Steel Sleeves: A New Look at a Widely-Used Repair Method

Chris Alexander
ADV Integrity, Inc. | Magnolia, Texas

Chip Edwards
Allan Edwards | Tulsa, Oklahoma

Tommy Precht
Allan Edwards | Lake Charles, Louisiana

Pipeline Pigging and Integrity Management Conference

Marriott Marquis Hotel, Houston, USA
February 18-22, 2019

Organized by
Clarion Technical Conferences
and **Tiratsoo Technical**

ABSTRACT

Steel sleeves play a critical role in the pipeline rehabilitation programs of most pipeline operators. Steel sleeves are used to repair a wide range of anomalies, including corrosion, dents, and crack-like features. Three full-scale studies were conducted to evaluate the performance of steel sleeves used to reinforce corrosion and dent features subjected to cyclic pressure service. One study, known as the Dent Validation Collaborative Industry Program (DV-CIP), was sponsored by a group of pipeline operators, ROSEN, and six repair companies that included Allan Edwards. In this study the effects of a filler material on the performance of steel sleeves used to reinforce dents was evaluated. The other two studies evaluated the performance of Type A and B steel sleeves used to reinforce corrosion and dents subjected to static burst and cyclic pressure conditions.

This paper provides valuable information regarding the importance of filler materials and also quantifying the strain reduction provided by steel sleeves used to reinforce corrosion and dent features. Of particular importance are the empirically-determined fatigue lives that can be used to provide both liquid and gas transmission pipeline operators with estimated service lives for corrosion and dent features reinforced with steel sleeves.

INTRODUCTION

The use of steel sleeves in repairing high pressure pipelines dates back to the earliest days of steel pipeline construction. With the pipeline industry's confidence in using carbon steel to construct steel pipelines, using the same material to fabricate repair sleeves was logical. Today's pipelines are repaired using a variety of materials that include steel from pre-tested pipe and rolled plate, as well as composite materials.

The adoption of composite materials for repairing high pressure pipelines started in the early 1990s, although one could argue the greatest technology advances and validations have occurred over the past decade. The reason that composite repair technologies are mentioned in a paper focused on steel sleeves is that the assessment process used to evaluate composite repairs is a model for the adoption of other pipeline repair systems. The adoption process required an extensive assessment that included full-scale destructive testing of reinforced-defects including corrosion, dents, mechanical damage, branch connections, wrinkle bends, vintage girth welds, and planar defects to name a few.

To the authors' knowledge limited research has been conducted in evaluating the performance of steel sleeves used to reinforce corrosion and dent features in high pressure transmission pipelines. In particular, limited data are available in the open literature concerning the magnitude of reinforcement[1] provided by steel sleeves to damaged pipelines. Although one could argue there has been minimal incentives for the pipeline industry to study the performance of steel sleeves because of their generally-universal acceptance, from an engineering standpoint it seems prudent to study why a repair technology is effectively working and how it might be improved or enhanced. For this reason, Allan Edwards participated in several studies and provided materials to quantify the performance of their

[1] In the context of this discussion, quantifying the magnitude of reinforcement of a particular repair system is achieved using strain gages installed in a defect beneath a repair. During loading the strain gage measurements quantify the level of strain reduced in the damaged section of the test pipe. This approach has been employed in testing on well over 1,000 pipe samples and is an effective method for comparing the performance of competing reinforcing technologies.

steel sleeves in reinforcing corrosion and dent features. The test results from these studies are the subject of this paper.

Provided in this paper are results obtained on Allan Edwards' steel sleeves used to reinforce corrosion and dent features in 12-inch and 24-inch NPS pipe materials. The presented results were evaluated in three different full-scale testing programs. The objectives in each study were somewhat different, but all sought to demonstrate the technical benefits associated in using steel sleeves. Of particular interest are results from a recent study that validated the acceptability in using rolled plate to manufacture steel sleeves. In this particular study the number of cycles to failure are expressed in terms of years of service considering varying cyclic pressure intensities (i.e., light to very aggressive based on the widely-recognized Kiefner pressure history survey[2]).

