Zinc Metallizing for External Corrosion Control of Ductile Iron Pipe

A.M. Horton, P.E., BSCHE, MSCEE

Sr. Process Engineering Manager, Technology & Product Development, U.S. Pipe and Foundry Co., 2023 St. Louis Ave., Bessemer, Alabama 35020; PH (205) 254-7964; email: mhorton@uspipe.com

ABSTRACT

Zinc metallizing with a high purity zinc wire has been utilized for external corrosion control of iron pipe for over 50 years. This paper summarizes publications and experiences of metallized zinc on iron pipe over that time period and discusses advantages and limitations of this method of corrosion protection. Advantages include but are not limited to: uniform cathodic protection of the iron pipe surface, thicknesses compatible with critical joint tolerances, no special considerations with respect to field cuts, tapping saddles, or corporation stops, no special handling or installation procedures required, ability to "self-heal" in many environments, minimal surface preparation required, and compatibility with current ductile iron pipe manufacturing processes. Limitations include: it is not recommended as a stand-alone method of corrosion control in severely corrosive soils or areas of stray electrical currents, it has limited cathodic protection at large areas of unrepaired damage in that it is a sacrificial coating that sacrifices itself to protect the iron substrate, and it is not compatible with some polymeric topcoats.

In severely corrosive soils or areas of stray electrical currents, polyethylene encasement conforming to AWWA C105 is used to supplement the metallic zinc coating. Previously unpublished results of corrosion studies, with and without polyethylene encasement, are also presented.

Key Words: Ductile Iron Pipe, metallic zinc coating, arc spray zinc, sacrificial cathodic protection, and polyethylene encasement.

INTRODUCTION

Water and wastewater infrastructure deterioration problems due to aging systems, and the need for funding in these areas have been widely publicized. In 2013, in their "Report Card for America", the American Society of Civil Engineers (ASCE) estimated that the U.S. needs to spend about $298 billion over the next 20 years to repair and expand wastewater and storm water systems, whose grade improved from a D- to a D (ASCE 2013). In 2002 the National Association of Corrosion Engineers estimated the annual direct cost of corrosion for water and sewer systems to be 36 billion (NACE, 2002). Efforts are currently underway to update these estimates, but they will no doubt be significantly higher now than estimates made in the early part of this century.

In the past, many types of asset preservation methods have been utilized for external corrosion protection of underground iron pipe. These include, but are not limited to: metallic zinc, metallic zinc alloys, polyethylene encasement, bonded coatings, galvanic cathodic protection, impressed current cathodic protection, concrete coatings, joint bonding and monitoring, trench improvement, and various combinations of the above. Over the past 50 years worldwide, the three methods which have been the most economical and widely used are metallic zinc, polyethylene encasement, and metallic zinc with polyethylene encasement.

Corrosion studies on the protection characteristics of metallic zinc on iron pipe were conducted as early as 1938. In 1975, Paris reported the following concerning the development and use of metallic zinc on iron pipe in Europe (Paris, 1975):

- Zinc coating on iron pipe first evaluated in 1938.
- Zinc coatings on iron pipe started to be commercially available in 1958-59.
- Between 1959 and 1975 (the time of the report), over 13 million iron pipes had been protected with this method of protection.
- In 1975, over 3,000 iron pipe per day were being coated with metallic zinc.

While most publications on metallic zinc coated iron pipe are based on experience and case histories from England and Europe, it should be noted that metallic zinc is, and has been used extensively for external corrosion protection of ductile iron pipe by China, India, the Middle East, Latin America, Africa, Korea, Japan, and others. Since first being made commercially available in 1958, millions of feet of iron pipe have been successfully protected worldwide with this method of external corrosion protection. Zinc coating for external corrosion protection of ductile iron pipe is such a recognized and established worldwide practice that there is an international standard, ISO 8179-1(Ductile Iron Pipes-External zinc-based coating-Part 1: Metallic Zinc with Finishing Layer) which was first issued in 1985 (ISO, 2004). This standard is discussed in detail in the section titled “Metallized Zinc Coating”.

