New Process For Structural Rehabilitation of Pressure Pipelines

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ABSTRACT

For the last twenty years rehabilitation of gravity pipelines by the cured-in-place pipe (CIPP) process has met with great success. Conversely, pressure pipe rehabilitation with this process has met with limited commercial success. There are fundamental, and seemingly intractable, issues that explain why this technology has not been overly successful for pressure applications, primarily the formation of an annulus between the host pipe and the liner. The annulus makes pressure pipe lining a significant challenge for all heat-cured, or heat-assisted, lining systems.

Protective coatings are routinely used in pressure pipelines. However, once a pipeline deteriorates beyond a certain point, often from external corrosion, the load bearing capability of the pipe cannot be regained with simply a protective coating.

Use of specialized, ultra-high-build, room temperature curing polymer materials and newly developed application tools portends an important evolutionary blend of protective coatings and CIPP concepts. The hybrid technology appears to be a viable solution for pressure pipeline structural rehabilitation. It has the capability to line virtually any type and any pipe diameter; asbestos cement, steel, cast iron, ductile iron, cement, clay, PVC and even well casings and other bores to thousands of feet in depth. Chemical resistance is highly adaptable through availability of many thermosetting polymer types suitable for use with the new process. Municipal entities, chemical, natural gas and petroleum companies will benefit by having a new no-dig rehabilitation process option to employ.

Keywords: structural, coating, protective, pipeline, pressure, polyurethane, polyurea, furan, polyester, phenolic, epoxy, industrial, potable, water, chemical, petroleum, municipal, ANSI/NSF, NSF, Standard 61, trenchless technology, rehabilitation, no-dig

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INTRODUCTION

In the last twenty-five years more than 70,000,000 linear feet of cured-in-place pipeline (CIPP) rehabilitation work has been performed on gravity pipelines in North America [1]. However, lining of pressure pipelines with this type of technology has proven to be more challenging than initially anticipated. A variety of pressure pipe protective coating systems are suitable solutions for non-structural protective lining purposes, but they cannot develop the strengths needed for rehabilitation of full-length deteriorated pipes. Some coating systems can be modified for very short length structural rehabilitations. A synthesis of CIPP design concepts with highly modified protective coating materials and concepts has led to the development of a promising new spray-on CIPP structural rehabilitation system. This paper reviews traditional pipeline protective coating processes and equipment, structural liner issues and describes how combining their best attributes yields a system which delivers an effective new tool to the pipeline owner.

BACKGROUND

<u>CIPP Pressure Pipe Lining Systems.</u> Since 1975, cured-in-place pipeline gravity sewer rehabilitation with a resin-impregnated felt carrier tube has been in commercial service throughout North American. The felt carrier tube is a means by which the structure-building, corrosion resistant, resin is placed against the pipe wall. A valuable and cost effective rehabilitation product, CIPP is widely accepted throughout the world. Attempts at employing this liner technology to deliver a commercially reliable pressure pipe product operating at greater than 50 Psi has been a generally disappointing endeavor.

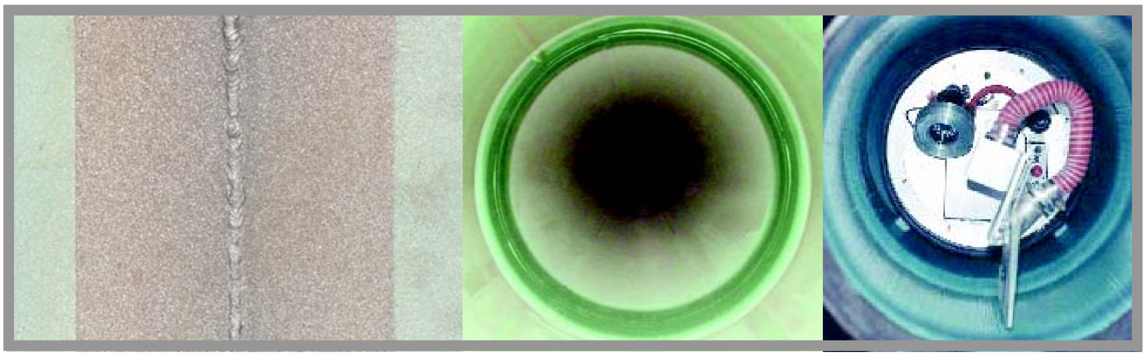
Various high performance reinforcing materials, installation techniques, resin types and cure strategies have been employed, but none have overcome one fundamental issue of physics; regardless of the type of liquid resin used, when heated the liquid expands volumetrically. After conversion to a solid and subsequently cooled to room temperature, it shrinks. A material’s coefficient of linear expansion and contraction is an unavoidable, and entirely predictable, physical response to temperature change. This is a very powerful force in which the volumetric expansion is about three times the linear coefficient [2]. The force cannot be eliminated, or ignored. When cooled, the new liner becomes smaller than the host pipe and an annulus develops that results in the liner having to bear the full weight of internal forces.

