State of the Art Internal Pipe Lining Material

Polyurethane per AWWA C222

The Largest Problem in Pipeline Infrastructure

The leading cause of pipeline failure is corrosion. The estimated capital investment needs for water & stormwater pipelines in the U.S. alone is $11.18B USD/ year, a majority of which is replacement cost due to corrosion.[1] The corrosion-related costs of the U.S. oil & gas industry pipelines is $7B USD/ year. [2]

Internal corrosion accounts for approximately 60% - 75% of all pipeline incidents caused by corrosion.[3]

Combining the Benefits of Plastic & Steel Pipe

High Density Polyethylene pipe is widely used due to its excellent resistance to water, abrasion resistance, and flexibility. Its Achilles heel is its structural integrity and pressure limitations.

Carbon steel pipe provides the best overall structural properties with an excellent strength to weight ratio and high ductility that allows it to bend without breaking. Its Achilles heel is that it will corrode when exposed to water and other environments.

The optimum solution is polyurethane lined and coated steel pipe, perfectly blending the strength and ductility of steel with the flexibility and corrosion-resistance of plastic.

HDPE pipe is widely used for low pressure applications.

Pipe pulled back during HDD operation. Polyurethane linings & coatings flex with the pipe and have no risk of cracking like epoxy.

LPS LINED PIPE SYSTEMS

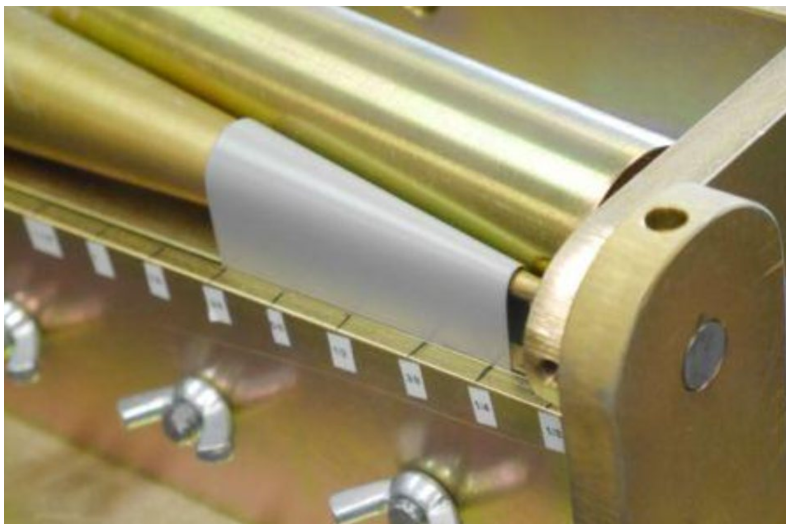
Thickness, Impact-Resistance, & Flexibility

A main differentiator between polyurethane and epoxy is that it can better withstand the construction process and remains flexible at thicknesses sufficient to eliminate any chance of leaks in the lining (750+μm, 30+ mils). The thicker an epoxy is applied the higher the risk of it cracking when the pipe flexes during handling, suffers sharp impacts, and undergoes cold bends during construction.

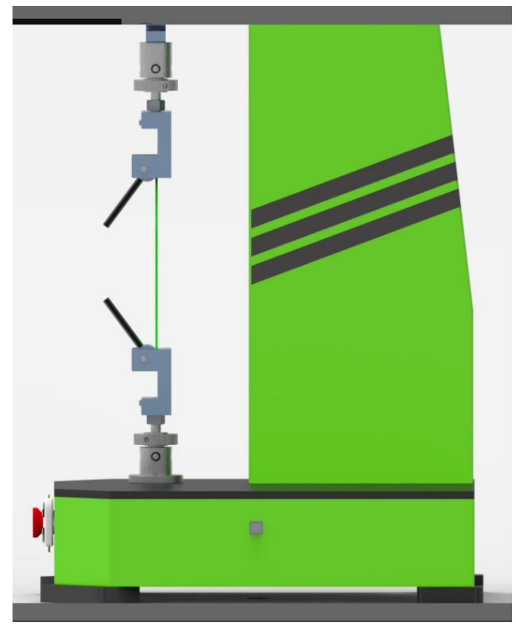
It is inevitable during the handling of thousands of pipes for a project that some will experience impact and flex that push the limits of brittle epoxy linings. Polyurethane linings & coatings flex with the pipe and have no risk of cracking like epoxy. Epoxies will often crack in a tiny spider-web fashion that is difficult to visually detect.

