Zinc-Coated Ductile Iron Pipe

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Abstract
Zinc has been used to protect ferrous materials against corrosion for many years. Metallized arc-spray zinc coatings are now available on ductile iron pipe produced in the United States. Zinc-coated ductile iron pipe has been widely accepted and specified in the 18 months it has been available. This paper will present an overview of corrosion principles, how zinc is applied to ductile iron pipe, how zinc inhibits the corrosion of ferrous materials, and additional enhancements that, in combination with zinc, further extend the life of an already long-lasting product. The paper will also briefly highlight the performance characteristics of ductile iron pipe related to pressure, surge, flow characteristics, thrust restraint, and sustainability.

Overview of Corrosion Principles
Corrosion is an electrochemical process involving chemical reactions and electron transfer. Within the corrosion family, galvanic and electrolytic corrosion occur in water systems.

Galvanic corrosion involves two dissimilar metals and a conductive path between them. The less noble metal is the anode. It gives up electrons and is the place where corrosion is evident. The more noble metal is the cathode. It receives electrons and does not show evidence of corrosion. Figure 1 shows a high-level galvanic series with metals arranged in order of their nobility. The metals to the left are less noble and more likely to corrode.
In a water utility system, different metal types are used for the various components within the system. Steel, iron, brass, copper, and other metals are all likely to be in use. These dissimilar metals can be protected by providing a uniform and non-conductive environment around them that will prevent or reduce the transfer of electrons, i.e., corrosion.

If the environment around a single type of metal varies sufficiently, electron transfer can occur from one part of that single metal to another. That is why one method of corrosion protection is to create a uniform environment around the metallic mass.

Electrolytic corrosion is caused by an external source of current instead of a dissimilarity of metals or a non-uniform environment. In these cases, stray current finds its way to a mass. The point at which electrical current leaves the mass is the anode, and ultimately the location of the corrosion.

The rate of corrosion varies and is influenced by such factors as the degree of metallic dissimilarity and the concentration and composition of the conductive environment. If two metals are near one another on the galvanic series, there will be little potential for corrosion. If they are far apart, such as platinum and magnesium, there will be greater likelihood of corrosion, and the less noble is the one that will corrode. As noted, another factor in the rate of corrosion is the concentration of the electrolyte between the dissimilar metals, also known as resistance, or the lack thereof. For example, a salt solution will more effectively conduct current between dissimilar metals and with other factors being equal, a higher rate of corrosion will occur.

As corrosion occurs, an equilibrium is approached. When equilibrium is reached, corrosion stops. A phenomenon known as passivation occurs when corrosion by-products encapsulate and protect the surface of an anode. An example of passivation is steel embedded in concrete. The alkaline environment provided by fresh cement promotes the formation of a passive oxide film on the surface of the steel and protects it from corrosion.

**Corrosion Specific to Water Utility Systems**

Corrosion affects all infrastructure, and all materials, for that matter. It’s a result of entropy, the Second Law of Thermodynamics. Some types of corrosion more common to water systems include concentration cells, pitting, impingement, and microbiologically influenced corrosion.
Concentration cells are small and localized, resulting from a variation in oxygen content. For example, the space between two layers of metal may have a low oxygen content; and the area outside that layer, a higher oxygen content. The metal in contact with the lower oxygen content will be anodic and corrode. This is another example of the importance of a uniform environment.

Pitting occurs when a protective layer or film is disturbed. The exposed area will become anodic and corrode.

A type of corrosion known as impingement occurs when the normal operation of a product results in the erosion of a surface area and the resultant corrosion of that area. For example, a high and concentrated flow rate of an abrasive fluid against an area can strip it of a protective film and that area may corrode. Pumps are often subject to impingement. (AWWA, 2014).

Water systems are also subject to Microbiologically Influenced Corrosion, commonly known as MIC. It is also known as microbial corrosion and biological corrosion, and is the result of microorganisms’ metabolic activity.