While Europe was testing and developing metallic zinc for external corrosion protection of iron pipe, the USA was pursuing a different method of external corrosion protection – polyethylene encasement. Since its first introduction in 1951, polyethylene encasement has been the most commonly used method of external corrosion protection for gray and ductile iron pipe in the USA (Cox, 2012)(Horton, 2008). In the 50 years of use, over 300 million feet of iron pipe have been installed domestically with polyethylene encasement (Horton, 2008), and over 300 miles of encased pipe installed with supplemental cathodic protection (Lindemuth, 2007). A pilot survey of 21 USA utilities conducted by the AWWA Engineering and Construction Division reported 95% of the utilities polled use polyethylene encasement for corrosion protection of ductile iron pipe (AWWA, 2000). Numerous reports, publications, and tests document that polyethylene encasement, when the correct film is utilized and properly installed, has been extremely successful (Bonds, 2005), (Horton, 1988).

METALLIZED ZINC COATING

ISO-8179. Metallic zinc coating on ductile iron pipe is normally applied in accordance with ISO 8179-1 Ductile Iron Pipes-External Zinc-Based Coating-Part 1: Metallic Zinc with a Finishing Layer (ISO, 2004). This standard was first published in 1985 and requires application of high purity zinc (minimum of 99.99% by mass zinc) to a minimum application rate of 130 grams/m^2 with a local minimum of 110 grams/m^2. Due to 1) inconsistencies in measuring the film thickness on ductile iron pipe having an irregular as-cast peen pattern surface with peaks normally 5 to 15 mils tall, 2) the thickness of the zinc layer normally being less than 3 mils, and 3) the presence of a tightly adherent, non-magnetic annealing oxide from heat treatment, the weight of zinc per unit area is specified in lieu of a minimum thickness. The typical as-cast peen pattern surface on ductile iron pipe is shown in Figure 1.

Figure 1 – Photo showing typical as-cast peen pattern surface on DI Pipe

The current requirements of ISO-8179 are summarized below. Comments by the author regarding the requirements are given in italics.

- The metallic zinc must have a zinc content of at least 99.99% by mass and a topcoat of bituminous paint or synthetic resin compatible with zinc. *Zinc wire is normally utilized for the application, and the zinc coating is always furnished with a topcoat unless otherwise specified by the customer. Some testing has indicated a metallic zinc alloy comprised of 85% zinc and 15% aluminum can result in improved performance (Gulec, et.al., 2011), but this material is proprietary worldwide, and is not included as part of ISO 8179.*
- The metallic zinc shall be applied to an as-cast annealed external pipe surface, or to a blast-cleaned or ground surface, at the manufacturer's discretion. *Heat treating ductile iron pipe to a temperature exceeding 1,700 deg. F produces a tightly adherent protective "skin" on the OD of the pipe (i.e. annealing oxide). Testing has shown that undamaged annealing oxide alone can reduce*

the corrosion rate by a factor of 10 (Bell, 2007). Other testing indicates the presence of the annealing oxide can supplement the protection from the zinc and it is beneficial to be present as long as it is tightly adherent (Gulec, et.al, 2011). The metallic zinc coating supplements the protective nature of the annealing oxide in that it sacrificially protects the pipe at any damaged areas to the oxide layer.

- The metallic zinc coating shall be applied by a spraying process in which metallic zinc is heated to a molten state and projected in small droplets by spray guns onto the pipe surface. *(Discussed under Method of Application)*
- The metallic zinc coating shall cover the surface of the pipe with a spiraled appearance being permissible as long as the zinc coating masses comply with the requirements of the standard. *The specialized procedure for measuring the zinc mass is specified in the standard.*
- Damaged areas of zinc coating caused by handling are acceptable, provided that the area of damage is less than 5 cm^2 per square meter, and that the minor dimension of the damaged area does not exceed 5 mm. Greater areas of damage shall be repaired utilizing either a metallic zinc spray, or a zinc-rich paint containing more than 85% zinc by mass. *Some unrepaired minor damage is allowed due to the protective nature and self-healing properties of the zinc.*
- The mean mass of the zinc coating shall be measured using procedures outlined in the standard, with the mean mass of the zinc coating not to be less than 130 g/m^2 with a local minimum of 110 g/m^2. *Some manufacturers have adopted an in-house more conservative standard of 200 g/m^2 nominal zinc coating (Nouail, et.al., 1993) (U.S. Pipe, 2013).*
- The zinc layer shall have a finishing layer of bituminous paint or synthetic resin compatible with the zinc coating. The mean dry film thickness of the finishing layer shall not be less than 70 micron (2.8 mils) with a local thickness not less than 50 microns (2.0 mils). In order to avoid blistering, the mean dry film thickness of the finishing layer shall not exceed 250 microns (10 mils). *In the USA, the main topcoat currently furnished is asphaltic. Many thick film bonded coatings (i.e. >10 mils) are not normally applied over the zinc coating due to blistering concerns.*

