Comparison of Spray on Linings used for Water and Wastewater Structures

The exponential growth of population across the globe has put grave trains on the existing water and wastewater infrastructure, the utility levels of which are greater than the designed parameters. The vast majority of pipelines running under our feet are well past their serviceable life. Thanks to sturdy materials used in the making of these pipelines, they have managed to live decades over their expected lifespan. Today, with the use of modern protective linings, coatings, and cathodic protection, buried pipelines can achieve incredibly long lives with very little added cost.

When the old water infrastructure reaches the end of its useful life, certain water main sections will become structurally deficient and must be replaced or refurbished to extend their life.

The labyrinth of varied sizes of pipes carrying water, sewage, cables, gas, etc. traverse the underground serving different purposes, making it difficult to replace these pipes without causing damage to one or more of the neighboring pipelines.

The conventional cement mortar linings which routinely used to shield concrete tanks and pipes carrying different types of water such as potable water, irrigation water and waste-water have outlived their intended lives. New polymer technologies on linings have severely exposed the structural limitations of cement mortar linings. Due to leaky and corroding linings, huge amounts of precious water is lost, which is commonly called as non-revenue water loss (NRW). A very high percentage of this water loss can be effectually mitigated by going for appropriate protective linings inside the pipelines and tanks.

Unlined cast-iron pipe was the material choice for water distribution systems from the beginning of this century to the mid-1960s. Although alternative products are increasingly being used, cast iron water mains account for the majority of pipe in most distribution systems in municipalities in Ontario and across
Canada. If their structural integrity is adequate, breaks should not occur, but their carrying capacity can be severely reduced due to a variety of factors.

Internal Corrosion

One major factor is the corrosion of steel, which is caused by the electrochemical process that requires the flow of an electric current as well as one or more chemical processes. As the corrosion process occurs, the interior wall of the pipe will develop pits as material is lost, resulting in the formation of tubercules. This corroded material, in combination with mineral deposits, is known as encrustation and tuberculation. Pipe deterioration will vary due to existing factors (in some cases necessitating complete replacement) but aggressive encrustation will force the issue of infrastructure renewal.

Steel pipe has a long history of effective internal corrosion control. For almost all water conditions, cement-mortar lining has provided high hydraulic flow capacity without the buildup of tubercles. The cement provides a high-pH environment in conjunction with a low oxygen supply, and self-healing characteristics.

Where non-potable liquids are being transported or in conditions of high velocities (over 20 feet per second), dielectric coating systems are recommended for lining of steel pipe.

Based on the fact that the structural integrity of the existing pipe is adequate, problems that can be corrected include:

- A severe reduction in pipe hydraulic carrying capacity,
- Aggressive corrosive build-up resulting in encrustation and tuberculation,
- Increased pumping and maintenance costs,
- Reduction in water quality,
- Increased bacteriological growth within the distribution system,
- Leakage water loss and infiltration,
- Existence of high lead content due to old joint corrosion,
- A chlorine residual deficiency,
- Decline in pipe material performance resulting in: unpleasant taste, offensive odor, turbidity and poor color.
Replacing the iron piping system is not financially realistic. Thus, rehabilitation to improve water quality with the use of various trenchless technology techniques has become a cost-effective alternative.

**Pipe Rehabilitation Options**

Structural integrity of deteriorated water main is historically addressed through replacement of the pipe. Replacement of pipe is costly, requires the removal and replacement of surface structures (e.g. roads and sidewalks), is disruptive to the public, and is challenging in restrictive work areas.

Structural lining is an alternative worth consideration. Innovative, trenchless technologies that will structurally rehabilitate ailing water mains.

**Different types of linings in water industry**

The development of spray-on structural or semi-structural pipeline linings has made a great transformation in the water industry which later became the trend for rehabilitation of the aging distribution pipelines. Some of the prominent linings used in water industry, were asphaltic concrete, brick lining, earth lining and most prominently, cement mortar lining. The more universally established benefit of linings was the apparent improvement in the water quality, while the unlined cast-iron pipelines were very often the source of complaints about water discoloration, taste and odor. Tuberculated, sediment-laden pipelines had become a common sight in the water industry.

