

Hot-dip Galvanizing for Corrosion Protection A Specifiers Guide



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Corrosion: What and Why

What is corrosion? Many people give the simple answer “corrosion is rust.” However, scientists who study corrosion could answer in terms of complex chemical and physical processes, while economists might sum up corrosion in dollars.

Corrosion Concerns

According to “Corrosion Costs and Preventive Strategies in the United States,” a study conducted by the National Association of Corrosion Engineers (NACE) in 2001, direct corrosion costs total approximately \$276 billion a year. A break down of the corrosion cost in five different sectors of the nation’s economy are displayed in *Table 1*. The direct cost of corrosion is only half of the picture. To really understand the cost of corrosion, one must consider the indirect costs (e.g. lost productivity, taxes, overhead), which at a minimum doubles the cost. Although corrosion is a naturally occurring phenomenon and can never be completely eliminated, there is a common misconception that nothing can be done. However, corrosion can be controlled if corrosion management practices are employed. It is estimated that 25-30% of annual corrosion costs could be eliminated if corrosion management practices were in place.

Metal and Alloy Corrosion

In order to understand how galvanizing protects steel from corrosion, it is important to first understand corrosion. Metal corrosion generally is defined as the undesirable deterioration of a metal or an alloy. In other words, corrosion is an interaction of the metal with its environment that adversely affects the properties of the metal. Throughout this guide, a more complete definition will evolve including specific types and causes of corrosion.

Galvanic Corrosion

Metals are rarely found in their pure state, but are almost always found in chemical combination with one or more nonmetallic elements. Significant energy must be applied to reduce the ore to a pure metal. This energy can be applied via metallurgical or chemical means. Additional energy also may be applied in the form of cold working or casting to transform the pure metal into a working shape. Corrosion can be viewed as the tendency for a metal produced and shaped as a result of substantial energy input to revert to its natural, lower energy state. From a thermodynamic perspective, the tendency to decrease in energy is the main driving force for the corrosion of metals.

Table 1: Annual Direct Corrosion Costs

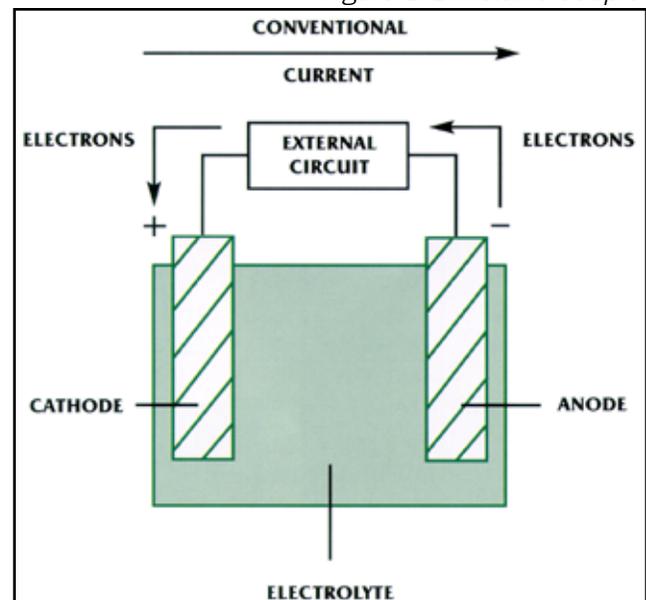
Industry Sector	Annual Direct Corrosion Costs
Infrastructure	\$22.6
Utilities	\$47.9
Transportation	\$29.7
Production & Manufacturing	\$17.6
Government	\$20.1
Billions of Current Dollars	
Source: 2001 NACE Study “Corrosion Costs and Preventative Strategies in the United States.”	

Corrosion of metals is an electrochemical process, meaning it involves both chemical reactions and the flow of electrons. A basic electrochemical reaction that drives the corrosion of metals is galvanic action. In a galvanic cell, current is generated internally by physical and chemical reactions occurring among the components of the cell.

The Corrosion Process

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,

Figure 1: Bimetallic Couple



there are four elements necessary for corrosion to occur:

Anode - An anode is an electrode at which negative ions are discharged and positive ions are formed, or other oxidizing reactions occur. Corrosion occurs at the anode.

Cathode - A cathode is an electrode at which positive ions are discharged, negative ions are formed, or other reducing reactions occur. The cathode is protected from corrosion.

Electrolyte - An electrolyte is a 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 return current path is 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 (*Figure 2*). Metals toward the top of the list are “less noble” metals and have a greater tendency to lose electrons than metals found lower on the list.

Corrosion of Steel

The actual corrosion process that takes place on a piece of bare steel is very complex due to factors such as variations in the composition/structure of the steel, presence of impurities due to the higher

Figure 2: Arrangement of Metals in the Galvanic Series

CORRODED END	Cathodic protections can occur when two metals are electrically connected. Any one of these metals and alloys will theoretically corrode while offering protection to any other that is lower in the series, so long as both are electrically connected.
Anodic or less noble (ELECTRONEGATIVE)	
Magnesium	
Zinc	
Aluminum	
Steel	
Lead	
Tin	
Nickel	
Brass	
Bronzes	
Copper	
Stainless Steel (passive)	
Silver	
Gold	
Platinum	
PROTECTED END	
Cathodic or more noble (ELECTROPOSITIVE)	

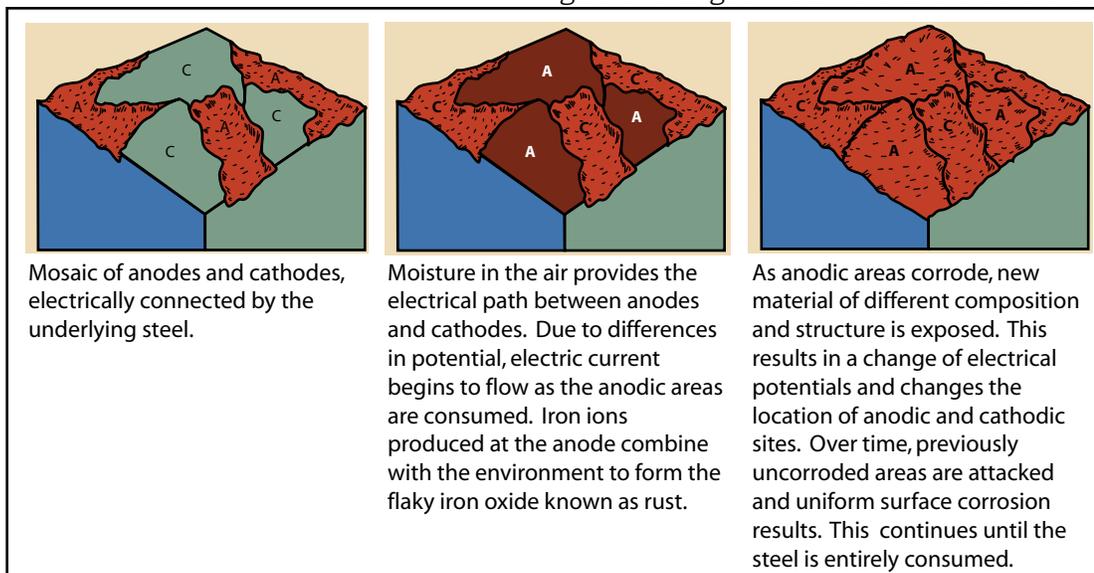
instance of recycled steel, uneven internal stress, or exposure to a non-uniform environment.

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

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 3*).

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.

Figure 3: Changes in cathodic and anodic areas



Hot-Dip Galvanizing for Corrosion Protection

Hot-dip galvanizing is the process of applying a zinc coating to fabricated iron or steel material by immersing the material in a bath of liquid zinc.

The process is inherently simple, and this simplicity is a distinct advantage over other corrosion protection methods. The process is described in more detail later in this guide.

History of Galvanizing

The recorded history of galvanizing dates back to 1742 when a French chemist named Melouin, in a presentation to the French Royal Academy, described a method of coating iron by dipping it in liquid zinc. In 1836, Sorel, another French chemist, obtained a patent for a means of coating iron with zinc after first cleaning it with 9% sulfuric acid and fluxing it with ammonium chloride. A British patent for a similar process was granted in 1837. By 1850, the British galvanizing industry was using 10,000 tons of zinc a year for the protection of steel.

Galvanizing is found in almost every major application and industry where iron or steel is used. The utilities, chemical process, pulp and paper, automotive, and transportation industries historically have made extensive use of galvanizing for corrosion control, and continue to do so today.

For over 150 years, galvanizing has had a proven history of commercial success as a method of corrosion protection in a myriad of applications worldwide.

Iron and Steel Protection Methods

Barrier protection is perhaps the oldest and most widely used method of corrosion protection. The “barrier” isolates the metal from the electrolytes in the environment. Two important properties of barrier protection are adhesion to the base metal and abrasion resistance. Paint is one example of a barrier protection system.

Cathodic protection is an equally important method for preventing corrosion. Cathodic protection requires changing an element of the corrosion circuit, introducing a new corrosion element, and ensuring the base metal becomes the cathodic element of the circuit. Hot-dip galvanizing provides excellent barrier protection as well as cathodic protection.

There are two major variations of the cathodic method of corrosion protection: impressed current and sacrificial anode. In the impressed current method an external current source is used to impress a cathodic charge on all the iron or steel to be protected. While such systems generally do not use a great deal of electricity, they are often very expensive to install.

The sacrificial anode method requires placing a metal or alloy anodic to the metal to be protected in the circuit, which will then become the anode. The protected metal becomes the cathode and does not corrode. The anode corrodes, thereby providing the desired sacrificial protection. In nearly all electrolytes encountered in everyday use, zinc is anodic to iron and steel. Thus, the galvanized coating provides cathodic corrosion protection as well as barrier protection.

Galvanizing Process

The galvanizing process consists of three basic elements: surface preparation, galvanizing, and inspection (*Figure 4*, next page).

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 a steel surface that is not perfectly clean. Any failures or inadequacies in surface preparation will be immediately apparent when the steel is withdrawn from the liquid zinc because the unclean areas will remain uncoated, and thus can be corrected.

