A New Generation of FRP Laminates for Repair of Pipelines in Gas Industry

Mo Ehsani, PhD, PE, SE, F.ASCE
President, PipeMedic, LLC and Professor Emeritus of Civil Engineering, University of Arizona, 2055 E. 17th St.,Tucson, AZ 85719; (520) 791-7000

ABSTRACT

The development of a new type of carbon and glass FRP laminate is introduced. The laminates offer unique solutions for strengthening deteriorated pipes. Independent tests have demonstrated that the laminate can bridge an opening as large as 24 inches without the need for a supporting pipe. The first application of this product to repair a cast iron gas main was recognized by the Trenchless Technology's *2011 Project of the Year Award*.

INTRODUCTION

The September 9, 2010 explosion of the 30-inch gas pipeline in San Bruno, CA was a stark reminder of the danger of our aging infrastructure. Within hours, 47 million cubic feet of natural gas was released. The gas explosion blasted a crater about 72 feet long and 26 feet wide and caused flames as high as 300 feet that resulted in 8 deaths, numerous injuries and millions in loss of property. The National Transportation Safety Board (NTSB) conducted a detailed investigation of this failure and published its findings nearly a year later (NTSB 2011). The cause of failure was the faulty welds in the 54 year old pipeline. "The accident pipe would not have met generally accepted industry quality control and welding standards in 1956," the report states, "indicating that those standards were overlooked or ignored."

Among the recommendations made by NTSB was to assess the condition of the pipes and if required repair or replace the deteriorated pipes. The challenge, however, is that many of these transmission lines run through populated areas and replacement would be prohibitively expensive. At the same time, while various methods for repair and strengthening of water and sewer pipes have been developed, few options are available for pipelines in the oil and gas industries.

This paper focuses on the development of one such product that has been independently tested and approved. The first application of this product by the Public Service Electric & gas Company (PSE&G) of New Jersey was recognized by the *2011 Trenchless Technology Project of the Year Award*.

PipeMedic™ Laminates

The development of PipeMedic™ laminates began in 2008 (Ehsani, 2009; Figure 1). Using a special manufacturing process, these laminates are constructed with one or more layers of carbon or

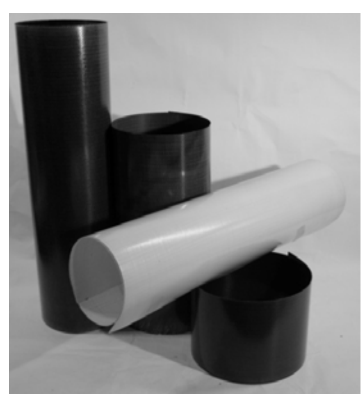

Figure 1. PipeMedic Laminates

glass fabric saturated with resin and pressed together to form a very thin solid sheet. The laminates are manufactured in rolls 4-ft wide x 150-ft long that can be easily cut to any size in the field. With a thickness of about 0.01-0.025 inches, the laminates are flexible enough to be coiled for insertion into pipes as small as 4 inches in diameter. The tensile strength of the laminates ranges between 60,000 – 145,000 psi.

It is noted that while thicker, unidirectional carbon plates have been available for years, that technology could not be used to manufacture the aforementioned laminates. Therefore, the development of this new generation of laminates is not a trivial matter.

The high strength of the laminates in two orthogonal directions allows them to resist both hoop and longitudinal stresses that could be present in certain applications. Furthermore, these laminates incorporate a thin glass veil on both surfaces; this allows the laminate to be in direct contact with steel pipe surfaces without any concern about galvanic corrosion that could result by allowing carbon fabric and steel to come in contact with each other.

The first application of these laminates was for bridging the gap in a gas main caused by an abandoned drip pot. The challenges in that application, the testing and field application are described below.

BRIDGING GAPS IN GAS PIPES

The earlier manufactured gas contained hydrocarbon fluids. In design of gas mains, 2-3 ft wide drip pots were frequently installed to collect these solutions that would be periodically syphoned at the street level through standpipes (Figure 2). Today's manufactured gas has no condensation and thus there is no need for these drip pots. As utility companies renew gas mains with Cured-In-Place (CIP) liners, these liners cannot bridge the gap created by abandoned drip pots; that is, the "non-structural" liners require a host pipe to resist the internal pipe pressure. There are also occasional abandoned T connections that introduce similar problems for lining with a CIP liner.