Objectives of Lining may include:

- Improve water quality
- Stop water loss/leaks
- Structurally renew existing pipeline
- Improve hydraulic characteristics
- Extend service life of pipeline
- Reduce cost
Comparison of Spray on Linings used for Water and Wastewater Structures

Linings

– Spray on

  • Cement Mortar Lining (CML)
  • Structural Lining (SIPP)

– CIPP

  • CIPP

Materials Used for SIPP

SIPP is not an entirely a new concept, for this method was followed in the early 1900’s with hand-applied cement mortar. A few decades later, cement mortar was applied using spray application in larger diameter pipes, and eventually, also in smaller diameter pipes.

For many decades, cement mortar was a popular choice for SIPP, however; cement mortar when hard lacks sufficient tensile strength to impart additional pressure capability and strength to a structurally deteriorated pipe, making it preferable only in pipes that still retained their structural integrity. Cement also requires sufficient setting time, thus requiring the pipeline to be out of service for a long period of time.

Other materials used for SIPP are polymers and epoxies that combine resin and a hardening agent, which are in a liquid state until combined and allowed to chemically react. Once the reaction is complete, they turn into 100% solids. Epoxy utilizes a resin – bisphenol A, and a hardening agent – epichlorohydrin. The reaction is initiated by introducing a catalyst and subjecting it to high temperatures. However, the setting time of certain epoxies requires an alternate service connection.

They do not add much to the structural strength of the host pipe and are best suited where cracks or gaps are to be filled in, and protection against corrosion is required. Polyurea and polyurethane are also lining materials that are very effective in SIPP lining methods because of their quick setting time and easy application.
These linings are produced using a compound of isocyanate, but each utilizes a different reacting resin. While polyurethane linings use a polyl ending blend, polyurea uses an amine ending blend as the resin.

- **Cement mortars**

cement mortar when hard lacks sufficient tensile strength to impart additional pressure capability and strength to a structurally deteriorated pipe, making it preferable only in pipes that still retained their structural integrity. Cement also requires sufficient setting time, thus requiring the pipeline to be out of service for a long period of time.

- **Epoxies**

The setting time of certain epoxies requires an alternate service connection. They do not add much to the structural strength of the host pipe and are best suited where cracks or gaps are to be filled in, and protection against corrosion is required.

- **Polyurea**

Very effective in SIPP lining methods because of their quick setting time and easy application. Polyurea. Polyurea SIPP restoration is a non-invasive procedure that uses polyurea inside a liner to create a new pipe inside deteriorated host piping systems. This lining is highly specific and can be used to span missing sections of pipe. Both strong and durable, Polyurea SIPP pipe lining system is a long-term solution for leaks and breaks, blockages, root intrusion, calcium build-up, water damage, mold, sewer backups and increases flow capacity.

**Benefits of SIPP (Spray-on Structural Liners)**

- Prevents Root Intrusion and Stops Leaks
- No Digging or Destruction. Minimize disruptions to community due to minimal access pits compared to open-cut
Cement Mortar Lining (CML)

Cement-mortar lining is the most commonly specified lining material in today’s water transmission industry. A lean mixture of three parts sand to one part cement is centrifugally spun onto the interior surface to create a dense, smooth surface.

According to AWWA Standard C602, the use of cement mortar lining of pipelines was first commenced in 1836, and the first factory lined cement mortar lining was laid in 1933 in New Jersey. The in-situ spray application of cement mortar lining was, however, limited to larger pipelines (600 mm and above) and in 1950, remotely controlled sprayers were developed, for the lining of smaller pipelines.

The actual cement application is performed by pumping or pouring a high slump cement mixture onto a slowly rotating length of pipe. The rotating speed is then increased so the proper centrifugal forces level out the wet mortar to a uniform thickness. Continued spinning removes the excess water and compacts the mixture to a dense and hard surface. After the spinning process, the lining is cured either by moist curing at ambient temperature or by an accelerated process using steam.

