Fill Your Void – Sleeve Life Extension with a Filled Annulus Space

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Abstract

Type B sleeves are a proven repair technique and are typically installed tight fitting with the ends fully welded. The sleeves are configured in a way to allow for load sharing from the carrier pipe to the sleeve and provide pressure containment when/if the underlying carrier pipe leaks. Once a leak occurs, the annulus space becomes pressurized which increases the stress on the side seams and fillet welds. Prior research has shown a resulting finite life of the sleeve as those welds can leak after some period based upon cyclic internal pressure loading and weld quality.

The use of filler material applied to the carrier pipe prior to applying the Type B sleeve is a common practice to increase load transfer, however, not required by any code and standard as the sleeve is pressure containing. While seemingly straightforward, the inconsistent application of filler material could result in unexpected results. This study examined and attempted to standardize the application of filler material, both locally applied and when the annulus space is pumped using a commercially available grout material.

The test program consisted of the repair of longitudinal seam weld features repaired by various sleeve configurations. These configurations included one installed without fill, with a locally applied fill, and a grouted annulus space. Each sample was repaired and cycled (until runout of 100,000 cycles). The grouted sample was the only to achieve runout reaching 100,000 cycles, 20x more cycles than any other sample. Metallurgical examination confirmed little, if any, growth occurred after repair, indicating the most advantageous load transfer and repair life.

Introduction

This study examines the optimal instillation method for Type B sleeves to provide more efficient and uniform load transfer. Type B sleeves are typically installed tight fitting with the ends fully welded, shown schematically in Figure 1. The sleeves are configured in a way to allow for load sharing from the carrier pipe to the sleeve and provides pressure containment when/if the underlying carrier pipe leaks. Once a leak occurs, the annulus space becomes pressurized which increases the stress on the side seams and fillet welds. This results in a finite life of the sleeve as those welds can leak after some period based upon cyclic internal pressure loading and weld quality. Based on this finite life, there's benefit to an optimized Type B sleeve install to minimize the likelihood (and increase time) to a leak occurring where failure of the underlying carrier pipe feature results in a pressurized annulus space. Conceptually, any repair system including steel sleeves require load sharing to prevent the underlying feature from growing and eventually failing. This can be accomplished in several ways:

- Nearly perfect interference fit between the internal steel sleeve surface and external carrier pipe surface.

  This route is ideal; however, out-of-roundness (ovality) and out-of-straightness of the carrier pipe and sleeve, create a scenario where some portions of the repair area are not ideally reinforced, especially for longer sleeves.

- The use of filler material to create a more advantageous load transfer locally where the feature is present.

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This route is common for deformation features and required for a Type A steel sleeve (non-pressure containing); however, filler material is not required for a Type B steel sleeve. While seemingly straightforward, applying the filler material in a consistent manner may be difficult as no industry standard or guidance exists.

- The use of filler material to create a more advantageous load transfer throughout the entire annulus space.

  This route is ideal as 100% load transfer would be achieved; however, this is not common field practice. This configuration would utilize two short tight-fitting sleeves bridged by a longer oversized sleeve. This creates an annulus space the thickness of the tight-fitting sleeve (commonly 3/8-inch thick). This configuration is schematically shown in Figure 2.

The use of a locally filled sleeve or completely filled annulus space could provide advantages in load transfer; however, neither are common industry practice. This study aims to further investigate the advantages of applied fill using a two-phased study:

Phase 1: Bench-top study with the goal of validating the appropriate amount of filler, a consistent approach to locally apply the filler material, and the appropriate grouting material.

Phase 2: Full-scale testing study with the goal of validating fatigue performance of the reinforced carrier pipe and steel sleeve.

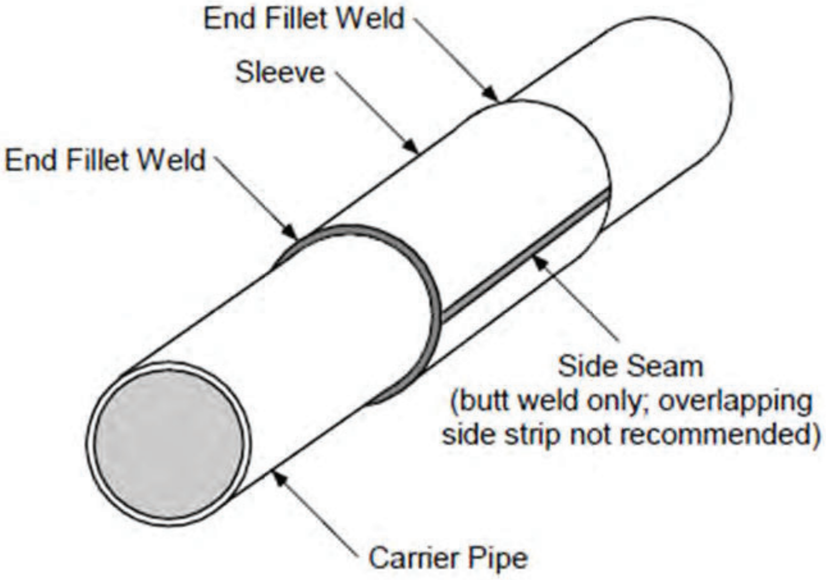

Figure 1. Schematic of Type B Sleeve (PRCI Repair Manual).

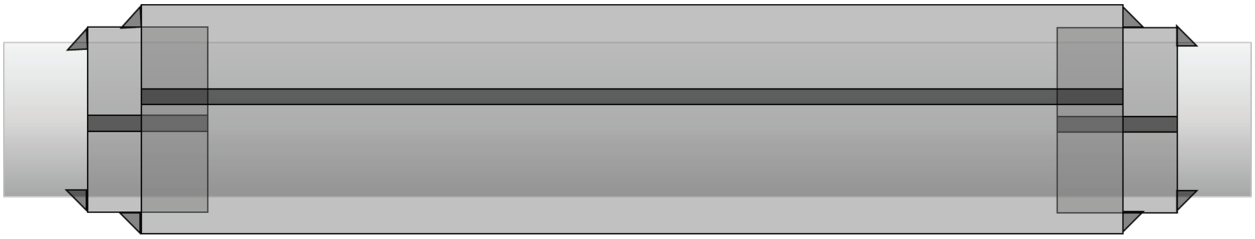

Figure 2. Schematic of intentional annulus space Type B Sleeve.

