Duplex Systems

Painting over Hot-Dip Galvanized Steel

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A playful, brightly colored duplex sign marking the entry to Paige Memorial Park in Boston, Massachusetts

INTRODUCTION

Though many specifiers are familiar with one type of corrosion protection or another, few realize the intrinsic value of utilizing two corrosion protection systems together, known as a duplex system. A duplex system is formed by painting or powder coating over hot-dip galvanized steel. When used together, the corrosion protection of the two systems combined is far superior to either protection system used independently.

Painting or powder coating hot-dip galvanized steel requires careful preparation and a good understanding of both systems. Many products have utilized a duplex system successfully for decades; automobiles and radio towers are two examples. When the galvanized surface is prepared correctly, paint and powder coating adhesion is excellent, and the duplex system becomes a highly successful method of corrosion protection. However, it is important to execute proper preparation to ensure this success.

Past experience provides excellent historical data for how best to achieve good paint or powder coating adhesion. Studying past adhesion failures and successes led galvanizers, paint companies, researchers, paint contractors, and other sources to create the specification ASTM D6386, *Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting,* and begin drafting a specification on preparing galvanized surfaces for powder coating.

HOW A DUPLEX SYSTEM WORKS

Before deciding how to protect steel from corrosion, it is important to understand how steel corrodes. Rust, iron's corrosion product, occurs because of differences in electrical potential between small areas on the steel surface involving anodes, cathodes, and an electrolyte (a medium for conducting ions). When an electrolyte, such as water touching the steel surface, connects the anodes to the cathodes, a corrosion cell is created. This results in a 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 barrier protection (blocking the electrolyte from the steel surface) and cathodic protection (the formation of another anode). Hot-dip galvanizing alone affords both types of protection; but painting or powder coating over hot-dip galvanizing creates an additional barrier layer on top of the zinc coating.

With thousands of cheering fans filling the Girard High School stadium every week, hot-dip galvanized steel was an ideal choice to protect the stadium from corrosion. The duplex system of paint over hot-dip galvanized steel will protect the structure from damaging corrosion, as well as accommodate a paint job featuring their school colors to encourage team spirit.

HOT-DIP GALVANIZING AFTER FABRICATION

After-fabrication hot-dip galvanizing is the process of dipping steel pieces into a molten zinc bath, creating a metallurgical reaction between iron and zinc. Prior to immersion in the zinc, the steel is thoroughly cleaned in both alkaline and acid baths. Zinc will not react with unclean 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, meaning the zinc coating is more than just a barrier coating; it actually becomes part of the steel and protects the substrate steel cathodically.

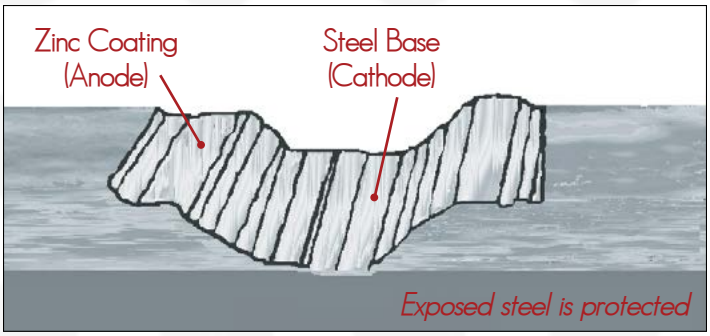
Barrier Protection

Barrier protection prevents corrosion simply by isolating the steel from the environment and potential electrolytes. The thicker or more dense a barrier coating is, the better the protection. 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. The undercutting of rust does not occur when the barrier coating has been applied over a galvanized coating.

Cathodic Protection

Cathodic protection, also referred to as sacrificial protection, is based on the knowledge 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.

For example, zinc is more anodic than iron; therefore, when zinc and steel are connected in the presence of an electrolyte, the zinc becomes the anode in the corrosion cell. As the zinc is slowly consumed, the steel acts as the cathode and is protected. Because of its cathodic protection, a galvanized coating is able to resist corrosion where small areas of steel are exposed, such as at scratches, drill holes, or cut edges.



