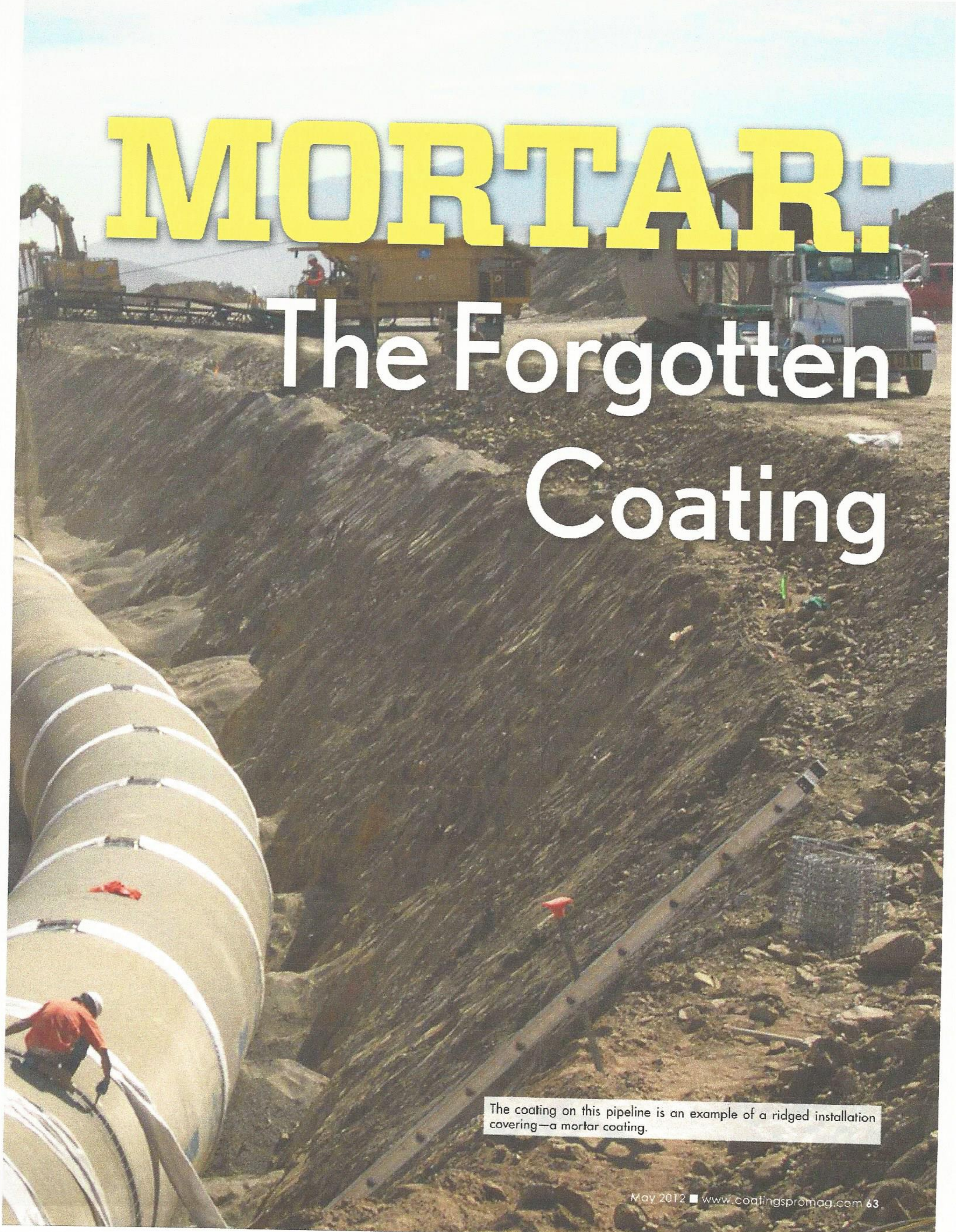
MORTAR: The Forgotten Coating



The coating on this pipeline is an example of a ridged installation covering—a mortar coating.

