Testing of PipeMedic™ Fiber Reinforced Polymer for Rehabilitation of Gas Pipe Mains

Final Report

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TESTING OF PIPEMEDIC FRP FOR REHABILITATION OF GAS PIPE MAINS

SUMMARY

The report presents the results of hydrostatic pressure tests performed on pipe sections with PipeMedic Fiber-Reinforced Polymer (FRP) composites and Cured-In-Place (CIP) Starline liner. The report includes the data from the test results and recommendations for the use of the PipeMedic FRP with the CIP liners in the rehabilitation of pipe sections with liquid-separator drip pots, abandoned tees or other fittings in gas main lines.

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Table of Contents

Table of Figures

List of Tables

Page

Executive Summary

Hydrostatic pressure tests were performed on pipe sections with PipeMedic Fiber-Reinforced Polymer (FRP) composites. The test sections consisted of 6, 12, and 16-inch diameter steel pipes with 24-inch free-span length of PipeMedic composites and Cured-In-Place (CIP) liners inside the pipes. The installation of the PipeMedic composites and the CIP liners were performed by the subcontractor Progressive Pipeline Management (PPM) according to the manufacturers' recommendations.

The pipe sections were tested under stepped hydrostatic pressures. The hydrostatic pressure was increased every 2 hours in 50 psig increments to 250 psig. The test results demonstrated that the liner-composite sections could stand the applied pressure without leakage.

The requirements for the CIP-pipe system as specified in the ASTM F-2207 standard include performing tests at pressures not less than twice the certified MAOP of the pipeline for a minimum of one hour without leakage. For gas mains operating at pressures up to 60 psig, the hydrostatic tests exceeded the above requirement and showed that the liner-composite sections could withstand pressures up to four times the operating pressure without leakage.

Strains of the PipeMedic composite sections were monitored at various locations during the tests and the applied stresses were estimated based on the composite sections properties. The PipeMedic carbon FRP was installed in 3 layers in the 16-inch pipe and the hoop stress in the section was less than 25 percent of the material tensile strength at the 250 psig test pressure.

The PipeMedic fiber glass FRP was used for the 12-inch and 6-inch pipes. The 2-layer laminates of the composite in the 12-inch pipe had a hoop stress of about 46 percent of the material tensile strength at pressure 250 psig.

The stress-strain measurements show that the 24-inch long free-span composite section, with additional 12 inches in each side of the adjacent pipes, can be used to carry the hydrostatic pressures of spanning gaps in liquid-separator drip pots, abandoned tees or other fittings in gas main lines. The testing program satisfied the pressure requirements of the liner-composite section as per ASTM F-2207. Other requirements are listed in the ASME B31.8 for the composite to perform similar to the original carrier pipe system; including its long-term strength and its performance under external loads. However, the composite section is not commonly subjected to external surface loads when these loads are still carried by the in-line fittings.

Introduction

The PipeMedic is a high-strength carbon fiber-reinforced laminate which is bonded together and to the substrate for the repair and strengthening of pressurized steel, cast iron, and concrete pipes. The material is planned for use in gas mains to provide a free-span section of the pipe across the 24-inch diameter liquid-separator drip pots in the line. This process will allow for the use of Cured-In-Place (CIP) liners to be installed for the rehabilitation of the pipes without the removal of these in-line fittings. Figure 1 shows a typical drip pot configuration in the gas main.

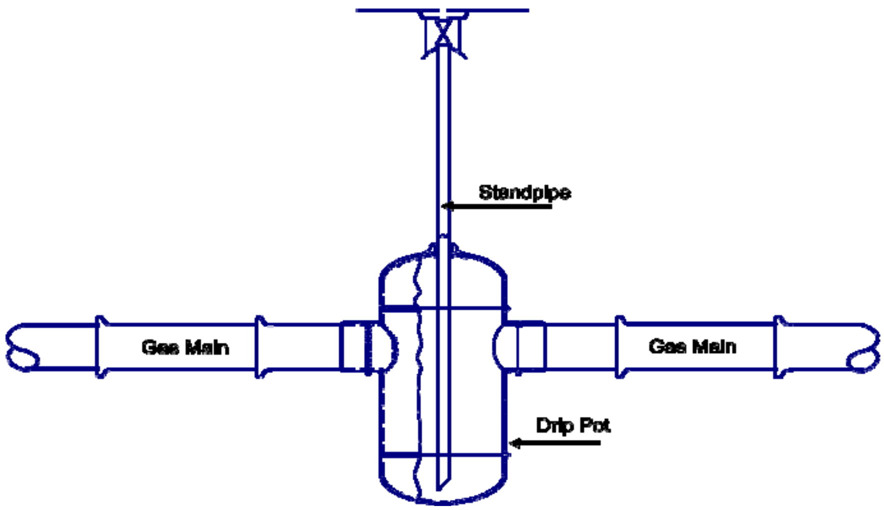

Figure 1 - A typical drip pot configuration

Since the CIP liner system relies on the structural integrity of the host pipe, the PipeMedic section is installed to perform as a stand-alone pressure-carrier section and interacts with the CIP liner similar to the original carrier pipe. The requirements for the CIP-metallic pipe system are specified in the ASTM F-2207 standard [*1*] and include performing pressure tests to demonstrate the strength of the pipe-liner composite. The pressure should not be less than two times the certified MAOP of the pipeline for a minimum of one hour without leakage.

The testing program included testing three sizes of steel pipe sections with diameters 6, 12, and 16 inches. Each test section included a 24-inch free-standing PipeMedic section which extended additional 12 inches in each side of the steel pipe. The PipeMedic-steel pipe system was lined with the CIP liner, capped at both sides, and connected to a hydraulic pressure system to apply controlled pressures. Strain gauges and displacement sensor were installed in the PipeMedic section to monitor its circumferential and longitudinal strains during the application of pressures up to 250 psig.

