ZINC COATINGS

A Comparative Analysis of Process and Performance Characteristics

Contents

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Zn

Zinc

INTRODUCTION

Zinc, a natural, healthy, and abundant element was first used in construction in 79 AD; thus, its characteristics as a well-suited corrosion protective coating for iron and steel products has long been known. The 27th most abundant element in the Earth's crust, zinc is naturally present in rocks, soil, air, water, and the biosphere, as well as in plants, animals, and humans. In fact, zinc is essential to life as all organisms require it to survive and complete normal physiological functions.

Today, more than 13 million tons of zinc are produced annually worldwide, 70% from mined ores, and 30% from recycled sources. More than half of the annual production is used in zinc coatings to protect steel from corrosion. Because zinc is an infinitely recyclable material, the level of recycling increases each year, and currently 80% of the zinc available for recycling is indeed reclaimed. However, because of zinc's excellent field performance as a corrosion protection coating, it often remains in service for generations before recycling.

Zinc, like all metals, corrodes when exposed to the atmosphere. However, because of its ability to form dense, adherent corrosion byproducts, the rate of corrosion is considerably lower than ferrous materials (10 to 100 times slower depending on the environment). Zinc corrosion products develop naturally on the surface as the coating is exposed to natural wet and dry cycles in the atmosphere and are often referred to as the zinc patina. The zinc patina acts as an additional barrier between the steel and the environment.

In addition to the natural barrier protection of the coating and patina, zinc also protects the base steel cathodically. The Galvanic Series of Metals (*Figure 1*) lists metals in order of their electrochemical potential in the presence of salt water. When two metals are connected, those higher on the list will become anodic and preferentially corrode to protect metals lower in the series. Therefore, zinc is anodic to steel and will sacrificially corrode to protect the underlying steel from corrosion.

There are a number of zinc coatings which are often generically termed "galvanizing," but each has unique characteristics. These characteristics not only affect applicability, but also economics and performance in the environment. The method of application, adhesion to the base metal, hardness, corrosion resistance, and thickness (*Figure 2*) of each zinc coating varies.

This practical aid examines the following zinc coatings: batch hot-dip galvanizing, continuous sheet galvanizing, zinc painting, zinc spray metallizing, mechanical plating, electrogalvanizing, and zinc plating; to help architects, engineers, and other specifiers assess and select the most suitable zinc coating for corrosion protection.

Arrangement of Metals in Galvanic Series

CORRODED END: Anodic or less noble (ELECTRONEGATIVE)

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

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

PROTECTED END: Cathodic or More Noble (ELECTROPOSITIVE)

Figure 1: Cathodic Protection from Zinc

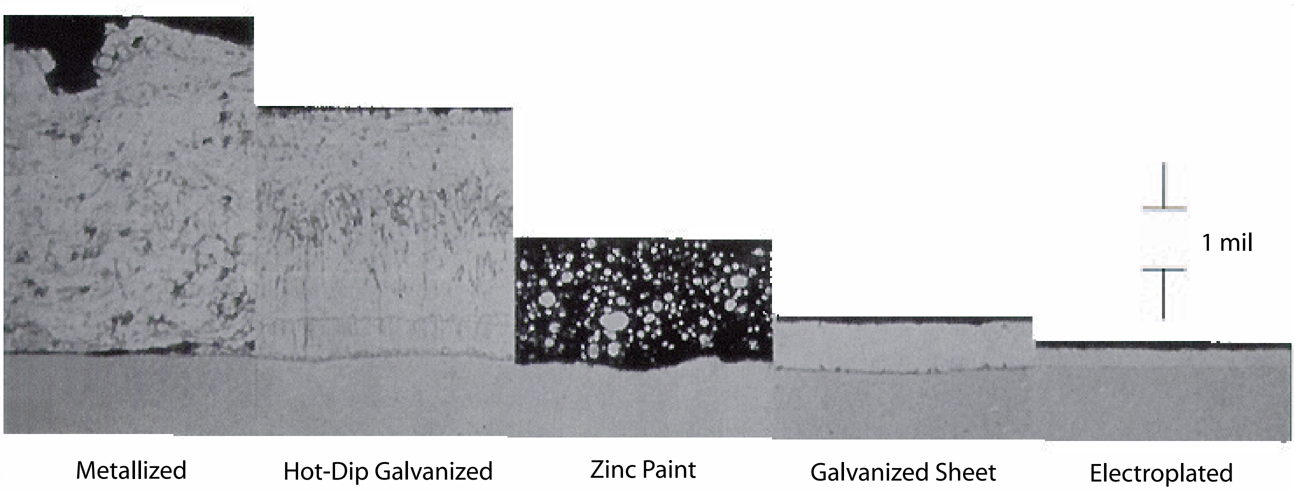

Figure 2: Microstructures of Various Zinc Coatings

BATCH HOT-DIP GALVANIZING

Zinc Application Process

Batch hot-dip galvanizing, also known as general galvanizing, produces a zinc coating by completely immersing the steel product in a bath (kettle) of molten zinc (*Figure 3*). Prior to immersion in the zinc bath, the steel is chemically cleaned to remove all oils, greases, soil, mill scale, and oxides. The surface preparation consists of three steps: degreasing to remove organic contaminants, acid pickling to remove scale and rust, and fluxing, which inhibits oxidation of the steel before dipping in the molten zinc. Surface preparation is critical as the zinc will not react with unclean steel.

