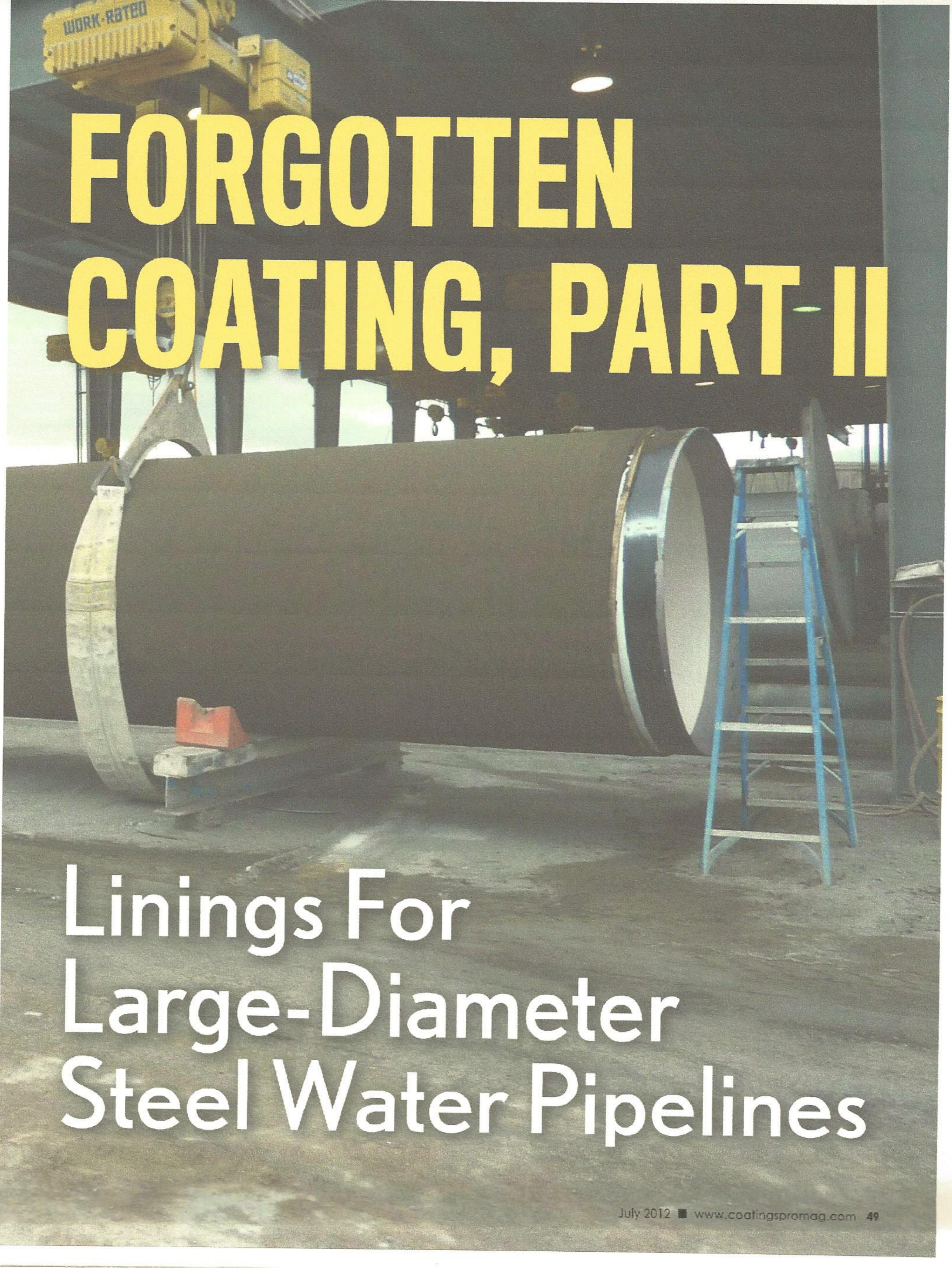

FORGOTTEN COATING, PART II

Linings For Large-Diameter Steel Water Pipelines

Mortar linings protect steel from corrosion through passivation and retarding oxygen penetration to the steel substrate.

