Duplex Systems

Painting Over Hot-Dip Galvanized Steel

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# DUPLEX SYSTEMS:
## Painting Over Hot-dip Galvanized Steel

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INTRODUCTION

For years, protecting steel from corrosion typically involved either the use of hot-dip galvanizing or some type of paint system. However, more and more corrosion specialists are utilizing both methods of corrosion protection in what is commonly referred to as a duplex system. A duplex system is simply painting or powder coating steel that has been hot-dip galvanized after fabrication. When paint and hot-dip galvanizing are used together, the corrosion protection is superior to either protection system used alone.

Painting galvanized steel requires careful preparation and a good understanding of both painting and galvanizing. Many products have been galvanized and painted successfully for decades; two examples are automobiles and radio towers. Past experience provides excellent historical data for how best to achieve good paint adhesion. Studying past adhesion failures and successes led galvanizers, paint companies, researchers, paint contractors, and other sources to create ASTM specification D 6386, Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting. When the galvanized surface is prepared correctly, paint adhesion is excellent and the duplex system becomes a highly successful method of corrosion protection.

HOW A DUPEX SYSTEM WORKS

Before deciding how to protect steel from corrosion, it is important to understand how steel corrodes. Corrosion takes place because of differences in electrical potential between small areas on the steel surface that become anodic and cathodic. When an electrolyte connects the anodes to the cathodes, a corrosion cell is created. Moisture in the air forming condensation on the steel surface is the most common electrolyte. In the electrolyte, a small electrical current begins to flow. The iron ions produced at the anode combine with the environment to form the loose, flaky iron oxide known as rust.

In order to protect steel from corrosion, something must interfere with the corrosion cell, either by blocking the electrolyte or by becoming the anode. Two common methods of corrosion protection are cathodic protection (the formation of another anode) and barrier protection (blocking the electrolyte from the steel surface). Hot-dip galvanizing alone affords both types of protection, and painting over hot-dip galvanizing adds an additional barrier layer on top of the zinc coating.

Cathodic Protection

Cathodic protection, also referred to as sacrificial protection, is based on the knowledge that anodic metals have a greater tendency to lose electrons than more noble metals. Metals are ranked in order of their susceptibility to corrosion, with the less noble, anodic metals, listed higher in the galvanic series than the more noble, cathodic metals (see Figure 1, next page). For example, zinc is more anodic than iron. When zinc and steel are connected in the presence of an electrolyte, the zinc becomes the anode in the corrosion cell and is slowly consumed, while the steel acts as the cathode and is protected. By providing cathodic protection, a galvanized coating is able to offer protection where small areas of steel are exposed, such as at scratches, drill holes, or cut edges. The zinc provides cathodic protection through decades of exposure until all the zinc is sacrificed.
Barrier Protection

Barrier protection prevents corrosion simply by isolating the steel from the environment and potential electrolytes. The thicker, more dense a barrier coating is, the better protection that is provided. Without cathodic protection, a barrier system only lasts as long as the coating stays intact and impenetrable. An incomplete or compromised barrier coating allows steel to rust in the exposed area. The rust will undercut the barrier coating near the exposed area and eventually cause failure of the barrier protection.

COATING CHARACTERISTICS

The corrosion protection characteristics of hot-dip galvanizing and paint largely affect how the two coatings will perform as a duplex system. Understanding the nature of both coatings helps ensure the success of a duplex system.

Hot-dip Galvanizing After Fabrication

The two major types of hot-dip galvanizing are after-fabrication and continuous sheet. Continuous sheet galvanizing involves sheet steel that is galvanized in coils and then fabricated into products. After-fabrication galvanizing involves steel that has been fabricated into parts and then galvanized. These two types of galvanizing have very different characteristics and should not be considered interchangeable. All the information in this publication pertains to materials that are hot-dip galvanized after-fabrication, according to ASTM A 123, Zinc (Hot-Dip Galvanized) Coating on Iron and Steel Products, and A 153, Zinc Coating (Hot-Dip) on Iron and Steel Hardware.

After-fabrication hot-dip galvanizing is the factory-controlled process of dipping properly cleaned steel into a bath of molten zinc. Prior to immersion in the zinc, the steel is thoroughly cleaned in both alkaline and acid baths. Zinc will not adhere to dirty steel, so the integrity of the coating is immediately apparent as the steel is removed from the galvanizing bath.

The galvanized coating is metallurgically bonded to the steel through a series of zinc-iron alloy layers capped by a free zinc layer. A galvanized coating is more than just a barrier coating; it actually becomes part of the steel surface and is anodic to the steel substrate.