On-site painting or other field-applied systems of corrosion protection may involve the use of different subcontractors and/or work groups to prepare the surface and apply the coating. This can result in problems with coordinating activities, leading to costly and time-consuming delays, errors, and disputes

Withdrawal from Galvanizing Bath



concerning responsibility and financial liability. Once a job has been delivered and accepted at the galvanizer's plant, there is one point of responsibility for ensuring the material leaves the plant properly galvanized — the galvanizer.

Surface preparation for galvanizing typically consists of three steps: caustic cleaning, acid pickling, and fluxing.

Degreasing - A hot alkali solution is often used to remove organic contaminants such as dirt, paint markings, grease, and oil from the metal surface. Epoxies, vinyls, asphalt, or welding slag must be removed before galvanizing by grit blasting, sand blasting, or other mechanical means.

Pickling - Scale and rust normally are removed from the steel surface by pickling in a dilute solution of hot sulfuric acid or ambient temperature hydrochloric acid.

Surface preparation also can be accomplished using abrasive cleaning as an alternative to or in conjunction with chemical cleaning. Abrasive cleaning is a process whereby sand, metallic shot, or grit is propelled against the steel material by air blasts or rapidly rotating wheels.

Fluxing - Fluxing is the final surface preparation step in the galvanizing process. Fluxing removes oxides and prevents further oxides from forming on the surface of the metal prior to galvanizing and promotes bonding of the zinc to the steel or iron surface.

Steel or iron materials are dipped in an aqueous solution of zinc ammonium chloride to apply the flux layer. The material is then thoroughly dried prior to immersion in liquid zinc.

Galvanizing

During the "galvanizing" process, the material is

completely immersed in a bath consisting of a minimum of 98% pure liquid zinc. The bath chemistry is specified by ASTM International in Specification B 6. The bath temperature is maintained at about 840 F (449 C).

Fabricated items are immersed in the bath long enough to reach bath temperature. The articles are withdrawn slowly from the galvanizing bath and the excess zinc is removed by draining, vibrating, and/or centrifuging.

The chemical reactions that result in the formation and structure of the galvanized coating continue after the steel is withdrawn from the bath as long as the steel is near the bath temperature. The articles are cooled in either water or ambient air immediately after withdrawal from the bath.

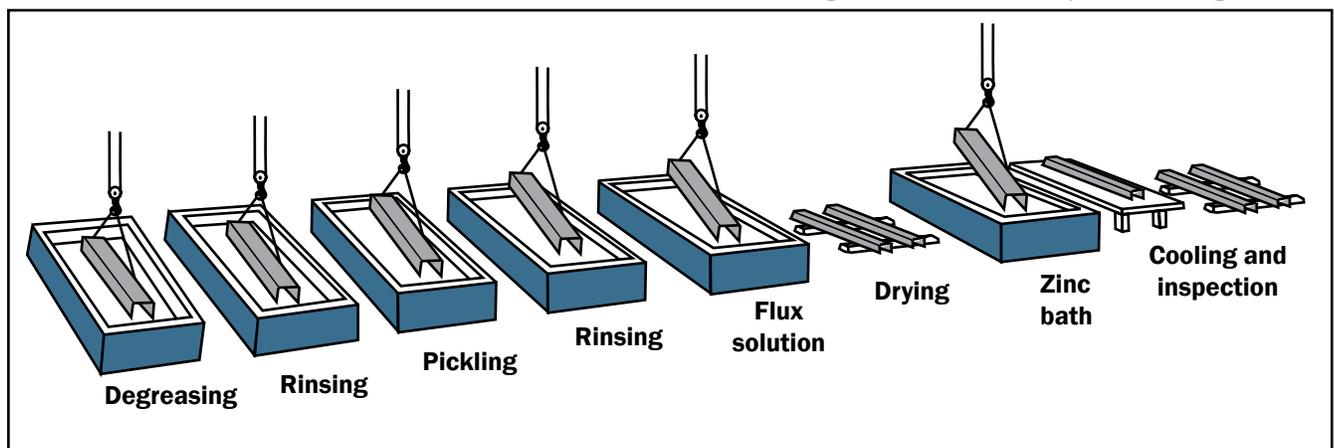
Inspection

The two properties of the hot-dip galvanized coating closely scrutinized after galvanizing 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, well-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 required coating thicknesses for various 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*,

Figure 4: Batch Hot-Dip Galvanizing Process



published by the American Galvanizers Association (AGA). This publication, as well as all others referenced in this guide, can be found in the literature section of the AGA website (www.galvanizeit.org).

The Metallurgical Bond

Galvanizing forms a metallurgical bond between the zinc and the underlying steel or iron, creating a barrier that is part of the metal itself. During galvanizing, the liquid zinc reacts with the surface of the steel or iron article to form a series of zinc-iron alloy layers. *Figure 5* is a photomicrograph of a galvanized steel coating's cross-section and shows a typical coating microstructure consisting of three alloy layers and a layer of pure metallic zinc. Moving from the underlying steel surface outward, these are:

- The thin **Gamma** layer composed of an alloy that is 75% zinc and 25% iron,
- The **Delta** layer composed of an alloy that is 90% zinc and 10% iron,
- The **Zeta** layer composed of an alloy that is 94% zinc and 6% iron, and
- The outer **Eta** layer that is composed of pure zinc.

Below the name of each layer in *Figure 5*, its respective hardness, expressed by a Diamond Pyramid Number (DPN) appears. The DPN is a progressive measure of hardness (i.e., the higher the number the greater the hardness). Typically, the Gamma, Delta, and Zeta layers are harder than the underlying steel. The hardness of these inner layers provides exceptional protection against coating damage through abrasion. The Eta layer of the galvanized coating is quite ductile, providing some resistance to impact.

The galvanized coating is adherent to the underlying steel on the order of several thousand pounds per square inch (psi). Other coatings typically offer adhesion rated at several hundred psi.

Hardness, ductility, and adherence combine to provide the galvanized coating with unmatched protection against damage caused by rough handling during transportation to and/or at the job site, as well

as in service. The toughness of the galvanized coating is extremely important since barrier protection is dependent upon the integrity of the coating.

Other coatings damage easily during shipment or through rough handling on the job site. Experts will argue all organic forms of barrier protection (such as paint) by their nature are permeable to some degree. Galvanized coatings are impermeable.

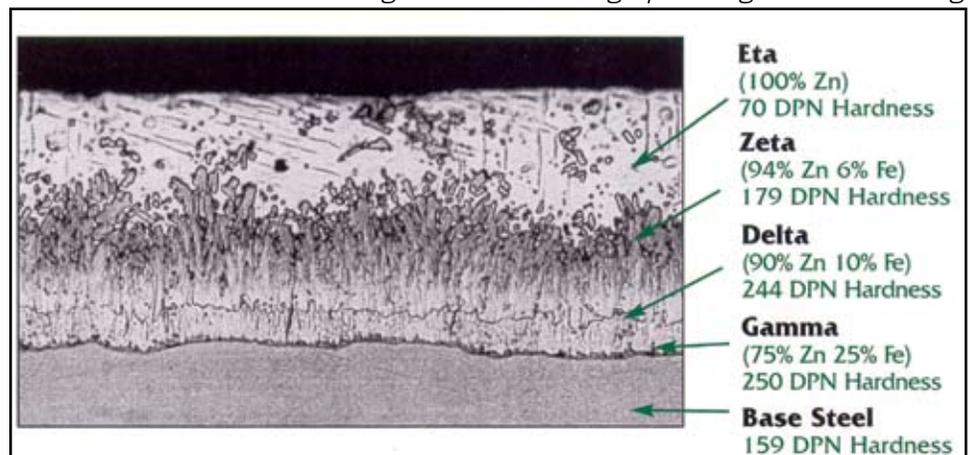
If the galvanized coating is physically damaged, it will continue to provide cathodic protection to the exposed steel. If individual areas of underlying steel or iron become exposed as much as 1/4 inch, the surrounding zinc will provide these areas with cathodic protection for as long as the coating lasts.

Figure 6 (next page) shows how corrosion will begin and immediately progress at a scratch or gap in a paint coating. *Figure 7* (next page) shows how corrosion will be prevented at a scratch or gap in a zinc coating.

The galvanizing process naturally produces coatings that are at least as thick at the corners and edges as the coating on the rest of the substrate. As coating damage is most likely to occur at the edges, this is where added protection is needed most. Brush or spray applied coatings have a natural tendency to thin at the corners and edges. *Figure 8* is a photomicrograph showing a cross-section of an edge of a galvanized piece of steel.

Because the galvanizing process involves total immersion of the material, it is a complete process; all surfaces are coated, including recesses and hard to reach corners. Galvanizing provides both outside and inside protection for hollow structures. Hollow structures that are only painted have no corrosion protection on the inside.

Figure 5: Photomicrograph of a galvanized coating



The inspection process for galvanized items is simple, fast, and requires minimal labor. Conversely, the inspection process required to assure the quality of many coatings applied by brush and spray is highly labor intensive and uses expensive, skilled labor.

Galvanizing continues at the factory under any weather or humidity conditions. Most brush and spray applied coatings are dependent upon proper weather/humidity conditions for correct application. This dependence on atmospheric conditions often translates into costly construction delays.

The galvanizer's ability to work in any type of weather allows a higher degree of assurance of on-time delivery. Working under these circumstances, galvanizing can be completed quickly and with short lead times. A turnaround time of two or three days is common for galvanizing.

Coating Thickness

ASTM, ISO, CSA, and AASHTO specifications establish minimum standards for thickness of galvanized coatings on various categories of items. These minimum standards are routinely exceeded by galvanizers due to the nature of the galvanizing process. Factors influencing the thickness and appearance of the galvanized coating include chemical composition of the steel, steel surface condition, cold working of steel prior to galvanizing, bath temperature, bath immersion time, bath withdrawal rate, and steel cooling rate.