A number of bacteria classified as aerobic (requiring oxygen) and anaerobic (oxygen will kill the bacteria) can attack carbon and stainless steels, and aluminum and copper alloys in soils and waters with pH levels from 4 to 9 and temperatures of 10 to 50 degrees Centigrade. An environment of concern for underground pipelines is clay soils with high moisture content and an approximately neutral pH in the presence of decaying organic matter as a source of sulfate-reducing bacteria.

MIC is addressed through the use of biocides and anti-microbial compounds similar to those found in cleaners and soaps or by providing a dry environment. Recent enhancements to polyethylene encasement for ductile iron pipe, known as V-Bio, have added anti-microbial compounds to the inside of the protective sleeve. These compounds neutralize the bacteria and prevent MIC. (WebCorr Corrosion Consulting Services, n.d.)

**Stress and Fatigue Corrosion**

Stress can accelerate corrosion or move an otherwise stable environment into a corrosive environment. Figure 2 shows a bracket where the areas experiencing stress are corroding and those not under stress, not so much.

Fatigue is a form of stress corrosion. An elementary and familiar example is the bending of a paper clip back and forth. In water systems, fatigue is a result of cyclic loading from pressure surges. It’s important that a material’s yield point not be exceeded in order for it to avoid failure from...
fatigue. While plastic is often thought to be immune from corrosion, it is very susceptible to fatigue and care should be exercised to design plastic water pipe so that pressure surges remain below the low yield strength. (Oliphant, 2012)

An effective barrier against fatigue is the use of joints with some flexibility and sufficient bedding in and around structures and connections. Ductile iron pipe joint systems have generous flexibility resulting in resistance to stress corrosion and fatigue. Failure from fatigue is shown in Figure 3.

Dezincification
Dezincification is the leaching of zinc from an alloy such as brass resulting in a porous material with little strength. The same characteristics that make zinc protective for some metals make it the source of dezincification. Recent advances in metallurgy have resulted in brasses used in water systems being more resistant to dezincification and material specifications more attuned to its prevention. (NACE International, n.d.)

Atmospheric Corrosion
Atmospheric corrosion occurs when metals are exposed to atmospheric humidity and an oxidizing agent, such as oxygen. Exposed interior treatment plant piping in pump rooms and galleries are examples of vulnerable conditions. Humidity control and appropriate topcoats with zinc-rich primers are effective barriers to atmospheric corrosion.

Use of Zinc as a Life-Extender, Corrosion Inhibitor
Zinc as a protective coating for iron pipe has been used since 1958, and an International Standards Organization protocol for it was developed in 1985. Every major worldwide producer of ductile iron pipe has the capability of applying zinc, and most offer it as standard.

The delayed embrace of zinc in the United States market is related to the emphasis on polyethylene encasement as a preferred protective system. Like zinc overseas, polyethylene encasement in the United States has proven its efficacy since the 1950s (Cox, 2012). Recent developments in adding anti-microbial compounds to the polyethylene sleeve will serve to make the loose wrap even more effective. The availability of zinc, with or without V-Bio polyethylene encasement, makes ductile iron suitable for demanding environments and effectively takes corrosion objections off the table. The service record of iron pipe with more than 600 United States utilities having iron pipe in continuous service more than 100 years supports this.
Application of Zinc to Ductile Iron Pipe

As noted above, the International Standards Organization, ISO, developed a standard for the application of zinc coatings to iron pipe in 1985. That standard, ISO 8179-1, *Ductile Iron Pipes-External Zinc Based Coating-Part 1: Metallic Zinc with a Finishing Layer*, is widely regarded as best practice. ISO 8179 calls for essentially pure (99.99%) zinc to be applied at a general minimum of 130 g/m² and local minimum of 110 g/m². Some manufacturers have adopted 200 g/m² as the coverage. Mass instead of thickness was selected as the control factor because of the peen pattern on ductile iron pipe where peen heights range from 5 to 15 mils. The familiar peen pattern of ductile iron pipe is shown in Figure 4.

