ALLAN EDWARDS

ALLAN EDWARDS TESTING STORY

VOL. I

ANNIVERSARY

1947 75 YEARS 2022

CELEBRATION

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ANNIVERSARY 1947 75 YEARS 2022 CELEBRATION

WHAT IF A SLEEVE MANUFACTURER DECIDED TO BECOME MORE THAN *JUST* A PIPELINE SUPPLIER?

In 2012, Allan Edwards embarked on a journey to elevate & redefine the industry standards for manufactured steel repair sleeves. It was no longer enough to provide a product that simply met industry requirements: we went above and beyond to craft a research-backed, data-driven product that excelled in every aspect of its performance – and we now have the data to back it.

Here is our sleeve story.

Enjoy.

TIMELINE: ALLAN EDWARDS TESTING INITIATIVES

2012: Testing Program: Pipeline Repair of Corrosion and Dents: A Comparison of Composite Repairs and Steel Sleeves

2014: Testing Program: Type A/B Steel Sleeve Study

2014: Testing Program: Dent Validation Collaborative Industry Partnership (DV-CIP)

2016: Begin Construction of New Steel Sleeve Manufacturing Facility

2017: Dr. Chris Alexander, PE & Tommy Precht visit PHMSA regulators in Washington D.C.

2018: New Steel Sleeve Manufacturing Facility is Completed

2018: Testing Program: JIP Study to Evaluate Sleeve Performance in Reinforcing Defects

2019: Testing Program: Burst Test of a 24-Inch Leaking Pipe Repaired with a Type B Sleeve

2019: Allan Edwards is Issued the Steel Sleeves Certificate of Quality (Version 1)

2020: Testing Program: OmegaWrap™ Composite Repair System

2020: Testing Program: Induction-Heated Compression Sleeve

2021: Testing Program: Steel Sleeve Fit-Up Test Program

2021: Testing Program: Bauschinger Effect - Tensile Testing of Rolled Sleeve

2021: Testing Program: OmegaWrap™ Carbon Composite Repair System

2021: Testing Program: Influence of Backing Strip Mill Groove on Integrity of Type B Sleeve

2021: Allan Edwards Elevates Sleeve Specification to Highest-Possible Quality Standard

2021: Testing Program: JIP for Composite Reinforcement of Crack Features

Though this timeline includes an exhaustive list of all Allan Edwards testing initiatives, this book is limited to sleeve testing only. Find out details about our other testing programs in Allan Edwards Testing Story, Vol. II

THE BACKSTORY

An act of generosity by a former Allan Edwards executive became the cornerstone on which our testing story is built.

John Disher – who worked as VP of Operations for nearly 50 years – became acquainted with Dr. Chris Alexander, PE., when he donated several sets of steel repair sleeves for an industry testing program that Dr. Alexander was participating in with another repair company. This program evaluated the performance of composite repair technologies relative to steel repair sleeves. Their relationship led John to meet Tommy Precht, an employee of Armor Plate and a fellow participant of the sleeves/composites testing program. Through John Disher, Tommy was later introduced to Chip Edwards, President of Allan Edwards and great-grandson of our company founder. Within 2 years of their meeting, Tommy left Armor Plate to join Allan Edwards as a sales representative.

Tommy Precht came to Allan Edwards already equipped with extensive knowledge of pipeline repair technologies, having spent several decades specializing in the development, sale and installation of composite repair technologies. As Tommy settled into his new role at Allan Edwards, he recognized significant crossover in the type of customers who would use composite technologies as a repair solution and those who could utilize steel repair sleeves as a comparable repair option. Tommy found that he could continue to call on many of the same customers despite changing companies and product specialties.

When visiting these familiar faces, Tommy began to notice a pattern: many customers did not consider manufactured repair sleeves to be a valid repair option. In fact, several expressed to Tommy that even if they wished to use manufactured repair sleeves, they could not: manufactured repair sleeves were not an approved repair method within their organizations.

Why were these operators seemingly not able to use manufactured repair sleeves? The answer was surprising.

The CFR 192 and 195 regulations are the only governing authority over the use of steel sleeves as a pipeline repair method. Tommy discovered that interpretation of these codes varied regarding whether sleeves must be comprised only of pre-tested pipe or if sleeves manufactured from rolled plate could be an equally valid repair option.

Unsure how to proceed, Tommy went directly to the code to examine verbatim what the regulations said of this type of pipeline repair method:

§ 192.717 Transmission lines: Permanent field repair of leaks.

Each permanent field repair of a leak on a transmission line must be made by -

(a) Removing the leak by cutting out and replacing a cylindrical piece of pipe; or

(b) Repairing the leak by one of the following methods:

(1) Install a full encirclement welded split sleeve of appropriate design, unless the transmission line is joined by mechanical couplings and operates at less than 40 percent of SMYS

(2) If the leak is due to a corrosion pit, install a properly designed bolt-on-leak clamp

(3) If the leak is due to a corrosion pit and on pipe of not more than 40,000 psi (267 Mpa) SMYS, fillet weld over the pitted area a steel plate patch with rounded corners, of the same or greater thickness than the pipe, and not more than one-half of the diameter of the pipe in size

(4) If the leak is on a submerged offshore pipeline or submerged pipeline in inland navigable waters, mechanically apply a full encirclement split sleeve of appropriate design

(5) Apply a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe

Referencing CFR 192.717(b)(1), there it was! A direct justification to use welded split sleeves to repair transmission lines.

So...what was the problem?

It came down to the *interpretation* of what constituted a "welded split sleeve." In the eyes of many of his customers, a welded split sleeve was *exclusively* a piece of pre-tested split pipe that had been subjected to exhaustive hydrotesting & other engineering validation tests. This interpretation *excluded* manufactured repair sleeves as a form of welded split sleeve because they were formed from rolled plate rather than pre-tested pipe.

The Bottom Line

A key segment of our customer base was alienated from using our repair sleeves because they did not have sufficient validation testing to be considered on par with the performance standards that governed the use of pre-tested pipe repair sleeves.

Neither did any other manufactured sleeve provider.

We resolved to take action. Because our goal was to lead, rather than follow.

Bound for Change

If there was any doubt that our sleeves could be used as an effective repair option, we needed to look further into how to boost their credibility. Besides the referenced CFR regulations, no other guidance existed to benchmark the performance requirements of steel repair sleeves. We turned our attention to CFR 192.717(b)(5). This section stated that alternate repair methods *could* be used as a valid repair option *as long as* these alternate methods were supported by “reliable engineering tests and analyses” that demonstrated that they could “permanently restore the serviceability of the pipe.”

This was our “in.”

We embarked on a sleeve validation testing journey unmatched by any other sleeve manufacturer in the industry. We knew these testing programs would boost our credibility and provide documented evidence of performance reliability. But they would also provide peace of mind to our customers that we had put in the work to ensure they could rest easy that our sleeves will always do what we say they will – and we have the data to validate that.

THERE'S A LOT THAT GOES INTO WHAT WE STAND FOR AS A COMPANY AND WHY WE CHOOSE TO GO ABOVE AND BEYOND WHEREVER POSSIBLE. TAKE A LOOK AT OUR PLEDGE HERE - IT'S OUR SIGNED COMMITMENT TO DO RIGHT BY EVERY CUSTOMER TO THE BEST OF OUR ABILITY.

SCAN ME

TESTING ASSUMPTIONS

Throughout the duration of the our testing programs, two assumptions were referenced repeatedly and used as baselines when forming conclusions from the testing results. These assumptions are summarized below:

The Kiefner Study

We routinely separated sleeve pressure cycling ranges into four classifications according to data compiled by John Kiefner: *Very Aggressive*, *Aggressive*, *Moderate*, and *Light*. These classifications, based on numerous industry surveys, have been used by the pipeline industry to help benchmark performance in recent years. A *Very Aggressive* condition would result in 276 cycles per year, and a *Light* condition would result in 10 cycles per year, assuming a pressure range of 72% SMYS *(Study to Evaluate Steel Sleeve Performance in Reinforcing Defects, 15)*. Testing programs designed to validate Allan Edwards sleeve performance were performed in adherence to the *Light* classification, as gas transmission pipelines typically experience minimal cycling. These classifications aided in quantifying the “design life” of Allan Edwards sleeves when exposed to various operating conditions.

