Polyethylene Encasement for External Corrosion Control for Iron Pipelines

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For nearly 200 years, cast iron pipe has been the standard piping material for modern water and wastewater systems in North America. Iron pipe has been the customary piping product of these industries because of its superior strength, reliability, and durability.

Gray and ductile cast iron pipe are ferrous structural conduits that can be susceptible to galvanic action if subjected to corrosive environments. When the presence of aggressive conditions is verified, the iron pipe industry advocates proper corrosion protection. The most common method of controlling corrosion for ductile iron pipelines is polyethylene encasement. All of the investigations included in this article were conducted on pipe installed with this type of corrosion protection.

The Beginning of Pipe Protection

The idea of protecting gray cast iron piping materials from external, electrochemical action with a loose polyethylene film started in the summer of 1951. At its inception, this method of corrosion control was employed to offer protection for cast iron mechanical joint bolts. Test specimens were installed in a testing ground of coal and cinder fill in Birmingham, Ala., in 1951, and in the organic swampland areas in Everglades City, Fla., and near Atlantic City, N.J., in 1952. The favorable results from these early testing locations led to the implementation of polyethylene encasement to grant protection for iron pipelines in municipal and utility installations starting in 1958. Through years of continued successful use, and added to further positive test site results in 1972, some 20 years after its inception and 14 years after its initial use, the first standard for polyethylene encasement, ANSI/AWWA C105/A21.5 (AWWA C105)[12], was published, which was the first of many other worldwide standards regarding this method of corrosion control for ductile iron pipe.

The results of extensive industry research have been coupled with numerous investigations of in-service installations conducted in cooperation with participating utilities over the past 55 years (Stroud, 1989; Bonds, 2005). Included in the inspections of in-service polyethylene-encased iron lines are field investigations commissioned by a manufacturer of ductile iron pipe. Its 22 inspection sites conducted in 1987 and 1988, with the supervision and assistance of a prominent geotechnical engineering consultant, further confirmed the efficacy of polyethylene encasement in the control of corrosion on iron pipelines (Malizio, 1986).

The results of three recent field investigations conducted by the Miami-Dade Water and Sewer Department (MDWSD) and the Ductile Iron Pipe Research Association (DIPRA) of some of the oldest installations of polyethylene-encased ductile iron pipe in the Miami-Dade area will be discussed. These and other physical excavations and inspections of in-service iron pipelines have demonstrated the overall effectiveness of polyethylene encasement as a means of external corrosion protection for iron pipelines.

Acceptance of this method of corrosion control for iron pipelines is highlighted in the results of a survey commissioned by the American Water Works Association (AWWA) and its Engineering and Construction Division. They reported that 95 percent of the surveyed utilities, municipalities, etc., responded that when external corrosion protection is required for their ductile iron water and wastewater pipelines, they employ polyethylene encasement (AWWA, 2000). Internationally, polyethylene encasement is covered by the International Standard ISO 8180, "Ductile Iron Pipelines: Polyethylene Sleeving for Site Application,"[18] and standards for the use of polyethylene encasement for corrosion control of ductile iron pipelines exist in Japan[19], Great Britain[15], and Australia[13], as well. There is also an American Society for Testing and Materials (ASTM) Standard A674, "Standard Practice for Polyethylene Encasement for Ductile Iron Pipe for Water or Other Liquids."

Investigation Procedures

At all of the investigation sites, ductile iron pipe was being protected with polyethylene encasement. Locations were generally selected by MDWSD because they offered relatively easy accessibility, required minimal traffic control, and contained soils that were known to be aggressive to ductile iron piping products. Observations at each test site and discussions with utility personnel verified that no sources of potential stray current were within the investigation areas.

The excavation process included carefully removing the soil from around the full circumference of the pipe to minimize the possibility of damage to the encasement so the in-place condition of the protective film could be determined; then, the polyethylene film was removed to facilitate inspection of the pipe. A sample of the salvaged film was subsequently forwarded to KOORC Enterprises Inc. for physical testing to determine how the properties of the film compared to the revision of AWWA C105, to which it was manufactured. It was noted that the iron pipelines were all encased in a method similar to Method "A" as described in AWWA C105.