After surface preparation, the steel is immersed in the molten (830 F) zinc bath. The bath consists of more than 98% pure zinc and less than 2% additives, most commonly aluminum, nickel, and bismuth, which help with zinc fluidity and consumption, coating appearance, etc. While in the galvanizing kettle, the molten zinc metallurgically reacts with the iron in the steel to form the coating. After removal from the zinc bath, the coating is inspected for conformance to ASTM, CSA, or ISO specifications.

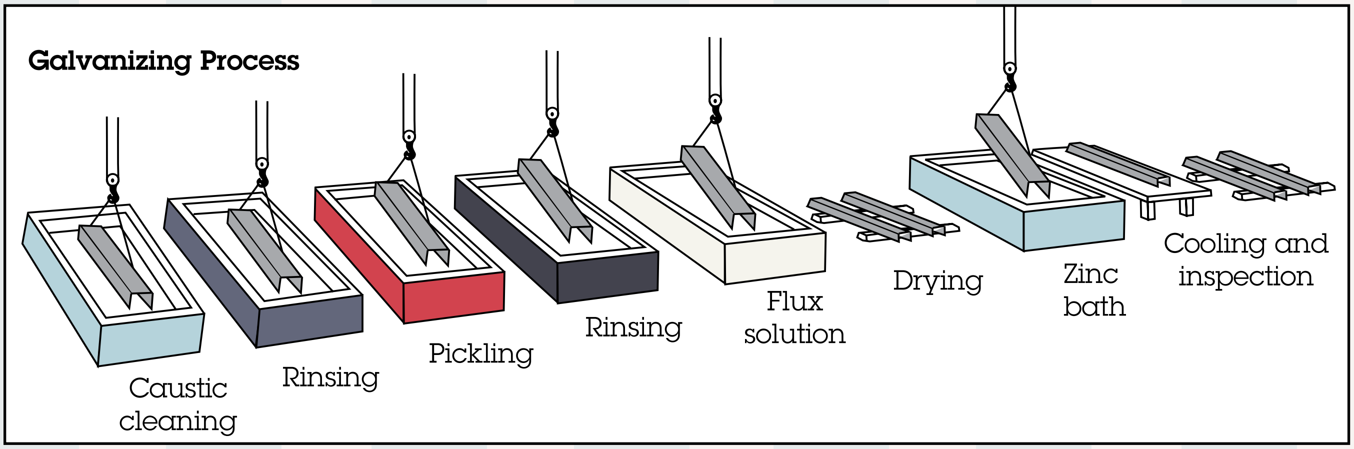

Figure 3: Batch hot-dip galvanizing processes

Coating Characteristics and Performance

The batch hot-dip galvanized coating consists of a series of zinc-iron alloy layers with a surface layer of pure zinc (*Figure 4*). The unique intermetallic layers are tightly bonded (3,600 psi) to and harder than the base steel, offering excellent abrasion resistance. The zinc-iron alloy layers are metallurgically bonded to the steel; and thus, become an integral part of the steel rather than just a surface coating. Furthermore, as mentioned previously, zinc is anodic to steel; therefore, even if the durable intermetallic layers of the hot-dip galvanized coating are damaged (up to ¼" in diameter) adjacent zinc will sacrificially protect the exposed steel until all of the surrounding zinc is consumed.

Another unique characteristic of the batch hot-dip galvanized coating is its uniform, complete coverage. During the diffusion reaction in the kettle, the zinc-iron alloy layers grow perpendicular to all surfaces, ensuring edges, corners, and threads have coating equal to or greater than flat surfaces. Additionally, because hot-dip galvanizing is a total immersion process, all interior surfaces of hollow structures and difficult to access recesses of complex pieces are coated. This complete, uniform coverage means critical points where corrosion commonly occurs are afforded the same protection as accessible flat, exterior surfaces.

