Proceedings of the 2020 13th International Pipeline Conference
IPC2020
September 28- October 1, 2020, Calgary, Alberta, Canada

IPC2020-9757

REPAIR OF LEAKS IN THIN WALL HIGH PRESSURE PIPELINES USING COMPOSITE REINFORCING TECHNOLOGIES

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ABSTRACT

A study was conducted to evaluate two composite repair technologies used to reinforce severe corrosion and thru-wall leaking defects in thin-walled pipe materials; conditions where the welding of conventional Type B steel sleeves cannot be conducted. This program involved the reinforcement of simulated 85% corrosion defects in 6.625-inch x 0.157-inch, Grade X52 pipe materials subjected to cyclic pressure and burst testing. The test matrix also included repaired pipe samples with thru-wall defects that were pressurized using nitrogen gas and buried for 90 days. The program was comprehensive in that it evaluated the following elements involving a total of 81 reinforced corrosion defects.

- Corrosion features with a depth of 85% of the pipe's nominal wall thickness in thin-walled pipe material (i.e., 0.157 inches, or 4 mm).
- Thru-wall defects having a diameter of 0.125 inches (3 mm).
- Repairs made with leaking defects having 100 psig (690 kPa) internal pressure.
- Strain gage measurement made in non-leaking 85% corrosion defects; it should be noted that the remaining "15%" ligament was 0.024 inches (0.6 mm); to the author's knowledge, no high-pressure testing has ever been conducted on such a thin remaining wall.
- Long-term 90-day test that included pressurization with nitrogen gas, followed by relatively aggressive pressure cycling up to 80% SMYS followed by burst testing.

This is the first comprehensive study conducted by a major transmission pipeline operator evaluating the performance of competing composite technologies used to reinforce severe corrosion features with thru-wall defects. The reinforcement of leaks has not been accepted by regulatory bodies such as the Canadian Energy Regulator (CER), or the U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA). A goal of the current study is to validate composite repair technologies as a precursor to regulatory approval.

The results of this study indicate that viable composite repair technologies exist with capabilities to reinforce leaks in pipelines that experience operating conditions typical for gas transmission systems (i.e., minimal pressure cycling).

Keywords: Composites, Leak Repair, Active Leaks

NOMENCLATURE

Flash Rust	a powdery rust in corrosion area
Elev. Temp	60°C [140°F]
SMYS	Specified Minimum Yield Strength
Severe-Corrosion	85% of wall thickness removed
Thru-wall leak	0.125-inch [3 mm] diameter hole

INTRODUCTION

A comprehensive full-scale testing program was conducted for TC Energy by ADV Integrity, Inc. to evaluate the ability of composite repair technologies to reinforce severe 85% corrosion defects that included through wall pin holes. The overall program was carefully designed to permit assessments of leaking defects, effects of cyclic pressure, quantifying strain reduction in thin wall ligaments (i.e., remaining wall thickness of 0.024 inch [0.61 mm]), and performance of leak-sealing samples subjected to a 90-day buried condition pressurized with nitrogen gas.

Initial testing began in 2018, and involved three phases of testing hereafter referred to as Stage I. From four original participating composite repair companies, two were selected for continued assessment; hence, an additional three phases of testing were conducted on technologies manufactured by Milliken (now CS-NRI) and Western Specialties in what is hereafter referred to as Stage II.

MATERIALS AND METHODS

Testing began in 2018 and was conducted over a two-year period that was divided into two stages of work: Stage I testing included three (3) phases, four (4) repair technologies, 28 pipe samples, for a total of 36 severe-corrosion defects. Figure 2 and Figure 3 show the installation procedures utilized by two of the composite repair companies, Milliken and Western Specialties (results for the other two repair companies are not included in this paper).