Because zinc readily reacts with the atmosphere, the galvanized coating is constantly changing. Zinc reacts with the environment to form zinc oxide, zinc hydroxide, and zinc carbonate. These zinc reaction products are known as the zinc patina. The zinc patina actually helps protect the galvanized coating, by providing additional corrosion protection. These changes and reaction on the surface of the coating affect how paint will adhere to the galvanized surface.

Paint

Painting steel provides a barrier film between the steel and the environment. A paint system involves the use of several layers of coating, and...
sometimes, different formulations of paint, depending on the type of environment in which the structure will be exposed.

The most important factor for the success of paint systems are adhesion and continuity. If paint does not adhere to the steel, it cannot protect it from the corrosive effects of the environment. Surface preparation is extremely important because the degree of paint adhesion may not be apparent immediately after application. Only after a few months in the field may poor surface preparation manifest itself in paint failure. Having a clean, properly prepared surface helps ensure that the full potential of the paint system is realized. This is especially true about duplex systems.

Continuity of the paint systems is extremely important for carbon steel, since pinholes and other imperfections quickly become rust pits. However, continuity is not as important in a duplex system because the zinc coating will not allow the steel to rust at these sites.

Synergistic Effect

When hot-dip galvanized steel is painted, the duplex system provides a more sophisticated manner of corrosion protection known as the synergistic effect. The galvanized coating protects the base steel, supplying cathodic and barrier protection. Paint, in turn, grants barrier protection to the galvanized coating. The paint slows down the rate at which the zinc is consumed, greatly extending the life of the galvanized steel. In return, once the paint has been weathered down or damaged, the zinc is still available to provide cathodic and barrier protection. When ungalvanized, painted steel corrodes, voluminous rust grows under the paint and eventually causes the paint to peel (see Figure 2, below). However, if the steel is galvanized, the zinc corrosion is minimal and the paint peeling is reduced, thereby greatly increasing the life of the structure.

One of the most frequent reasons for paint failure is discontinuity (pinholes) in the paint coating. A galvanized coating will eliminate early rusting at pinholes, and thus, the life of the steel product is greatly increased.

The synergistic effect is particularly important at edges and corners, where galvanized coatings are often thicker due to the diffusion reaction between zinc and the base steel (see figure 3, below).

A duplex system affords greater corrosion protection than paint or hot-dip galvanized can provide alone. In fact, many tests have shown that a duplex system lasts from 1.5 to 2.5 times the normal combined life of both zinc and the paint systems. A periodic maintenance schedule can extend this synergistic lifetime even longer.

WHY USE A DUPILEX SYSTEM

Each individual project raises unique reasons as to why a duplex system should be utilized, and the advantages for choosing to do so are many.
Extended Corrosion Resistance

The most obvious and most important reason for using a duplex system is the added corrosion protection it provides. Other corrosion protection system cannot match the corrosion resistance provided by painting over hot-dip galvanized steel.

Synergistic Effect

It’s typical for a duplex system to provide corrosion protection 1.5 to 2.5 times longer than the sum of the lifetime of zinc or paint used individually. For example, if a galvanized coating is expected to be maintenance-free for 40 years and a paint system is expected to last ten years, galvanizing and paint combined should protect the substrate steel for at least 75 years, or 1.5 times the sum of both systems.

Economic Benefit

Because duplex systems greatly extend the service life of a product, maintenance costs are significantly decreased. Additionally, a product lasts longer before it must be replaced, thus decreasing the life-cycle cost. The cost of a product that has been protected by galvanizing and painting is lower over the entire life of the product than most single system methods of corrosion protection.

Ease of Repainting

As the paint film weathers, the zinc in the galvanized coating is present to provide both cathodic and barrier protection until the structure is repainted. The exposed zinc surface then can be repainted with minimal surface preparation.

Aesthetics

Galvanizing has an attractive metallic-gray appearance suitable for a myriad of applications, but painting can offer aesthetic advantages. One might choose to paint over a galvanized coating so that a project matches its specific environment—such as a stadium, theme park, or natural habitat.

Safety Marking

A duplex system of galvanized steel and paint may be used to conform to safety regulations. For example, the Federal Aviation Administration (FAA) requires structures over 200 feet tall to be painted in the alternating pattern of white and international orange.

Color Coding

Painting over galvanized steel also increases safety in many environments by color-coding gas, steam, or chemical pipes, identifying hazardous work areas and walkways, and marking high-voltage electrical lines and equipment.

Extend Life of Previously Galvanized Steel

Paint is a logical choice to extend the life of galvanized structures once the zinc coating has substantially and naturally weathered away. Instead of being completely replaced, the galvanized structure can easily be painted, extending its useful life. Organic zinc-rich paints are specifically suited to this application.