Miner’s Rule

The performance of Allan Edwards steel sleeves was further quantified by measuring “cycles to failure.” These values were based on a sum of applied pressure cycles using Miner’s Rule, assuming a pressure range equal to 72% SMYS *(Study to Evaluate Steel Sleeve Performance in Reinforcing Defects, 14)*.

$$\sum_{i=1}^{k} \frac{n_i \times S_i}{N_i \times S_i} = C$$

Miner's Rule states that “the damage done by each stress repetition at a given stress level is equal, meaning the first stress cycle at a uniform stress level is as damaging as the last. Miner's Rule operates on the hypothesis that the portion of useful fatigue life used up by a number of repeated stress cycles at a particular stress is proportional to the total number of cycles in the fatigue life, if that were the only stress level applied to the part” *(Rexnord.com)*.

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

Our pilot third-party testing program evaluated the performance of Type A and B repair sleeves relative to a different type of repair technology: a composite wrap. The program featured various corrosion and dent anomalies, tested using Type A & Type B repair sleeves from Allan Edwards. The composite wrap was provided from a different repair company. The dent anomalies, 15% deep, were installed in the carrier pipe through use of a specialized tool called an "indenter." Corrosion defects were also simulated by machining out a section of the carrier pipe to represent a 75% loss in wall thickness. The program included both burst testing and cyclic pressure testing and delivered promising results.

Objective

As stated in our white paper, authored by Chris Alexander, PE, of ADV Integrity: 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.

Procedure

Nine total samples were tested:

1. 12.75-inch x 0.375-inch, Grade X42 pipe with 75% corrosion

- a. Type A sleeve, burst tested
- b. Type B sleeve, burst tested
- c. Composite wrap, burst tested
- d. Type A sleeve, pressure cycled ΔP = 36% to 72% SMYS (890 to 1,780 psi)
- e. Type B sleeve, pressure cycled ΔP = 36% to 72% SMYS (890 to 1,780 psi)
- f. Composite wrap (APPW), pressure cycled ΔP = 36% to 72% SMYS (890 to 1,780 psi)

2. 12.75-inch x 0.188-inch, Grade X42 pipe with 15% deep initial dent (3% residual)

- a. Type A sleeve, pressure cycled ΔP = 8% to 72% SMYS (100 to 890 psi)
- b. Type B sleeve, pressure cycled ΔP = 8% to 72% SMYS (100 to 890 psi)
- c. Composite wrap (APPW), pressure cycled ΔP = 8% to 72% SMYS (100 to 890 psi)

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

Results

In all tests, the sleeve samples either experienced failure outside the repair zone or achieved runout with no failures.

Burst Testing:

- All three corrosion samples failed outside repair zone
- No dent samples were burst tested

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

Repair Type	Hoop Strain (με)				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	1,035	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	1,536	132	N/A	N/A	2,043	1,250	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.

Pressure Cycling:

- The corrosion samples reinforced with the Type A and Type B repair sleeves both surpassed the runout threshold, reaching 302,465 cycles before cycling was stopped because the run-out condition was exceeded
- The corrosion sample repaired with APPW failed in the corrosion area after 198,550 cycles
- Dent samples reinforced with Type A and Type B repair sleeves both surpassed the runout condition, and testing was halted after 239,897 cycles
- The dent sample reinforced with APPW failed in the dent after 149,913 cycles

Table 4: Test Sample Pressure Data

Sample Type	Composite	Type A	Type B
Number of experimental cycles to Failure			
Dent fatigue (ΔP = 72% SMYS)	149,913	239,897	239,897
Corrosion fatigue (ΔP = 36% SMYS)	198,550	302,465	302,465
Life in "years" with fatigue safety factor of 10 for "moderately" aggressive cycling			
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.

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

Insights & Conclusions

The results of this study clearly demonstrated the ability of steel sleeves to restore integrity to damaged pipelines. The fact that both steel sleeve samples either failed outside the repair zone (meaning the integrity of the sleeve itself was not a factor in the failure) or surpassed the designated runout maximum threshold of pressure cycles demonstrated the durability of Allan Edwards sleeves when used to reinforce pipeline defects.

An important observation in reviewing the first column of Table 1 is that all measured strains are within 15% of each another for "Center Under Repair." The indicates that both the repair sleeves and the composite wrap helped reduce hoop strain similarly for the burst tested corrosion samples. The primary purpose of a repair sleeve or composite wrap is to bear as much load as possible from the pipe. The similar strains among all samples indicate that these repair methods performed similarly in that regard *(Pipeline Repair of Corrosion and Dents: A Comparison of Composite Repairs and Steel Sleeves, 3).*

If the pressure cycle data for the 75% corrosion fatigue sample is used 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 – although it could be larger as no failures occurred in either the Type A or B steel sleeve samples *(Pipeline Repair of Corrosion and Dents: A Comparison of Composite Repairs and Steel Sleeves, 3).*

TYPE A/B STEEL SLEEVE STUDY

The Type A/B Steel Sleeve Study involved the repair of corrosion and dent anomalies using Type A and Type B repair sleeves from Allan Edwards. Dents, 15% deep, were installed in the carrier pipe through use of a specialized tool called an “indenter.” Corrosion defects were also simulated by machining out a section of the carrier pipe to represent a 75% loss in wall thickness. The program included both burst testing and cyclic pressure testing.

Objective

The first objective was to quantify strain reduction provided by the steel sleeves used to reinforce corrosion and dent anomalies. The second objective was to demonstrate the increase in burst pressure capacity and pressure cycle fatigue life of our sleeves. **Finally, the value of this testing program was to leverage full-scale testing programs as a means of quantifying the capacity of our steel repair sleeves to reinforce specific anomalies in terms of burst pressures and pressure cycle fatigue lives** *(White Paper on Validating Steel Sleeve Performance, 4).*

Procedure

Six total samples were tested:

1. 12.75-inch x 0.375-inch, Grade X42 pipe with 75% corrosion

- a. Type A sleeve, burst tested
- b. Type B sleeve, burst tested
- c. Type A sleeve, pressure cycled ΔP = 36% to 72% SMYS (890 to 1,780 psi)
- d. Type B sleeve, pressure cycled ΔP = 36% to 72% SMYS (890 to 1,780 psi)

2. 12.75-inch x 0.188-inch, Grade X42 pipe with 15% deep initial dent (3% residual)

- a. Type A sleeve, pressure cycled ΔP = 8% to 72% SMYS (100 to 890 psi)
- b. Type B sleeve, pressure cycled ΔP = 8% to 72% SMYS (100 to 890 psi)

**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.*

TYPE A/B STEEL SLEEVE STUDY

Results

In all tests, samples either experienced failure outside the repair zone or achieved runout with no failures.

Burst Testing:

- All corrosion samples failed outside repair zone
- No dent samples were burst tested

Table 2: Burst pressures and hoop strains for 75% corrosion burst samples

Repair Type	Hoop Strain (με)				Burst Pressure (psi)
	Center Under Repair	2-inch off Center Under Repair	Outside Repair	Base Pipe	
Sleeve "A"	1,919	1,577	446	871	4,233
Sleeve "B"	2,153	2,437	416	789	4,290

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

Pressure Cycling:

- Corrosion samples surpassed the runout threshold, reaching 302,465 cycles before failure
- Dent samples surpassed the runout threshold, and testing was halted after 239,897 cycles

Table 7: Test Sample Pressure Data

Sample Type	Type A	Type B
Number of experimental cycles to Failure		
Dent fatigue (ΔP = 72% SMYS)	239,897	239,897
Corrosion fatigue (ΔP = 36% SMYS)	302,465	302,465
Life in “years” with fatigue safety factor of 10 for “moderately” aggressive cycling		
Dent fatigue life	952 years	952 years
Corrosion fatigue life	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.

Insights & Conclusions

The results of this study clearly demonstrated the ability of steel sleeves to restore integrity to damaged pipelines. The fact that all samples either failed outside the repair zone (meaning the integrity of the sleeve itself was not a factor in the failure) or surpassed the designated runout maximum threshold of pressure cycles demonstrated the durability of Allan Edwards sleeves when used to reinforce pipeline defects.

OUR FIRST SIGNIFICANT INVESTMENT: DENT VALIDATION COLLABORATIVE INDUSTRY PROGRAM (DV-CIP)

The DV-CIP was a collaborative industry program co-sponsored by ROSEN and involved five transmission pipeline operators and six repair companies, with Allan Edwards being among them. The purpose of the study was to evaluate sleeve performance across several different dent configurations.

