HOT-DIP GALVANIZING FOR CORROSION PROTECTION

a specifier's guide

american galvanizers association

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Corrosion:

what & why

Corrosion and repair of corrosion damage are multi-billion dollar problems – the latest estimates show metallic corrosion costs the United States approximately $423 billion annually ($52 billion in Canada), or about 3% of each nation's GDP. However, the cost of corrosion is much greater than just financial, it can also lead to waste of natural resources, hazardous failures, and many other indirect costs. Corrosion is a natural phenomenon which can never be completely eliminated; however, it is a misconception nothing can be done. Employing adequate corrosion protection systems at the start of a project, such as hot-dip galvanizing, can significantly reduce these annual costs.

For more than 100 years, hot-dip galvanizing after fabrication has been specified to combat steel corrosion in the harshest environments throughout various markets. However, the specification and use of hot-dip galvanized steel evolves constantly as new markets emerge. Once considered only as a means of corrosion protection, hot-dip galvanizing is now specified for an array of reasons including lower initial cost, durability, longevity, availability, versatility, sustainability, and even aesthetics. Understanding the characteristics and performance of hot-dip galvanized steel will facilitate and increase the specification of the coating in applications where galvanizing will enhance the project.

corrosion process

Corrosion, which can be simply defined as rust, is more appropriately the tendency for metals to revert to their natural, lower energy state of ore. Metallic corrosion is an electrochemical process meaning it involves both chemical reactions and the flow of electrons. A basic electrochemical process that drives the corrosion of metals is galvanic action, where current is generated internally by physical and chemical reactions occurring among the components of the cell.

corrosion costs the US

$423 BILLION

annually

galvanic corrosion

There are two primary types of galvanic cells that cause corrosion: the bimetallic couple and the concentration cell. A bimetallic couple (*Figure 1*) is like a battery, consisting of two dissimilar metals immersed in an electrolyte solution. An electric current (flow of electrons) is generated when the two electrodes are connected by an external continuous metallic path. A concentration cell consists of an anode and cathode of the same metal or alloy and a return current path. The electromotive force is provided by a difference in concentration of the solutions contacting the metal(s). In a galvanic cell, there are four elements necessary for corrosion to occur:

- ***Anode*** - Electrode at which negative ions are discharged and positive ions are formed, or other oxidizing reactions occur. Corrosion occurs at the anode.
- ***Cathode*** - Electrode at which positive ions are discharged, negative ions are formed, or other reducing reactions occur. The cathode is protected from corrosion.
- ***Electrolyte*** - Conducting medium in which the flow of current is accompanied by movement of matter. Electrolytes include water solutions of acids, bases, and salts.
- ***Return Current Path*** - The metallic pathway connecting the anode to the cathode. It is often the underlying substrate.

Removing any one of these elements will stop the current flow and corrosion will not occur. Substituting a different metal for the anode or cathode may cause the direction of the current to reverse, resulting in a change of the electrode experiencing corrosion.

The galvanic series lists metals and alloys in decreasing order of electrical activity. Metals toward the top of the list are "less noble" and have a greater tendency to lose electrons than metals found lower on the list. Utilizing hot-dip galvanized steel exploits this phenomenon by sacrificing zinc (anode) to protect the underlying steel (cathode).

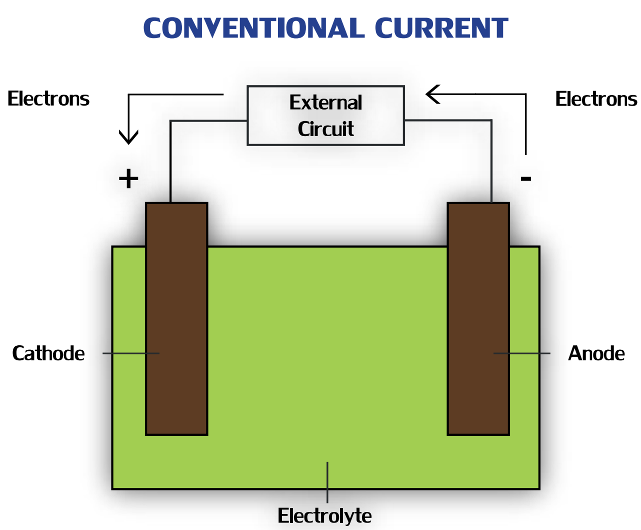
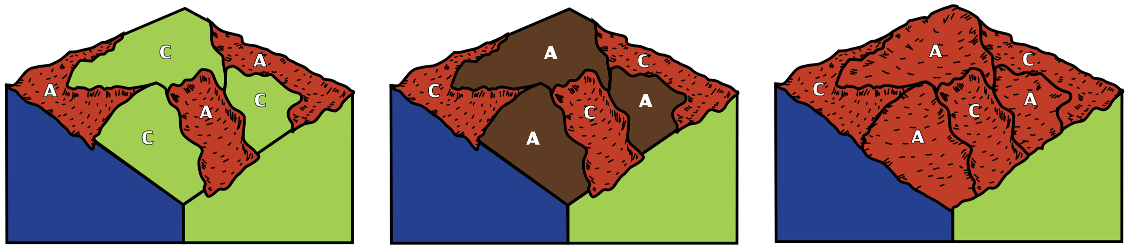


Figure 1: Bimetallic Couple

corrosion of steel

The corrosion process that takes place on a piece of bare steel is very complex due to variations in the composition/structure of the steel, presence of impurities due to the higher instance of recycled steel, uneven internal stress, or exposure to a non-uniform environment.

It is easy for microscopic areas of the exposed metal to become relatively anodic or cathodic, and many of these areas can develop in a small section of the exposed metal. Therefore, it is highly possible several different galvanic corrosion cells are present in the same small area of the actively corroding piece of steel.



Mosaic of anodes and cathodes, electrically connected by the underlying steel.

Moisture in the air provides the electrical path between anodes and cathodes. Due to differences in potential, electric current begins to flow as the anodic areas are consumed. Iron ions produced at the anode combine with the environment to form the flaky iron oxide known as rust.

As anodic areas corrode, new material of different composition and structure is exposed. This results in a change of electrical potentials and changes the location of anodic and cathodic sites. Over time, previously uncorroded areas are attacked and uniform surface corrosion results. This continues until the steel is entirely consumed.

Figure 2: Changes in cathodic and anodic areas

As the corrosion process progresses, the electrolyte may change due to materials dissolving in or precipitating from the solution. Additionally, corrosion products might tend to build up on certain areas of the metal. As time goes by, there may be a change in the location of cathodic and anodic areas and previously uncorroded areas of the metal are attacked and corrode (*Figure 2*).

The corrosion rate of metals is controlled by factors such as temperature, humidity, pH of the electrolyte, and the electrical potential and resistance of anodic and cathodic areas.

Hot-Dip Galvanizing (HDG)

for corrosion protection

Hot-dip galvanizing is the process of immersing fabricated steel or iron into a kettle or bath of molten zinc. The process is inherently simple which provides a distinct advantage over other corrosion protection methods. Originating more than 250 years ago, here is a tour of the history and process in more detail.

history of galvanizing

The recorded history of galvanizing dates back to 1742 when P.J. Malouin, a French chemist described a method of coating iron by dipping it in molten zinc in a presentation to the French Royal Academy. Thirty years later, Luigi Galvani, galvanizing's namesake, discovered more about the electrochemical process that takes place between metals. Galvani's research was furthered in 1829 when Michael Faraday discovered zinc's sacrificial action, and in 1836, French engineer Sorel obtained a patent for the early galvanizing process. By 1850, the British galvanizing industry was using 10,000 tons of zinc a year for the protection of steel, and in 1870, the first galvanizing plant opened in the United States. Today, galvanizing is found in almost every major application and industry where iron or steel is used. Hot-dip galvanized steel has a proven and growing history of success in myriad applications worldwide.