Repair of Hot-dip Galvanized Steel

Zinc-rich paints can also be used to touch-up and repair damaged areas on a galvanized coating in order to comply with ASTM A 780, Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings. Repairing a galvanized coating will significantly extend the useful life of a product.
HOW TO SPECIFY HOT-DIP GALVANIZED STEEL FOR PAINTING/PowDER COATING

Surface Characteristics of Galvanized Steel

The surface chemistry of galvanized steel differs depending on the age of the coating, which dictates the surface preparation required. ASTM D 6386 provides detailed surface preparation techniques for all ages of galvanized steel.

As a galvanized coating begins to age, its appearance changes. Gradually, the zinc reacts with the atmosphere to form the patina of zinc oxide, zinc hydroxide, and zinc carbonate. As the patina forms, the coating slowly begins to take on a matte gray finish. Although the zinc begins reacting with the environment immediately upon removal from the galvanizing bath, the zinc patina can take up to two years to completely form, depending on the characteristics of its environment, (humidity, moisture, chlorides, etc).

The zinc patina has different characteristics at each stage of its formation, and thus must be treated differently when preparing hot-dip galvanized steel for painting. After galvanizing, the top layer of zinc combines with oxygen and moisture to form particulates of zinc oxide and zinc hydroxide. These particulates are loosely attached to the zinc metal and can be dissolved in water. If paint is applied to the galvanized coating when these particles are on the surface, the paint may experience adhesion problems over time, as the particles detach from the zinc surface.

When the full zinc patina has formed—after about one to two years of exposure to the atmosphere—the surface becomes a thin, solid film. This film is a mixture of zinc oxide, zinc hydroxide, and zinc carbonate, which cannot be dissolved in water and adheres very tightly to the zinc metal. Paint can be applied directly onto this clean surface and exhibit excellent adhesion.

Most people paint galvanized steel during the most difficult time period to do so—between 48 hours and one year after galvanizing. During this time frame, zinc is very reactive with the atmosphere and proper surface preparation is critical. Successful surface preparation—including the removal of loose zinc oxide or zinc hydroxide particles—will prevent adhesion problems from occurring.

Post-Treatments for Galvanized Steel

After a piece of steel has been galvanized, it is sometimes quenched or treated by the galvanizer in order to halt the reaction between the iron and zinc (and to facilitate immediate shipment of the galvanized steel). The most common post-treatments are water-quenching, chromate-quenching, and phosphating. Both quenching methods (water and chromate) can adversely affect the bond between the galvanized steel and the paint; communicating with the galvanizer prior to galvanizing helps avoid post-treatments that can be detrimental to paint adhesion.

Paint Selection

A partial listing of available paint, paint systems, and powder coatings that are compatible with galvanizing are listed in the following table (see table 1, next page). The paint manufacturer can provide more thorough information about the compatibility of specific systems with galvanized steel. Always consult the paint manufacturer prior to painting galvanized steel. Different physical and chemical characteristics for the same types of paint may have varied reactions with a galvanized surface. The paint manufacturer and galvanizer can assist in the creation of a successful duplex system.

Use of post-treatments, such as water-quenching, can undermine the success of a duplex system by causing adhesion failure.
CONCLUSION

Duplex systems generally perform extremely well when care is taken with surface preparation and paint selection. Be sure to take the following simple, logical steps to ensure a successful duplex system:

Let your galvanizer know your steel is to be painted. This will facilitate proper surface preparation—such as making sure the steel is not quenched after galvanizing and any coating imperfections are remedied.

Take the time to correctly determine the age and characteristics of the galvanized coating. Duplex systems require proper surface preparation, and newly galvanized, partially weathered, and fully weathered galvanized steel each require different methods and amounts of surface preparation.

Proper cleaning and profiling is key prior to painting. Be sure to choose the cleaning and profiling methods appropriate to your situation, closely following the recommended guidelines.

Select a paint system that is compatible with the galvanized coating on the steel.

Discuss coating characteristics with the galvanizer, and always consult the paint manufacturer prior to painting galvanized steel.

As with any paint system, proper surface preparation of the hot-dip galvanized coating to be painted is critical. The combination of the zinc of the galvanized coating and paint synergistically provides an excellent corrosion prevention system that has been utilized for over 40 years.

Newly galvanized steel (above) typically exhibits a bright, shiny appearance. Weathered galvanized steel (below) usually possesses a dull, mottled gray appearance.
**DUPLEX SYSTEMS IN ACTION**

**Grantville Station**

Grantville Station is a highly visible and heavily trafficked trolley station in the Mission Valley area of San Diego. The station is located in an urban area and a marine environment, so it is exposed to many corrosive elements such as exhaust from vehicles and the salt air from the proximity to the ocean. The engineer selected a duplex system of hot-dip galvanizing and paint to protect the spiral stairs, shade canopies, and pedestrian restraints from corrosion. The combination of galvanizing and paint will provide steel corrosion protection up to 2.5 times longer than the sum of a galvanized or painted structure alone.

