FlexiTube®: Trenchless Strengthening of Pressure Pipelines

by
Mo Ehsani, PhD, PE, SE
Professor Emeritus of Civil Engineering, U. of AZ and President, PipeMedic, LLC
Mo@QuakeWrap.com; Tel: (520) 250-7020

This paper describes a new patent-pending technique for repair and strengthening of oil and gas pipelines and seeks industrial partnership for testing and further development of the technology.

Background:
This paper describes a patent-pending economical technique (called *FlexiTube®*) for repair and strengthening of pressure pipes used in oil and gas industries. These pipes may have diameters ranging between 6-48 inches which would be impossible or very costly to repair with current techniques.

Introduction:
At least once a month, there is a major news story about a gas pipeline failure, explosion, death, etc. The most severe recent failure in the U.S. was the San Bruno pipeline and the news of how PG&E is dealing with the $11 billion dollar repair bill still lingers in the media. Just this week there was another news story about a federal lawsuit settlement caused by a gas line explosion due to corroded welds. With billions of dollars spent on repairs and fines and considering the aging pipeline infrastructure there is clearly a need to address this issue and develop cost-effective methods to strength and extend the life of these pipelines.

The method presented here can be used to strengthen any pipe including cast iron and steel pipes for larger through-put capacity. This technique works equally well for corroded pipes and undamaged pipes. In both instances, the installation of FlexiTube® will strengthen the pipe so that the pipe can be operated safely at a higher pressure which would allow for a larger volume of materials to be transported through the pipe.

Traditional design of pipes in the oil and gas industries has relied on the Specified Minimum Yield Strength (SMYS) of the steel. Typically a design value of 20-25% of SMYS is selected as the allowable pressure based on the classification of the pipeline. As described in more detail in the section on Design Alternatives the proposed repair approach may require a reexamination of this limit in light of the proposed strengthening technique.

Objective:
The objective of this study is to:
1. Demonstrate the feasibility of using a flexible carbon liner to strengthen existing pipelines,
2. Develop the proposed tooling and equipment necessary to allow for fast and trenchless repair of long segments of pipes with FlexiTube®.

Proposed Technique:
Based on 25 years of research and development on applications of Fiber Reinforced Polymer (FRP) in infrastructure, and having received several awards for repair of pressure pipes, we are developing a new trenchless technique that will allow economical repair of long segments of pressure pipelines. FRP is constructed of fabrics made with glass or carbon that are saturated with epoxy resin; when they cure they reach a strength about 3 times that of steel. Depending on the type of fabric used, carbon or glass, the end product is referred to as CFRP or GFRP, respectively.

The patent-pending technique involves the use of braided tubes made of high- strength, high-modulus carbon fibers as shown in Fig. 1. The tube has a thickness of less than 0.05 inches. Unlike all other FRP tubes used in repair of pipes that have a fixed diameter, the unique design of these tubes allows them to change their diameter by approx. ± 25% of the base diameter. For repair of steel pipes, the tube can include an outer glass skin layer to prevent galvanic corrosion by avoiding contact between carbon and steel

Fig. 1. Sample of FlexiTube®

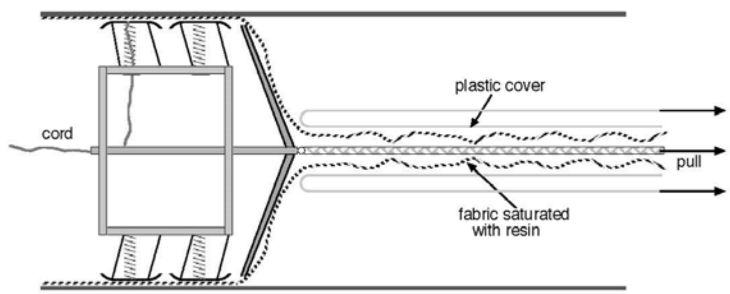

Fig. 2. Saturated braided tube positioned inside a plastic bag being installed in a host pipe

While the installation can take many forms, one approach is to saturate the braided tube with resin and pull it into the host pipe; the resin has a very long pot life at ambient temperature, which gives the workers ample time to complete the repair. A simple robot or pig can press/expand the FlexiTube® against the host pipe (Fig. 2). Heated plates or heating lamps, etc. can provide the required 200-300F temperature that will cure the resin in several minutes! We can also use resins that continue to cure on their own once the heating source is removed after a couple minutes. If necessary, a second braided tube can be similarly installed to further increase the pressure rating of the pipe. A final sprayed coating such as polyurea or a liner such as Starline™ can be applied to seal the inside of the pipe and make it fully impervious.