The chemical composition of the steel being galvanized is perhaps the most important. The

Figure 8: Coating thickness consistent on corners

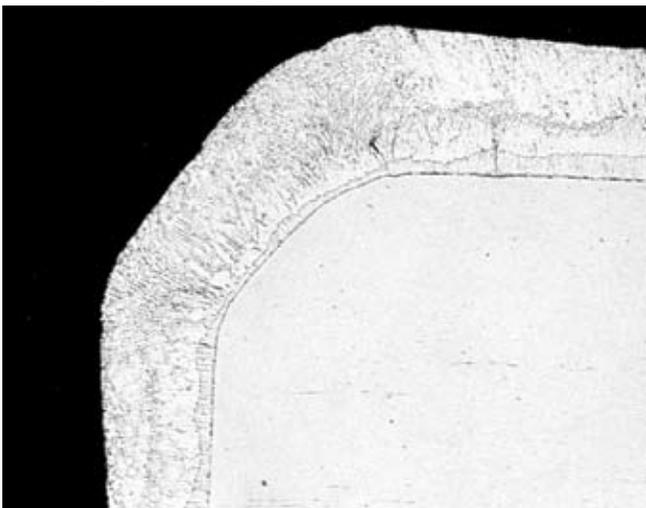
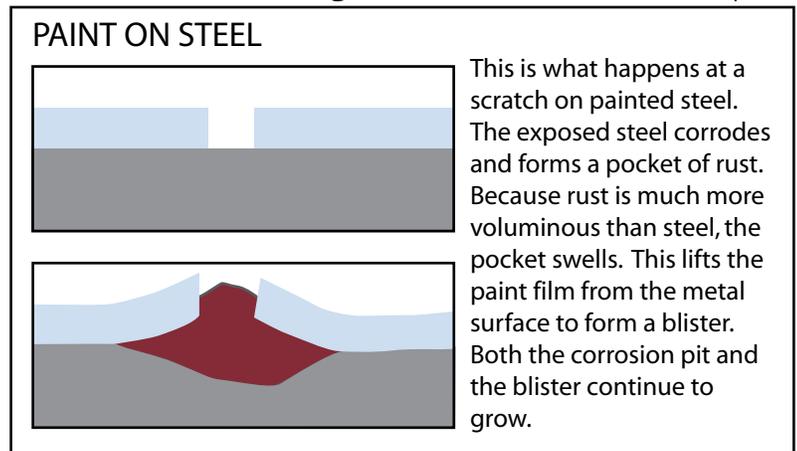
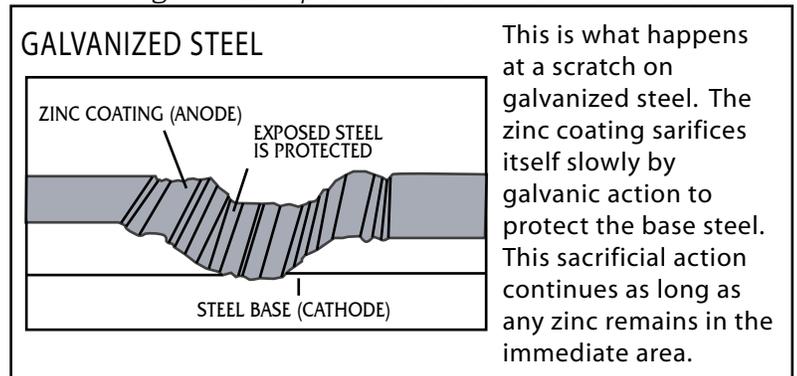


Figure 6: Rust undercuts scratched paint



This is what happens at a scratch on painted steel. The exposed steel corrodes and forms a pocket of rust. Because rust is much more voluminous than steel, the pocket swells. This lifts the paint film from the metal surface to form a blister. Both the corrosion pit and the blister continue to grow.

Figure 7: Zinc protects base steel even when scratched



This is what happens at a scratch on galvanized steel. The zinc coating sacrifices itself slowly by galvanic action to protect the base steel. This sacrificial action continues as long as any zinc remains in the immediate area.

amount of silicon and phosphorus in the steel strongly influences the thickness and appearance of the galvanized coating. Silicon, phosphorous, or combinations of the two elements can cause thick, brittle galvanized coatings. The coating thickness curve shown in *Figure 9*, (next page) relates the effect of silicon in the base steel to the thickness of the zinc coating. The carbon, sulfur, and manganese content of the steel also may have a minor effect on the galvanized coating thickness.

The combination of elements mentioned above, known as "reactive steel" to the galvanizing industry, tends to accelerate the growth of zinc-iron alloy layers. This may result in a finished galvanized coating consisting entirely of zinc-iron alloy. Instead of a shiny appearance, the galvanized coating will have a dark gray, matte finish. This dark gray, matte coating will provide as much corrosion protection as a galvanized coating having a bright appearance.

It is difficult to provide precise guidance in the area of steel selection without qualifying all of the grades of steel commercially available. The guidelines discussed below usually result in the selection of steels that provide good galvanized coatings.

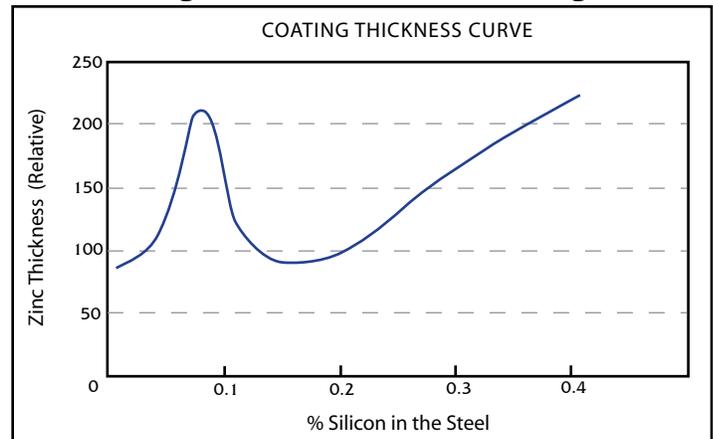
- Levels of carbon less than 0.25%, phosphorus less than 0.04%, or manganese less than 1.35% are beneficial
- Silicon levels less than 0.04% or between 0.15% and 0.22% are desirable.

Silicon may be present in many steels commonly galvanized even though it is not a part of the controlled composition of the steel. This occurs primarily because silicon is used in the deoxidation process for the steel.

The phosphorus content should never be greater than 0.04% in steel intended for galvanizing. Phosphorus acts as a catalyst during galvanizing, resulting in rapid growth of the zinc-iron alloy layers.

Because the galvanizing reaction is a diffusion process, higher zinc bath temperatures and longer immersion times generally will produce somewhat heavier alloy layers. Like all diffusion processes, the reaction proceeds rapidly at first and then slows as layers grow and become thicker. Continued immersion beyond a certain time will have little effect on further coating growth. When galvanizing reactive steels, the diffusion process significantly changes.

Figure 9: Effect of silicon on coating thickness



The thickness of the outer pure zinc layer is largely dependent upon the rate of withdrawal from the zinc bath. A rapid rate of withdrawal causes an article to carry out more zinc and generally results in a thicker coating.

ASTM, CSA, and AASHTO specifications and inspection standards for galvanizing recognize that variations occur in both coating thickness and compositions. Thickness specifications are stated in average terms. Further, coating thickness measures must be taken at several points on each inspected article to comply with ASTM A 123/A 123M for structural steel and A 153/A 153M for hardware.

Design of Products for Galvanizing

Corrosion prevention must begin on the drawing board. This is true regardless of the system selected. Specifying galvanizing as the means of corrosion prevention for a particular product has minimal design limitations. Certain practices should be followed in designing structures for effective and safe galvanizing. These practices are easily applied and in most cases are routine methods used to ensure maximum corrosion protection.

Most ferrous materials are suitable for galvanizing. These include cast iron, malleable iron, cast steels, hot rolled steels, and cold rolled steels, structural steel shapes (including those of high strength), and low alloy materials. Material with a tensile strength greater than 150ksi (1034mpu) is susceptible to hydrogen embrittlement in the standard galvanizing process. The embrittlement problem can be handled by special cleaning if there is prior knowledge of this property. Material with a tensile strength of 150ksi

or less may be hot-dip galvanized after fabrication to obtain the long lasting protection afforded by the zinc coating.

The most satisfactory way to ensure the safe, effective, and economical galvanizing of articles is for the designer, fabricator, and galvanizer to work together before the product is manufactured. For more information, please refer to the AGA publication *The Design of Products to be Hot-Dip Galvanized After Fabrication*. In addition to covering the essential considerations for proper design and providing specific technical specifications and details, illustrations demonstrate both proper and improper design practices. These practices are also described in ASTM A 143, A 384, and A 385.

Sizes, Shapes, and Dimensions

Iron and steel pieces specified for galvanizing after fabrication range from small pieces of hardware to

large welded steel assemblies or castings weighing several tons. Galvanizing kettles up to 40-feet long are available in most areas, and it is common to find kettles approaching 60 feet. Through progressive dipping (sometimes called “double-dipping” – for products too deep or too long to fit into the kettle), it is possible for the galvanizer to process articles that exceed kettle dimensions. If you have questions about a product’s galvanizability, contact your galvanizer or the AGA.

Mechanical Properties

According to studies by the BNF Metals Technology Centre in the United Kingdom (as well as numerous other national and international studies), hot-dip galvanizing produces no significant changes in the mechanical properties of the structural steels or welds commonly used throughout the world. The galvanized substrate steel is chemically and metallurgically equivalent to the uncoated steel.

Other Design Considerations

Galvanizing requires cleaning solutions and liquid zinc flow into, over, through, and out of fabricated articles. Designs that promote the flow of zinc are optimal.

Filling and vent holes must be provided to prevent pickling or other cleaning bath fluids from becoming trapped in the piece. It is best to avoid narrow gaps between plates, overlapping surfaces, and back-to-back angles and channels. When overlapping or contacting surfaces cannot be avoided, all edges should be completely sealed by welding but provided with a small hole or a short gap in the welding to relieve pressure build-up in overlapping areas that

exceed 12 square inches. See the AGA’s publication *Recommended Details for Galvanized Structures* for more information on this topic.

Welding

When welded items are galvanized, both the cleanliness of the weld area after welding and the metallic composition of the weld itself affect galvanizing quality and appearance. Some welding techniques that lead to good results include:

- Use of an uncoated electrode where possible,
- Thorough removal of all welding flux residues if a coated electrode is used,
- Producing little or no slag,
- Use of a submerged arc method for heavy weldments,
- Selection of welding rods providing a deposited weld composed of the same materials as the parent metal, and
- Avoiding welding rods high in silicon.