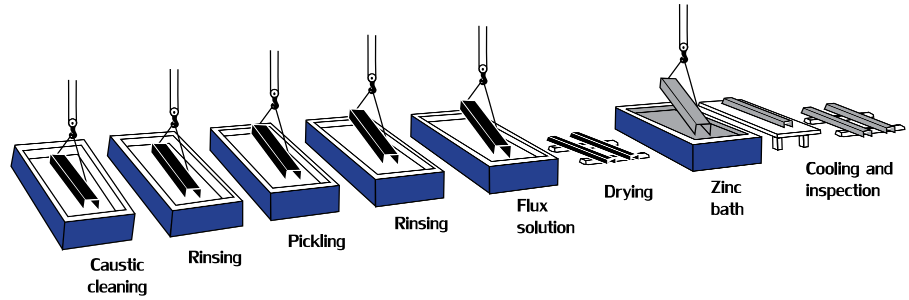


Figure 3: Batch Hot-Dip Galvanizing Process

galvanizing process

The galvanizing process consists of three basic steps: surface preparation, galvanizing, and inspection (*Figure 3.)*

surface preparation

Surface preparation is the most important step in the application of any coating. In most instances where a coating fails before the end of its expected service life, it is because of incorrect or inadequate surface preparation.

The surface preparation step in the galvanizing process has its own built-in means of quality control because zinc simply will not react with unclean steel. Any failures or inadequacies in surface preparation will be immediately apparent when the steel is withdrawn from the zinc bath because the unclean areas will remain uncoated, and immediate corrective action can be taken.

Surface preparation for galvanizing consists of three steps:

- ***Degreasing -*** A hot alkali solution, mild acidic bath, or biological cleaning bath removes organic contaminants such as dirt, paint markings, grease, and oil from the metal surface. Epoxies, vinyls, asphalt, or welding slag, which cannot be removed by degreasing, must be removed before galvanizing by grit-blasting, sand-blasting, or other mechanical means.
- ***Pickling –*** A dilute solution of heated sulfuric acid or ambient hydrochloric acid removes mill scale and iron oxides (rust) from the steel surface. As an alternative to or in conjunction with pickling, this step can also be accomplished using abrasive cleaning or air blasting sand, metallic shot, or grit onto the steel.
- ***Fluxing –*** The final surface preparation step in the galvanizing process, a zinc ammonium chloride solution, serves two purposes. It removes any remaining oxides and deposits a protective layer on the steel to prevent any further oxides from forming on the surface prior to immersion in the molten zinc.

galvanizing

During the actual galvanizing step of the process, the material is completely immersed in a bath of molten zinc. The bath chemistry is specified by ASTM B6, and requires at least 98% pure zinc maintained at approximately 840 F (449 C).

While immersed in the kettle, the zinc reacts with the iron in the steel to form a series of zinc/iron intermetallic alloy layers. Once the fabricated items' coating growth is complete, they are withdrawn slowly form the galvanizing bath, and the excess zinc is removed by draining, vibrating, and/or centrifuging.

The metallurgical reaction will continue after the articles are withdrawn from the bath, as long as the article remains near bath temperature. Articles are cooled either by immersion in a passivation solution or water or by being left in open air.

inspection

The inspection of hot-dip galvanized steel is simple and quick. The two properties of the hot-dip galvanized coating closely scrutinized are coating thickness and coating appearance. A variety of simple physical and laboratory tests may be performed to determine thickness, uniformity, adherence, and appearance.

Products are galvanized according to long established, accepted, and approved standards of ASTM, the International Standards Organization (ISO), the Canadian Standards Association (CSA), and the American Association of State Highway and Transportation Officials (AASHTO). These standards cover everything from the minimum coating thicknesses required for various categories of galvanized items to the composition of the zinc metal used in the process.

Testing methods and interpretation of results are covered in the publication, *The Inspection of Products Hot-Dip Galvanized after Fabrication,* published by the American Galvanizers Association (AGA). This publication, as well as all others referenced in this guide, can be found on the AGA website (**www.galvanizeit.org**).

Why Specifiers Choose hot-dip galvanizing

Traditionally, hot-dip galvanized steel is specified for its superior corrosion protection, especially in harsh environments. Though corrosion resistance is inherent any time galvanizing is utilized, more and more specifiers select hot-dip galvanized steel for other reasons, including lowest initial cost, durability, longevity, availability, versatility, aesthetics, and sustainability.

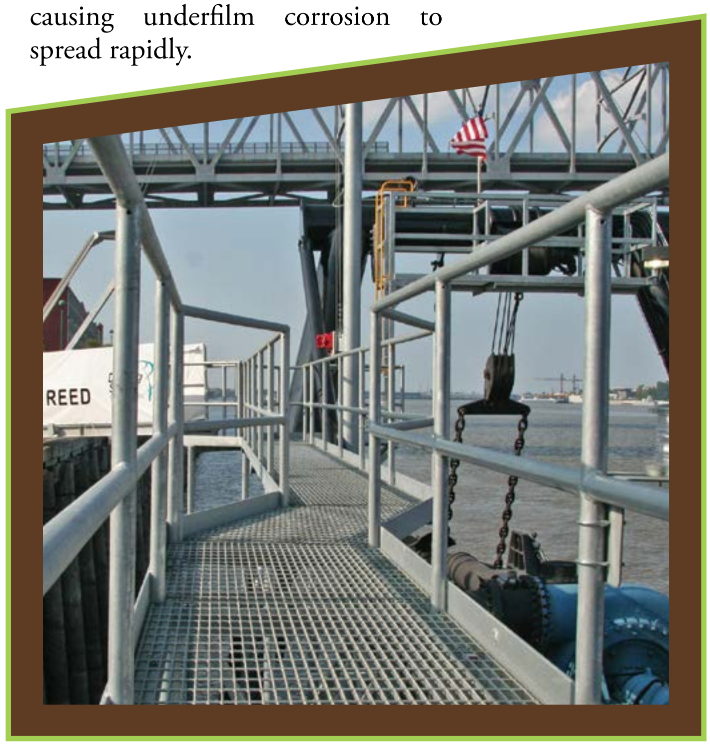
corrosion protection

Steel is an abundant, efficient building material that provides specifiers design freedom. However, for projects exposed to the atmosphere and other harsh environments, it is critical to coat the steel for corrosion protection. Often large construction projects target a 50-100 year design life, highlighting the need for durable, long lasting corrosion protection. Hot-dip galvanizing (HDG) provides three levels of corrosion resistance to steel: barrier protection, cathodic protection, and the zinc patina.

barrier protection

The first line of corrosion defense is barrier protection. Like paints, the hot-dip galvanized coating provides protection by isolating the steel from the electrolytes in the environment. As long as the barrier is intact, the steel is protected and corrosion will not occur. However, if the barrier is breached, corrosion will begin.

Because a barrier must remain intact to provide corrosion resistance, two important properties of barrier protection are adhesion to the base metal and abrasion resistance. The tightly-bonded, impervious nature of zinc metal makes it a very good barrier coating. Coatings such as paint that have pin holes are susceptible to penetration by elements causing underfilm corrosion to spread rapidly.