Bench Top Study

A bench-top study was performed to investigate several aspects of steel sleeve installation and design. A bench-top study was chosen to investigate different fillers/grouts and installation methods in a cost-effective manner rather than performing more cost-intensive full-scale tests. Two main topics were examined during the bench-top study and discussed in the sections below:

1. Developing a repeatable process for the application of filler material locally on the outside of the carrier pipe immediately prior to the installation of the Type B sleeve.

2. Determine an appropriate method for the application of a flowable grout when using a sleeve designed with an intentional annulus space (such as that shown in Figure 2).

Process for the Application of Local Fill

As discussed earlier, any repair method benefits from a tight interference fit as it allows for the offloading and sharing of load from the carrier pipe to the sleeve. The use of filler material can assist in this fit-up; however, it’s ineffective to apply filler material to the full repair length especially when the feature being repaired is localized, such as a crack. Application of filler across the entire internal sleeve surface is feasible, but excessive filler would interfere with the longitudinal seam weld when clamped to the pipe or result in poor fit-up at the sleeve ends. Therefore, there remains a need for a defined process for filler material application.

To develop this process, a series of mock-up tests were performed using a short section of nominal 12-inch OD pipe with corresponding tight fitting steel sleeve. Various amounts of filler material were applied to the outside of the carrier pipe followed by steel sleeve fit-up and clamping. Two application methods were examined: 1) hand applied and 2) tool applied. The sleeve was removed once cured (at least 48-hours) to examine the effectiveness of the filler application.

Hand applied methods were examined first. This included three scenarios:

- 2-inch diameter circle, ~1/4 inch thick
- 2-inch diameter circle, ~1/2 inch thick
- 4-inch diameter circle, ~1/4 inch thick

A quarter-inch thick region of filler material was the thinnest realistically obtainable when mixing and applying by hand. Photographs of the filler material before and after installation of the sleeve is shown in Figure 3. ADV concluded the following after removing the sleeve:

- Hand applied filler material was largely inconsistent, especially when covering larger areas.

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- Filler material acted in an inconsistent river bottom-like appearance when unable to evenly seep during sleeve fit-up and clamping.
- There remains a need for a tool to aid in consistent application.
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Based on the limited data above, it was determined that too large of volume would impact the performance of the filler material and its ability to flow evenly when the sleeve was installed. Therefore, the use of a filler material applied in a long length and short circumferential distance would be most beneficial for linear features. A machined squeegee was designed to accomplish this by forming a half-moon shape fit for the specific pipe diameter with two recesses of 1/16-inch and 1/8-inch. These recesses were chosen as API 5L out-of-roundness limits are ~1% (dependent on pipe diameter) which results in a gap of approximately 1/16-inch for a tight tolerance sleeve and smaller diameter pipe. A 2D rendering of the squeegee utilized for the nominal 12-inch OD pipe in this study is shown in Figure 4.

Photographs showing the application of filler using the squeegee is shown in Figure 5. The squeegee applied a uniform layer of filler material in a repeatable manner. Photographs of the cured filler material are shown in Figure 6. It was determined that the 1/8-inch squeegee gap provides sufficient "bonding" to sleeve material while remaining thin enough to not seep in a river bottom-like appearance.

Regardless of the method of filler material application, the sleeve should be clamped and ready for welding while the filler material is still pliable. This is dependent on the ambient temperature; however, will likely be within 15 minutes in common environmental conditions. Keeping the sleeve long seam weld approximately 90-degrees from the applied filler material will also reduce the chance of extruding filler into the weld bevel and reduce flammability concerns. Locating the sleeve 90-degrees from the filler material is also dependent on the welder's ability to weld at the orientation requested.

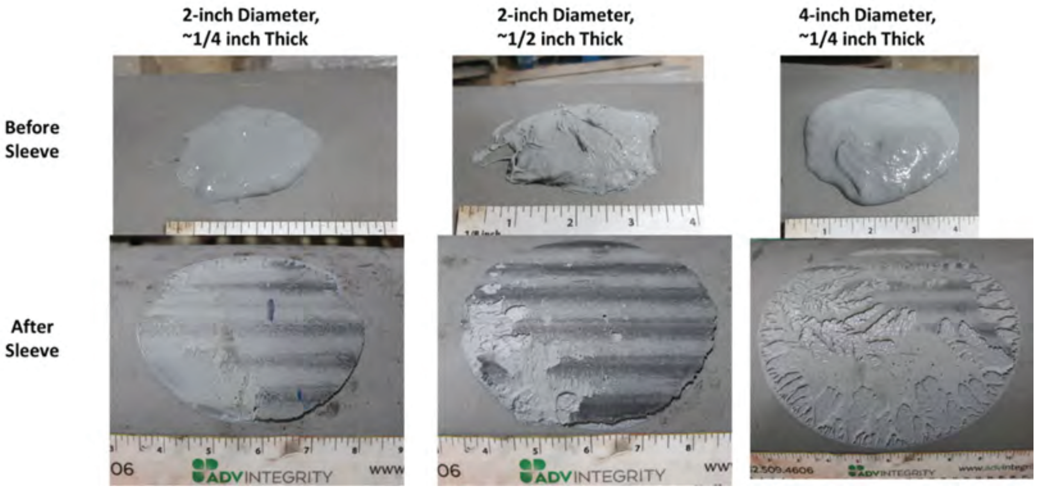

Figure 3. Photographs of filler material before and after installing the sleeve.

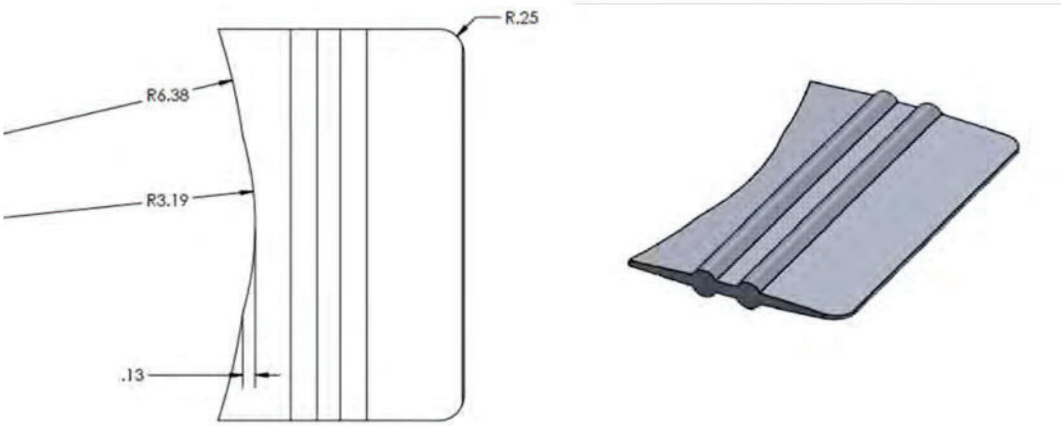

Figure 4. Computer drawing of contoured squeegee for applying filler material.