Method of Application. Metallic zinc wire is normally thermally sprayed utilizing either an arc spray process or a flame spray process. Most DI pipe manufacturers around the world utilize an arc spray process as it is more compatible with the pipe manufacturing process. In a flame spray system, a high purity zinc wire is passed through a high temperature flame generated by an oxidizing fuel gas (e.g. acetylene) in combination with oxygen, and then clean, compressed atomizing air propels the molten zinc droplets to the surface being coated. In an arc spray system, two high purity zinc wires are brought together under a high electrical potential which results in the wires being melted at the point of contact (i.e. the electric arc). The molten zinc droplets are then propelled to the surface being coated by clean compressed atomizing air. A diagram of the arc spray metallizing process is shown in Figure 1, and a representative photograph of the actual plant process is shown in Figure 2.

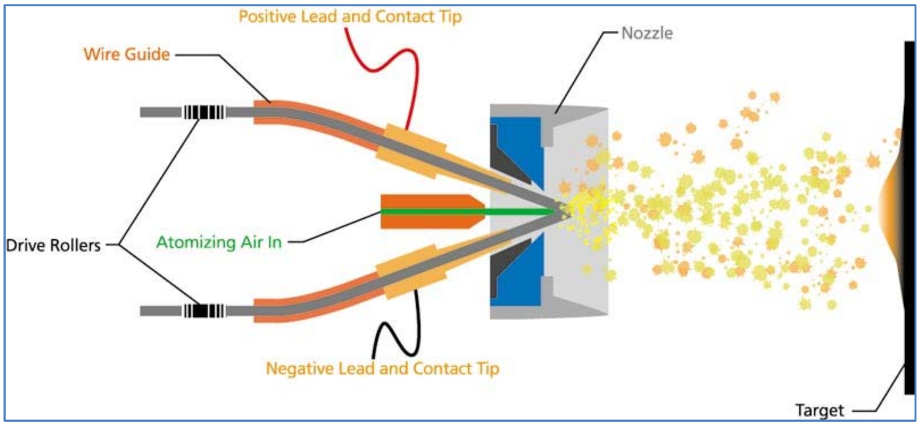

Figure 1 – Metallic arc spray metallizing process

Figure 2 – Ductile Iron Pipe being zinc coated utilizing arc spray process

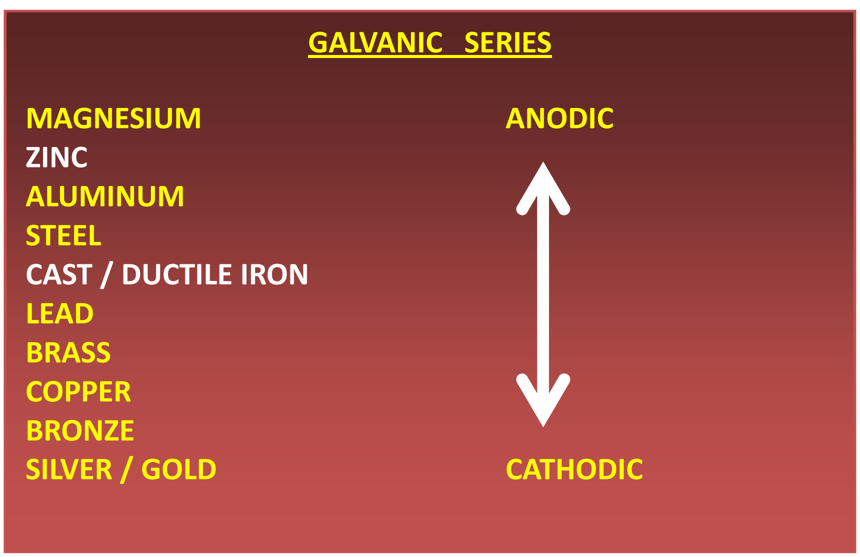

Figure 3 – Galvanic Series showing Zinc is anodic to Cast and Ductile Iron.