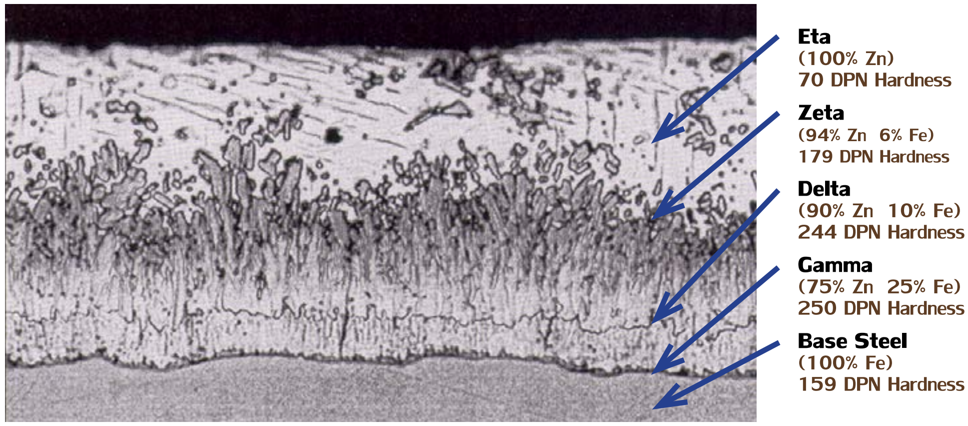


Figure 5: Photomicrograph of a galvanized coating

cathodic protection

In addition to barrier protection, hot-dip galvanizing protects steel cathodically, which means zinc will preferentially corrode to protect the underlying base steel.

The Galvanic Series of Metals (*Figure 4*) is a list of metals arranged in order of electrochemical activity in seawater (the electrolyte). This arrangement of metals determines what metal will be the anode and cathode when the two are put in an electrolytic cell. Metals higher on the list are anodic to the metals below them meaning they provide cathodic or sacrificial protection when the two are connected. Therefore, zinc protects steel. In fact, this cathodic protection ensures even if the HDG coating is damaged to the point bare steel is exposed (up to ¼ inch in diameter), no corrosion will begin until all the surrounding zinc is consumed.

zinc patina

And the final factor in HDG's long-lasting corrosion protection is the development of the zinc patina. The zinc patina is the formation of zinc corrosion by-products on the surface of the steel. Zinc, like all metals, begins to corrode when exposed to the atmosphere. As galvanized coatings are exposed to both moisture and free flowing air, corrosion by-products will naturally form on the coating surface. The formation of these by-products (zinc oxide, zinc hydroxide, and zinc carbonate) occurs during natural wet and dry cycles in the environment. The zinc patina, once fully developed, slows the corrosion rate of zinc to about 1/30th the rate of steel in the same environment and acts as an additional passive, impervious barrier for the hot-dip galvanized coating.

durability

Another aspect of hot-dip galvanizing is proven durability. Hot-dip galvanized steel has been specified extensively in petro-chemical, industrial, power/utility, and bridge/highway projects because of its unmatched durability in these harsh environments. Hot-dip galvanizing remains durable thanks to its abrasion resistance, uniform protection, and complete coverage.

abrasion resistance

A unique characteristic of the hot-dip galvanized coating is the development of tightly-bonded (~3,600 psi), abrasion resistant intermetallic layers. *Figure 5* is a cross-section of a galvanized steel coating showing the three intermetallic layers (Gamma, Delta, and Zeta) and top layer of pure zinc (Eta). During the galvanizing process, these layers develop naturally during a metallurgical reaction between the iron in the steel and zinc in the kettle. As the photomicrograph also shows the hardness of each of the layers as a Diamond Pyramid Number (DPN), you can see the three intermetallic layers are harder than the base steel, while the eta layer has ductility which makes damaging the HDG coating very difficult.

CORRODED END
Anodic or less noble

Magnesium
Zinc
Aluminum
Cadmium
Steel
Lead
Tin
Nickel
Brass
Bronzes
Copper
Nickel-Copper Alloys
Stainless Steels (passive)
Silver
Gold
Platinum

Cathodic or most noble
PROTECTED END

Any one of these metals and alloys will theoretically corrode while offering protection to any other which is lower in the series, so long as both are electrically connected. In actual practice, however, zinc is by far the most effective in this respect.

Figure 4: Galvanic Series

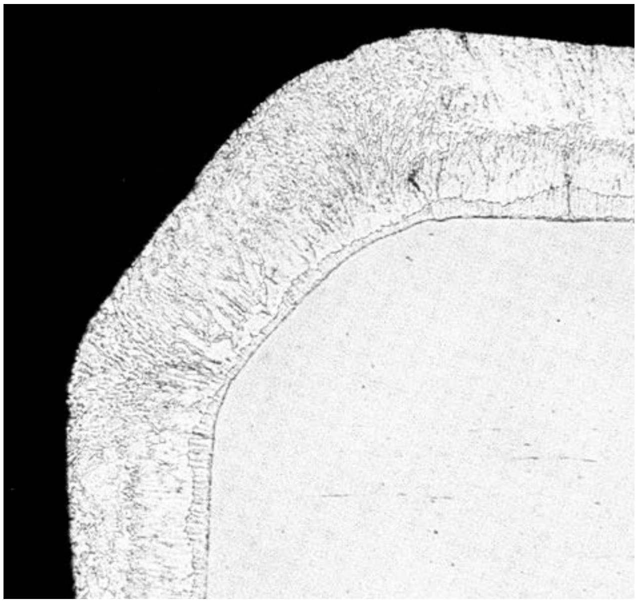


Figure 6: Zinc coating around curved edge

Hot-dip galvanizing's abrasion resistance provides unmatched protection against damage caused by rough handling during transport and erection, as well as in service. Other coatings with lower bond strengths (300-600 psi) can be easily damaged during shipment and construction, weakening their effectiveness, as barrier protection is dependent upon the integrity of the coating.

uniform protection

Another aspect of HDG's durability is its uniform protection. During the metallurgical diffusion reaction in the galvanizing kettle, the galvanized coating grows perpendicular to all surfaces. Therefore, the coating is naturally as thick on corners and edges as flat surfaces (*Figure 6*). Since coating damage commonly occurs at edges, added protection at these junctures is important. Brush- or spray-applied coatings have a natural tendency to thin at corners and edges leaving the part prone to attack. The uniform protection of hot-dip galvanized steel leaves no weak points for accelerated corrosion.

complete coverage

Hot-dip galvanizing is a total immersion process, meaning the steel is fully submerged into cleaning solutions and the molten zinc coating all interior and exterior surfaces. This complete coverage ensures even the insides of hollow and tubular structures and the threads of fasteners are coated. As corrosion tends to occur at an increased rate on the inside of hollow structures where humidity and condensation occur, interior coverage is very beneficial. Hollow structures that are painted have no corrosion protection on the inside. Fully coating fasteners is equally important as they are utilized at connection points which are critical to structural integrity.

Durability

Abu Dhabi Aggregate Recycling Plant
Abu Dhabi, United Arab Emirates

This recycling plant is subject to extremely harsh environmental and operational conditions. Located in Abu Dhabi, the facility is subjected to constant UV rays, 120 degree plus heat, and even sandstorms. It is also constantly abraded by the conditions created by the rough usuage of an aggregate crusher.

More than a million pounds of structural steel, conveyor sections, hoppers, and stairway steel were galvanized for this project. To protect against the harsh environment, the superior barrier and corrosion protection of hot-dip galvanized steel will work to preserve this structure and keep it running smoothly.