Figure 5. Photograph during squeegee applied filler material.

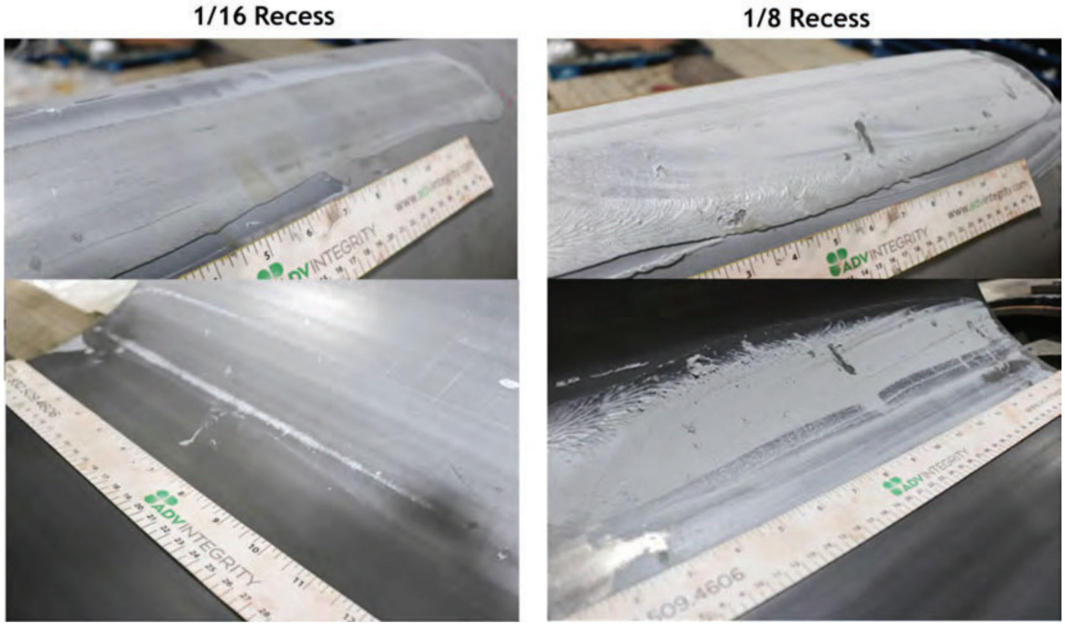

Figure 6. Photograph of filler material after removing the sleeve. Top photos are external surface of the pipe. Bottom photos are internal surface of the sleeve.

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Process for the Application of a Flowable Fill

The second step of the bench-top study were a series of mock-ups to determine an appropriate method for the application of a flowable grout when using a sleeve designed with an intentional annulus space (such as that shown in Figure 2). As discussed earlier, this design is different than what is typically done in the field. A common practice would be to install a tight-fitting sleeve (typically in lengths of 10 feet) and then joined to adjacent tight-fitting sleeves via an oversized sleeve (commonly referred to as a wedding band). This configuration would require short tight-fitting sections installed and then bridged together by a long, oversized sleeve. The annulus space is then filled allowing for more uniform load transfer from the pipe to the sleeve.

Two sample geometries were used during this portion of the study. The first was as described above with an intentional annulus space. The second had a typical field installed sleeve (10-foot tight fitting sleeve). These geometries are schematically shown in Figure 7 and Figure 8, respectively. Five Star Fluid Grout 100 was selected as the filler material due to its cost, ease of use, and application using a hand pump rather than machinery. This is described as a cement-based, nonmetallic, non-shrink fluid grout manufactured by Five Star Products, Inc. designed for supporting machinery and equipment.

The filler was applied using a large funnel and diaphragm pump connected to the sleeve ports with a non-metallic hose. Multiple check points (o-lets) were installed on the outside of the sleeve to monitor the progression of the filler material. General observations during the application of both are described below:

- Took approximately 5 minutes to fill entire loose fitting sleeve
- Took approximately 15 minutes to fill tight fitting sleeve (grout exited wedding band outlet, not other o-lets)
- Easy to handle, mix, pump, and dispose
- Relatively inexpensive (3 sacks to fill the 10 foot annulus space cost approximately $100)

Most importantly it has the ability to fill annulus spaces, even those associated with a tight-fitting sleeve. ADV further examined the mock-up test samples by saw cutting across the sleeve. Photographs showing the tight and intentional annulus space sleeve filled with Five Star Fluid Grout are shown in Figure 9. All the cuts across the Five Star Fluid Grout samples appeared to contain a uniform layer of filler material. Uniformity of the filler material allows for more effective load transfer.

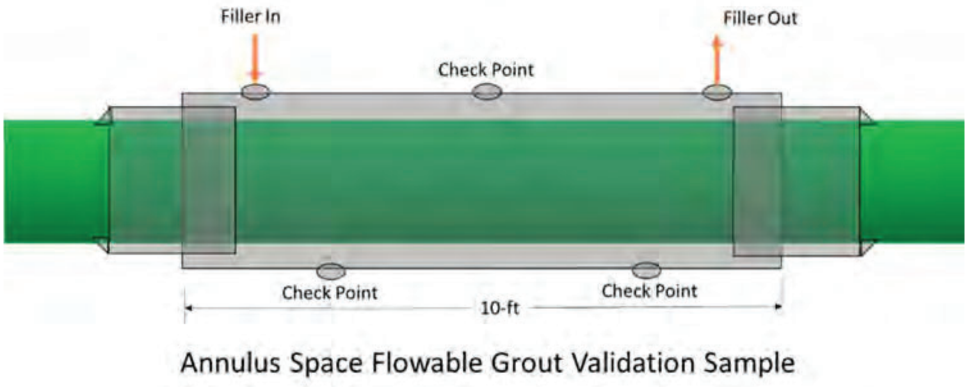

Figure 7. Schematic of intentional annulus space mock-up sample.