Mechanism of Protection. A metal can be protected from corrosion in an electrolyte by electrically connecting it to a more reactive metal (Refer to Figure 3). This method of protection is known as sacrificial cathodic protection. In the case of a metallic zinc coating on a ductile iron pipe, the zinc is more reactive and becomes the anode which sacrifices itself to protect the more noble ductile iron cathode (Refer to Figure 3). Thus, if a scratch or area of damage occurs in the coating, a galvanic couple is created between the iron (Fe) and the zinc (Zn) and the exposed iron is protected. Studies (Paris, 1975) and (Marchal, 1981), have shown that in most soils, once the zinc sacrifices itself it leaves behind a protective matrix of zinc compounds at the damaged area and keeps on providing protection to the pipe surface even though the zinc itself is expended (refer to Figure 4). Zinc coated pipe that have been exhumed after years in aggressive soils have been reported to be covered by a protective white layer of Zn corrosion products.

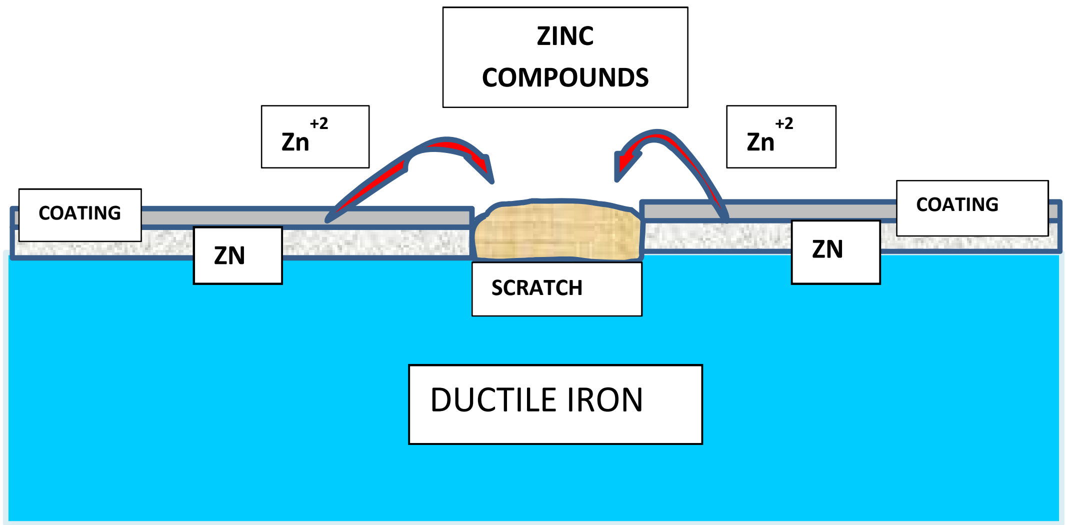

FIGURE 4 – Sacrificial protection from the zinc and zinc corrosion products.

Paris reported on studies in severely corrosive soils (i.e. sea water impregnated clay with less than 200 ohm-cm resistivity) that after 19 years "the metallic zinc had disappeared nearly everywhere, and had been transformed into a compact layer of corrosion product." No visible attack of the iron was observed on the samples with zinc coatings and tar varnish (Paris, 1975). Paris went on to report: "the pore-sealing qualities of the varnish allow the zinc to be transformed slowly in situ into an insoluble water tight and adherent layer. X-ray analysis by diffraction of this layer shows the presence of zinc carbonate, oxy-chloride of zinc and other more complex combinations. This layer once formed protects the pipe against all further attacks."