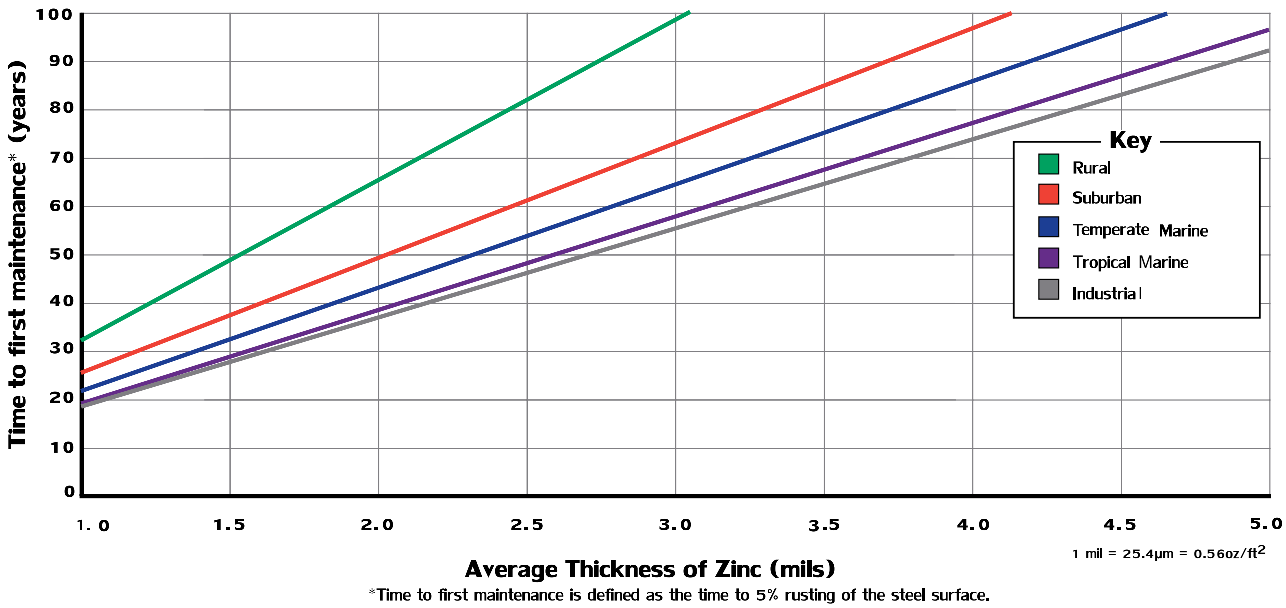


Figure 7: Time to First Maintenance Chart

longevity

Hot-dip galvanized steel is often utilized in some of the harshest environments imaginable, yet it provides maintenance-free longevity for decades. The corrosion resistance of hot-dip galvanizing varies according to its surrounding environments, but generally corrodes at a rate of 1/30 of bare steel in the same environment. Measurements of the actual consumption rate of the coating during the first few years of service provide good data for projecting a conservative estimate for the remaining life to first maintenance, because as zinc corrosion products build on the surface, which in most environments are adherent and fairly insoluble, the corrosion rate often slows as time progresses.

Whether exposed in the atmosphere, subjected to blazing UV rays, snow, and/or other elements, submerged in water, or embedded in soil or concrete, hot-dip galvanized steel can withstand the different corrosive elements and fulfill the intended design life. More information about hot-dip galvanized steel's longevity can be found in the AGA's publication *Performance of Hot-Dip Galvanized Steel Products.*

in the atmosphere

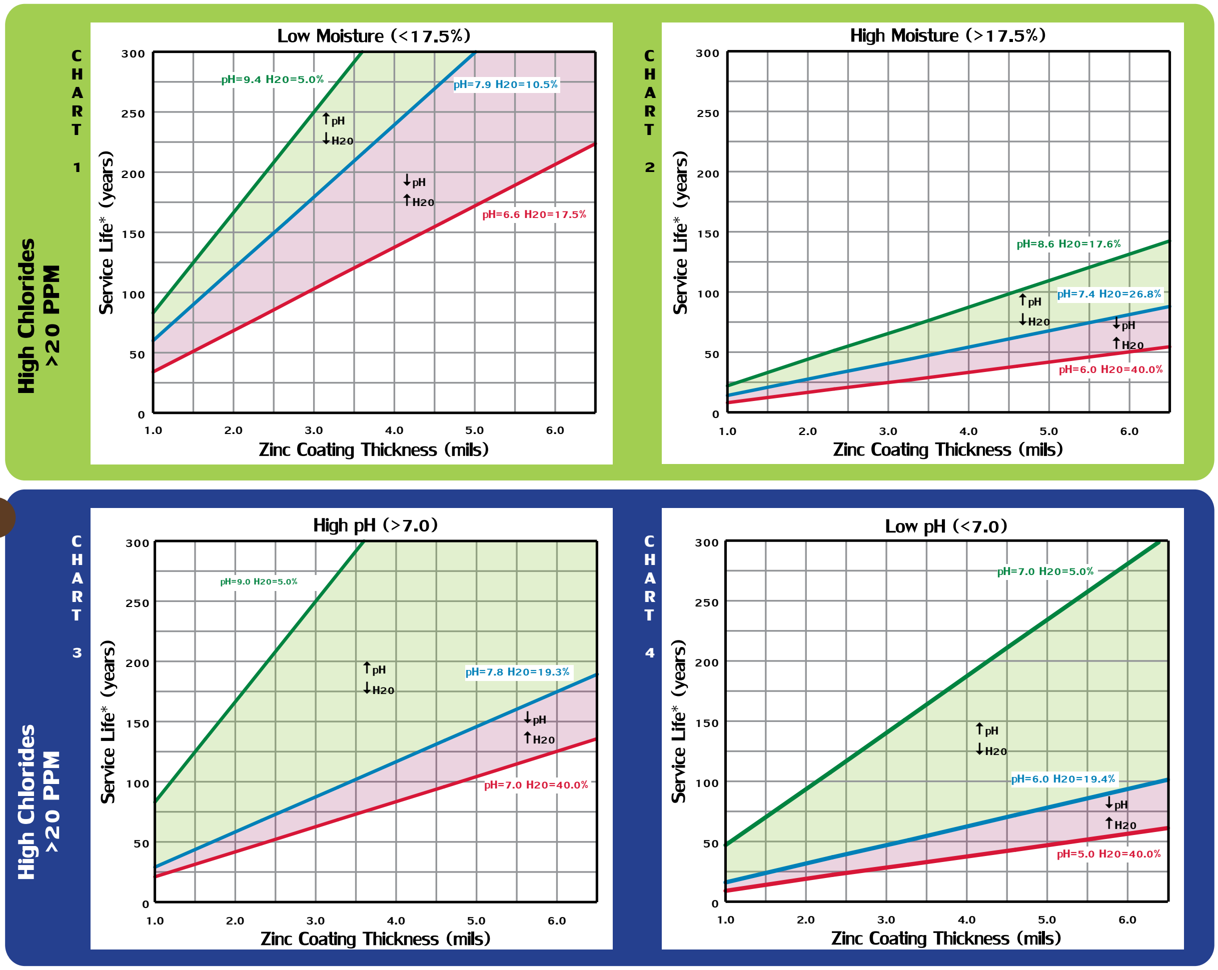
The most common exposure environment for hot-dip galvanized steel is atmospheric. As hot-dip galvanized steel is exposed to the atmosphere, the zinc interacts with free flowing air and moisture to develop the zinc patina. The zinc patina is critical to the longevity of galvanized steel in the atmosphere; and thus, accelerated, salt-spray tests that do not mimic real world exposure conditions are not an accurate predictor of HDG's longevity.

The performance of atmospherically exposed hot-dip galvanized steel depends on five main factors: temperature, humidity, rainfall, sulfur dioxide (pollution) concentration in the air, and air salinity. None of these factors can be singled out as the main contributor to zinc corrosion, but they all play a role in determining the corrosion protection hot-dip galvanized (zinc) coatings can provide in certain atmospheric conditions.