Gross service pressure fluctuations in high-pressure systems (hammer) may combine with localized pressure changes to create significant dynamic movement within what must be conservatively considered a non-bonded, flexible membrane. Ultimately, the membrane may fatigue sufficiently to fail as stress is placed on the defects created during the installation process and by unavoidable localized weaknesses created during liner manufacturing. High strength reinforcement fibers can help a liner handle greater forces, but the cost impact can be significant.

The many dynamics influencing installed cured-in-place linings make performance difficult to reliably characterize. Pressure liner design is a real challenge to the manufacturer, particularly when considering the ultimate installed cost to the pipeline owner.

<u>Robotic Applied Joint Coating Method</u>. Joint coating is routinely performed with remotely controlled robotic equipment [3] that, under self-contained power, is often driven up to 5,000

feet into pipelines, and under special circumstances to 10,000 feet. Robot functions are controlled with low-power radio frequency signals. Primarily used to coat the inside of welded joints, the robot is also capable of localized structural rehabilitation as well as short-length protective linings. Coating volume is limited to onboard capacity, but can be extended when either a resin carrier unit or supply umbilical is attached.



a) Grit Blasted Surface   b) Coated Joint   c) Inspection

Figure 1. Depiction of the dual-pig lining process

Proper pipe cleaning is needed to assure an adequate coating bond. One of the many unique capabilities of the robot is its on-board grit-cleaning tool. Surface preparation to NACE standards is achieved that has proven to deliver long-term coating durability.

<u>Dual-Pig In Situ Lining Method</u>. This method uses a pair of pigs with a slug of resin constrained between them "extruding" resin onto the pipe wall while propelled through the pipe. A very thin film is deposited at each pass, with three passes typical. Surface preparation includes mechanical and chemical cleaning, followed by surface pacification, drying and coating. The cleaning process is effective and excellent bond strength is achieved. The process is suitable for protective coating of very long of pipes without side connections (Figure 2) [4] [5].

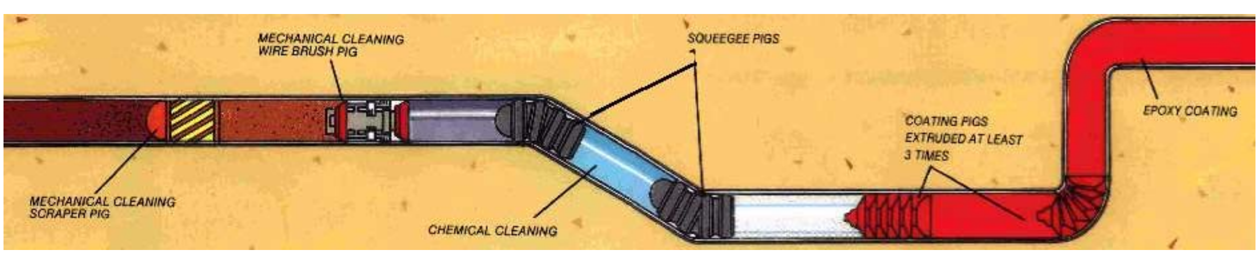


Figure 2. Depiction of the dual-pig lining process

Reciprocating Pump Driven Pipeline Coating Systems. In situ spray-on protective coating of water pipelines has been commercially performed for about two decades. The applicator heads are fed by reciprocating, air-driven slave pumps feeding hoses of sufficient length to coat up to 600 linear feet. Low viscosity resin is centrifugally expelled through a high-speed rotating applicator head to create a thin-wall, protective, non-structural coating.

The coating is generally used in pipes of 2 to 24 inch diameter, although more commonly in the range of 4 to 18 inches and applied at 40-mils. Building a structural wall is not possible since the resin readily drains or “slumps” on vertical surfaces when applied at higher thickness. This lining system was developed in England [6] to improve water quality. Issues such as pinholes, “fisheyes” and slump are concerns.

Reciprocating pumps, although almost universally employed to move coating resins, induce uncontrollable variables when lining pipelines with a centrifugal casting head. A description of the reciprocating pump equipment’s operating principal will help to illustrate the issue. One of the most powerful and sophisticated examples of reciprocating pump equipment is the Graco SuperCat [7]. This pump delivers up to 6.1 gallons per minute at 3333 psi when cycling at 40 pump strokes per minute; twenty strokes up, twenty strokes down.