There were several objectives associated with these studies. The first objective was to quantify strain reduction provided by the steel sleeves in reinforcing corrosion and dent anomalies. The second objective was to demonstrate the increase in burst pressure capacity and pressure cycle fatigue life, although it is doubtful anyone in the pipeline industry questions the reinforcing benefits of Type A and Type B steel sleeves. The final objective, and one unique in nature to the authors' knowledge, was to demonstrate the importance in having a load transfer material installed in the annulus between the pipe and steel sleeve.[3]

The sections of this paper that follow include a *Test Methods* section that provides an overview of the test samples that were used in the three studies. The *Presentation and Discussion of Test Results* section includes research findings, such as cycles to failure and strain gage measurements. The *Discussion* section provides important insights on what the test results mean in terms of actual pipeline operation. Finally, the *Closing Comments* section provides a few concluding remarks related to findings from the test programs.

TEST METHODS

The assessment of pipeline repair methods involving full-scale testing have utilized a relatively consistent approach. Corrosion defects have been machined into pipe materials, having depths ranging from 25% to as deep as 90%. Dents have been generated by pressing indenters of various shapes and sizes into pressurized pipe samples. Strain gages are typically installed in the defect regions, including those installed beneath repairs on the test pipes; permitting test engineers to quantify the levels of reinforcement provided by repairs in studying the magnitude of strain reduction in the reinforced sections of pipe.

In addition to testing reinforced samples, most research programs have tested unreinforced samples with the intention of generating "baseline data sets" against which results for the reinforced samples are compared. The benefit in employing consistent approaches when conducting these full-scale testing programs has been to provide the pipeline industry with a means for comparing the overall performance of competing repair technologies.

---

[2] 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.

[3] Interested readers are encouraged to read paper IPC2016-64104 that addressed the performance of different load transfer materials, Alexander, C., Beckett, A., *An Experimental Study to Evaluate the Performance of Competing Filler Materials Used with Type B and Stand-Off Steel Sleeves*, Proceedings of IPC 2016 (Paper No. IPC2016-64104), 11th International Pipeline Conference, September 26-30, 2016 Calgary, Alberta, Canada.

Listed below are details on the samples tested in the programs referenced in this paper. Included for each of the three test programs is the *Testing Objective* associated with each study. As noted in each of these studies, cyclic pressure testing was the primary means for loading the pipe samples. Results for the Type A/B Steel Sleeve Study are not included in this paper, but interested readers are encouraged to read the paper presented at the 2014 International Pipeline Conference[4].

Type A/B Steel Sleeve Study

Testing Objective: Quantify the magnitude of strain reduction provided by both Type A and B steel sleeves used to reinforce corrosion and dent features.

- 12.75-inch x 0.375-inch, Grade X42 pipe with 75% corrosion
  - Type A sleeve, burst tested
  - Type B sleeve, burst tested
  - Type A sleeve, pressure cycled ΔP = 36% to 72% SMYS (890 to 1,780 psig)
  - Type B sleeve, pressure cycled ΔP = 36% to 72% SMYS (890 to 1,780 psig)
  - Steel sleeves 0.375-inch thick
- 12.75-inch x 0.188-inch, Grade X42 pipe with 15% deep initial dent (3% residual)
  - Type A sleeve, pressure cycled ΔP = 8% to 72% SMYS (100 to 890 psig)
  - Type B sleeve, pressure cycled ΔP = 8% to 72% SMYS (100 to 890 psig)
  - Steel sleeves 0.188-inch thick

Dent Validation Collaborative Industry Program (DV-CIP)

Testing Objective: Quantify the effects in having a filler / load transfer material in the dented region beneath steel sleeve subject to cyclic pressure loading

- 24-inch x 0.250-inch, Grade X42 pipe with 15% deep initial dent (3% residual) and Type B sleeves:
  - No filler material, pressure cycled ΔP = 11% to 72% SMYS (100 psi to 630 psig)
  - Filler material, pressure cycled ΔP = 11% to 72% SMYS (100 psi to 630 psig)
  - Steel sleeves 0.250-inch thick

Steel Sleeve Qualification Study

Testing Objective: Demonstrate the ability of steel sleeves rolled plate to reinforce corrosion and dent features subject to cyclic pressure loading.