Limitations of CML
The foremost structural inadequacy of cement mortar is its inherent poor tensile strength. Because of the occurrence of shrinkage while curing, cement mortar normally develops cracks. The cracks may be visible (macro) or invisible (micro), but where they occur, the tensile strength is almost zero.

Some of these cracks will self heal when the lining is wet. Wetting the cement lining also causes the lining to swell, which increases strength and adherence. Cement-mortar linings can add significant stiffness for resistance to deflection forces. The strength of the mortar lining may be added to the strength of the steel when calculating stiffness.

Even without cracks, the tensile strength of a high quality mortar is very low, around 3-4 MPa, whereas ductile steel exhibits around 350 MPa. And as a result, even thin steel pipeline has much more hoop or bending strength than a very thick mortar lining. Cement mortar also has a fairly low strain limit (0.0002) in tension, which manifests as cracks when a pipeline is bent or strained through pressurization. The cracks thus developed in the CML allow water to seep through the lining.

Soft, aggressive waters, as well as prolonged contact with heavily chlorinated water, may be injurious to cement-mortar linings. Cement-mortar linings perform best when flow velocity is 20 feet per second or less.

Bonded dielectric linings have been used as protective linings for above-ground applications for many years. There are two major categories of liquid film linings in the waterworks industry at this time: epoxies and polyurethane-based products.

**Water quality of CML**

In public water supplies, the quantity and quality of water are of great importance, with the latter being more significant. Cement mortar lining which protects water distribution pipes against electro-chemical corrosion will slowly leach lime (Ca(OH)2) from the mortar itself. Besides leading to structural deterioration of the lining, the calcium loss due to leaching also impairs the water quality by increasing its pH, alkalinity and calcium concentration.

Another risk to water quality in cement-mortar lined pipelines is the aluminum leaching. Aluminum is found in cement as tri-calcium aluminate and this compound is believed to dissolve in water due to the following reaction:
Ca₃Al₂O₆ + 6H₂O → 3Ca²⁺ + 2Al³⁺ + 12OH⁻

Aluminum poses serious health risks to hemodialysis patients. The European Union (EU) limits the aluminum content in drinking water to 30 µg/L. Another study raised concerns about the presence of high levels of heavy metals in drinking water, when the cement comes from kilns where hazardous waste fuel is used for a portion of the fuel, because such kiln incineration is sometimes used as a method of disposal for hazardous wastes.

**Spray-on polymer linings for potable water**

Because of the rampant water quality deterioration issues in the cement mortar lined pipes and the profuse water leaks through the cracks, various waterbodies around the globe, started looking for substitute linings and concluded that spray-on-polymer linings would unravel most of the problems encountered by them. Among the innumerable polymer linings shortlisted, the three polymers that stood out in the final analysis, because of their inherent physical and mechanical properties, were epoxy, polyurethane and polyurea. Compared to cement mortar linings, these polymers have appreciable tensile and bending strengths, without the need for additional reinforcements. The life expectancy of the polymer linings is lab-tested by methods like electrical impedance spectroscopy (EIS), dry film thickness, holiday density, and cross-cut adhesion and the tests conducted on the selected linings using these standard methods proved that they have better lives compared to CML. These polymer linings are not applied by conventional methods like brush, roller or airless or air assisted sprays, but by plural component airless spray systems (Graco, WIWA), because of their extremely short pot lives (10-60 seconds).

**EPOXY**

Epoxy is a thermosetting epoxide polymer, which is formed by reacting bisphenol A with epichlorohydrin, and then cured with amines. These coatings are fortified with ceramic powders that enhance the fluid flow characteristics. They are typically used to improve system hydraulics, prevent water quality problems at the customer’s tap, and as a means of extending the life of the pipelines by reducing internal corrosion. Generally, they are applied thinly with a standard thickness of 1 mm. Epoxy linings formulated with typical hardeners are food grade and so are used for internal linings of raw water and potable water. These products are high viscous and applied in-situ by plural spray equipment. Use of epoxy was first officially
approved in 1985 in U.K and by 1995, epoxy linings were well established in the UK, Japan, Sweden and Germany. AWWA Standard C620-07 for in-situ applied epoxy lining gained approval in 2008 in US.