After initial inspection of the encased piping and removal of the polyethylene encasement, the surface of the exposed pipe was cleaned and examined for evidence of galvanic action, pitting, and/or graphitization. The examination procedures included cleaning the pipe with water and a steel wire brush with a scraper, and sounding the pipe barrel with a pointed hammer. At the conclusion of each investigation, the pipe was encased with new 8-mil linear low-density polyethylene film, and the excavation site was properly backfilled.

Observations

Investigation Site 1: Jan. 10, 2013; NE 57th St., Miami

An 8-in. ductile iron water line, owned and operated by MDWSD and protected from aggressive soils with black, 8-mil thick loose polyethylene encasement, was inspected on Jan. 10, 2011, to determine the effectiveness of the protection.

In 1990, several hundred ft of 8-in. ductile iron water main were installed during the construction of a subdivision development. This water piping conveys potable water at approximately 65 to 70 pounds per sq in. (psi).

Two soil samples were procured at this excavation site. As the excavation was initiated, white clayey sand and gravel were encountered; however, as the excavating progressed to the three-and-one-half- to 6-ft depth, black organic clayey muck was exposed. Both types of soil were removed and tested per the Design Decision Model® (DDM®) with the muck testing in a range that is considered corrosive to ductile iron pipe (Table 1).

The location of this inspection was along the north side of 57th St. at Bayshore Drive. Some 8 to 10 ft of the water line was excavated by MDWSD and it was observed that the polyethylene had been somewhat loosely encased around the pipe. After this initial observation, the exposed ends of the protected pipe were sealed off with circumferential wraps of polyethylene tape to secure the length of piping to be examined. Next, the plastic sleeving was severed, some 4 to 5 ft, and removed from the pipeline. The polyethylene film, installed in 1990, was tested and appeared to be in very good condition. The physical properties of the film exceeded the values put forward in ANSI/AWWA C105/A21.5-88. The average results of the tests compared to standard values are outline in Table 2. As the polyethylene wrapping material was being cut, it was clear that there was moisture trapped between the encasement and the pipe surface.

Upon full exposure of the pipe, it was found that not only was there some moisture, but some of the native backfill had been trapped between the protective barrier and the pipe. The amount of soil was such that there was not enough of this material to test for its aggressiveness. Also, during this portion of the investigation, it was noted that oxidation appeared to be over most of the exposed pipe barrel. However, as the outside surface of the pipe was cleaned with water and the previously referenced instruments, it was quickly seen that this rust was superficial in nature and that much of the asphaltic shop coating was fairly well intact (Figure 1). As the inspection continued, the exposed pipe surface was completely sounded and probed for evidence of galvanic action, and it was noted that the pipe had suffered no pitting and/or graphitization after some 20 years of service.

Investigation Site 2: Jan. 10, 2014; NE 58th St., Miami

Another 8-in. ductile cast iron water main owned and operated by MDWSD and protected from corrosive soil with 8-mil-thick, loose black polyethylene encasement, was also inspected on Jan. 10, 2011. This water line was installed in 1990 during the same subdivision improvement as the previous investigation. Similar to the first location, this piping has push-on-type joints and conveys potable water at around 65 to 70 psi.

Two soil specimens were also procured at this excavation site. As the excavation commenced, white clayey sand and gravel were found to be prevalent; however, as the digging progressed to the three-and-one-half- to 6-ft depth, black organic clayey muck was again encountered. Both types of soil were removed and tested per the DDM® with the muck testing in a range that is considered aggressive to ductile iron pipe (Table 1).