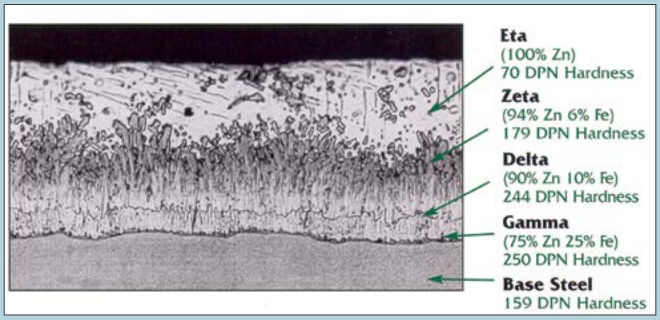

Figure 4: Photomicrograph of a Galvanized Coating

Batch hot-dip galvanizing produces a coating thicker and/or denser than other zinc coating processes. The governing specifications for hot-dip galvanizing; ASTM A123, A153, and A767 as well as CSA specification G 164, and ISO 1461 contain minimum coating thickness

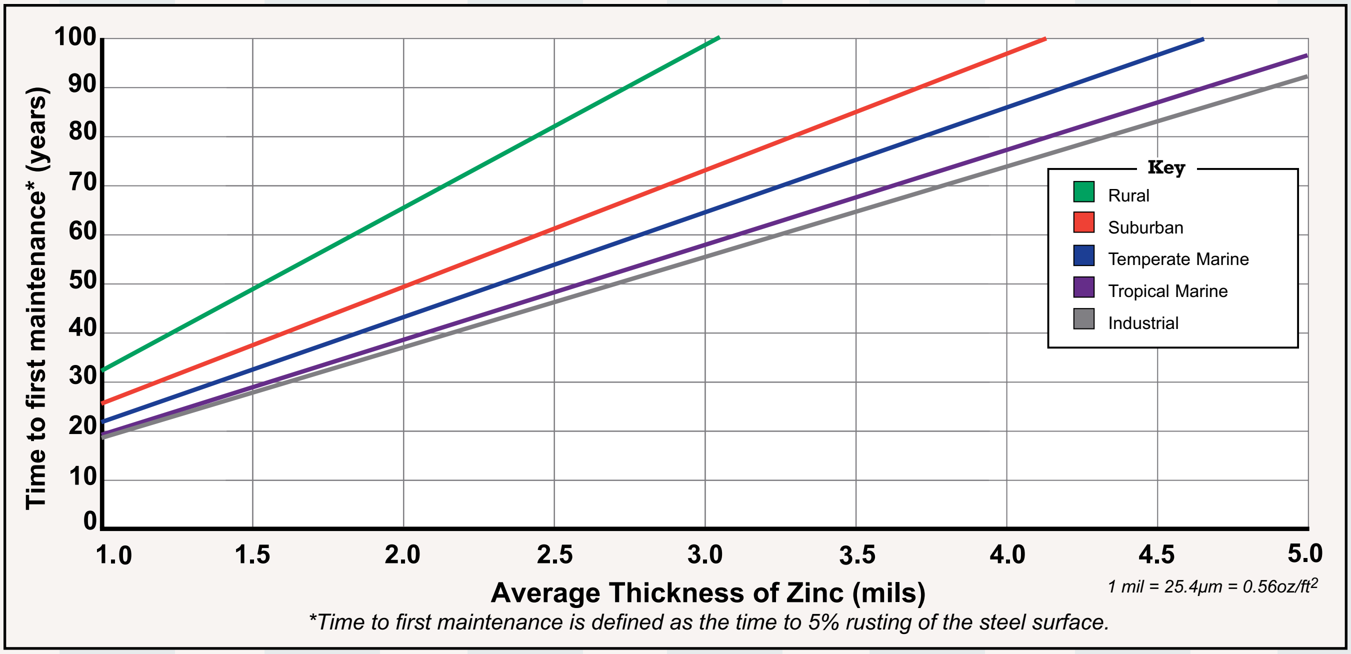

Figure 5: Time to First Maintenance Chart

requirements based on steel type and thickness. The Time to First Maintenance Chart (*Figure 5*) shows the linear relationship between zinc coating thickness and maintenance-free service life. For example, according to ASTM A123, structural steel greater than or equal to ¼ inch thick has a minimum coating requirement of 3.9 mils, which equates to a maintenance-free life of around 72 years in an industrial environment.

Applications/Exposure Conditions

Hot-dip galvanized coatings are used on a multitude of materials in myriad construction sectors from electric utility to artistic sculptures. Ranging in size from small parts such as nuts, bolts, and nails to very large structural shapes, galvanizing is integral to the North American infrastructure. Most commonly batch hot-dip galvanizing is used in atmospherically exposed steel; however, it is also used in fresh and salt water applications, buried in the soil, embedded in concrete, and much more. For more information on the performance of batch hot-dip galvanizing in various environments, see the American Galvanizers Association's publication, *Performance of Hot-Dip Galvanized Steel Products.*

Size can be one limitation to the application of batch hot-dip galvanizing; however, the average length of zinc baths in North America is 40 feet and 55-60 foot kettles are common. Utilizing progressive dipping (immersing one portion of the product and then the other) significantly increases the maximum size that can be accommodated to nearly double the bath size.