- 24-inch x 0.375-inch, Grade X65 pipe with 50% corrosion
  - Type B sleeve, pressure cycled ΔP = 5% to 72% SMYS (100 to 1,463 psi)
  - Steel sleeves 0.375-inch thick
- 24-inch x 0.250-inch, Grade X52 pipe with 15% deep dent
  - Type B sleeve, pressure cycled ΔP = 9% to 72% SMYS (100 to 780 psi)
  - Steel sleeves 0.250-inch thick

Several photos are included from the Steel Sleeve Qualification Study showing various stages of the testing process:

- Figure 1: End view of indentation frame with 24-inch pipe
- Figure 2: View of simulated dent
- Figure 3: Strain gage locations for the dented samples

[4] Alexander, C., Vyvial, B., and Wilson, F., *Pipeline Repair of Corrosion and Dents: A Comparison of Composite Repairs and Steel Sleeves*, Proceedings of IPC 2014 (Paper No. IPC2014-33410), 10th International Pipeline Conference, September 29 - October 3, 2014, Calgary, Alberta, Canada.

PRESENTATION AND DISCUSSION OF TEST RESULTS

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 providing an in-depth quantitative comparison of the performance between different repair systems. The second means for comparing performance involves the use of strain gages installed in 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 paper provides test results and discussions on the impact of filler materials on the performance of reinforced dents (from the DV-CIP study), as well as results from the more recent Steel Sleeve Qualification Study.

Installation of Filler Material

In the reinforcement of pipeline anomalies, filler materials installed in defect regions contribute significantly to the level of load transfer that takes place between the damaged pipe and reinforcing sleeve. In the 2015 DV-CIP study, Allan Edwards conducted tests that compared the installation of sleeves with and without filler materials. The dent configuration in this study involved the reinforcement of 24-inch x 0.250-inch, Grade X42 pipe with initially 15% deep dents (approximately 3% residual dent depths) cycled from 100 psig to 72% SMYS.

Provided in

Table 1 are results from the DV-CIP study that include results for the following:

- Unreinforced dent
- Reinforced dent with filler material
- Reinforced dent with no filler material

As noted, the absence of the filler material only increased the fatigue life of the unreinforced dent by approximately 75%, which 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 1 – 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)

Comparison of Experimental Fatigue Lives

Cyclic pressure fatigue is typically a 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 of competing repair technologies; which is useful even for gas pipeline operators. 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.

A benefit in reviewing results from the studies presented in this paper is quantifying the performance of the sleeves manufactured by fabricators, such as Allan Edwards. Full-scale destructive testing is the ideal means for quantifying the capacity of steel sleeves to reinforce specific anomalies by comparing the experimentally-determined fatigue life of the failure relative to operating conditions of the pipeline. For example, if a reinforced dent reaches 300,000 cycles to failure in testing and a pipeline cycling at the same equivalent pressure range experiences 1,000 cycles per year (cpy) the design life is 30 years assuming a fatigue safety factor of 10 (i.e., 300,000 cycles / 1,000 cpy / 10 = 30 years). With current pipeline regulations moving towards performance rather than prescriptive criteria, having full-scale destructive test data is invaluable to support the use of manufactured steel sleeves.

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 is 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 six test samples are presented in Table 2. 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 2 – 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

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)**
(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 initial two repaired 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%).

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. There is generally 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, the hoop strain for both samples with Allan Edwards' sleeves were 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 3 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 3 – Hoop Strain Measurements for the Corrosion Samples

Number of Cycles (ΔP = 5% to 72% SMYS)	Hoop Strain Measurements		
	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 4. 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.

A longitudinally-oriented crack developed in the unreinforced sample after 32,579 cycles, as shown in Figure 4. 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 5 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 6.

Table 4 – Hoop Strain Measurements for the Dent Samples

Number of Cycles (ΔP = 5% to 72% SMYS)	Hoop Strain Measurements		
	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

CLOSING COMMENTS

This paper has provided results from three full-scale testing programs 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 lives of pipelines, especially those manufactured using rolled plate.

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 liquid operators should evaluate the estimated fatigue lives in relation to their particular pressure histories. Once pressure was permitted in the annual between the pipe and steel sleeve, the sleeves' longitudinal and girth welds were subjected to stresses that eventually contributed to their failures.

Several key aspects that affect the quality of a steel sleeve repair have been identified. It has been shown that poor fit up of steel sleeves can reduce their effectiveness in reinforcing pipelines. Using a filler material improves the load transfer between the pipe and the repair allowing for longer service life. Along with the importance of a good fit-up, it is also to ensure the filler material has been properly installed to ensure good load transfer from the pipe to the sleeve.

