbows and tees.

Historically, steel sleeves have been used to repair damaged pipelines. The Type A sleeve involves steel half shells that are not welded on the ends to the carrier pipe, while the Type B sleeve may be a pressure containing full-encirclement sleeve with welded ends. Armor Plate, Inc. initiated a study to compare the relative performance of steel sleeves to the Armor Plate® Pipe Wrap (APPW) composite repair system; a system that employs E-glass fibers in a two-part epoxy matrix. This study involved the repair of corrosion and dents using both steel and composite reinforcement. Loading included pressure to failure and cyclic pressures. Strain gages were installed on the damaged pipe beneath the repairs. Evaluating the relative performance of the repairs was achieved through destructive full-scale testing, but also by comparing the level of reinforcement provided by each repair system based on the measured strain gage results.

The sections of this paper that follow include *Test Methods* and *Test Results* sections that provide specific details on the testing program. A *Discussion* section addresses specific insights gained in reviewing the test results, including evaluating the relative performance of the steel and composite repairs. The *Conclusions* section includes a few closing remarks regarding the implication of these results in relation to repairing in-service pipelines.

TEST METHODS

Two sample defect configurations were tested in this program, corrosion and plain dents. Samples having a machined region to simulate corrosion with 75% wall loss were fabricated for both burst and fatigue testing. An incompressible load transfer putty-type material was used to fill the dent and corrosion regions of the samples. The dent samples were used only in the fatigue phase of the test program as plain dents are not typically associated with reduced pressure-carrying capacity. The details for the pipe materials used in this test program are listed below.

75% Corrosion Samples

- Nominal Diameter: 12.75 inches
- Wall Thickness: 0.375 inches
- Grade: X42
- SMYS: 2,470 psi
- MAOP: 1,780 psi (72% SMYS)

Dent Samples

- Nominal Diameter: 12.75 inches
- Wall Thickness: 0.188 inches
- Grade: X42
- SMYS: 1,239 psi
- MAOP: 890 psi (72% SMYS)

Corrosion Sample Preparation

Listed below are the steps that were completed in preparing the corrosion test samples.

1. Weld end caps to samples.
2. Machine simulated corrosion area in pipe as shown in Figure 1.
3. Install strain gages as shown in Figure 2.
4. Sandblast samples.
5. Install composite repair, Type A sleeve, and Type B sleeve. The thickness of the composite was 0.625 inches (10 layers) based on design calculations performed prior to making the repair.

Dent Sample Preparation

Listed below are the steps that were completed in preparing the dented pipe test samples.

1. Install end caps.
2. Install three (3) dents per sample having an initial dent depth of 15% using a 4-inch spherical end cap as the rigid indenter using the following process (see Figure 4):
 - a. Install first dent to 15% depth (1.9 inches for 12.75-inch OD pipe) and hold the indenter in place while sample is then pressurized to 72% SMYS (890 psi). In this regard, the simulated defect represents an in-service dent generated while the pipeline is operating.
 - b. Record load required to generate dent and collect load-deflection data during the indentation process.
 - c. Release load on indenter and measure profile of residual dent depth without internal pressure
 - d. Continue process (steps a through c) and install the two (2) remaining dents – all dents will be made with internal pressure.
 - e. Apply 10 pressure cycles from 0 to 100% MAOP (0 to 890 psi) and then measure all dent profiles.
3. Sandblast pipes where the composite repair material will be installed.
4. Install strain gages near dents in transition area on “halo” region of dent. Refer to details shown in Figure 2.3 for strain gage locations
5. Install composite repair, Type A sleeve, and Type B sleeve. The thickness of the composite was 0.313 inches (5 layers, 1.5 times the pipe wall thickness of 0.188 inches) based on design calculations performed prior to making the repair.

Burst Testing Procedure

Listed below are the steps that were completed in performing the burst tests.

1. Started the data acquisition system in order to record data. Recorded data at 1 scan per second.
2. Increased pressure at a rate not to exceed 10 psi per second up to the designated 5 minute pressure holds
 - a. 1,780 psi (72% SMYS)
 - b. 2,470 psi (100% SMYS)
3. Increased pressure until failure occurs.

Fatigue Testing Procedures

Listed below are the steps that were completed in performing the pressure cycle fatigue tests.