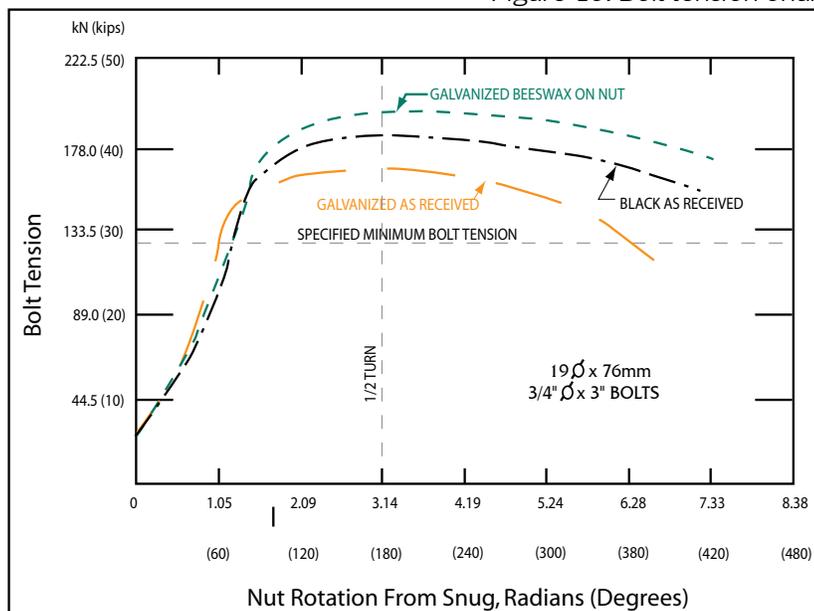
Galvanized materials may be welded easily and satisfactorily by all common welding techniques. The American Welding Society (AWS, www.aws.org) has produced a book detailing all aspects of welding galvanized items. In general, anything that can be welded before galvanizing can be welded with relative ease after galvanizing. A copy of the AWS recommended welding practices is available from the AGA or your local galvanizer.

Bolting

Hot-dip galvanizing is a well established and widely used process for coating mechanical fasteners and welded joints. The prime mechanical fasteners used for making field connections in steel are bolts that conform to ASTM A 307, A 325, and A 394 and are galvanized in accordance with ASTM A 153/A 153M and CSA standards. Bolted galvanized structural joints can be designed for both bearing- and friction-type connections. Galvanized joints of this type have an outstanding performance history.

Figure 10 is a representative chart for bolt tension of galvanized versus black bolts. A lubricated galvanized bolt can develop greater joint tension than a black bolt. For more information, refer to the AGA publication *Bolted Galvanized Structural Joints*. It provides additional information

Figure 10: Bolt tension chart



on the characteristics and advantages of bolted galvanized structures and bolting procedures.

Painting Galvanized Steel

Galvanized articles are easily and successfully painted. The two factors critical to success are proper post-galvanizing surface preparation and proper paint system selection. Galvanized steel is painted for a number of reasons: aesthetics, safety marking, and the desire for even longer lasting protection. Galvanizers must be notified if galvanized steel is to be subsequently painted so they can avoid applying a post galvanizing treatment that affects paint adhesion.

A corrosion protection system consisting simply of galvanizing provides long-term, cost-effective corrosion protection. Often the expected service life of the galvanized coating actually exceeds the design life of the structure it protects. However, a duplex system, (paint over galvanizing), greatly extends the period effective corrosion protection is provided. A useful rule of thumb is a duplex system will provide corrosion protection for 1.5 times the sum of the service lives of the individual systems. For example, if the life of the galvanized coating in a particular environment is 35 years and the expected service life of the paint system is 10 years, the expected service life of the duplex system will be 67.5 years [i.e., $1.5 \times (35+10)$]. While such duplex systems often have a premium first cost, they are usually the lowest life-cycle cost solution. They may be the only feasible solution for structures in aggressive environments where later in-service painting is extremely difficult or impossible.

The synergy of duplex systems in corrosion protection stems from three known factors:

- The paint film extends the life of the galvanized coating by providing additional barrier protection to the zinc layers,
- An underlying layer of zinc tends to prolong the life of a paint coating by preventing an underlying layer of corrosion from developing, and
- The corrosion products of zinc and its alloys further retard paint coating damage by sealing cracks and pores in paint films.

Some galvanizers do have facilities to shop-apply paint coatings after galvanizing.

The specifier should check with the galvanizer to determine if these facilities are available. When the design life of a fabricated item exceeds the service life of the galvanized coating without a duplex system, the initial galvanized coating can provide subsequent corrosion protection by adding a brush or spray applied paint system. When a paint-based corrosion protection system on bare steel reaches the end of its service life, abrasive blasting or grinding back to white steel is frequently necessary in order to repaint. Preparation of a previously galvanized surface for a properly selected paint-based system of corrosion protection is normally much simpler.

Two AGA publications give more information on duplex systems; *Duplex Systems: Painting Over Hot-Dip Galvanized Steel*, and *Practical Guide for Preparing Hot-Dip Galvanized Steel for Painting*. In addition to providing a wealth of technical details and a discussion of the suitability of a number of different types of paints for application after galvanizing, these publications also present a number of specific applications and color photographs of duplex systems.

Environmental Compliance

United States Environmental Protection Agency (EPA), in addition to many state and local environmental protection agencies, has established restrictions governing volatile organic compounds (VOCs). Many brush and spray applied corrosion protection systems contain VOCs and are thus subject to this regulation. The galvanized coating contains no VOCs and is compliant with these regulations.

Example of a duplex system (painting over galvanized steel)



Economics of Galvanizing

Economical Analysis

Any exposed steel must be protected to ensure an effective service life. The cost of corrosion protection for a structure will range from 0.5% to 5% of the cost of the project. In exceptional cases, where a large area of lightweight steel is exposed to corrosive attack, the corrosion protection system may represent a much more significant part of the project budget.

First Cost

Looking at the two primary corrosion protection systems, galvanizing and paint, it is necessary to define the specifications for each so a reasonable cost comparison can be conducted. The galvanized material normally would be specified to ASTM A 123/ A 123M. This calls for a minimum coating thickness of 2.3 ounces of zinc per square foot of steel surface. Based on a 2006 survey of galvanizers nationwide, the cost of the galvanizing component package in the fabricated steel price is approximately \$240 - \$440 per ton, depending upon size, geographic area, and type of project. Assuming a 20% markup by the fabricator, the cost to a contractor would range from \$288 - \$528 per ton.

A high-performance paint system frequently specified in competition with galvanizing consists of an inorganic zinc primer, a high-build epoxy intermediate coat, and a polyurethane topcoat. To function properly, this high-performance system must be applied over a steel surface blasted to a Society for Protective Coatings (SSPC) Specification of at least SP 10. Using the 2006 coatings economics survey published by the National Association of Corrosion Engineers (NACE) as a baseline for the estimated cost for shop application, costs for this paint system are approximately \$874 per ton.

These numbers indicate galvanizing is far more economical than the paint system it is often compared to. Remarkably, even more costs savings are realized when the total project cost, or life-cycle cost are compared.

Life-Cycle Cost

Based on a moderate exposure to corrosive elements, the galvanized system will have a projected life (to 5% surface rust) in excess of 75 years. The paint system, based on the same NACE report, will require repainting in approximately 21 years. Therefore, when designing a structure with an anticipated

life of 40-50 years, future repainting costs must be added to the total corrosion protection costs.

Maintenance painting consumes a significant and escalating portion of operating and maintenance budgets. As more focus is placed on controlling maintenance costs, a reliable, low-maintenance corrosion protection system can be estimated by using commonly accepted economic formulas.

Cost-Per-Square-Foot-Per-Year Value Theory

The current method for evaluating any coating system is to determine its cost in dollars per square foot per year over the life of the structure. Concern with the cost of corrosion protection per square foot of steel has attracted significant attention among specifiers, engineers, and corrosion consultants. The cost-per-square-foot-per-year method seeks to minimize costs by analyzing all cost components including first cost, operating costs, and maintenance costs. An economic analysis that includes both initial costs and future maintenance costs should be used to select the most economical protective coating system. When constructing a comparison of costs, each system must be examined in detail for possible additional costs and savings.

Galvanizing's Advantage: a Capitalized Expenditure

Generally accepted accounting practices for building maintenance dictate maintenance painting be considered an operating expense. The expenses of galvanizing can be capitalized because these expenses generally occur during construction. Under this accounting practice, galvanizing does not compete for precious operating dollars.

Cost Factor Associated with Other Corrosion Control Methods

A multitude of cost elements exist typically not included in an economic analysis:

- Surface preparation in the field when repainting,
- Environmental compliance in the field when repainting,
- Downtime during painting operations,
- Containment systems,
- Materials disposal,
- Weather delays, and
- Insurance and other unknown, uncontrollable factors.

These factors may cause the cost of repainting

to accelerate well beyond the projected cost as determined by the economic analysis. As a case in point, the State of Ohio Department of Transportation has projected a 43% increase in maintenance painting costs in one year.

Galvanizing requires little if any maintenance in comparison to the maintenance demands of paint systems. When all elements in the economic analysis are included, galvanizing has the lowest life-cycle costs.

Galvanizing vs. Painting

The Leaside Bridge, owned by Metropolitan Toronto, extends 1300 feet over the Don Valley Parkway at Millwood Road and originally was built in 1927 using painted structural steel.

