Study to Evaluate Steel Sleeve Performance in Reinforcing Defects

Prepared for Allan Edwards, Inc.

Project No. AE-17-006

November 2021

Testing performed by ADV Integrity, Inc.

Study to Evaluate Steel Sleeve Performance in Reinforcing Defects

Prepared for

Allan Edwards

Tulsa, Oklahoma

November 2021



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November 2, 2021

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Dear Chip and Tommy:

Enclosed you will find the report on the steel sleeve full-scale testing study. The purpose in conducting this study was to evaluate the performance of Allan Edwards' sleeves in reinforcing corrosion and dent features. The test program evaluated the reinforcement of both corrosion and plain dents that were pressure cycled to failure. A total of six samples were tested in this program, which included two samples with unreinforced defects that served as baseline data points.

The test results illustrate that both the Allan Edwards' steel sleeves increased fatigue lives of the reinforced corrosion and dent features. Considering the experimental results and pressure cycle conditions for a typical gas transmission pipeline, the Allan Edwards fatigue "design" lives for the reinforced corrosion and dent features were found to be 640 and 607 years, respectively.

Provided in this report are details on the test methods that were employed and the associated results. In addition to insights gained regarding overall performance of the sleeves, information was also obtained regarding the importance of the filler materials in relation to fit-up of the sleeves.

Thank you for the opportunity to conduct this study. Please contact me if you have any questions.

Regards,



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1.0 EXECUTIVE SUMMARY

A steel sleeve study was conducted by ADV Integrity, Inc. (ADV) to evaluate the performance of Allan Edwards' steel sleeves. The purpose in conducting this study was to use full-scale testing to evaluate the performance of steel sleeves manufactured using rolled plate (i.e., Allan Edwards' sleeves). Testing included Type B steel sleeve configurations that were pressure cycled to failure. Although gas transmission pipelines do not experience a large number of pressure cycles, cyclic pressure loading is a more aggressive loading condition; especially if one considers that burst testing alone would have uniformly resulted in failures outside the reinforced sleeves.

The testing program included a total of six samples, three with simulated corrosion features and three with plain dent features. The corrosion samples were fabricated using 24-inch x 0.375-inch, Grade X65 pipe material. The corrosion samples were fabricated by machining 12-inch long by 6-inch wide 50% deep simulated corrosion defects. The dented samples were fabricated using 24-inch x 0.250-inch, Grade X52 pipe material. The samples were then pressurized to 50% SMYS and dented with a hydraulic press. Finally, strain gages were installed on all pipe samples to measure strains in both the reinforced and unreinforced test samples.

Of the six test samples, one unreinforced corrosion sample and one unreinforced dent sample were tested to produce baseline performance metrics. To simulate a Type B configuration, the reinforced samples underwent 50,000 pressure cycles after which a small hole was drilled in the pipe sample to simulate a thru wall leak and the sleeve was sealed using a plugged thread-o-let. The samples were then cycled until failure, which typically resulted in leaking in one of the sleeve welds. Because the pipe samples were pressure cycled at different pressure ranges, Miner's Rule was used to calculate an equivalent number of pressure cycles assuming a constant pressure range of 72% SMYS.

Strain gages were installed in the corrosion and dent regions and monitored during pressure cycling. Both the Allan Edwards and pipe material half shells lowered strains in the damaged regions. On average, the reinforced corrosion features had hoop strain ranges that were approximately one-half the strain ranges observed in the unreinforced sample. For the reinforced dents, the hoop strains in the Allan Edwards reinforced samples were between 22% and 28% of the unreinforced sample.

The Allan Edwards increased the longevity of both the reinforced corrosion and dent features. Because the corrosion and dent samples were cycled at different pressure ranges, an equivalent pressure cycle

range using Miner's Rule was calculated to permit a direct comparison among all samples. Further, providing only the number of cycles to failure is not as useful as providing service life in "years" as shown in the following table.

Summary of Pressure Cycle Results

Sample Numbers	Defect Type	Reinforcement Type	Cycles to failure at ΔP = 72% SMYS (1)	Design Cycles (Cycles to failure / 5) (2)	Life in Years ("Light" Cycling) (3)	Life in Years ("Very Aggressive" Cycling)	Failure Ratio (Reinforced / UR)
Corrosion Test Samples							
24C-UR-1	Corrosion	Unreinforced	5,336	1,067	106 Years	3 Years	1.00
24C-AESS-3	Corrosion	Allan Edwards Steel Sleeve	21,247	4,249	424 Years	15 Years	3.98
24C-AESS-7	Corrosion	Allan Edwards Steel Sleeve	32,020	6,404	640 Years	23 Years	6.00
Dent Test Samples							
24D-UR-4	Plain Dent	Unreinforced	13,004	2,601	260 Years	9 Years	1.00
24D-AESS-6	Plain Dent	Allan Edwards Steel Sleeve	29,743	5,949	594 Years	21 Years	2.29
24D-AESS-8	Plain Dent	Allan Edwards Steel Sleeve	30,391	6,078	607 Years	22 Years	2.34
24D-AESS-306	Dent	Allan Edwards Steel Sleeve	42,551	8,510	851 Years	31 Years	3.27

NOTES:
(1) The "cycles to failure" values presented are based on a sum of applied pressure cycles using Miner's Rule assuming a pressure range equal to 72% SMYS.
(2) A fatigue safety factor of 5 was selected for this study.
(3) The "Light" and "Very Aggressive" pressure cycle conditions are based on work by Kiefner et al as reported in "Estimating Fatigue Life for Pipeline Integrity Management" (IPC2004-0167).
(4) COLOR CODING: **Unreinforced (BLACK) | Allan Edwards Steel Sleeves (BLUE) | Additional Sample performed in 2021 (RED)**
(5) Allan Edwards samples 24C-AESS-7 and 24D-AESS-8 were re-tests to evaluate the effect of sleeve fit-up as concerns existed regarding the make-up of the earlier two samples. As noted, the fatigue life for the corrosion sample increased by 50%, but minimal improvement was observed with the dent sample (i.e., 2%).
(6) Sample 24D-AESS-306 was an additional re-test performed in mid-2021 (ADV PN 100306) due to minor changes in manufacturing that effect sleeve fit-up.

Several important observations are made in reviewing the data presented in the preceding table.

- Had holes not been drilled in the test samples to induce a "Type B" sleeve condition, it is highly unlikely a failure would ever have occurred before the 100,000-cycle runout condition was reached. The reinforcement provided by the sleeves would have prevented leaks from developing in the corrosion and dent features.

- The test results illustrate that the Allan Edwards' sleeves increased fatigue lives of the reinforced corrosion and dent features. The Allan Edwards fatigue "design" lives for the reinforced corrosion and dent features were found to be 640 and 607 years, respectively.
- Failures in the reinforced steel sleeve samples were all associated with leaks in either the long seam or girth welds. These failures occurred due to the application of cyclic pressures present in the annulus between the pipe surface and sleeves after holes had been drilled in the pipe samples.

The primary conclusion from this study is that both the Allan Edwards' sleeves were effective in reducing strain in both the corrosion and dent features. Correspondingly, the fatigue lives of the unreinforced samples were increased. The presence of internal pressure in the annulus between the pipe and inside surface of the sleeves accelerated failure of the test samples.

For the gas pipeline operators who experience "light" pressure cycling conditions, the minimum life for any of the reinforced samples in this program was 424 years. With the technical information provided in this study, gas pipeline operators can proceed with confidence in using steel sleeves manufactured by Allan Edwards.

2.0 INTRODUCTION

In terms of steel sleeve repair materials, some pipeline operators have interpreted the CFR 192 and 195 regulations as requiring the use of only pre-tested pipe materials. In discussions with regulators, it does not appear as if there they are interpreting the regulations in the same manner. During a meeting with PHMSA representatives in Washington, D.C. in November 2017, the regulators were pleased to hear this study was being conducted. With the current regulatory environment being moved towards "performance, rather than prescriptive" regulations, the full-scale testing approach used in this study is encouraged by regulators.

To evaluate the performance of steel sleeves made from Allan Edwards' rolled plate, a study was conducted to evaluate the performance via full-scale testing. The study included the reinforcement of corrosion and dent features and involved both Type A and Type B sleeve configurations, where after a designated number of pressure cycles a through-wall hole was drilled in the pipe material beneath the steel sleeves to generate pressure in the annulus between the pipe and sleeve material. This configuration ultimately tests the long seam and girth welds.

The main objective in testing was to quantify performance of Allan Edwards' steel sleeves by pressure cycling the samples to failure. Because most gas transmission pipelines experience minimal pressure cycling, the test conditions considered in this study represent relatively aggressive loading conditions. Evaluating steel sleeve performance using burst testing alone would have minimal benefit from a performance validation standpoint. Using Miner's Rule to "sum" the applied pressure cycles, test results were used to quantify service life considering typical pipeline operating conditions. A secondary objective was to obtain strain measurements to determine how much of the load is transferred to the steel reinforcement.

The sections of this report that follow include the *Test Methods* section that provides details on the specific activities that occurred before and during testing. The *Test Results* section provides results from testing, including measurements made by the strain gages. The *Discussion* and *Closing Comments* sections include comments on observations from testing and their applicability in terms of actual pipeline operation. Included in Appendix A are material testing results, while a welding procedure used for welding the steel sleeves is provided in Appendix B. Appendix C provides photos showing installation of the Allan Edwards sleeves used to reinforce one of the corrosion samples.

3.0 TEST METHODS

This section of the report provides details on the methods used to conduct tests on the unreinforced and reinforced dent and corrosion samples. Included are details on fabrication of the test samples, associated defects, installed instrumentation, and pressure cycling conditions.