For nearly a century, independent and industry testing of samples in five environments (industrial, rural, suburban, tropical marine, and temperate marine) have yielded real-world performance data for hot-dip galvanized steel. Using this real-world corrosion data, statistical methods, and neural network technology, Dr. Gregory Zhang of Teck Metals Ltd. developed the Zinc Coating Life Predictor (ZCLP) to estimate the life of hot-dip galvanized coatings in atmospheric conditions. Using the ZCLP, you can input specific parameters for any environment and get an estimated time to first maintenance (TFM) for the galvanized coating (*Figure 7*).

Time to first maintenance is defined as 5% rusting of the base steel surface, which means 95% of the zinc coating is still intact, and an initial maintenance is recommended to extend the life of the structure. According to ASTM A123, the governing specification for hot-dip galvanizing, steel ¼-inch thick or greater must have at least 3.9 mils of zinc on the surface, but more often than not, there will be greater than the minimum requirement. Therefore, using the TFM chart, hot-dip galvanized structural steel (>1/4-inch thick) provides 72-73 years of life to first maintenance even in the most corrosive atmosphere, industrial.

Hot-Dip Galvanized Steel's Estimated Service Life in Soil



* Service life is defined as the time to necessary part replacement or underground maintenance. 1 mil = 25.4 µm = 0.56 oz/ft2

Figure 8: Soil Charts

in soil

Another common exposure for hot-dip galvanized steel is partially or fully buried in soil. With more than 200 different types of soil identified in North America, hot-dip galvanizing's performance in soil is varied and hard to predict. The main factors that dictate the corrosivity of the soil are moisture content, pH level, and chlorides. These soil conditions are affected by additional characteristics such as aeration, temperature, resistivity, and texture or particle size. A general rule of thumb is galvanizing performs well in brown sandy soils, and not as well in gray, clay-like soils. This is because soil with larger particles wick moisture away from the surface more quickly so the galvanized piece has less exposure to moisture.

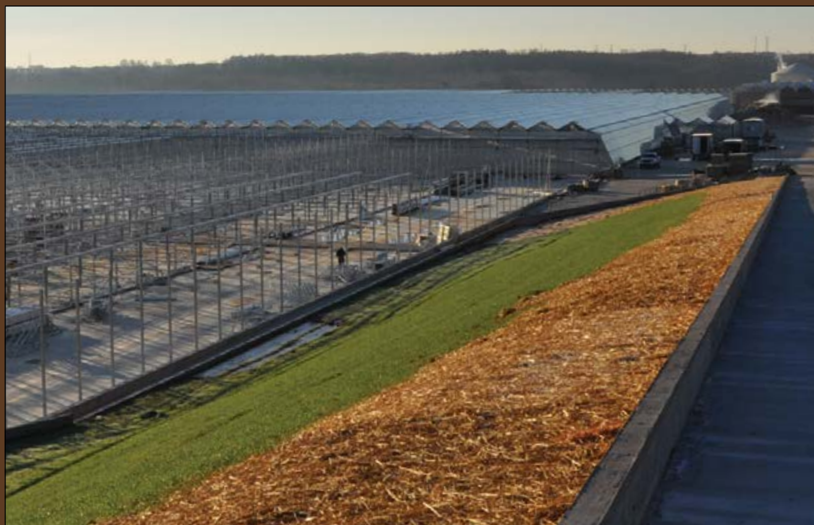
The first step to estimating the performance of hot-dip galvanized steel in soil is to classify it. And as the corrosion rate of steel in soil can range from less than 20 microns per year in favorable conditions, to 200 microns per year or more in very aggressive soils, misclassifying the soil can lead to unpredicted performance. The AGA has developed a chart for estimating HDG's performance in soil based on real world corrosion data. In this case, service life is defined as total consumption of the coating plus 25%, and is an indication of when the structure should be replaced.

There are four different charts based on the classification of the soil (*Figure 8*). Using the chart, the first classification is by chloride content — Charts 1 and 2 (top row) are used for soils with high chlorides (>20 PPM) and Charts 3 and 4 (bottom row) are used for soils with low chlorides (<20 PPM).

Once you have identified the chloride content, there is a second classification to determine the correct chart to use. For soils with high chlorides, the second determination would be moisture content. Soils with low moisture (<17.5%) fall on Chart 1, while soils with high moisture (>17.5%) fall on Chart 2. For low chlorides, the second determination is the pH level. Soils with high pH levels (>7.0) fall on Chart 3, while soils with low pH (<7.0) fall on Chart 4.

The blue line on all four charts represents the average for soils surveyed in that characteristic group. The green line represents the best soil in the category sampled, and the red line represents the worst soil in the category from the study. The shaded areas show how the changes in pH and moisture content affect the estimated service life. Assuming 3.5 mils as a minimum thickness for HDG buried in soil, the chart shows the average life in the harshest soils (uncommon) would be approximately 50 years and in the best soils exceed 120 years.

Longevity



Metrolina Greenhouses
Huntersville, North Carolina

Established in 1971 with a 20,000-square-foot greenhouse on 3 acres in Charlotte, North Carolina, Metrolina Greenhouses has grown to be the largest single site greenhouse in the United States. The first greenhouse was a one acre plastic covered galvanized structure. Hot-dip galvanizing, used from day one, has been integral to all new expansion and construction. Galvanized steel was engineered into the first buildings and all future construction will include it to protect the steel from the moist environment of the greenhouse.

Metrolina Greenhouses' newest $50 million addition will bring the total size of the building to 5.8 million square feet. They employ 550 people year round and use an additional 300 temporary workers during the peak times of the year. Every year more than 75 million plants and over 700 varieties are grown in this heated greenhouse.

Metrolina's founder referenced the exceptionally long life of galvanized steel in the hot, moist greenhouse environment as integral to their construction and production goals. After 41 years, hot-dip galvanized steel has protected the greenhouse structures from corrosion in a perenially wet environment, and will continue to do so maintenance-free for several more decades of greenhouse activity and plant production.

in moisture-rich environments

A less common environment for galvanized steel is submerged in or exposed to water. Moisture is highly corrosive to most metals including steel and zinc. However, because of the development of the passive, mostly non-soluble zinc patina, the corrosion rate of galvanized steel is much slower than bare steel. There are many different types of water (pure water, natural fresh water, potable water (treated drinking water), and seawater) and each has different mechanisms that determine the corrosion rate.

Similar to soils, the varieties of water make predicting corrosion rates difficult. Though pH level has the most profound effect, many parameters affect corrosion of metals in a water environment including oxygen content, water temperature, agitation, the presence of inhibitors, and tide conditions. Despite the difficulty of predicting corrosion, hot-dip galvanizing steel is one of the best methods of corrosion protection for submersed applications because of its complete, uniform coverage.

Water with high free oxygen or carbon dioxide content is more corrosive than water containing less of these gases, and hard water is much less corrosive than soft water. A natural scale of insoluble salts tends to form on the galvanized surface under conditions of moderate or high water hardness. The salts combine with zinc to form a protective barrier of calcium carbonate and basic zinc carbonate.

Similar to fresh water, galvanized coatings provide considerable protection to steel when immersed in sea water and exposed to salt spray. Influencing factors in the corrosion of zinc in fresh water also apply to sea water; however, the dissolved salts (primarily sulfides and chlorides) in sea water are the principal determinants of the corrosion behavior of zinc. Given the high level of chloride in sea water, a very high corrosion rate might be expected. However, the presence of magnesium and calcium ions has a strong inhibiting effect on zinc corrosion.

in concrete

Concrete is an extremely complex material. The use of various types of concrete in construction has made the chemical, physical, and mechanical properties of concrete and its relationship to metals a topic of ongoing studies. Reinforcing steel bars (rebar) are embedded in concrete to provide strength, and are critical to the integrity

and performance of the structure throughout its life. As concrete is a porous material, corrosive elements such as water, chloride ions, oxygen, carbon dioxide, and other gases travel into the concrete matrix, eventually reaching the rebar. Once the concentration of these corrosive elements surpasses steel's corrosion threshold, the rebar starts to corrode. As the rebar corrodes, pressure builds around the bar leading to cracking, staining, and eventually spalling of the concrete (*Figure 9*).