As the pistons reach the end of their stroke, and reverse direction, they momentarily stop. At this point, a discernable pressure drop occurs. The direction changes and corresponding lack of pressure is readily observed at the fluid pressure gauges when the indicator needles rapidly drop. The rapid zero-flow and recovery is transmitted through the length of fluid hose as a shock wave. When the hose ends are open, the shock is apparent as a regularly repeating fluid pulse. The flow generally does not completely stop since, when the pump is moving, the hose accumulates pressure through expansion and upon contraction helps continue the flow, although at rapidly dissipating volume.

Pulsation is not generally a significant problem with typical high-pressure spray systems since they use small orifice spray nozzles, commonly 0.028 to 0.045 inch. Behind the nozzle, which acts like a pressure buffer, fluid hoses to the pumps are sized accordingly to perform as pressure accumulators, keeping the pressure sufficiently high to maintain a consistent spray pattern during pump directional changeovers, and yet light enough for a man to handle. However, if the pressure drops too far and then recovers, the resulting pressure change appears outside the orifice as a spray fan “wink”.

When long hoses are used, friction decreases the working pressure at the tip and the potential for winking is amplified. Hose lengths, diameters and backpressure inducing orifices are designed to maintain the pressure needed to maintain a proper spray pattern. Under the best of circumstances, most high-pressure spray system hose lengths do not extend beyond 200 feet. Longer lines can be constructed with adequate temperature and hose diameter is increased to compensate for friction losses. However, handling becomes a significant issue as weight, bulk and length increase with larger hose assemblies. A 350-foot long hose umbilical can weigh up to 1,500 pounds and can only be handled by a powered winch.

How does the above relate to pipeline structural rehabilitation? Long hose lengths are required to line pipelines. Hose friction is additive with length so backpressure inducing orifices cannot be employed to prevent pulsation. If a backpressure orifice were placed at the hose end, it would be impossible to delivery sufficient quantity resin to the applicator head without significantly reducing hose length, or massively increasing hose diameter.

Maximum fluid delivery through an acceptably sized umbilical requires essentially an open-ended hose configuration. However, an open-ended configuration allows pump pulsation to be transmitted through the hose and converted by the linear moving application head into a surface wave. The surface wave can be either high or low frequency, while its amplitude is reflective of fluid delivery rate and umbilical retraction speed. A wave will describe the entire pipe circumference. In the trade the wave is described as a “rib”.

Depending on amplitude and frequency, the rib may, or may not, be of any consequence, although it is not a beneficial attribute since the average wall thickness will have to be increased to assure the minimum design thickness is achieved. The greater the wave height, the thinner the wall at the minimum wave height. Overlining can address thin areas, but depending upon the alignment of the second lining pulse wave with the first, the amplitude may be subtractive, additive or neutral. If additive, the rib grows proportionately higher and increases its influence on flow characteristics.

IMPROVED IN SITU PRESSURE PIPE SYSTEM

An improvement over traditional lining methods and tools, the system delivers a structural liner that is less sensitive to pipe surface preparation than protective coatings and more capable of pressure bearing than CIPP. By curing the liquid polymers at ambient temperature, instead of elevated temperature, the influences of coefficient of thermal expansion are eliminated. If the lined pipe is operated at higher than ambient temperature, thermal expansion serves to tighten the liner to the host pipe. Since the structural liner stands fast against the host pipe, negative pressure influences are eliminated and a flexible membrane condition is avoided.

Physical access to pipelines is frequently limited at industrial, petroleum and municipal treatment facilities. Often very harsh chemicals are present. Speed of application, reduced man accessibility requirements, and a wide selection of resins suitable for the known operating parameters are significant features that bring value to the pipeline owner. A partial list of system capabilities follows:

- Structural linings and protective coatings.
- Diameter range: 2 inches, and up.
- Wall thickness: To 350 mils per pass.
- Lining length, high viscosity resin: 650 feet.
- Lining length, low viscosity resin: 2000 feet.
- Lining lengths of large bore: Unlimited.
- Vertical “down hole” lining: To 3000 feet
- Potable water capable per ANSI/NSF Standard 61.
- Prevents internal corrosion and reduces biofilm growth.
- Pressure carrying capability: Dependent upon design.

- Reestablishes pressure capability to deteriorated pipes.
- An extensive range of thermoset polymers may be used:
    - Epoxy
    - Polyurea
    - Polyurethane
    - Furan
    - Phenolic
- Service temperature: To 350°F, depending on resin type.
- Exposures: Potable water, petroleum, chemical, municipal wastewater, gasses.