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PHOTOS COURTESY OF AMERON INTERNATIONAL CORPORATION

Editor's Note: This is the second part of a two-part series exploring mortar coatings. Part one, "Mortar: The Forgotten Coating" can be found in CoatingsPro, *March 2012.*

Transmission of water for residential, industrial, and agricultural uses requires large diameter pipelines, and steel pipe is often specified. These pipelines typically range from 1' (0.3 m) to more than 12' (3.7 m) in diameter. This public infrastructure is typically expected to have a minimum service life of 50 to 100 years. To preserve this buried, and thus hidden, asset from the corrosive effect of the transported water, the lining system must be able to withstand the stresses placed on it during handling, installation, backfilling, and service. Some of these stresses to the lining take the form of pipe deflection and pressurization, abrasion from particulates in the transported water, pipe settlement, and liquid and vapor water penetration.

Linings have been used for more than 175 years to protect the interior of steel water pipelines from corrosion. As demonstrated over the years, some lining systems are better than others at extending the service life of water transmission pipelines with virtually no maintenance. Some systems, for various reasons, are no longer used. Other systems introduced in the past 15 years have yet to prove their ability to provide long-term service life in actual installed conditions.

The requirements of lining systems used on large-diameter steel water pipes are primarily given in internationally used waterworks standards, such as those developed by the American Water Works Association (AWWA). The predominant lining currently used is portland cement mortar. However, other linings, such as coal tar enamel, liquid and fusion-bonded epoxies, and polyurethanes, have been or are currently being used but to a much lesser extent, as shown in Table 1.

Table 1: History, AWWA Standards, Thickness, Blast Cleaning, Surface Profile Depth, Application Temperature, and Estimated Cost of Linings Used on Large Diameter Steel Water Pipe

Lining System	First Use	AWWA Standard	First Edition of AWWA Standard	% Pipe with Lining in U.S.	Thickness	Blast Cleaning Requirement	Surface Profile, mil (microns)	Metal Temp above Dew Point/Surface Appearance	Estimated Cost, \$/ft^{2}	
									Shop-Applied	Field-Applied
Portland Cement Mortar	Before 1836	C104 C205 C602	1939 1941 1955	>95	½" (1.2 cm) minimum	Not Applicable	Not Applicable	Not Applicable	0.50 to 0.75	~3 to 7
Coal Tar Enamel	Mid 1930s	7A.4 & .5 C203	1940 1973 Lining	<1	3/32"±1/32" (2.4±0.8 mm)	Commercial	1.5-3.5 (38-89)	>5°F (>2.7°C)	No Current Information	No Current Information
Liquid Epoxy	1950s	C210	1978	<3	0.016" (0.41 mm) minimum	Near White	2.0-4.0 (50-100)	>5°F (>2.7°C)	2.00 to 3.00	No Current Information
Fusion-Bonded Epoxy	1960 (gas line)	C213	1979	<1	0.012-0.015" (0.30-0.38 mm)	Near White	1.5-4.0 (38-100)	No Rust Bloom	>6.50	Not Applicable
Polyurethane	1980s	C222	1999	<2	0.020" (0.51 mm) minimum	Near White	2-4 (50-100)	>5°F (>2.7°C)	2.75 to 3.95	~5 to 8[1] ~1 to 4[2]

[1] Initial lining cost. [2] Maintenance lining cost.

PORTLAND CEMENT MORTAR

The predominant lining system used on steel pipelines in the water industry is portland cement mortar. It is not well known outside of the water pipeline industry. This minimum ½"-thick (1.2 cm) lining made using portland cement, fine aggregate (sand), and water protects the interior of steel pipe from corrosion by the process called passivation. Passivation is the same process that provides corrosion resistance to stainless steels.