Epoxies are applied per AWWA C210 and polyurethanes per AWWA C222.

These linings have excellent water and chemical resistance properties and can be used as an alternative to cement mortar lining. They can be applied at various thicknesses and are factory applied to provide an excellent dielectric lining. Bonded dielectric lining systems can be applied as either a single or a multiple coating process. They are tough, resilient, and extremely abrasion resistant, making them an ideal lining choice for high internal velocities. Bonded dielectric lining systems are an excellent choice for extreme conditions such as wastewater or other industrial applications, including both gravity sewer and sanitary force mains.

Epoxy systems do have some drawbacks that must be considered prior to application. A critical performance factor to all film linings is the surface preparation of the metal surface. In most cases, a near-white blast surface is required for proper adhesion, and this will require good inspection. Curing times and curing temperatures must adhere to critical tolerances. With proper surface preparation, controlled applications, and strict curing procedures, thin-film materials can provide a strong, resistant, long-lived lining.

Epoxy systems are typically solvent-based, although some 100% solids epoxies are now available. The 100% solids materials contain no VOCs. The epoxies are typically mixed and then applied by airless spray or brushed on to the pipe. Epoxies typically cure in a matter of hours to days, whereas polyurethanes may be handled in a matter of minutes.

**Polyurethane**

Of late, polyurethane has been gaining momentum as lining material, particularly in UK, where they are quickly supplanting both epoxy and cement mortar linings. The principal advantage of polyurethane is its rapid cure time, which has enabled same day return-to-service for rehabilitated water mains, thus avoiding the need for bypass piping systems. Polyurethane is formed by reaction of an isocyanate (-N=C=O) group with a hydroxyl (-OH) group, which is triggered by catalysts. Other typical components of the polyurethanes include cross linkers, surfactants, pigments, and fillers.
Technical Document

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Epoxy and polyurethane systems do have some drawbacks that must be considered prior to application. A critical performance factor to all film linings is the surface preparation of the metal surface. In most cases, a near-white blast surface is required for proper adhesion, and this will require good inspection. Curing times and curing temperatures must adhere to critical tolerances. With proper surface preparation, controlled applications, and strict curing procedures, thin-film materials can provide a strong, resistant, long-lived lining.

The aromatic polyurethanes are 100% solids material. The 100% solids materials contain no VOCs. The polyurethanes require heated, plural-component equipment.

Polyurea

Polyurea is the reaction product of an isocyanate and amine which rapidly cures to an elastomeric film without the aid of catalyst. Polyureas appear to have better elongation and tear strength than polyurethanes where as polyurethanes provide more toughness. Structural grade Polyureas have better toughness and tensile strength. Short curing time (both polymers achieve their physical properties within minutes after application) is the primary advantage to both polymers. Insensitivity to moisture is the great advantage of polyurea over polyurethane. Polyurea coatings are designed to create highly elastic linings that are resistant to chemicals and abrasion. These fast cure, no VOC, no odor coatings are suitable for use in wastewater industry because they offer ultra-high film build and dry in as little as 30 seconds. When coated with polyurea systems, substrates such as concrete and steel can be submerged, buried, or driven upon in just minutes. In contrast, traditional and even fast-cure epoxies can take a week to cure fully. Because of their elasticity, polyurea coatings are ideal for substrates such as concrete which has the tendency to crack. As an elastomer, these coatings have the ability to stretch and bridge gaps up to 3mm. Due to this flexibility, polyurea coatings are not limited by extremes of temperature, while rigid coatings like epoxies tend to crack as the substrate expands or contracts under these conditions.

Polyurea Spray-on Structural Liner

Polyurea liners have a very short setting time and harden quickly, also producing 100% solid materials. The application process is different than polyurethane liners and does not necessarily require a catalyst, rather it requires high pressure and high temperature for application. The application system for polyurea lining is done either by a robot system or can be applied by hand to develop a pipe inside a pipe, with thickness varying from 20 mils to inches.
While traditional coatings are typically limited to thin films and tend to be brittle in nature, Aegis polyurea offers a high build, non-brittle coating without sacrificing physical properties. Tough, but flexible polyureas, withstand mechanical shock and snap cure allows for immediate return to service. These high build, seamless coatings are perfect for waterproofing and encapsulation applications where rapid return to service is required.