BATCH HOT-DIP GALVANIZING SUMMARY

- Factory controlled
- Available 24/7/365
- Complete coverage
- Superior bond to steel
- Coating is harder than the steel
- Good for exterior and interior use

CONTINUOUS SHEET GALVANIZING

Zinc Application Process

Continuous sheet galvanizing is also a hot-dip process, but is only applied to steel sheet, strip, and wire. A coil to coil process, steel sheet from 0.010 to 1.70 inches (0.25 mm to 4.30 mm) thick and up to 72 inches (1,830 mm) wide is passed as a continuous ribbon through cleaning baths and molten zinc at speeds up to 600 feet per minute.

Preparing the steel for the continuous hot-dip coating begins with cleaning in an alkaline liquid combined with brushing, rinsing, and drying. Then, the steel passes into the heating or annealing furnace to soften it and impart the desired strength and formability. In this annealing furnace, the steel is maintained under a reducing gas atmosphere, composed of hydrogen and nitrogen, to remove any oxide that may be on the surface. Just as in the batch process, the steel must be completely clean of oxides and contaminants for a successful coating.

As the steel exits the furnace, it enters into a vacuum chamber, or snout, before entering the molten zinc bath to prevent any air from reoxidizing the heated steel product. The steel is then sent around a submerged roll in the molten bath to create the bonded coating and removed in a vertical direction. As the product is withdrawn from the bath, precisely regulated, high-pressure air (air knife) is used to remove any excess zinc to create a closely controlled coating thickness. The steel is then allowed to cool and solidify before contacting another roll to avoid transferring or damaging the coating.

Today, this continuous hot-dip process is used to make seven different types of sheet products including galvanized (zinc), galvannealed (90-92% zinc/8-10% iron alloy), two alloys of zinc and aluminum (55% aluminum/45% zinc alloy and 95% zinc/5% aluminum alloy), two aluminum based alloys (100% aluminum, 89-95% aluminum/5-11% silicon alloy), and the terne coating (85-97% lead/3-15% tin alloy).

Continuous Sheet Galvanizing				
Coating Grade	Total Both Sides	Per Side		
	oz/ft^2	oz/ft^2	mils	µm
G360	3.60	1.80	3.24	82.3
G300	3.00	1.50	2.70	68.6
G235	2.35	1.18	2.12	53.7
G210	2.10	1.05	1.89	48.0
G185	1.85	0.93	1.67	42.3
G165	1.65	0.83	1.49	37.7
G140	1.40	0.70	1.26	32.0
G115	1.15	0.58	1.04	26.3
G90	0.90	0.45	0.81	20.6
G60	0.60	0.30	0.54	13.7
G40	0.40	0.20	0.36	9.1
G30	0.30	0.15	0.27	6.9
G01	no minimum			
Continuous Sheet Galvanizing: The number following the ‘G’ coating grade designation correlates to the total thickness of zinc applied to both sides of the steel sheet.				

Table 1: Continuous Sheet Galvanizing Thicknesses

Coating Characteristics & Performance

Because both are hot-dip processes, continuous sheet and batch hot-dip galvanizing are often confused. One major difference in the two coatings is the thickness. The continuous sheet galvanizing process has greater control and preciseness when it comes to zinc thickness as the air knife used after galvanizing ensures a uniform thickness across the steel sheet. The coating is mostly unalloyed zinc, though minimal alloy layers are present, and is ductile and able to withstand deep drawing or bending without damage. This is important as the coating is applied prior to final fabrication such as punching, bending, and cutting.

Because of the precise control of coating thickness, continuous sheet is stocked in a variety of coating weights. One of the most common zinc coatings is Class G90, which has 0.9 oz/ft^2 of zinc (total both sides) or about 0.80 mils (20 μm) per side. *Table 1* (page 4) shows the available coating grades of continuous sheet galvanizing.

As mentioned before, service life for all zinc coatings is linear to zinc thickness (*Figure 5*, page 3). Because the continuous sheet coating is applied pre-fabrication, final forming and placement often includes punching holes, bending, cutting, etc., which creates uncoated areas. Like batch hot-dip galvanizing, the surrounding zinc of continuous sheet coatings will provide cathodic protection to these uncoated areas; however, as there is much less zinc present, best practice is to touch up any exposed areas after fabrication to extend service life.

Applications/Exposure Conditions

As the name states, the continuous galvanizing process is only applied to sheet steels. The most common applications are in car bodies, appliances, corrugated roofing and siding, duct work, and culvert pipe. The smooth coating does allow it to be treated for painting, which will increase service life. Because of the relatively thin coating, unpainted continuous sheet galvanizing is recommended for interior applications or where exposure to corrosive elements is mild.