After Stage I testing was complete, the top two repair technologies were further evaluated where Stage II testing explored the performance limitations of these two repair technologies beyond what was addressed in the Stage I phase of work. Stage II included three (3) phases, two (2) repair technologies, 33 pipe samples, for a total of 45 severe and thru-wall corrosion defects. Figure 5 and Figure 4 show the installation procedures utilized by these two companies. The installation procedures in Stage II were adapted by both companies based on the knowledge and insights gained in Stage I. Water was utilized in all phases of testing, except the buried gas phases of testing.

All pipe samples were fabricated using NPS 6 [163.3 mm] x 0.157-inch [4 mm] WT x Grade X52 [Grade 359] pipe. The primary defect tested throughout the study is a 2-inch [51 mm] long x 1-inch [25 mm] wide corrosion area machined to a depth of 85% of the wall thickness. In most of the samples, a leak was simulated by drilling a thru-wall hole (diameter 0.125-inch [3 mm]) to simulate a pinhole leak. Please refer to Figure 1 for a view of the severe-corrosion thru-wall defect utilized in this body of work.

Stage I Test Parameters

Provided below are specific details on this stage of the testing program.

- Phase 1: Short-Term Burst Testing
  - 85% corrosion with non-leaking defects
  - strain gauges installed in the corroded region to quantify repair performance
- Phase 2: Pressure Cycle Testing
  - 85% corrosion with leaking defects (0.125-inch [3 mm] hole)
  - One repair installation with 100 psig [0.69 MPa] shop air internal sample pressure
  - Pressure range: ΔP = 985 psig [6.79 MPa] to 1,577 psig [10.87 MPa] (40% to 64% SMYS)
- Phase 3: Long-Term 90-Day Holds
  - 85% corrosion with through wall defects (0.125-inch [3 mm] hole)
  - 90-day hold with nitrogen gas followed by:
  - 50 cycles from 100 psig [0.69 MPa] to 1,971 psig [13.59 MPa] (4 – 80% SMYS)
  - 50 cycles from 1,478 psig [10.19 MPa] to 1,971 psig [13.59 MPa] (60–80% SMYS)
  - burst testing

Stage II Testing Parameters

Provided below are specific details on this stage of the testing program.

- Phase 1: Short-term Burst Testing
  - 85% corrosion with through wall defects (0.125-inch [3 mm] hole)
  - Four installation conditions tested:
  - 0 psig installation pressure
  - 100 psig [0.69 MPa] installation pressure
  - 150 psig [1.03 MPa] installation pressure
  - Flash Rust with 0 psig installation pressure
  - Elevated temperature burst tests:
  - 0 psig during repair installation
  - Burst testing conducted @ 60°C [140°F]
  - Burst tested one (1) unreinforced sample non-leaking 85% corrosion defect for safety/baseline?
- Phase 2: Pressure Cycle Testing
  - 85% corrosion with through wall defects (0.125-inch [3 mm] hole)
  - Each repair system testing with the following conditions:
  - Flash Rust with High Pressure Cycling – ΔP = 100 psig [0.69 MPa] – 80% SMYS (1,972 psig [13.6 MPa])
  - Mid Pressure Cycling – ΔP = 100 psig [0.69 MPa] – 40% SMYS (985 psig [6.79 MPa])
  - High Pressure Cycling @ Elev. Temp:
    - ΔP = 100 psig [0.69 MPa] - 80% SMYS (1,972 psig [13.60 MPa])
    - 60°C [140°F]
- Phase 3: Long-term 90-day Holds
  - 85% corrosion with through wall defects (0.125-inch [3 mm] hole)
  - 90-day hold period with nitrogen gas
  - Following 90-day holds samples subjected to pressure cycles
  - High pressure samples:
    - 50 cycles from 100 psig [0.69 MPa] to 1,971 psig [13.59 MPa] (4–80% SMYS)
    - 50 cycles from 1,478 psig [10.19 MPa] to 1,971 psig [13.59 MPa] (60–80% SMYS)
  - Low pressure samples – 50 cycles 100 psig [0.69] to 986 psig [6.80 MPa] (4–40% SMYS)

Any samples that survived the pressure hold were subjected to a pressurization to failure burst test.