Design Alternatives:
As stated earlier, the traditional design of steel pipes relies on SMYS. FRP Products in general have a lower modulus of elasticity than steel; CFRP has a modulus of roughly 40% that of steel while glass FRP has a modulus of about 20% that of steel. Consequently, when a pipe is lined internally with FRP, as the pipe is pressurized, initially a larger portion of the load is resisted by the host steel pipe until the steel yields. At that point, the post-yield

stretching of the pipe will not take place since the FRP liner will begin to resist the internal pressure until the FRP fails in tension. That is, a CFRP liner will increase the ultimate failure pressure of the pipe after the steel has yielded. So, one option is to re-examine the concept of SMYS for pipes that have been subsequently lined with CFRP. This is a task to be undertaken by the appropriate technical committee(s). Perhaps a higher, e.g. 40% of SMYS is not unreasonable for such pipes considering that the ultimate capacity of the repaired pipe (the sum of the original pipe strength and that of the CFRP liner) has been raised significantly.

A second approach for calculating the allowable pressure in pipes repaired with CFRP is to recognize the fact that the CFRP liner will stretch as it is subjected to internal pressure. It is possible to first line the pipe with a thin coat of a compressible material. This material can be sprayed on the pipe surface. Depending on the pipe diameter, a small thickness, e.g. 0.05 inch may be sufficient. Under this scenario, the CFRP liner can be designed to take the entire operating pressure of the pipeline, relieving the old steel pipe of any internal pressure! As the CFRP liner is pressurized, it will expand and that expansion will cause a reduction in thickness of the sprayed compressible coating, without transferring any of the pressure to the host pipe. This concept of “a pipe inside a pipe” may be attractive as little if any reliance will be placed on the original pipe for any future operations once the lining is complete.

In consultation with our industry partners, we will determine which of these two alternatives may be more appropriate for the proposed repair system.

Advantages:
FlexiTube® offers significant advantages over current methods of repair of pressure pipes. These include:

1. The braided carbon tube can be designed to resist high pressures independent or in conjunction with the host pipe (depending on which design alternative is selected);
2. Long segments of pipe (over 2,000 feet) can be repaired in a single step;
3. Pipes in diameters of 6-48 inch are ideal candidates for this technique;
4. The trenchless technique only requires a small access point (less than 12-inch in diameter) at each end of the repair segment;
5. The CFRP tube liner offers excellent durability and long service life;
6. The long pot-life of the resin at ambient temperature makes the repairs easier;
7. The unique construction of the flexible braided tubes allows them to be installed through elbows and bends; the diameter of the tube will change in these regions allowing the tube to remain in full contact with the host pipe at all points throughout the bend; conventional FRP liners create a choke point at those locations;
8. The technique is very cost-effective.

Proposed Research:
There is certainly good justification for using a small fraction of the SMYS for the design of new steel pipes. In recent years, however, the use of fiberglass pipes in oil and gas industry has risen. Fiberglass is an inferior version of the FlexiTube® system we are proposing here. But like FlexiTube®, fiberglass does not yield prior to failure. So there is already a precedent for using “non-yielding” materials in at least some segments of the gas pipeline

industry. We will take advantage of these developments as we try to develop new design guidelines for our proposed retrofit system.

It is worth noting that similar issues have been encountered in other industries. For example, the use of FRP to retrofit beams and columns in buildings and bridges (a field that I pioneered in the late 1980s) was also initially viewed skeptically. Engineers preferred using steel that would yield prior to failure. However, gradually that view point changed. As more test results and case studies became available, engineers became more open to embracing these new approaches as long as they were safe and met the intent of the current codes and standards.

For these reasons, I see major advantages if we follow the second Design Alternative that was introduced earlier. In this approach we will insert the FlexiTube® inside the host steel pipe and all future internal pressure will be resisted by the FlexiTube®, leaving the old host pipe to primarily serve as a shell that would resist gravity loads from soil overburden and traffic, etc. The overall research activity can be divided into multiple phases; possible scenarios are described below.

Phase I: Proof of Concept – Before we try to seek input from various agencies as to possible changes in design philosophy, it is prudent to conduct one or two preliminary tests to demonstrate the proof of concept. This will eliminate months or years of discussion among various committees for a system that may ultimately be proven ineffective! Against that background, it is proposed that we construct one or two test samples as shown in Fig. 3. The test specimen will comprise of the following parts:

1. A steel pipe representing the existing host pipe
2. A layer of compressible material about 0.1 inch thick applied to the interior surface of the steel pipe; this material will most-likely be sprayed on the pipe surface
3. A layer of Carbon FlexiTube® saturated with resin and cured in place such that it is in full contact with the inside face of the compressible layer; we have special heating laminates that can be coiled and inserted inside the pipe to raise the temperature of the resin to 200-300F for the curing
4. An impervious coating or an airtight hose that will prevent any leakage, for example a cured-in-place liner.