1. Both corrosion and dent samples were pressure cycled; details provided below for each.
 - a. Fatigue test dent samples to failure by applying a cyclic pressure range of 72% SMYS (72% SMYS is 890 psi for the dent samples; $\Delta P = 100$ to 990 psi)
 - b. Fatigue test corrosion samples to failure by applying acyclic pressure range of 36% SMYS (36% SMYS is 890 psi for the corrosion samples; $\Delta P = 890$ to 1,780 psi).
2. Record strain gage data for 10 cycles at the following test intervals: start-up, 100, 200, 500, 1000, 2000, 5000, and 10000 cycles (assuming the strain gages survive).
3. For the dent sample as failures occur, cut out the failed leaking dent, re-weld, and continue pressure cycling.

Photographic Presentation of Sample Preparation

A significant amount of work was completed prior to testing in association with the installation of composite repair and welding of the Type A and Type B steel sleeves. Provided below is a list of several photographs showing the installations efforts.

- Figure 5: Photograph of the composite installation.
- Figure 6: Photograph of hole in sleeve for strain gage wires
- Figure 7: Photograph of metal backing strip between sleeves chained to pipe
- Figure 8: Photograph of Type B steel sleeve

TEST RESULTS

Results are presented for the corrosion burst test, corrosion pressure cycle fatigue test, and the dented pressure cycle fatigue test. The presentation of results includes a comparison of results between the composite repair and the steel sleeves. In addition to the pressure cycle to failure results, results for the strain gage measurements are also presented.

Burst Test of 75% Corrosion Samples

The actual burst pressure and hoop strains at 72% SMYS are listed in Table 1. All three 75% corrosion samples failed outside of the repaired region in the base pipe as shown in Figure 9.

Fatigue Test of 75% Corrosion Samples

The maximum hoop strains and ranges for the fatigue 75% corrosion samples at 1,000 cycles are listed in Table 2. The sample repaired with APPW failed in the corrosion area after 198,550 cycles. No failures occurred in the steel sleeves samples as they reached 302,465 cycles before cycling was stopped because the run-out condition was exceeded.

Fatigue Test of Dent Samples

The maximum hoop strains and ranges for the fatigue dent samples at 1,000 cycles are listed in Table 3. The composite repair sample failed in the dent after 149,913 cycles. The steel sleeves reached 239,897 cycles before cycling was stopped after the samples had exceeded the run-out condition. Figure 10 plots hoop strain measurements made during fatigue testing of the dent samples. As observed, data for the strain gages was recorded up to 150,000 cycles.

DISCUSSION

The fundamental objective of this study was to evaluate the performance of composite repair system in reinforcing corrosion and dent defects in a pipeline relative to the performance of Type A and B steel sleeves. This particular study is an extension of previous studies where the composite repair system was tested in repairing corrosion and dents. The results from previous test programs actually exceeded the performance of the results presented in this report. Listed below are the contrasting results.

- Repair of 75% corrosion in 12.75-inch x 0.375-inch, Grade X42 pipe pressure cycled from 890 to 1,780 psi ($\Delta P = 36\%$ SMYS)
 - Current results: 198,550 cycles to failure
 - Previous results: 259,537 cycles to failure (Year 2010)
- Repair of 15% deep dent in 12.75-inch x 0.188-inch, Grade X42 pipe pressure cycled from 100 to 990 psi ($\Delta P = 72\%$ SMYS)
 - Current results: 149,913 cycles to failure (Current study)

- Previous results: 250,000 cycles no failure (run-out), although ERW seam in pipe failed at 358,470 cycles (Year 2010)

One can conclude in reviewing the above data that the current test results for the composite repair system, as presented in this report, are more conservative than the previously-reported test results. The expected performance is dependent on the service requirements for the pipeline being repaired; however, for a typical gas pipeline the test results presented in this report demonstrate that as a minimum the repair represents a 30 year design life (refer to Table 4.1). This is an important point as the results presented in this report are a conservative estimate of the reinforcing capabilities of the Armor Plate® Pipe Wrap system in repairing both corrosion and dent defects. Consider Table 4 that presents the pressure cycle fatigue results in terms of an estimated design life. As shown, an estimated design life in years (as opposed to number of cycles) for each of the repairs assuming a “moderately aggressive” pressure cycle condition for a gas pipeline (337 cycles per year at 36% SMYS; 25 cycles per year at 72% SMYS). As observed in this table, the estimated design life for the composite repair dent repair sample was 297 years, while the life for the corrosion repair sample was 29 years. Both of these fatigue life estimates include a fatigue safety factor of 20 relative to the cycles to failure data. As mentioned previously, testing in 2010 on another 75% corrosion sample failed at 259,537 cycles, which corresponds to 39 years of service for the “moderately aggressive pressure” cycle condition.