In 1969, it was decided that the bridge would be widened from four to six lanes. When bids were tendered, three different approaches were solicited:

Option 1: Blast clean and paint all structural steel (specified as blast clean, zinc rich primer, and two-coat vinyl). Initial cost: \$294,000

Option 2: Galvanize new steel in the expansion, and blast clean and repaint the bridge's original steel in the field (same paint specifications as above). Initial cost: \$230,000

Option 3: Galvanize the new steel and zinc metallize the original. Initial cost: \$271,000

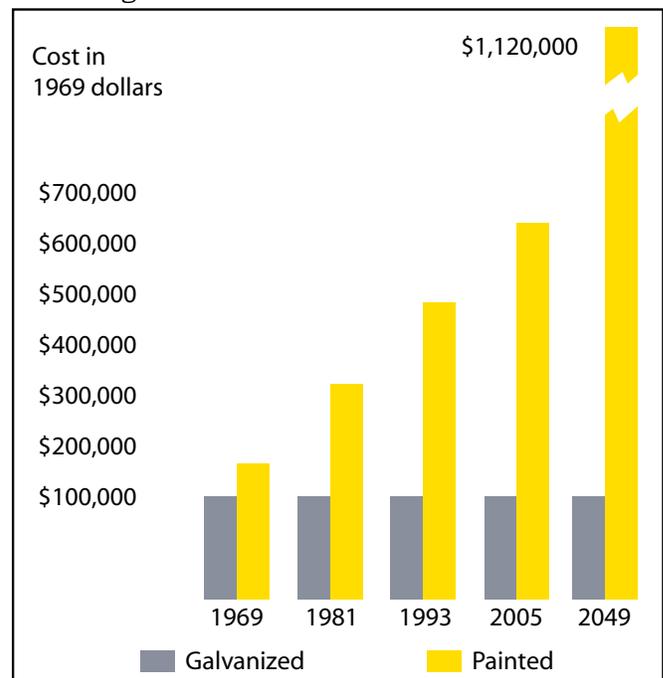
Option 2, the lowest initial cost option, was selected. After more than 30 years in Toronto's moderately industrial atmosphere, the galvanized steel is in excellent condition. Readings taken in 1995 showed a coating thickness of at least seven mils of zinc, which ensures

a maintenance-free life for at least 50 more years.

The painted steel received a paint recoating in 1969 during bridge expansion. Another painting was done in the fall of 1980 and the summer of 1981. Localized touch-up painting was done again in 1991 and had already started to fail in 1997.

Figure 11 shows the cumulative estimated future costs for maintaining the structure in 1969 dollars. The cost for the galvanized structure is fixed during the 80-year span, but the costs for the paint option grow rapidly. Galvanizing saves money on the first cost and savings increase as long as the structure exists.

Figure 11: Cumulative future maintenance costs



Corrosion Resistance of Galvanized Coatings

Galvanized coatings have a proven commercial history under numerous environmental conditions. The corrosion resistance of zinc coatings varies according to its surrounding environment. In most commonly encountered environments, the galvanized coating generally corrodes at a rate between 1/10 and 1/30 of ungalvanized steel.

The predictability of the lifetime of a coating is important for planning and financing required maintenance. Measurements of the actual

consumption rate of the galvanized coating during the first few years of service provide good data for projecting remaining life until first maintenance. Due to the build-up of zinc corrosion products, which in most environments are adherent and fairly insoluble, the corrosion rate may slow as time progresses. Therefore, based upon measurements taken during the first few years of service, estimates of service life until first maintenance of a galvanized coating will often be conservative.

Environments in which galvanized steel and iron commonly are used include outdoor atmospheres, indoor atmospheres, hundreds of different chemicals, fresh water, sea water, soils, concrete, and in contact with other metals. Because of the many years galvanizing has been used for corrosion protection, a wealth of real-world, long-term exposure data on zinc coating performance in a wide variety of environments is available.

Atmospheric Conditions

Zinc oxide is the initial corrosion product of zinc in relatively dry air. It is formed by a reaction between the zinc and atmospheric oxygen. In the presence of moisture, it is converted to zinc hydroxide. The zinc hydroxide and zinc oxide react with carbon dioxide in the air to form zinc carbonate. The zinc carbonate film is tightly adherent and relatively insoluble. It is primarily responsible for the excellent and long-lasting corrosion protection provided by the galvanized coating in most atmospheric environments.

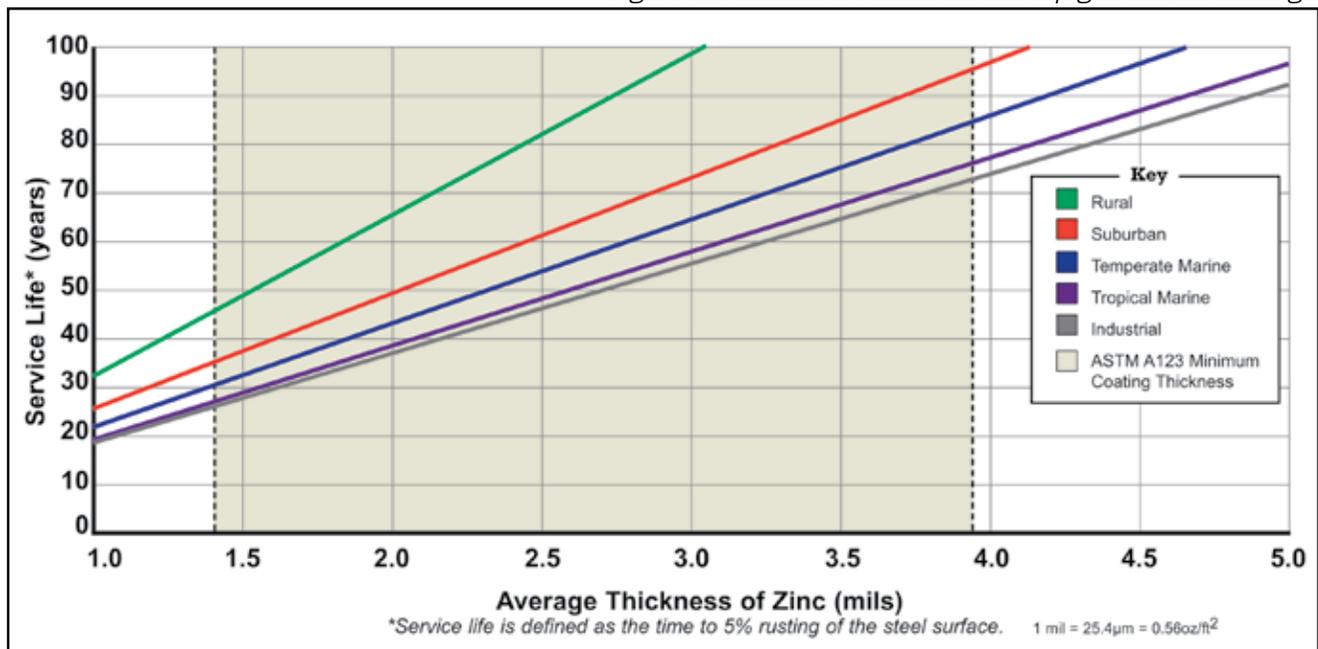
Since 1926, ASTM Committees A05 (Metallic Coated Iron and Steel Products) and G01 (Corrosion of Metals), and other organizations have been collecting continuous records of the behavior of zinc coatings under various categories of atmospheric conditions. These atmospheric exposure tests have been conducted throughout the world to obtain corrosion rate data for exposed zinc. Precise comparison of the corrosion behavior of the galvanized coating in various atmospheric environments is influenced by many factors. Such factors include the prevailing wind direction, type

and density of corrosive fumes and pollutants, amount of sea spray, number of wetting and drying cycles, and the duration of exposure to moisture. Although there is a range in observed corrosion rates, actual observed rates rarely exceed 0.3 mils per year. It is also worthwhile to note that when exposed indoors, the life of the galvanized coating will be at least two to three times longer than outdoor exposure in the same environment.

Figure 12 shows the estimated service life for hot-dip galvanized coatings in five atmospheric environments. The chart was developed using test coupons of hot-dip galvanized steel exposed in thousands of locations throughout the world and a heuristic mathematical model. A galvanized coating's protective life is determined primarily by coating thickness and the severity of exposure conditions. The shaded area of the chart represents minimum thickness requirements found in the hot-dip galvanized specification ASTM A 123. Galvanized coating thicknesses commonly exceed the minimum requirement, typically ranging between 3 and 7 mils. The expected service life is defined as the life until 5% rusting of the steel substrate. At 5% surface rust, there is no steel integrity lost; however, it indicates it is time to consider applying new corrosion protection methods.

Moderately Industrial Atmospheres are generally the most corrosive. Air emissions may contain some sulfides and phosphates that cause the most rapid consumption of the zinc coating. Automobiles, trucks, and plant exhaust are examples of these

Figure 12: Service-life chart for hot-dip galvanized coatings



emissions. Most city or urban areas are classified as “moderately industrial.”

Suburban Atmospheres are generally less corrosive than moderately industrial areas and, as the term suggests, are found in the largely residential, perimeter communities of urban or city areas.

Temperate Marine Atmospheres vary in corrosiveness depending on proximity to the coastline and prevailing wind direction and intensity. In marine air, chlorides from sea spray can react with the normally protective zinc corrosion products to form soluble zinc chlorides. When these chlorides are washed away, fresh zinc is exposed to corrosion. Nevertheless, temperate marine atmospheres are less corrosive than suburban atmospheres.

Tropical Marine Atmospheres are similar to temperate marine atmospheres except they are found in warmer climates. Possibly because many tropical areas are removed from industrial areas, tropical marine climates tend to be somewhat less corrosive than temperate marine climates.

Rural Atmospheres are the least aggressive of the five atmospheric types. This is primarily due to the relatively low level of sulfur and other emissions found in such environments.

Chemical & Liquid Environments, Solution pH

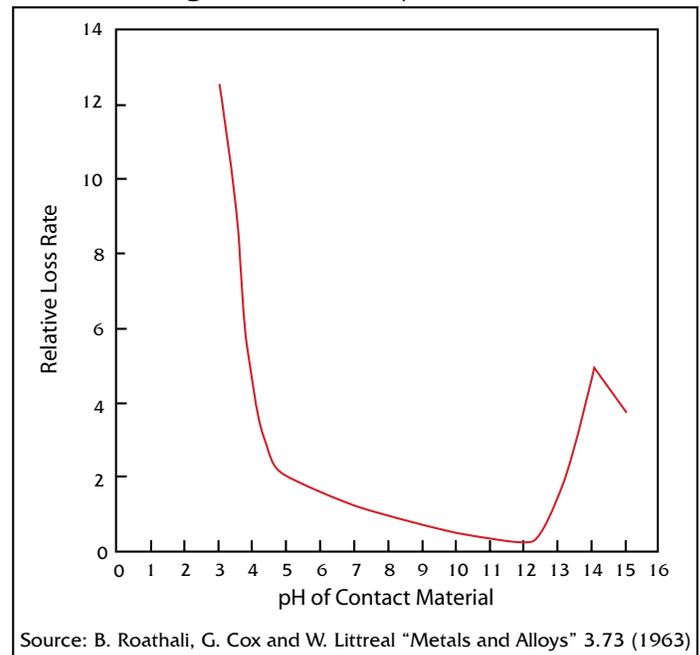
A primary factor governing corrosion behavior of the galvanized coating in liquid chemical environments is the pH of the solution. Galvanizing performs well in solutions of pH above 5.5 and below 12.5 (*Figure 13*). This should not be considered a hard and fast rule, because factors such as agitation, aeration, temperature, polarization, and the presence of inhibitors may change the rate of corrosion. Within the pH range of 5.5 to 12.5 a protective film forms on the zinc surface of the galvanized coating and protects the steel by slowing corrosion. The exact chemical composition of the protective film is somewhat dependent upon the specific chemical environment.