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Transmission of water for residential, industrial, and agricultural uses requires large diameter pipelines, and steel pipe is often specified. These pipelines typically range from one foot (0.3m) to over 12 feet (3.7m) 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 corrosion, the coating system used to protect this infrastructure must be able to take the stresses placed on it during handling, installation, backfilling, and long-term burial. Some of these stresses take the form of soil movement, pipe settlement, liquid and vapor water penetration, chemical attack, and cathodic protection.

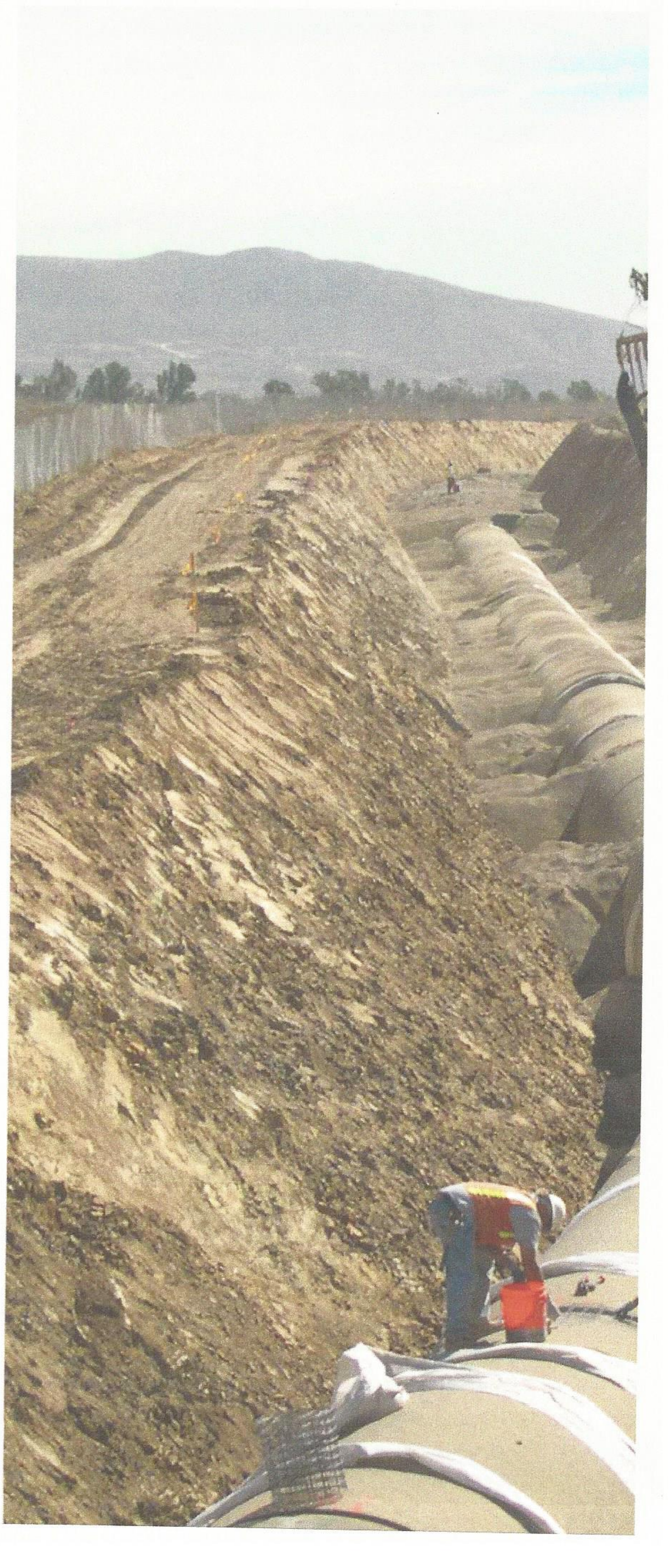
Coatings have been used for more than 150 years to protect the exterior of steel water pipe from corrosion. As demonstrated over the years, some coating systems are better than others at extending the service life of water transmission pipelines with virtually no maintenance. Some systems, for various 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 coating systems used on large diameter steel water pipe are primarily given in internationally used waterworks standards, such as those developed by the American Water Works Association (AWWA). The predominant coating currently used is portland cement mortar. However, other coatings, such as coal tar enamel, liquid and fusion-bonded epoxies, tape wraps, extruded polyolefins, and polyurethanes, have been or are currently used but to a lesser extent. (See Table 1)