Polyurethane: Thickness with Flexibility

Polyurethane is a relatively thick flexible plastic membrane that is aggressively adhered to the steel substrate. AWWA C222 requires that the material pass a bend test at a thickness of 500µm - 809µm. Epoxy becomes brittle at these thicknesses.



AWWA C222 specifies that, per ASTM D522, the polyurethane material be applied to a 0.8mm thick steel panel at a thickness of 508 – 809µm (.020 - .035”). The panel is bent 180º over a 3” mandrel and the polyurethane cannot display any cracking.



Typical polyurethane coatings have an elongation of at least 8% per ASTM D412.

Bendability Comparison: Polyurethane vs. Epoxy

	Flexibility / Bendability Testing	Analysis
Polyurethane per AWWA C222	Tested per ASTM D522. AWWA C22 requires bending a plate coated with 508 - 889 µm (20 - 35 mils) of polyurethane 180° over a 75mm (3 inch) mandrel. One typical polyurethane, Lifelast DS210, passed this test when bent over a 25mm (1 inch) mandrel. Elongation of polyurethanes are greater than 8%.	Polyurethane applied at a much higher thickness than FBE does not exhibit cracking when bent over a mandrel 1/6 the diameter of the requirement for FBE in AWWA C213.
Fusion bonded (FBE) epoxy per AWWA C213	AWWA C213 requires bending a plate coated with 356 +/-50 µm (14 +/- 2 mils) of FBE 180° over a 159 mm (6.25 inch) mandrel. Owner specifications often require bending the specimen over a mandrel that is 2.5° x pipe diameter at -30° C and then warming it to 20° C. (CSA Z245.20) Elongation of FBE is generally not measured but is less than 5%.	Cold bending of pipe coated with epoxy is always a consideration. Epoxies applied at thicknesses below 400 µm (16 mils) onto properly prepared steel will withstand bending and flexing of pipe. However, higher thicknesses or sub-standard surface preparation may result in cracking. In summary, there is much less margin for error in epoxy application and a much higher risk of epoxies cracking than with polyurethane (where the problem does not exist at all).
Liquid epoxy per AWWA C210	AWWA C210 does not require bendability testing nor any testing of mechanical properties. Elongation of LBE is not measured.	