When a galvanized steel piece is scratched, the zinc in the coating sacrifices itself slowly by galvanic action to protect the base steel. This continues as long as surrounding zinc remains.

Zinc Patina

As the zinc coated pieces are put into use and begin reacting with the atmosphere, the galvanized coating begins developing zinc byproducts (zinc oxide, zinc hydroxide, and zinc carbonate) known as the zinc patina. This zinc patina actually provides another layer of protection for the galvanized coating. These zinc byproducts affect how paint or powder coating will adhere to the galvanized surface.

COATING CHARACTERISTICS

Paint

Painting 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. Poor surface preparation may only manifest itself in paint failure after a few months in the field, and is evidenced by blistering, peeling, or flaking paint. Having a clean, properly prepared surface helps ensure 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.

Powder Coating

Similar in some ways to painted steel, powder coated steel also provides barrier protection to the substrate steel. The process of powder coating involves covering a surface with powder material, then curing it in an oven to set the finish.

This can be achieved either by spraying electrostatically charged powder onto the piece, or by lowering it into a fluidized bed of powder. Powder coatings can incorporate color or be comprised of various formulations to address specific needs, such as protection from chemicals, abrasion, and ultraviolet rays.

Once coated with powder, the piece is then cured in an oven heated to between 375 F and 400 F to melt, flow together over the piece, gel into a smooth film, and then dry with a firm, durable finish. The final coating can vary from high gloss to matte depending on the formulation of the powder.

As with paint, adhesion is critical to provide a consistent, uniform powder coating free of any sags, drips, runs or bubbles. Though it is not metallurgically bonded to the metal, a powder coating installed with care and regularly maintained will not crack, chip, or peel as paint can.

Case Study

Fenway Park Right Field Stands
Boston, Massachusetts

Over 3 million people a year eat, cry, stomp, and spill beer on the stands at Fenway Park, so protecting the appearance and structural safety of the stands is a critical priority.

When the time came to refurbish the right field stands of the stadium, there was obvious pressure to match the historic Fenway Park green, as well as the challenge of a tight between-season deadline. To meet these dual needs, a duplex system utilizing hot-dip galvanized steel and paint was specified.

Hot-dip galvanizing has been used for all refurbishment projects at Fenway Park, so the choice for corrosion protection was easy to make. The galvanizer was able to successfully dip the large steel structural elements and then perfectly match the stadium paint colors to create an effective and appealing duplex system.

Red Sox fans will not be disappointed with the new look of the stands, and can look forward to even more galvanized steel updates in the future. The owners were so impressed with the performance of the duplex system, they have already specified paint over hot-dip galvanizing for future projects in the off-season. Hot-dip galvanized steel will keep this stadium safe and corrosion-free for many seasons to come.

Synergistic Effect

When hot-dip galvanized steel is painted or powder coated, the duplex system provides a more sophisticated manner of corrosion protection known as the synergistic effect. Used independently, both paint/powder coatings and galvanizing provide corrosion protection to steel; however, when utilized together, the two coatings work in synergy.

The exterior layer of paint or powder coating slows down the rate at which the zinc is consumed, greatly extending the life of the galvanized steel. In return, once the exterior layer has been weathered down or damaged, the zinc beneath is still available to provide cathodic and barrier protection.

As a result, the substrate steel is afforded corrosion protection for 1.5 to 2.3 times the sum of the expected life of each system alone. For example, if a galvanized coating alone on black steel would provide 50 years of maintenance-free protection and a paint coating would not require any maintenance for 10 years, the combination duplex system would provide maintenance-free protection for 90 to 138 years in the same environment. A periodic maintenance schedule can extend this synergistic lifetime even longer.

In mathematical form, the synergistic effect would be defined:

$$M_{duplex} = 1.5 \text{ to } 2.3 (M_{galvanizing} + M_{paint})$$

M = time to first maintenance

This equation assumes no maintenance will be performed on the paint or powder coating, and as it naturally wears away, the underlying galvanizing would provide the majority of the corrosion protection. Likely, however, the owner will maintain the paint system for aesthetics. Therefore, the synergistic effect is realized in the delayed maintenance cycle (touch-up, maintenance repaint, and full repaint) of the paint/powder coating of the duplex system.