In 1981, Marchal presented a paper at the International Conference on the Internal and External Protection of Pipes which reported on additional studies confirming the healing and protective properties of the zinc coating (Marchal, 1981). Marchal reported: "These healing properties, which are the essential characteristics for the active coating, have proved to be of the utmost importance in protecting pipes against the serious corrosion which may result from the action of highly aggressive soils on damaged areas of traditional “passive” coatings such as bitumen, varnish, or coal tar.” Regarding the zinc corrosion products at an area of damage, Marchal went on to report: “the damaged point acted as cathode of the macrocouple existing between the bare metal and the remaining zinc coated surface: it has been protected by the galvanic effect of this macrocouple and the “healing” layer is the result of the cathodic activity (OH-), of the migration of zinc ions (Zn^{++}) from the anode area and of secondary reactions with the medium (HCO_3^-, Cl^-…). X-ray investigations of this layer show that its main components are basic carbonates and zinc oxy-chlorides.”

When discussing the self-healing, protective nature of the zinc corrosion products, it is important to point out that there are certain environments where these protective products do not form, or do not form effectively. Environments where metallic zinc coating is not recommended alone without some additional form of protection such as polyethylene encasement are discussed under “Limitations”.

POLYETHYLENE ENCASEMENT

Polyethylene encasement is an engineered corrosion control system manufactured using specially designed virgin material with specific thickness and mechanical requirements. Material specifications and installation instructions are given in national and international standards (AWWA, 2010) (ASTM, 2010) (ISO, 2006). As discussed previously, when the correct film is utilized and properly installed, this method of corrosion protection for ductile iron pipe has been extremely successful (Bonds, 2005), (Horton, 1988).

Corrosion protection by polyethylene encasement is achieved by encasing the pipe with a tube or sheet of loose polyethylene at the trench immediately before installation. Once installed, the encasement acts as an un-bonded film, which prevents direct contact of the pipe with the corrosive soil. It also effectively limits the electrolyte available to support corrosion activity to whatever moisture might be present in the very thin annular space between the pipe and wrap. Although polyethylene encasement is not a watertight system, the weight of the earth backfill and surrounding soil after installation normally prevents any significant exchange of groundwater between the wrap and the pipe. Although some groundwater will typically seep beneath the wrap, the water’s corrosive characteristics are soon depleted by initial corrosion reactions, usually oxidation. It provides a uniform environment around the pipe, thereby mitigating local galvanic cells caused by variations in soil composition, pH, and aeration, etc. (Horton & Ash, 2013). Polyethylene encasement has also been shown to be effective in eliminating or reducing stray current corrosion at most current levels encountered in the field.

METALLIC ZINC COATING WITH POLYETHYLENE ENCASEMENT

Studies in Europe in past decades have indicated that combining metallic zinc coating with polyethylene encasement produces a synergistic corrosion protection system in that the zinc will protect the pipe at unrepaired damage to the encasement, and the encasement will 1) extend the life of the zinc, 2) will enhance the development of zinc corrosion products as the zinc sacrifices itself, 3) will create a homogeneous environment around the pipe with some biocidal characteristics, and 4) will allow the zinc to be utilized in some severe environments where it is otherwise not recommended.

One of the earliest evaluations of metallic zinc coating with polyethylene encasement was reported by Paris on pipe buried in 1969 (Paris, 1975). Paris theorized that in a soil with a pH of 4, the added protection of polyethylene encasement would allow the protective coating to form and give long life protection to the pipe. Micrographic analysis after 4 years confirmed the theory in that it permitted the formation of a uniform layer of corrosion products of the zinc.

In 1991Tiratsoo reported on a 19 year corrosion study in which zinc coated pipe, with and without supplemental polyethylene encasement, were buried in a severely corrosive soil with very low resistivities ranging from 250 to 490 ohm-cm (Tiratsoo, 1991). Tiratsoo reported the following: "After 19 years the zinc protected DCI pipes are wholly intact, and presumably the initial corrosion cell (iron-zinc) at the damaged area) has been inactive for years (the previous examinations, after 7 years, showing a complete self- healing already accomplished). The long term protective zinc layer has formed under the coal-tar varnish and the PE sleeving. The sleeve decreases and regulates the water flow (containing dissolved salts) to the pipe surface. Moreover the electrolyte in contact with the coating has the effect of increasing its zinc bactericide effect. The appearance of the zinc coated DCI pipes with PE sleeving after 19 years are not different from those examined after 7 years. It is indicative of a controlled corrosion process."