Objective

The primary objective of this program was to observe how sleeve performance varied with and without the presence of filler material installed between the dent feature and the Type B repair sleeve. Allan Edwards supplied two steel sleeve samples for the program.

Procedure

This full-scale testing program included pressure testing the two samples listed below, along with a third unreinforced, dented carrier pipe that acted as a performance baseline.

The testing sample details are as follows:

- 24-inch x 0.250-inch, Grade X42 pipe with 15% deep initial dent (3% residual)
    - Type B sleeve installed with NO filler material
    - Type B sleeve installed WITH filler material
    - Unreinforced carrier pipe sample (containing NO sleeve and NO filler material)

Results

- **The dent sample that was pressure cycled with filler material *never* failed.** Its projected design life in "years," according to assertions made in the Kiefner Study were as follows:
    - Minimum of 20 years (*Aggressive* cycling)
    - Maximum of 567 years (*Light* cycling)

- **The dent sample that was pressure cycled without filler material failed in the dent zone after 40,877 cycles.** Its projected design life in "years" were as follows:
    - Minimum of 8 years (*Aggressive* cycling)
    - Maximum of 227 years (*Light* cycling)

OUR FIRST SIGNIFICANT INVESTMENT: DENT VALIDATION COLLABORATIVE INDUSTRY PROGRAM (DV-CIP)

Table 5: 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) 87,260 (B)	After failure occurred in dent (A), hole in sleeve plugged and sample continued cycling to failure in sleeve seam weld (B)

- After the sample without filler material failed in the dent zone after 40,877 cycles, the hole in the sleeve (which was placed to allow strain gauge data to be collected to analyze the stresses on the dent) as well as the hole in the dent itself were both plugged. The sample was then allowed to continue cycling. **The sample without filler material failed again at the sleeve seam weld at the 87,260 cycle mark.** Its projected design life in "years" were as follows:
    - Minimum of 17 years (*Aggressive* cycling)
    - Maximum of 485 years (*Light* cycling)
- Additional Information:
    - In this program, the pressure-cycling max pump capability was 2,500 psi with a maximum flow rate of 30 gpm. The pressure range of cycling of 100 psi to 630 psi (72% SMYS) – i.e., ΔP = 61% SMYS *(White Paper on Validating Steel Sleeve Performance, 12)*

Why Was the Sample Without the Filler Material Plugged and Allowed to Continue Cycling?

As stated above, a hole was drilled in the steel sleeve to permit strain gauge cables to run from the dented region between the pipe surface and steel sleeve. **This strain gauge collected valuable data about the stress levels that impacted the dent that was not reinforced with filler material.** After the failure occurred in the "unfilled" dent after 40,877 cycles, this hole was plugged, and cycling was continued. A failure in the weld between the two halves of the steel sleeve occurred at 87,260 cycles.

OUR FIRST SIGNIFICANT INVESTMENT: DENT VALIDATION COLLABORATIVE INDUSTRY PROGRAM (DV-CIP)

Insights & Conclusions

Filler Material Is Highly Beneficial for Dent Reinforcement!

The filler material played an important role in reducing strain in the reinforced dent. The reinforced dent beneath the Allan Edwards' steel sleeve with the filler material had a stress concentration factor (SCF) of 1.05 (compared to the SCF of the unreinforced dent, which was *much* higher at 4.54). **This corresponds to a stress reduction of 75% in the filler-reinforced dent compared to the unreinforced dent.**

Why Does Filler Material Help Sleeve Performance?

A sleeve will naturally provide some degree of compression to the carrier pipe over which it is installed. The tighter the fit, the better the compression. However, when a dent is present on the carrier pipe, a cavity will exist between the sleeve & the surface of the dent, no matter how tightly the sleeve fits over the carrier pipe. Strain gauge data during this testing program showed that without filler material present between the dent and sleeve, the hoop strain range was 3,720 microstrain. **In contrast, when the dent was filled with the load transfer material, the dent experienced a strain factor reduction of 4.3, down to 870 microstrain.**

The Bottom Line: Use a Filler Material When Reinforcing Dent Features with Steel Sleeves!

This testing program demonstrated that without a filler material, strains in the dent were comparable to what would be expected for an unreinforced dent. In other words, when there was no filler material present, **no load was transferred from the dented region of the pipe to the steel sleeve.** When internal forces applied outward pressure on the dent feature, nothing on the outside of the carrier pipe could apply a counteracting force to help bear the load.

This test successfully demonstrated that the presence of filler material increased the life of the dent and sleeve by at least 117%.

RESUMING OUR STORY

Resuming Our Story

After two full-scale testing programs, during which Allan Edwards sleeves were tested in far more exhaustive conditions than would likely be realistic for in-service pipelines, several operators desired a still-more-comprehensive testing program to demonstrate the effectiveness of Allan Edwards sleeves. With numerous operators continuing to believe that the CFR 172 recognized only pre-tested pipe as legitimate welded split sleeves, Tommy knew that further action was needed by Allan Edwards before our sleeves were commonly accepted by all operators.

The Start of a New Joint-Industry Program (JIP)

At this point, Allan Edwards was just getting started on our validation testing journey. Conversations with Dr. Chris Alexander, PE, of ADV Integrity, eventually gave birth to a new round of full-scale testing. Building on the results of the DV-CIP, a similar but more expansive testing program was pitched to several operators. Ultimately, five operators joined ADV Integrity & Allan Edwards in executing this new Joint-Industry Program (JIP): Enable Midstream, TC Energy, Dominion Energy, Alyeska Pipeline & Southern Star.

We Went to Washington

Though PHMSA does not issue approval or advise pipeline companies on regulatory compliance, we knew their insight into this new JIP venture would be invaluable. Just before Thanksgiving in November 2017, Dr. Chris Alexander, PE & Tommy Precht flew to Washington, D.C., to meet with regulators and inform them about this new JIP program prior to its kickoff. As stated in our report, “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 [was] encouraged by regulators” *(Study to Evaluate Steel Sleeve Performance in Reinforcing Defects, 4).*

With a full roster of JIP participants and the encouragement of PHMSA regulators, we began our third full-scale testing program.

JIP STUDY TO EVALUATE SLEEVE PERFORMANCE IN REINFORCING DEFECTS

Similar to the DV-CIP, this study compared sleeve performance on dent features with and without filler material installed over the defect to see how they performed under the sleeve. However, there were some important distinctions in this testing program:

1. A 1/2-inch hole was drilled into each of the six sleeve samples to simulate Type B situation
2. Instead of only testing dent performance, this study observed sleeve performance with corrosion features as well

Objective

The primary objective of this testing program was to observe the performance of a steel repair sleeve when a thru-wall leak is present. The 1/2-inch hole drilled into the carrier pipe ensured that the Type B sleeve was immediately made pressure-containing. This enabled data to be collected while the sleeve was experiencing aggressive pressure cycling while in load-bearing conditions.

Procedure

- A total of six samples were tested: three with simulated corrosion & three with simulated dents

- Allan Edwards steel repair sleeves were installed on the pipe samples. These reinforced samples underwent an initial 50,000 pressure cycles to simulate pressure-containing conditions

- After this initial cycling, a small hole was drilled in the pipe sample to simulate a thru-wall leak. The sleeve was then sealed using a plugged thread-o-let. Finally, the samples were cycled until failure or 100,000 cycles

- The **corrosion samples** were 24-inch x 0.375-inch, Grade X65:

1. 24C-UR-1: This sample was unreinforced *(no sleeve, no filler material)*
2. 24C-AESS-3: This sample was reinforced *(installed Allan Edwards sleeve, no filler material)*
3. 24C-AESS-7: This sample was reinforced *(installed Allan Edwards sleeve with filler material)*

- The **dent samples** were 24-inch x 0.250-inch, Grade X52:

4. 24D-UR-4: This sample was unreinforced *(no sleeve, no filler material)*
5. 24D-AESS-6: This sample was reinforced *(installed Allan Edwards sleeve, no filler material)*
6. 24D-AESS-8: This sample was reinforced *(installed Allan Edwards sleeve with filler material)*

JIP STUDY TO EVALUATE SLEEVE PERFORMANCE IN REINFORCING DEFECTS

- Strain gauges were installed on all pipe samples

- Cycled pressure for Corrosion samples:
  - ΔP = 100 psi to 1,015 psi (50% SMYS) for 32,000 cycles
  - ΔP = 100 (5% SMYS) to 1,462 psi (72% SMYS) until failure