In addition to the pressure cycle fatigue results, it is useful to consider to the strain gage results presented previously in Table 3 for the 75% corrosion burst results. This table presented strains in the reinforced regions for all three test 75% corrosion samples at 72% SMYS. The hoop strain data are as follows:

- Composite reinforced: 2,191 $\mu\epsilon$
- Type A reinforced: 1,919 $\mu\epsilon$
- Type B reinforced: 2,153 $\mu\epsilon$

An important observation in reviewing the above data is that all measured strains are within 15% of each another. The second important fact is that the sample reinforced with the composite material reduces hoop strain levels to those similar to both Type A and Type B sleeves. Although the pressure cycle fatigue results for the steel sleeves exceeded the results for the composite repaired sample, the test results demonstrate that during a quasi-static burst test, the composite material is able to provide reinforcement to the machined corrosion region similar to what could be expected for a steel sleeve.

A final comment is made regarding the general performance of the steel sleeves. This study validates that steel sleeves work when properly installed. This is no surprise to the pipeline industry; and, what makes the work included in this report unique is the level of in-depth assessment that has been conducted, especially with regards to the strain gage measurements. The question when considering the performance of composite repair systems is not necessarily are they better than steel sleeves, but are repairs using composite materials a viable alternative considering the operational requirements for a particular pipeline system? Operational requirements include factors such as cyclic pressure and temperature. The cycles to failure and predicted service life results presented in Table 4 are an example of the type of assessment that is required for evaluating the ability of any repair to meet the service requirements for a particular pipeline.

Pipeline companies and other operators use composite materials for multiple reasons with several including ease of installation, no need for welding on a live pipeline, and the ability of the repair system to conform to a variety of pipe geometries including ovality, tees, and bends. In addition to the results presented in this report, the Armor Plate® Pipe Wrap system has been certified to meet the requirements of Article 4.1 (Nonmetallic and Bonded Repairs) of the ASME PCC-2 standard, Repair of Pressure Equipment and Piping.

The results of this study have demonstrated that when properly designed (including testing verification) and installed, composite repairs can be used to repair pipelines having corrosion and dent defects subjected to static and cyclic pressure loading.

CONCLUSIONS

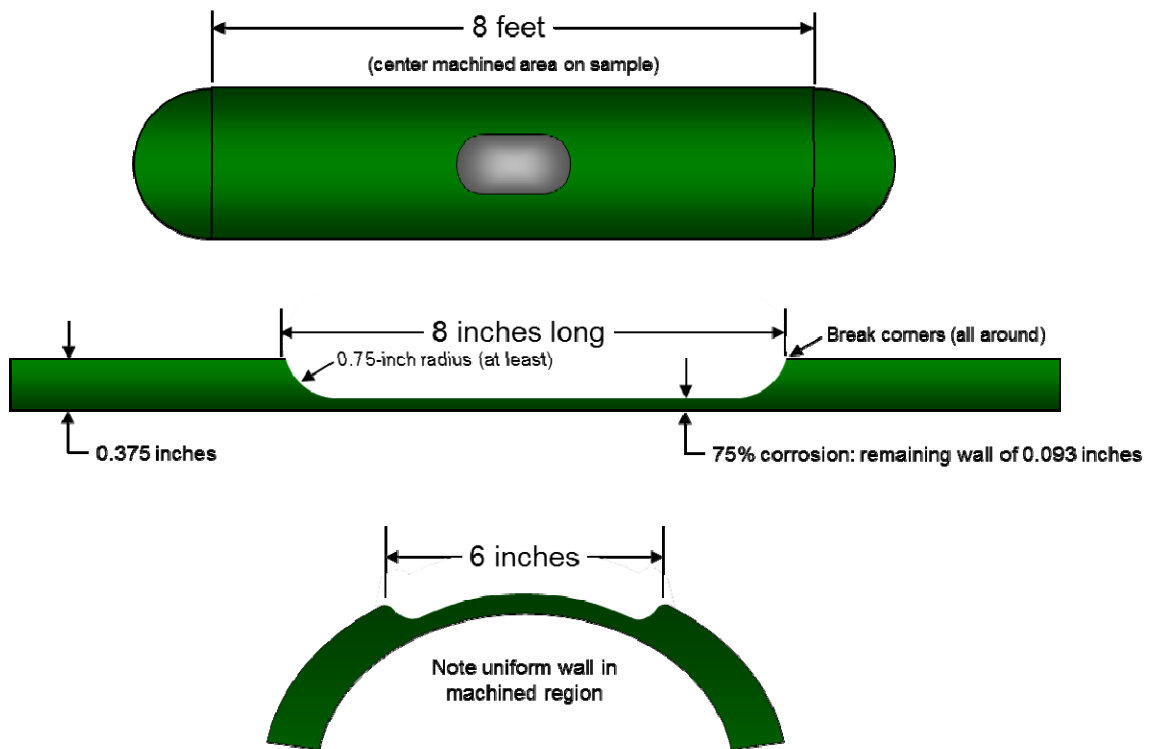
This paper has provided results on full-scale tests performed to evaluate the reinforcement provided by composite repair system in reinforcing corrosion and dents relative to the performance of welded Type A and Type B sleeves.