PORTLAND CEMENT MORTAR

As stated above, the predominant coating system used on steel pipelines in the water industry is portland cement mortar coating. It is not well known outside of the water pipeline industry. This ¾-inch-to 1-inch-thick (1.9cm-2.5cm) coating made using portland cement, fine aggregate (sand), and water protects the steel pipe from corrosion by a process called passivation. Passivation is the same process that provides corrosion resistance to stainless steels.

Mortar coatings on steel water lines date back to at least 1855 when a 12-inch (30cm) diameter



RIGHT ▶ This section of 12" (30.48cm) diameter mortar-coated riveted-steel water pipe was installed in 1855 and removed from service in 1963 after 108 years of service. The mortar coating passivated the steel and prevented corrosion from occurring.

riveted-steel pipeline was installed in the city of St. John, New Brunswick, Canada. A section of this pipeline was removed from service due to line relocation in 1963 after 108 years of service. The steel pipe was free of corrosion due to passivation of the steel surface provided by the mortar coating. This line was in service for almost a century before the first mortar coating standard (AWWA C205) was developed in 1941.

Mortar-coated steel pipelines were first installed in the United States in the late 1800s, and mortar coatings continue to be the predominant means to protect the exterior of buried large diameter steel water pipelines from corrosion. It is estimated that 45 to 55 percent of steel water pipelines in service are mortar coated.

Mortar coating application requires minimal, if any, surface preparation of the steel. Abrasive blast cleaning and a surface profile are not required, and minor corrosion and mill scale on the steel surface does not affect the corrosion inhibiting (passivation) properties of the mortar coating. 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.

Portland cement consists of calcium oxide and small quantities of potassium and sodium ions that convert to calcium, potassium, and sodium hydroxides when water is added to the cement and sand mix during coating application to 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 chloride and oxygen is kept from the steel surface. Diffusion of water and oxygen without chloride through mortar coating does not reduce passivation.

Mortar coatings are very durable, with an estimated material and application cost of $0.75 to $1.20 per square foot of steel surface area. This cost is the least expensive of the various coatings systems used on steel pipe and is due to the lower material costs of sand and portland cement, the negligible steel surface preparation required, and the ability to coat in any humidity condition and a wider range of temperatures than typical dielectric coatings.

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

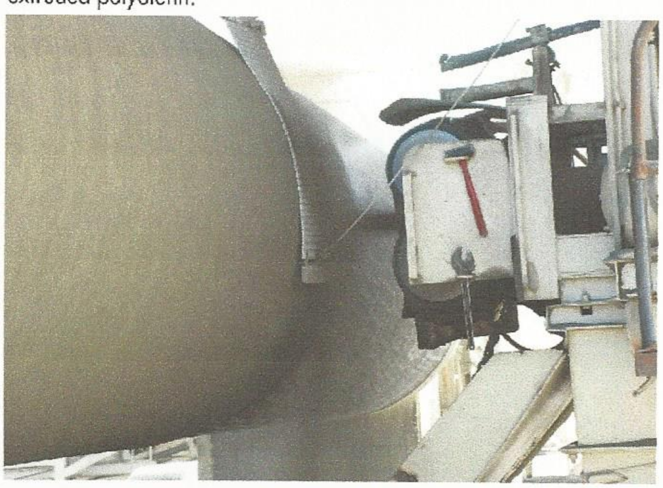
COAL TAR ENAMEL (CTE) COATING

Coal tar enamel-coated steel pipe is the second most predominant coating system used to protect the exterior of large diameter steel pipelines in the water industry up to the 1980s. The performance of CTE has also been extensive and excellent since the 1930s. A primary reason for its excellent performance is due to its roughly 1/8-inch (0.3cm) thickness that is typically applied and its low rate of water permeability. From 1941 to 1978, portland cement mortar (C205) and CTE (C203) were the only two coatings for steel water pipe in AWWA standards.