The use of mortar linings on steel water lines dates back to at least 1855 when a 12"-diameter (30 cm) riveted-steel pipeline was installed in the city of St. John, New Brunswick, Canada. A section of this pipe was removed from service due to line relocation in 1963 after 108 years of service transporting relatively aggressive potable

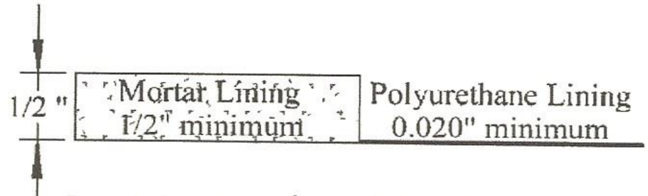


Figure 1: Comparison Of Lining Thickness Of Two Lining Systems

water. The steel pipe was free of corrosion due to passivation of the steel surface provided by the mortar lining. This line was in service for almost 70 years before the first mortar lining standard for cast-iron pipe (AWWA C104) was developed in 1922.

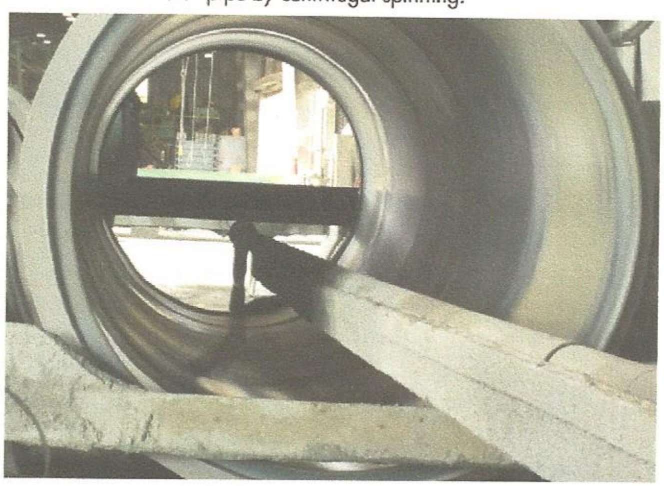
Cement mortar-lined steel pipe was first used in the United States in the late 1800s, and mortar linings continue to be the predominant means to protect the interior of buried large-diameter steel water pipelines from corrosion. Besides being used on steel pipes, the need for a better lining to combat tuberculation at pinholes of hot-dip bituminous-lined cast-iron pipe led to the first use of portland cement mortar linings in cast-iron pipe in 1922 (AWWA C104). Use of mortar lining in water transmission steel pipelines for at least the past 50 years is estimated at greater than 95%. The remaining small percentage of steel water pipelines that do not use portland cement lining systems are typically penstocks and above-ground pipelines.

Portland cement mortar is also the predominant lining system for cast- and ductile-iron water pipelines. Portland cement mortar or portland cement concrete is always used as the lining system in concrete pressure pipe.

Mortar lining application requires minimal, if any, surface preparation of the steel. Abrasive blast and a surface profile are not necessary, and minor corrosion and mill scale on the steel surface do not affect the corrosion-inhibiting (passivation) properties of the mortar lining. It can be applied at temperatures from 40°F to 95°F (4°C to 35°C) with no concern for dew point requirements and under all humidity conditions.

The passivating property of portland cement mortar is due to calcium oxide and small quantities of potassium and sodium ions

BELOW ▼ This is an example of the application of mortar lining to the interior of steel water pipe by centrifugal spinning.



in portland cement that convert to calcium, potassium, and sodium hydroxides when water is added to the cement and sand mixture immediately prior to application of the lining to the interior of the steel pipe. This hydration process produces a high pH environment — greater than 12.5. At this pH, steel passivates and does not corrode, provided a combination of substantial chloride ions and oxygen is prevented from reaching the steel surface. Diffusion of water and oxygen, with the amount of chloride ions found in potable water, through the mortar lining does not reduce passivation.

Mortar linings are very durable with an estimated material and application cost of $0.50 to $0.75 per square foot of steel surface area. This cost is the least expensive of the various lining systems used on steel pipe and is due to the lower material cost of sand and cement, the negligible steel surface preparation required, and the ability to line in any humidity condition and under a wider range of temperatures than typical dielectric materials.