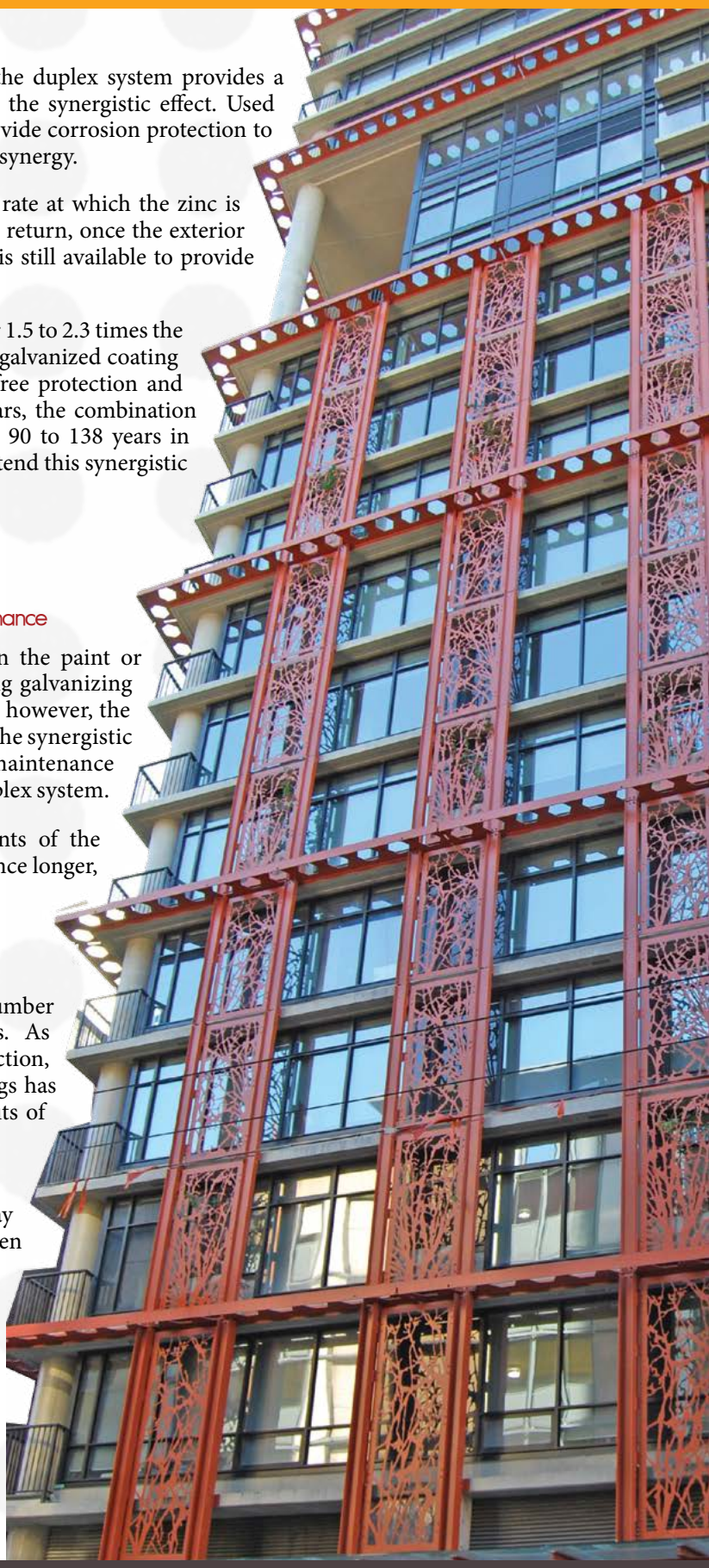
This delay of 1.5 to 2.3 times for each of the three elements of the maintenance cycle means holding capital set aside for maintenance longer, and fewer maintenance cycles over the life of the project.