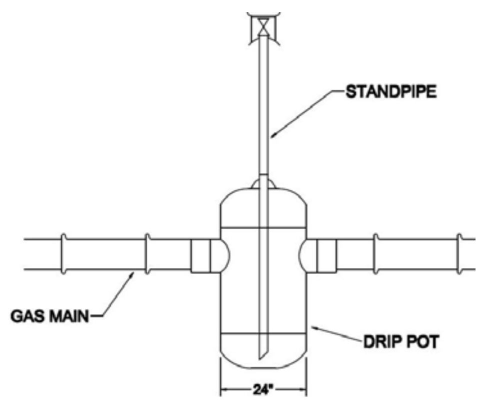

Figure 2. Drip pot

In many cases, these drip pots or abandoned Ts are in hard-to-reach places where open trench repair techniques to add a new steel pipe are not viable. The challenge then is to create a structurally strong pipe that would span across that gap and would provide support for the CIP liner. The ideal product must also be suitable for trenchless installation from access points that may be several hundred feet away.

Faced with this challenge, the PSE&G engineers became interested in the laminates that had just been developed. It was decided to demonstrate the feasibility of this approach at the contractor's facilities. Simulating the pending field application, two 16-inch diameter pipes were positioned with a 24-inch wide gap between the pipes representing the unsupported span or gap across the drip pot.

Considering that the 18 inch pipe has a circumference of 4.2 feet, a 13.5 ft. long piece of laminate was required to provide a 3-ply liner with a 12-inch extension. The 4-ft wide laminate would span the 2-ft gap with a 1-ft support length resting on each of the steel pipes. The major steps for installation include the following:

1. Apply adhesive to the laminate (Figure 3a).
2. Wrap laminate around the inflatable bladder (Figure 3b).
3. Insert the bladder into the pipe (Figure 3c).
4. Inflate the bladder to expand laminate at simulated drip pot gap (Figure 3d).
5. PipeMedic™ laminate section bridging 24-inch gap and curing (Figure 3e).

(a)

(b)

(C)

(d)

(e)

Figure 3. Steps in field demonstration: (a) apply epoxy to laminate, (b) wrap laminate around inflatable packer; (c) insert assembly into pipe, (d) position the assembly over gap that simulates drip pot location and inflate packer, and (e) completed installation.

The successful demonstration affirmed the concept that laminates could be used to act as a bridge spanning across the gap introduced by the presence of drip pots. A video of this installation can be viewed online (PipeMedic 2009).

TESTING AT GAS TECHNOLOGY INSTITUTE

Before the laminates could be used on the pipeline renewal job, the material's strength and stiffness and its suitability for such an application had to be tested and confirmed. Gas Technology Institute (GTI) was selected by PSE&G to develop a test protocol that would satisfy the requirements of ASTM F-2207 and manage the overall testing program of using the laminates for rehabilitation of gas pipelines. GTI's work included providing and installing the necessary instrumentation, overseeing and conducting the testing, analyzing the test data and presenting the results of this work in the form of a final report with appropriate recommendations (Farrag 2011).

Testing was performed by GTI personnel at the contractor's facility. The testing program included testing three pipe diameters. The first sample was the 16-inch diameter pipe that was constructed during the demonstration phase (Figure 3); that repair included 3 plies of a biaxial carbon laminate. In addition, two smaller samples with diameters of 6 and 12 inches, respectively, were constructed and tested. These two specimens were retrofitted with a biaxial glass laminate applied in two plies. All three specimens included a 24-inch free-standing laminate section, which extended an additional 12 inches into each side of the pipe.

The laminate-steel pipe system was lined with CIP, capped at both ends, thrust-restrained and connected to a hydraulic pressure system to apply controlled test pressures. Strain gages and displacement sensors were installed as shown in Figure 4 to monitor circumferential and longitudinal strains in the laminate during the loading.

Figure 4. Instrumented laminate during test.

The requirements for the CIP system as specified in ASTM F-2207 include performing test at a pressure not less than twice the certified maximum allowable operating pressure (MAOP) of the pipeline for a minimum of one hour without leakage. For these gas mains, MAOP is 60 psig. All pipe sections were tested under hydrostatic pressure that was increased every two hours by 50 psi up to the maximum pressure of 250 psi, more than 4 times the MAOP.

Sample strain measurements for the 16-inch pipe are shown in Figure 5. The measured strains in the laminate were about 1/4 the ultimate values, indicating that the system could have resisted pressures as much as 900 psi. The loading imposed on the laminate causes a combination of hoop and longitudinal stress. This can be seen from the measured strains. The longitudinal gauges that were positioned at 4 inches from the end of the laminate, recorded an average strain of 0.085% that is 43% of the average strain measured in the hoop direction. This clearly demonstrated the importance of a laminate constructed with sufficient strength in longitudinal and transverse directions to resist the imposed loads.