Determining if the synthesis of CIPP and coatings is an effective pressure pipeline product. Eight one foot long sections of 12 inch (305-mm) steel pipe, untreated except for mechanical grinding at the ends for a pressure seal, were drilled with holes from 1/16 to 3 inches (1.6 to 76-mm). Each pipe was drilled with three holes of the same diameter. Sharp edges from drilling were removed and all holes filled with a removable plug material shaped smoothly to the pipe inside radius.

Each pipe was lined with a 100% solids epoxy. After curing at ambient, the plug material was removed, the pipes palletized and shipped by truck to an independent third party test laboratory for bust pressure testing [8]. The testing procedure called for increasing the fluid pressure to a maximum of 2000 psi, or epoxy failure.

Table 1: Burst Pressure of Epoxy Lined Pipe

Steel Pipe Hole Diameter Inch (mm)	Epoxy Wall Average Thickness Inches (mm)	Applied Internal Pressure Psi (bar)	Comments
0.0625 (1.6)	0.232	2000 (137.9)	No epoxy failure
0.125 (3.18)	0.205	2000 (137.9)	No epoxy failure
0.25 (6.35)	0.236	2000 (137.9)	No epoxy failure
0.5 (12.7)	0.226	2000 (137.9)	No epoxy failure
0.75 (19)	0.228	2000 (137.9)	No epoxy failure
1.5 (38)	0.171	1200 (82.7)	Failure of epoxy
3.0 (76)	0.168	1050 (72.3)	Failure of epoxy

Improved polymer pumping equipment. To overcome the limitations of reciprocating pump systems, a new pumping system was developed which delivers resins from ounces per minute to hundreds of gallons per minute. The pump system has no discernable pulsation and is capable of simultaneously delivering two, or more, components at ratios from 1:1 to 1:1000. Very high ratioing accuracy is achieved by on-the-fly micro-adjustments tied to temperature, specific gravity and volume. Ratio adjustments are in discrete steps, 6000 steps through the range of the pumps capacity. Resin-type independent, fully programmable, highly instrumented and failsafe enabled, the system provides excellent control over plural component chemistry and volume. All chemistry is based on mass weight measurement of components. The ability of the equipment to measure mass while pumping and instantly adjust ratio means that total control over the mixed product, and therefore it's physical and chemical properties, is assured.

Rotating applicator head improvement. When lining with a high speed rotating centrifugal casting head, the head diameter and rotational velocity must be sufficient to impart a velocity that propels the resin onto the pipe wall. Ideally, the applicator head is located centrally within the pipe. In this condition, the heads outer rotating surface is off-center and closer to the pipe wall by half the head diameter. For example, a four-inch pipe with a 1-inch rotating applicator head, the outer surface will be 1.5 inches from the pipe wall (Figure 3).

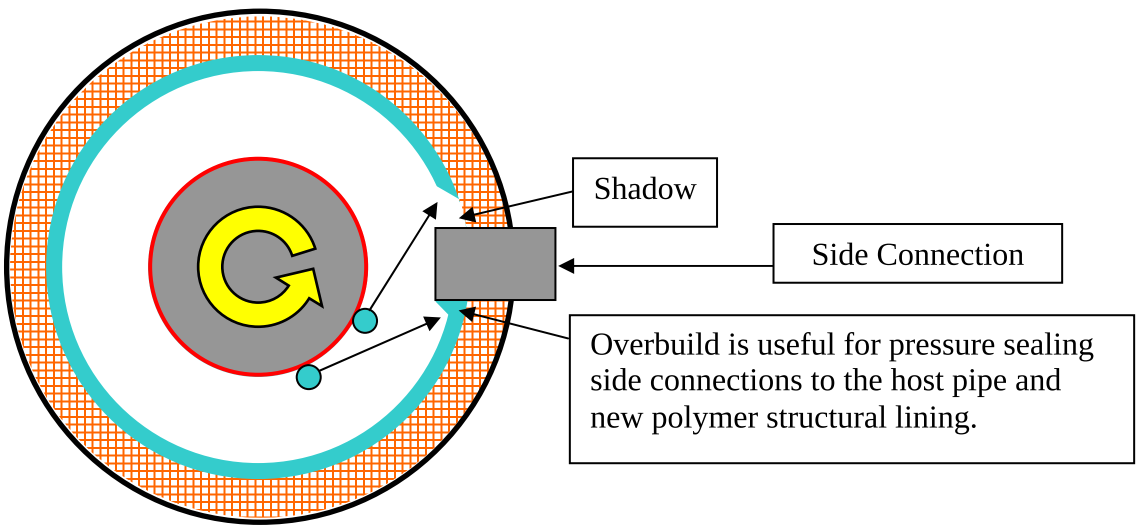


Figure 3. Head location and impact pattern for a unidirectional applicator head.