WHY USE A DUPLEX SYSTEM?

In addition to the synergistic effect (detailed above), there are a number of other reasons why utilizing a duplex system is advantageous. As more specifiers understand the importance of corrosion protection, galvanized steel used in conjunction with paint/powder coatings has risen. In addition to extended life, here are some other benefits of specifying a duplex system.

Aesthetics

Hot-dip galvanized steel provides an attractive, metallic-gray finish many specifiers have come to appreciate. However, when the industrial finish of galvanizing does not suit a particular project, painting or powder coating can offer an aesthetic alternative. Whether the architect prefers a vibrant color, or the owner prefers the project blend with its surrounding environment, painting or powder coating over galvanized steel provides superior corrosion protection along with the color preference. Duplex systems are becoming a common trend in university and professional stadiums as the top coat provides team branding, and the underlying galvanized steel provides the corrosion protection and service life required.



Color Coding/Safety

A duplex system also may be used to conform to safety regulations. Duplexing increases safety in many environments by enabling color-coding of gas, steam, or chemical pipes, identifying hazardous work areas and walkways, and marking high-voltage electrical lines and equipment. 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. Duplexing these types of projects ensures the proper color coding is in place without sacrificing corrosion protection on often difficult to maintain structures.

Galvanized pipes can be painted or powder coated for safety. Because pieces are totally immersed during the galvanizing process, the zinc will protect the pipes inside and out.

Extended Corrosion Resistance

Because of the synergy between paint/powder coatings and galvanizing provide, an obvious and important reason for specifying duplex systems is the added corrosion protection it provides. In harsh environments where galvanizing or paint/powder coatings alone have difficulty protecting steel, utilizing a duplex system can provide the necessary corrosion resistance.

In addition to extended corrosion resistance initially, employing a duplex system to a galvanized structure already in place is a great way to extend its service life. Hot-dip galvanized steel, which provides decades of maintenance-free longevity on its own, often outlasts the design life of the project for which it is specified. However, at times, a galvanized structure reaches the point where maintenance is needed to prolong the life of the project. As regalvanizing would require disassembly of the structure, adding a duplex system in the field is a much more viable option. In this instance, it would be best to touch-up and repair any areas of the galvanized coating where corrosion has begun with a zinc-rich paint, solder, or metallizing as outlined in the specification ASTM A780 *Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanizing*. Then, apply a one or two coat paint system to the structure.

Ease of Repainting

As outlined in the synergistic effect section, an important advantage of painting over galvanizing is the extension of the maintenance cycle. In addition to an extended maintenance-cycle, painting on a galvanized surface also facilitates the maintenance 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.

Applying a coat of paint.

Ease of Powder Coating Touch-Up

While the substrate galvanized steel will provide both barrier and cathodic protection for decades, similar to paint, the exterior powder coating may, in time, need to have small nicks or scratches touched up. This can be achieved in the field by using automotive touch-up paint, which is both relatively inexpensive and will provide a durable seal. It can, however, be somewhat difficult to match colors exactly using this method.

To apply touch-up paint, the affected area must be prepared by removing a small amount of powder coating surrounding the breach, roughening the metal and adjacent powder coating with a polymer abrasive pad, then wiping away any sanding by-products with an isopropyl alcohol wipe. Then the touch-up material may be applied with a brush application.

Case Study

Center for Great Apes
Wauchula, Florida

With a winding maze of chutes and walkways woven throughout the treetops, the Center for Great Apes is a charitable organization created to provide sanctuary for chimpanzees and orangutans that have retired from the entertainment industry, completed research, or formerly served as pets.

After working in Borneo observing orangutans, Patti Ragan developed a passion for great apes and had the vision and desire to provide long-term care for the animals. Ragan created the facility to provide the animals with a habitat as close to natural as possible. The clinic, night house, and all habitats are connected by a system of chutes and walkways elevated 10 – 15 feet above the ground to give the apes the feeling of traveling through the trees.