3.1 Elements of the Testing Program

A total of six samples were tested to evaluate the fatigue life performance of corrosion and dent defects reinforced with steel sleeves manufactured by Allan Edwards using rolled plate material. Of the six test samples, two were unreinforced and served as baseline reference cases. The defects considered in this study were relatively severe in that the target number of cycles to failure for the unreinforced samples was 25,000 cycles. The corrosion feature was 50% of the pipe's nominal wall thickness, while the dent geometry had an initial depth that was 15% of the pipe's outside diameter (i.e., after pressurization the remaining "residual" depths for these dents is typically on the order of 2% to 3% of the pipe's diameter). Listed in Table 1 is a summary of the test matrix.

Table 1 – Test Sample Matrix

Sample Numbers	Defect Type	Reinforcement Type
24C-UR-1	Corrosion	Unreinforced
24C-AESS-3	Corrosion	Allan Edwards Steel Sleeve
24C-AESS-7	Corrosion	Allan Edwards Steel Sleeve
24D-UR-4	Plain Dent	Unreinforced
24D-AESS-6	Plain Dent	Allan Edwards Steel Sleeve
24D-AESS-8	Plain Dent	Allan Edwards Steel Sleeve
24D-AESS-306	Plain Dent	Allan Edwards Steel Sleeve

NOTES:

1. Two additional samples were added to the original test matrix, *24C-AESS-7 and 24D-AESS-8*. Allan Edwards provided funding for these additional tests in an effort to gain additional insights on the effects of filler material installation and sleeve fit-up during welding.
2. Sample 24D-AESS-306 was an additional re-test performed in mid-2021 (ADV PN 100306) due to minor changes in manufacturing that effect sleeve fit-up.
3. COLOR CODING: **Unreinforced (BLACK) | Allan Edwards Steel Sleeves (BLUE) | Additional Sample performed in 2021 (RED)**

Provided below are details on the pipe materials used in this study, including material properties based on mechanical tests performed on the provided pipe and sleeve materials. Allan Edwards provided steel sleeve material. Neptune Research, a manufacturer of composite repair technologies from Florida, donated the filler materials used to reinforce the corrosion and dent features.

50% Corrosion Samples

- Nominal Diameter: 24 inches
- Wall Thickness: 0.375 inches
- Grade: X65 (Actual yield strength of 84.2 ksi and ultimate tensile of 98.0 ksi)
- SMYS pressure: 2,031 psig
- MAOP: 1,463 psig (72% SMYS)

15% Dented Samples

- Nominal Diameter: 24 inches
- Wall Thickness: 0.250 inches
- Grade: X52 (Actual yield strength of 56.5 ksi and ultimate tensile of 75.6 ksi)
- SMYS pressure: 1,083 psig
- MAOP: 780 psig (72% SMYS)

Provided in Table 2 are the yield and ultimate tensile strengths for both pipe materials, as well as material data for the sleeve material provided by Allan Edwards. The mechanical test reports from Bryan Labs are provided in Appendix A.

Table 2 – Material Strengths Based on Mechanical Testing

Material	Yield Strength (psi)	Tensile Strength (psi)
DENT: 24-inch x 0.250-inch, Grade X52 (pipe material)	56,500	75,600
CORROSION: 24-inch x 0.375-inch, Grade X65 (pipe material)	84,200	98,000
24-inch x 0.250-inch (Allan Edwards steel sleeve material)	65,500	80,800
24-inch x 0.375-inch (Allan Edwards steel sleeve material	77,900	93,700

Mechanical properties based on testing completed by Bryan Labs of Houston, Texas. Reports provided in Appendix A.

The sections that follow provide specific details on the corrosion and dent samples. Strain gages were used to measure the level of load transfer between the pipe and steel sleeve reinforcements. Samples were pressure cycled to failure, or 100,000 cycles, whichever occurred first. After 50,000 cycles, a small hole was drilled into the sample to simulate a thru-wall leak via a weld-o-let installed in the steel sleeve. After the hole was drilled, the weld-o-let was plugged. This process basically converted the repair from a non-pressure-containing to a pressure containing (Type “B”) sleeve. As will be shown in the results, the simulated leak after 50,000 cycles placed additional loading on the sleeves’ long seam and girth welds not present in the Type “A” configuration.

3.2 Corrosion Samples

The corrosion pipe samples were 10 feet in length and utilized 24-inch x 0.375-inch, Grade X65 pipe material provided by Dominion Energy (refer to Table 2 for actual pipe material properties). The simulated corrosion defect was 12 inches in length and 6 inches wide as shown in Figure 1 and Figure 2. Centered on the sample, the defect had a depth equal to 50% of the pipe's nominal wall thickness. In the reinforced samples, a two-part epoxy filler material was utilized as part of the repair process, while the unreinforced sample did not include filler material. The pressure scheme was cyclic, and linearly-ramped between ΔP = 100 psi to 1,015 psi (50% SMYS max). Initially, the pressure cycles did not produce a crack in the unreinforced samples in a reasonable number of cycles (i.e., 25,000 cycles), so the pressure cycle range was increased to accelerate the failure. After 32,000 cycles were applied, the pressure range was increased to ΔP = 100 to 1,462 psi (72% SMYS max) and the samples were then cycled to failure.

3.2.1 Sample Preparation

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

1. Welded end caps to samples and installed 1-inch NPT bossets.
2. Machined simulated corrosion area in pipe as shown in Figure 1.
3. Sandblasted samples.
4. Installed strain gages in the corroded region as shown in Figure 3.
5. Installed two-part epoxy filler material in the defect region for the reinforced samples.
6. Installed Allan Edwards Steel Sleeve (AESS) repairs using the weld procedure provided in Appendix B.

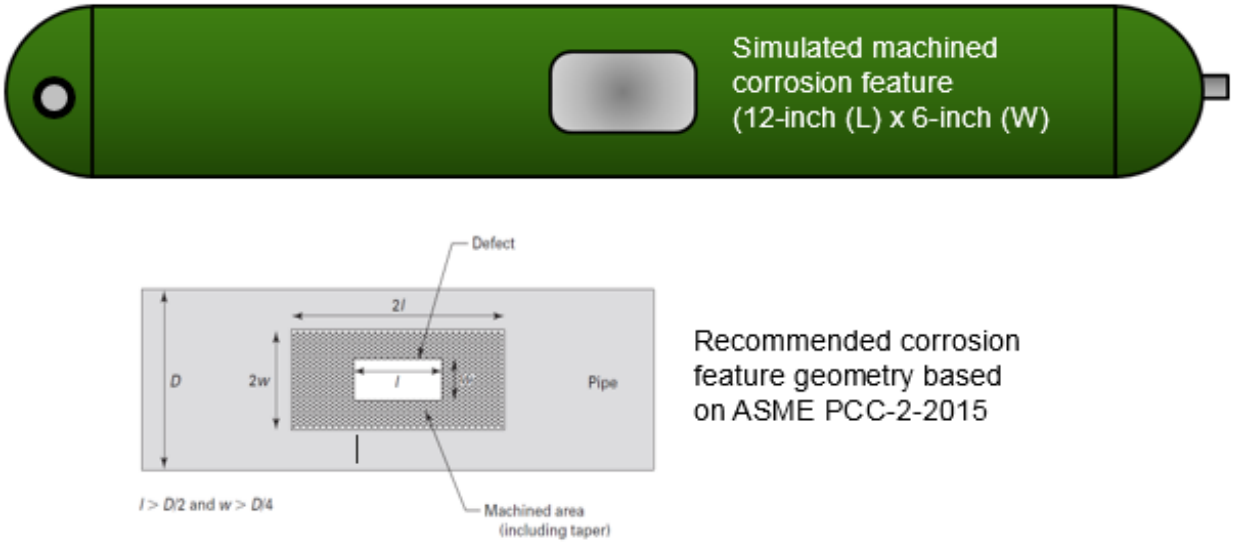


Figure 1 – Corrosion Sample Configuration



Figure 2 – View of Machined Simulated Corrosion Feature

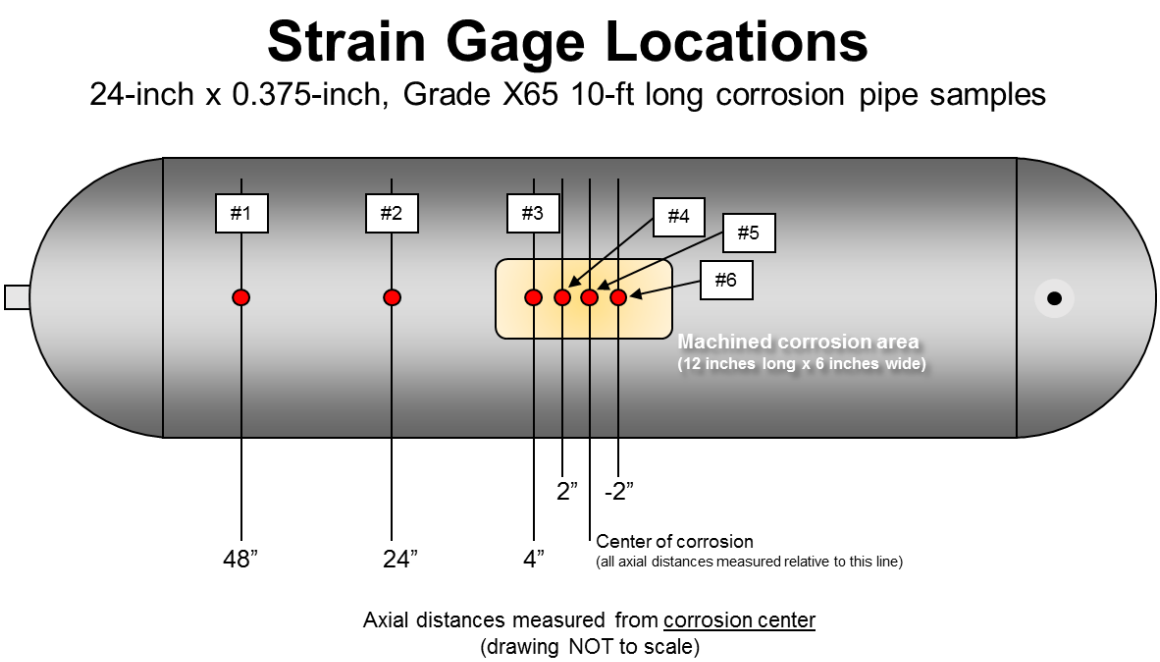


Figure 3 – Strain Gage Locations for the Corrosion Samples

3.2.2 Steps for Pre-testing and Testing

Provided below are steps completed prior to testing as part of the set-up process, as well as specific steps carried out during testing.