CONTINUOUS SHEET GALVANIZING SUMMARY

- Factory controlled
- Precise and consistent coating thickness
- Interior applications only (unless painted over)
- Available in annealed condition for formability
- Mostly pure zinc coating – softer than steel

ZINC PAINTING

Zinc Application Process

Zinc painting, often erroneously termed cold galvanizing, is the application by brush or spray of zinc dust mixed with organic or inorganic binders. Prior to application, the steel must be cleaned by sand blasting to near white metal (SSPC–SP 10), commercial blast cleaning (SSPC-SP 6) or white metal (SSPC-SP 5). The zinc dust must be mixed with a polymeric-containing vehicle and constantly agitated during application to produce a homogenous mixture and proper adhesion. Zinc-rich paints typically contain 92-95% metallic zinc in dry film. When spray applying, feed lines should be kept as short as possible to prevent settling of zinc dust and uneven film coats. Zinc painting can be applied in either the shop or the field.

Coating Characteristics and Performance

Like all paint coatings, zinc-rich paint is a surface coating, mechanically bonded to the steel at a few hundred pounds per square inch (psi). Zinc-rich paints are either organic, consisting of epoxies, chlorinated hydrocarbons, and other polymers, or inorganic based on organic alkyl silicates. The organic or inorganic paints are applied to a dry film thickness of 2.5 to 3.5 mils. If applied too thick, cracking may occur.

One commonality of all zinc coatings examined thus far is the cathodic protection afforded. Zinc-rich paint coatings are different than the other coatings as there is a binding material used to adhere the zinc particles. For cathodic protection to be possible, the zinc dust must be at a concentration high enough to provide for conductivity between the zinc particles and the steel. This is another reason constant agitation and homogenous mixture is important during application. There is some question as to whether cathodic protection is possible at all if the zinc particles are encapsulated in the binder and the binder is non-conductive.

Inorganic and organic zinc-rich paints vary somewhat in their performance. Inorganic zinc-rich paints, which adhere to the steel with mild chemical reactivity, have good solvent resistance and can withstand temperature up to about 700 F (375 C). Inorganic zinc-rich paints do not chalk, peel, or blister readily, are easy to weld and provide simpler cleanup than organics. The density of inorganic zinc-rich paints are about half the density of zinc per mil of batch hot-dip galvanized coatings.

The properties of organic zinc-rich paints depend on the solvent system. Multiple coats may be applied within 24 hours without cracking. Organic zinc-rich paints do not have the same temperature resistance of inorganic zincs, as they are limited to 200-300 F. They are also subject to ultraviolet (sunlight) degradation, and are not as effective as inorganics in corrosion protection.

Applications

Zinc-rich paint can be applied to steel of any size and shape, though application is difficult on more complex fabrications. Zinc-rich paints are widely used as primers to high-performance two and three coat systems and for touch-up and repair of batch hot-dip galvanized coatings. In mild environments, inorganic zinc paint may be used independently for corrosion protection, but should be top coated in more severe environments to extend service life.

ZINC PAINTING SUMMARY

- In-shop or field application
- Weak bond to steel
- Thinner coating on corners and edges
- Coating thickness consistency depends on skill of application
- Durability depends on zinc content in dry film condition

ZINC SPRAY METALLIZING

Zinc Application Process

Zinc spraying, or metallizing, is accomplished by feeding zinc powder or wire into a heated gun, where it is melted and sprayed onto the part using combustion gases and/or auxiliary compressed air to provide the necessary velocity (*Figure* 6). Prior to metallizing, the steel must be abrasively cleaned.

The 100% zinc coating can be applied in the shop or field, but is more commonly done in the shop where heat for melting is more readily available. The heat is supplied by combustion of an oxygen-fuel gas flame or by electric arc. Processes have been developed for feeding molten zinc directly into the spray nozzle, but only for in shop applications. Following the zinc application, the coating is normally sealed with a low viscosity polyurethane, epoxy-phenolic, epoxy, or vinyl resin.

Coating Characteristics and Performance

The metallized zinc coating is rough and slightly porous, with density about 80% that of batch hot-dip galvanizing. As the metallized coating is exposed to the atmosphere, zinc corrosion products tend to fill the pores providing consistent cathodic protection. Metallizing covers welds, seams, ends, and rivets well and can be applied in excess of 10 mils (254 µm). However, the mechanically-bonded pure zinc coating can be inconsistent and requires a skilled operator for best application. Coatings tend to be thinner on corners and edges, and no coating is applied to interior surfaces or difficult to access recesses and cavities.

Applications/Exposure Conditions

Zinc spray metallizing can be applied to materials of any size, though complexity of the structure is important. Metallizing is commonly used as an alternative to batch hot-dip galvanizing when the part is too large for immersion in the galvanizing kettle. And though more often and easily applied in the shop, metallizing in the field is a great option for extending the life of already erected batch galvanized structures. The biggest limitations to metallizing applications are availability (skilled operator and equipment) and a significant cost premium.