Because failure of the rebar leads to compromised or failing structural capacity, protecting against premature rebar failure is key. Similar to in the atmosphere, galvanized rebar extends the life of the steel in concrete. The corrosion mechanisms in concrete are quite different than atmospheric exposure, and one of the biggest factors is chloride concentration. Galvanized rebar can withstand chloride concentration at least four to five times higher than black steel, and remains passivated at lower pH levels, slowing the rate of corrosion.

In addition to the higher chloride tolerance, once zinc corrosion products are formed from the galvanized rebar, they are less voluminous than iron oxide and actually migrate away from the bar. *Figure 10* shows the white zinc particles particles migration away from the bar (galvanized coating) and into the pores of the concrete matrix. This migration prevents the pressure buildup and spalling caused by iron oxide particles.

The total life of galvanized steel in concrete is made up of the time taken for the zinc to depassivate, plus the time taken for consumption of the zinc coating, as it sacrificially protects the underlying steel. Only after the coating has been fully consumed in a region of the bar will localized steel corrosion begin. Additional studies and information on galvanized rebar can be found at **www.galvanizedrebar.com** and in the AGA publication *Hot-Dip Galvanized Reinforcing Steel: A Specifier's Guide* or on the AGA website at **www.galvanizeit.org.**

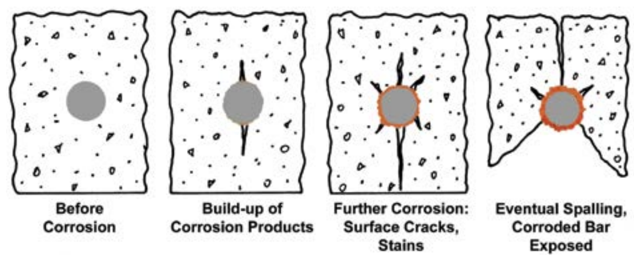


Figure 9: Spalling concrete

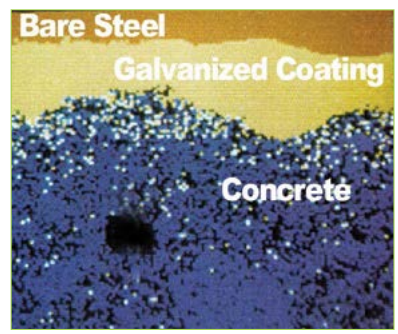


Figure 10: Zinc migration in rebar

in other environments

There are a number of other environments where hot-dip galvanized steel is commonly specified for its longevity. Some environments where hot-dip galvanized steel can perform well are in chemical solutions with neutral pH (4-13), in contact with treated wood, and in extreme temperatures (-40 F to 392 F). Environments where HDG is not recommended are chemical solutions with pH levels outside those listed, and in contact with other metals. Two exceptions to the dissimilar metals rule are aluminum and stainless steel unless they are in the presence of salt water or air with a high chloride content.

availability & versatility

Hot-dip galvanized (HDG) steel is versatile and readily available. A wide variety of shapes and sizes ranging from small nuts, bolts, and fasteners to larger structural pieces, to even the most intricately detailed artistic pieces, can be galvanized. Because of the total immersion process, even complex fabrications can be coated entirely for corrosion protection.

Many corrosion protection methods depend on proper temperature and humidity conditions for correct application. However, because hot-dip galvanizing is a factory controlled process, it can be accomplished 24/7/365 rain or shine. Zinc solidifies upon withdrawal from the bath, so there are no delays for curing; and galvanized steel could realistically be galvanized, shipped to the site, and erected on the same day. On the other hand, if the galvanized material does not need to be installed immediately, it is easily stored outside, as UV rays do not degrade the coating's integrity.

abundant materials

As North America continues to strive for sustainable development, the same thinking should be applied to the materials used in construction. Another characteristic of zinc, making it ideally suited for this job is its abundance. The main materials used in the galvanizing process, zinc and steel are common; in fact, zinc is the 27th most abundant material in the earth's crust, and iron is the 4th. Zinc and steel are also both 100% recyclable without the loss of any chemical or physical properties – steel is the most recycled material in the world.

Zinc is a natural element found in air, soil, and water. Approximately 5.8 million tons of zinc are cycled through the atmosphere annually through natural phenomena. Zinc is also common and essential to life. Zinc is found in a number of products we use daily such as cosmetics, tires, cold remedies, baby creams to prevent diaper rash, treatments for sunburns, and sunscreens. In fact, zinc oxide blocks more UV rays than any other single ingredient used in sunscreen. Furthermore, we all require zinc to live as it helps with regular functions such as vision, reproduction, digestion, and breathing.

efficiency

With galvanized steel, you can do more with less. Because of the high strength-to-weight ratio, specifying projects with steel saves materials and energy. In fact, on average one ton of steel provides the same strength as 8 tons of concrete, and according to the World Steel Association, the strength-to-weight ratio minimizes substructure costs and can also save money on transportation and handling.

Availability & Versatility

Talbot Substation
Dayton, Washington

One of the great benefits of utilizing hot-dip galvanized steel for corrosion protection is galvanized pieces can be easily stored for future use. This means owners can stockpile elements they know they will need for replacement or expansion, buying when prices are low and creating a stockpile of usable goods for the future.

This can be especially advantageous for structures such as substations, distribution towers, cell phone towers, highway and transportation products (guardrail, sign poles, light poles, handrails) and more.

A substation, like the one above, can easily stockpile and even store elements on site, exposed to the elements. As they lie in wait to be used, the durable zinc barrier and cathodic protection will keep the pieces corrosion-free and ready for use at a later date.

Forty-seven tons of steel were galvanized for the Talbot substation, including all structural steel, fasteners, anchor bolts, concrete embeds, bollards, light fixture mounting brackets, and all switch operator grounding platforms. Replacement parts for these pieces and more could easily be bought ahead of time and stored, waiting for use, with the protection of galvanized steel.

In addition to the abundance and quick turnaround time, galvanized steel also facilitates the expansion of existing structures due to its flexibility and stockability. Galvanized steel members are easy to retrofit and expand by welding, bolting, and/or splicing of existing vertical and horizontal structural elements and adding reinforcement. Adding to existing structures allows maximum efficiency of available space. Steel members are lighter than many other materials but still provide great strength, so expansion within the same footprint is possible.

Furthermore, because of hot-dip galvanized steel's durable, maintenance-free nature, elements can be stockpiled outside for years without compromising the zinc coating and its corrosion protection. The zinc coating of HDG is unaffected by UV rays, extreme temperatures, rain, snow, or humidity, so with proper storage it is simple to keep an inventory on-hand for quick replacement in an emergency. Stocking frequently used parts until they are needed saves time, and if bought when prices are low, saves money.

safety

Structural safety and stability are critically important to the integrity of steel construction, and cannot be maintained if the structure has been weakened by the ravages of corrosion. Hot-dip galvanized steel pieces which remain corrosion resistant for decades preserve the structural integrity of steel construction and protect against disaster.

One area of safety where hot-dip galvanized steel provides advantages is in areas of seismic activity. Steel elements are more ductile and lighter, reducing the inertia effects of seismic loading. Able to bend within reason without breaking, the tensile strength of hot-dip galvanized steel can protect structures from damage or even total failure during seismic activity.

aesthetics

Aesthetics are important to nearly every construction project. Whether an attractive, artfully designed sculpture or architecturally exposed steel element, or bridge, bus station, or other infrastructure element, galvanized steel offers design flexibility, and an attractive, natural gray finish – or if color is desired it can be easily painted or powder coated.