As an individual resin particle flies from the applicator's off-of-center surface it immediately encounters normal air friction and some turbulence created by interaction of the spinning head to the static pipe wall. The resultant particle trajectory is generally a straight line tangential to the rotating head. Particle impact with the pipe wall is more of a decelerating slide rather than a bullet-straight splash. The impact vector is important when pipe wall intrusions or depressions are present, such as intruding side connections. Resin strikes and accumulate on the impact side of an intruding surface while "shadowing" the opposite side. The result is that the shadowed area remains uncoated. A solution for shadowing is to overline from the opposite direction. An improved solution is to use a counter-rotating head that is spun in the opposite direction on a second pass from the original lining station.

Low-pressure, high-volume spray tools. For economical lining, maintaining maximum fluid flow to the applicator is important. High-volume, low-pressure applicators, in addition to their use in pressure pipeline rehabilitation, address the needs of traditional infrastructure coating work, such as wet wells, sumps, clarifiers and manholes. It is noteworthy that low-pressure, high volume applicator tools generate much less overspray than high-pressure applicators. Additionally, low-pressure applicator tools have a number of attributes that aid successful application of high-build structural linings and protective coatings (Table 2).

Table 2: Comparison of high-pressure and low-pressure applicator spray equipment

Orifice Size (Mils)	Applied Force (Psi)	Particle Size	Particle Velocity	Impact Force	Overspray Level
25 - 47	2300 - 5000	Small	High	High	Higher
250 – 500	40 - 100	Large	Low	Low	Lower

High-pressure orifices are subject to frequent plugging, forcing the application technician to stop work and clean the orifice. If orifice plugging become a frequent and irritating interruption to the lining process, it may cause the technician to make errors in judgment that impact the linings long-term durability. Low-pressure tip orifices are approximately 10 times larger than high-pressure orifices, and consequently, plugging is eliminated so work progresses without interruption. Large orifice size improves lining speed since more material can be delivered per minute. Higher volume delivery generally translates to lower end user cost.

Low-pressure systems spray at lower particle velocity, larger particle size and impact the surface more gently than high-pressure sprays. A less violent particle impact allows for a higher single-pass build. Larger particles have greater mass and greater inertia that carries it farther. Lower mass, smaller particles are more influenced by air friction and turbulence and cannot travel as far (Figure 3). A particle stream that travels farther means that the applicator tool can extend its "reach." This feature is a district advantage for overhead applications in large-bore pipe where the effect of gravity can seriously influence the distance a high-pressure particle can travel.

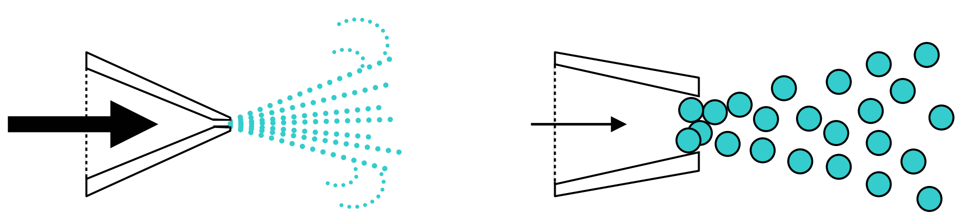


Figure 3. Relative atomizing force, overspray, particle size and fluid volume

Moving a high-velocity applicator tip farther from the target surface to soften the impact creates a rougher surface and increased overspray. High-pressure systems can be used to build multi-layer structural linings, but they are best employed in a manner that places them as multiple thin coats with an initial cure developed prior to allying the next coat. Low-pressure systems are overall more satisfactory for producing structural walls.

CONCLUSION

The new pipelining tools and materials deliver unique capabilities that satisfy the need for reliable cured-in-place pressure pipeline rehabilitation methods. Pipeline owners can expect to reliably obtain from the new technologies a concurrent improvement in fluid quality, flow capacity and enhanced structural load bearing capacity. For industrial, petroleum and municipal pipeline owners, the availability of an improved process to rapidly rehabilitate and return to service critical process and waste lines may be a crucial consideration. Pressure pipes can be rehabilitated with reduced environmental impact, improved fluid quality and improved service life.

Useful within a wide range of pipeline lengths, overhead and underground, small and large diameters, horizontal and vertical orientations; the tools are solutions for newly developing rehabilitation needs. Flexibility to choose resins ideally suited for a specific chemical effluent, operating temperature and pressure, brings a finely tuned approach to infrastructure rehabilitation.

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