The following sections present the preparation and instrumentation of the test specimens, the hydrostatic pressures tests, and the results of the testing program.

Test Sections and Instrumentation

Figure 2 shows a schematic of the test section setup. The PipeMedic section had a 24-inch free-standing part and extended 12 inches inside each side of the steel pipe. The preparation of the test sections was performed at the Progressive Pipeline Management (PPM) facility in NJ.

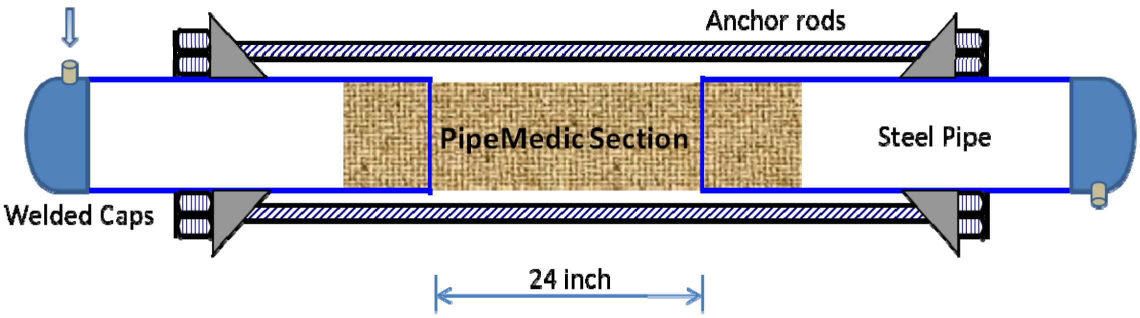

Figure 2 - A schematic diagram of test specimen

Strain gauges were installed on the PipeMedic fiber-reinforced laminates at the GTI labs before their installation on the test section. The instrumented composite laminates were tested in extension tests to investigate the gauges installation and the range of measured strains on the laminates.

The procedure for preparing the surface of the laminate for strain gauge bonding followed the standard procedures described by the strain gauge manufacturer (Micro-Measurements) for gauges installation on composite material [*2, 3*].

The composite material surface was first cleaned with isopropyl alcohol to remove any greasy material to successfully bond the surface. The surface was abraded with 320-grit silicon carbide paper to produce a satisfactory finish. Loose particles were dusted off and wiped with surface cleaning solvent and gauze sponges. The procedure was repeated until the surface had a satisfactory matte finish. A final cleaning with Micro-Measurements M-Prep Conditioner A and Neutralizer 5A was performed following the solvent cleaning and abrasion.

Strain gauge types: Micro-Measurements CEA-06-250-UW350 and CEA-06-500-UW350 were installed on the laminates. These gauges have a resistance of 250 ohms and gauge lengths of 0.25 and 0.5 inches, respectively. The gauges were installed using Micro-Measurements M-Bond-200 adhesive. The adhesive was applied using a one-minute thumb pressure, followed by several minutes delay at ambient temperature of 70^{O}F. A general-purpose coating type M-Coat A was applied and the test specimens were left to set for several hours.

Longitudinal strips of the laminates with length of 8 inches and width of 1.5 inches were tested in controlled stepped-extension tests using the MTS loading machine at GTI. Figures 3 and 4 show the extension test setup and the composite specimen, respectively.