TEST RESULTS

Provided in the following sections are results from Stages I and II of the 2-year study. Table 1 and Table 2 provide a summary of results for the entire test program.

Stage I Test Results

The overall program involved two stages of work that started in 2018 and concluded in late 2019. Stage I started in 2018 and evaluated four different composite repair technologies, followed by Stage II that only evaluated two repair systems. A key element from the Stage I testing were the low strains measured in the severely corroded features. Over the past 10 years, more than 200 burst tests have been completed on composite-reinforced corrosion features that included strain gauges installed beneath repairs in the machined corrosion defects. In evaluating the results of these previous studies, a hoop strain limit of 0.4% has been determined as appropriate and validated by others in the industry [1]. In this program, all systems except one had hoop strains in the severely corroded region that were less than 0.4% (4,000 $\mu\varepsilon$).

Stage II Test Results

Stage II testing was designed to build on the Stage I body of work in terms of pipe sample geometry and performance metrics, but included additional test variables such as elevated temperatures, increased installation pressures, and higher test hold-pressures during the 90-day test.

After Milliken adjusted their installation procedures for the Stage II phases of testing, the performance between the two systems became more comparable. In fact, when comparing the Stage II – Phase 1 burst pressures, the Milliken system performed better at elevated temperatures and the average failure pressure was 3,669 psig [25.30 MPa] for ambient temperature, and 2,800 psig [19.31 MPa] for the 60°C [140°F] elevated temperature. While Western Specialties' average failure pressure was 3,679 psig [25.4 MPa] for ambient temperature, and 1,966 psig [13.6 MPa] for the 60°C [140°F] elevated temperature. Milliken's failure pressures were reduced an average of 869 psig [6.0 MPa] at the 60°C [140°F] elevated temperature, while Western Specialties was reduced by 1,713 psig [11.8 MPa] on average. This advantage is also seen in the Stage II – Phase 2 cycle test results. Milliken's average cycles to failure at the 60°C [140°F] elevated temperature was 2,192 cycles, while Western Specialties was 437 cycles.

CONCLUSION

This paper has provided details on results associated with a full-scale testing program focused on the composite reinforcement of severe corrosion and leaking defects in 6.625-inch [168.3 mm] x 0.157-inch [4 mm], Grade X52 pipe material. Key takeaways from the testing program include the following:

- The results of this study indicate that composite repair technologies exist with capabilities for reinforcing leaks in pipelines that experience operating conditions typical for gas transmission systems that experience minimal pressure cycling.
- Repair stiffness is a critical design variable in composite leak repair. In the context of composite repair technologies, stiffness is the product of elastic modulus and thickness. The technologies employed in this study used steel and carbon, both of which have high modulus values compared to conventional E-glass composite technologies (i.e., typical elastic modulus values for steel, carbon-epoxy, and E-glass-epoxy systems are 200 GPa, 70 GPa, and 25 GPa, respectively).
- Elevated temperatures can reduce performance of composite leak repairs. This occurs because the resins used in the repair systems "soften" at elevated temperatures, resulting in a reduction of their strength and ability to resist deformation that is necessary from a structural strength standpoint.
- Compressing a rubber or putty over the leaking defect is more effective than plugging the hole with a screw or some type of threaded plugging device.
- Repairs of leaking features placed in service should be monitored as part of a pilot study as even the top performing repairs in this program could not contain a nitrogen leak with 100% success.

ACKNOWLEDGEMENTS

The authors would like to extend their appreciation to the staff at Milliken and Western Specialties for their contributions of materials and personnel for completing the installations. Specifically, we would like to thank Mr. Casey Whalen of Milliken and Mr. Ryan Lavergne of Western Specialties.