1. Labeled sample numbers as follows:
    a. 24C-UR-1 (Unreinforced)
    b. 24C-AESS-3 (Allan Edwards Steel Sleeve)
    c. 24C-AESS-7 (Allan Edwards Steel Sleeve, additional sample for re-testing)
2. Took photos during various stages of testing.
3. Completed installation of additional strain gages.
4. Monitored pressure and strain during testing, recording data at 1 scan per second.
5. Cycled pressure:
    a. ΔP = 100 psi to 1,015 psi (50% SMYS) for 32,000 cycles
    b. ΔP = 100 to 1,462 psi (72% SMYS) until failure
6. Output: EXCEL file for each test that includes time stamp, internal pressure, and hoop strain gage results.

3.3 Dented Samples

The dented samples were 10 feet in length and utilized 24-inch x 0.250-inch, Grade X52 pipe material. The samples were created by pressurizing the pipe material to 540 psig (50% SMYS) and then installing a dent having an initial depth of 15% of the pipe diameter. After the initial indentation the sample was pressure cycled 10 times from 0 to 780 psig (72% SMYS) to simulate re-rounding of the dent, as would occur in actual pipeline operation. Epoxy filler material was used in the reinforced samples, while the unreinforced sample did not utilize an epoxy filler. The pressure range of the dented samples was cycled between ΔP = 100 psi to 780 psi (72% SMYS max). Samples were cycled to failure and did not require any adjustments to the pressure range as failure in the unreinforced samples occurred within a reasonable number of cycles (i.e., less than 25,000 cycles).

3.3.1 Sample Preparation.

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

1. Welded end caps to samples and 1-inch NPT bossets.
2. Pressurized sample to 50% SMYS and installed dent as shown in Figure 4, Figure 5, and Figure 6.
3. Sandblasted samples.
4. Installed strain gages as shown in Figure 7.
5. Installed two-part epoxy filler material in the defect region for the reinforced samples,
6. Installed the AESS repairs using the weld procedure provided in Appendix B.

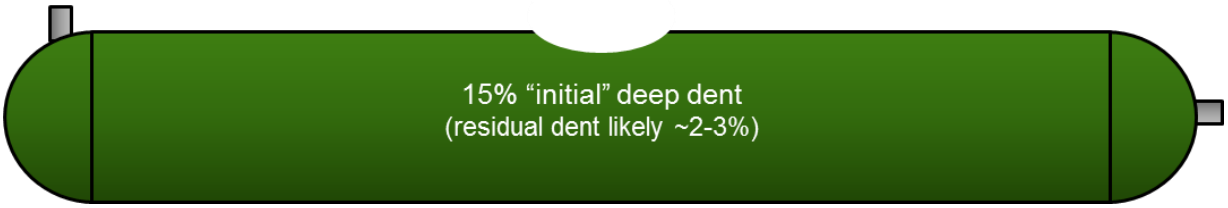


Figure 4 – Dented Sample Configuration



Figure 5 – Hydraulic Press Denting Apparatus



Figure 6 – View of Simulated of Dent

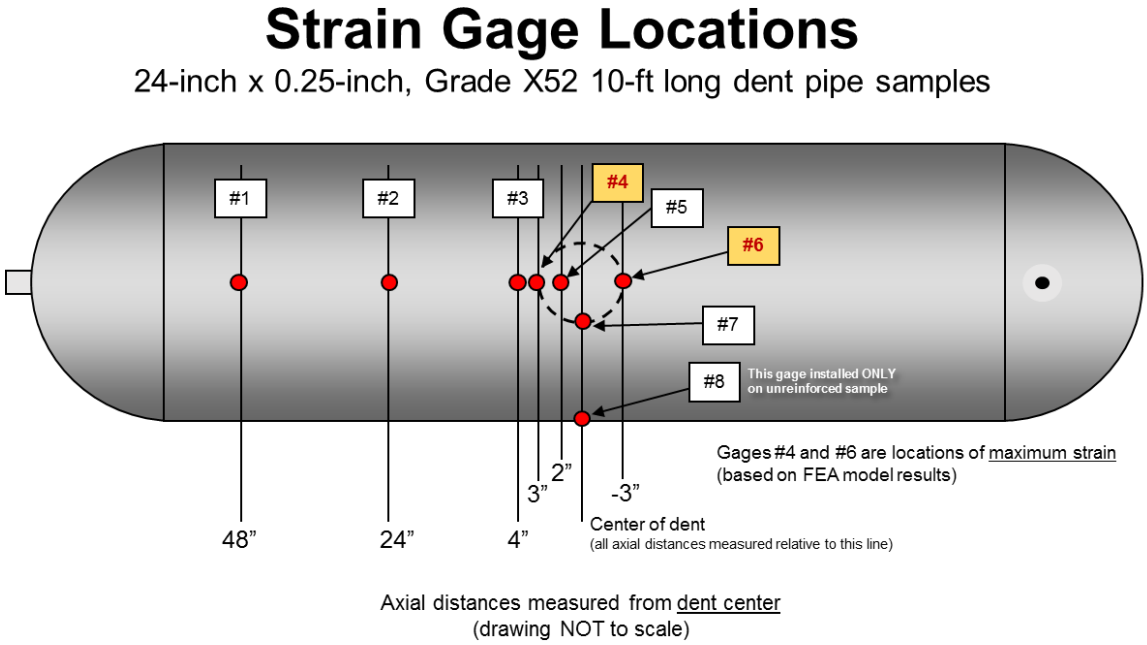


Figure 7 – Strain Gage Locations for the Dented Samples

3.3.2 Steps for Pre-testing and Testing

Provided below are steps completed prior to testing as part of the set-up process, as well as specific steps carried out during testing.

1. Labeled sample numbers as follows:
    a. 24D-UR-4 (Unreinforced)
    b. 24D-AESS-6 (Allan Edwards Steel Sleeve)
    c. 24D-AESS-8 (Allan Edwards Steel Sleeve, additional sample for re-testing)
2. Took photos during various stages of testing.
3. Installed strain gages as shown in Figure 7**.**
4. Monitored pressure and strain during testing, recording data at 1 scan per second.
5. Cycled pressure:
    a. ΔP = 100 psi to 780 psi (72% SMYS)
6. Output: EXCEL file for each test that includes time stamp, internal pressure, and hoop strain gage results.

4.0 TEST RESULTS

This section of the report provides details on the results obtained in conducting the pressure cycle testing of the unreinforced and reinforced corrosion and dent samples. Presentation of results includes number of cycles to failure and strain gage results measured as functions of the number of applied pressure cycles.

A separate discussion is provided on the fatigue test results in the *Discussion* section that includes an explanation on how Miner's Rule was used to determine an "equivalent" number of pressure cycles so that all test results could be compared in a meaningful manner. Results for both the corrosion and dent tests are included.

4.1 Pressure Cycle Fatigue Results

As stated previously, the test samples were pressure cycled to failure, or 100,000 cycles, whichever occurred first. Several tables are used to present the pressure cycle results.

- The first table is Table 3 that presents a summary of the pressure cycle to failure results for all six tested samples. This data is "raw" in that no additional processing is provided. Because multiple pressure cycle ranges were applied, the usefulness of this data is limited. However, it does allow one to observe the number of total applied pressure cycles to failure for each sample. Note that results are included for the two "re-tested" Allan Edwards samples, 24C-AESS-7 and 24D-AESS-8. Although an improvement in fatigue life was observed with the corrosion sample when compared to the previous Allan Edwards sample, a minimal increase in cycle life was observed with the re-tested dent sample. Possible explanations as to why this occurred are provided in the *Discussion* section.
- The second table provided is Table 4, which integrates fatigue test results using Miner's Rule. This table also integrates Kiefner's pressure cycle categories that are used to express fatigue life in "years" and not just "cycles to failure". In reviewing the results presented in Table 4 the following observations are made:
    - The most important data presented in this table is the one classified as "Cycles @ ΔP = 72% SMYS". These fatigue test results were calculated using Miner's Rule to determine a single equivalent pressure cycle for each test sample, even though multiple pressure cycle ranges might have been applied to that sample (e.g. the corrosion samples were subjected to two different pressure cycle ranges). To permit a direct comparison among all eight samples, an

assumed pressure range of 72% SMYS was used (ΔP = 1,463 psig for the corrosion samples and ΔP = 780 psig for the dent samples).

- Because of the inherent scatter in fatigue data, it is necessary to apply a fatigue safety factor. When significant uncertainties exist in a cyclic loading conditions (e.g., non-uniform cyclic loading, corrosion, unknown material data, etc.), it is necessary to use safety factors that could be as large as 20. For the current study a fatigue safety of 5 was used in calculating the "Design Cycles", which involved dividing the number of "equivalent" pressure cycles at ΔP = 72% SMYS by 5.
- The other data presented in this table that is of interest to pipeline operators are the last two columns that present design lives in "years" and not "cycles". For some time, the pipeline industry has employed the data compiled by John Kiefner where he classified pressure cycling in four categories based on industry surveys: *Very Aggressive*, *Aggressive*, *Moderate*, and *Light* (refer to data presented in Table 5). As noted, a *Very Aggressive* condition will result in 276 cycles per year and a *Light* condition will result in 10 cycles per year assuming a pressure range of 72% SMYS. Gas transmission pipelines typically experience minimal cycling, so a *Light* pressure cycle condition is appropriate. The minimum life calculated for any of the six reinforced samples was 424 years (considering the *Light* pressure cycle condition), and that corresponded to results for the original Allan Edwards Steel Sleeve sample, 24C-AESS-3. This is a significantly long fatigue life.