- Cycled pressure for Dent Samples:
  - ΔP = 100 psi to 780 psi (72% SMYS)

Results

Performance improved for both the corrosion samples and the dent samples with the application of filler material. **However, the corrosion sample saw the greatest improvement, gaining an additional 10,773 cycles before failure when a filler material was added, or a 58% increase in life expectancy.**

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 *(Study to Evaluate Steel Sleeve Performance in Reinforcing Defects, 3).*

An important takeaway from this testing program is that had there not been a 1/2 -inch thru-wall hole present on the samples, it is highly unlikely that a failure would have occurred before the 100,000-cycle run-out threshold. The reinforcement provided by the sleeve would have prevented leaks from developing in the corrosion and dent features *(Study to Evaluate Steel Sleeve Performance in Reinforcing Defects, 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)
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

JIP STUDY TO EVALUATE SLEEVE PERFORMANCE IN REINFORCING DEFECTS

Additional Testing: November 2021

Though both the corrosion & dent samples saw an improvement in performance after the application of filler material, we saw the minimal cycling improvement in dent sample's performance (an increase of 648 cycles) as **insufficient**. In November of 2021, after several improvements were made to the Allan Edwards in-house sleeve manufacturing process, a dent sample was re-tested according to the same criteria used during the JIP study. The sample was cycled until failure at 42,551 cycles. **Thanks to manufacturing improvements, the life expectancy of the sleeve installed with filler material over the dent increased by 40% when exposed to the same pressure cycling conditions as those benchmarked during the JIP.** This demonstrates that our sleeve fabrication process, while already more than satisfactory, had improved markedly in the three years since the conclusion of the Steel Sleeves JIP.

Insights & Conclusions

The primary conclusion from this study is that both the Allan Edwards sleeve samples were effective in reducing strain in both corrosion and dent features on pipelines. 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 (evidenced by the presence of the 1/2-inch thru-wall drilled hole) accelerated failure of the test samples *(Study to Evaluate Steel Sleeve Performance in Reinforcing Defects, 3).*

When a filler material was used in conjunction with a steel sleeve, performance improved significantly, by as much as 43% (in the # of cycles) for the dent samples and 50% for the corrosion samples (even with the presence of a 1/2-inch thru-wall hole!).

According to the results of this study, the design life in years of Allan Edwards Type B sleeves installed with filler material under typical *Light* cycling conditions (the standard pressure cycling conditions experienced by most transmission pipelines according to John Kiefner's Study) are 640 years and 851 years, respectively, for corrosion & dent features. Even without the presence of filler material, the adjusted *Light* cycling life cycles are an impressive 424 & 594 years for corrosion & dent features *(Study to Evaluate Steel Sleeve Performance in Reinforcing Defects, 3).*

BURST-TESTING OF A 24-INCH LEAKING PIPE

After concluding the sleeve validation JIP, Allan Edwards began to leverage these powerful test results to promote the reliability of our steel repair sleeves. Testing results were presented to several operators who had initially been skeptical of the capabilities of our repair sleeves. The JIP results demonstrated that our steel repair sleeves had met and exceeded the standards put for in **§ 192.717(b)(5) Transmission lines: Permanent repair of leak:**

> **(5)** Apply a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe

Because our engineering data validated our assertion that steel repair sleeves could be used to restore serviceability of a pipeline by indicating design lives of up to 851 years in *Light* cycling conditions – a standard of 10 pressure cycles annually when cycling at delta P = 72% SYMS as postulated by John Kiefner – we felt confident that we had not only complied with regulations but exceeded them by a considerable fatigue safety factor of 5.

One operator remained skeptical of the sleeve testing programs that had been done and suggested a supplemental testing program with one key difference: **instead of one dent and one 1/2inch thru-wall hole drilled into the pipe, the operator suggested a much more aggressive approach involving nine (9) 1/2-inch drilled holes spaced along the carrier pipe to ensure the entire repair was fully pressurized throughout the test. The holes were to be spaced according to the graph on the right:**

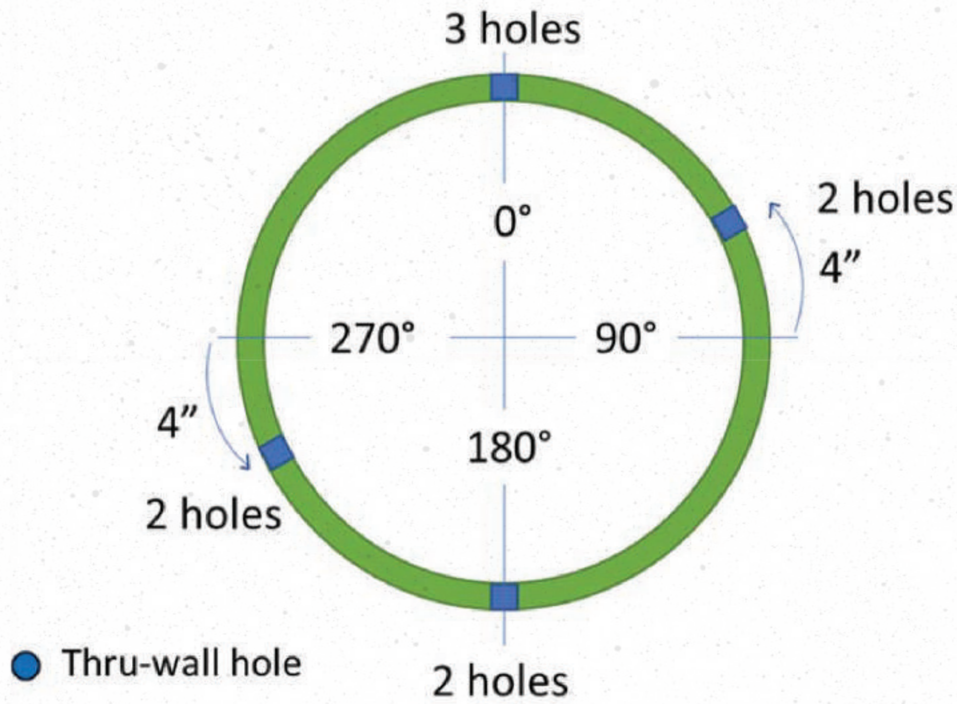

Figure 2: Locations of the nine (9) ½-inch thru-holes in carrier pipe

BURST-TESTING OF A 24-INCH LEAKING PIPE

Objective

Allan Edwards accepted the proposal from the operator and again partnered with ADV Integrity to design a testing program to fit the requested criteria: nine (9) 1/2 -inch thru-wall holes were drilled into the carrier pipe, and the samples were burst tested, rather than pressure cycled. The primary objective of this test as to evaluate whether sleeves manufactured by Allan Edwards could reinforce a leaking defect past the maximum allowable operating pressure of the carrier pipe with a considerable safety margin *(Burst Test of a 24-inch Leaking Pipe Repaired with a Type B Sleeve, 5).*

Procedure

Type B repair sleeve, 24-inch-long x 0.375-inch-thick ASTM A572 Grade 65 plate.

Thru-wall holes installed:

- Three (3) holes were installed at 0° (12 o-clock position)
- Two (2) holes at 180°
- Two (2) holes 4 inches above 90°
- Two (2) holes 4 inches below 270°

The seam welds for the Type B sleeve were installed at 90° and 270°.

Figure 1: Installation of ½-inch holes into carrier pipe

BURST-TESTING OF A 24-INCH LEAKING PIPE

ADV installed two (2) biaxial strain gauges on the carrier pipe and three (3) biaxial strain gauges the repair sleeve to monitor strains during testing:

- One (1) biaxial gauge on the carrier pipe 24 inches from sample center (center of sleeve)
- One (1) biaxial gauge on the carrier pipe 48 inches from sample center (center of sleeve)
- Three (3) biaxial gauges on repair sleeve at 0°, 180°, and 4 inches above the sleeve seam weld at 90° (positioned over the holes installed in the carrier pipe)

The sample was pressurized sample at approx. 10-15 psig/sec and perform the following 5-minute holds:

- 1,469 psig (72% SMYS) +/- 50 psig
- 2,041 psig (100% SMYS) +/- 50 psig

Results

The test sample failed at a pressure of 2,578 psig (126% SMYS).