In addition to corrosion protection, mortar linings also contribute substantially to pipe stiffness, which the other lining systems do not.

COAL TAR ENAMEL

Coal tar enamel (CTE) linings have been used on water pipelines since the mid-1930s (AWWA C203). The primary reason for its excellent performance is due to the 3/32" (2.4 mm) thickness of the lining that had been typically applied when compared to the much thinner linings used in the other dielectric lining systems. The use of CTE has decreased substantially during the past two decades due to its suspected carcinogenic nature, its volatile organic compound (VOC) content, and the odor emitted during application, which caused stringent permitting requirements for its use in populated areas. These issues have forced some water agencies to curtail specifying CTE and some pipe manufacturers from applying CTE to pipe. It is estimated that less than 1% of steel pipelines in service are lined with CTE.

The application of CTE requires a minimum commercial blast (NACE No. 3/SSPC-SP6) with a surface profile of 1.5 mils to 3.5 mils (38 to 89 microns) and a metal temperature greater than 5°F (2.7°C) above the dew point. Due to the lack of use of CTE linings, no current cost data is available.

LIQUID AND FUSION-BONDED EPOXIES

From 1941 until 1978, portland cement mortar and coal tar enamel were the only two lining materials listed in AWWA standards. In the 1950s, liquid epoxies began to be used on oil and gas pipelines, and the first AWWA standard for liquid epoxy systems (C210) was approved in 1978. In the 1960s, fusion-bonded epoxy (FBE) systems began to be used on gas pipelines, and the first AWWA standard for FBE systems (C213) was approved in 1979.

Liquid epoxies and FBE make up less than 3% and 1% of the linings on large-diameter steel water pipe, respectively. Liquid epoxies can be applied by brush, roller, or spray, and this flexibility in application methods eases their use in fittings and special sections of pipe.

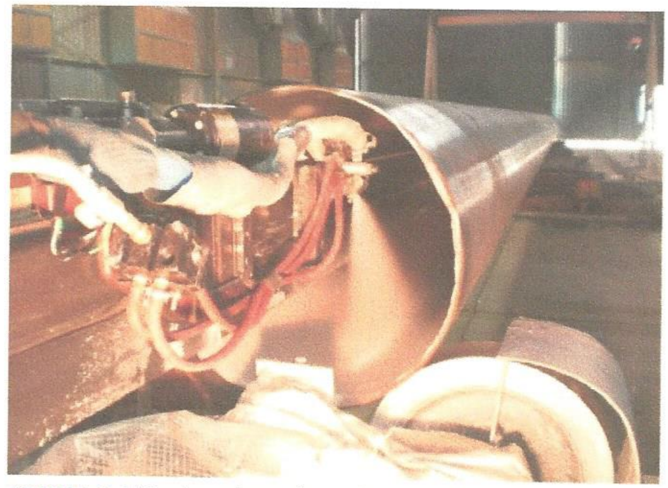
The inherent characteristics of epoxies make them relatively rigid as they age, and the required thickness of

When specifying linings for—or applying them to—large-diameter steel water pipelines, there are some helpful facts to remember:

- Portland cement mortar linings have been used on large diameter steel water pipelines for more than 175 years.
- Service histories of dielectric linings vary widely.
- Coal tar enamel (CTE) linings have been used on steel water pipelines since the mid-1930s. In the past several decades, usage has substantially declined due to its suspected carcinogenic nature, odor, and VOC content.
- Portland cement mortar is the predominant lining system for steel, cast-iron, and ductile-iron water pipelines. Portland cement mortar or concrete is always used as the lining system in concrete pressure pipelines.
- Dielectric linings have limited performance histories. Any such application should anticipate regular inspection and maintenance.
- Portland cement mortar linings are thick, durable, easily repaired, require essentially no steel surface preparation, can be applied in almost all weather conditions, passivate steel, and retard oxygen diffusion to protect steel from corrosion. They contribute greatly to pipe stiffness in contrast to dielectric linings.
- Portland cement mortar linings benefit from exposure to and penetration of water from the transported water while dielectric linings must be formulated to be impermeable to liquid water and water vapor.
- Dielectric linings and portland cement mortar linings are smooth, resulting in similar Hazen-Williams flow coefficients (C-factor) ranging from 140 to 155.
- Portland cement mortar linings are considerably less expensive than dielectric linings, require less maintenance, and are easier to repair.
- In seismically active areas, dielectric linings are expected to perform well. Portland cement linings have proven to have excellent performance in severe earthquakes conditions.