The location of this inspection was along the north side of 58th St. at Bayshore Drive. Some 8 to 10 ft of the water line were excavated by MDWSD and it was observed that the polyethylene had been properly installed. It was tightly encased around the exposed pipe barrel and was fully intact with no apparent damage (Figure 2). After this initial observation, the exposed ends of the protected pipe were sealed off with circumferential wraps of polyethylene tape to secure the length of piping to be examined. Next, the plastic sleeving was severed and removed from the pipeline. The polyethylene film, installed in 1990, was tested and found to be in very good condition. The physical properties of the film exceeded the values put forward in C105/A21.5-88. The av-

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Table 1. Soil Test Results[17]

Location	Property	Transverse	Longitudinal	Standard (Min.)
NE 57th St.	Thickness (in.)	0.0074	0.0074	0.0072
	Tensile (psi)	2,463	2,654	1,200
	Elongation (%)	454	511	300
NE 58th St.	Thickness (in.)	0.0073	0.0073	0.0072
	Tensile (psi)	2,448	2,775	1200
	Elongation (%)	582	484	300
NE 87th St.	Thickness (in.)	0.0086	0.0086	0.0072
	Tensile (psi)	1,758	3,763	1,200
	Elongation (%)	1,102	889	300

Table 2. Polyethylene Film Test Results.

Location	Resistivity (ohm-cm)	pH	Redox (mV)	Sulfides	Moisture	Chlorides	Soil Description
NE 57th St. (a)	6,000	7.2	+ 245	Negative	Wet	N/A	White clayey sand and gravel
NE 57th St. (b)	1,040	7.2	- 30	Positive	Wet	Positive	Organic black clayey muck
NE 58th St. (a)	2,440	7.3	+ 240	Negative	Wet	N/A	White clayey sand and gravel
NE 58th St. (b)	440	6.8	- 10	Positive	Wet	Positive	Organic black clayey muck
NE 87th St. (a)	520	7.4	+ 240	Negative	Wet	Positive	Reddish-brown silty sand and gravel
NE 87th St. (b)	228	7.0	- 40	Positive	Wet	Positive	Organic black clayey muck
NE 87th St. (under the wrap)	268	7.1	+ 140	Negative	Wet	Positive	Brown clayey sand and gravel
NE 87th St. (groundwater)	92	7.6	+ 115	Negative	Wet	Positive	Brown clayey sand and gravel

Results of physical testing of polyethylene film samples removed from inspection locations. The results of the testing are compared to the minimum values set forth in ANSI/AWWA C105/A21.5-72, the first such standard for polyethylene encasement.

Figure 1. NE 57th St., Miami, after cleaning and inspection of pipe surface. Pipe exhibited no evidence of corrosion pitting or graphitization after 20 years of service.

Figure 2. NE 58th St., Miami, after cleaning and inspection of pipe surface. Surface of pipe is free of corrosion pitting or graphitization after 47 years of service.

Figure 3. NE 87th St., Miami. Surface of pipe is free of corrosion pitting or graphitization after 11 years of service.

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erage results of the tests compared to standard values are outline in Table 2.

As the polyethylene was being removed, the pipe was immediately found to have very little, if any, surface oxidation along its fully exposed circumference. As the outside of the pipe was cleaned and completely sounded and probed for evidence of external corrosion, it was further found that no electrochemical action, pitting, and/or graphitization, had taken place (Figure 2).

Investigation 3: Jan. 11, 2015; NE 87th St., Miami

Another 8-in. ductile iron water line owned and operated by MDWSD and protected from aggressive soils with black, 8-mil thick loose polyethylene encasement was inspected on the following day, Jan. 11, 2011, to determine the effectiveness of the protection.

In 2000, several hundred ft of 8-in. ductile iron water main were installed as part of another subdivision development. This water piping also conveys potable water at an operating pressure of some 65 to 70 psi.

As in the previous inspections, two soil samples were procured at this excavation site. As this third excavation was initiated, white clayey sand and gravel were encountered, and as the excavating continued to the three-and-one-half- to 6-ft depth, black organic clayey muck was found once more. Both types of soil were removed and tested per the DDM® with the muck testing in a range that is considered aggressive to ductile iron pipe (Table 1).