The humid coastal environment coupled with abuse from apes scratching and chewing provide extreme challenges for corrosion protection. A duplex system of paint over hot-dip galvanized steel was the ideal solution for the structure as it would blend with the natural environment, without sacrificing long-lasting, maintenance-free durability. Now home to more than 40 great apes, the Center will stand strong and achieve Ragan's dream of an efficient, safe, and happy home for these retired animals.

Economic Benefit

Duplex systems provide tremendous economic advantages because of the extended time to first maintenance and delayed maintenance cycle. Initially, the cost of a duplex system is high because you must pay for both corrosion protection systems. However, because of the synergistic effect the initial premium cost pays off over the life of the project and in the end is less expensive than coating bare steel.

For duplexed projects where the paint/powder system is used strictly to prolong life and the color finish is not critical, the initial cost can also be your final cost. But for most duplex projects, the top coat will be maintained and on these projects, the delayed maintenance cycle can significantly decrease the cost over the life-cycle.

To explore the economic benefits of utilizing a duplex system, consider the following case study of a two-coat paint system on black steel and galvanized steel. The study utilizes nationwide cost data collected from the galvanizing industry and paint manufacturers for initial costs, surface preparation, and maintenance costs.

PROJECT PARAMETERS:

- 50,000 ft^2 (typical mix of structural pieces)
- 60 Year Life
- C3 – Moderately Industrial Environment
- 3% inflation; 4% interest
- Initial Cost Table/Maintenance/Life-Cycle

	INITIAL COST	LIFE-CYCLE COST
Paint over Black Steel	$1.60/ft^2	$801,000[A]
Duplex System	$3.68/ft^2	$493,000[B]

A: Maintenance Cycle - years 11, 14, 20, 31, 34, 40, 51, 54 (8 Touch-ups Total)
B: Maintenance Cycle - years 19, 24, 35, 54, 59 (5 Touch-ups Total)

Figure 1: Economic Comparison Case Study

As *Figure 1* shows, the cost of utilizing a duplex system is more expensive initially than using a paint system alone. However, specifying a duplex system of paint over hot-dip galvanized steel means less money will be spent on maintenance over the life of the structure. As a result, the life-cycle cost of the paint system only is nearly double that of the structure that utilized a duplex system.

The delayed maintenance cycle of the duplex system resulted in three less maintenance cycles during the 60-year life (see *Figure 1*), allowing the owner more time to earn interest on the money, and ultimately providing a 67% return on investment. The initial 'premium' cost of the duplex system pays for itself over the life of the project – delivering maximum value as well as aesthetic appeal. In summation, decreased maintenance costs over the life of the project result in lower life-cycle costs for a structure utilizing a duplex system.

TYPE	COMPATIBILITY	COMMENTS
Acrylics	Sometimes	If the pH of the paint is high, problems may occur due to ammonia reacting with zinc
Aliphatic Polyurethanes	Yes	IF used as a top coat for a polyamide epoxy primer, it is considered a superior duplex system
Bituminous	Yes	Used for parts that are to be buried in soil
Chlorinated Rubbers	Yes	High VOC content has severely limited their availability
Coal Tar Epoxies	Sometimes	Rarely used, only if parts are to be buried in soil
Epoxies	Sometimes	If paint is specifically manufactured for use with galvanized steel
Epoxy-Polyamide Cured	Yes	Has superior adherence to galvanized steel
Latex-Acrylics	Yes	Has the added benefit of being environmentally friendly
Latex-Water-based	Sometimes	Consult paint manufacturer
Oil Base	Sometimes	Consult paint manufacturer
Portland Cement in Oil	Yes	Has superior adherence to galvanized steel
Silicones	No	Not for use directly over galvanized steel, can be beneficial in high temperature systems w/ base coat
Vinyls	Yes	Usually requires profiling, high VOC's have severely limited their availability
Powder Coating	Yes	Low temperature curing powder coatings work exceptionally well over galvanized steel

Figure 2: Galvanizing Compatible Paint & Paint Systems

HOW TO SPECIFY HOT-DIP GALVANIZED STEEL FOR PAINTING/POWDER COATING

Surface Characteristics of Galvanized Steel

The surface chemistry of the zinc byproducts of galvanized steel differs depending on the age of the coating, which dictates the surface preparation required. ASTM D6386 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 or powder coating. 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 an additional duplex coating is applied to the galvanized coating when these particles are on the surface, it may experience adhesion problems over time, as the particles detach from the zinc surface.