ZINC SPRAY METALLIZING SUMMARY

- Factory controlled
- Quality varies by skill of labor
- Inconsistent coverage and coating thickness
- Weak mechanical bond of zinc to steel
- Interior or exterior use
- Labor intensive

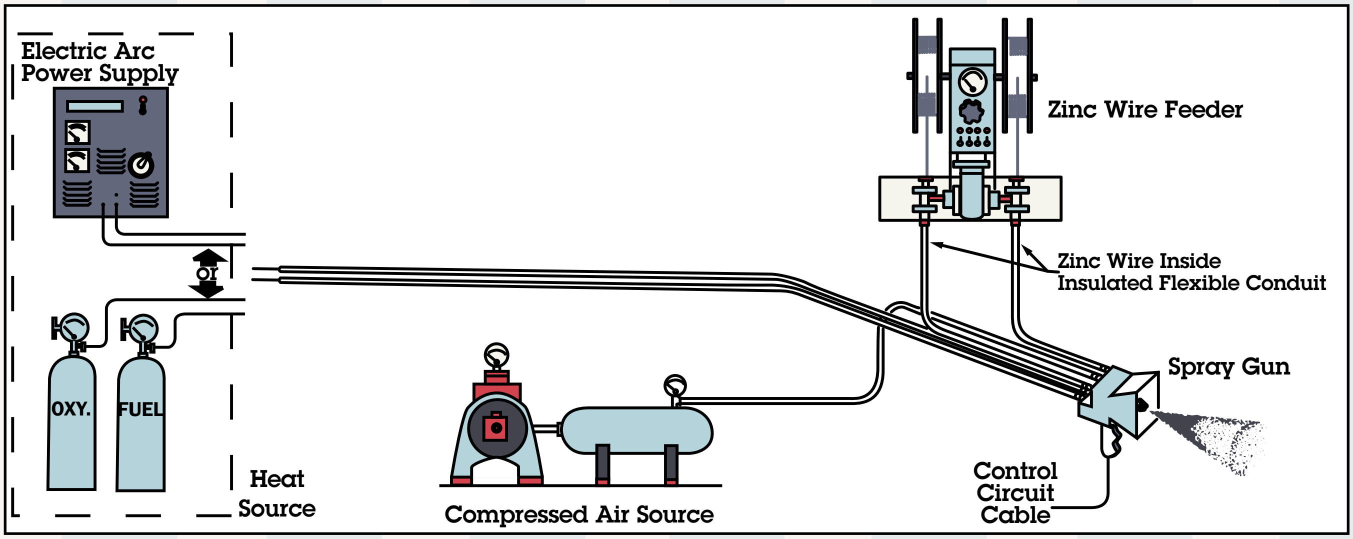

Figure 6: Zinc Spray Metallizing

MECHANICAL PLATING

Zinc Application Process

Mechanical zinc plating is accomplished by tumbling small parts in a drum with zinc and proprietary chemicals. Small iron and steel parts – usually limited in size to about 8-9 inches (200-300 mm) and weighing less than one pound (0.5 kg) – are cleaned and flash copper coated before loading into a plating barrel. The barrel is then loaded with proprietary chemicals, glass beads and zinc powder and tumbled (*Figure 7*). During tumbling, the glass beads peen zinc powder onto the part. Once finished, the parts are dried and packaged, or post-treated with a passivation film, dried, and packaged.

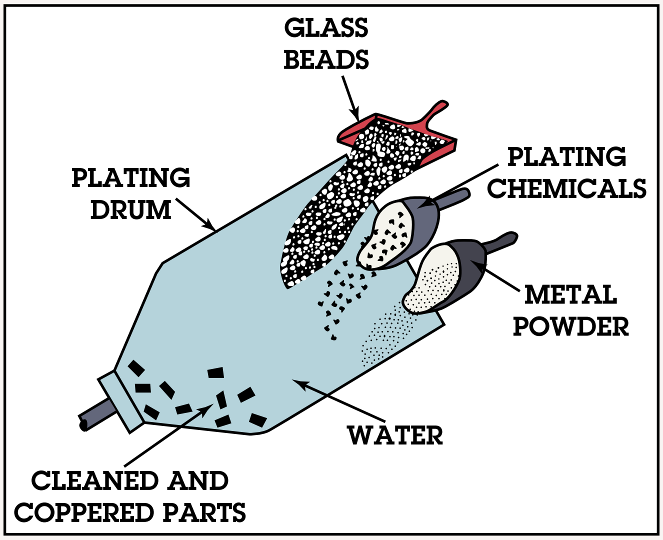

Figure 7: Mechanical Plating

Coating Characteristics & Performance

Mechanical plating consists of a flash coating of copper followed by the zinc coating. Coating thickness requirements specified in ASTM B695 range from 0.2 to 4.3 mils (5 to 110 µm). While thicker coatings are possible, the common thickness on commercial fasteners is 2 mils (50 µm). Coating thickness is regulated by the amount of zinc charged to the plating barrel and the duration of tumbling time. The coating has a density of about 70% compared to a batch hot-dip galvanized coating density. The hot-dip coating has over 30% more zinc per unit volume than a mechanical coating.