ADVANTAGES AND LIMITATIONS

Advantages: In terms of manufacturing, handling, and installation in the field, thermally applied zinc coatings have many advantages over traditional thick film bonded coatings. These advantages include but are not limited to: uniform cathodic protection of the iron pipe surface, thicknesses compatible with critical joint tolerances, no special considerations with respect to field cuts, tapping saddles, or corporation stops, no special handling or installation procedures required, ability to "self-heal" in many environments, minimal surface preparation required, no cure time required after application, and compatibility with current ductile iron pipe manufacturing processes.

Limitations: The primary limitation of zinc coating on DI pipe is that there are certain environments where the protective corrosion products do not form, or do not form effectively. As zinc is a sacrificial coating, it has limited service life in environments were the protective corrosion products do not form, and/or where there is significant coating damage. Environments where metallic zinc coating is not recommended alone without some additional form of protection are: “High acid soils (pH < 4.5/5), peat soil, certain artificial backfill polluted by chemical products or cinders with sulfur, very basic soils (pH > 9), pipelines laid on the sea bed and subject to intensive running water, and pipelines subject to outside mechanical abrasive and corrosive conditions” (Paris, 1975). This study, and other studies (Marchal, 1981), (Tiratsoo, 1991), and (Nouail, Mailliard, & Barbier, 1993) report that zinc can be effectively utilized in many of these severe environments when utilized in combination with polyethylene encasement.

Other limitations include it has limited cathodic protection at large areas of unrepaired damage (maximum size of allowable damage is described in ISO 8179), it is not recommended alone in areas of stray electrical currents, and it is not compatible with some thick film polymeric topcoats (i.e. ISO-8179) which states: “In order to avoid blistering, the mean dry film thickness of the finishing layer shall not exceed 250 µm” (i.e. ~10 mils))(ISO, 2004).

STUDIES OF METALLIC ZINC ON IRON PIPE

Studies in Europe conducted on metallic zinc coating on iron pipe over the past 50 years have been discussed previously in this paper. Evaluations of this method of corrosion control on ductile iron pipe have also been conducted in highly corrosive soils in the USA since 1975 by the Ductile Iron Pipe Research Association (DIPRA, 2002). These results, which agree with findings of European studies and confirm polyethylene encasement should be utilized to supplement the zinc in severely corrosive environments, are summarized below:

USA Test Environments

- Everglades, Florida- AWWA C105 “Uniquely Severe” (80 to 200 ohm-cm “muck”, fluctuating tidal brackish water, high potential for bacteria MIC)
- Watsonville, CA (840 ohm-cm silt & clay)
- Logandale, NV (44 ohm-cm, 38,700 ppm sulfates, 8,700 ppm chlorides, silt/clay)

Results of Pipe Examinations

1975 Installation: 130 g/m^2 zinc plus 1 mil varnish (with & without encasement)

- Everglades, Fl.
    - No Polyethylene Encasement
        - 3 years : ~100% of zinc gone, no measurable pitting
        - 8 years: Corrosion pitting up to 0.036” deep
    - With Polyethylene Encasement
        - 3 years: Most of zinc present, no measurable pitting
        - 8 years: Most of zinc present, no measurable pitting

- Watsonville, CA
    - No Polyethylene Encasement
        - 4 years: ~75% of zinc gone, no measurable pitting
        - 9 years: ~100% of zinc gone, no measurable pitting
    - With Polyethylene Encasement
        - 4 years: Most of zinc coating present, no measurable pitting
        - 9 years: Most of zinc coating present, no measurable pitting