To the authors' knowledge, programs evaluating the performance of steel sleeves as presented in this paper have 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.

REFERENCES

1. Alexander, C., *Study to Evaluate Steel Sleeve Performance in Reinforcing Defects*, Report prepared for Allan Edwards, Project No. AE-17-006, December 2018.
2. Alexander, C., and Beckett, A., *An Experimental Study to Evaluate the Performance of Competing Filler Materials Used with Type B and Stand-Off Steel Sleeves*, Proceedings of IPC 2016 (Paper No. IPC2016-64104), 11th International Pipeline Conference, September 26-30, 2016 Calgary, Alberta, Canada.
3. Dotson, R.L., Ginten, M., Alexander, C.R., Bedoya, J.J., and Schroeer, K., *Combining High Resolution In-Line Geometry Tools and Finite Element Analysis to Improve Dent Assessments*, Paper No. PPIM-ILI2-16, Pipeline Pigging & Integrity Management Conference, Houston, Texas, February 10-13, 2014.
4. Alexander, C., Vyvial, B., and Wilson, F., *Pipeline Repair of Corrosion and Dents: A Comparison of Composite Repairs and Steel Sleeves*, Proceedings of IPC 2014 (Paper No. IPC2014-33410), 10th International Pipeline Conference, September 29 - October 3, 2014, Calgary, Alberta, Canada.
5. *Dent Validation Collaborative Industry Program (DV-CIP): Full-Scale Testing and Numerical Modeling*, report prepared by Stress Engineering Services, Inc. for DV-CIP Participants (Operators and Repair Companies), copy of report provided by Allan Edwards and ROSEN, August 2015.
6. 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 1: End view of indentation frame with 24-inch pipe