Because of the application process (tumbling and peening), the coating thickness can vary throughout the part. Complex designs with recesses or blind holes as well as edges, corners and threads can have inconsistent or non-existent coatings due to inaccessibility to the peening action of the glass beads. It is also important the compaction agents (beads) are large enough to avoid being lodged in any cavities, recesses, or small threads in the part. The coating is mechanically-bonded to the steel with a similar adhesion to zinc plating.

Applications/Exposure Conditions

As mentioned, mechanical plating can only be applied to small parts limited to the capacity of the drum. Furthermore, the materials must be simple in design to ensure peening to all surfaces. Mechanical zinc plating is most commonly used on high-strength fasteners and other small parts not suitable for hot-dip galvanizing.

MECHANICAL PLATING SUMMARY

- Factory controlled
- Small parts only
- Poor/no coverage in recesses
- Variable thickness of coating depending on tumbling time
- Inconsistent coating thickness
- Thinner coating on edges and corners

ELECTROGALVANIZING

Zinc Application Process

Electrogalvanized (electroplated) coatings are created by applying zinc to steel sheet and strip by electro-deposition. Similar to sheet galvanizing, the operation is continuous and coating thickness is minimal. Applied in a steel mill, sheet or strip is fed through entry equipment into a series of washes and rinses then into the zinc plating bath.

The most common zinc electrolyte-anode arrangement uses lead-silver, or other insoluble anodes and electrolytes of zinc sulfates. Soluble anodes of pure zinc are also used. The coating develops as positively charged zinc ions in the solution are electrically reduced to zinc metal and deposited on the positively charged cathode (sheet steel). Grain refiners may be added to help produce a smooth, tight-knit zinc coating on the steel.

Coating Characteristics and Performance

This electro-deposited zinc coating consists of pure zinc tightly adherent to the steel. The coating is highly ductile remaining intact even after severe deformation. Produced on strip and sheet materials, the coating weight ranges up to 0.2 oz/ft^2 (60 g/m^2), or thicknesses up to 0.36 mils (9.1 µm) per side, while on wire, coating weights may reach up to 3 oz/ft^2 (915 g/m^2). The coating of pure zinc is thinner than continuous sheet galvanizing, mechanically-bonded, and there are no alloy layers, but provides a smoother finish. Heat-treated and electro-coated wire can be cold drawn to about 95% reduction in area, depending on the chemical composition of the wire, heat treatment, and diameter.

Applications/Exposure Conditions

Electrogalvanized coatings are applied to sheet steels and wire, and therefore are used in similar applications to continuous sheet galvanizing or wire galvanizing. The most common applications are in automobile and appliance bodies and fasteners. Furthermore, to extend the service life, electrogalvanized coatings can be treated to make them suitable for painting, and this is often recommended due to the extremely thin zinc coating.

ELECTROGALVANIZING SUMMARY

- Factory controlled
- Very thin/consistent coating
- Interior use only
- Ductile coating of pure zinc
- Exposed/bare steel edges when slit or cut-to-length

ZINC PLATING

Zinc Application Process

Zinc plating is identical to electrogalvanizing in principle because both are electro-deposition processes. However, zinc plating is used on small parts such as fasteners, crank handles, springs and other hardware items rather than sheet metal. The zinc is applied as an expendable electrode in a cyanide, alkaline non-cyanide, or acid chloride salt solution. Cyanide baths are the most operationally efficient but can potentially create pollution and are hazardous.

After alkaline or electrolytic cleaning, pickling to remove surface oxides, and rinsing, the parts are loaded into a barrel, rack, or drum and immersed in the plating solution. Various brightening agents may be added to the solution to add luster, but careful control is needed to ensure a quality product. Post-plating treatments may be used to passivate the zinc surface as well as impart various translucent colors or to extend the life of the coating.

Coating Characteristics & Performance

Typical zinc-plated coatings are dull gray with a matte finish, although whiter, more lustrous coatings can be produced, depending on the process or agents added to the plating bath or through post-treatments. The pure zinc coating is thin, up to a maximum thickness of 1 mil (25 µm), and mechanically bonded to the surface with a hardness of about a third to a half that of most steels. The governing specification, ASTM B633, lists four classes of zinc-plating: Fe/Zn 5, Fe/Zn 8, Fe/Zn 12 and Fe/Zn 25 where the number indicates the coating thickness in microns (µm).

Applications/Exposure Conditions

Zinc plating is typically used for screws and other small fasteners, light switch plates, and various small parts that will be exposed in interior or mildly corrosive conditions. For use in moderate or severe environments, the materials must be chromate-conversion coated for additional corrosion protection.