If one uses the pressure cycle data for the 75% corrosion fatigue sample as a benchmark for performance, for a “moderately aggressive” pressure cycle condition for a gas pipeline the estimated design life for the composite repair was 58 years, while the estimated design life for the steel sleeves was at least 90 years (could be larger as no failures occurred in either the Type A or B steel sleeve samples). Previous testing using Armor Plate® Pipe Wrap determined the service life could be as high as 75 years (259,537 cycles to failure). Additionally, the estimated design life for the composite repair dent sample was 594 years (significantly longer life as the pressure range for the dent sample was two times the pressure range applied to the corrosion sample)..

Although the samples reinforced with steel sleeves achieved more pressure cycles than the samples reinforced with the composite, this study validates previous findings and reports that the Armor Plate® Pipe Wrap system is a viable means for reinforcing pipeline defects such as corrosion and dents when properly designed and installed considering the estimated design lives.

REFERENCES

1. ANSI/ASME PCC-2-2011, Repair of Pressure Equipment and Piping, Repair Standard, Article 4.1, Non-metallic Composite Repair Systems for Pipelines and Piping: High Risk Applications, American Society of Mechanical Engineers, New York, 2011.
2. Alexander, C., and Bedoya, J., Repair of Dents Subjected to Cyclic Pressure Service Using Composite Materials, Proceedings of IPC2010 (Paper No. IPC2010-31524), 8th International Pipeline Conference, September 27–October 1, 2010, Calgary, Alberta, Canada.
3. Vyvial, B.A., and Alexander, C.R., *Steel Sleeves versus Armor Plate® Pipe Wrap for Repairing Corroded and Dented Pipelines*, Reported prepared for Armor Plate, Inc., September 2012.



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

Figure 1: Simulated corrosion details

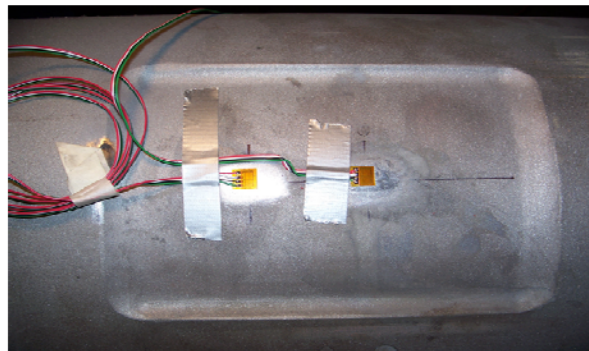
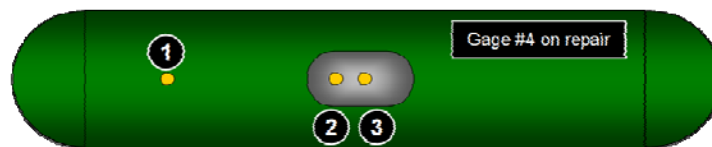
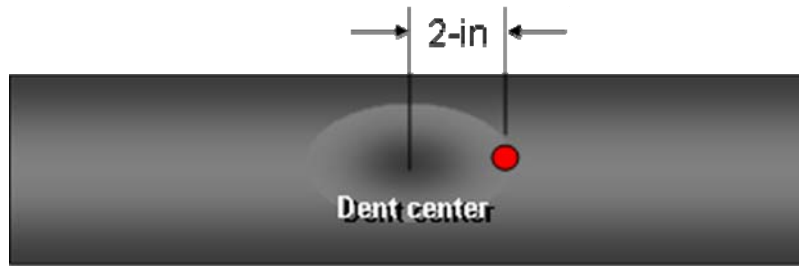