![Figure 4. Exterior peen pattern of ductile iron pipe.](image1)

The zinc is applied to AMERICAN ductile iron pipe with a metallized arc spray process in which two zinc wires are fed together with a high electrical potential causing the zinc to melt at 787 F. It is then diffused with clean compressed air and adheres tightly to the pre-heated, approximately 175 degrees Fahrenheit pipe surface. This is generically illustrated in Figure 5.

![Figure 5. The metallized arc spray process. (Kalivas, 2003)](image2)

Following the metallized arc spray application of zinc at 200 g/m², a finishing top coat is applied to the zinc. The role of the top coat will be explained in the paragraphs to come. Figure 6 shows a display piece of zinc coated pipe with finishing topcoat.
How Zinc Works with Ductile Iron Pipe

Referring to the galvanic series noted earlier, in an aggressive environment, zinc is the anode and sacrifices itself to protect the more noble ductile iron cathode. In this process, corrosion by-products known as zinc salts or zinc patina form a dense, tightly adherent layer between the annealing scale and the finishing topcoat. This layer creates a rugged and long-lasting protective barrier between the iron pipe and the surrounding environment. (American Galvanizers Association, 2011).

In an often-cited study, Paris (Paris, 1975) reported that after 19 years in a very aggressive environment, “the metallic zinc had disappeared nearly everywhere, and had been transformed into a compact layer of corrosion product.” His report continued, “The pore-sealing qualities of the varnish [finishing topcoat] 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.” (Paris, 1975) and (Horton, 2014).

In the event the finishing topcoat is scratched and the zinc or the underlying annealing scale is exposed, a galvanic couple develops between the iron and the zinc. The sacrificing zinc will leave behind a protective matrix of zinc compounds over the damaged area not unlike a scab on human skin. (Paris, 1975) and (Marchal, 1981) Zinc-coated pipe recovered after years in aggressive environments were discovered to have a white protective layer of zinc corrosion by-products, (Horton, 2014).

In his 1981 paper, Marchal stated, “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.”

**Evidence of Zinc’s Efficacy**
Numerous field tests have been conducted by the Ductile Iron Pipe Research Association and others (DIPRA, 2002). A 1991 Everglades, Florida, field test was conducted in soils deemed to be “uniquely severe.” This was muck with fluctuating brackish ground water conducive to MIC and resistivities ranging from 80 to 200 ohm-cm. The sample pipe was coated with 200 g/m² of zinc with an asphalt finishing topcoat. Specimens were buried with three configurations: without polyethylene encasement, with intentionally damaged polyethylene encasement, and with intact polyethylene encasement. Excavation 10.7 years later revealed:

- Without polyethylene encasement: average corrosion pitting of 0.061 inches
- With intentionally damaged polyethylene encasement: average corrosion pitting of 0.027 inches at only the area of damage
- With intact polyethylene encasement: no corrosion pitting.

**Other Attributes of Ductile Iron Pipe**
In addition to being exceptionally suitable for life-extension by using zinc, ductile iron pipe has a strong collection of attributes making it an excellent product for pressure pipe applications. These include robust pressure ratings up to 350 psi with a surge pressure of 100 psi and a safety factor of 2.0 applied to their sum; toughness to resist handling and demanding environments; a larger-than-nominal inside diameter resulting in lower pumping costs and a reduced carbon footprint; a variety of joint restraint systems including seismic and trenchless applications; and a third-party sustainability rating known as SMaRT.

**Conclusion**
Zinc represents the latest metallurgical innovation and advancement in the United States’ ductile iron pipe industry. Irrespective of whether one’s soils are corrosive, the application of metallized arc spray zinc coating to ductile iron pipe will add years of service to a product that has already been proven to have an exemplary service life. How much life depends on many environmental factors. If those factors are uniquely severe, the use of previously mentioned V-Bio polyethylene encasement will add yet another layer of protection resulting in an exceptionally secure pipeline.

From an economics standpoint, if zinc adds 10 percent to the cost of the product and adds 50 percent to its service life, exceptional value has been received.

**References**