Impact Resistance Comparison: Polyurethane vs. Epoxy

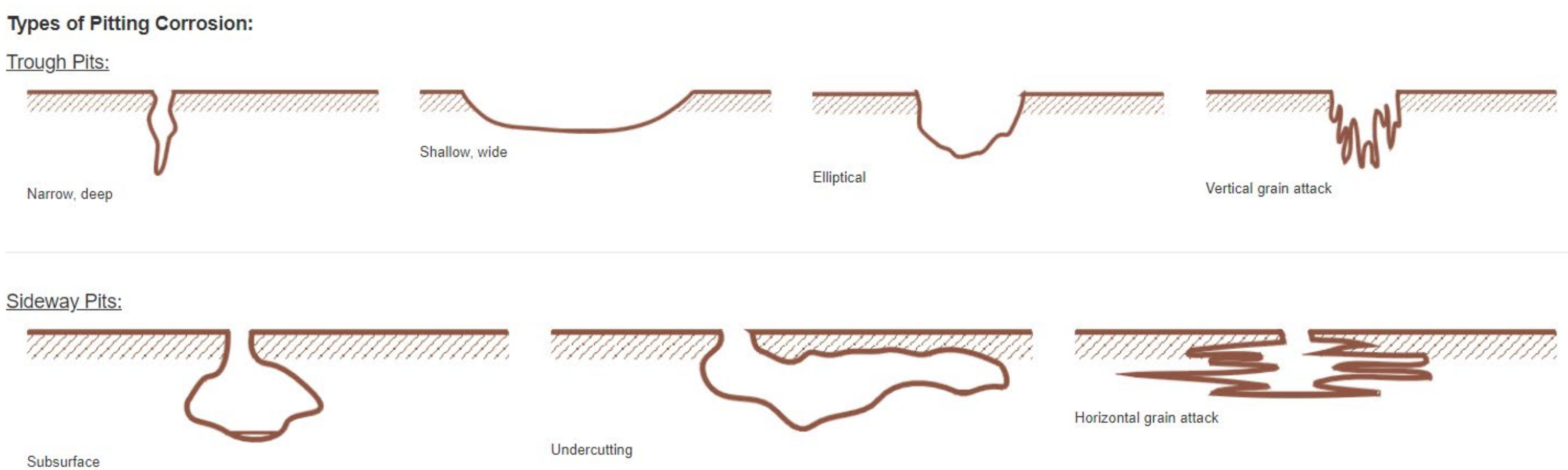
	Impact Resistance Testing	Analysis
Polyurethane per AWWA C222	Tested per ASTM G14 "Falling Weight Test". Steel plates are coated with polyurethane thickness up to 1,905 µm (75 mils). Two-pound and four-pound weights dropped from various heights and coating is inspected microscopically for cracks. Impact strength above 8.5 Joules (75 in·lb) is required. Heights are increased until a crack or disbondment is observed. Measured strength of typical polyurethane, Lifelast DS210, is 180 in·lb, measured on plates with coating thickness ranging from 939 - 1270 µm (39 - 50 mils).	Polyurethane is tested at a much higher thickness (in the case of Lifelast DS210 it was tested at ~300% the thickness of FBE per AWWA C213).
Fusion bonded (FBE) epoxy per AWWA C213	Tested per ASTM G14 "Falling Weight Test". Steel plates are coated with FBE at a thickness of 305 - 355 µm (12 - 14 mils). Two-pound and four-pound weights dropped from various heights and coating is inspected using holiday detector for cracks.Impact strength above 11.3 Joules (100 in·lb) is required.	The impact test is conducted on FBE applied at a thickness of 355 µm (14 mils). If the FBE was much thicker it would crack at a force much lower than 11.3 Joules (100 in·lb).
Liquid epoxy per AWWA C210	No impact test required per AWWA C210. A confidential 2020 specification from a prominent engineering company listed the minimum required impact resistance as 5 Joules. In the same specification it lists the minimum required impact resistance for FBE as 11.3 Joules (same as AWWA C213)	Indicates that liquid epoxies have significantly less impact resistance than FBE.

Lining Thickness Matters: Corrosion Pitting

Polyurethane linings are applied at a thickness sufficient to essentially “bury” metal imperfections, sharp edges and irregularities. Thin epoxy linings run the risk of having pinholes form on isolated locations or scratches. Leaks through thin linings frequently occur on isolated thin spots over time AFTER having passed an initial holiday test.

Microscopic discontinuities in a lining are eventually catastrophic to the pipeline. *“A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system… Fatigue and stress corrosion cracking may initiate at the base of corrosion pits.”* [4]

Corrosion is accelerated at the leak through the lining because it is constant contact with the electrolyte (water) while the adjacent surfaces are not. This results in the exposed steel serving as an anode and corrosion rates at this location are accelerated.



*Source: https://www.nace.org/resources/general-resources/corrosion-basics/group-1/pitting-corrosion

Impact & Abrasion Resistance

There are many different ways an internal lining can be scratched or impacted by a foreign object. Polyurethane provides superior impact resistance compared to epoxy. Its abrasion resistance is similar to epoxy, but the additional thickness provides a much larger buffer between the object and the steel.