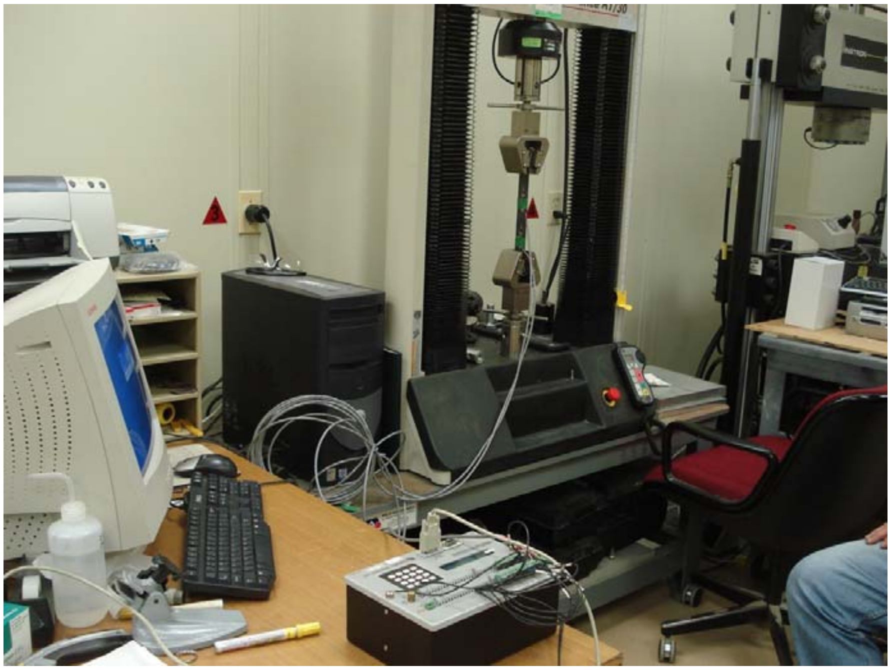

Figure 3 - Extension test of the composite laminate with strain gauges

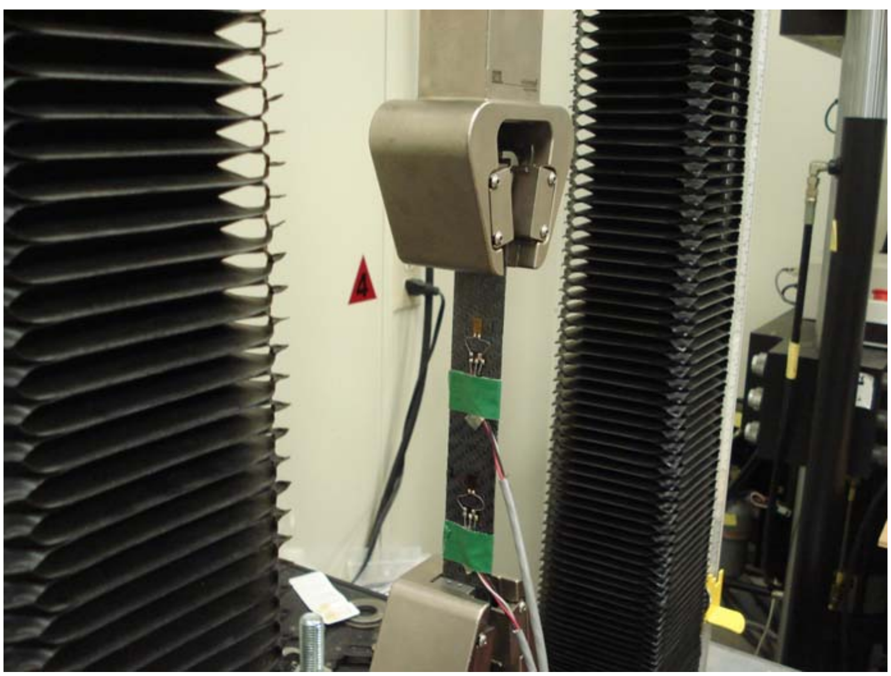

Figure 4 - View of the instrumented PipeMedic composite laminate

Strain gauge measurements from several extension tests are shown in Figure 5. The results show repetitive measurements of the strain gauges on the PipeMedic RFP laminates.

The strain gauges were then installed on the pipe test sections at the PPM facility in NJ. A total number of 8 to 10 strain gauges were installed on each of the three pipe sections to provide repetitive measurements. A schematic diagram of the locations of the strain gauges on the pipe sections is shown in Figure 6.

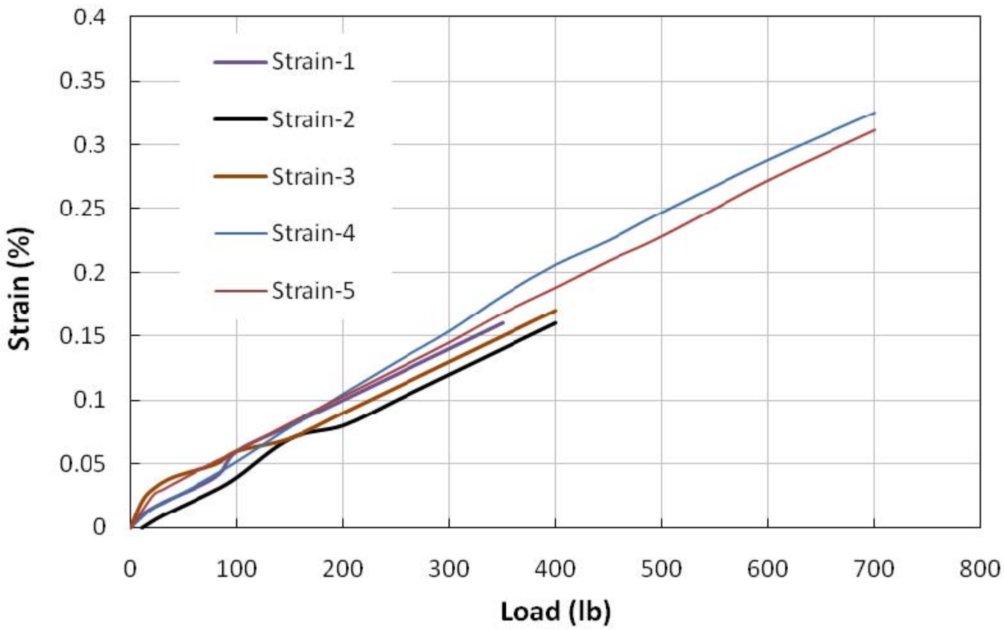

Figure 5 - Strain gauge measurements in extension test

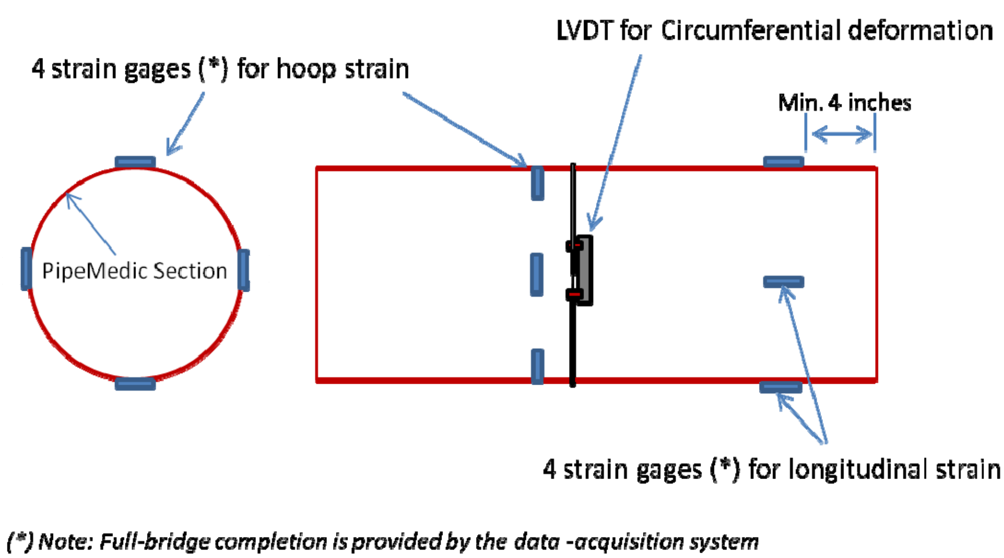

Figure 6 - Schematic of the strain gauges locations

Hydrostatic Pressure Tests

The testing plan included the following:

- Test three (3) steel pipe sizes, namely 16-inch, 12-inch, and 6-inch diameter pipes.
- Install the PipeMedic composite material, with a free span of 24-inches in the three pipe sizes. The composite extended 12 inches at both sides inside the host pipe.
- Install strain gauges on the outer surface of the PipeMedic sections. The strain gauges were installed at both the hoop and longitudinal directions as shown in Figure 6. A minimum of 4 strain gages were installed in each direction.
- A Linear Variable Differential Transformer (LVDT) was installed by placing a collar around the PipeMedic section to monitor circumferential deformation during the pressure tests. A thermocouple sensor in the data collection system was used to monitor air temperature
- The CIP liner was installed in the pipe sections and the hydrostatic pressure was applied up to 250 psig, which is about four times the MAOP of the pipeline at 60 psig. The ASTM standard states that for a given pipeline operating pressure rating, the liner shall be tested at a minimum pressure of two times the certified for a minimum of one hour without leakage.
- The hydrostatic pressure was applied in 50 psig increments, up to 250 psig. The pressure was held for a minimum of 2 hours at each increment. In the pressure test of the 16-inch pipe, the pressure was held for a minimum of 3 hours. In the 6-inch pipe test, the initial pressure of 50 psi was held overnight.
- The data acquisition system monitored and stored pipe strains and deformations every 2 seconds during the pressure tests.

a) Hydrostatic Test of the 16-Inch Pipe

The PipeMedic laminate product: PC26.16 was used in the 16-inch pipe section. It is a high-strength biaxial composite constructed with carbon fiber with the properties shown in Table 1.

A specimen length of 48 inches was wrapped in 3 layers and bonded to form the composite section. The composite extended 12 inches inside each side of the steel pipe. Figure 7 shows the 16-inch pipe section during testing.

The strain gauge measurements are shown in Figure 8. The figure shows the increase in the strains with the incremental loading. Each strain increment in the figure represents a sample of the measurements at the beginning and the end of the 3-hour loading increment.

The corresponding circumferential and longitudinal strains are shown in Figure 9. The figure shows average circumferential strain of 0.2 percent and longitudinal strain of 0.085 percent at the 250 psig pressure.

Table 1 - Properties of the Pipe Medic PC26.16

Property	ASTM Test	Value
Longitudinal (0º) Direction:		
Tensile Strength	ASTM D3039	101,000 psi
Modulus of Elasticity	ASTM D3039	7,150,000 psi
Ultimate Elongation	ASTM D3039	0.85 %
Transverse (90º) Direction:		
Tensile Strength	ASTM D3039	62,400 psi
Modulus of Elasticity	ASTM D3039	2,920,000 psi
Ultimate Elongation	ASTM D3039	1.42%
Ply Thickness		0.026 inch