The test results further demonstrated that the liner–composite sections could stand the applied pressure without leakage.

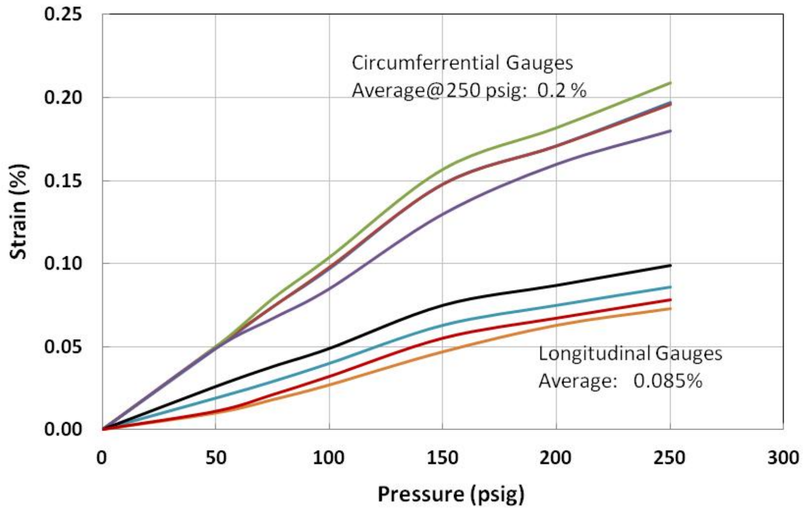

Figure 5. Measured strains in the laminate.

FIELD INSTALLATION

The first installation of PipeMedic™ was in a 16-inch pipe in Paterson, NJ. The installation was completed in February 2011 by Progressive Pipeline Management (PPM) with supervision and training for the installation of PipeMedic™ provided by QuakeWrap. The overall length of the pipe to be lined was 700 feet and the drip pot was located directly under the railroad tracks nearly 85 feet away from the access point (Figure 6). Considering the adverse winter weather, the job offered unique challenges that had to be overcome (Carbone et al. 2012).

A closed circuit camera was used to locate the exact location of the drip pot and the installation followed the steps described in the demonstration project. In carrying such repairs, the standpipe inside the drip pot has to be removed . PPM developed a robotic arm to cut the ¾ inch steel standpipe that was obstructing the installation (Figure 7 a). The robot cut the standpipe in two locations (below the invert and above the crown) allowing the standpipe pieces to fall inside the drip pot. The pipe was also laden with debris (Figure 7b) that had to be blasted away to achieve a clean uniform surface (Figure 7c).

The bladder was also modified by adding a sled that would allow it to cross the 24-inch opening without falling into the drip pot. Figure 7d shows the laminate ready to be inserted into the pipe and Figure 7e shows the installed laminate. The next step was the lining of the complete 700-ft section with the CIP liner. As shown in Figure 7f, the small thickness of the laminate (nearly 0.1 inch) makes it virtually undetectable after the liner has been installed. The newly lined pipe is expected to

Figure 6. Project site showing the existing pipe layout and drip pot location under the railroad tracks.

last fifty years, which was the same service life for the pipeline when it was originally installed.

The many unique features of this application resulted in the the project receiving the *2011 Trenchless Technology Rehab Project of the Year Award* (Bueno 2011).

IMPLICATIONS OF THE REPAIR

As noted earlier, the primary cause of failure for the San Bruno pipe accident was the weak welds in the aging pipeline. In many cases, a very small weakened or corroded portion of the pipe can result in a catastrophic failure. The project described here clearly demonstrates how such pipes can be retrofitted even when large pieces of pipe have become weak; in the extreme application shown here, *a 24-inch piece of the pipe was totally missing*. The repair system presented here can significantly benefit the gas industry by allowing it to repair rather than replace such deteriorated pipes.

It is recognized that the spot repair presented here is somewhat time-consuming for repair of long sections of pipelines. To that end, the author is focusing on development of robots that allow the installation of these laminates in a much more efficient manner. Such robots could, for example, apply 1-ft wide bands of these laminates in a continuous spiral manner on the inner surface of the pipe. The development of such technology would have a significant impact on public safety as well as maintenance and construction costs as the gas pipelines rapidly approach their design service life.