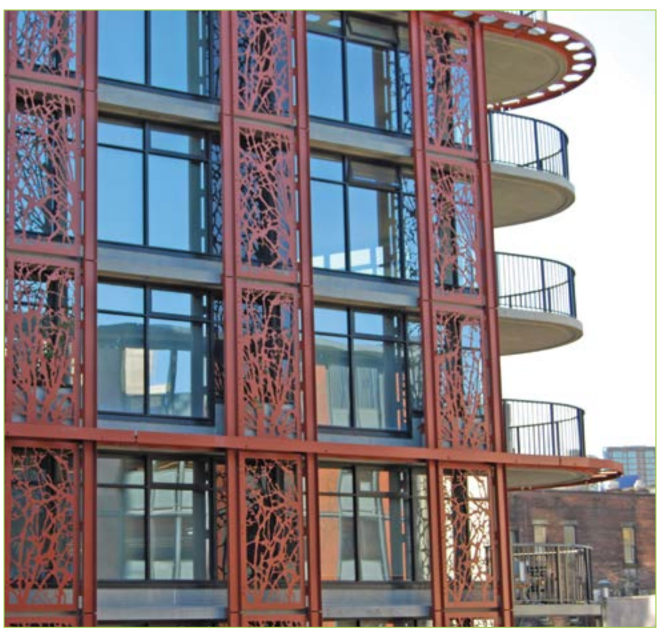
Aesthetics

El Andaluz Commercial Offices & Residences
Santa Barbara, California

El Andaluz takes galvanizing from functional to fantastic, incorporating structural and artistic galvanized elements strikingly juxtaposed with a bold kaleidoscope of ornately colored ceramic tile floors, fountains, ledges and stairs. The commercial offices of El Andaluz, coupled with residential condominiums, prominently display hot-dip galvanized steel elements in the architects adaptation of a similar picturesque courtyard six blocks from the Pacific Ocean in Santa Barbara.

With a reputation for favoring galvanized steel elements in his creations, the architect was depending on the zinc patina finish, which develops in the months after galvanizing to enhance the look of his artistic creation. As the patina develops, the galvanized steel not only takes on a uniform matte gray appearance, completing the architect's vision, but will also ensure long-lasting protection for the project. The galvanized steel was incorporated to assure the structural integrity of the architectural display for decades to come, as well as for the aesthetic appeal.

In addition to the appealing metallic color, the steel was able to be formed and cut into artistic shapes. In other projects, galvanized steel beams have also been bent and arched to create curvatures, or even wavy paneling. Galvanized steel pairs aesthetics, visual flexibility, and durability into successful structures that last for generations.



natural blending with surroundings

For some galvanized steel projects, such as electric substations, solar panels, or rail line infrastructure, the goal is often to blend seamlessly with the surroundings. As galvanized steel weathers and the zinc patina forms, the coating becomes a uniform matte gray. Whether in rural, wooded areas that are wildlife sensitive or in the city where non-reflectivity is important, the natural, non-intrusive finish of hot-dip galvanizing compliments and blends in with any environment.

architecturally exposed

In addition to providing a natural, blendable appearance, utilizing hot-dip galvanizing on architecturally exposed structural steel (AESS) provides visual peace of mind the steel is in good condition. AESS elements are often designed to be centerpieces and talking points of steel construction.

The high strength-to-weight ratio and ductility of steel allows for curves, arches, and intricate patterns and designs when planning AESS elements. However, when AESS elements are exposed to the atmosphere, it is important to ensure they remain beautiful design elements by protecting them against corrosion. Hot-dip galvanized AESS elements can fight corrosion for decades without stifling your design freedom.

duplex systems

The natural, matte gray finish does not suit every project of every specifier – as sometimes color is preferred or needed for branding, safety marking, etc. However, by specifying a duplex system – galvanizing your project and then painting or powder coating over to the desired color ensures you don't have to sacrifice the corrosion protection benefits and extended maintenance of HDG steel.

Duplex systems provide more benefit than just aesthetic options. The combination of hot-dip galvanized steel and paint or powder coating provide a synergistic effect. The paint/powder extends the life of the coating by providing an additional barrier coating to the zinc layers, while the galvanized steel prolongs the life of the paint coating by preventing underfilm corrosion and peeling.

The result of the two coatings working in synergy is extended corrosion protection. The service life of a duplex system is 1.5 to 2.3 times the sum of the individual systems. For example, if the life of the galvanized coating in a particular environment is 70 years, and the expected life of the paint is 10 years, the expected life of the duplex system would be at least 120 years (1.5 x (70+10)).

This extended service life assumes no maintenance will be done to keep the paint or powder coating intact. Realistically, if someone invests the premium cost upfront for a duplex system, they likely plan to keep the color on the structure. So, in practical terms, the synergistic effect of utilizing a duplex system is the extended maintenance cycle it provides. With hot-dip galvanized steel as a "primer," the time to first maintenance of the paint or powder coating is extended 1.5 to 2.0 times what it would be for bare steel. The AGA's publication *Duplex Systems: Painting Over Hot-Dip Galvanized Steel* and instructional DVD guides *Preparing HDG Steel for Paint* and *Preparing HDG Steel for Powder Coating* provide more information on specifying duplex systems.

sustainability

Sustainable development is the social, economic, and environmental commitment to growth and development that meet the needs of the present without compromising the ability of future generations to meet their own needs. As the social pressure continues to mount to construct the built environment sustainably, specifiers are becoming more invested and analytical in the materials they choose. Hot-dip galvanized steel's maintenance-free longevity provides positive environmental and economic benefits to future generations.

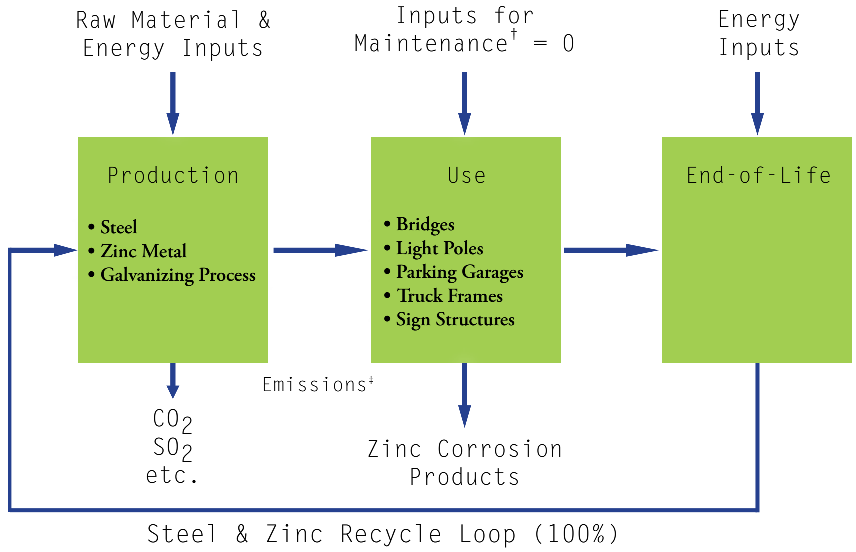
environmental advantages

As previously stated, zinc exists naturally in the air, water, and soil and is the 27th most abundant element in the Earth's crust. More than 5.8 million tons of zinc is naturally cycled through the environment by plant and animal life, rainfall, and other natural activity. And zinc is essential for all life – from humans to the smallest microorganisms. Therefore, utilizing hot-dip galvanized steel is not harmful to the environment as the zinc is already naturally found in the area.