The failure occurred in the seam weld of the Type B repair sleeve. The backing strip of the repair sleeve seam weld was pushed between the two sleeve halves.

Insights & Conclusions

This burst test successfully demonstrated that the Type B repair sleeve manufactured and supplied by Allan Edwards could reinforce a leaking defect past the maximum allowable design pressure of the carrier pipe with a considerable safety margin *(Burst Test of a 24-inch Leaking Pipe Repaired with a Type B Sleeve, 5).*

The failure occurred at 2,578 psig (126% SMYS), which exceed the maximum allowable operating pressure of 1,470 psig (72% SMYS) for this 24-inch OD x 0.375-inch WT, Grade X65 pipe by a factor of 1.75.

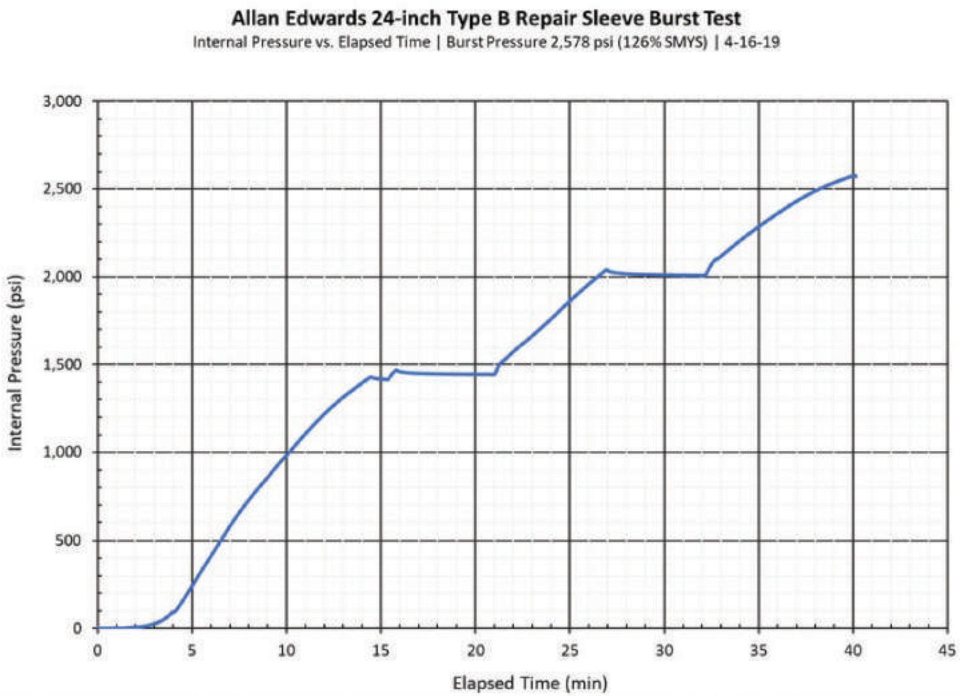

Figure 5: Internal pressure vs. elapsed time for 24-inch Type-B repair sleeve burst test

BURST-TESTING OF A 24-INCH LEAKING PIPE

Why Did the Failure Not Occur Outside the Repair Zone?

The carrier pipe used for this testing program, although also Grade 65, had a much higher yield strength than the repair sleeve being tested. The carrier pipe's yield strength of 84.2 ksi corresponded to a predicted yield pressure of 2,631 psig. In order for the failure to have occurred outside the repair sleeve, the sleeve for this carrier pipe would have had to be oversized in both wall thickness and material grade. The welding material would have also needed to be a higher-strength construct. However, this oversizing would have been unnecessary as the repair sleeve was designed to contain a leaking defect in a Grade X65 carrier pipe, which was successfully demonstrated in this test *(Burst Test of a 24-inch Leaking Pipe Repaired with a Type B Sleeve, 5).*

Having a higher-strength carrier pipe was advantageous from a testing standpoint as it allowed our sleeves to be pushed well beyond any pressure condition that would actually occur in service *(Burst Test of a 24-inch Leaking Pipe Repaired with a Type B Sleeve, 5).*

Figure 8: Close-up of burst test failure location – failure pressure of 2,578 psig (126% SMYS)

OFFICIAL STEEL SLEEVE CERTIFICATE OF QUALITY

Following the conclusion of the *Burst Test of a 24-inch Leaking Pipe Repaired with a Type B Sleeve* program, the operator requested that a certification document to be produced that summarized the implications of both *Study to Evaluate Steel Sleeve Performance in Reinforcing Defects* and *Burst Test of a 24-inch Leaking Pipe Repaired with a Type B Sleeve.* Dr. Chris Alexander, PE, of ADV Integrity, drafted and signed the document, which has since been used to further leverage the Allan Edwards commitment to quality. Every piece of manufactured sleeve that leaves our facilities today conforms to this criteria.

ALLAN EDWARDS

6468 N. Yale Ave. | Tulsa, Oklahoma 74117

Certificate of Quality

This document has been prepared to certify that Allan Edwards' manufactured steel sleeves meet the quality requirements set forth in their Quality Management System (November 2018). This includes adherence to policies and procedures associated with personnel / management, operational practices, production / manufacturing, material reporting and quality control, and documentation.

Additionally, Allan Edwards' manufactured steel sleeves have been subjected to rigorous full-scale testing involving the reinforcement of leaking corrosion and dent features subjected to cyclic pressure and burst pressure. The following reports were prepared by ADV Integrity, Inc. and can be referenced for specific details on these testing programs that validate the performance of Allan Edwards' manufactured steel sleeves.

- *Study to Evaluate Steel Sleeve Performance in Reinforcing Defects*, 12-inch NPS pipe samples, ADV Project Number AE-17-006, January 2019.
- *Burst Test of a 24-inch Leaking Pipe Repaired with a Type B Sleeve*, ADV Document No. 100101-RP01-Rev2-042219, April 2019. Respectively, the yield strength (YS) and ultimate tensile strength (for the pipe material were 84.2 ksi and 98.0 ksi; whereas the steel sleeve YS and UTS were 72.9 ksi and 84.3 ksi.

All testing was completed using 24-inch diameter pipe material. From a diameter qualification standpoint, having completed testing using 24-inch diameter pipe qualifies repairs on nominal pipe diameters ranging from 12 inches to 48 inches in accordance with the methodology in ASME PCC-2-2018, *Repair of Pressure Equipment and Piping*, Section 202-3.2.1.1, Part 2 Welded Repairs. This particular section of the code provides guidance for burst test procedures (Section 202-3.2: Burst Test Procedure), stating that an alternative to an engineered design approach is conducting burst testing using a mock-up design. In particular are the following conditions:

- Paragraph (b): *The specified minimum tensile strength of the item does not exceed that of the mock-up base material tested.*
- Paragraph (i): *The nominal diameter is not less than one-half or more than 2 times the diameter of the mock-up tested.*
- Paragraph (j): *The nominal thickness / diameter ratio (t/D), is not less than one-half or more than 3 times the t/D ratio tested.*

Based on the above references, the applicable range of performance standards for the Allan Edwards sleeves based on the completed testing programs is as follows:

- Steel sleeves with tensile strengths not exceeding 84.3 ksi (Paragraph 202-3-2-1-1(b)).
- Pipe diameters ranging from 6-inch to 48-inch NPS (Paragraph 202-3-2-1-1(i)).
- Nominal thickness / diameter (t/D) ratios ranging from 0.008 to 0.047, which corresponds to diameter to wall thickness ratios (D/t) from 21 to 128 (Paragraph 202-3-2-1-1(j)).

Allan Edwards IV — 9/9/2021

Allan J. Edwards, IV — Date
President, Allan Edwards, Inc.

Chris Alexander — August 31, 2021

Dr. Chris Alexander, PE — Date
President, ADV Integrity, Inc.

ADV INTEGRITY

STATE OF TEXAS — CHRISTOPHER R. ALEXANDER — 108453 — LICENSED PROFESSIONAL ENGINEER

STEEL SLEEVE FIT-UP TEST PROGRAM

This sleeve testing program began with a simple thought that occurred to Chip Edwards as he was driving home from work one day. Allan Edwards had always operated under the assumption that a tighter-fitting sleeve made for a higher-performing repair because of the compression applied to the carrier pipe and defect area. But at the end of the day, it was just an assumption until it was tested. Chip called Tommy Precht, and their conversation went something as follows:

Chip: "We always say that repair sleeves should be tight-fitting, right?"