Figure 7 - The 16-inch pipe specimen during testing

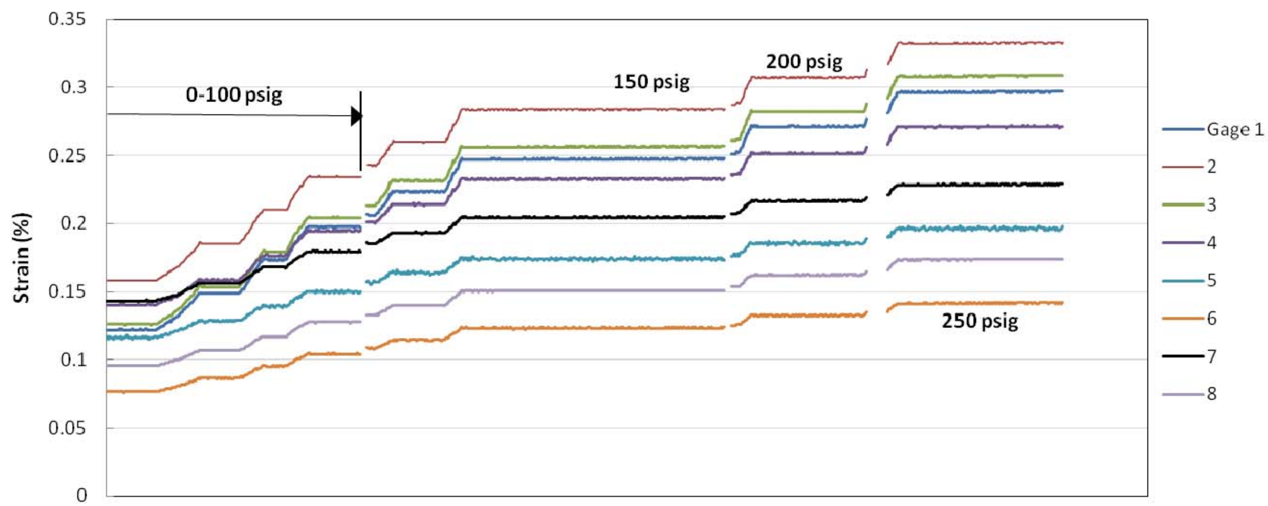

Figure 8 - Strain measurements in the 16-inch pipe

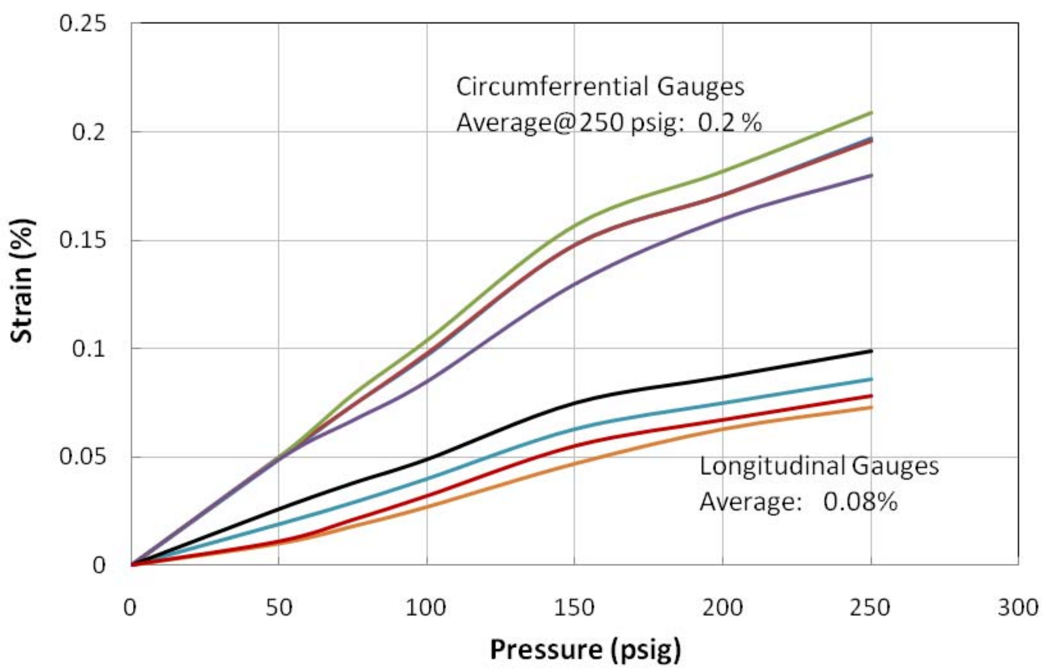

Figure 9 - Circumferential and Longitudinal strain in the 16-inch pipe

b) Hydrostatic Test of the 12-Inch Pipe

The PipeMedic composite laminate used in the 12-inch pipe was PG16.15. It is a high-strength biaxial laminate constructed with glass fibers. It is more flexible than the carbon fiber used in the 16-inch pipe, which allowed for its use inside the smaller 12 and 6-inch diameter pipes. Figure 10 shows the 6-inch and 12-inch diameter pipes and Table 2 shows the mechanical properties of the glass fiber.

In the 12-inch pipe section, a specimen length of 48 inches was wrapped in 2.5 layers and bonded to form the composite section. Strain gauges No. 1 to 5 were installed circumferentially on the composite. Gauges No. 6 to 8 were installed longitudinally at a distance of 4 inches from the metal pipe. A view of the pipe specimen with the strain gauges is shown in Figure 11.

The strain gauge measurements are shown in Figure 12. The figure shows the increase in the strains with the incremental loading. Each strain increment in the figure represents a sample of the strains at the beginning and the end of the 2-hour loading increments. The last increment in the figure shows the strains at the completion of the test after releasing the pressure. Most of the strains were elastic with some plastic deformations that kept the final strains higher than their initial values before loading.

The corresponding circumferential and longitudinal strains are shown in Figure 13. The figure shows an average circumferential strain of 0.75 percent and longitudinal strain of 0.27 percent at the end of the 250 psig pressure increment.

Figure 10 - The 12-inch and 6-inch pipe specimens

Table 2- Properties of the Pipe Medic PG 16.15

Property	ASTM Test	Value
Longitudinal (0º) Direction:		
Tensile Strength	ASTM D3039	62,000 psi
Modulus of Elasticity	ASTM D3039	3,501,000 psi
Ultimate Elongation	ASTM D3039	1.31 %
Transverse (90º) Direction:		
Tensile Strength	ASTM D3039	60,000 psi
Modulus of Elasticity	ASTM D3039	3,650,000 psi
Ultimate Elongation	ASTM D3039	1.06%
Ply Thickness		0.026 inch