Table 3 – Summary of Pressure Cycle Test Results

Sample Numbers	Defect Type	Reinforcement Type	Mode of Failure	Cycles @ ΔP = 100 to 780 psig	Cycles after End Cap Repair	Cycles @ ΔP = 100 to 1,015 psig	Cycles @ ΔP = 100 to 1,462 psig	Total Cycle Count
24C-UR-1	Corrosion	Unreinforced	Crack in Corrosion Area	-		32,006	573	32,579
24C-AESS-3	Corrosion	Allan Edwards Steel Sleeve	Crack in seam weld of sleeve	-		32,000	21,665	53,665
24C-AESS-7	Corrosion	Allan Edwards Steel Sleeve	Crack in seam weld of sleeve	-		32,000	36,003	68,003
24D-UR-4	Plain Dent	Unreinforced	Crack in Dent Area	22,513		-	-	22,513
24D-AESS-6	Plain Dent	Allan Edwards Steel Sleeve	End cap weld failure repaired, eventual crack in sleeve seam weld	33,295	18,195	-	-	51,490
24D-AESS-8	Plain Dent	Allan Edwards Steel Sleeve	End cap weld failure repaired, eventual crack in sleeve seam weld	41,275	11,337	-	-	52,612
24D-AESS-306	Plain Dent	Allan Edwards Steel Sleeve	End cap weld failure repaired, eventual crack in sleeve fillet weld	23,881	79,784	-	-	73,665

Table 4 – Pressure Cycle Results Integrating Miner's Rule and Kiefner's Pressure Categories

Sample Numbers	Defect Type	Reinforcement Type	Cycles @ ΔP = 100 to 780 psig	Cycles @ ΔP = 100 to 1,015 psig	Cycles @ ΔP = 100 to 1,462 psig	Total Cycle Count	Cycles @ ΔP = 72% SMYS	Design Cycles (Cycles to failure / 5)	Life in Years ("Light" Cycling) [1]	Life in Years ("Very Aggressive" Cycling) [2]
24C-UR-1	Corrosion	Unreinforced	-	32,006	573	32,579	5,336	1,067	106 Years	3 Years
24C-AESS-3	Corrosion	Allan Edwards Steel Sleeve	-	32,000	21,665	53,665	21,247	4,249	424 Years	15 Years
24C-AESS-7	Corrosion	Allan Edwards Steel Sleeve	-	32,000	36,003	68,003	32,020	6,404	640 Years	23 Years
24D-UR-4	Plain Dent	Unreinforced	22,513	-	-	22,513	13,004	2,601	260 Years	9 Years
24D-AESS-6	Plain Dent	Allan Edwards Steel Sleeve	33,295	-	-	51,490	29,743	5,949	594 Years	21 Years
24D-AESS-8	Plain Dent	Allan Edwards Steel Sleeve	41,275	-	-	52,612	30,391	6,078	607 Years	22 Years
24D-AESS-306	Plain Dent	Allan Edwards Steel Sleeve	23,881	-	-	73,665	42,551	8,510	851 Years	31 Years

NOTES:

1. According to the Kiefner pressure assessment work (cf. Figure 5), the "Light Cycling" condition corresponds to 10 cycles per year when cycling at ΔP = 72% SMYS. As an example, the number of Design Cycles for Sample 24C-UR-1 is 1,067 cycles. For a "Light Cycling" condition this corresponds to 106 years (1,067 cycles / 10 cycles per year).
2. The "Very Aggressive Cycling" condition corresponds to 276 cycles per year when cycling at ΔP = 72% SMYS. As an example, the number of Design Cycles for Sample 24C-UR-1 is 1,067 cycles. For a "Very Aggressive Cycling" condition this corresponds to 3 years (1,067 cycles / 276 cycles per year).
3. Sample 24D-AESS-306 was an additional re-test performed in mid-2021 (ADV PN 100306) due to minor changes in manufacturing that effect sleeve fit-up.
4. COLOR CODING: **Unreinforced (BLACK) | Allan Edwards Steel Sleeves (BLUE) | Additional Sample performed in 2021 (RED)**

Table 5 – Annual Cyclic Pressure Conditions Based on Kiefner Study Industry Survey[1]
(Estimated number of annual cycles as a function of cyclic pressure condition)

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 annual cycles with ΔP as noted				
72%	276	67	25	10
61%	512	124	47	18
36%	3,683	889	337	128

4.2 Corrosion Samples

This section of the report provides photographs of the failures and also includes strain gage results for the corrosion samples. A longitudinally-oriented crack developed in the unreinforced sample after 32,579 cycles, as shown in Figure 8. In a similar manner the two Allan Edwards samples, 24C-AESS-3 and 24C-AESS-7, increased the fatigue lives of the unreinforced corrosion defect to be 53,665 and 68,003 cycles, respectively. As shown in Figure 9 a leak developed in the long seam weld of 24C-AESS-3; however, in sample 24C-AESS-7 a leak developed in the girth weld of the sleeve as shown in Figure 10.

In addition to the photos provided of the failures, hoop strain range (i.e., maximum – minimum strain) measurements in the corroded region are provided in Figure 11 as functions of cycle number. As observed, the hoop strains measured for 24C-AESS-7 were noticeably lower than results for the other two unreinforced samples. Also, noted in this figure is the increase in hoop strain after 32,000 cycles when the pressure range was increased from ΔP = 100 to 1,015 psig to ΔP = 100 to 1,463 psig to accelerate failure in the unreinforced sample.

[1] 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.