The structural systems are constructed of pipe and tube brace frames and wide-flange moment frames. Galvanized in 2004, the structure required special venting and care during the HDG process because of the complexity and size of the very large prefabricated sections. Furthermore, because the steel was specified for a duplex system, a smooth finish was required for the paint coating.

With the long-term corrosion protection the zinc coating provides to the duplex system, Grantville Station will be able to withstand the corrosive elements of the city and marine environment. This will allow the station to remain an attractive showpiece for the city of San Diego and the hot-dip galvanizing industry for many years to come.

**Germantown Avenue Bridge**

The Germantown Avenue Bridge located in Philadelphia was built in 2003. Although the bridge contains over 40 tons of hot-dip galvanized open floor deck grating, covered by cedar planking, the focus of the bridge is the 25 tons of duplex coated railing. The powder coating duplex system was specified partially because of the positive results of a nearby duplex coated bridge. However, the duplex system was ultimately chosen because the city of Philadelphia and the surrounding Chestnut Hill community desired a long-lasting and aesthetically appealing bridge and they had high expectation that a duplex system would provide a corrosion-free structure.

Because of the extreme public visibility of the bridge and the desire for an aesthetically pleasing structure, it was important that the bridge and the railing be flawless. The galvanizer and fabricator worked diligently to ensure the fabricated handrail was best suited for galvanizing, because any imperfections in the handrail welds, bends, etc. would be magnified by the zinc coating of hot-dip galvanizing, and further highlighted by the powder coating applied over the zinc.

The quality control and inspection of this project were superior, and the Germantown Avenue Bridge is now in place for all of the residents of Philadelphia to admire.
DUPLEX SYSTEMS IN ACTION

Skaneateles Community Center  Skaneateles, NY

The Skaneateles Community Center is located in an affluent community along Skaneateles Lake in Skaneateles, New York. The community center was designed to give the residents a place for winter activities and keep “cabin fever” to a minimum. The center contains an ice skating rink, pool, meeting rooms, game rooms, basketball courts, and a cafeteria. The architect wanted a uniform appearance that flowed from the humid indoor pool area to the cool ice rink, while the owner wanted a long-lasting center that could withstand the constant traffic of excited children. The architect specified a duplex system of hot-dip galvanized steel for its corrosion performance in the humid, acidic (chlorine) pool area and in the low temperature of the ice rink, and paint to maintain a uniform appearance throughout the center.

All of the railings were galvanized and then painted, and other structural components were galvanized as well. Because of the high visibility and heavy traffic of the railings, all the galvanized material required a very smooth finish to prepare for the paint coating.

The durability the duplex coating provides will give the Skaneateles community a long-lasting, corrosion-free center to cherish for many years into the future.

Kanawha RTA Trolley Bus  Charleston, WV

The Kanawha Regional Transit Authority (KRTA) had been experiencing severe corroding of the frame and superstructure of their trolley buses. The frames and superstructures of the buses had been painted, and the harsh winters and road salts used in the area were causing serious, unsightly corrosion. However, the wheel wells, which had been galvanized and arguably had the most exposure to the salt spray, had only minimal deterioration. Taking this into account, the KRTA decided to independently research the performance of hot-dip galvanized steel and found it to be the best solution to the corrosion problem on its trolley buses.

The decorative skin, windows, rails, steps, landings, and wood accessories were removed from the buses, and a new frame and superstructure were fabricated. Then the pieces were hot-dip galvanized for corrosion protection, and painted for aesthetic appeal. The frames and superstructure required special care to avoid any warping and distortion so the doors, windows, steps, landings, exterior wood panels, and other accessories could be reused and reinstalled on the buses.

Although very little of the duplex system area is visible, the duplex coating will make the trolley buses more durable, providing low-maintenance costs for the KRTA, and give the public a unique, visually appealing mode of transportation for generations to come.
RELATED SPECIFICATIONS

American Society for Testing and Materials (ASTM)
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A 123 Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
A 780 Specification for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
B 201 Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces
D 6386 Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting
E 376 Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Test Methods

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G 164-M Hot Dip Galvanizing of Irregularly Shaped Articles

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Surface Preparation Specification No. 1 Solvent Cleaning
Surface Preparation Specification No. 2 Hand Tool Cleaning
Surface Preparation Specification No. 3 Power Tool Cleaning
Surface Preparation Specification No. 7 Brush-Off Blast Cleaning
Paint Specification No. 27 Basic Zinc Chromate-Vinyl Butyrol Wash Primer

Related Materials

Corrosion and Electrochemistry of Zinc,
Duplex Systems,
Suggested Specification for Painting over Hot Dip Galvanized Steel,
American Galvanizers Association, Centennial, Colorado, 1998
Wet Storage Stain,
American Galvanizers Association, Centennial, Colorado, 1997