The location of this inspection was along the north side of NE 87th St. at Bayshore Drive. Some 8 to 10 ft of the water line were once again uncovered by MDWSD. As the polyethylene-wrapped ductile iron line was being exposed, the surrounding soil was removed such that the piping and its protective sleeve could be inspected along their full circumference. It was seen that this time, like the first inspection, the polyethylene had been loosely encased around the pipeline. As excavation proceeded, it was observed that groundwater from the adjacent bay area was constantly flowing into the trench and had to be dewatered. Some of this liquid was procured and tested per the DDM® and its characteristics can be found in Table 1. This fluid was in a testing range that would be considered aggressive to ductile iron piping products.

After this initial observation, as before, the exposed ends of the protected pipe were sealed off with circumferential wraps of polyethylene tape to secure the length of piping to be examined. Next, the plastic wrapping was severed and removed from the pipeline. The polyethylene film, installed in 2000, was tested and seemed to be in very good condition. The physical properties of the film exceeded the values put forward in ANSI/AWWA C105/A21.5-99. The average results of the tests compared to standard values are outlined in Table 2. As some 4 to 5 ft of the polyethylene protection was being cut and laid open, it was clear that there was not only a great deal of native groundwater trapped between the encasement and the pipe surface, but a fairly large amount of the native soil and backfill was also found to be under the wrap. This soil was procured and immediately tested and found to be in a testing range per the DDM® that is considered corrosive to ductile iron piping (Table 1).

Also, during this portion of the investigation it was noted that surface oxidation looked to be over most of the exposed pipe barrel (Figure 3). However, as the outside surface of the pipe was cleaned with water and the referenced instruments, it was quickly seen that this rust was superficial in nature and that much of the asphaltic shop coating was fairly well intact (Figure 3). As the inspection continued, the exposed pipe surface was completely sounded and probed for evidence of galvanic action, and it was noted that the pipe had suffered no pitting and/or graphitization after some 11 years of service.

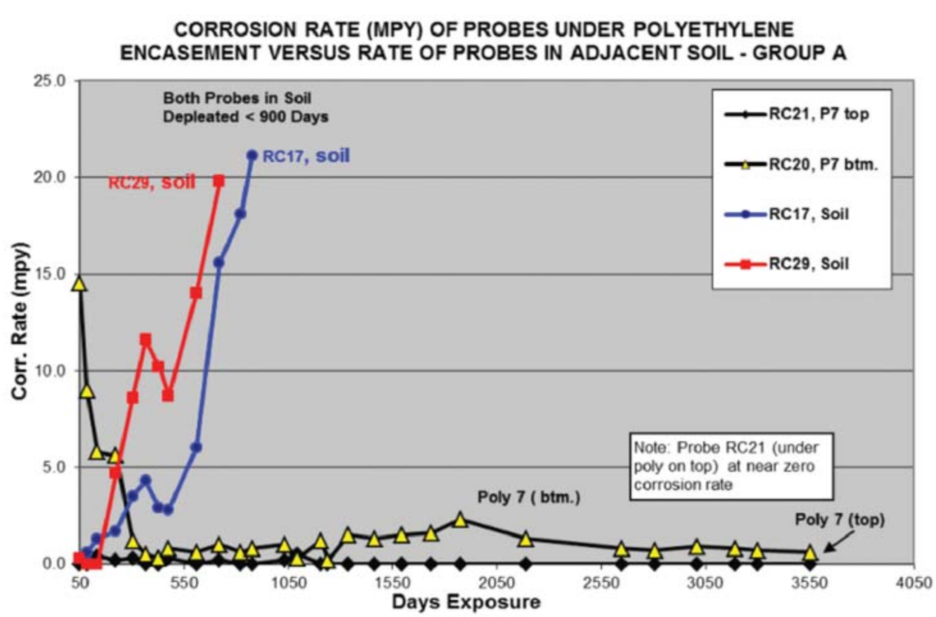

Figure 4. Corrosion rates of probes under polyethylene encasement versus corrosion rates of probes in soil adjacent to the test pipe.