1985 Installation: 130 g/m^2 zinc plus 1 mil asphalt (no encasement)

- Everglades, Fl
    - 3 years: Average corrosion pitting of 0.048”
    - 6 years: Average corrosion pitting of 0.069”
    - 9.6 years: Average corrosion pitting of 0.169”
    - 12 years: Average corrosion pitting of 0.242”
- Logandale, NV
    - 3 years: Average corrosion pitting of 0.034”
    - 6 years: Average corrosion pitting of 0.054”
    - 8.8 years: Average corrosion pitting of 0.070”
    - 12 years: Average corrosion pitting of 0.117”

1991 Installation: 200 g/m^2 zinc plus 4 mils asphalt topcoat (no poly, damaged poly, and undamaged poly) – Everglades, Fl

- 10.7 years: No encasement: Avg. corrosion pitting of 0.061”
- 10.7 years: Damaged encasement: Avg. corrosion pitting of 0.027” at damage (approximately equal to initial surface roughness)
- 10.7 years: Undamaged encasement: Zero corrosion pitting

1992 Installation: 200 g/m^2 zinc plus 2 mils asphalt topcoat plus undamaged poly – Everglades, Fl

- 5 years: Three pipe sections: Zero corrosion pitting
- 10 years: Three pipe sections: Zero corrosion pitting

SUMMARY

Over 50 years of worldwide testing and use has shown that thermally applied metallic zinc and polyethylene encasement are both economical and effective methods of external corrosion control methods for iron pipe in many soils. As with any corrosion protection system, there is no “one size fits all” solution. In environments where neither zinc nor polyethylene encasement are recommended individually, studies in Europe and the USA have shown that combining metallic zinc coating with polyethylene encasement produces a synergistic corrosion protection system in that the zinc will protect the pipe at any unrepaired damage to the encasement, and the encasement will 1) extend the life of the zinc, 2) will enhance the development of zinc corrosion products as the zinc sacrifices itself, 3) will create a homogeneous environment around the pipe with some biocidal characteristics, and 4) will allow the zinc to be utilized in some severe environments where it is otherwise not recommended. Past publications and studies on zinc coated ductile iron pipe have reported the following:

- The existence of the varnish or asphaltic topcoat stops a rapid attack of the zinc.
- The zinc supplements the protective nature of the annealing oxide.
- The pore-sealing qualities of the topcoat allows the zinc to be transformed slowly in-situ into an insoluble water tight and adherent layer, and this layer once formed, protects the pipe against further attacks.
- Laboratory and field tests verify the protective qualities of the layers of corrosion products once the zinc metal has disappeared.
- In highly corrosive soils, studies have indicated pipe with a nominal 200 g/m^2 of zinc exhibit better protection and a longer life than pipe with 130 g/m^2 of zinc.
- Advantages of thermally applied zinc coatings include but are not limited to: uniform cathodic protection of the iron pipe surface, thicknesses compatible with critical joint tolerances, no special considerations with respect to field cuts, tapping saddles, or corporation stops, no special handling or installation procedures required, ability to "self-heal" in many environments, minimal surface preparation required, no cure time required after application, and compatibility with current ductile iron pipe manufacturing processes.
- Limitations include: it is not recommended as a stand-alone method of corrosion control in severely corrosive soils or areas of stray electrical currents, it has limited cathodic protection at large areas of unrepaired damage as the zinc sacrifices itself, and it is not compatible with some polymeric topcoats. Soils where zinc coating alone is not recommended include but are not limited to: environments with a pH below 4.5 or greater than 9, in industrial contaminated soils, soils with stray electrical currents, or in areas of flowing water. In these areas, supplemental protection such as polyethylene encasement is typically recommended.

REFERENCES:

ASCE (2013), "U.S Water Infrastructure Given "D" Grade by ASCE Group", American Society of Civil Engineers", Internet Article by P. Green, www.bloomberg.com/news/2013-03-19, American Society of Civil Engineers, Reston, VA

ASTM A 674 (2010), "Polyethylene Encasement of Ductile Iron Pipe Systems", ASTM, West Conshohocken, PA

AWWA (2000), American Water Works Association, "AWWA Engineering and Construction Division Survey", MainStream, October 2000, Denver, Colorado

AWWA (2010), ANSI/AWWA C105/A21.5 (2010), "Polyethylene Encasement for Ductile-Iron Pipe Systems", New York, NY: ANSI and Denver, CO: AWWA