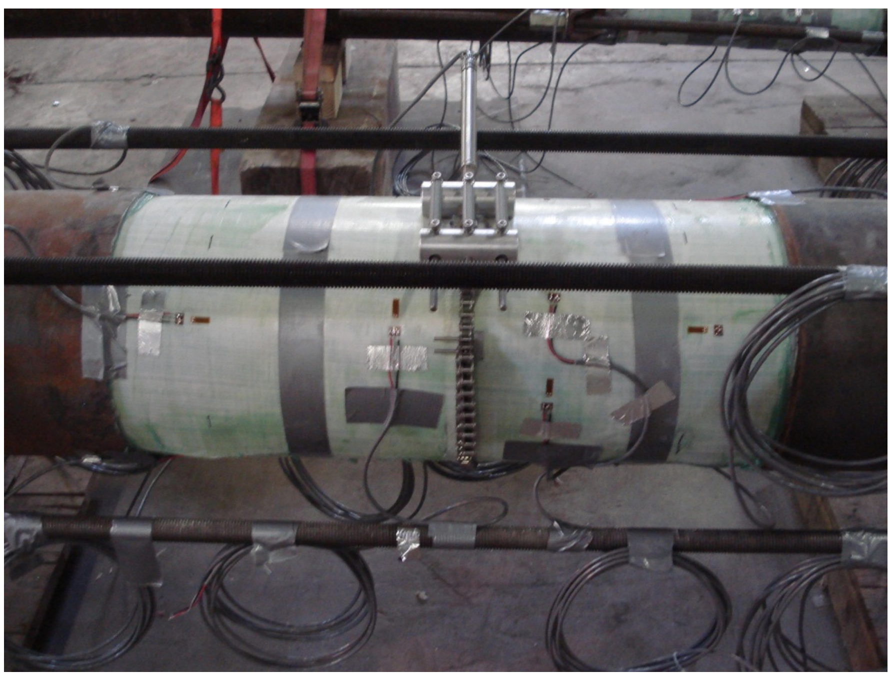

Figure 11 - The instrumented composite section in the 12-inch pipe

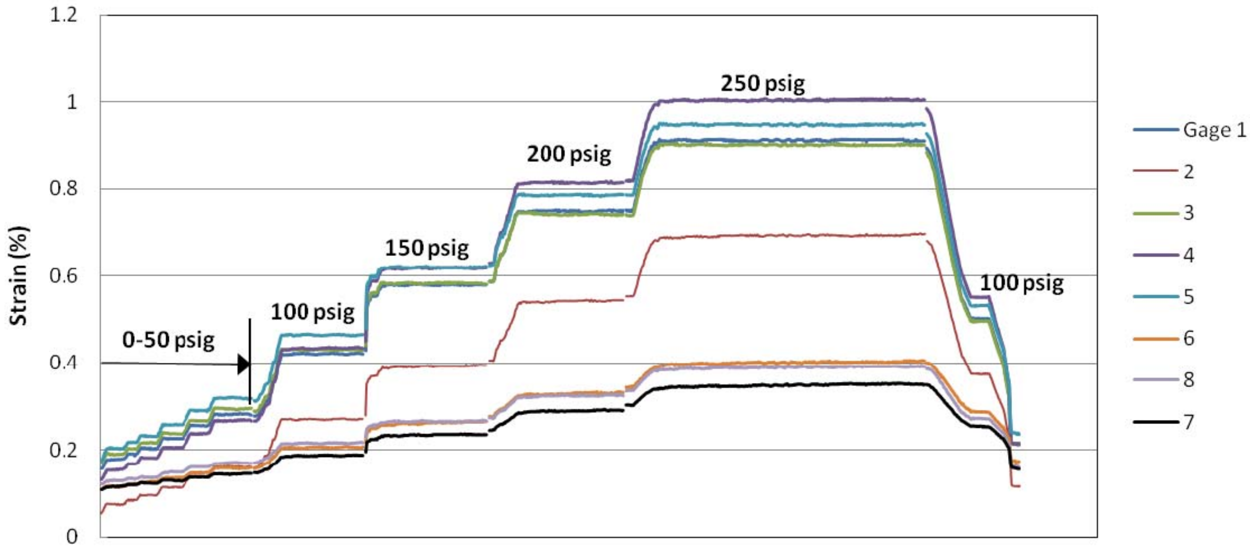

Figure 12 - Incremental strain measurements in the 12-inch pipe

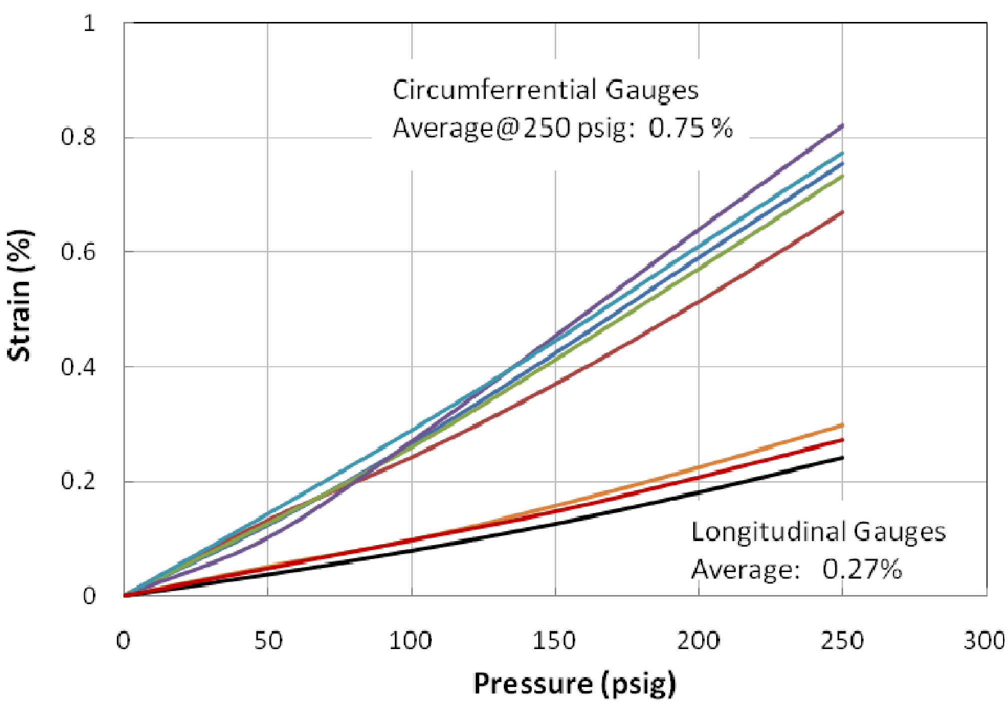

Figure 13 - Circumferential and Longitudinal strain in the 12-inch pipe

The measurements of the circumferential deformations of the composite were taken using the LVDT shown in Figure 11. Figure 14 shows the LVDT measurements and the circumferential deformations calculated from the strain gauges. The LVDT measurements had lower initial deformations, possibly due to an initial offset of the LVDT at the low pressure of 50 psig. The LVDT compared well with the strain measurements at higher pressures. The LVDT measurements are not shown for the 16-inch and 6-inch pipes due to slippage of the chain used with the LVDT in these two tests.