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 about five to 10 percent of steel pipelines in service are coated with CTE.

The application of CTE requires a minimum commercial blast (SSPC-SP6, NACE No. 3) with a surface profile of 1.5 to 3.5 mils (38 microns to 89 microns) and a metal temperature greater than 5°F (2.7°C) above the dew point. The estimated material and application costs of CTE range from $2.00 to $3.00 per square foot of steel surface area.

BELOW ▼ Application of mortar coating to steel water pipe using counter rotating brushes. The same mortar coating process is used to apply a rock-shield over dielectric coatings such as tape, epoxy, and extruded polyolefin.



LIQUID AND FUSION-BONDED EPOXIES, TAPE, AND EXTRUDED POLYOLEFINS

From 1978 to 1988, four additional coating standards for steel pipe were developed by AWWA. 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. Extruded polyolefins began to be applied to steel pipe in 1956 using a cross-head die extrusion system. In 1965, side extrusion systems were introduced in Europe and became available in the United States in 1972. In the 1980s, two- or three-layer tape systems (C214) and extruded polyolefin systems (C215) began to be specified for large diameter steel water pipelines.

Liquid epoxies and FBE make up less than one percent of the coatings on large diameter steel water pipe. About 35 to 45 percent of large diameter steel water pipe is tape wrapped, and five percent to 10 percent are coated with extruded polyolefins.

The inherent characteristics of epoxies make them brittle as they age, and the typical thickness of 0.012 to 0.015 inch (0.03cm-0.04cm) for FBE and minimum thickness of 0.016 inch (0.04cm) of the liquid epoxies makes these coatings susceptible to cracking due to the flexible nature of large diameter steel pipe. As such, they 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 is up to 20 years and not the minimum 50-year life typically required for buried water pipelines.

The two- and three-layer tape systems and extruded polyolefins are more flexible than epoxies and are applied thicker than epoxies. Tape thickness requirements range from 0.050 inch to 0.080 inch (0.13cm-0.20cm). When a cement mortar rock-shield is used over a tape system, only the two-layer 50-mil (1300 microns) tape system is required. The third (middle) tape layer in the 80-mil (2000 microns) systems is designed for mechanical protection and, therefore, is not needed when a rock-shield is employed. Extruded polyolefin thickness requirements are a minimum 0.008 inch (0.02cm) for the adhesive layer and a minimum 0.060 inch (0.15cm) for the polyolefin layer, resulting in a minimum coating thickness of 0.068 inch (0.17cm) for 38-inch (96cm) diameter or larger steel pipe.

The application of the liquid epoxies requires a minimum near white blast (SSPC-SP10, NACE No. 2) with a surface profile depth of 2.0 to 4.0 mils (50 microns-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 blast (SSPC-SP10/NACE No. 2) with no rust bloom and a surface profile of 1.5 to 4.0 mils (38 microns-100 microns).

The application of tapes and extruded polyolefins requires a minimum commercial blast (SSPC-SP6/NACE No. 3) with a surface profile of 1 to 3 mils (25 microns-76 microns) for tape and 1.5 to 3.5 mils (38 microns-89 microns) for extruded polyolefins and a metal temperature greater than 5°F (2.7°C) above the dew point.

The estimated material and application costs of liquid epoxies range from $2.00 to $3.25 per square foot of steel surface area. In addition, liquid epoxies cause handling concerns immediately after application since epoxies takes a substantial time period to become tack free and hard enough to place on a berm. This problem increases the cost of using liquid epoxies. Tapes and extruded polyolefins can be placed on berms immediately after application.

Material and application costs of FBE are dependent on the throughput of the coating 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 (204°C-260°C) to fuse the epoxy powder. Even so, with high throughput volumes, the costs can be close to the cost of mortar coating.

The estimated material and application costs of 0.080–inch-thick (0.20cm) tape systems range from $1.35 to $1.50 per square foot of steel surface area. The estimated material and application costs of extruded polyolefins range from $1.35 to $1.75 per square foot of steel surface area.