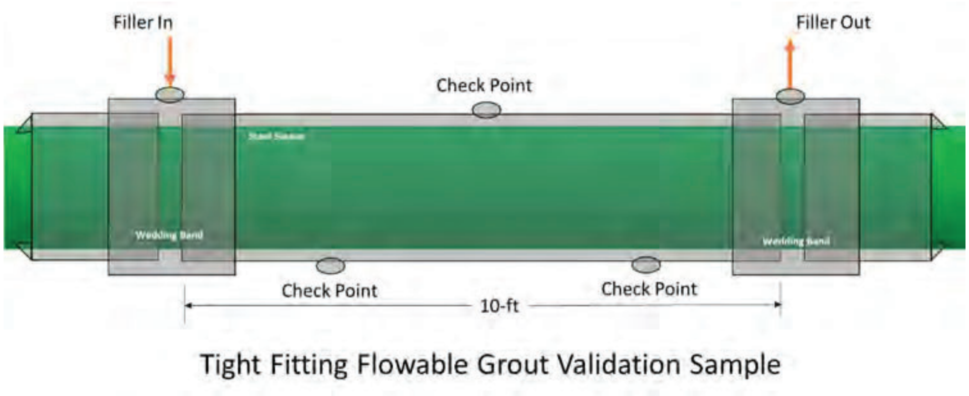

Figure 8. Schematic of tight-fitting annulus space sample.

Figure 9. Resultant Five Star Fluid Grout 100 fill.

Full-Scale Testing

The full-scale testing program goals were to:

1. Determine the effectiveness of filler material when repairing crack-like features in preventing feature growth resulting in the pressurization of the sleeve's annulus space (on both modern and vintage pipe material).
2. Determine the fatigue life of the sleeves once the annulus space is pressurized.
3. Evaluate the fatigue life of Type B longitudinal seam welds with backing strips and circumferential sleeve fillet welds.

Full-scale testing was performed with the following bounds/conditions:

- The full-scale testing program included vintage and modern pipe material, summarized in Table 1. Modern pipe was included in the test program to validate that any trends were consistent across expected pipe toughness.
- All samples contained EDM notches that were precycled to generation a crack at the base of the EDM notch. The precycling targeted a 50% deep starting crack coinciding with the ERW bondline. The crack was oriented 45-degrees from the steel sleeve long seam weld for the repaired samples.

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- Both pipe types (vintage and modern) included unreinforced and reinforced pipe samples. Samples also varied the type and amount of filler material applied. Sample geometries and sample details are summarized in Table 2 and schematically shown in Figure 10 through Figure 12. Comparing the results of each sample highlighted the benefit of a Type B steel sleeve, locally applied filler, and grouted annulus space.
- Steel sleeves were nominal 0.375-inch WT, ASTM A572 Grade 50. Sleeves were installed using chain clamps and welded using SMAW E7018 electrodes.
- Once repaired, all samples were pressure cycled between 148 psig and 1,477 psig. This resulted in 8% SMYS to 80% SMYS pressure range for the vintage 14-inch OD pipe, and 7% SMYS to 72% SMYS pressure range for the modern 12-inch OD pipe.
- Once the carrier pipe crack leaked into the annulus space, each sleeve was capped and the cycle test continued to examine the fatigue life of a pressurized steel sleeve.

Table 1. Summary of Pipe Material

Phase	Outer Diameter (in)	Wall Thickness (in)	Grade	Seam Type
Modern	12.75	0.250	X52	HF-ERW
Vintage	14	0.281	X46	LF-ERW

Table 2. Summary of Full-Scale Test Samples

#	Pipe	Configuration	Sample
12-1	12.75-inch OD Modern Pipe	Unreinforced	3-inch long 50% EDM notch
12-2		Reinforced	3-inch long 50% EDM notch repaired with a Type B sleeve and locally applied filler material per the optimized procedure determined via bench-top study
14-1	14-inch OD Vintage Material	Unreinforced	3-inch long 50% EDM notch
14-2		Reinforced	3-inch long 50% EDM notch repaired with a Type B sleeve (no filler)
14-3			3-inch long 50% EDM notch repaired with a Type B sleeve and locally applied filler material per the optimized procedure determined via bench-top study
14-4			3-inch long 50% EDM notch repaired with an extended length Type B sleeve and injected with flowable grout (Five Star Fluid Grout)

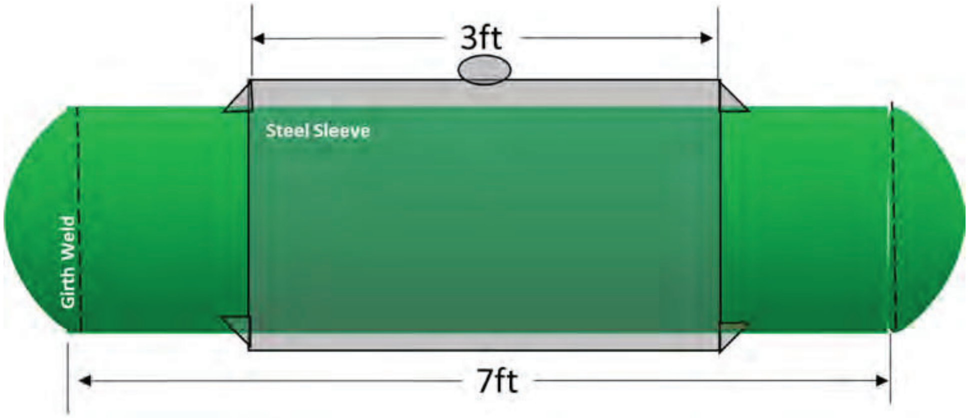

Figure 10. Schematic of sample without filler material.

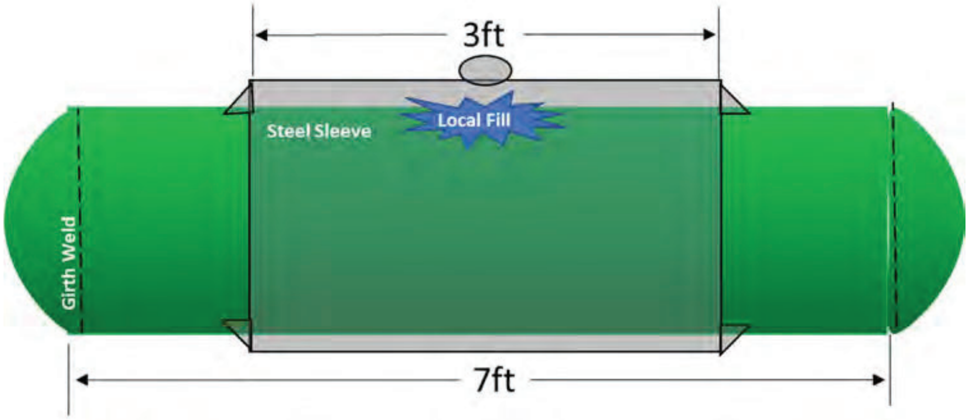

Figure 11. Schematic of sample with local filler material.