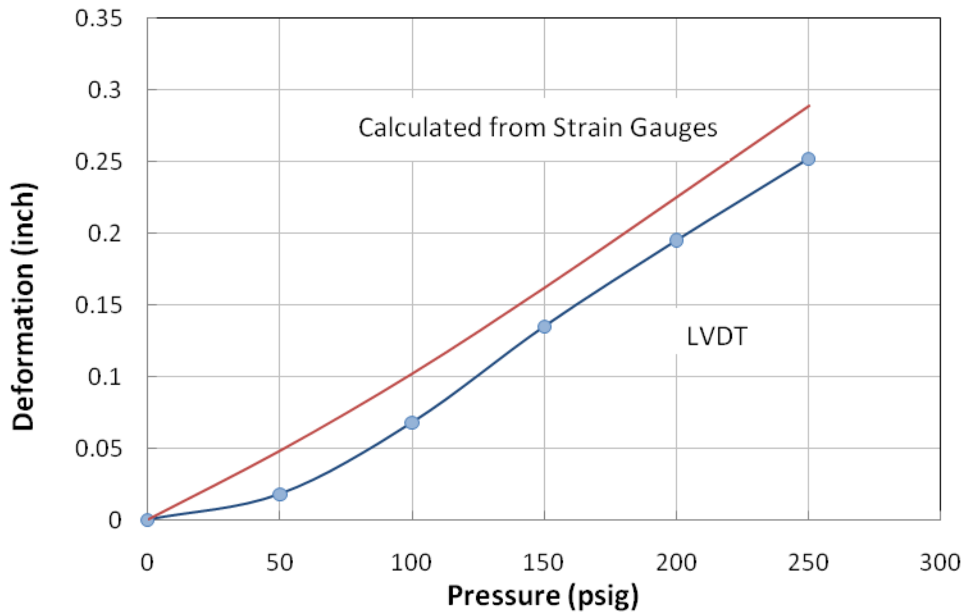

Figure 14 - Circumferential deformations in the 12-inch pipe section

c) Hydrostatic Test of the 6-Inch Pipe

The composite laminate used in the 6-inch pipe was the same type as the one in the 12-inch pipe, namely glass fiber PG16.15.The composite was wrapped in 2.5 layers and bonded inside the steel pipe. Strain gauges No. 1 to 4 were installed circumferentially and gauges No. 5 to 8 were installed longitudinally as shown in Figure 15.

Figure 16 shows the strain gauge measurements with the incremental loading. Each strain increment in the figure represents a sample of the strains at the beginning and the end of the 2-hour loading increments.

The corresponding circumferential and longitudinal strains are shown in Figure 17. The figure shows an average circumferential strain of 0.32 percent and longitudinal strain of 0.07 percent at the end of the 250 psig pressure increment.