Tommy: "Right"

Chip: "Well...why don't we prove it?"

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Just like that, a new testing program was born.

Objective

The study compared the performance of two samples. One was a tight-fitting steel repair sleeve designed to have maximum contact with the pipe, while the other was a loose-fitting repair sleeve. The sleeve classified as "loose" had an observable gap between the sleeve and pipe surface, while the "tight" sleeve maintained contact with at least 90% of the pipe's outside surface. Both samples had a 1/2-inch thru-hole drilled into the base pipe to simulate a live leak, forcing pressure into the annulus between the pipe and inside surface of the steel sleeve. The presence of these holes ensured that the entire repair sleeve was pressurized during the pressure cycle fatigue test *(Allan Edwards Steel Sleeve Fit-Up Test Program, 1).*

STEEL SLEEVE FIT-UP TEST PROGRAM

Procedure

Table 1: Sample Description

Sample ID	Pipe Size	Hole Size (in)	Sample Length	Sample Description
100160-24RT	24-inch x 0.25-inch, Grade X52	1/2	10-feet	Tight Fit
100160-24RLT	24-inch x 0.25-inch, Grade X52	1/2	10-feet	Loose Fit

RT: Reinforced Tight
RLT: Reinforced Loose

- Two (2) 24-inch OD x 0.25-inch WT, Grade X52 pipe samples
- ADV Integrity installed two (2) biaxial strain gauges on the assembly, which included:
  - One (1) biaxial gauge on the repair sleeve located 1 inch from seam weld (90°) in middle of the sleeve
  - One (1) biaxial gauge on the base pipe halfway between the end cap and the steel sleeve located 90° from the seam weld
- Pressure cycled the samples from 100 to 867 psig (9% to 80% SMYS)
  - Peak-peak pressure of 780 psig
  - Cycle to failure or runout (100,000 cycles)

Results

The "tight" repair sleeve survived 4,934 pressure cycles before a leak developed in the sleeve seam weld. The "loose" sleeve failed after only 1,382 pressure cycles when a similar leakage developed in the seam weld.

The tight sleeve (Allan Edwards standard installation) outperformed the loose fit sleeve by reaching 3,552 more pressure cycles (Allan Edwards Steel Sleeve Fit-Up Test Program, Summation Letter). This was a 257% productivity increase when measured in terms of cycles before failure.

Table 3: Results Summary

Sample ID	Sample Description	Cycles to Failure
100160-24RT	Tight Fit	4,934
100160-24RLT	Loose Fit	1,382

STEEL SLEEVE FIT-UP TEST PROGRAM

Insights & Conclusions

A major takeaway from this study was how much more quickly the loose-fitting repair sleeve begin to experience high stress levels. Hoop strain in the loose sleeve "spiked" much sooner than the increase in strain observed in the tight sleeve configuration. Almost immediately, the strain gauge on the loose sleeve began to show a noticeable increase in hoop strain, while the strain gauge located on the tight sleeve only began to show a notable increase in strain after 3,000 pressure cycles had been applied *(Allan Edwards Steel Sleeve Fit-Up Test Program, 5).*

Also notable is the much lower hoop strain levels present in the loose-fitting repair sleeve. From the beginning, the hoop strain in the loose sleeve was less than 50% of the levels in the tight-fitting sleeve before it began to rise exponentially. This indicated that the loose sleeve was not "picking up the load" as well as the tight-fitting sleeve and therefore not providing the same level of reinforcement (or restraint) as observed with the tight sleeve.

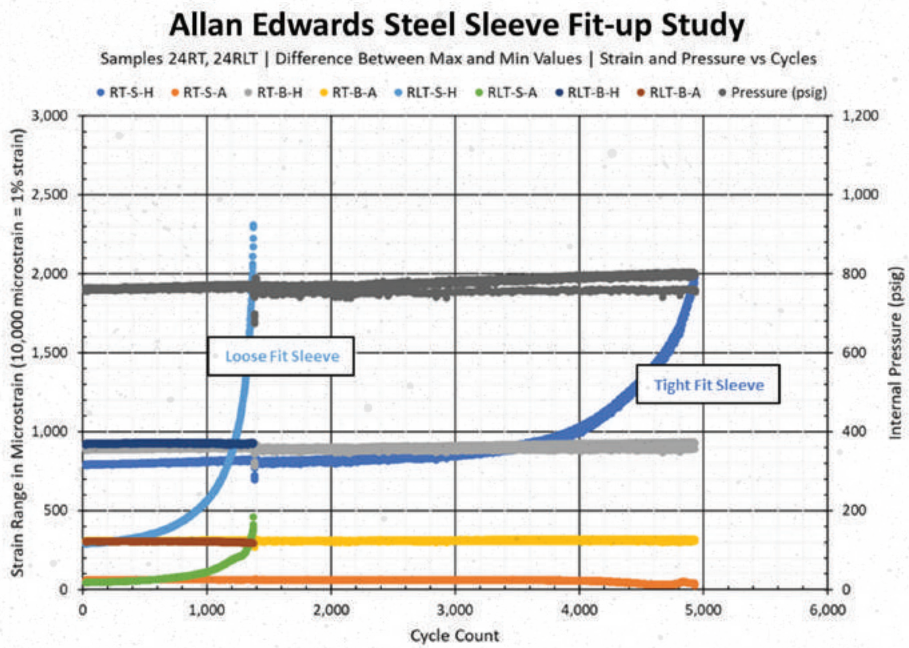


Figure 5: Strain and internal pressure vs. cycles for both Samples 24RT (tight) and 24RLT (loose)

As stated in our report, the goal with any reinforcing sleeve is to "pick-up" load as soon as possible after pressurization. The presence of a lag in load transfer results in higher stresses being generated in the carrier pipe *(Allan Edwards Steel Sleeve Fit-Up Test Program, 5).*

The Bottom Line: For sleeves to perform as intended, they must be tight to minimize stresses in the reinforced pipe and minimize stresses in the sleeve welds.

TESTING PROGRAM TO EVALUATE THE INFLUENCE OF A BACKING STRIP MILL GROOVE ON INTEGRITY OF TYPE B SLEEVE

Mill grooves are commonly installed on repair sleeves to enable the backing strip to sit flush against the sleeve. This allows for tighter contact between the sleeve and the pipe. As demonstrated in our previous study, *Allan Edwards Steel Fit-Up Test Program,* a tighter sleeve-to-pipe fit-up significantly increases the life of the sleeve and optimizes overall performance. Furthermore, by "notching" the inside of the sleeve along the long seam to allow the backing strip to slide in behind the milled area, the backing strip is prevented from shifting during sleeve fit-up, reducing or eliminating the risk of welding directly to the carrier pipe.

While mill grooves are a common practice and provide many benefits, they do locally reduce the sleeve wall thickness along the length of the sleeves long seam compared to a non-mill-grooved sleeve, raising questions about their effect on the long-term integrity of the sleeve. Prior to this testing program, no testing had been conducted to examine any lasting effects a mill groove may have on the long-term integrity of a sleeve *(Testing Program to Evaluate the Influence of a Backing Strip Mill Groove on Integrity of Type B Sleeve, 2).*

We decided to change that.

Objective

The program was designed to apply maximum stress at the sleeve long seam weld by placing a carrier pipe dent directly behind the sleeve long seam weld. Although this configuration is not typical of field installations, it applied the greatest amount of stress to the sleeve long seam weld. Two samples were tested: one with a mill groove, one without. Dents on both samples were reinforced with a hardenable filler material *(Testing Program to Evaluate the Influence of a Backing Strip Mill Groove on Integrity of Type B Sleeve, 2).*

TESTING PROGRAM TO EVALUATE THE INFLUENCE OF A BACKING STRIP MILL GROOVE ON INTEGRITY OF TYPE B SLEEVE

Procedure

- Two (2) 12.75-in OD samples
  - One with a mill groove and one without
  - Hardenable filler material installed in the dent
- Both samples were pressure cycled from 132-psig (8% SMYS) to 1318-psig (80% SMYS) until failure or 100,000 cycles

We projected that early failure of the sleeve during pressure cycling would occur in the event the mill groove influenced the long-term integrity of the sleeve.