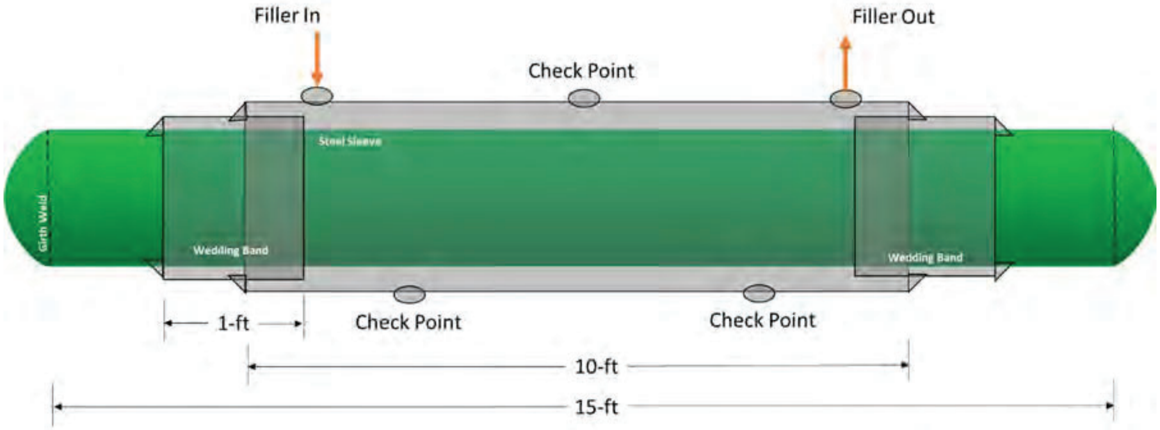

Figure 12. Schematic of intentional annulus space sample.

Full-Scale Testing Results

Testing was completed over a several month period at ADV's facility. Samples are referenced through this section as they are defined in Table 2. Cycling was conducted with pressures corresponding to 8% to 80% SMYS based on the nominal 14-inch OD vintage pipe material. Cycling of the repaired samples occurred in two stages. In the first stage, the samples were pressure cycled until the repaired crack-like feature went thru-wall. Once the feature was thru-wall, the annulus was capped allowing pressurization of the sleeve.

Table 3 summarizes the number of cycles to failure for each sample (both in the carrier pipe and sleeve). Note that Sample 14-4 achieved runout of 100,000 cycles without carrier pipe failure. Following the runout of 100,000 cycles, ADV drilled a hole through the carrier pipe allowing pressurization of the sleeve and testing continued. The sleeve failure location is summarized in Table 4.

The "Number of Cycles at Sleeve Failure" in Table 3 are the total number of cycles experienced by the sample in the test program. A sleeve fatigue life is also presented in Table 3 as the difference between the carrier pipe failure and the sleeve failure (i.e., sleeve fatigue life). Finally, a repair life

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extension is presented as the difference between each repaired sample and the corresponding unreinforced sample (either vintage or modern).

It should be noted that the carrier pipe leaked on Sample 14-2 (reinforced with no fill) at a cycle count lower than the unreinforced (36 vs. 952 cycles, respectively). This is likely due to local variations in the ERW seam weld properties/cleanliness, which will be further examined via metallurgical examination below.

Table 3. Summary of Full-Scale Test Results

Sample ID	Description	# of Cycles at Carrier Pipe Failure	# of Cycles at Sleeve Failure	Sleeve Fatigue Life	Repair Life Extension
12-1	Unreinforced	1,775	N/A		
12-2	Reinforced Local Fill	4,363	16,264	11,901	2,588 (2.5x)
14-1	Unreinforced	952	N/A		
14-2	Reinforced No Fill	36	1,657	1,621	-916
14-3	Reinforced Local Fill	4,712	21,580	16,868	3,760 (4.9x)
14-4	Reinforced Flowable Fill (5 Star)	100,000 (runout)	103,771	3,771	>99,048 (>105x)

Table 4. Summary of Failure Location

Sample	Sleeve Failure Location
12-2	Fillet Weld
14-2	Side Seam
14-3	Fillet Weld
14-4	Side Seam

Metallurgical Examination

ADV performed a series of metallurgical examinations after completion of the full-scale testing. This examination was performed to determine the crack depth and growth at runout (for Sample 14-4).

ADV removed the installed notches from all six (6) full-scale samples, further sectioned, chilled them in liquid nitrogen, and broke them open to reveal the fracture surface. Each notch was heat tinted after precycling to provide a demarcation of crack depth at the time of repair. Resultant EDM notch depth, repaired crack depth, and growth after repair are summarized in Table 5. Photographs of the notches and their dimensions are shown in Figure 13 through Figure 19. All samples except Sample 14-4 (sample with grout) leaked. Sample 14-4 showed 0.020-inch of crack growth after 100,000 cycles, extending 7.1% of the nominal wall thickness.

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Table 5. Summary of Feature Depth

Sample	Description	EDM Notch Depth		Repaired Crack Depth		Growth after Repair	
		in	%NWT	in	%NWT	in	%NWT
12-1	Unreinforced	0.085	34.0	0.122	48.8	0.128	51.2
12-2	Reinforced Local Fill	0.079	31.6	0.122	48.8	0.128	51.2
14-1	Unreinforced	0.098	34.9	0.150	53.4	0.131	46.6
14-2	Reinforced No Fill	0.090	32.0	0.116	41.3	0.165	58.7
14-3	Reinforced Local Fill	0.085	30.2	0.134	47.7	0.147	52.3
14-4	Reinforced Flowable Fill (5 Star)	0.111	39.5	0.139	49.5	0.020	7.1