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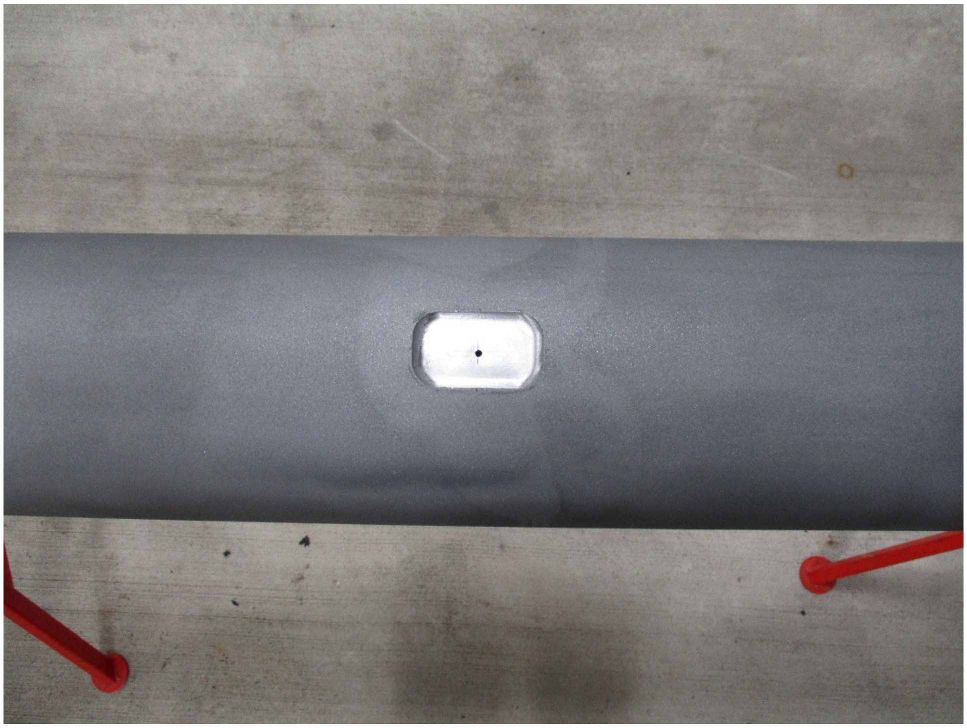