Since many liquids fall within the pH range of 5.5 to 12.5, galvanized steel containers are widely used in storing and transporting many chemical solutions. *Figure 14*, (next page) shows an abbreviated list of some commonly used chemicals successfully stored in galvanized containers.

Fresh Water

Galvanizing is successfully used to protect steel

Figure 13: Effect of pH on corrosion of zinc



in fresh water exposure. “Fresh water” refers to all forms of water except sea water. Fresh water may be classified according to its origin or application. Included are hot and cold domestic, industrial, river, lake, and canal waters. Corrosion of zinc in fresh water is complex, controlled largely by the impurities found in the water. Even rain water contains oxygen, nitrogen, carbon dioxide, other dissolved gases, dust and smoke particles.

Ground water carries microorganisms, eroded soil, decaying vegetation, dissolved salts of calcium, magnesium, iron, manganese, and suspended colloidal matter. All of these substances and other factors such as pH, temperature, and motion affect the structure and composition of the corrosion products formed on the exposed zinc surface. Relatively small differences in fresh water content or conditions can produce substantial changes in corrosion products and rate. Thus, there is no simple rule governing the corrosion rate of zinc in fresh water.

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. *Table 2*, (next page) indicates the service life of galvanized steel in various fresh waters.

Figure 14 : Chemicals successfully stored in galvanized containers (partial list)

Hydrocarbons Benzene (benzole) Toluene (toluole) Xylene (xyole) Cyclohexene Petroleum ethers Heavy naphtha Solvent Naphtha Alcohols Methyl parafynol (methyl pentynol) Morpholinoisopropanol Glycerol (glycerin) Halides Carbon tetrachloride Amyl bromide Butyl bromide Butyl chloride Byclohexyl bromide Ethyl bromide Propyl bromide Propyl chloride Trimethlyene bromide (1, 3-dibromopropane) Bromobenzene Chlorobenzene Aroclors & Pyrolors (chlorobiphenyls)	Nitriles (cyanides) Diphenylacetoneitrile p-chlorobenzglycyanides Esters Allyl butyrate caproate formate propionate Ethyl butyrate sobutyrate caproate caprylate propionate succinate Amyl butyrate sobutyrate caproate caprylate Methyl butyrate caproate propionate succinate Benzyl butyrate sobutyrate propionate succinate Octyl butyrate caproate	Butyl butyrate sobutyrate caproate propionate succinate titanate Propyl butyrate isobutyrate caproate formate propionate Iso-Butyl benzoate buytrate caproate Iso-Propyl benzoate caproate formate propionate Cyclohexyl buytrate Phenols Phenol Cresols (mehtylphenols) Xylenols (dimethylphenols) Biphenol (dihydroxybiphenyl) 2, 4-dichlorophenol p-chloro-o-cresol Chloroxylenols	Amine and Amine Salts Pyridine Pyrrolidine Methylpiperazine Dicarbethoxypiperazine 1-benzhydryl-4-methylpiperazine 2-4-diamino-5-(4-chlorphenyl-6) ethlpyrimidine Hydorxyethylmopholine (hydroxyethyl-diethylenimideoxide) paminobenzenesulphonylguanidine Butylamine oleate Piperazine hydrochloride monohydrate Carbethoxypiperazine hydrochloride (dry) Amides Formamide Dimethylformamide Miscellaneous Glucose (liquid)Benzilideneacetone p-chlorobenzopheone Sodium azobenzensulphonate Melamine resin solutions Crude cascara extract Creosote Chlorofluorocarbons
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Sea 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 have a strong inhibiting effect on zinc corrosion. One should be very skeptical of accelerated laboratory test results that sometimes use a simple sodium chloride (NaCl) solution to simulate the effects of sea water exposure on galvanized steel. Real world results often differ significantly.

Soils

More than 200 different

types of soils have been identified and are categorized according to texture, color, and natural drainage. Coarse and textured soils, such as gravel and sand, permit free circulation of air, and the process of corrosion may closely resemble atmospheric corrosion. Clay and silt soils have a fine texture and hold water, resulting in poor aeration and drainage. Generally

Table 2 : Corrosion of zinc coated steel in selected natural fresh waters

Location and water	Type of Zinc	Type of Test	Agitation	Corrosion rate mil/year
Gatun Lake, Canal Zone Tropical fresh water	Intermediate	Immersion	Stagnant	0.52
Gatun Lake, Canal Zone Tropical fresh water	Intermediate	Immersion	Stagnant	0.41
Pedro Miguel Locks Panama, Fresh water	Special high grade	Immersion	--	0.71
Pedro Miguel Locks Panama, Fresh water	High grade	Immersion	--	0.53
Pedro Miguel Locks Panama, Fresh water	Intermediate	Immersion	--	0.44
Pedro Miguel Locks Panama, Fresh water	Select	Immersion	--	0.55
Pedro Miguel Locks Panama, Fresh water	Prime Western	Immersion	--	0.53
River Water Hardness 7-6° (German)	99% zinc	Immersion Lab	Still	0.56
River Water Hardness 7-6° (German)	99% zinc	Immersion Lab	Still	0.24

speaking, sandy, well-aerated soils with neutral or slightly basic pH cause only limited corrosion, most likely below 10 μm/year (0.4 mil/year).

The National Corrugated Steel Pipe Association (NCSIPA) in collaboration with the American Iron and Steel Institute (AISI) have produced a chart, (Figure 15) that estimates galvanized steel invert life if the pH and resistivity of soil are known. This chart is a good predictor of all galvanized steel service life in soil because the coating does not vary by product.

Resistivity and pH are the most influential soil characteristics on the corrosion rate of galvanized steel. If the resistivity is greater than 2,000 ohm-cm and the pH is between 6 and 10, a very common range, galvanized steel will perform well.

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. Steel wire or reinforcing bars (rebar) are often embedded in concrete to provide added strength.

Figure 16 : Study of galvanized vs black reinforcing steel

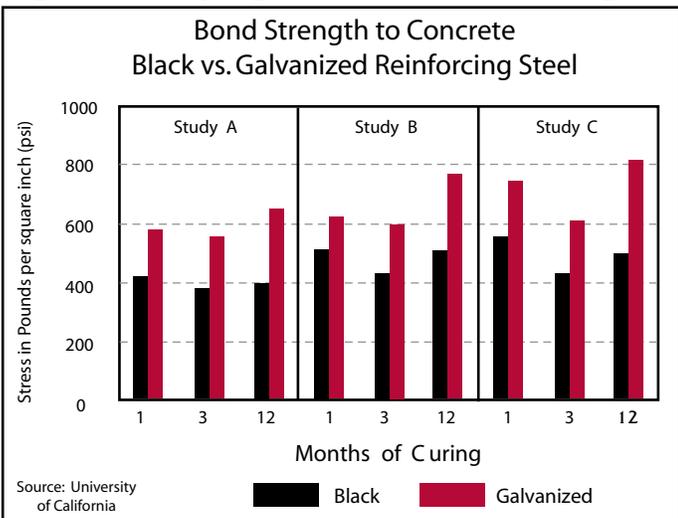
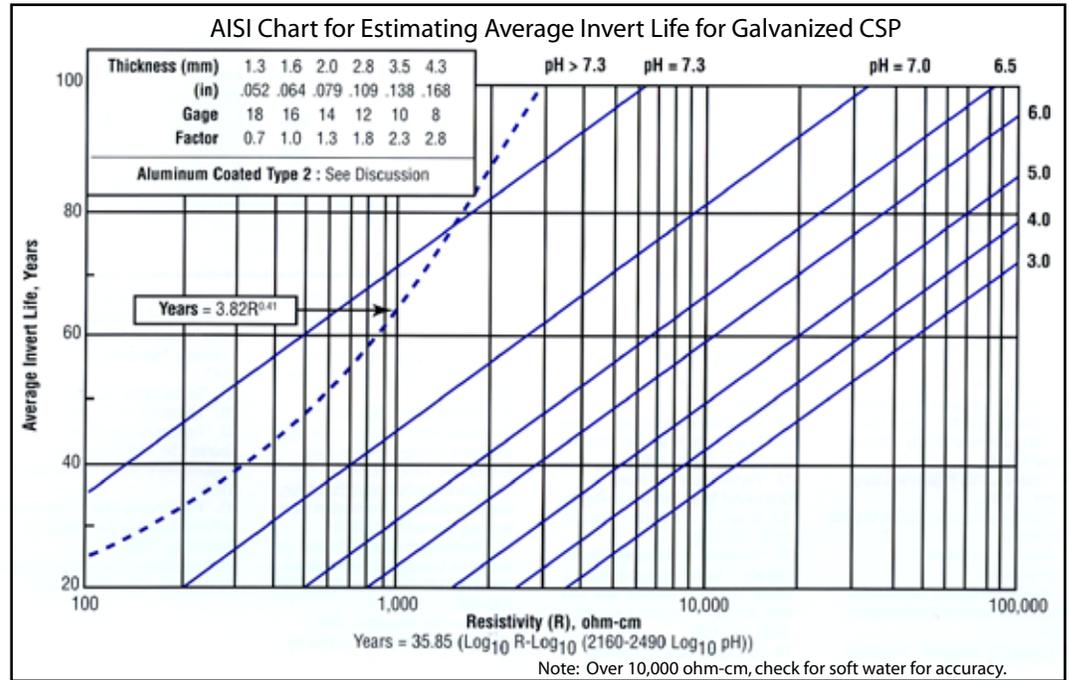


Figure 15 : Corrosion of galvanized steel pipe in contact with a variety of soils



Rebar can be galvanized to retard corrosion, providing barrier and sacrificial protection. As the corrosion products of zinc are much less voluminous than those of steel, the cracking, delamination, and spalling cycle is greatly reduced when using galvanized rebar. Laboratory data supports, and field test results confirm, reinforced concrete structures have a substantially longer service life when galvanized rebar is used as opposed to black steel rebar.