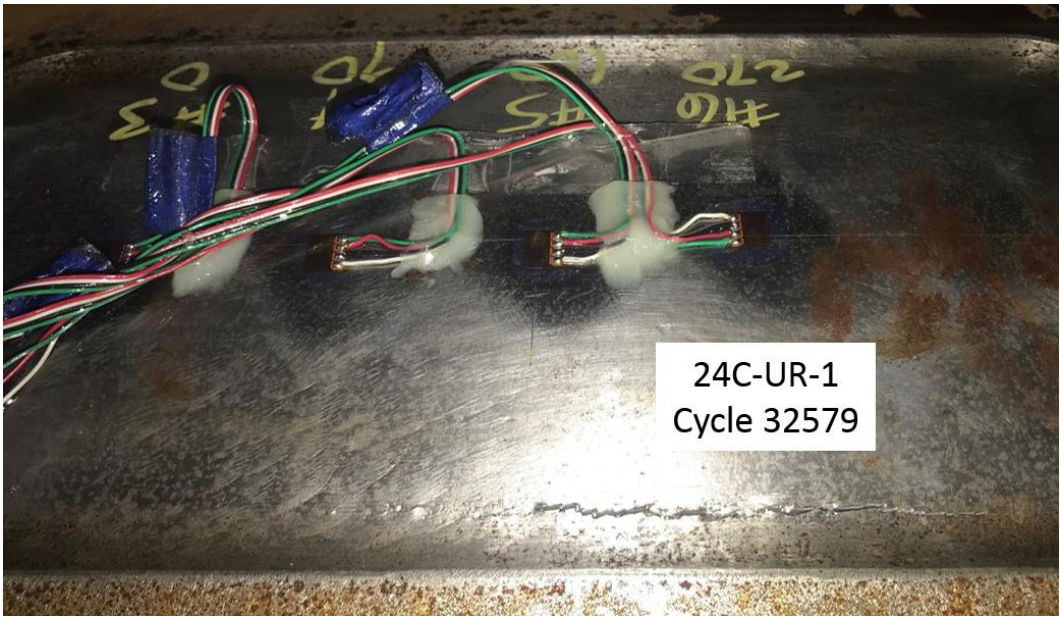


Figure 8 – View of Failure in 24C-UR-1

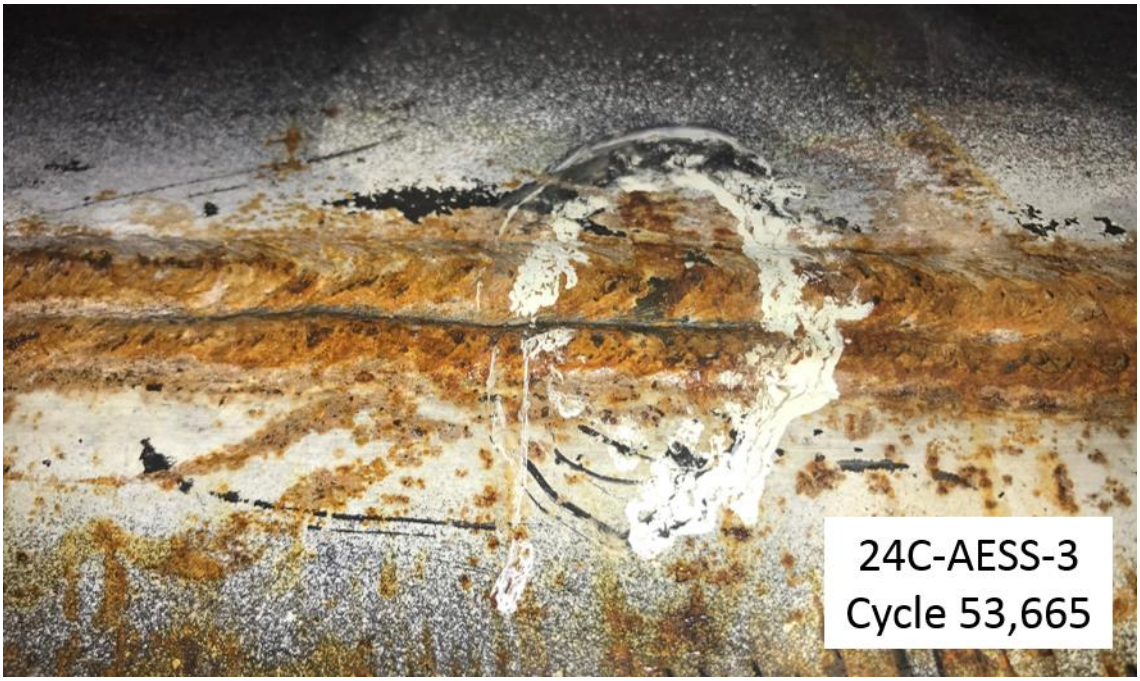


Figure 9 – View of Failure 24-AESS-3

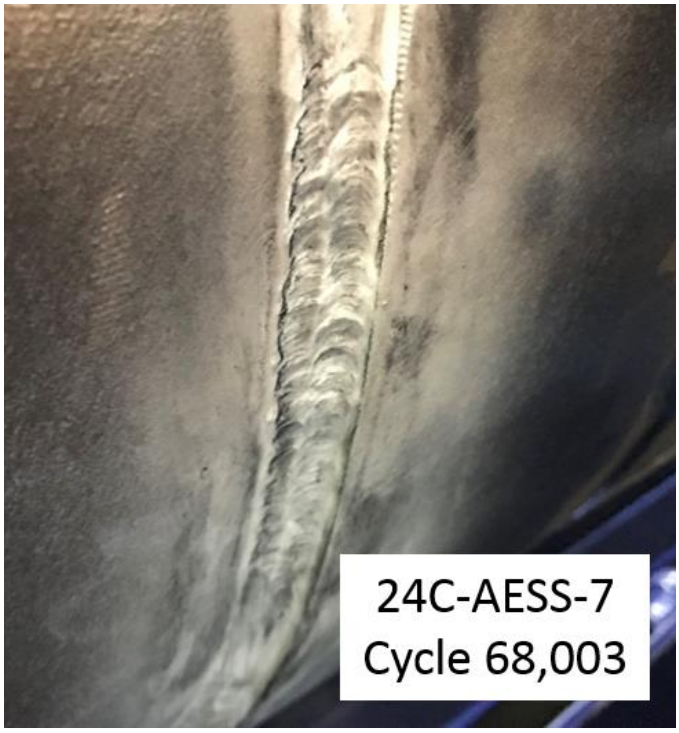


Figure 10 – View of Failure 24C-AESS-7

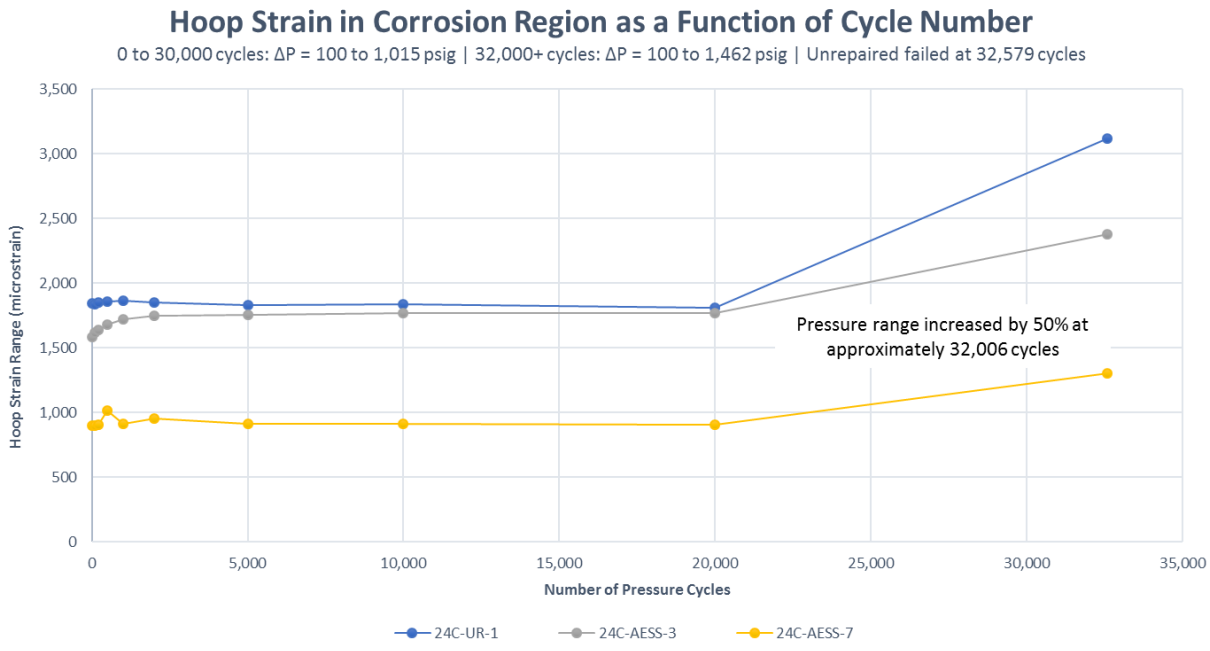


Figure 11 – Hoop Strain Range Measurements for the Three Corrosion Samples

4.3 Plain Dent Samples

The unreinforced dent sample, 24D-UR-5, developed a longitudinally-oriented fatigue crack after 22,513 cycles as shown in Figure 12. Both of the reinforced samples experienced cracks in end caps mid-test (33,295 and 41,275 cycles). These end cap cracks were repaired and cycling of the samples continued. Samples 24D-AESS-6 and 24D-AESS-8 leaked after a total of 51,490 and 52,612 cycles were reached, respectively. The leaks that developed in the long seam welds of 24D-AESS-6 and 24D-AESS-8 are shown in Figure 13 and Figure 14.

Hoop strain range as functions of cycle number for the four dented samples are shown in Figure 15. The hoop strains measured for all three reinforced samples were lower than the results for the unreinforced dented sample. Also, noted in this figure is the increase in hoop strain for the unreinforced sample with increasing cycle count up to approximately 2,000 cycles.