In addition to being natural, zinc, like steel, is infinitely recyclable without the loss of any physical or chemical properties. Approximately 30% of the world's zinc supply comes from recycled sources each year, and more would be recycled if it were available. Furthermore, steel is the most recycled material in the world with virtually 100% of structural steel coming from recycled sources, making galvanized steel an infinitely renewable material.

A life-cycle assessment (LCA) is an objective measurement of a product's environmental impact. Often called a "cradle-to-grave" study, LCA quantifies the environmental impact of a process or product from raw material acquisition, energy inputs and emission outputs during production and use, and end-of-life management (recycling/disposal). LCAs have begun to gain favor in the specification community as a means of gauging a product's sustainability.

In 2008, the International Zinc Association (IZA) hired internationally renowned LCA experts Five Winds International and PE International to conduct a life-cycle inventory (LCI) and life-cycle assessment (LCA) for hot-dip galvanized steel. Utilizing data from worldwide sources regarding energy consumption and air/fluid/solid emissions measured during zinc production and during the actual galvanizing process, combined with analogous survey data collected from the steel industry, an LCA for hot-dip galvanized steel was compiled. *Figure 11* shows an overview of the impact of hot-dip galvanized steel from production to end-of-life.



† For all but the most aggressive, corrosive environmental conditions, there are no energy or raw material inputs during use (75+ years).
‡ For hot-dip galvanized steel, naturally occurring zinc oxide, zinc hydroxide, and zinc carbonate.

Figure 11: LCA of Galvanizing

Hot-dip galvanizing is unique in that all material and energy inputs and emission outputs are isolated to the production phase, as there is no maintenance required for 70 years or more in most environments, and it is 100% recyclable at the end-of-life. The AGA's publication *Hot-Dip Galvanizing for Sustainable Design* has more information on galvanized steel's sustainability, including the full LCA study.

economic advantages

In addition to building structures that are environmentally-friendly, for true sustainability these structures must also be economically responsible for future generations. Hot-dip galvanized steel can provide economic savings both initially and throughout the life of a project, freeing up money for new construction rather than costly maintenance.

There has long been a perception in the specifying community that hot-dip galvanized steel is cost prohibitive on an initial basis. However, due to regular process improvements, galvanized steel is not only competitive but often less expensive than other corrosion protection systems initially. Furthermore, because of quick turnaround and erection, utilizing hot-dip galvanized steel often provides wider-ranging cost savings during construction.

Though initial cost is important, analyzing the costs throughout the life of the project provide a more comprehensive cost picture for future generations. Life-cycle cost (LCC) takes into account not only the initial cost, but the direct maintenance costs throughout the life of the structure, and the time value of money over the project life utilizing net present value (NPV) and net future value (NFV) calculations.

Sustainability

M-102 Bridge Rail Reconstruction
Detroit, Michigan

With the original steel guardrail panels galvanized back in 1955, the rails on the MI/M-102 Bridge and Rail Project were due for corrosion repair. Fortunately, because of the protection provided by the galvanized coating on the railing panels, highway traffic damaged only 15-20 percent of the more than 300 tons of steel that would need replacement in the repair. The specifier had learned many states have been taking old guardrail, stripping, regalvanizing, and returning it to service - so MDOT decided to regalvanize the existing steel guardrail panels.

MDOT felt recycling the existing steel was an excellent opportunity to contribute to the "Keep It Green" initiative being supported by the department. The state saved more than half of the budget earmarked for this project because they only had to replace 20 percent of the old material. This is a great example of the recyclability of steel - rather than downsampling at end-of-life, the project continues on using the original steel. Hot-dip galvanized steel provided this project with cradle-to-cradle sustainability, as well as durable, maintenance-free protection.

Because hot-dip galvanized steel provides decades of maintenance-free corrosion protection, often the initial cost is the final, life-cycle cost. Evaluating LCC can be cumbersome, so to facilitate the analysis, the AGA developed the Life-Cycle Cost Calculator at **lccc.galvanizeit.org.** The online calculator allows users to input the parameters for a project and compare the initial and life-cycle costs of hot-dip galvanizing to more than 30 other corrosion protection systems based on published cost data. For more information, visit the online calculator or read the AGA's publication *Hot-Dip Galvanizing Costs Less, Lasts Longer.*

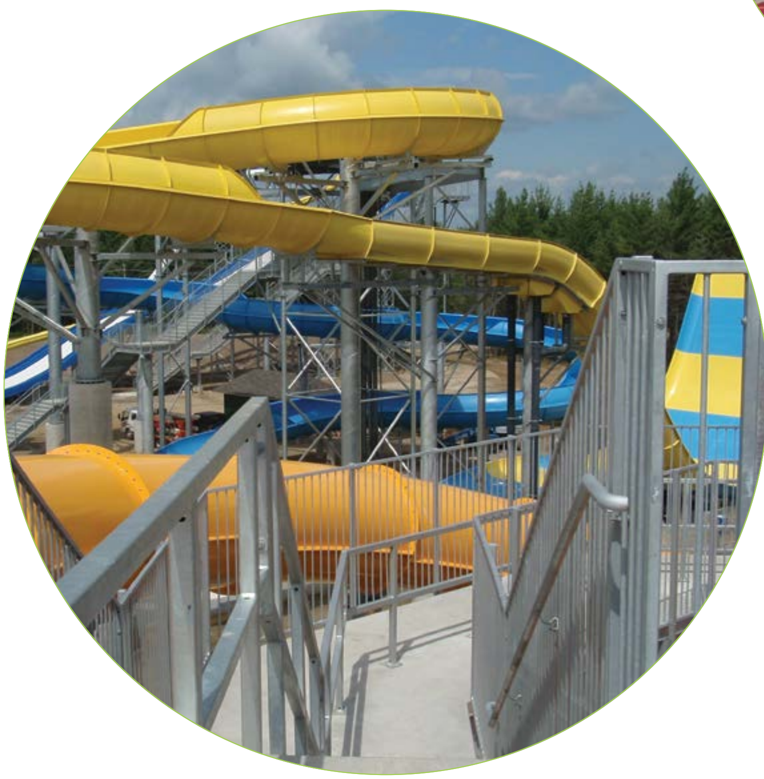
Specifying
hot-dip galvanizing

Once the decision has been made to specify hot-dip galvanized steel, it is important to open the lines of communication between the specifier, fabricator, and galvanizer. Communication early in the design process is key to producing optimum quality galvanized coatings, minimize cost, and improve turnaround times. Corrosion protection begins at the drawing board, and incorporating appropriate design details and principles will ensure success. The AGA's publication *The Design of Products to Be Hot-Dip Galvanized after Fabrication* provides information based on well-established specifications.

There are three main specifications that govern the coating thickness, adherence, and finish for hot-dip galvanized coatings – ASTM A123, A153, and A767. A123 is the main specification, and covers all types of galvanized products except fasteners and small parts which are covered by A153, and reinforcing steel bars, covered by A767. There are a handful of supporting specifications referenced in these specifications that cover design practices, repair and touch-up, and painting over galvanizing. In conjunction with ASTM, the AGA publishes a compilation of these specifications, *Selected Specifications for Hot-Dip Galvanizing,* which can be purchased from the AGA.

Conclusion

As the world continues to evolve, so too do the specification practices and designs of construction. Developers of the built environment shoulder the responsibility of creating a better world for future generations by constructing buildings, infrastructure and other elements that are sustainable. Hot-dip galvanized steel, which has been used successfully for more than 100 years, provides sustainability through its superior corrosion protection, durability, longevity, availability, and versatility. The natural, recyclable matte gray finish of hot-dip galvanized steel transcends time with little environmental and economic impact, improving the quality of life in the future.



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