Figure 2: View of simulated dent after indenter removal

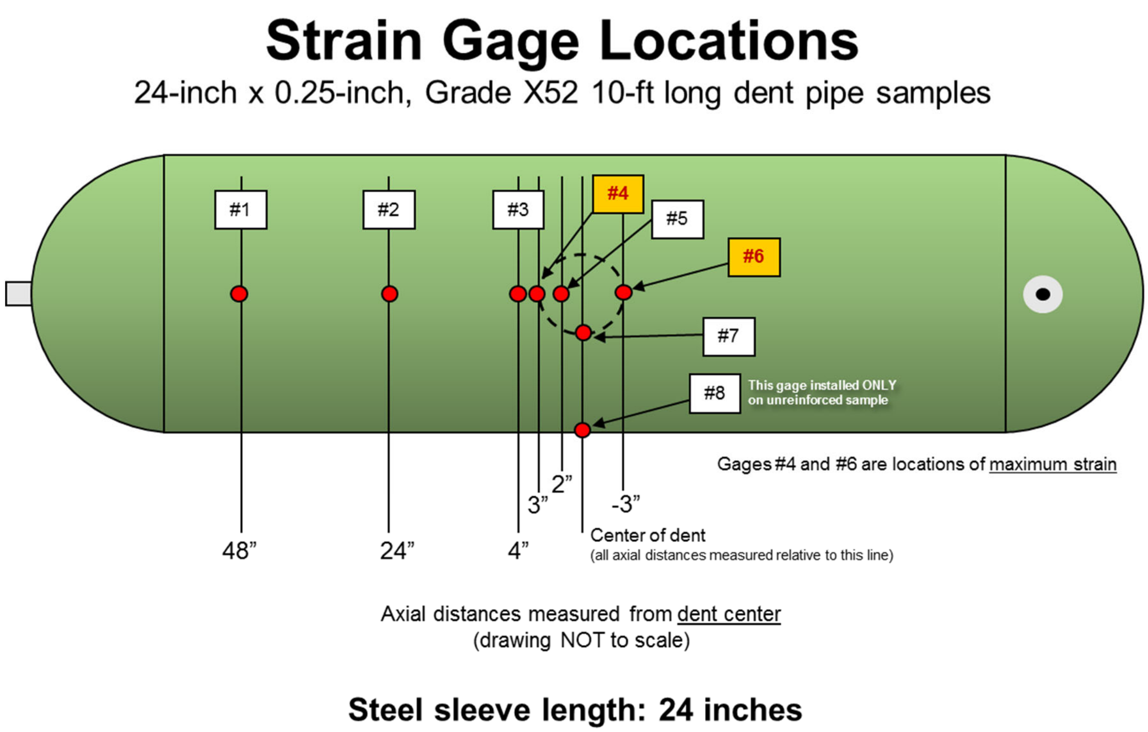

Figure 3: Strain gage locations for the dented samples

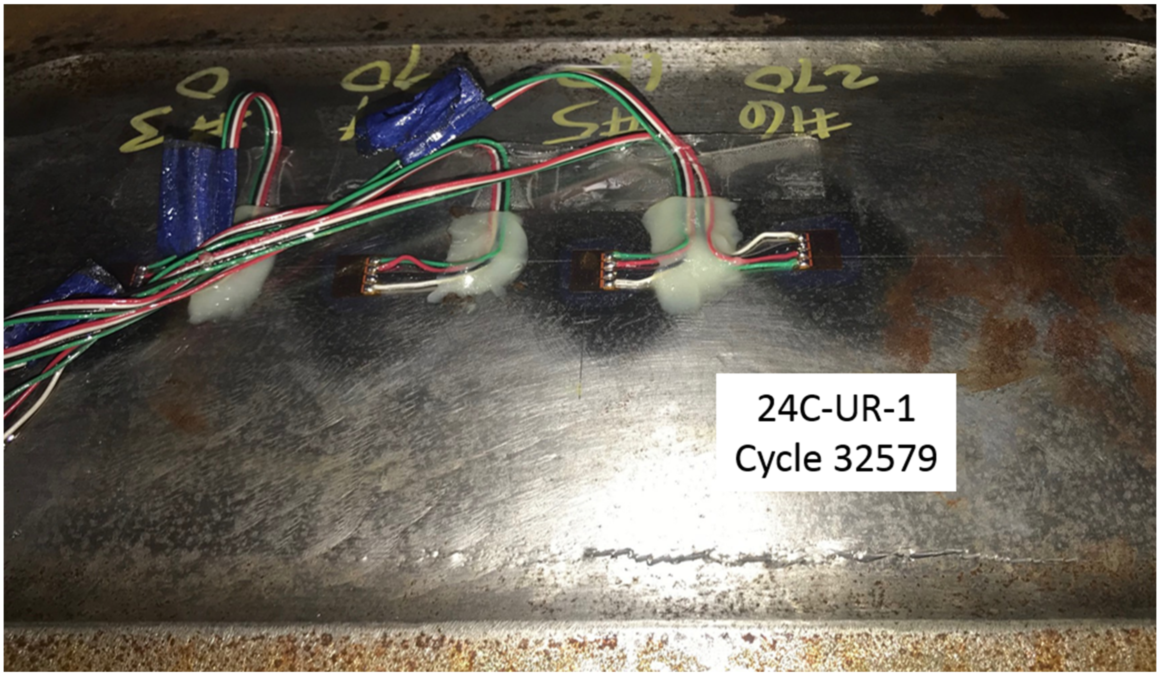