Figure 5. Left photo: Petri dish showing effectiveness of biocide component after more than four years of burial in the Everglades with 100 percent kill rate. Right photo: Flasks showing effectiveness of inhibitor with three ductile iron (DI) samples in 5 percent salt solution after five years. The flask on the right is bare DI, the flask in the middle is bare DI wrapped with conventional polyethylene encasement, and the flask on the left is bare DI wrapped in enhanced (with biocide and inhibitor) polyethylene film.

Conclusions and Summary

The inspections conducted by MDWSD and DIPRA highlight the effectiveness of polyethylene encasement as an external corrosion control system for iron pipe. The three case histories involving iron pipelines that range from 11 to 20 years of age demonstrate the long-term, cost-effective corrosion protection afforded by polyethylene encasement. Loose polyethylene encasement offers this protection, even though it is not bonded to the surface of the pipe or completely sealed. It has been historically theorized that the moisture that is often found between the pipe and the protective barrier becomes stagnant over time and depleted of the oxygen necessary for corrosion to proceed (Horton, 1988). This moisture could be generated from temperature condensation or from initial seepage of natural groundwater. When properly installed, this moisture becomes trapped and it does not tend to be replenished; therefore, over a relatively short period of time, it loses its dissolved oxygen content through its reaction with the surface of the pipe (as evidenced by the typical presence of superficial oxidation of the pipe surface), thus becoming less aggressive (Horton, 1988). Basically speaking, galvanic corrosion takes place initially; however, once the oxygen and/or other depolarizing agents are depleted, the surface of the pipe polarizes and additional electrochemical corrosion is dramatically reduced. Simply stated, polyethylene encasement separates the pipe from its surrounding soil and replaces a nonuniform, aggressive environment (the soil) with a homogenous, nonaggressive environment, such as passivated water (Horton, 1988).

No longer is this just a theory. Work by Schiff Associates (now HDR/Schiff) in recent studies revealed that the dissolved oxygen does indeed decrease very rapidly; also, the pH of the moist environment under the film is inclined to increase. Both of these chemical changes in the water have a propensity to make the dominant corrosion mechanism uniform surface oxidation. Since this mild form of corrosion tends to consistently be superficial, the actual measured corrosion rate under the polyethylene film is generally quite small (Bell, Moore, Solis, 2009; Moua, Bell, 2008).

Further work conducted with corrosion probes installed under the polyethylene encasement at a testing site in Everglades City generated similar results. It was found that the corrosion rate

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Figure 6. Left: Bare DI pipe after three years burial with corrosion pits up to 0.18 in. Right: Bare DI pipe with polyethylene encasement containing biocide and corrosion inhibitor after six years burial in the Everglades with zero pitting.

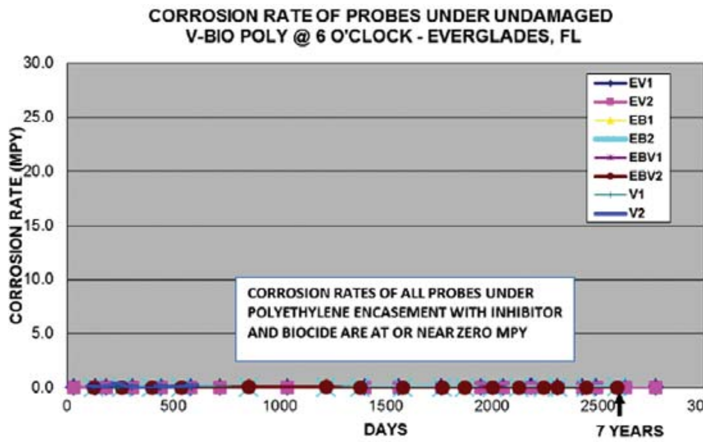

Figure 7. Corrosion rate (mpy) of probes under undamaged V-Bio™ Poly at the 6-o'clock position showing zero or near-zero corrosion rate during the test period. Corrosion rates of probes under V-Bio™ with cathodic protection were also at zero corrosion rate during the test period.