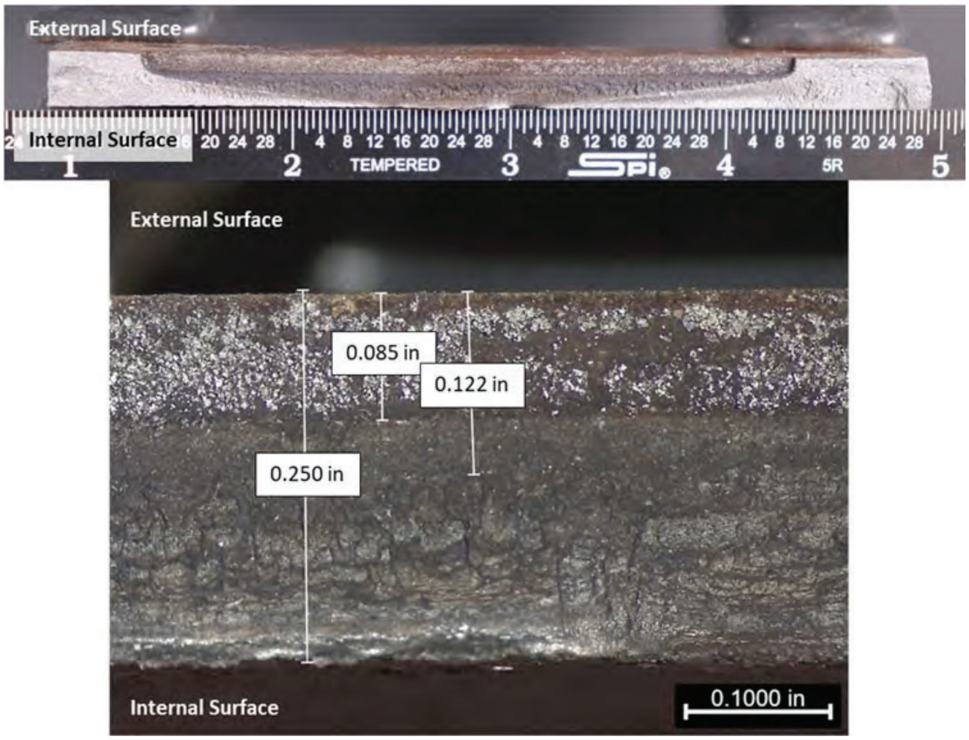

Figure 13. Photograph of notch/crack from Sample 12-1.

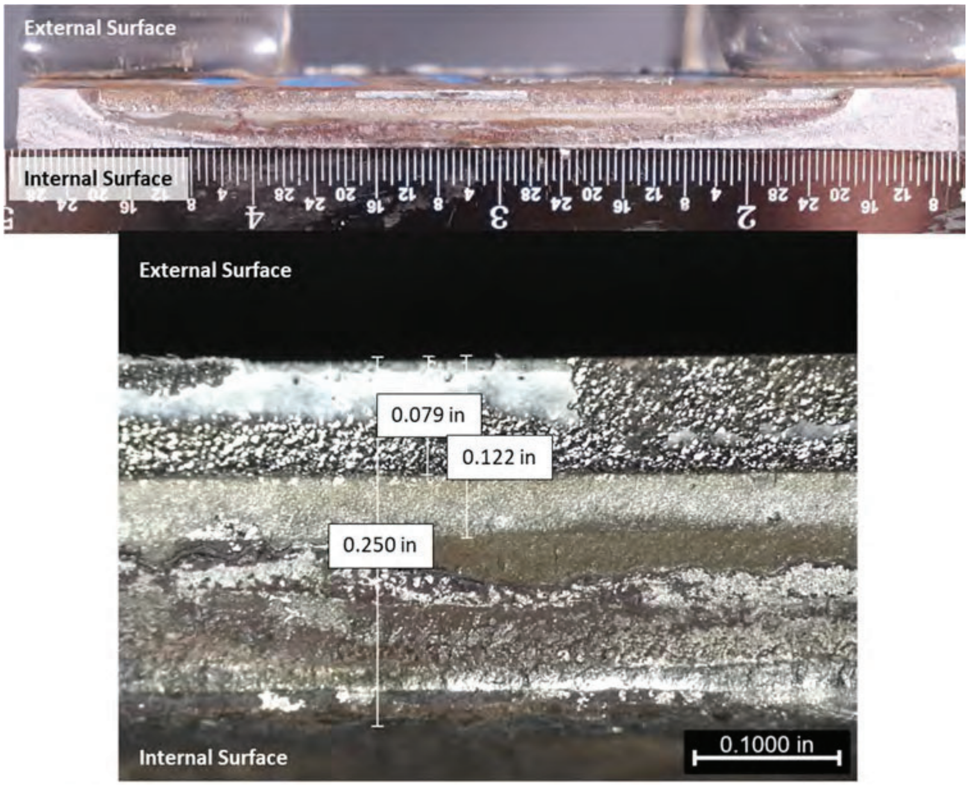

Figure 14. Photograph of notch/crack from Sample 12-2.

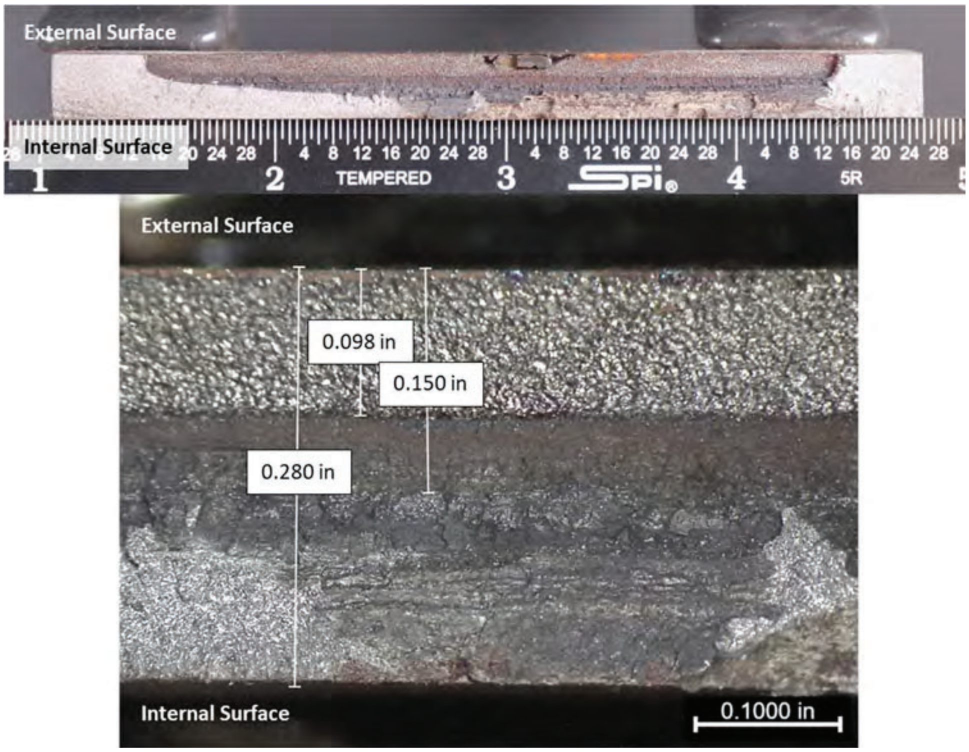

Figure 15. Photograph of notch/crack from Sample 14-1.