Polyurea SIPP is an excellent choice for pipeline rehabilitation in the sewage, oil and gas industry, potable water pipelines, chemical sewers, sanitary waste pipes, storm drain culverts and secondary containment applications.

- Outstanding abrasion and corrosion resistance
- High build, non-brittle coating without sacrificing physical properties
- Tough, but flexible. High flexural strength. Possess excellent pressure ratings
- High tolerance to both steel and concrete
- Allows high-build applications on a variety of structures ranging from 100–250 mils per pass (and higher upwards to inches when applied in multiple passes).
- Withstands mechanical shock, abrasion, corrosion
- Provides resistance against many known chemicals found in collection systems and in other similar wastewater systems; hydrogen sulfide gas, acids, microbial buildup etc.
- sets quickly. eliminate the need for an alternate service line. Immediate return to service
Polyurea SIPP Specifications

Sprayed-in-place pipe (SIPP) system creates a protective, structural pipe inside the existing host pipe system, without digging or destruction to buildings or landscape.

Polyurea pipe liner creates a seamless, jointless, pipe-within-a-pipe that is used to rehabilitate deteriorating sanitary drain and storm sewer lines, including mechanical systems, with minimal disruption.

Polyurea pipe liner enhances the structural strength of host pipe and acts as a stand-alone pipe within a pipe, meeting or exceeding ASTM D790, F1216, D638 and D543 Standards.

Water quality in lined pipes

Monitoring of water quality in lined pipelines is avital measure to decide when a newly lined water main will be ready for service. This is done after the line has been isolated from the system, rehabilitated, flushed, pressure tested, and disinfected. It is important to note that the rate of leaching of organic compounds typically decreases exponentially over time. A few polymeric linings have been found to impart taste and odor (T&O) to the drinking water.

Mary Modayil from California Dept of Public health evaluated different lining materials for drinking water and established that the epoxy lining, sprayed at 2 mm thickness, was able to protect the underlying pipes that had corroded up to 2mm depth. By testing for several potable water quality parameters, the water passing through the epoxy-lined mains was found to be of excellent quality. No leached chemicals were detected in field or laboratory water samples as long as the system was flushed according to the manufacturer’s standard lining and cleaning procedures.
Spray-on-linings for wastewater

Unlike fresh water, wastewater contains many toxic chemicals, residues, contaminants which make it very corrosive and erosive. Further, wastewater from sewage lines produces hydrogen sulfide gas that reacts with cement mortar leading to the rapid breakdown and deterioration of concrete surfaces. This leads to potential spills, increased maintenance costs, and potentially catastrophic failures. Prolonged corrosive action by carbonic and sulfuric acids deteriorates cement and mortar linings, corrodes and weakens steel, and jeopardizes integrity and service life of even newly built underground structures. This includes wet wells, lift stations, manholes, vaults, chemical tanks, wastewater treatment plants, and virtually any type of exposed or improperly coated concrete. Corrosion may also be caused or facilitated by the activity of microorganisms living on the pipe walls. Referred to as micro biologically induced corrosion (MIC), this particular type of corrosion can occur when nutrients are available for microorganisms inside the pipelines to thrive on and colonize microbes.

Polyurea coatings are best suited for lining of wastewater lines because of their extreme resistance to hydrogen sulphide. Polyurea coatings have found many uses for wastewater industry applications such as sewage digesters, clarifying tanks, internal and external linings, sewage tanks, secondary containment areas etc. The advantages of Polyurea coatings over CML are manifold such as increased flow, lower lining thickness, impermeability, bendability of pipes, resistance to hydrogen sulphide, crack bridging ability, higher tensile strength and rapid return to service.