Our hypothesis is that as the pipe is internally pressurized, the FlexiTube® will resist the pressure. The FlexiTube® will stretch slightly in the radial direction and this will cause the compressible material to become thinner, but in this process no load will be passed on to the host steel pipe. That is why the use of the compressible material is a major part of this repair that will shield the steel pipe from exposure to any stresses caused by the internal pressures. To validate this hypothesis, we plan to perform the following test.

The ends of the pipe assembly will be sealed and it will be filled with water. Strain gages will be mounted on the outside surface of the steel pipe. The water in the pipe is gradually pressurized internally, and we will monitor the strains on the outer surface of the steel pipe. The test will be successful if we can show that there is little or no increase in the strain in the pipe while we increase the pressure inside the pipe. We will also test an identical unretrofitted steel pipe as a control specimen and compare its performance with the retrofitted pipe. FlexiTube® can be designed to withstand different pressure levels. To keep the cost down, we will use one of our current samples of FlexiTube®. Once the proof of concept is successful, we can change the design of the FlexiTube® to resist higher pressures (if necessary) in future tests.

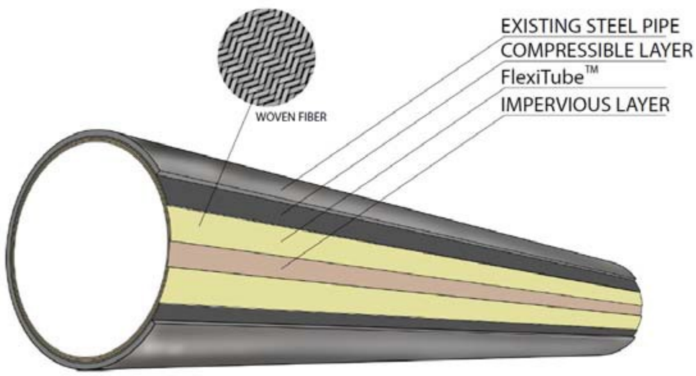

Fig. 3. Proposed test specimen for Phase I investigation

Phase II: Product Development - If the proof-of-concept tests are successful, then a more comprehensive R&D effort must be undertaken before this system can be implemented in the field. Below is a list of some of the key tasks to be undertaken for the development of this technology; these may be done in one or more phases:

1. Perform a more comprehensive testing of pipes of various sizes repaired with FlexiTube®; these tests may be conducted at an independent agency such as the Gas Technology Institute.
2. Develop the tooling and equipment necessary for saturating and transporting the FlexiTube® inside the pipe, heat curing of the resin, ability to handle bends in the pipe, applying the compressible material to the pipe surface, etc.
3. Perform a field demonstration project (possibly including pressurization of the pipe) and document the results.

A part of this R&D effort requires discussion among pipeline owners, regulators, design engineers, etc. to reach a consensus as to how this new promising technology can be safely incorporated into codes and standards for rehabilitation of pipelines. There are many issues such as the regulatory requirements and standards that the new liner has to be tested to, how to classify the new liner, what ASTM to follow (or perhaps develop a new one), etc. These are all valid questions that require input from the larger community. Other researchers who have looked at internal repair of pipes in the gas industry using FRP products have also faced similar concerns. For example, Bruce et al. (2006) note that:

"*We can define several criteria for acceptability of the liner repair. One will involve the strength of the liner under maximum pressure. One simple test is that the liner should not be at greater risk of bursting than the remote un-repaired pipe under the pressure to reach a stress equal to the standard minimum yield strength of the pipe material. Using Barlow's formula, the pressure P to reach this hoop stress in the remote pipe is SMYS t/R or 11.3 MPa (1,646 psi).*"

While we will participate and provide technical input, I believe such an undertaking is beyond the scope of this study which is primarily focused on the development of a new technique for retrofit of pipes. In fact, to maintain impartiality of the results, no single system-provider should be allowed to develop these guidelines on its own. We will gladly join the industry leaders and collectively develop the appropriate standards, test methods, quality assurance protocols, etc.

Moving Forward:
We are seeking "seed level" funding from the industry to perform only the Phase I research as outlined above. The work can be done either at university or government laboratories or in collaboration with pipeline contractors such as Progressive Pipeline Management, West Deptford, NJ. We have an excellent working relationship with this company. In 2011 we jointly received the Trenchless Technology Project of the Year Award for internal repair of a 16-inch (400mm) gas main for PSE&G using another CFRP laminate system that I have developed.

Depending on the outcome of the Phase I study, we will examine how it is best to pursue the Phase II of this study.

References:
Bruce, B., et al. 2006. "Internal Repair of Pipelines – Final Technical Report," DOE Award No. DE-FC26-02NT41633, Edison Welding Institute, Columbus, OH 238 pp. *(A copy of the report is available on our website at http://goo.gl/msYnA6).*