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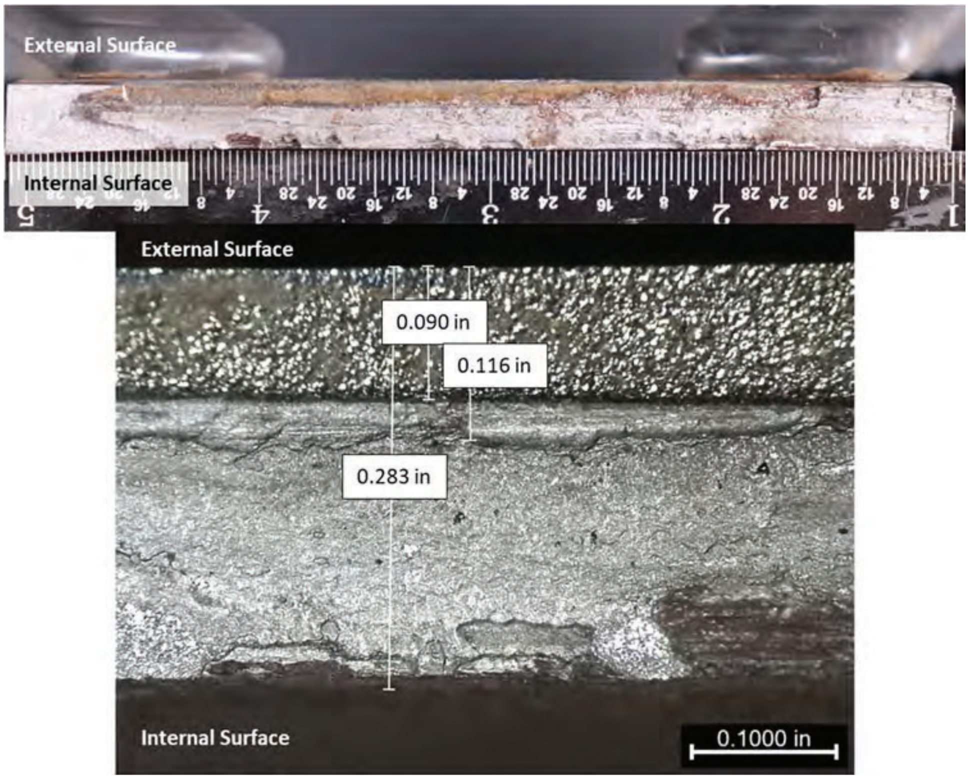

Figure 16. Photograph of notch/crack from Sample 14-2.

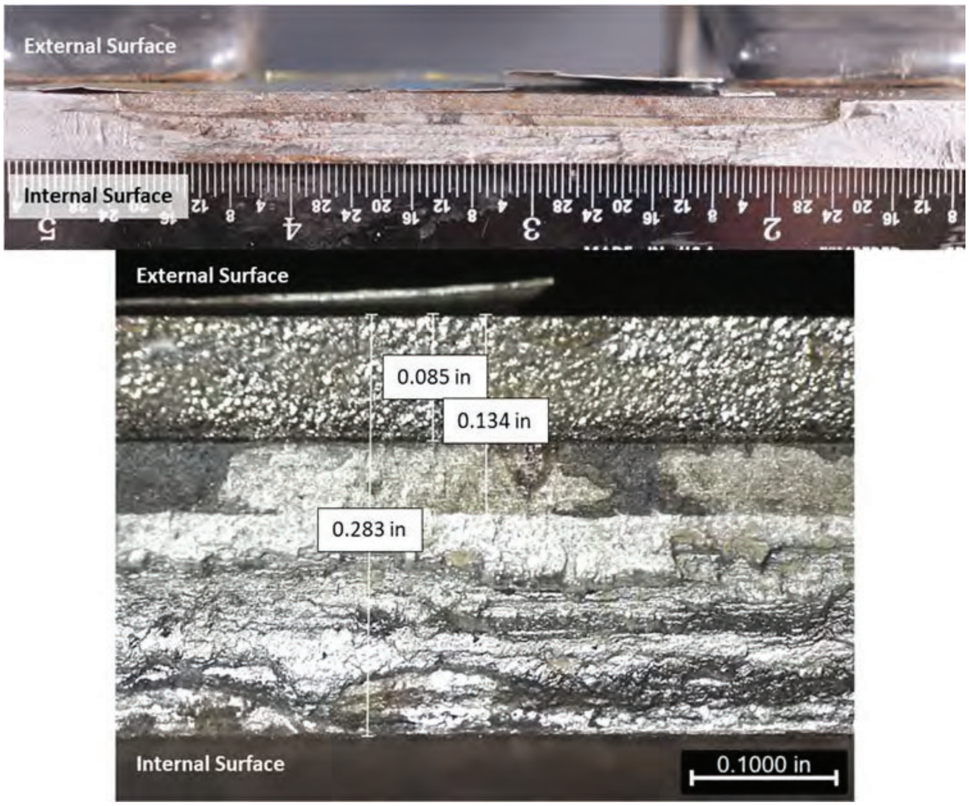

Figure 17. Photograph of notch/crack from Sample 14-3.

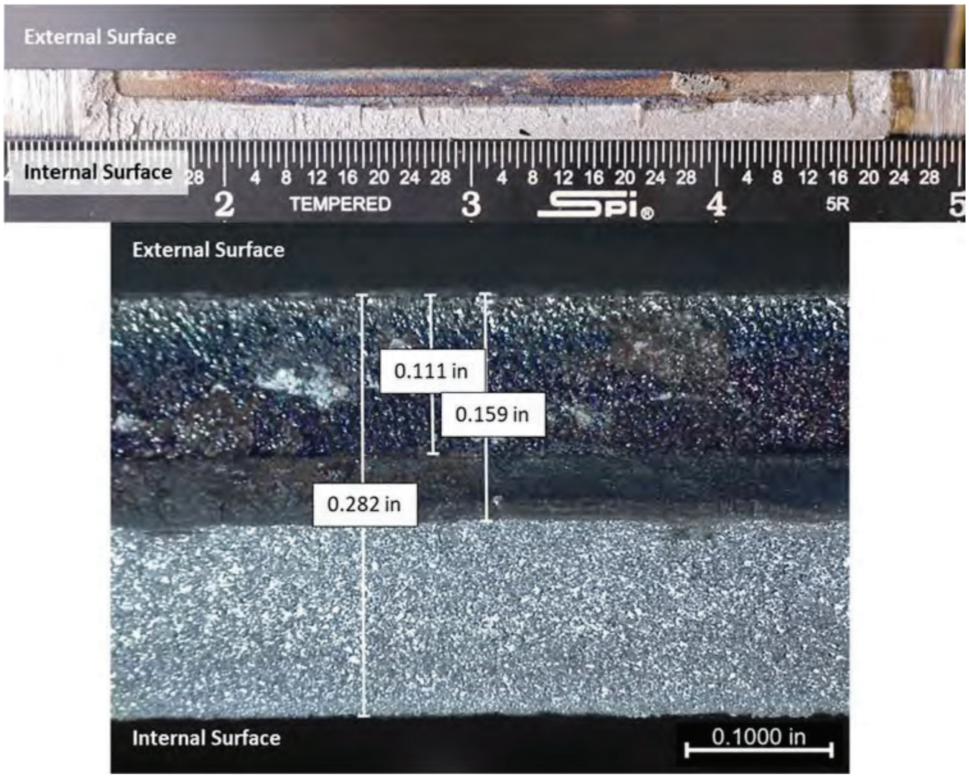

Figure 18. Photograph of notch/crack from Sample 14-4.