POLYURETHANES

In 1999, a coating standard for polyurethanes (C222) for large diameter steel pipe was developed by AWWA. The inherent characteristics of polyurethanes tend to make them more flexible and more abrasion resistant than epoxies and less prone to impact damage. Polyurethanes can be formulated to harden in seconds, providing for easy handling of pipe shortly after coating. However, the liquid water and water vapor transmission of polyurethanes makes them relatively susceptible to disbondment due to corrosion under the coating. 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 requirements requires further research.

The application of polyurethanes requires a minimum near white blast (SSPC-SP10 NACE/No. 2) with a surface profile depth of 2 to 4 mils (50 microns-100 microns) and a metal temperature greater than 5°F (2.7°C) above the dew point.

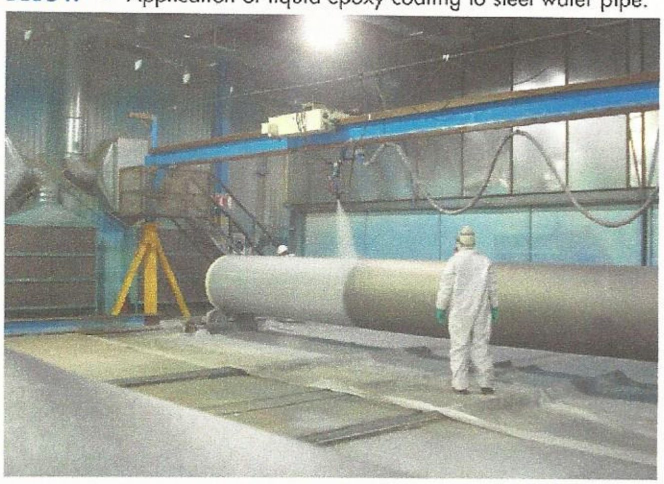
The estimated material and application costs at a minimum thickness of 0.025 inch (0.06cm) range from $1.35 to $1.75 per square foot of steel surface area.

Due to its more recent introduction to the water pipe market, less than five percent of large diameter steel water pipelines are estimated to be coated with polyurethane. Polyurethanes use has increased substantially 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 coating family.

COATING SERVICE LIFE

Service life prediction is a contentious issue, particularly for newer coatings, yet it is an important consideration when looking at life cycle costs. A recoating that may be required during a 50-year service life, for example, would far outweigh typical initial savings. The U.S. National Institute of Standards and Technology (NIST) is reportedly developing standards to predict the service life of polymer coatings and has available a comprehensive report entitled "Methodologies for Predicting the Service Lives of Coating Systems" that details the important considerations in determining the useful lives of these coatings. The report is available at http://tinyurl.com/74hv4aj .

BELOW ▼ Application of liquid epoxy coating to steel water pipe.



BELOW ▼ Application of a three-layer tape coating to steel water pipe.

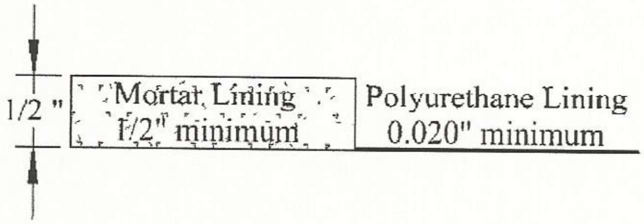


Figure 1 – Comparison of coating thickness of several coating systems.

COMPARISON OF COATING THICKNESS

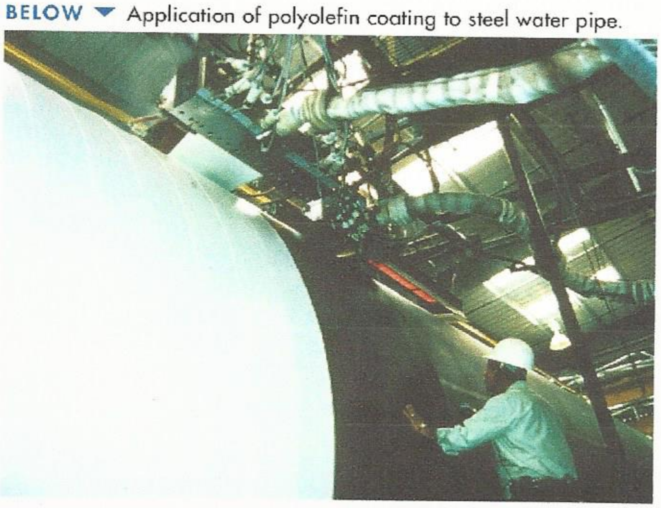
Figure 1 shows a comparison of the thickness of several of the coating systems. The minimum thickness of the portland cement coating is ¾ inch (1.9cm), which is substantially thicker than any of the dielectric coating systems. The minimum thickness of the five dielectric coating systems, except for the coal tar enamel system, range from 0.012 to 0.080 inch (0.03cm-0.20cm).