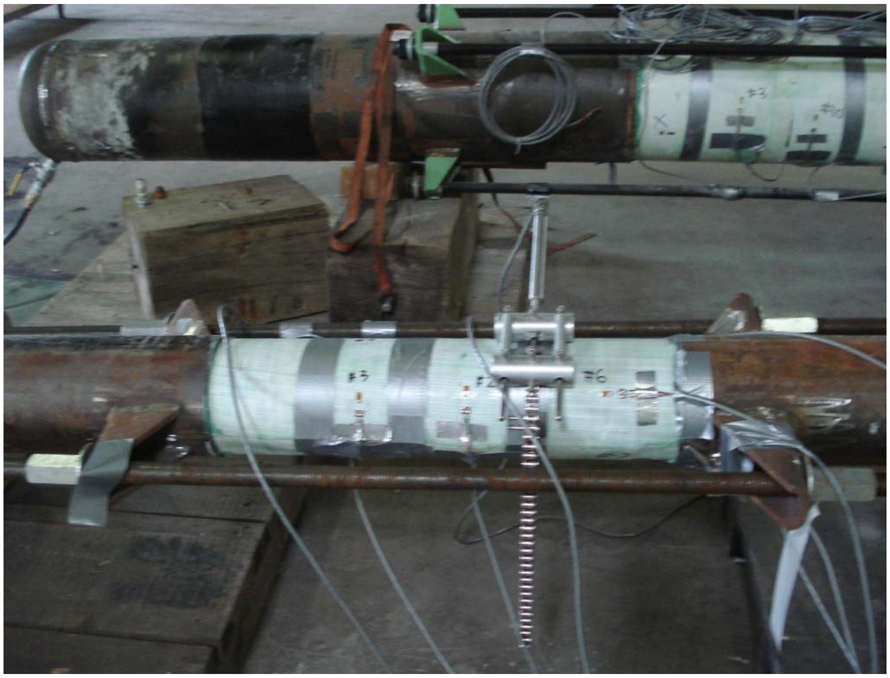

Figure 15 - The composite section of the 6-inch pipe

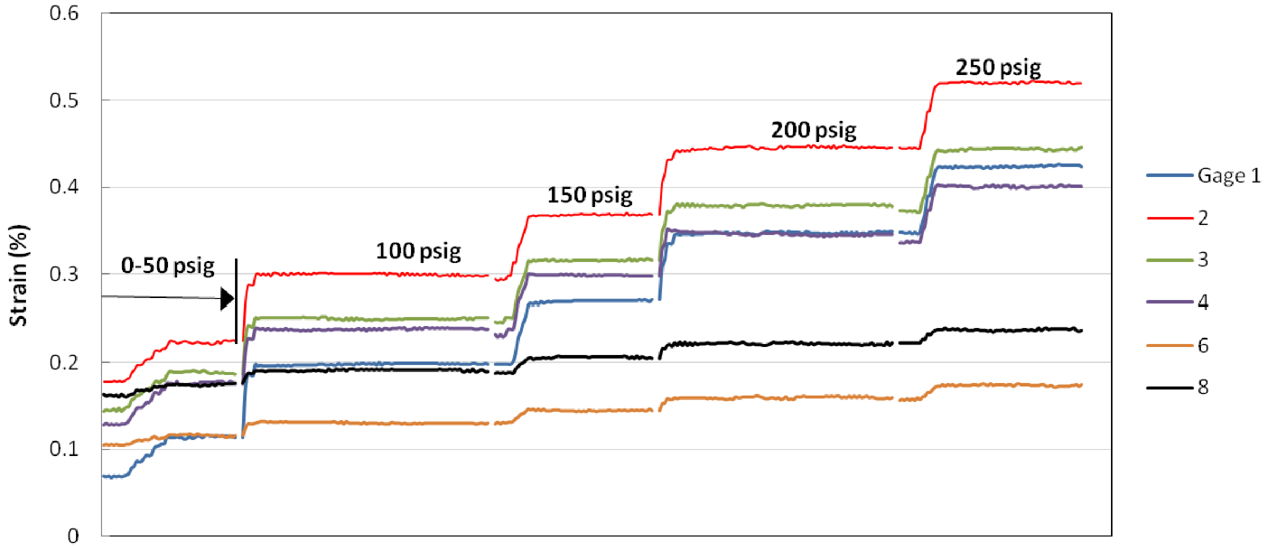

Figure 16 - Incremental strain measurements in the 6-inch pipe

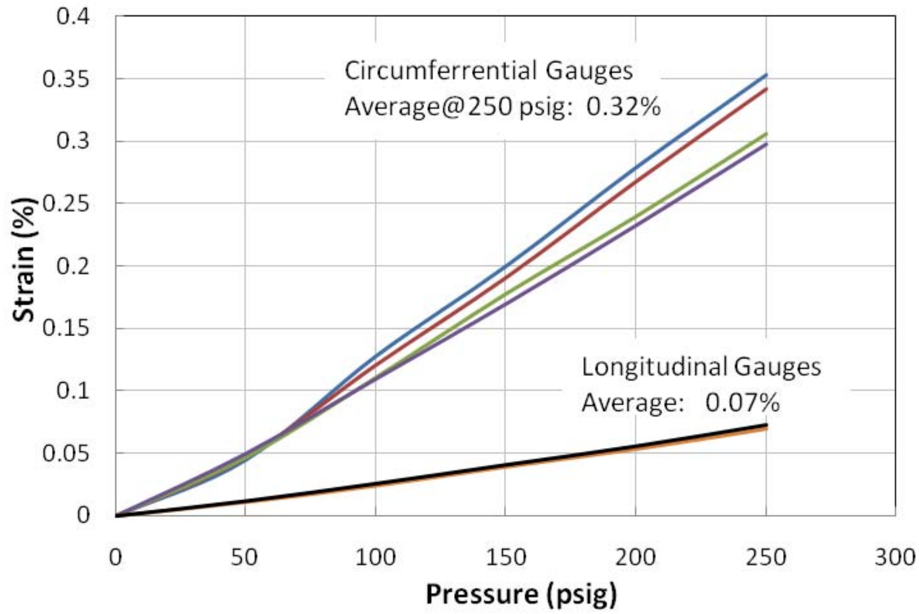

Figure 17 - Circumferential and Longitudinal strain in the 6-inch pipe

Conclusions

Hydrostatic pressure tests were performed on pipe sections with PipeMedic Fiber-Reinforced Polymer (FRP) composites. The test sections consisted of steel pipes of 6, 12, and 16 inch diameter. A 48-inch long PipeMedic composite was installed inside the pipes with 24-inch free-span length. Cured-In-Place (CIP) liners were installed inside the pipes and the pipe sections were tested under stepped hydrostatic pressures.

The hydrostatic pressure was increased every 2 hours in 50 psig increments up to 250 psig and the liner-composite sections could stand the applied pressure without leakage.

The strains of the PipeMedic sections were monitored using strain gauges. Strain measurements in the two types of PipeMedic composites in the testing program were as follows:

- In the 16-inch pipe, three layers of the PipeMedic carbon FRP type PC26.16 were tested. At the maximum pressure of 250 psig, the maximum hoop strain was 0.2 percent.
- In the 12-inch and 6-inch pipes, 2 layers of the PipeMedic fiber glass FRP Type PG16.15 were tested. At the pressure of 250 psig, the maximum hoop strains were 0.75 percent and 0.32 percent in the 12-inch and 6-inch pipes, respectively.

An estimate of the applied hoop stress (S_H) in the pipes was performed. For the pipe wall thickness *t*, the hoop stress acting circumferentially on the pipe diameter *D* due to pressure *P* is determined by Barlow's formula:

$$S_H = PD/2t$$

Table 1 shows the results of the strains and hoop stresses at pressure level of 250 psig in comparison to the ultimate strains and tensile strengths of the composite material.

Table 3 - Hoop stresses and strains of the composite pipe sections

Pipe Diameter (inch)	PipeMedic Composite	No. of Layers	Hoop Strain (%)	Ultimate Material Strain (%)	Hoop Stress (psi)	Tensile Strength (psi)
16	Carbon fiber	3	0.2	0.85	26,641	101,000
12	Glass fiber	2	0.75	1.31	28,846	62,000
6	Glass fiber	2	0.32	1.31	14,423	62,000

The PipeMedic carbon FRP is a high strength material and its hoop stress in the 16-inch pipe (with 3 layers of the composite) was about 25 percent of its tensile strength at this test pressure.

The PipeMedic carbon FRP material was too rigid for use in the smaller diameter pipes and a more flexible PipeMedic fiber glass FRP was used for the smaller 12-inch and 6-inch pipes. The 2-layer laminates of the composite in the 12-inch pipe had a hoop stress of about 45 percent of the material tensile strength. More fiber glass layers may be used in the field to reduce the hoop stress of the composite section and reach a stress level comparable to the rigid carbon fiber.

The PipeMedic composite is planned to provide a free-span section which carries the hydrostatic pressure across gaps in drip pots and inline fittings in the gas mains. This process allows for using the CIP liners for the rehabilitation of the pipes without the removal of these in-line fittings. Since the CIP liner system relies on the structural integrity of the host pipe, the PipeMedic section performs similar to the original carrier pipe. Further requirements for the qualification of carrier pipes are stated in the ASME B31.8; including the long-term performance, chemical resistance, and performance under external loads. These requirements were not a part of the testing program. However, the composite sections installed inside the drip pot enclosures are not commonly subjected to external surface loads.

The requirements for the CIP-pipe system as specified in the ASTM F-2207 standard include performing tests at pressures not less than twice the certified MAOP of the pipeline for a minimum of one hour without leakage. For gas mains operating at pressures up to 60 psig, the hydrostatic tests exceeded the above requirement and showed that the composite sections could withstand pressures up to four times the operating pressure without leakage.

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