When the full zinc patina has formed—after one to two years of exposure in 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. A duplex coating can be applied directly onto this clean zinc patina surface and exhibit excellent adhesion.

Most people paint or powder coat 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 or powder coating adhesion.

Paint Selection

A partial listing of available paint and paint systems compatible with galvanizing are listed in *Figure 2*. 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.

TYPE	COMMENTS
Epoxy	Tough, chemically resistant, poor exterior durability (chalking)
Hybrid	Decorative film performance similar to epoxies, some UV and overbake advantages, not exterior durable
Polyester Urethane	Exterior durable, thin film powder coating
Polyester TGIC	Exterior durable, good edge coverage, approved for thicker films
Acrylic	Excellent weatherability, excellent appearance, good impact resistance

Figure 3: Types of Powder Coating

Powder Coating Selection

As with paint, the powder coating supplier will be able to provide the best information about how to pair specific formulations with galvanized steel. To make the best determination, it is important to outline the requirements for the finished product before selection. For instance, will the piece be constantly exposed to UV rays? What about road salts and chemicals? Test and identify performance challenges before consulting with the supplier to make the best selection.

There are several general types of thermosetting powder to address different specifications. *Figure 3* breaks down the various types of powders and their attributes. Pairing the correct type of coating with the protection of hot-dip galvanized steel will give the piece decades of durability.

Case Study

Thurston Avenue Bridge
Ithaca, New York

Set above a dramatic gorge in the midst of a copse of trees, the Thurston Avenue Bridge is located on the campus of Ivy League school Cornell University in Ithaca, New York.

The renowned school, visited by scholars around the world, is highly visible to the public, and is passed over by up to 8500 vehicles, 950 pedestrians, and 60 bicycles per day.

The city wanted the railings and metal structure of the bridge to complement the LED illuminated railings, as well as blend with the other structural steel used in the bridge. A duplex system of powder coating over hot-dip galvanized steel was implemented to battle the corrosive effects of winter weather and road salts in this upstate New York location.

Hot-dip galvanized steel, which provides decades of maintenance-free longevity on its own, often outlasts the design life of the project for which it is specified—but the combined protection of galvanized steel with powder coating means this bridge will be in service for generations.

CONCLUSION

By taking advantage of the synergistic effect of paint or powder coating over hot-dip galvanized steel, duplexed steel elements take advantage of multiple layers of protection that will extend the life of the piece. The initial barrier protection of the exterior paint or powder coating will serve as a first line of defense, while the hot-dip galvanized steel beneath will utilize barrier, cathodic, and zinc patina protection to keep the piece corrosion free for decades.

To ensure success of the duplex system, be sure to remember the following simple, logical preparation steps.

- 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 ensuring 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 prior to painting or powder coating is key. Be sure to choose the appropriate cleaning and profiling methods, closely following the recommended guidelines.
- Select a paint or powder coating system compatible with the galvanized coating.
- Discuss coating characteristics with the galvanizer, and always consult the manufacturer prior to painting or powder coating galvanized steel.

For more information on preparing galvanized steel for paint, request a copy of either of the AGA's instructional DVDs: ***Guide to Preparing Hot-Dip Galvanized Steel for Paint*** or ***Guide to Preparing Hot-Dip Galvanized Steel for Powder Coating.***

As with any paint or powder coating 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 or powder coating synergistically provides an excellent corrosion prevention system that has been utilized for more than 40 years.

Top: Salvador Dali Museum in St. Petersburg, Florida
Center: Tustin High School Student Quad Plaza in Tustin, California
Bottom: Bridge of Lions in St. Augustine, Florida

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