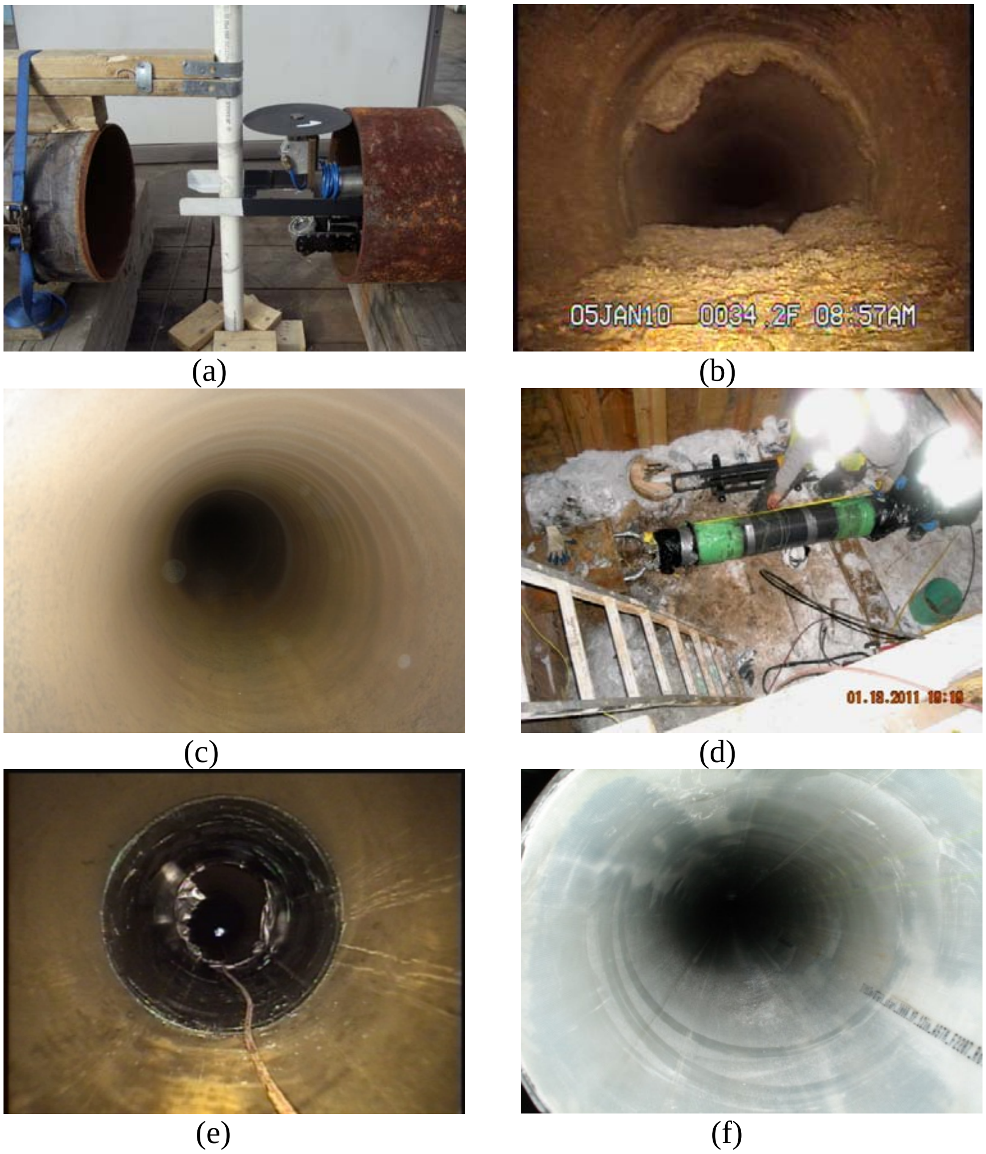

Figure 7. Field installation: (a) robot to cut the standpipe, (b) debris-laden pipe, (c) cleaned pipe, (d) laminate and packer assembly, (e) laminate installed across the drip pot, and (f) completed installation.

SUMMARY AND CONCLUSIONS

The paper describes the development of a new generation of FRP laminates that offer unique structural capabilities for repair and strengthening of pipelines. Independent tests by GTI have proven that unlike other liners, these laminates can bridge a gap in a pipe, creating a very strong pipe without the need for the support of a host pipe. The first application of this product was completed in 2011 and was recognized by a major industry award. It is envisioned that this technology along with the development of robots that would allow faster installations could have a profound impact on how the aging gas pipeline infrastructure will be rehabilitated.

ACKNOWLEDGEMENT

The PipeMedic™ laminates and method of repair of pipes described in this paper are subject to pending U.S. and international patents by PipeMedic, LLC. Support of the Progressive Pipeline Manufacturing staff in testing and field installation is greatly appreciated. Funding of the testing program was provided by PSE&G.

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