Figure 1: View of Severe Leaking Corrosion Defect

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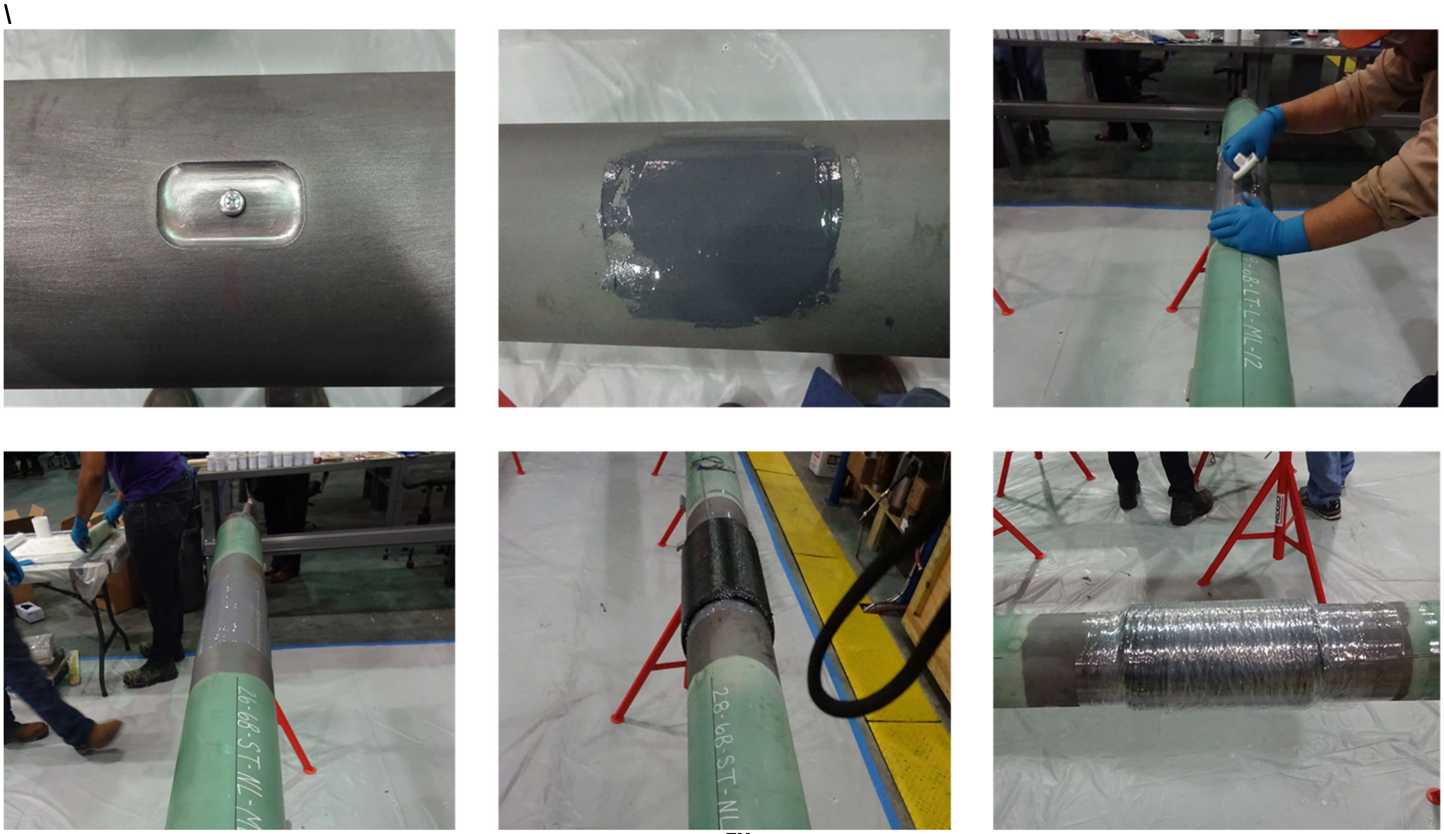

Figure 2: Milliken Atlas™ Installation (Stage I)

Figure 3: Western Specialties Installation (Stage I)

Figure 4: Milliken Atlas™ Installation (Stage II)

Figure 5: Western Specialties Installation (Stage II)

Table 1: Summary of Stage I Test Results

Test Description	Milliken	Western Specialties
Stage I – Phase1: Short-term Burst Testing (3 samples x 4 technologies) **85% corrosion with non-leaking defects**		
Test Description	**Milliken**	**Western Specialties**
Maximum Recorded Hoop Strain:	3,937 psig [27.14 MPa] 3,957 psig [27.28 MPa] 4,006 psig [27.62 MPa] (2,269 με)	3,971 psig [27.38 MPa] 3,561 psig (1) [24.55 MPa] 4,016 psig [27.69 MPa] (3,167 με)
Stage I – Phase2: Pressure Cycle Testing (2) (3 samples x 3 defects per sample x 4 technologies) **85% corrosion with leaking defects**		
Test Description	**Milliken**	**Western Specialties**
One repair made with 100 psig [0.69 MPa] shop air ΔP = (40% to 64% SMYS)	Leaked by 10 cycles	3,300 & 4,900 cycles (3)
Stage I – Phase 3: Long-Term 90-day holds (3 samples x 4 technologies) **85% corrosion leaking defects**		
Test Description	**Milliken**	**Western Specialties**
1. 90-day hold at 40% SMYS - nitrogen	4% pressure drop	3% pressure drop
2. 50 cycles (4-80% SMYS) - liquid	3,996 psig [27.5 MPa]	4,040 psig [27.8 MPa]
3. 50 cycles (60-80% SMYS)- liquid	4,038 psig [27.8 MPa]	3,912 psig [27.0 MPa]
4. Burst Testing - liquid	3,898 psig [26.9 MPa]	3,813 psig [26.3 MPa]

NOTES:

1. The failure pressure for this sample was lower than the other two Western Specialties samples as a groove had to be machined in the sample to permit the strain gauge wire to run from beneath the steel sleeve.
2. One defect per sample was repaired with 100 psig [0.69 MPa] shop air present during installation.
3. After first defect failed at 3,300 cycles, failure removed and remaining two defects were pressure cycled. The second failure occurred at 4,900 cycles.
4. Sample pressure monitored during 90-day hold. Generalized pressure results shown in **BLUE**.