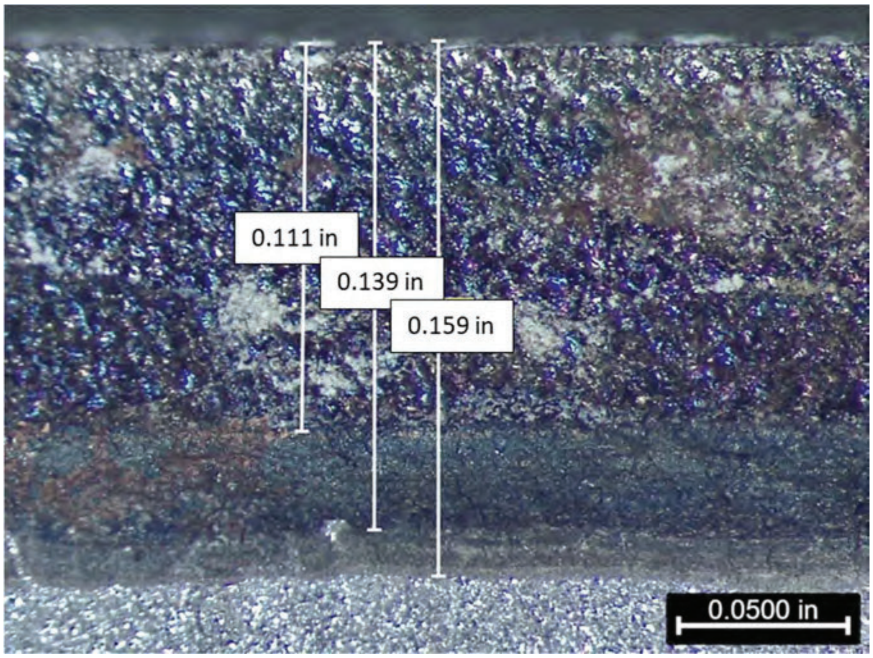

Figure 19. Notch dimensions from Sample 14-4.

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Closing Comments

Multiple bench-top and full-scale test samples resulted in the following observations:

- The use of a tool, such as a machine squeegee, resulted in a consistent application of filler material across the feature. This should be done in a way to account for the potential out-of-roundness (ovality) of the pipe and/or sleeve. It was identified that a rounded gap contour of 1/8-inch resulted in a uniform filler application. Hand applied filler material resulted in an inconsistent application based on visual inspection.
- Grouted samples provided the most consistent fill around the circumference of the pipe/sleeve.
- The Five Star filled sample was the only to achieve runout reaching 100,000 cycles, 20x more cycles than any other sample. Metallurgical examination confirmed little, if any, growth occurred after repair, indicating the most advantageous load transfer and repair life.
- The fatigue life of the sleeve welds is largely dependent on the quality of the side seams and fillet welds. Features such as lack of fusion and high lo were identified within the samples failing at a lower cycle count.

To better compare the differences in fatigue life of the full-scale samples, Miner's Rule of Cumulative Damage was utilized to correlate the pressure range and number of cycles to actual pipeline service. The correlations were made using estimated pressure cycle conditions from published data. A study published by Kiefner et al[1] provides estimated pressure cycles for transmission pipelines that were based on an industry-wide survey. This study categorized pressure ranges operating from "very aggressive" to "light" conditions. Gas transmission pipelines typically fall within "light" conditions. Table 6 summarizes the results of Kiefner's study as the number of pressure cycles at each pressure range. The pressure ranges are listed as percentages of the specified minimum yield strength (% SMYS).

Table 7 further translates the full-scale test results into a cyclic life (in years) based upon the Kiefner TT05 study for both light and aggressive cycle conditions. The grouted sample resulted in a >100x life increase, the exact life increase is unknown as the sample met runout conditions (100,000 cycles). A slight increase (~5x) was observed with a locally filled sleeve; however, the results were still significantly better utilizing the grouted sleeve configuration.

The sleeves were pressurized after the annulus space leaked, resulting in a wide range of life. It's expected that the sleeve life greatly depends on the quality of the side seams and fillet welds. A minimum and maximum life considering a light pressure cycling range was determined to be 162 years and 1687 years.

The testing occurred in an ideal scenario allowing sufficient time for the filler to cure prior to starting the fatigue test. This is especially the case with the Five Star Fluid Grout 100 sample (Sample 14-4), which resulted in the best performance. Any growth that may have occurred during the time required for the grout to cure or the effect of pressure at the time of installation/curing was not explored in this study.

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Table 6. Estimated Annual Pressure Cycle Conditions[1]

Estimated Annual Pressure Cycle Conditions				
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 cycles with ΔP as noted				
72[1]	276	67	25	10
65[2]	404	98	37	14
50	1,078	260	99	38
36	3,683	889	337	128
Notes: 1 Pressure range for Vintage Pipe 2 Pressure range for Modern Pipe				

Table 7. Estimated Fatigue Life based on Table 6

Sample	**Cycle Conditions**	**Carrier Pipe (years)**	**Sleeve (years)**	**Total Life (years)**
12-1 (unreinforced)	Aggressive	18	N/A	18
	Light	127		127
12-2 (local fill)	Aggressive	45	121	166
	Light	312	850	1162
14-1 (unreinforced)	Aggressive	14	N/A	14
	Light	95		95
14-2 (no fill)	Aggressive	0.5	24	24.5
	Light	3.6	162	165.6
14-3 (local fill)	Aggressive	70	252	322
	Light	471	1687	2158
14-4 (grout)	Aggressive	>1493	56	>1549
	Light	>10000	377	>10377

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[1] Kiefner et al. Estimating Fatigue Life for Pipeline Integrity Management. International Pipeline Conference IPC2004-0167.