Bell, G. (2007), "Development and Application of Ductile Iron Pipe Electrical Resistance Probes for Monitoring Underground External Pipeline Corrosion", NACE CORROSION 2007, Paper #07335, National Association of Corrosion Engineers, Houston, TX

Bonds, R.W, Barnard, L.M, Horton, A.M., Oliver, G.L. (2005), "Corrosion and Corrosion Control of Iron Pipe", Journal American Water Works Association Vol 97: No. 6, June 2005

Cox, A. (2012) "Fifty-Year History of External Corrosion Control for Iron Pipelines with Polyethylene Encasement", Materials Performance, June 2012, Vol. 51 No. 6, p46, National Association of Corrosion Engineers, Houston, Tx

DIPRA (2002), Summary of internal data generated from unpublished pipe examinations conducted by DIPRA, circa 1978-2002, Ductile Iron Pipe Research Association, Birmingham, AL

Gulec, A., Cevher, O., Ustel, F., Turk, A., Akinci, A. (2011), "Performance Comparison of Thermal Sprayed Coatings for Ductile Iron Pipe", Materials Performance, February 2011, Vol. 50, No. 2, p30, National Association of Corrosion Engineers, Houston, TX

Horton, A.M., Ash, G.A. (2013), "Evaluating PE Encasement on DI Pipe in a Severely Corrosive Environment", Materials Performance, June 2013, Vol. 52, No.6, p64, National Association of Corrosion Engineers, Houston, TX

Horton, A.M. (2008). "Polyethylene Encasement as an Asset Preservation Method", 2008 ASCE Pipeline Conference, July 22-24, 2008, Atlanta, GA

Horton, A. M. (1988), "Protecting Pipe with Polyethylene Encasement, 1951-1988," AWWA Water World News 4, 3 (1988): p. 26-28.

ISO (2004). ISO 8179-1 Ductile Iron Pipes-External Zinc-Based Coating-Part 1: Metallic Zinc with Finishing Layer, International Standards Organization, Geneva, Switzerland

ISO (2006), "ISO 8180 - Ductile Iron Pipes—Polyethylene Sleeving", International Standards Organization, Geneva, Switzerland

Lindemuth, D., Kroon, D. (2007), "Cathodic Protection of Pipe Encapsulated in Polyethylene Encasement", NACE CORROSION 2007, paper no. 07040, National Association of Corrosion Engineers, Houston, TX.

NACE (2002), "Corrosion Cost and Protection Strategies in the United States", Publication FHWA-RD-01-156, National Association of Corrosion Engineers, Houston, TX

Marchal, R. (1981), "Protection of Buried Ductile Iron Pipelines with a Zinc Based Coating-Healing Power of Coating Damages", Fourth International Conference on the Internal and External Protection of Pipes, Leeuwenhorst Congres Centre, Noordwijkerhout, The Netherlands, Sept. 15-17, 1981, BHRA Fluid Engineering, Cranfield, Bedford, England

Nouail, G., Mailliard, J., & Barbier, J.P., (1993), In Service behavior of buried Zinc Coated Ductile Iron Water Pipes", 10th International Conference on the Internal and External Protection of Pipes, Amsterdam, Nov 10-12, 1993, BHRA Fluid Engineering, Cranfield, Bedford, England

NACE (2002), "Corrosion Costs and Preventative Strategies in the United States", National Association of Corrosion Engineers, Houston, TX

Paris, M. (1975), "Zinc based Coating for Protecting Buried Gray and Ductile Iron Pipes Against Corrosion", First International Conference on the Internal and External Protection of Pipes, University of Durham, Sept. 9-11, 1975, BHRA Fluid Engineering, Cranfield, Bedford, England

Tiratsoo, J. (1991), "Zinc Based External Protection for Ductile Iron Pipes", 1991 Pipe Protection Conference, Beaconsfield, UK, BHR Group, Ltd.

U.S. Pipe (2013), "Zinc Coating for Ductile Iron Pipe", Brochure, United States Pipe and Foundry Company, Birmingham, AL