0.012" to 0.015" (0.30 to 0.38 mm) for FBE and the minimum thickness of 0.016" (0.41 mm) of the liquid epoxies make these linings susceptible to cracking due to the flexible nature of large-diameter steel pipes. As such, the epoxies specified need to be reviewed carefully to determine if they are appropriate for project requirements and specified appropriately to reduce damage during shipping, installation, and backfilling. In addition, the typical service life of epoxies with periodic maintenance is up to 20 years and not the minimum 50-year life typically required for buried water pipelines.

The application of the liquid epoxies requires a minimum near-white blast (NACE No. 2/SSPC-SP10) with a surface profile of 2.0 mils to 4.0 mils (50 to 100 microns) and a metal temperature greater than 5°F (2.7°C) above the dew point. The application of FBE requires a minimum near-white metal blast (NACE No. 2/ SSPC-SP10) with no rust bloom and a surface profile of 1.5 mils to 4.0 mils (38 to 100 microns).



ABOVE ▲ This photo shows the application of liquid epoxy lining to the interior of a rotating steel water pipe. A similar process is used for polyurethane linings.

The estimated material and application costs of liquid epoxies range from $2.00 to $3.00 per square foot of steel surface area. In addition, the use of liquid epoxies, like all painted linings that depend on a substantial bond to the substrate, raises concerns regarding the ability to handle internal stresses in the film. These stresses are caused by the movement of the steel substrate due to pipe deflection and pressurization. Some formulations are better suited to handle these long-term stresses.

Material and application costs of FBE are dependent on the throughput of the lining application process. The steel pipe needs to be pre-heated, and FBE requires large expenditures of energy to heat the steel pipe to 400°F to 500°F (200°C to 277°C).

POLYURETHANES

In 1999, a lining standard for polyurethanes (C222) for large-diameter steel water pipe was developed by AWWA. The inherent characteristics of polyurethanes tend to make them more flexible and abrasion-resistant than epoxies and less prone to impact damage, but polyurethanes typically have a substantially greater water vapor transmission rate. Modifying the polyurethane formulation to tighten the molecular structure and reduce water vapor transmission also makes the resulting polyurethane less flexible. Polyurethanes can be formulated to harden in seconds, providing for easy handling of pipe shortly after lining. The liquid water and water vapor transmission of polyurethanes makes them relatively susceptible to disbondment due to corrosion under the lining. This under-film corrosion can be difficult to detect. Since many polyurethanes have a liquid surface tension that prevents easy wetting-out of the steel surface, adhesion to the steel is more highly dependent on surface preparation and application techniques. Recent testing of polyurethanes after water exposure has revealed issues with loss of adhesion over time. This type of testing and physical property specification requirement requires further research.

The application of polyurethanes requires a minimum near-white blast (NACE No. 2/SSPC-SP10) with a surface profile of 2 mils to 4 mils (50 to 100 microns) and a metal temperature greater

Table 2: Comparison of Typical Physical and Performance Characteristics of Linings on Buried Steel Pipelines