Figure 2: Simulated corrosion strain gage locations



Close-up View of Dented Region

Figure 3: Dent configuration with strain gage locations



Figure 4: Set-up for dent installation



Figure 5: Installation of composite material



Figure 6: Photograph of hole in sleeve for strain gage wires

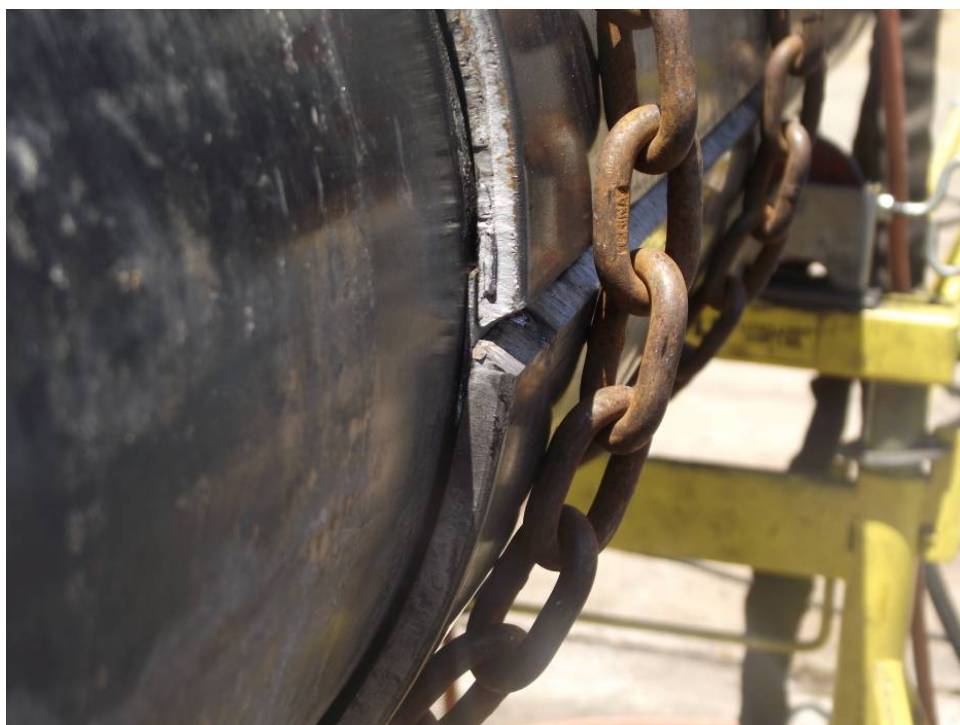


Figure 7: Photograph of metal backing strip between sleeves chained to pipe



Figure 8: Photograph of Type B steel sleeve



Figure 9: Photograph of Burst Failures

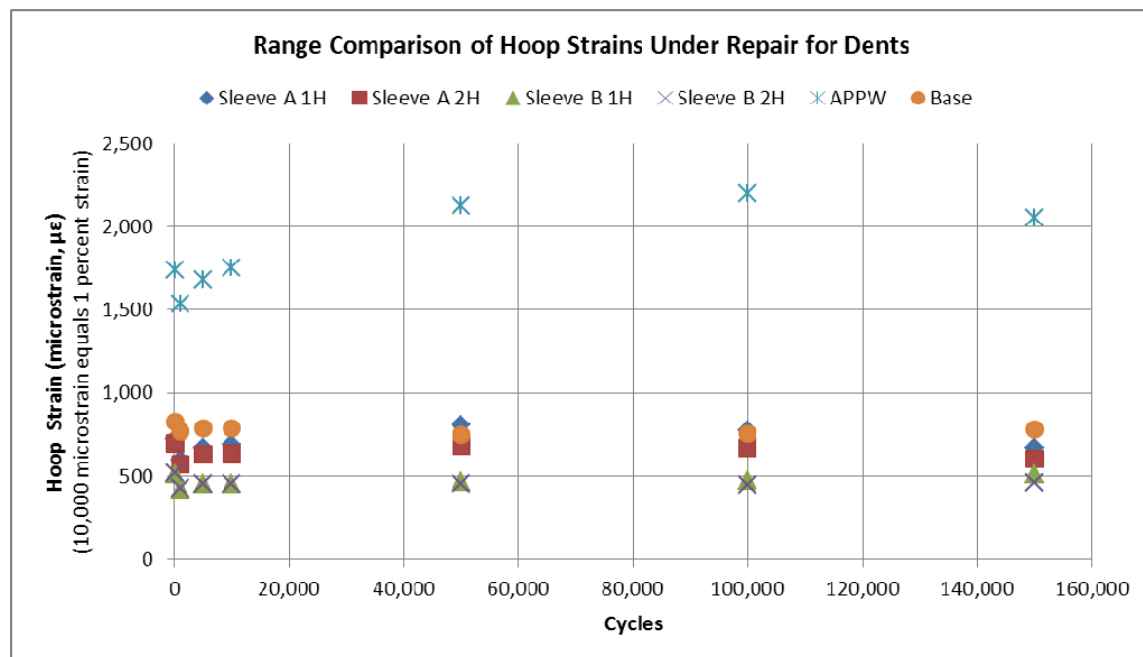


Figure 10: Strain measurements made during fatigue testing of the dent samples

Table 1: Burst pressures and hoop strains for 75% corrosion burst samples

Repair Type	Hoop Strain ($\mu\epsilon$)				Burst Pressure (psi)
	Center Under Repair	2-inch off Center Under Repair	Outside of Repair	Base Pipe	
APPW	2,191	2,283	950	818	4,480
Sleeve "A"	1,919	1,577	446	871	4,233
Sleeve "B"	2,153	2,437	416	789	4,290

Table 2: Hoop strains recorded at 1,000 cycles for the 75% corrosion samples

Repair Type	Under Repair (μϵ)				On Repair (μϵ)		Base Pipe (μϵ)	
	Center		2" Off Center		Center			
	1 Hoop	1 Axial	2 Hoop	2 Axial	3 Hoop	3 Axial	4 Hoop	4 Axial
APPW	1035	193	985	252	350	409	N/A	N/A