Polymer linings and their applications

We have a few innovative technologies at our hand like epoxy, polyurethane and polyurea to tackle the pertinent lining issues faced by the water industry. All these three polymers have their own inherent strengths and weaknesses and hence cannot be wholly substituted by each other. For example, epoxy is a very hard polymer, well known for its uses in lining of food and beverage cans and unmistakably food grade. Polyurethane offers excellent chemical resistance but is not good in immersed conditions because of the breakdown of ester linkages. Polyurea is rapid setting, very tough and flexible and offers good resistance to aggressive chemicals present in waste-water. Table II gives an idea of their intended uses in water industry.
## Physical Properties Comparison

<table>
<thead>
<tr>
<th>Properties</th>
<th>Cement Mortar Lining</th>
<th>Epoxy</th>
<th>Polyurethane</th>
<th>Polyurea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AWWA C205-85</td>
<td>AWWA C620-07</td>
<td>AWWA C222-08</td>
<td>AWWA D102 ICS#4</td>
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<tr>
<td>AWWA Specification</td>
<td></td>
<td></td>
<td></td>
<td>AWWA Manual M28</td>
</tr>
<tr>
<td>Chemistry</td>
<td>Cement Hydration</td>
<td>Bisphenol A + Epi chlorohydrin</td>
<td>Isocyanate + Hydroxyl groups</td>
<td>Isocyanate + Amine</td>
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<tr>
<td>Thickness of Lining</td>
<td>&gt;10 mm</td>
<td>1-2 mm</td>
<td>1-2 mm</td>
<td>&gt;3mm .3mm up to inches</td>
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<tr>
<td>Tensile strength</td>
<td>3-4 MPa</td>
<td>20-25 MPa</td>
<td>15-20 MPa</td>
<td>20-30 MPa 35-45 MPa</td>
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<tr>
<td>Elongation</td>
<td>0%</td>
<td>2-3%</td>
<td>200-300%</td>
<td>300-500% &lt;5%</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Suitability for Drinking Water</td>
<td>Currently in use, but quality of water inferior</td>
<td>Food Grade</td>
<td>Food Grade</td>
<td>Food Grade</td>
</tr>
<tr>
<td>Suitability for waste water</td>
<td>No</td>
<td>Not recommended</td>
<td>Not recommended</td>
<td>Yes Yes</td>
</tr>
<tr>
<td>Shore D</td>
<td>---</td>
<td>60-70</td>
<td>60-70</td>
<td>45-55 75-85</td>
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<tr>
<td>Adhesion on Steel</td>
<td>OK. Value not available</td>
<td>7-9 MPa</td>
<td>7-9 MPa</td>
<td>7-9 MPa 7-9 MPa</td>
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<tr>
<td>Adhesion on Concrete</td>
<td>OK. Value not available</td>
<td>2-5 MPa</td>
<td>2-5 MPa</td>
<td>2-5 MPa 2-5 MPa</td>
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<tr>
<td>Tear Strength</td>
<td>---</td>
<td>30-40 KN/m</td>
<td>60-70 KN/m</td>
<td>90-120 KN/m 130-150 KN/m</td>
</tr>
</tbody>
</table>
## Conclusion

Several studies conducted by water bodies have substantiated beyond doubt that cement mortar linings currently used in water industry have severe limitations. Most of the developed countries have already preferred polymer linings to CML in order to stop water leaks and upsurge the water quality. However, in our country, change is a big mind block to many. The major factors that can attribute to the general hesitancy to switch over to innovative technologies are lack of awareness of these technologies, defensive mind-sets and the regulatory regimes wherein many different health agencies would need to be convinced before the new lining system is specified and introduced. However, it is indeed a welcome sign for the country that a few water bodies have already started implementing these new technologies.

<table>
<thead>
<tr>
<th>Return to Service</th>
<th>Several Days</th>
<th>3-7 days</th>
<th>1-7 days</th>
<th>8-24 hours</th>
<th>8-24 hours</th>
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<tbody>
<tr>
<td>Pot Life of Mixed Components</td>
<td>Hours</td>
<td>A few minutes</td>
<td>A few minutes</td>
<td>&lt;20 seconds</td>
<td>&lt;20 seconds</td>
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</tbody>
</table>