Although it takes slightly longer to develop, lab and field tests show the bond between galvanized rebar and concrete is stronger than the bond between black rebar and concrete (Figure 16).

A comparison of the qualitative and quantitative characteristics of galvanized rebar and epoxy coated rebar is shown in Table 3 (next page). Additional studies on the uses of galvanized steel reinforcing bars in concrete can be found at www.galvanizedrebar.com and in the AGA publication Galvanizing for Corrosion Protection: A Specifier’s Guide to Reinforcing Steel and Rebar: A Processing and Inspection Guide for Quality Hot-dip Galvanized Reinforcing Steel. Table 4, (next page) shows the field performance of galvanized rebar in five different projects.

Other Metals

Under atmospheric or aqueous condition, if zinc comes in contact with another metal, the potential for corrosion through a bimetallic couple exists.

The extent of the corrosion depends upon the position of the other metal relative to zinc in the galvanic series (*Figure 2*, page 2).

Installation requiring contact between galvanized materials and copper or brass in a moist or humid environment, can cause rapid corrosion. Even run-off water from copper or brass surfaces can contain enough dissolved copper to cause rapid corrosion. If contact with galvanized items is unavoidable, precautions should be taken to prevent electrical contact between the two metals. Joint faces should be insulated with non-conducting gaskets and connections should be made with insulating, grommet-type fasteners. The design should ensure water is not recirculated and flows from the galvanized surface towards the copper or brass surface and not the reverse.

Under atmospheric conditions of moderate to mild humidity, contact between a galvanized surface

Table 3: Comparison of epoxy-coated and hot-dip galvanized reinforcing steel bars

Comparison Factor	Hot-Dip Galvanized	Epoxy-Coated
Earliest Use	Early 1900's	1974
Requires care in handling	No	Yes
Can be dragged on ground	Yes	No
MUST be touched up	No	Yes
Has barrier protection	Yes	Yes
Has cathodic protection	Yes	No
Bond strength to concrete	Excellent	Poor
UV Resistance	Good	Questionable
After fabrication application	Simple	Difficult
Widely used	Yes	Yes
Cost	Comparable	Comparable*
Lead time	1-3 days	3 weeks
Availability of coating for other embedded items	Readily available	Scarce
* Epoxy prices vary widely throughout the US and Canada and wide variations should be expected		

and aluminum or stainless steel is unlikely to cause substantial incremental corrosion. However, under very humid conditions, the galvanized surface may require electrical isolation through the use of paint or joining compounds. The galvanic behavior of galvanized coatings in contact with various metals in atmospheric and immersion environments is summarized in *Table 5*, (next page).

Table 4: Field performance of bridges with galvanized reinforcing steel

Location	Installed	Inspection Date	Chlorides	Zinc Coating Thickness	
			(lb/yd ³)	mils	µm
Boca Chica Bridge, FL*	1972	1975	1.95	5.1	130
		1991	2.02	4.0	102
		1999	3.21	6.7	170
Tioga Bridge, PA*	1974	1981	0.58	5.9	150
		1991	1.06	8.8	224
		2001	2.23	7.8	198
Curtis Road Bridge, MI	1976	2002	6.88	6.1	155
Spring Steel Bridge, VT	1971	2002	4.17	7.5	191
Evanston Interchange, WY	1975	2002	2.55	9.3	236

* Multiple inspections were made on these bridges. Since concrete cores are drilled out of the bridge, it is impossible to perform this inspection in the same spot. When performing subsequent inspections, the cores must be drilled in different areas which doesn't allow for corrosion monitoring in one particular area. Hot-dip galvanized coating thicknesses vary slightly over the length of the bars. This explains how a greater coating thickness can be read when measuring the same bridge at a later date.

Table 5 : Additional corrosion of zinc and galvanized steel resulting from contact with other metals

Metal in Contact	Environment				
	Atmospheric			Immersed	
	Rural	Industrial/ Urban	Marine	Fresh Water	Sea Water
Aluminum and aluminum alloys	0	0-1	0-1	1	1-2
Aluminum bronzes and silicon bronzes	0-1	1	1-2	1-2	2-3
Brasses - high tensile (HT) brass (manganese bronze)	0-1	1	0-2	1-2	2-3
Cadmium	0	0	0	0	0
Cast irons	0-1	1	1-2	1-2	2-3
Cast iron (austentic)	0-1	1	1-2	1-2	1-3
Chromium	0-1	1-2	1-2	1-2	2-3
Copper	0-1	1-2	1-2	1-2	2-3
Cupro-nickels	0-1	0-1	1-2	1-2	2-3
Gold	(0-1)	(1-2)	(1-2)	(1-2)	(2-3)
Gunmetals, phosphor bronzes, and tin bronzes	0-1	1	1-2	1-2	2-3
Lead	0	0-2	0-2	0-3	(0-2)
Magnesium an magnesium alloys	0	0	0	0	0
Nickel	0-1	1	1-2	1-2	2-3
Nickel copper alloys	0-1	1	1-2	1-2	2-3
Nickel-chromium-iron alloys	(0-1)	(1)	(1-2)	(1-2)	(1-3)
Nickel-chromium-molybedenum alloys	(0-1)	(1)	(1-2)	(1-2)	(1-3)
Nickel silvers	0-1	1	1-2	1-2	1-3
Platinum	(0-1)	(1-2)	(1-2)	(1-2)	(2-3)
Rhodium	(0-1)	(1-2)	(1-2)	(1-2)	(2-3)
Silver	(0-1)	(1-2)	(1-2)	(1-2)	(2-3)
Solders hard	0-1	1	1-2	1-2	2-3
Solders soft	0	0	0	0	0
Stainless steel (austenitic and other grades containing approximately 18% chromium)	0-1	0-1	0-1	0-2	1-2
Stainless steel (martensitic grades containing approximately 13% chromium)	0-1	0-1	0-1	0-2	1-2
Steels (carbon and low alloy)	0-1	1	1-2	1-2	1-2
Tin	0	0-1	1	1	1-2
Titanium and titanium alloys	(0-1)	(1)	(1-2)	(0-2)	(1-3)

KEY 0 Zinc and galvanized steel will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Zinc and galvanized steel will suffer slight or moderate additional corrosion that may be tolerable in some circumstances.

2 Zinc and galvanized steel may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Zinc and galvanized steel may suffer severe additional corrosion and the contact should be avoided.

() - Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Note: The table is in terms of additional corrosion and the symbol "0" should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

Source: British Standards Institution, pp. 6484: 1979, Table 23

Practical Uses of Galvanized Steel

Corrosion of exposed steel is a major problem, but galvanizing is an effective solution. This guide has explained the corrosion process, how galvanized coatings are produced, and how well the coating protects against corrosion. The remainder of this guide is dedicated to identifying the many applications of galvanizing in specific, real-world projects. To see examples, visit www.galvanizeit.org/ref/projects.

Additional detailed information on the use of galvanizing for corrosion protection in these and other applications is available from the AGA or your local galvanizer.



Bridges & Highways

Bridge Superstructure

Anchor Bolts
Anti-suicide Rail
Base Plates
Bearing Assemblies
Bearing Plates
Bolts
Box Rail
Bridge Rail
Cable Connectors
Cables
Channel Shear Connectors
Cross-bracing
Curb Angles
Diaphragms
End Dams
Expansion Dams
Finger Joint Expansion Dams
Floor Gratings
Flooring Grid
Girders
Guardrail and Posts
Inspection Catwalks
Jersey Barrier Embedments
Light Poles
Pipe Railing
Pipe Supports
Piping
Pot Bearings
Pour-in-place Forms
Reinforcing Splice Clips
Reinforcing Steel
Scuppers and Drains
Shear Studs
Sign Supports
Signal Light Poles
Spiral Shear Connectors



Splice Plates
Steel Divider Barrier
Stringers
Trench Drains

Bridge Substructure

Access Doors
Bin-type Retaining Walls
Bolts
Catwalks
Drainage Supports
Drainage Systems
Driven Piling
Fencing
Ground Anchors
Ladders
Pier Piling
Reinforcing Splice Clips
Reinforcing Steel
Retaining Walls
Sheet Piling
Sign Supports

Temporary Bridges

Complete "Bailey Bridge"
Structures
Insert Modules

Highways

Anchor Bolts
Anti-suicide Rail
Base Plates
Box Rail
Break-aways
Culverts
Curb Angles
Delineators
Fencing
Gates
Guardrail and Posts
Jersey Barrier Embedments
Light Poles
Overhead Sign Supports
Pedestrian Overpass Bridge
Pipe Railing
Reinforcing Steel
Scuppers and Drains
Sign Supports
Signal Light Poles
Signal Supports

Sound Barriers
Steel Divider Barriers
Trench Drains

Power Generation

Buildings

Beams
Brick Ties
Brick Ledges
Columns
Dock Levelers
Equipment Supports
Girts
HVAC Supports
Lintels
Overhead Cranes
Purlins
Relieving Angles
Roof Hatches
Structural Steel

Yard Equipment

Bollards
Bridges
Catwalks
Coal Handling Equipment
Conveyor Supports
Corner Guards
Cranes
Fencing
Flagpoles
Gates
Guardrail and Posts
Hopper Structures
Ladders
Mechanical Screens
Pipe Bridges
Pipe Supports
Railings
Reinforcing Steel
Sheet Piling
Sign Supports
Steel Grating
Steel Stairs
Trench Covers
Truck Lifts
Truck Scale
Valve Stands

Power Transmission &

Distribution

Anchor Bolts
 Bollards
 Concrete Embedded Reinforcement
 Electrical Boxes
 Equipment Supports
 Faraday Cages
 Fasteners
 Fencing
 Gates
 Handrails
 Ladders
 Lattice Towers
 Light Poles
 Light Brackets
 Pole Arms
 Posts
 Sign Supports
 Steel Stairways
 Transmission Poles
 Tubular Towers
 Walkways