METHODS OF CORROSION PROTECTION

The only purpose of coatings on buried steel water pipelines is to protect the steel from corrosion and the resulting leaks that occur. The dielectric coatings (CTE, liquid epoxies, FBE, tape, extruded polyolefins, and polyurethanes) protect steel from corrosion by isolating the electrolyte (soil and water) from the metal. They act as a barrier to the corrosive effects of soil and groundwater. Water and oxygen diffusion through these dielectric coatings is detrimental to the protection of the steel surface. Mortar coatings protect steel from corrosion through passivation. In contrast to dielectric coatings, water and oxygen diffusion through mortar coating enhances passivation of the steel.

Cathodic Protection (CP) is a corrosion control method typically used in conjunction with dielectric coatings to protect the steel exposed to soil and water at flaws, pinholes, or breaks in the dielectric barrier coatings. It supplies an electric current, which counteracts the corrosion currents. Due to U.S. Department of Transportation regulations, all dielectrically coated oil and gas pipelines are required, for all practical purposes, to be cathodically

BELOW ▼ Application of polyolefin coating to steel water pipe.



ABOVE ▲ Since minor corrosion and mill scale won't affect the passivation properties of mortar coatings, abrasive cleaning and surface profiles are not required prior to installation.

ABOVE ▲ In addition to corrosion protection, mortar coatings also provide another benefit unmatched by the other coating systems. Mortar coatings contribute to pipe stiffness.

protected to control corrosion at any exposed steel at pinholes, flaws, and cracks in the coating. The use of CP on water pipelines is not regulated, but since the 1990s, more and more large diameter steel water pipelines that are dielectrically coated are being retrofitted with CP to protect this expensive asset. CP of mortar-coated steel pipelines is rarely required.

PHYSICAL AND PERFORMANCE CHARACTERISTICS OF COATINGS

Various physical and performance characteristics of the coating systems used on large diameter steel water pipe are summarized in the table below. Dielectric coatings are more prone to damage during transportation, installation, and backfilling than mortar coatings, which are more durable. As a result, mortar coatings are often placed over dielectric coatings as a protective armor shield, which also greatly contributes to pipe stiffness.

Without cathodic protection, the design life of mortar coatings is greater than 50 to 100 years while dielectric coatings typically have a design life of 15 to 30 years. CP

Table 1: Comparison of Typical Physical and Performance Characteristics of Coatings on Buried Steel Pipelines

Characteristic	Mortar Coating (AWWAC205)	Dielectric Coating (AWWA C203, C210, C213, C214, C215, C222)
Corrosion Control	Excellent	Good to Very Good
Method of Corrosion Control	Passivation	Barrier – Isolation
Water Absorption	Enhances Passivation	Detrimental
Experience	>160 years	75 years Coal Tar Enamel >30 years Tape >10 years Polyurethane
Design Life -Durability	>50 to 100 years	15 to 30 years
Physical Damage During Delivery/ Installation	Easily Repaired in Field	Specialized Equipment & Material and Skilled Labor Required
Maintenance	Virtually None	CP System
Cathodic Protection (CP)	Not Required, Rarely Needed	Typically Recommended
Stray Current Discharge	Prolonged Exposure without Corrosion	Steel Corrodes Immediately – 20 lbs/Amp/year
Thickness	0.75" (1.9cm) Minimum	1/16"-1/8" (0.16cm-0.32cm) CTE Min. 0.012"- 0.080" (0.03cm-0.20cm) Others
Cracking or Pinholes	Passivation	Steel Corrodes or CP Needed
Pipe Stiffness	Contributes Greatly	No Contribution
Soil Stresses	Not Affected	May Cause Disbondment or Wrinkling of Coating