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under the wrap was initially high, but then rapidly decreased, which is more than likely due to polarization, as the oxygen in the moisture under the encasement was depleted. As seen in Figure 4, the decreasing corrosion rates of the probes under the plastic wrap in this study is consistent with past observations. Corrosion rates on probes covered by the encasement dropped to low levels after approximately three months of exposure. If one were to discount these initial three months of exposure, average corrosion rates under the loose protection at the 6-o'clock position were lowered to an average rate of 0.7 mils per year (mpy), down from 1.2 mpy (Figure 7). This compares to corrosion rates as high as 30 to 40 mpy on adjacent unprotected pipe (Horton and Ash, 2013)

The latest study and research with polyethylene encasement has been conducted with the newest advancement in polyethylene wrapping material. The idea of adding an inhibitor and biocide to negate the initial corrosion action has been developed, as V-Bio™, which is a patented method of corrosion control that employs proven technological advancements designed to virtually eliminate generalized electrochemical action, as well as controlling microbiologically induced corrosion (MIC). It differs from conventional polyethylene material in that it takes advantage of a modern co-extruded method of production to provide multifunctional elements at different zones across the cross sectional matrix of the film. This new product meets the requirements of C105/A21.5, and the innermost layer of this material contains a volatile corrosion inhibitor (VCI) to control initial galvanic action, as well as biocide components employed to control MIC.

Some of the initial experimental efforts with V-Bio™ began at an Everglades testing ground and in a laboratory. The biocide and inhibitor were tested over a four- and five-year term, respectively. The results showed a 100 percent kill rate for the biocide component at the Everglades site, while the inhibitor with biocide produced, in essence, no corrosion and virtually zero rusting over a five-year period with iron specimens in a 5 percent salt solution (Figure 5). Some other fields that work with V-Bio™-wrapped ductile iron pipe specimens have disclosed some additional very promising results. The V-Bio™-encased pipe exhumed after only three years and eight months of installation shows no pitting and/or graphitization, in conjunction with virtually no superficial oxidation (Figure 6). This can be compared with some unprotected ductile iron pipe segments with only six months of installation (Figure 6).

As the testing continued in the field, corrosion probes were employed to monitor the effectiveness of the newly developed wrap. Testing with the biocide and inhibitor-laced film exposed corrosion probe corrosion rates equal to or near zero mils per year for the past seven years (see Figure 6).

There is, of course, no perfect corrosion protection system for buried ferrous piping networks, and problems have been recorded with every kind of pipeline corrosion control method. Polyethylene encasement, as with any form of corrosion mitigation, has its limitations and might not be used alone to mitigate every corrosive condition. In such cases, it may be appropriate to augment polyethylene encasement with cathodic protection. However, in the majority of known corrosive environments, properly installed polyethylene encasement has demonstrated great efficacy in the mitigation of corrosive conditions for ductile iron pipe. There are also times when construction circumstances may prohibit proper installation procedures, such as rigorous river crossings. In "uniquely severe environments" as defined in Appendix "A" of C105/A21.5 and in unusually high-density stray current conditions, a single layer of polyethylene might not offer the level of desired protection. As with all corrosion control systems, the success with polyethylene encasement is governed by proper installation procedures[16].

Since the early 1950s, the iron pipe industry has researched several systems of corrosion control for gray and ductile iron pipe, including several field and laboratory investigations, along with in-place water and wastewater installations all over the United States and Canada. Various encasement materials, external pipe coatings, and the use of select backfills have all been evaluated. Nearly 60 years of experience, highlighted by the in-place excavations outlined in this article and elsewhere, have demonstrated the effectiveness of polyethylene encasement in protecting cast and/or ductile iron pipe in a wide range of soil conditions. Properly installed, polyethylene-encased iron pipelines are effectively protected from the majority of potential external corrosion conditions encountered by the water and wastewater industry.

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