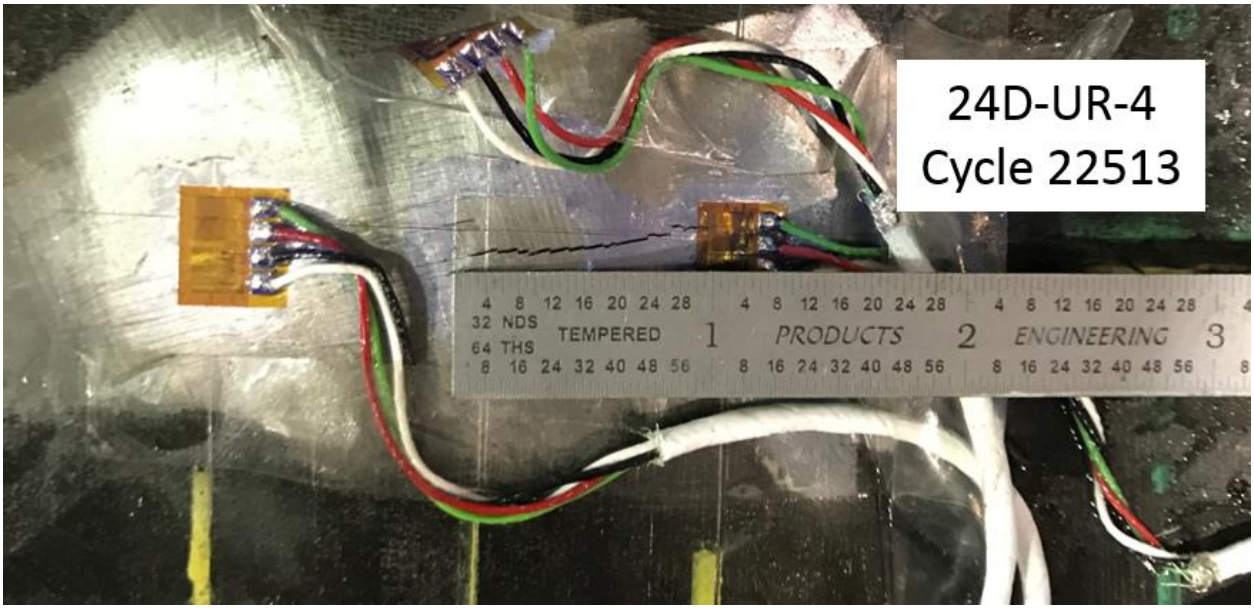


Figure 12 – View of Failure 24D-UR-4



Figure 13 – View of Failure 24D-AESS-6

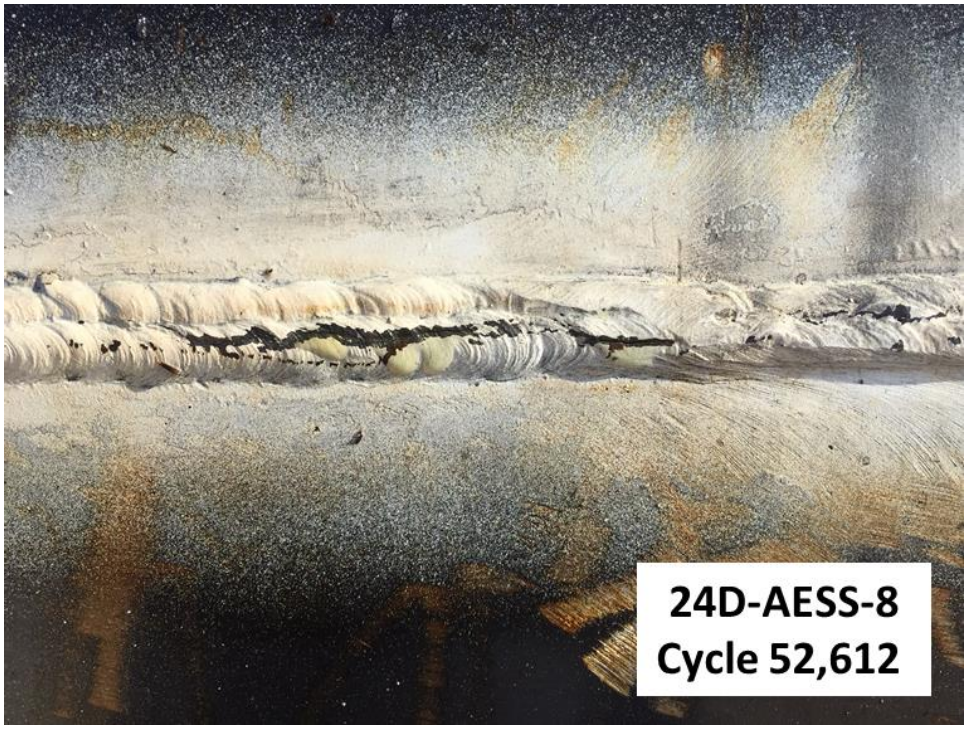


Figure 14 – View of Failure 24D-AESS-B

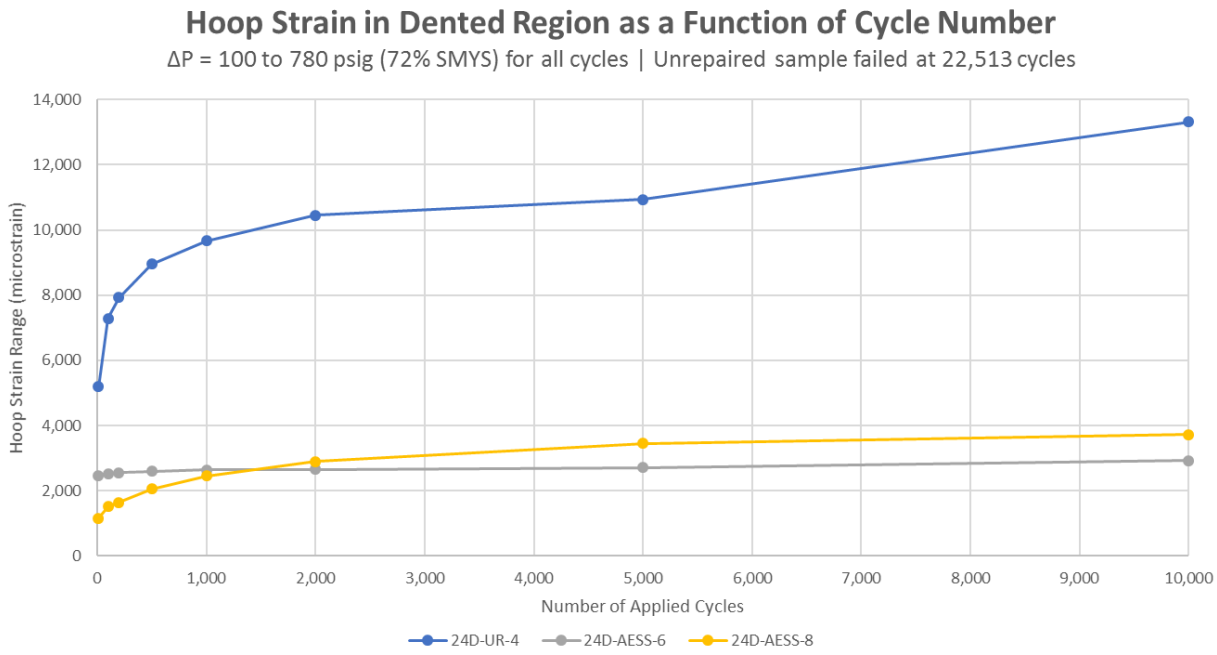


Figure 15 – Hoop Strain Range Measurements for the Three Dent Samples

5.0 DISCUSSION

There were two primary means for comparing results for unreinforced features and the performance associated with those reinforced with Allan Edwards' steel sleeves. The first was quantifying the number of cycles to failure. While the number of cycles to failure is useful for quantifying service life, it is rather limited in provided an in-depth quantitative comparison of the performance between different repairs. The second means for comparing performance involves the use of strain gages installed in the corrosion and dent regions. The strain measurements obtained during pressure cycling can be analyzed, allowing a quantitative means of evaluating reinforcing systems, which in this study happened to be Allan Edwards' steel sleeves. This section of the report provides discussion on both of these areas. Discussions are also provided on techniques associated with installation of the filler material and subject matter related to regulatory compliance.

5.1 Comparison of Experimental Fatigue Lives

As stated previously, cyclic pressure fatigue is a far greater concern for liquid operators than gas transmission operators. However, testing involving cyclic pressure loading conditions provides an ideal means for comparing the relative performance between competing repair technologies. Unfortunately, burst testing alone typically fails to capture improvements in competing repair technologies, especially when even an average-performing repair system will cause a failure outside a reinforced defect when test articles are pressurized to failure.

The original intent in this study was to achieve failures in the unreinforced samples in a relatively low number of cycles (e.g., less than 25,000 cycles). While this was achieved in the unreinforced dent sample, the original pressure cycle range (ΔP = 10 to 1,015 psig) for the corrosion sample failed to achieve a failure in less than 25,000 cycles; therefore, after 32,006 cycles the pressure range was increased to ΔP = 10 to 1,463 psig (maximum pressure of 72% SMYS). After this increased pressure range was applied, the sample failed after only 573 additional cycles. For consistency, this was done for all of the remaining corrosion samples.

The installation of the steel sleeves increased the fatigue lives of the corrosion features; however, it was necessary to use Miner's Rule to combine the two pressure cycle ranges into a single equivalent number of pressure cycles. For consistency, a reference pressure range of 72% SMYS (ΔP = 1,463 psig) was used as reflected in the following equation for the corrosion samples.

$$N_{72\%\,SMYS} = N_{1015}\left(\frac{1{,}015-100}{1{,}463}\right)^4 + N_{1463}\left(\frac{1463-100}{1{,}463}\right)^4$$

Where:
$N_{72\%\,SMYS}$ = Number of applied cycles at ΔP = 72% SMYS (or 1,463 psig)
N_{1015} = Number of applied cycles at ΔP = 100 to 1,015 psig
N_{1463} = Number of applied cycles at ΔP = 100 to 1,463 psig

Because only one pressure range was applied to the dent sample, the equation used to convert the experimentally-applied number of pressure cycles for ΔP = 72% SMYS was simpler:

$$N_{72\%\,SMYS} = N_{780}\left(\frac{780-100}{780}\right)^4$$

Where:
$N_{72\%\,SMYS}$ = Number of applied cycles at ΔP = 72% SMYS (or 780 psig)
N_{780} = Number of applied cycles at ΔP = 100 to 780 psig

Using the Miner's Rule formulation, equivalent cycle numbers were calculated for both the corrosion and dent samples assuming a pressure range of 72% SMYS. Results for all eight test samples are presented in Table 6. Also, included in this table are the estimated service lives in "years" based on the Kiefner formulation, as well as the last column in this table that reflects the fatigue life of the reinforced feature relative to results achieved for the unreinforced sample. As observed, the minimum calculated fatigue life of all the reinforced samples is 424 years considering the "light cycling" condition, which most represents the operating conditions of a natural gas transmission pipeline system.

Table 6 – Summary of Pressure Cycle Results

Sample Numbers	Defect Type	Reinforcement Type	Cycles to failure at ΔP = 72% SMYS (1)	Design Cycles (Cycles to failure / 5) (2)	Life in Years ("Light" Cycling) (3)	Life in Years ("Very Aggressive" Cycling)	Failure Ratio (Reinforced / UR)
24C-UR-1	Corrosion	Unreinforced	5,336	1,067	106 Years	3 Years	1.00
24C-AESS-3	Corrosion	Allan Edwards Steel Sleeve	21,247	4,249	424 Years	15 Years	3.98
24C-AESS-7	Corrosion	Allan Edwards Steel Sleeve	32,020	6,404	640 Years	23 Years	6.00
24D-UR-4	Dent	Unreinforced	13,004	2,601	260 Years	9 Years	1.00
24D-AESS-6	Dent	Allan Edwards Steel Sleeve	29,743	5,949	594 Years	21 Years	2.29
24D-AESS-8	Dent	Allan Edwards Steel Sleeve	30,391	6,078	607 Years	22 Years	2.34
24D-AESS-306	Dent	Allan Edwards Steel Sleeve	42,551	8,510	851 Years	31 Years	3.27

NOTES:
(1) The "cycles to failure" values presented are based on a sum of applied pressure cycles using Miner's Rule assuming a pressure range equal to 72% SMYS.
(2) A fatigue safety factor of 5 was selected for this study.
(3) The "Light" and "Very Aggressive" pressure cycle conditions are based on work by Kiefner et al as reported in "Estimating Fatigue Life for Pipeline Integrity Management" (IPC2004-0167).
(4) COLOR CODING: **Unreinforced (BLACK) | Allan Edwards Steel Sleeves (BLUE) | Additional Sample performed in 2021 (RED)**
(5) Allan Edwards samples 24C-AESS-7 and 24D-AESS-8 were re-tests to evaluate the effect of sleeve fit-up as concerns existed regarding the make-up of the earlier two samples. As noted, the fatigue life for the corrosion sample increased by 50%, but minimal improvement was observed with the dent sample (i.e., 2%).
(6) Sample 24D-AESS-306 was an additional re-test performed in mid-2021 (ADV PN 100306) due to minor changes in manufacturing that effect sleeve fit-up.

