

Zinc-Coated Ductile Iron Pipe

by Maury D. Gaston

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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 and shipped within the United States. AMERICAN zinc-coated ductile iron pipe has been widely accepted and specified domestically since its introduction in the spring of 2015.

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.

Overview of Corrosion Principles

Corrosion is manifestation of the Second Law of Thermodynamics, the principle of entropy, the inevitable tendency toward disorder. It is universal, but it can be managed.



Figure 1. Corrosion is the manifestation of the Second Law of Thermodynamics, entropy, the inexorable march toward disorder.

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. The anode 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 2 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.

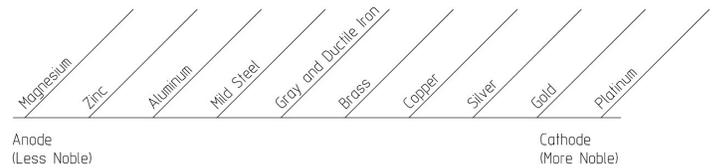


Figure 2. A galvanic series showing less noble (anodic) metals to the left and more noble (cathodic) metals to the right.

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, in other words, 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. Polyethylene encasement is an example of such an application.

Electrolytic corrosion is caused by an external source of current as compared to 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. 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. This is illustrated by the photograph in Figure 3 where the metal in contact with the lower oxygen content has become anodic and corroded. This is another example of the importance of a uniform environment.



Figure 3. Concentration cell resulting from variation in oxygen content.

Pitting occurs when a protective layer or film is disturbed. The exposed area will become anodic and corrode. An example is shown in Figure 4.



Figure 4. Pitting from a compromised coating.

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 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 and shown in Figure 5, 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.)

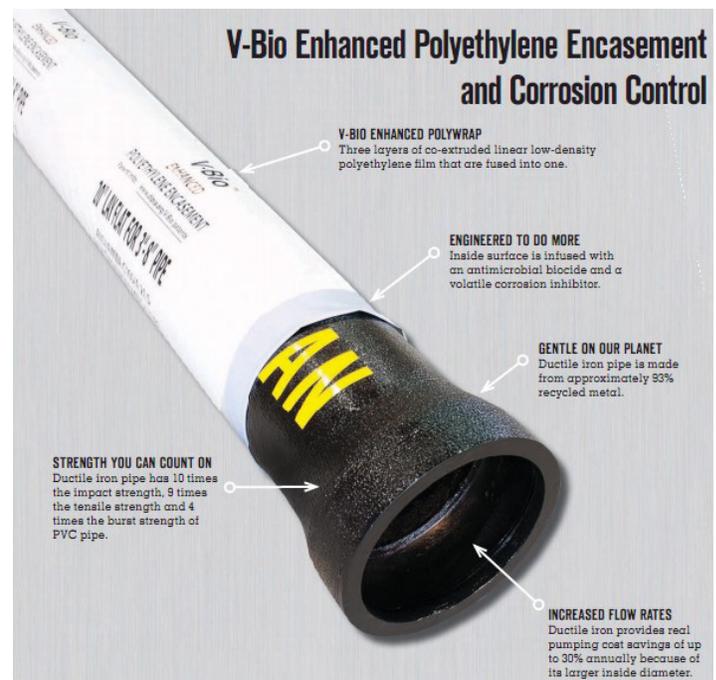


Figure 5. V-Bio polyethylene wrap contains an anti-microbial agent to shut down microbiologically influenced corrosion.

Stress and Fatigue Corrosion

Stress can accelerate corrosion or move an otherwise stable environment into a corrosive environment.

Figure 6 shows a bracket where the areas experiencing

stress are corroding and those not under stress, not so much.



Figure 6. A bracket exhibiting stress corrosion.

Fatigue is a form of stress corrosion and failure from it is shown in Figure 7. An elementary and familiar example of fatigue 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 during cyclic loading in order to avoid failure from fatigue. While plastic is often thought to be immune from corrosion, because of its lower yield strength, it is quite 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)



Figure 7. Stress corrosion of a small diameter supply line resulting from fatigue from cyclic loading. (Metallurgical Technologies, Inc., n.d.)

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 offer generous flexibility resulting in resistance to stress corrosion and fatigue.

Dezincification

Dezincification is the leaching of zinc from an alloy such as brass resulting in a porous material with little strength. An illustration of dezincification is shown in Figure 8. The same characteristics that make zinc protective for some metals make it the source of dezincification for others. 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.)

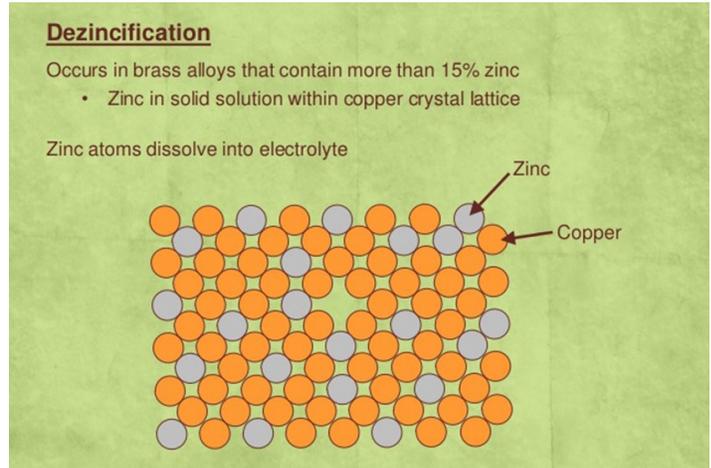


Figure 8. Dezincification results in a porous material with little strength.

Atmospheric Corrosion

Atmospheric corrosion occurs when metals are exposed to atmospheric humidity and an oxidizing agent, such as oxygen. Exposed interior and exterior 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. An example of a storage tank's atmospheric corrosion is shown in Figure 9.