Sleeve "A"	765	42	726	32	215	67	N/A	N/A
Sleeve "B"	655	42	722	107	275	61	N/A	N/A

Note: Hoop strains listed in microstrain (10,000 microstrain = 1% strain)

Table 3: Hoop strains at 1,000 cycles for dent samples

Repair Type	Under Repair (μϵ)				On Repair (μϵ)		Base Pipe (μϵ)	
	Apex of Dent		Apex of Dent		Center			
	1 Hoop	1 Axial	2 Hoop	2 Axial	3 Hoop	3 Axial	4 Hoop	4 Axial
APPW	1536	132	N/A	N/A	2043	1250	767	156
Sleeve "A"	595	66	571	75	414	90	767	156
Sleeve "B"	424	35	431	44	760	190	767	156

Note(s)

- (1) Hoop strains listed in microstrain (10,000 microstrain = 1% strain)
 (2) N/A – data not available due to issues with the strain gages.

Table 4: Test Sample Pressure Data

Sample Type	Composite	Type A	Type B
<i>Number of experimental cycles to Failure</i>			
Dent fatigue ($\Delta P = 72\%$ SMYS)	149,913	239,897	239,897
Corrosion fatigue ($\Delta P = 36\%$ SMYS)	198,550	302,465	302,465
<i>Life in "years" with fatigue safety factor of 10 for "moderately" aggressive cycling</i>			
Dent fatigue life	594 years	952 years	952 years
Corrosion fatigue life	58 years	90 years	90 years

Note: Fatigue results for the repairs having Type A and Type B sleeves are lower bound estimates as failures did not actually occur in these samples.