Other Power Generation

(Natural Gas, Hydroelectric, Solar, Wind)

Anchor Bolts
 Equipment Supports
 Fencing
 Fish Ladders
 Flood Control Gates
 Flow Restrictors
 Gas Turbine Skids
 Generator Housings
 Generator Support Platforms
 Light Poles
 Penstock
 Platforms
 Railings
 Reinforcing Steel
 Sheet Piling
 Solar Panel Backs and Supports
 Solar Control Boxes
 Tower Ladders
 Tower Supports
 Trash Racks and Booms
 Windmill Towers

Transportation

(Rail, Rapid Transit, Marine, Air)

Advertising Shelters
 Anchor Bolts
 Anchorage Clips
 Baggage Conveyor Supports
 Ballast Stops



Bearing Plates
 Benches
 Bicycle Racks
 Bollards
 Brick Ledges
 Brick Ties
 Building Trim
 Bulkheads
 Cable Trays
 Canopy Supports
 Catenaries
 Catwalks
 Crash Barriers
 Curb Angles
 Decorative Emblem Supports
 Dock Bumpers
 Drain Pipes
 Drains
 Edge Angles
 Electrical Boxes
 Electrical Panels
 Electrical Sub-station Framing
 Exterior Stairway Systems
 Fencing
 Flagpoles
 Floor Grating
 Fountain Accessories
 Gangplanks
 Guide Rail
 Handrails
 Handicap Rail
 Hangers
 Ladders
 Leveling Plates
 Light Fixtures
 Light Poles
 Lightning Rods
 Lintels
 Manhole Covers
 Map/Sign Supports
 Mesh
 Ornamental Fencing
 Ornamental Steel
 Pilings
 Pipe Sleeves
 Post and Chain Fence
 Pre-Engineered Building Exteriors
 Pre-cast Hardware
 Railings
 Reinforcing Steel
 Relieving Angles
 Roof Hatches
 Scuppers
 Signal Bridges
 Signal Equipment
 Signal Structures
 Sound Barriers
 Stair Tread
 Structural Support Steel
 Tie Toe Plates
 Trash Containers
 Tree Grates
 Tree Guards
 Tunnel Liners
 Utility Covers and Grates

Vehicle Washing Equipment
 Walkway Structures
 Window Wall Supports
 Window Washing Rails

Water & Waste Water Treatment

Aeration Tanks
 Aerators
 Anchor Bolts
 Angles
 Basin Wear Plates
 Beams
 Bollards
 Brick Ledges
 Brick Ties
 Bridges
 Catwalks
 Channel Iron
 Columns
 Composting Equipment
 Composting Conveyors
 Conduit
 Conveyor Supports
 Dock Levelers
 Embedded Frames
 Fencing
 Flagpoles
 Floor Gratings
 Floor Plates
 Gates
 Girts
 Grit Chambers
 Guardrail
 Guardrail Posts
 Guide Rail
 HVAC Platforms
 Ladders
 Light Poles
 Lintels
 Mechanical Screens
 Moving Structures
 Overhead Bridge Cranes
 Overhead Trusses
 Pipe Bridges
 Pipe Supports
 Piping Hangers
 Piping Rods
 Pre-cast Veneer Hardware
 Purlins
 Reinforcing Steel
 Relieving Angles
 Scum Baffle
 Scum Well
 Skimmer
 Steel Column Beams
 Steel Doors
 Steel Frames
 Steel Grating
 Steel Retaining Walls
 Steel Stairs
 Structural Steel
 Transmission Towers
 Truck Scales
 Valve Stands
 Weirs

Buildings

Anchor Bolts
Anchoring Clips
Architectural Panels
Attachment Devices
Atrium Supports
Balcony Rails
Beams
Benches
Bicycle Racks
Bleacher Supports
Brick Ties
Brick Ledges
Building System Frames
Canopy Supports
Catwalks
Columns
Crash Barriers
Curb Angles
Drain Pipes
Drains
Embedments
Equipment Screens
Fascia Support Steel
Fencing
Fire Escapes
Flagpoles
Foot Bridges
Fountain Accessories
Garage Support Steel
Gates
Girts
Grating
Handicap Railings
Hatches
HVAC Supports
Integrated Steel Anchors
Ladders
Leveling Plates
Light Fixtures
Light Poles
Lightning Rods
Lintels
Louvers
Manhole Covers
Metal Sculptures
Ornamental Steel
Pipe Bollards
Pipe Hangers
Playground Equipment
Post and Chain Fence
Pre-cast Hardware
Purlins
Railings
Relieving Angles
Roof Trusses
Scuppers
Security Gates
Sign Posts
Stadium Seating
Stair Stringers
Sun Screens
Trash Containers
Tree Grates

Tree Guards
Trellises
Utility Covers
Window Washing Rails
Window Wall Supports

Agriculture & Food Processing

Building Structures
Conveyor Casing
Electrical Conduits
Equipment Hooks
Equipment Supports
Farm Buildings
Farm Implements
Fasteners
Feeding Equipment
Fencing
Gates
Grain Conveyors
Grain Drying Equipment
Grain Elevators
Grain Hoppers
Grain Mixing Equipment
Grating
Growing Racks
High Speed Freezing Equipment
Irrigation Equipment
Light Poles
Meat Conveyors
Panels
Power Take-off Shifts
Pre-engineered Buildings
Processing Equipment
Railings
Refrigeration Brackets
Refrigeration Shelves
Side Frames
Silo Extraction Equipment
Slotted Floors
Stanchions
Steel Bands
Sub-station Structures
Supporting Structures
Tractor Parts
Trailers
Transmission Poles
Truss Plates
Vegetable Washing Machine



Veterinary Equipment
Waste Conveyor Systems
Waste Handling Equipment Pumps
Watering Troughs
Wheel Tractor Hubs
Window Frames

Petrochemical & Chemical

Ambient Temperature Ducts
Anchor Bolts
Beams
Belt Guards
Cathodic Protection Rectifiers
Catwalks
Checkeder Plate
Cogeneration Equipment
Columns
Conveyor Systems
Cooling Tower Structure
Crane Supports
Cross-bracing
Decks
Drain Pipes
Drive Piling
Electrical Cable Ducts
Electrical Conduits
Embedded Items
Equipment Guards
Equipment Screens
Fasteners
Fencing
Fire Extinguishing Equipment
Flare Towers
Flat Plates
Girts
Gratings
Handrails
Heat Exchanger Tubing
Ladders
Marine Terminal Structures
Off-shore Structures
Outside Switch Gear Frames
Pipe Bridges
Pipe Racks
Pipe Supports
Pipeways
Platforms
Precipitator Structure
Prefab Building Structures
Process Equipment Skids
Process Piping
Process Vessels
Purlins
Railings
Safety Equipment
Sag Rods
Scuppers
Stairways
Stringers
Transmission Poles
Walkways
Wastewater Treatment Equipment

Pulp and Paper

Anchor Bolts



Benches
 Bleach Plant Structures
 Boiler Recovery Structures
 Bollards
 Bolts
 Brick Ledges
 Brick Ties
 Cable Tensioning Clips
 Cable Trays
 Canopy Supports
 Catwalks
 Conduit Bridges
 Conveyor Assemblies
 Conveyor Supports
 Crane Support Steel
 Cranes
 Cross-braces
 Curbing Angles
 Dam Gates
 Dock Levelers
 Drain Pipes
 Drive Piling
 Electrical Conduits
 Electrical Penetration Seals
 Elevated Tank Platforms
 Equipment Bridges
 Equipment Screens
 Fencing
 Fire Extinguisher Piping
 Fire Escapes
 Fire Ladders
 Flagpoles
 Floor Seals
 Floor Support Steel
 Foot Bridges
 Gas Sub-stations
 Gates
 Girts

Gratings

Guardrail
 Handrails
 Hangers
 Hatch Covers
 HVAC Support Steel
 Kick-plates
 Leveling Plates
 Lighting Towers
 Lightning Rods
 Lime Kiln Structural Steel
 Lintels
 Louvers
 Manhole Covers
 Microwave Towers
 Non-insulated Pipe Bridges

Pipe Bridges
 Pipe Sleeves
 Pipe Stanchions
 Plates
 Platforms
 Pollution Control Structures
 Power Distribution Towers
 Power Line Transmission Towers
 Power Sub-stations
 Pre-engineered Structures
 Purlins
 Reinforcing Mesh
 Reinforcing Steel
 Relieving Angles
 Roof Hatches
 Safety Cages
 Safety Guards
 Safety Railings
 Scale Equipment
 Screen Room Structural Steel
 Scuppers
 Sheet Piling
 Sign Supports
 Stack Supports
 Stair Stringers
 Stairways
 Steel Pipe
 Structural Steel
 Tank Supports
 Trash Containers
 Trash Racks
 Trench Edging
 Tunnel Liners
 Utility Covers
 Vehicle Washing Equipment
 Waste Water Digesters Support Steel
 Window Washing Rails
 Wood Yard Conveyor Structures

Original Equipment Manufacturing

Amusement Rides
 Antennas
 Bicycle Racks
 Boat Anchors
 Boat Stabilizers
 Boat Trailers
 Bolts
 Buckets
 Cable Drums
 Cable Trays
 Car Parts
 Cellar Doors
 Conduit
 Cooling Tower Parts
 Dock Hardware
 Dock Levelers
 Dumpsters
 Electrical Enclosures
 Fencing
 Flagpoles
 Frames
 Garbage Cans
 Grating
 Guardrail
 Handrails

Hardware Items
 Industrial Trolley Caster Frames
 Light Brackets
 Light Duty Vehicle Ramps
 Light Poles
 Microwave Mounts
 Nails
 Net Reels
 Park Benches
 Picnic Table Frames
 Pipe Hangars
 Portable Building Frames
 Refrigeration Brackets
 Refrigeration Shelves
 Scaffolding
 Scales
 Security Cage Frames
 Security Gates
 Spiral Staircases
 Storm Shelters
 Towers
 Trailer Door Hardware
 Trash Receptacles
 Truck Parts
 Utility Trailers
 Wheelbarrows





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