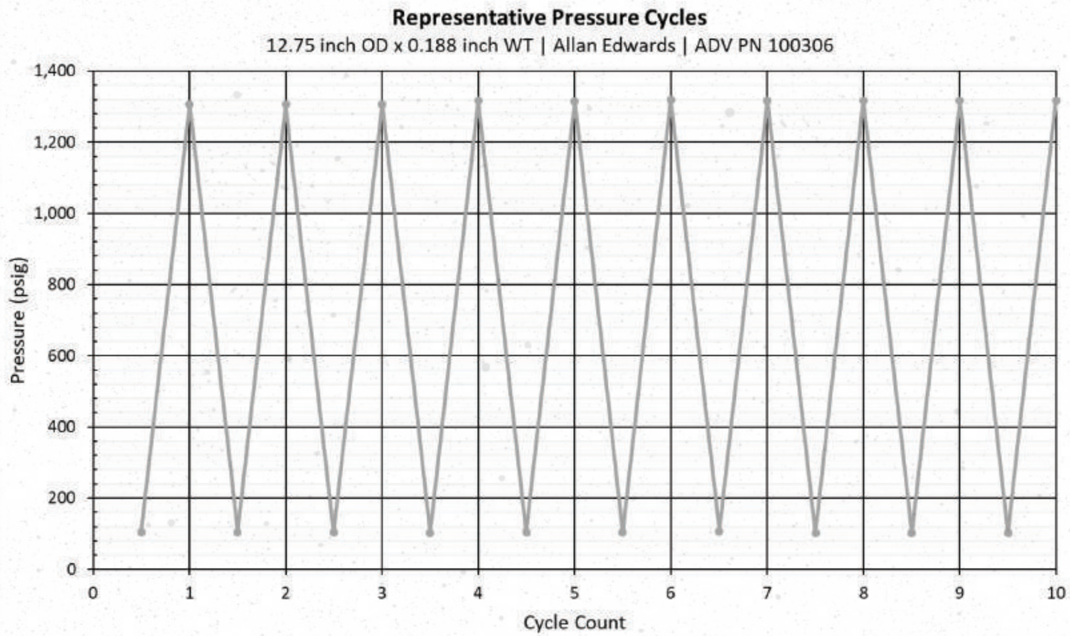


Figure 3-6: Ten (10) Pressure Cycles for the 12” AE Type B Reinforced Samples

Results

Both samples hit the runout condition of 100,000 cycles without failure.

Therefore, the mill groove did not influence the long-term cyclic integrity of the sleeve (at least to 100,000 cycles between 10 and 72% SMYS).

This 100,000-cycle threshold was chosen based on the Kiefner Study Industry Survey for pressure cycling regimes.

TESTING PROGRAM TO EVALUATE THE INFLUENCE OF A BACKING STRIP MILL GROOVE ON INTEGRITY OF TYPE B SLEEVE

Insights & Conclusions

The mill grooves greatly benefited the fit-up between the sleeve and the pipe and did not hinder the sleeve's integrity throughout the test.

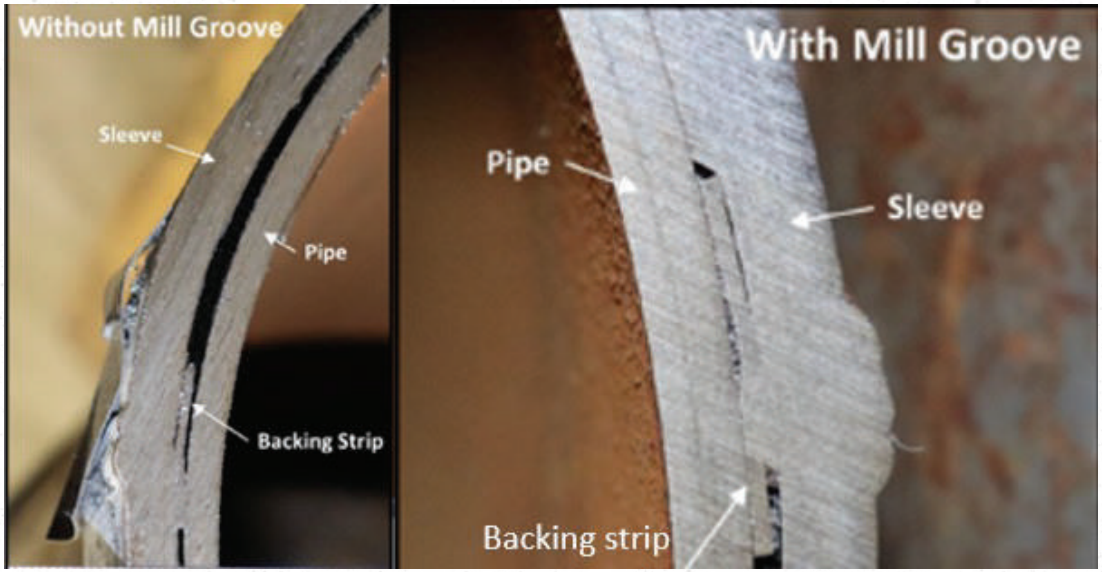
The mill groove provided relief for the approximately 1/16-inch-thick backing strip, resulting in a tighter fit.

The gap generated due to the backing strip in the non-mill groove sample resulted in a looser fit-up. The effect of sleeve fit-up was examined in a previous study performed at ADV Integrity and funded by Allan Edwards, *Allan Edwards Steel Fit-Up Test Program.*

This study found that a looser fitting sleeve resulted in an expected life 3.5 times shorter than a tighter fitting sleeve once the annulus is pressurized.

This result only occurs when the annulus becomes pressurized, so if the underlying feature remains stable, this effect does not come into consideration *(Testing Program to Evaluate the Influence of a Backing Strip Mill Groove on Integrity of Type B Sleeve, 10).*

Because the installed mill groove locally reduces the wall thickness along the length of the sleeve, it seems reasonable to account for and consider the reduction in wall thickness when specifying the sleeve wall thickness to ensure full pressure capacity either to the pipeline's maximum operating pressure or full pressure capacity based on the nominal carrier pipe properties. However, as noted in this study, a reduction in wall thickness did not result in decreased performance for the testing samples with the mill groove *(Testing Program to Evaluate the Influence of a Backing Strip Mill Groove on Integrity of Type B Sleeve, 10).*



BAUSCHINGER EFFECT: TENSILE TESTING OF ROLLED SLEEVE

Objective

The purpose of this testing program was to evaluate the extent, if any, that plastic deformation reduces the strength of a manufactured steel sleeve. In certain cases, operators may be hesitant to use manufactured sleeves because of suspected structural weakening attributable to the Bauschinger Effect. Steel utilized by Allan Edwards for repair sleeves is initially formed as a hot-rolled coil and is flattened out prior to sale. Allan Edwards purchases this flat plate and "rolls" it to form a manufactured repair sleeve. The Bauschinger Effect states that, "plastic deformation of a polycrystalline metal, caused by stress applied in one direction, reduces the yield strength when stress is applied in the opposite direction" *(Tensile Testing of Rolled Sleeve, 1).* The primary concern is that stresses across the steel wall thickness could result in slight reductions of the yield strength, impacting the sleeve's calculated pressure capacity.

Procedure

Allan Edwards contacted ADV Integrity to draft a report that interpreted data findings from a series of tensile tests performed by Element Materials Technology, a lab testing company contracted by Allan Edwards.

Tensile testing involved a 6-5/8-inch internal diameter pipe (tight fit to a 6-5/8-inch outer diameter pipe), ASTM A572, Grade 50, with a nominal wall thickness of 0.375 inch in the following conditions:

- Material test report (MTR) data showing the yield and tensile strength
- Longitudinal and transverse tensile tests of the flat plate *before rolling into sleeves*
- Longitudinal and transverse round bar *tensile tests of rolled sleeves.* The use of round bar eliminated the need to re-flatten the tensile strap
- Longitudinal and transverse *flattened tensile tests of the rolled sleeves*

To summarize, the plate was:

1. Tensile tested when it was flat
2. Tested again after it had been rolled into a sleeve
3. Tested a third time after it had been re-flattened

BAUSCHINGER EFFECT: TENSILE TESTING OF ROLLED SLEEVE

Results

Fairly consistent yield and tensile strengths were measured across the various test configurations, likely within the scatter expected for a typical tensile test of rolled carbon steel material.