Foreign objects: Experienced pipeline constructors have seen just about everything removed from a pipeline when a cleaning pig is sent through during commissioning. Whether its welding consumables, weld slag, nails, tools, rodents, rocks, etc., it is important that the lining withstand the impact and abrasion from potential foreign objects.

Silt and particles: At high flow rates minute particles and silt can wear linings thin. Polyurethane can be applied at any thickness required for the projected amount of abrasion.

Internal lineup clamps and bending mandrels: If used during construction, heavy internal lineup clamps and bending mandrels have the potential to scratch linings, particularly if they pinch or drag small pebbles through a pipe.

General Corrosion Resistance Properties

Polyurethane, liquid epoxy, and fusion bonded epoxy all provide excellent protection from steel corrosion as long as the steel is properly grit blasted and free of contaminants.

AWWA C222 (polyurethane), AWWA C213 (fusion bonded epoxy), and AWWA C210 (liquid epoxy) each have different standards for measuring water absorption and all are known to gain less than 2% weight from water absorption.

Cathodic disbondment testing is used to gauge a coating's ability to remain bonded to steel despite introducing a discontinuity in the coating, immersing it, and subjecting it to an electric current. This is particularly important for pipeline coatings since cathodic protection is used. AWWA C222, C213, and C210 all specify a maximum distance the coating can disbond from the discontinuity (C222 is 12mm, C213 is 15mm, and C210 is 10mm).

All three materials have sufficient adhesion to withstand coating disbondment. Excellent adhesion is important for a number of reasons, including withstanding the force of the water molecule to cause separation of the material after osmotic permeation. Per ASTM D4541 AWWA C222 requires 10,350 kPa (1,500 psi), AWWA C210 requires 5,515 kPa (800 psi), and AWWA C213 requires a shear adhesion test not directly comparable to the straight pull-off adhesion test per ASTM D4541. Reference white paper titled *"Denver Water's Assessment of Interior Polyurethane Coating of 108 inch Water Pipeline" (Bambei, Kelemen, Mielke)* for long-term adhesion performance of an early version of polyurethane used for pipe lining.[5]

Polyurethane is more forgiving of sub-standard steel surface preparation and surface irregularities. Reference white paper titled *"Denver Water's Assessment of Interior Polyurethane Coating of 108 inch Water Pipeline"* for information on polyurethane performance when applied over debris. While not applied per current standards, this demonstrates how polyurethanes can "bury" steel defects due to their thickness that epoxies cannot.[5]

All three materials have extensive successful case history in immersion when the steel is properly prepared and when mechanical damage has not been introduced.

Polyurethane Linings: Current State of the Art

North American water agencies are rapidly increasing the use of polyurethane to protect their pipeline infrastructure for future generations:

Owner Agencies Using Polyurethane

Alaska Electric Light & Power | Alaska Power & Telephone | City of Amarillo, TX | American Electric Power | City of Anacortes, WA | Arlington County, VA | City of Atlanta, GA | Aurora Brule Rural Water System | Aurora Water, CO | City of Aurora | City of Austin, TX | City of Baltimore, MD | Baltimore DOT | City of Baton Rouge, LA | British Columbia Hydro | Bear River Canal Company | Belize Water Authority | Benton Irrigation District | Big Horn Regional Joint Powers Board | Big Wood Canal Co | Birch Power Company | Bitter Root Irrigation District | Boise Project Board of Control | Boston Water & Sewer, MA | City of Boulder, CO | Brazos River Water Authority | City of Broken Arrow, OK | Brookfield Renewable Power | City of Broomfield, CO | Brushy Creek Regional Utility Authority | CAASD | City of Calgary | Canadian Hydro Developers/Canadian Projects Limited | Canadian River Municipal Water Authority | CANTARELL | Cascade Water Alliance | CEA Campeche (ST Water Commission) | CEA Edo Mexico (ST Water Commission) | Central Arkansas Water Authority | Central Oregon Irrigation District | Central Utah Water Conservancy District, UT | Central Vermont Public Service |