5.2 Comparison of Strain Gage Measurements

Strain gages installed in corrosion and dent features beneath reinforcing systems provide an ideal means for determining the level of load transfer between the reinforcing technology and pipe. Strain gages also provide an ideal means for quantifying the level of load transfer between competing technologies. For more than 20 years the author has utilized strain gages as a means for quantifying the relative performance of steel sleeves and composite repair technologies. Typically, there is a direct correlation between the magnitude of strain reduction and increase in fatigue life (when compared to unreinforced defect configurations).

In reviewing results for the corrosion-reinforced results, both samples with the Allan Edwards' sleeves reduced although sample 24C-AESS-7 achieved a greater level of reinforcement (i.e., strain reduction) than observed with sample 24C-AESS-3. When installing the sleeves on sample 24C-AESS-3, it is believed the filler material cured prematurely and prevented the top half of the sleeve from properly fitting to the pipe. For this reason, Allan Edwards opted to fund two additional tests (a corrosion sample, 24C-AESS-7, and a dent sample, 24D-AESS-8, to determine what impact an improved fit-up might have on

performance. Special care was taken to ensure the filler material did not cure prior to installation and welding of the steel sleeves. As will be shown, in the case of the corrosion sample the improvement was significant.

Provided in Table 7 are results for the original corrosion sample, 24C-AESS-3, and the re-tested sample, 24C-AESS-7. As noted in the results, hoop strains in the re-tested sample (24C-AESS-7) were approximately 50% of those measured in the original sample (24C-AESS-7). This is a significant reduction in strain and reinforces the importance in making quality installations and ensuring that a tight fit-up is achieved when installing steel sleeves. Operators reviewing the results of this study should verify that their steel sleeve installation procedures capture the insights gained in this important observation.

Table 7 – Hoop Strain Measurements for the Corrosion Samples

Number of Cycles	Sample 24C-UR-1	Sample 24C-AESS-3 (original)	Sample 24C-AESS-7 (re-tested)
10	1,842 με	1,582 με	898 με
100	1,839 με	1,621 με	901 με
200	1,851 με	1,642 με	904 με
500	1,861 με	1,684 με	1,015 με
1,000	1,864 με	1,719 με	914 με
2,000	1,849 με	1,747 με	957 με
5,000	1,831 με	1,759 με	914 με
10,000	1,840 με	1,769 με	910 με
20,000	1,809 με	1,772 με	909 με
32,579	3,120 με	2,379 με	1,302 με

Note: 10,000 με = 1% strain

Hoop strain measurements are presented for all four dent samples in Table 8. Even though the Allan Edwards re-tested dent sample was not able to significantly increase the fatigue life of the original reinforced sample, a noticeable reduction is hoop strain was achieved in comparing the results for Sample 24D-AESS-6 (original) and Sample 24D-AESS-8 (re-tested). These results confirm the importance concerning proper installation of filler materials and ensuring a good fit-up between the pipe and sleeve materials.

Table 8 – Hoop Strain Measurements for the Dent Samples

Number of Cycles	Sample 24D-UR-4	Sample 24D-AESS-6 (original)	Sample 24D-AESS-8 (re-tested)
10	5,193	2,469	1,155
100	7,285	2,528	1,519
200	7,932	2,556	1,641
500	8,952	2,596	2,054
1,000	9,671	2,635	2,455
2,000	10,454	2,662	2,897
5,000	10,934	2,711	3,450
10,000	13,311	2,925	3,722

Note: 10,000 με = 1% strain

5.3 Installation of Filler Material

In the reinforcement of pipeline anomalies, filler materials installed in the defect region of the pipe contribute significantly to the level of load transfer that takes place between the damaged pipe and reinforcing sleeve. In a 2015 joint industry study focused on the reinforcement of dents known as the *Dent Validation Collaborative Industry Program* (or DV-CIP), Allan Edwards conducted tests that compared the installation of Allan Edwards sleeves with and without filler materials. The dent configuration in the DV-CIP study was the same basic configuration as the one used in this study (i.e., 24-inch x 0.250-inch, Grade X42 pipe with 15% deep dents cycled from 100 psig to 72% SMYS). Provided in Table 9 are results from the DV-CIP study that include results for the following:

- Unreinforced dent (note cycles to failure very close to 22,513 cycles to failure in this study)
- Reinforced dent with filler material
- Reinforced dent with no filler material

As noted, the absence of the filler material only increased the fatigue life over the unreinforced dent by approximately 75% and was significantly less than the sleeve with the filler material installed. The conclusion from the DV-CIP was that the presence of a filler material was critically-important to maximizing performance of the steel sleeve.

Table 9 – Summary of DV-CIP Test Results

Sample ID	Dent Type	Number of Cycles to Failure	Notes
Unrepaired	Plain Dent	23,512	Sample failure in dent (axial crack)
AE-PD-24-1	Plain Dent (filler material)	101,999	Sample achieved runout (no failure)
AE-PD-24-2 (A & B)	Plain Dent (no filler material)	40,877 (A)	After failure occurred in dent (A), hole in sleeve plugged and sample continued cycling to failure in sleeve seam weld (B)
		87,260 (B)	

NOTE: Pressure range from 100 to 630 psig, or 72% SMYS (i.e., ΔP = 61% SMYS)

5.4 Regulatory Compliance and Interpretation

Prior to starting this test program, one of the questions posed by operator participants concerned possible differences in performance in comparing sleeves manufactured from pipe material and sleeves from rolled plate, such as those manufactured by Allan Edwards. Interestingly, one of the original concerns posed by some operators was the pressure capacity of the sleeve material; however, as this study demonstrated the real issue were the sleeve's long seam and girth welds. Although historically some operators have interpreted the CFR as requiring the use of pre-tested pipe, based on discussions with regulators it appears as if this might not be required. Performance-based programs, such as the one associated with this JIP, are encouraged by regulators and recognized as a means for supporting performance-based regulations. In November 2017 ADV and Allan Edwards met with regulators in Washington, D.C. and apprised them of this study. Using insights from this study, they encouraged JIP participants to propose wording for submission as a means for possibly modifying future regulations.

A final comment concerns the Allan Edwards-provided plate materials that were evaluated in this study. Allan Edwards primarily uses A572-50 structural grade plate for fabricating their steel sleeves, although when requested by an operator they will use pressure vessel grade materials. The material tested in this program provided by Allan Edwards was A572-50 material. There is no reason to believe that in-service the steel sleeve materials provided by Allan Edwards will perform any differently than exhibited in this study.

6.0 CLOSING COMMENTS

This report has provided details on results associated with a large-scale testing program focused on evaluating the fatigue life performance of steel sleeves manufactured by Allan Edwards used to repair corrosion and dent features in transmission pipelines. Pipeline operators and regulators are interested to know how steel sleeve reinforcements can extend the service life of pipelines, especially those manufactured using rolled plate. Due to the performance-based nature of the current regulatory climate, it is important to quantitively determine the impact these repairs can have on fatigue life. Based on the extensive pressure cycle testing performed in this program that involved more than 280,000 pressure cycles, Type B welded steel sleeve reinforcements can improve the number of design cycles for both dent and corrosion defects.

To the author's knowledge, a program evaluating the performance of steel sleeves of this magnitude has never been conducted. Looking at load transfer levels between the pipe and steel sleeves, evaluating the effects of filler material installation, and quantifying the performance of long seam welds in sleeves subjected to cyclic internal pressure have provided several noteworthy insights. For the gas transmission operators, the fatigue lives based on the presented test results are extensive and represent many years of services. The provided test results are also of benefit to liquid operators, although it is recognized that liquid transmission pipelines typically experience a greater number of pressure cycles than gas transmission pipelines. The performance-based test results associated with this study validate that the installation of Allan Edwards' manufactured steel sleeves increases the pressure cycle fatigue lives of corrosion and dent features to be at least 424 years.

APPENDIX A: MECHANICAL TEST RESULTS

Bryan Laboratory, Inc.
Metallurgical Consultation - Inspection - Testing
Analytical Services - Failure Analysis
6919 Almeda Road (77021)
P. O. Box 300366
Houston, TX 77230-0366
Telephone 713/747-7470 800/922-7470 Fax 713/747-7477

REPORT

Lab. No. B1L8-0217 **March 13, 2018**

ON: Steel Pipe

TO: Mechanical Testing Services, LLC
20530 Stokes Road
Waller, Texas 77484-8804
Attention: Mr. Corey Duncan

IDENTITY: Purchase Order Number MTS-2571; Two samples identified as 24" O.D., 0.250" W.T., marked MTS-2531, X52, HT# SU83946 (our A) and 24" O.D., 0.375" W.T., marked MTS-2531, X65, HT# 746104 (our B)

CHEMICAL ANALYSIS

Sample	-	A	B
Carbon, %	-	0.07	0.05
Manganese, %	-	0.99	1.55
Phosphorus, %	-	0.020	0.008
Sulfur, %	-	0.003	0.003
Silicon, %	-	0.20	0.19
Chromium, %	-	0.03	0.14
Nickel, %	-	0.02	<0.01
Molybdenum, %	-	<0.01	0.11
Copper, %	-	0.02	<0.01
Aluminum, %	-	0.03	0.04
Vanadium, %	-	<0.01	<0.01
Titanium, %	-	<0.01	0.02
Niobium, %	-	0.02	0.05
Boron, %	-	<0.001	<0.001

TENSION TESTS

Specimens	-	Transverse, 1-1/2" wide reduced sections, 90° from the weld	
Sample	-	A	B
Yield Strength*, psi	-	56,500	84,200
Tensile Strength, psi	-	75,600	98,000
Elongation in 2", %	-	37.0	31.5

*At 0.5% total extension

Respectfully submitted,
BRYAN LABORATORY, INC.

Signature on Original Only

Christopher M. Corbin

/cd

NOTICE
The samples and/or specimens remaining from these tests or analyses will be discarded seven days after the date of this report, unless arrangements are made to the contrary.