Figure 9. Atmospheric corrosion of a storage tank.

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, especially on smaller diameter distribution sizes.

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 supports this with more than 600 United States utilities having iron pipe in continuous service more than 100 years.

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/m^2 and local minimum of 110 g/m^2 . AMERICAN has adopted 200 g/m^2 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 10.

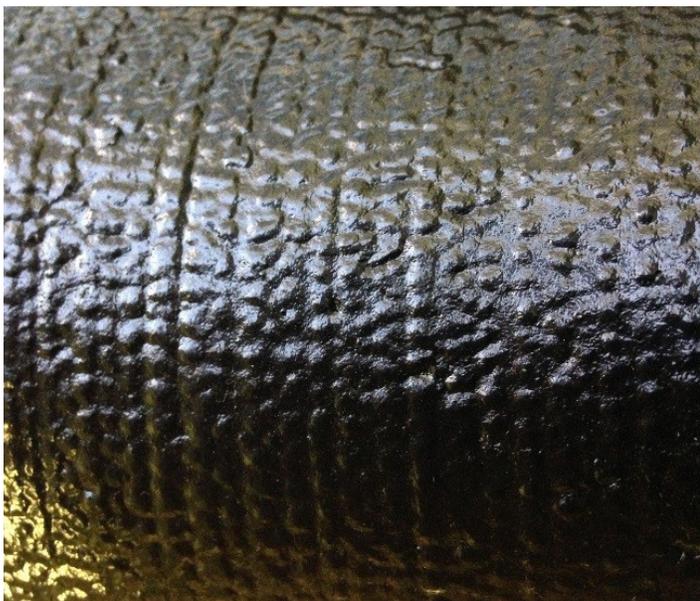


Figure 10. Exterior peen pattern of ductile iron pipe.

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 $175\text{-degree Fahrenheit}$ pipe surface. This is schematically illustrated in Figure 11.

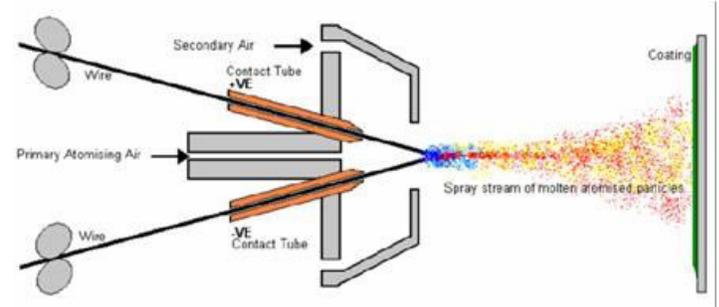


Figure 11. The metallized arc spray process. (Kalivas, 2003)

Following the metallized arc spray application of zinc at 200 g/m^2 , a finishing top coat is applied to the zinc. The role of the top coat will be explained in the paragraphs to come. Figure 12 shows a display piece of zinc coated AMERICAN ductile iron pipe with an exposed band of zinc undercoat and the finishing topcoat.



Figure 12. A display piece of zinc-coated AMERICAN ductile iron pipe with an exposed band of zinc undercoat and the 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 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) This is illustrated in Figure 13.

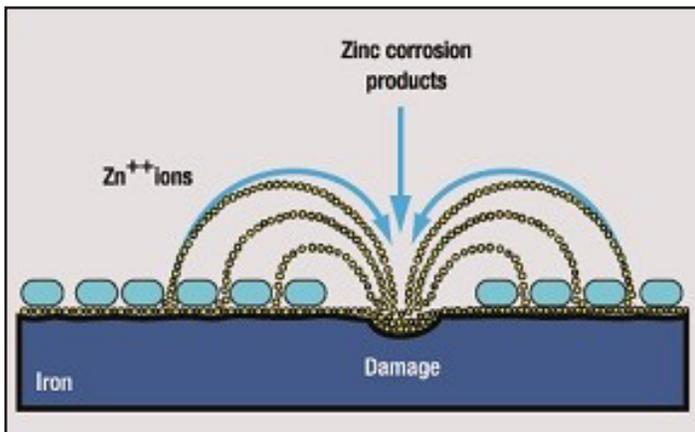


Figure 13. Sacrificing zinc leaving a protective matrix of zinc compounds.

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 a 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.

Clearly, zinc protects in all conditions; and with polyethylene encasement, no corrosion was evident in this very aggressive environment.

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 additional 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 or even doubles its service life, exceptional value has surely been received. The Washington Suburban Sanitary Commission has doubled their projected design life to 150 years by adding metallized arc-spray zinc coating and upgrading from traditional wrap to V-Bio polyethylene encasement. (Development Services Group of WSSC, Electronic Communication, February 26, 2016) Zinc-coated AMERICAN ductile iron pipe is the latest in innovative and sustainable resilience for leading water agencies across the country and around the world.

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About the Author

Maury D. Gaston is a 34-year veteran of the water industry and a member of the American Society of Civil Engineers and the American Water Works Association. In April 2016, ASCE presented him with an innovation award for his writings on trans-basin pipelines. Within AWWA, he is a member of the A21 committee concerning ductile iron pipe products and chairs sub-committee 1 dealing with design and manufacturing standards of ductile iron pipe.

Gaston has held numerous sales and marketing responsibilities across the country during his career at AMERICAN, and is currently Manager of Marketing Services for AMERICAN Ductile Iron Pipe and AMERICAN SpiralWeld Pipe.

Gaston is also a Director and past Chairman of the state of Alabama Engineering Hall of Fame, and served as Chairman of the Auburn University Alumni Engineering Council. He was recognized as Auburn's 2014 Mechanical Engineering Alumnus of the Year.

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