Table 2: Summary of Stage II Test Results

Test Description	Milliken [2]	Western Specialties [3]
Stage II – Phase 1: Short-term Burst Testing (7 samples x 2 technologies) [1] **85% corrosion leaking defects**		
Test Description	**Milliken [2]**	**Western Specialties [3]**
Low Pressure Installation 0 psig [0 MPa]	3,637 psig [25.1 MPa]	4,133 psig [28.5 MPa]
Mid Pressure Installation 100 psig [0.69 MPa]	3,697 psig [25.5 MPa]	2,470 psig [17.0 MPa]
High Pressure Installation 150 psig [1.0 MPa]	3,722 psig [25.6 MPa]	3,984 psig [27.4 MPa]
Flash Rust Installation	3,623 psig [24.9MPa]	4,130 psig [28.4 MPa]
Elev. Temp Burst @ 60°C [140°F]	2,400 psig [16.5 MPa]	1,900 psig [13.1 MPa]
Elev. Temp Burst @ 60°C [140°F]	3,600 psig [24.8 MPa]	2,400 psig [16.5 MPa]
Elev. Temp Burst @ 60°C [140°F]	2,400 psig [16.5 MPa]	1,600 psig [11.0 MPa]
Stage II – Phase 2: Pressure Cycle Testing (3 samples x 3 defects per sample x 2 technologies) **85% corrosion leaking defects**		
Test Description	**Milliken [2]**	**Western Specialties [3]**
	Cycles to Failure	**Cycles to Failure**
Flash Rust Installation, ΔP =4%-80% SMYS	3,222/2,195/12,643	880/10,301/10,301
ΔP = 4%-40% SMYS	124,920/35,238/32,517	26,677/26,677/1,645
Elev. Temp ΔP = 4%-80% SMYS @ 60°C [140°F]	**2,472/1,633/2,472**	**397/397/519**
Stage II – Phase 3: Long-Term 90-day holds (6 samples x 2 technologies) **85% corrosion leaking defects**		
Test Description	**Milliken [2]**	**Western Specialties [3]**
High Pressure Samples (3 Samples)	***High Pressure***	***High Pressure***
1. 90-day hold at (80% SMYS) - nitrogen	95% Drop – 4,035 psig [27.8 MPa]	24% Drop – 3,940 psig [27.1 MPa]
2. 50 cycles (4-80% SMYS) - liquid	None – Leaked during cycling	None – Leaked during cycling
3. 50 cycles (60-80% SMYS) - liquid	None – 3,591 psig [24.7 MPa]	None – Leaked during cycling
4. Burst Testing - liquid		
Low Pressure Samples (3 Samples)	***Low Pressure***	***Low Pressure***
1. 90-day hold (40% SMYS) - nitrogen	None – 3,944 psig [27.2 MPa]	None - 4,082 psig [28.1 MPa]
2. 50 cycles (4-40% SMYS) - liquid	None – 3,650 psig [25.1 MPa]	85% Drop - 3,720 psig [25.6 MPa]
3. Burst Testing - liquid	None – 3,415 psig [23.5 MPa]	None - 4,084 psig [28.1 MPa]

NOTES:
1. One unreinforced sample tested with non-leaking defect tested. Burst pressure 1,273 psig [8.8 MPa].
2. Note that Milliken changed their installation procedures to include a magnet and a hose clamp for Stage II.
3. Western specialties also changed their installation procedures to include a neoprene ball for all repairs made with 0 installation pressure. Repairs made with installation pressure did not include the neoprene ball.