Notable Findings

1. There was a *decrease in yield strength* from the MTR to the flat plate material as the MTR was likely measured pre-coiling
2. There was an *increase in yield strength* from the flat plate to the as-rolled sleeve (round bar) likely due to strain hardening and cold working
3. There was a *decrease in yield strength* from the as-rolled sleeve (round bar) to the flattened strap potentially due to strain softening

Insights & Conclusions

Results were not highly significant to the point where definitive conclusions could be drawn. **However, it seems reasonable to slightly over-specify material used for steel sleeves to account for the Bauschinger Effect.** A yield strength margin of 5% (the percentage difference in yield strength from the as-rolled sleeve to the MTR of the same heat) would account for any possible strength reduction after sleeve rolling. If a Grade 50 material is required, consider specifying the SMYS of Grade 50 + 5%, or a yield strength of 52,500 psi (50,000 psi x 1.05 = 52,500 psi) on the MTR chosen for rolling *(Tensile Testing of Rolled Sleeve, 2).*

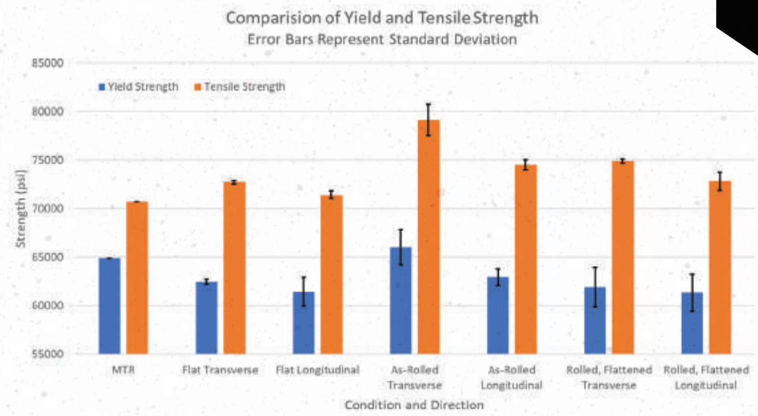


Figure 1: Comparison of Yield and Tensile Strength

Table 1: Comparison of Measured Yield Strength Values

Specimen Location	Direction	Yield Strength (psi)	% Difference, Minimum Yield Strength (psi)	Average Yield Strength (psi)	% Difference, Average Yield Strength (psi)
Coil MTR Heat A012022	Transverse	64,900	N/A	64,900	N/A
Flat	Transverse	62,200			
Flat	Transverse	62,700	-4.16	62,433	-3.80
Flat	Transverse	62,400			
Flat	Longitudinal	60,000			
Flat	Longitudinal	62,900	-7.55	61,433	-5.34
Flat	Longitudinal	61,400			
As Rolled	Transverse	68,000			
As Rolled	Transverse	64,500	-0.62	66,000	+1.69
As Rolled	Transverse	65,500			
As Rolled	Longitudinal	62,000			
As Rolled	Longitudinal	63,200	-4.47	62,933	-3.03
As Rolled	Longitudinal	63,600			
Rolled, Re-flattened	Transverse	60,000			
Rolled, Re-flattened	Transverse	61,700	-7.55	61,900	-4.62
Rolled, Re-flattened	Transverse	64,000			
Rolled, Re-flattened	Longitudinal	59,400			
Rolled, Re-flattened	Longitudinal	61,300	-8.47	61,333	-5.50
Rolled, Re-flattened	Longitudinal	63,300			

OPTIMIZED STEEL SLEEVE MANUFACTURING SPECIFICATION

In 2021, Allan Edwards further elevated our manufacturing specification for steel repair sleeves so that every sleeve conformed to the highest quality expectations. Many operators differ significantly on specified standards when ordering manufactured sleeves, with some having much more stringent requirements than others. Historically, Allan Edwards has accommodated both ends of the spectrum, but these varying requirements often limited the sleeve inventory that could be used for certain customers. Rather than continuing to segregate by customer, we decided to elevate all sleeves manufactured by Allan Edwards to a single top-tier specification, ensuring any sleeve could be made available to any customer at any time, regardless of their stated requirements.

Through a combination of enhanced inspection instruments, seamless traceability, stringent Carbon Equivalent (CE) requirements & overall process refinement, we were able to achieve this significant milestone to ensure every Allan Edwards sleeve exceeds the highest compliance standards.

Carbon Equivalent Requirement Formula

a) For Steel with C > 0.12%:

$$CEiiw = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

b) For steel with C ≤ 0.12%:

$$CEpcm = C + \frac{Si}{30} + \frac{(Mn + Cu + Cr)}{30} + \frac{Mo}{15} + \frac{Ni}{60} + \frac{V}{10} + 5B$$

Ultrasonic Testing (UT)

Notably among the manufacturing spec enhancements was 100% Ultrasonic Testing. This enabled us to detect any potential anomalies in our steel plate with pinpoint precision prior to sleeve rolling.

What Is UT?

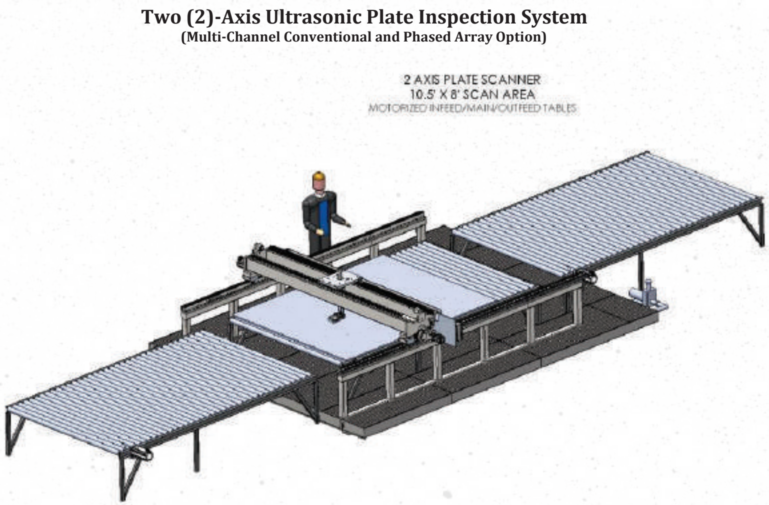
According to the ASTM specification, UT is an examination method for repair sleeves that “detect[s] internal discontinuities parallel to the rolled surfaces.” The entirety of the plate surface is scanned and evaluated for any potential disqualifying anomaly in its composition.

7. Acceptance Standard—Level A

7.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane (within 5 % of plate thickness) that cannot be encompassed within a circle whose diameter is 3 in. [75 mm] or 1⁄2 of the plate thickness, whichever is greater, is unacceptable *(ASTM A578)*.

What Is Reported?

- All recordable indications listed in Section 6 of A 578/A 578M- 07
- A sketch of the plate with sufficient data to relate the geometry and identity of the sketch to those of the plate
- Test parameters including:
  - Make and model of instrument
  - Test frequency
  - Surface condition
  - Transducer (type and frequency) and couplant.
- Date of test



Allan Edwards Ultrasonic Testing Machine

How Are We Different?

While Conventional UT is a common steel plate validation method, most UT inspection on steel plate for repair sleeves *only scans around the longitudinal edges of a plate, penetrating roughly nine (9) inches inward from the edge*.

Our UT machine uses Phased-Array to scan 100% of the surface of the steel plate with a 10% scan overlap to catch any harder-to-scan areas of the plate for maximum accuracy.

A full UT report is included with the MTRs on all repair sleeves manufactured and sold by Allan Edwards.

WHERE TO NOW?

Through exhaustive testing, Allan Edwards sleeves have been repeatedly stretched beyond their limits and evaluated across a wide range of cycling conditions experienced by in-service pipelines today. This testing has validated our repair sleeves as an effective permanent repair option for transmission pipelines and provides a baseline comparison for operators that no other sleeve manufacturer can match. We've invested in these extensive testing programs not only for our own peace of mind, but most importantly, for yours. In such a high-stakes industry as ours, you can't afford to second-guess a faulty repair. Thanks to our testing, now you'll never have to.

Have a Testing Idea?

We're always ready to consider new ideas and proposals. If you see a testing gap that we can fill, let us know!

Get In Touch!

SCAN ME

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Visit Our Website: allanedwards.com

ANNIVERSARY 1947 75 YEARS 2022 CELEBRATION