Figure 4 – View of Failure in 24C-UR-1

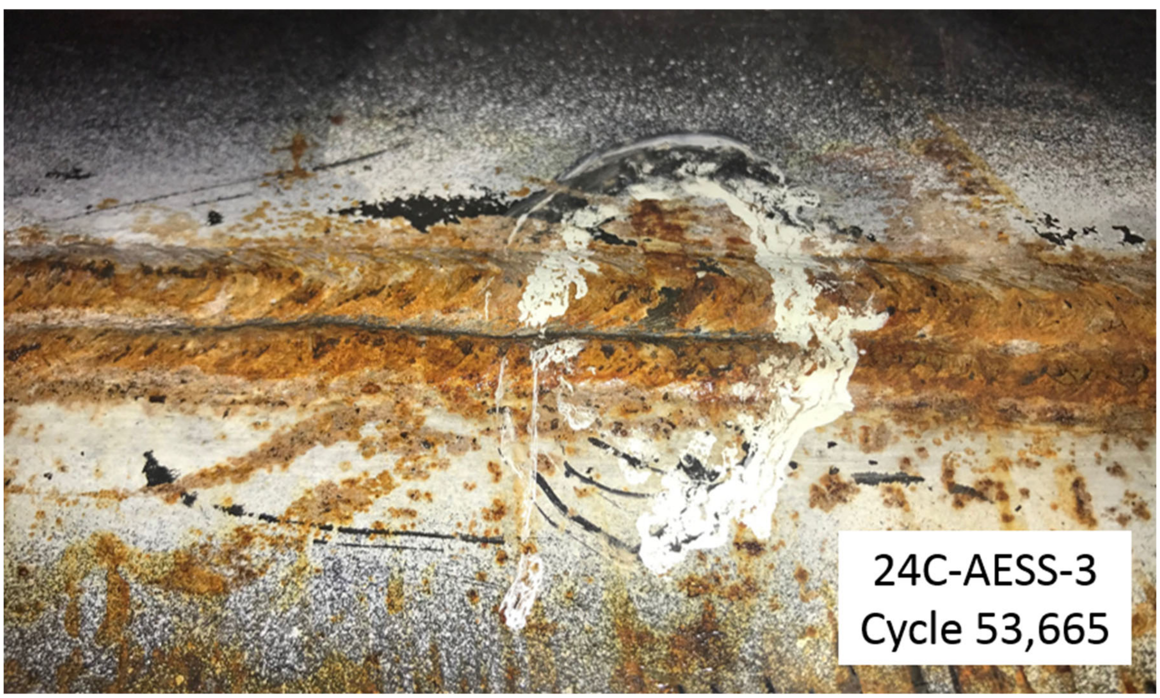

Figure 5 – View of Failure 24C-AESS-3

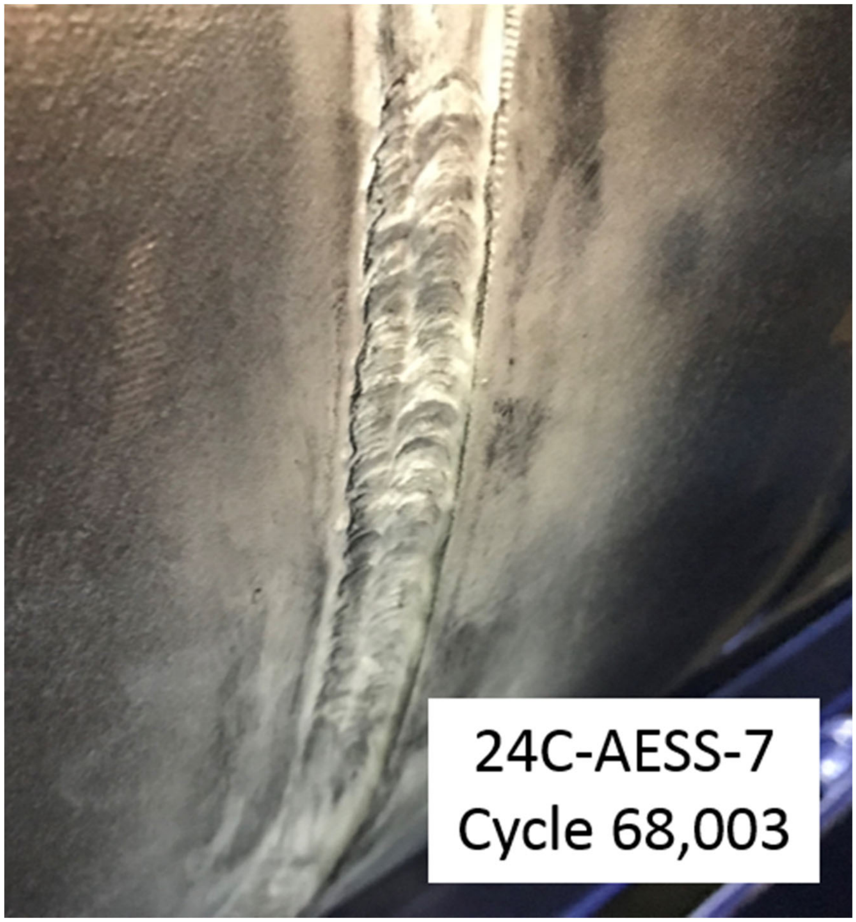

Figure 6 – View of Failure 24C-AESS-7