Characteristic	Mortar Lining (AWWA C205)	Dielectric Lining (AWWA C203, C210, C213, C222)
Corrosion Control	Very Good to Excellent	Variable
Method of Control	Passivation Negligible oxygen diffusion	Barrier – Isolation
Water Absorption	Enhances Passivation	Detrimental
Experience	>175 years	Varies by Material, See Table 1
Design Life - Durability	>50 to 100 years	20 to 30 years
Physical Damage During Delivery/ Installation	Easily Repaired in Field	Specialized Equipment & Material
Maintenance	Virtually None	Inspection Every 5 to 7 years Recommended
Thickness	0.50" (1.2 cm) minimum	1/16"-1/8" Coal tar enamel Min. 0.012" - 0.020" Others
Cracking or Pinholes	Passivation & Autogenous Healing	Steel Corrodes
Pipe Stiffness	Contributes Significantly	No Contribution
Flow Velocity	Up to 20 ft/sec (6 m/sec); May vary depending upon special circumstances	Varies; Up to 20 ft/sec (6 m/sec)
Empty Buried Pipeline	Maintain Humidity	Not Affected
Seismically Active Areas	Excellent	Excellent
Water Flow, Flow Friction (Surface Smoothness)	High Hazen-Williams C-Factor – 140 to 150	High Hazen-Williams C-Factor – 140 to 150

than 5°F (2.7°C) above the dew point. These fast-curing formulations must be spray-applied, and this can result in a more difficult satisfactory application when the irregular surfaces of fittings and special pipe sections are considered.

The estimated material and shop-applied costs at a minimum thickness of 0.020" (0.51 mm) range from $2.75 to $3.95 per square foot of steel surface area. Estimated field-applied costs range from $5 to $8 per square foot with estimated maintenance costs ranging from $1 to $4 per square foot. In addition, polyurethanes have the same concerns regarding long-term bonding when in a stressed condition, as was described for painted liquid epoxy linings previously. Some formulations are better suited to handle these long-term stresses.

Due to its more recent introduction to the water pipe market, less than 2% of large-diameter steel water pipelines are estimated to be lined with polyurethane. Use of polyurethanes as linings on large-diameter steel water pipelines has increased in the past 10 years but still has a relatively limited service history. Lack of formulation standardization has resulted in varying quality performance expectations from this family of linings. Maximum service life for polyurethane linings receiving periodic maintenance is estimated at 20 years.

COMPARISON OF LINING THICKNESS

Figure 1 shows a comparison of the thickness of several of the lining systems. The minimum thickness of the portland cement lining is ½" (1.2 cm), which is substantially thicker than any of the dielectric lining systems. The minimum thickness of the four dielectric lining systems, except for the coal tar enamel system, ranges from 0.012" to 0.020" (0.30 to 0.51 mm).

METHODS OF CORROSION PROTECTION

The primary purpose of linings on steel water pipelines is to protect the steel from corrosion and the resulting leaks that occur. The dielectric linings (CTE, liquid epoxies, FBE, and polyurethanes) protect steel from corrosion by isolating the electrolyte (the transported water) from the metal. They are intended to act as a barrier to the corrosive effects of the water. Water and oxygen diffusion through these dielectric linings is detrimental to the protection of the steel surface. Mortar linings protect steel from corrosion through passivation and retarding oxygen penetration to the steel substrate. In contrast to dielectric linings, such as epoxies and polyurethanes, water diffusion through mortar linings enhances passivation of the steel.

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF LININGS

Various physical and performance characteristics of the lining systems used on large-diameter steel water pipe are summarized in Table 2. Dielectric linings are more prone to damage during transportation, installation, and backfilling than mortar linings, which are more durable and easier to repair in the field.

MAINTENANCE

It is reported (Helsel, et. al., 2008) that for fresh or potable water immersion, the estimated service life of liquid epoxy systems ranges from eight to 17 years before first maintenance re-lining. The dry film thickness (DFT) of the epoxy systems listed ranged from 6 mils to 40 mils (150 to 1000 microns) with a minimum near-white metal blast required. It is also reported (Helsel, et. al., 2008) that the estimated service life of 100% solids 20-mil-thick (500 micron) polyurethane lining systems range from 14 to 16 years before first maintenance re-lining. Portland cement mortar linings require virtually no maintenance under most installation conditions. CP

References

Helsel, J. L., Lanterman, R., and Wissmar, K. (2008). "Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work." *CORROSION 2008 Paper No. 08279, NACE International, Houston, TX.*