We estimate that since 2000, approximately **8,700,000 Feet (~ 1,650 Miles)** of Polyurethane Lined and/or Coated Steel Pipe has been used in Municipal Water Transmission and Distribution, Wastewater and Penstock Applications in the US and Canada

Regional Wastewater Reclamation Department | Pima-Maricopa Irrigation Project | Plutonic Power Corporation | PNM Resources | Polarconsult Alaska | City of Port Huron, MI | Port of Walla Walla | Portland Bureau of Environmental Services | Portland Water Bureau, OR | Prince William County Service Authority | Progress Energy | Provo River Water Users Association | Public Service of New Hampshire | Public Utilities Board | Puget Sound Energy | City of Rapid City, SD | Region of Peel | Regional Municipality of Wood Buffalo | Regional Power Inc. | San Diego County Water Authority, CA | Regional Transportation District of Denver | City of Rochester, MN | City of Round Rock, TX | S. Nevada Water Authority | San Antonio Water System | Santa Clara Valley Water District | Seattle Public Utilities, WA | San Francisco Public Utility Commission, CA | Saskatoon Water | City of Sheridan | Sheridan Area Water Supply | Silt Water Conservancy District | Skagit County PUC | City of Southlake, TX | City of St. Joseph, MI | City of Statesville, NC | Swalley Irrigation District | Swift Power | Symbiotics LLC | Tacoma Public Utilities | Tarrant Regional Water District | Tennessee Valley Authority | City of Thornton, CO | Trinity River Authority | City of Tucson, AZ | US Bureau of Reclamation | Utah DOT | Velasco Drainage District | City of Virginia Beach, VA | Washington County Water Conservancy District | DC-WASA | City of Waxahachie, TX | Weeminuche Construction Authority | Westar Energy | Western Wake Water | Authority | City Wichita, KS

Source: Northwest Pipe Company, the United States' largest manufacturer of pipe for domestic water use

100 Year Design Life

Excerpt from *"Longest Polyurethane Lined and Coated Steel Pipeline in North America" Budge, Rahman ASCE Pipelines 2012* [6]

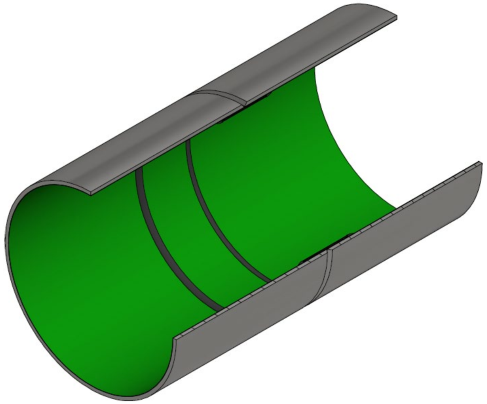
Literature Review: Steel pipes have been lined and coated with polyurethanes since the 1980's, but the first American Water Works Association (AWWA) standard for polyurethanes, AWWA C222 (2008) wasn't published until 1999 and was last updated in 2008. In recent years, the use of polyurethane lining and coating systems on municipal steel pipelines has grown substantially. Literature is replete with case histories of successful projects in a variety of applications. Bambei at al. (2011) reported on adhesion testing performed periodically on polyurethane lining in a 108-inch water transmission line placed into service at Denver Water in 1997. The lining was reported to be in good condition after fourteen years of service, and still meets the coating system's original performance requirements. Rivera et al. (2010) reported on a case study of a raw-sewage application in Pima County, AZ, where polyurethane was used to line and coat a 42-inch diameter WSP sanitary sewer line, buried 30-ft deep. The coating system was evaluated for acceptability under the Pima County/City of Tucson 2003 SSPI, Maricopa Association of Government (MAG) Standards, the City of Los Angeles Green Book Standard Specification, and the State of Washington Dept. of Ecology Criteria for Sewer Works Design; the Arizona Dept. of Environmental Quality (ADEQ) provided final approval of the product. The line was designed for a minimum 100-year service life. Bass et al. (2011) report on the fully structural rehabilitation by Sliplining of a 48-inch diameter PCCP water transmission main at Halifax Water, utilizing polyurethane lined-and-coated, gasket-joint, WSP. Compared to all other rehab options, the engineer determined that the polyurethane coating system would best withstand the high chloride concentrations within the surrounding backfill of the host PCCP line. The rehab solution was designed to provide a 100-year service life.