THE HARD FACTS ABOUT MORTAR AS A COATING

By Jen Kramer and Sylvia Hall

Often portland cement mortar is not thought of as a coating, but actually it is one of the first coatings and was the predominant coating used in steel pipelines. Here is a quick breakdown of the facts:

- Portland cement mortar coatings have been used on steel water pipelines for more than 150 years. One of the first known instances of the use of portland cement mortar as a coating was on a 12" (30cm) diameter riveted steel pipeline in St. John, New Brunswick, Canada in 1855. The pipeline remained in service until 1963.
- From 1941 to 1978, American Water Works Association (AWWA) standards only specified two coatings for use in steel water pipes: portland cement mortar and coal tar enamel.
- Service histories of dielectric coatings vary widely. (A dielectric coating is a nonconductive, or insulating, coating.)
- Coal tar enamel coatings have been used on steel water pipelines since the mid-1930s. Liquid epoxies have been used on oil and gas pipelines since the 1950s.
- Fusion-bonded epoxies have been used on gas pipelines since the 1960s.
- Two- and three-layer tape systems became popular in the 1980s.
- Extruded polyolefin systems also have been used on large diameter steel water pipelines since the 1980s.
- In 1999, AWWA established a standard for using polyurethanes in large diameter steel pipes.
- In the past several decades, usage of coal tar enamel coatings has declined due to their suspected carcinogenic nature, odor, and VOC content.
- Liquid and fusion-bonded epoxies become brittle with age and have a typical service life of up to 20 years in buried water pipelines.
- Two- and three-layer tape systems and extruded polyolefin systems are more flexible than epoxies and have a slightly longer service life than their epoxy coating counterparts in service in buried water pipelines.
- The liquid water and water vapor transmission of polyurethanes renders them susceptible to disbondment due to corrosion under the coating.
- Application of coal tar enamels requires minimum surface preparation of Commercial Blast (NACE No. 3/ SSPC-SP 6) with a surface depth profile of 1.5 to 3.5 mils (38 microns to 89 microns).
- Application of liquid and fusion-bonded epoxies requires minimum surface preparation of Near White

Blast (NACE No. 2/SSPC-SP 10) with a surface profile depth of 2.0 to 4.0 mils (50 microns to 10 microns).
- Application of two- and three-layer tapes requires minimum surface preparation of Commercial Blast (NACE No. 3/SSPC-SP 6) with a surface profile depth of 1 to 3 mils (25 microns to 76 microns).
- Application of extruded polyolefins requires a minimum surface preparation of Commercial Blast (NACE No. 3/ SSPC-SP 6) with a surface depth profile of 1.5 to 3.5 mils (38 microns to 89 microns).
- Application of polyurethanes requires minimum surface preparation of Near White Blast (NACE No. 2/ SSPC-SP 10) with a surface depth profile of 2 to 4 mils (50 microns to 10 microns).
- Portland cement mortar coatings are thick, durable, easily repaired, and they contribute greatly to pipe stiffness in contrast to dielectric coatings.
- Application of portland cement coatings require essentially no steel surface preparation.
- Portland cement mortar coatings can be applied in almost all weather conditions and benefit from exposure to and penetration of water from the surrounding environment while dielectric coatings must be formulated to be impermeable to liquid water and water vapor.
- Portland cement mortar coatings are typically less expensive than dielectric coatings, require less maintenance, and are easier to repair.
- Unlike dielectric coated pipelines, portland cement mortar coated steel water pipelines rarely require cathodic protection because the cement passivates the steel and therefore does not require a secondary source of passivation (i.e. the cathodic protection).

The mix of portland cement, hydrated lime, aggregate/ sand, and water forms one of the oldest and most durable coatings. In spite of all the technology and science behind coatings, sometimes simpler can be better. CP