Bryan Laboratory, Inc.
Metallurgical Consultation - Inspection - Testing
Analytical Services - Failure Analysis
6919 Almeda Road (77021)
P. O. Box 300366
Houston, TX 77230-0366
Telephone 713/747-7470 800/922-7470 Fax 713/747-7477

REPORT

Lab. No. B1L8-0245 **March 19, 2018**

ON: Steel

TO: Mechanical Testing Services, LLC
20530 Stokes Road
Waller, Texas 77484-8804
Attention: Mr. Corey Duncan

IDENTITY: Purchase Order Number MTS-2579; Two samples identified as from pipe sleeves, 24" O.D., 0.250" W.T., marked MTS-2531, HT# A705772 (our A) and 24" O.D., 0.375" W.T., marked MTS-2531 (our B)

CHEMICAL ANALYSIS

Sample	-	A	B
Carbon, %	-	0.07	0.15
Manganese, %	-	0.88	1.23
Phosphorus, %	-	0.013	0.008
Sulfur, %	-	0.003	0.002
Silicon, %	-	0.02	0.05
Chromium, %	-	0.06	0.11
Nickel, %	-	0.04	0.11
Molybdenum, %	-	0.01	0.04
Copper, %	-	0.09	0.22
Aluminum, %	-	0.03	0.05
Vanadium, %	-	0.06	0.05
Titanium, %	-	<0.01	<0.01
Niobium, %	-	<0.01	0.04
Boron, %	-	<0.001	<0.001

TENSION TESTS

Specimens	-	Transverse, 1-1/2" wide reduced sections	
Sample	-	A	B
Yield Strength*, psi	-	65,500	77,900
Tensile Strength, psi	-	80,800	93,700
Elongation in 2", %	-	35.2	34.1

*At 0.5% total extension

Respectfully submitted,
BRYAN LABORATORY, INC.

Signature on Original Only

Christopher M. Corbin

/cd

NOTICE
The samples and/or specimens remaining from these tests or analyses will be discarded seven days after the date of this report, unless arrangements are made to the contrary.

APPENDIX B: SHIELDED METAL ARC WELDING PROCEDURE

APPROVED

WPS No. 9-SM [1] LH

REV# 0 Date 2/24/1996

PQR No. SMAW-62LH

Welding Process(es) SHIELDED METAL ARC WELDING (SMAW)

Type (manual,automatic,semi-auto) MANUAL

JOINTS (QW-402)

Joint Design SINGLE GROOVE TEE JOINT

Backing No X Yes ____ Backing Material (Type) ____

BASE METALS (QW-403)

P-No. 1 Group No. 1 to P-No. 1 Group No. 1

Specification Type and Grade SA-105 AND SA-106 GRADE B

to Specification Type and Grade SA-105 AND SA-106 GRADE B

Base Metal Thickness Range Groove 0.188" THRU 0.750" Fillet ALL

Pipe Diameter Range Groove ALL Fillet ALL

Other ALL API 5L GRADES ARE ACCEPTABLE FOR ANSI B31.8 SYSTEMS (GATHERING & COMPRESSOR/METER STATIONS)

FILLER METALS (QW-404) Each base metal filler combination should be recorded individually

Spec. No. (SFA)	5.1		
AWS No. (Class)	E7018		
Filler Metal F-No.	4		
Weld Metal Analysis A-No.	1		
Size of Filler Metal	3/32" - 1/8" - 5/32"		
Groove Thickness Range	0.188" THRU 0.750"		
Fillet Thickness Range	UNLIMITED		
Electrode-Flux Class	N/A		

Other ____

POSITIONS (QW-405)

Position(s): Groove ALL Fillet ALL

Welding Progression: Up E7018 Down ____

POSTWELD HEAT TREATMENT (QW-407)

Temperature Range N/A

Time Range N/A

PREHEAT (QW-406)

Preheat Temp. Min. MINIMUM 75 F

Interpass Temp. Max 450 F MAXIMUM

Preheat Maintenance PROPANE TORCH

GAS (QW-408)

	Gas(es)	% Composition	Flow Rate(cfm)
Shielding	N/A		
Trailing			
Backing			

ELECTRICAL CHARACTERISTICS (QW-409)

Weld Layers	Process	Filler Metal Class	Filler Metal Dia.	Current Type Polarity	Current Amp. Range	Volt Range	Travel Speed Range	Other (hot wire addition, technique, torch angle, etc.)
1	SMAW	E7018	3/32-1/8	DCRP	70 - 130	15 - 26	5 - 10 IPM	
2	SMAW	E7018	3/32-1/8	DCRP	70 - 130	15 - 26	5 - 15 IPM	
BALLANCE	SMAW	E7018	3/32-1/8-5/32	DCRP	70 - 150	15 - 26	5 - 15 IPM	

TECHNIQUE (QW-410)

String or Weave Bead STRINGER BEAD FOR ROOT AND HOT PASS - EITHER TECHNIQUE FOR BALANCE AND CAP

Orifice or Gas Cup Size ____ Contact tube to work distance N/A Oscillation N/A

Initial and Interpass Cleaning (Brushing, Grinding, etc.) HAND OR POWER BRUSHING AND GRINDING

Method of Back Gouging GRINDING OR AIR-ARC

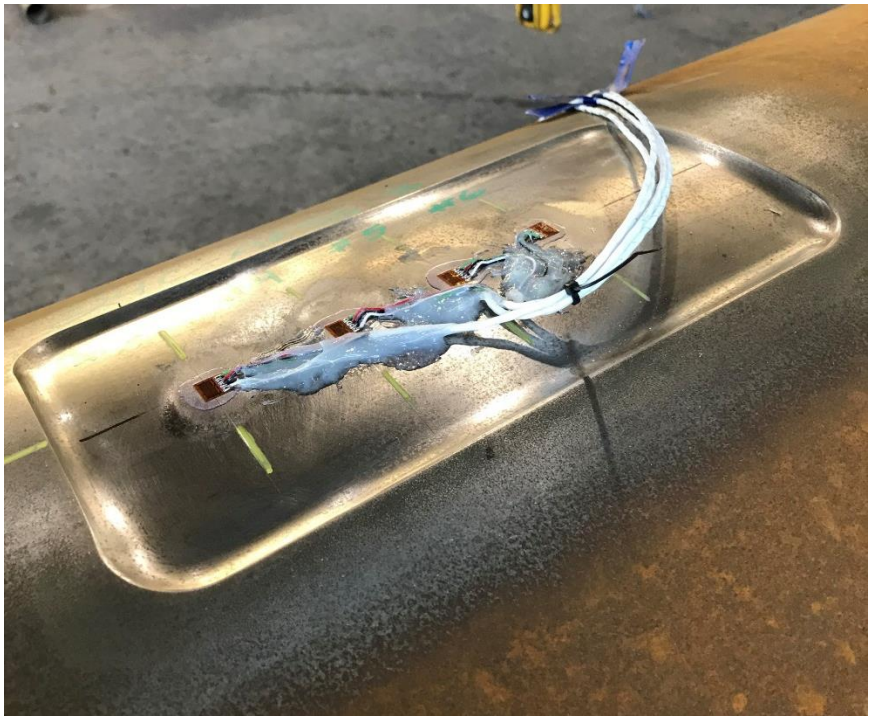
Multiple or Single Pass (per side) MULTIPLE Multiple or Single Electrodes SINGLE

Peening N/A

Other ____

Additional Comments THIS WPS IS APPLICABLE FOR WELDING P1 MATERIALS USING THE SMAW PROCESSES ON MATERIALS FROM 0.188" THRU 0.750" THICK - WITH OR WITHOUT BACKING - API MATERIALS ARE NOT APPROVED FOR USE IN ANSI B31.3 SYSTEMS (IN-PLANT)

APPENDIX C: PHOTOS OF ALLAN EDWARDS SLEEVE INSTALLATION



Machined corrosion feature with strain gages installed



Filler (load transfer) material used to fill the corrosion and dent features



Lowering of top sleeve over corrosion feature filled with load transfer material

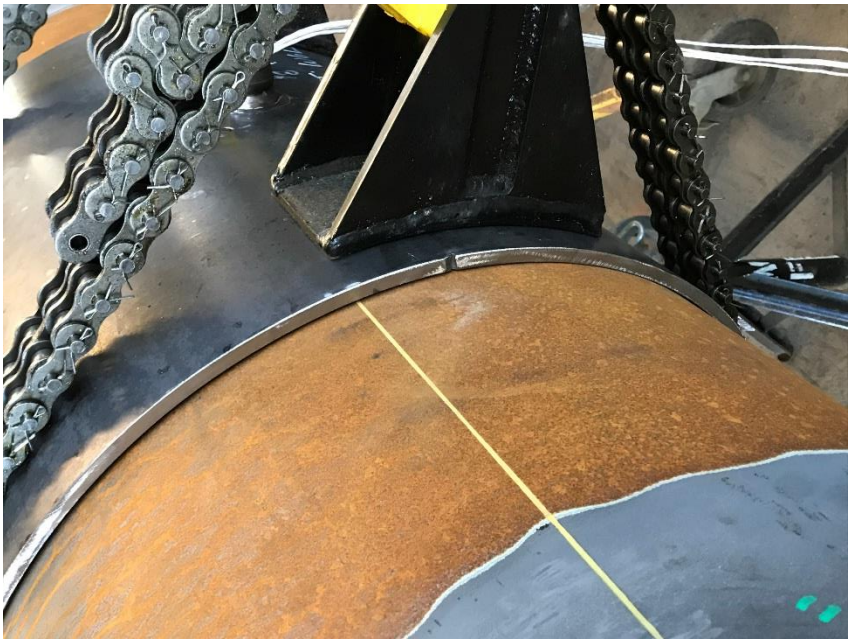


Photo showing fit-up of top sleeve with Allan Edwards' Mechanical Pipe Jacks