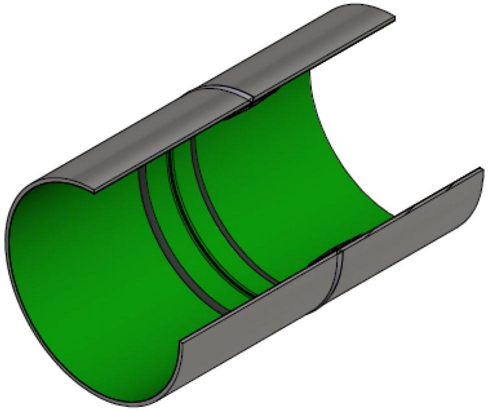
LPS Joint Technology Permits Use of Polyurethane Linings

LPS' FlexSleeve™ system works with any internal lining.

Robots are the other main option to line the interior of joints after welding on pipelines larger than 18" diameter. They struggle with the quality of field-applied linings due to climate conditions, steel temperatures, and obtaining pinhole-free linings over jagged weld penetrations.

LPS technology completely avoids all issues with field-applied patches at joints and FlexSleeve™ can be lined with the same material as the parent pipe.





Inquire for more information on how LPS technology permits full penetration welded joints, standard pipeline construction methods, and permanently seals off the weld zone from corrosion.

Sources

Specifications: AWWA C222, AWWA C213, AWWA C210, CSA Z245.20, ASTM D522, ASTM D412, ASTM G14, ASTM G95, ASTM D4541, Confidential Internal Lining Specification (2020), Technical Data Sheets for FBE from Axalta & 3M. Technical Data Sheets for polyurethane from Lifelast.

Technical Papers/Reports:

[1] NACE 2016 IMPACT report http://impact.nace.org/documents/summary-supplement.pdf

[2] U.S. Federal Highway Administration 2002 “Corrosion Costs and Preventive Strategies in the United States”

https://www.nace.org/resources/general-resources/cost-of-corrosion-study

[3] US Department of Transportation https://primis.phmsa.dot.gov/comm/FactSheets/FSInternalCorrosion.htm (60%)

Confidential mining industry study (75%)

[4] NACE website https://www.nace.org/resources/general-resources/corrosion-basics/group-1/pitting-corrosion

[5] ASCE Pipelines 2011 “Denver Water’s Assessment of Interior Polyurethane Coating of 108 inch Water Pipeline” (Bambei, Kelemen, Mielke)

[6] ASCE Pipelines 2012 “Longest Polyurethane Lined and Coated Steel Pipeline in North America” (Budge, Rahman)

Additional white papers referenced on page 11 regarding 100 year design life:

ASCE Pipelines 2010 “Raw Sewage through Steel Pipe: A Unique Application on the Pima County Plant Interconnect” (Rivera, Lucie, Rahman, Ast)

ASCE Pipelines 2011 “Innovative Joint Proves Successful in Critical Slipline Project” (Baas, Gardner, Mielke)

Additional relevant white papers:

Middle East Corrosion Conference 2001 “100% Solids Polyurethane Coatings Technology for Corrosion Protection in Water and Wastewater Systems” (Guan)

ASCE Pipelines 2003 “100% Solids Polyurethane Coatings Technology and Its Application to Pipeline Corrosion Protection” (Guan)

“It’s what’s on the inside that counts”

State of the Art Internal Pipe Lining Material
Polyurethane per AWWA C222

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