ZINC PLATING SUMMARY

- Factory controlled
- Small parts only
- Interior use only
- Very thin coating

SELECTION OF ZINC COATINGS

Once the decision has been made to use a zinc coating for corrosion protection, a few additional factors must be considered to ensure the proper coating is selected for the application and service environment. Each zinc coating reviewed provides varying degrees of corrosion protection and it is important to identify the corrosiveness of the exposure environment to ensure the coating selected will provide adequate service life. Some zinc coatings will be eliminated by their nature alone, e.g. zinc coatings whose processes are limited to small parts or sheet steels cannot be considered for the protective coating of structural steel members; while others may be ruled out based on cost, appearance, availability, performance, etc. The following information examines a few factors in more detail, while *Table 3* (page 12) provides a snapshot of each of the zinc coatings based on several criteria.

Coating Thickness vs. Coating Weight

As has been stated several times throughout this guide, the service life of zinc coatings is linear to zinc coating thickness. However, zinc coating thickness evaluated alone can be deceiving when the zinc has been applied by different processes. In addition to thickness, the amount of available zinc per unit volume, or density, is also important. Keeping in mind various ASTM and/or other specifications require different weights or thicknesses, it is important to convert all coatings to a common denominator for comparison.

While coating densities for some types of zinc coatings are nearly identical, others differ considerably. One logical common denominator for comparing zinc coatings would be to convert all coatings into an equal weight per unit area of zinc; which in theory would provide equal service lives. *Table 2* represents the coating thickness required by each zinc application method to equal 1 oz of zinc/ft^2 of surface. Therefore, according to the conversions, 1.7 mils of hot-dip galvanized coating would give the same service life as 2.2 mils of mechanical plating or 3 to 6 mils (depending on the paint formulation) of zinc-rich paint.

Hot-dip galvanizing (batch or continuous) electrogalvanizing, zinc plating	1.7 mils (43 µm)
Zinc spraying (metallizing)	1.9 mils (48 µm)
Mechanical plating	2.2 mils (55 µm)
Zinc-rich paint	3-6 mils (75-150 µm)

Table 2: Coating Densities

It is also important to remember for all continuous galvanized sheet materials, including electrogalvanized, the coating weight is given for the total zinc weight for both sides of the sheet. To obtain the amount of zinc per unit area of surface, the weight given must be divided in two, assuming equal distribution on both sides. For example, an ASTM A653 Class G90 sheet contains 0.90 oz zinc/ft^2 of zinc or about 0.45 oz/ft^2 per side (*see Table 1*, page 4).

Economic Considerations

Initial cost will always be considered when specifying steel corrosion protection. However, in addition to the initial cost, evaluating the performance of the zinc coating in the intended environment also impacts the economics of the protective system. Hidden costs, such as accessibility of the site, production loss due to maintenance recoating, and rising wages for labor-intensive coatings, such as metal spraying and painting must also be considered.

The choice of the most economical system is not precise, because neither the timing nor the cost of future maintenance can be accurately predicted. In addition, depreciation of capital investment, tax relief for investment and maintenance cost and the time value of money must be considered and can change.

However, to get the most realistic cost of the coating system throughout the project's life, economic models for comparing the life-cycle costs of different coatings have been developed. As the calculation of life-cycle cost is complex and cumbersome, the American Galvanizers Association developed an automated online Life Cycle Cost Calculator to facilitate the process at lcc.galvanizeit.org. The online life-cycle cost calculator utilizes the same economic formula as the one recommended in ASTM A1068, and the data is provided by real-world field performance and published reports (NACE Paper 8279, 2008).

CONCLUSION

Though all of the coatings in this publication are comprised of zinc and often lumped under the umbrella term "galvanizing," each is very different in its application, characteristics, and performance in various environments. It is important to evaluate the exposure condition of each project before selecting the most effective zinc coating for that particular application, because as this aid points out, not all zinc coatings are created equally.

Zinc C

METHOD	APPLICATION VENUE/ CONDITIONS	SPECIFICATION	COATING THICKNESS MINIMUM/TYPICAL	SIZE	CURE TIME
Batch Hot-Dip Galvanizing	In shop factory-controlled; no special requirement	ASTM A123, A153, A767, CSA G164, ISO 1461	1.4 to 3.9 mils[a]/ 2 to 8.0 mils	Fasteners to 90' beams	<1 hr
Continuous Sheet Galvanizing	In shop factory-controlled; no special requirement	ASTM A653	0 to 3.2 mils[b]/ 0 to 3.2 mils	Sheet steel 0.010"-1.70" thick, 72" wide	<1 hr
Zinc Painting	In shop or field; conditions are subjective and prone to human error	SSPC-PS Guide 12.00, 22.00; SSPC-PS Paint 20; SSPC-PS 12.01	0.6 to 5.0 mils/coat/ 4.0 to 6.0 mils	Unlimited	24-72 hrs
Zinc Spray Metallizing	In shop or field	AWS C2.2	3.3 mils/ 4.0 to 6.0 mils	Unlimited	<24 hrs[d]
Mechanical Plating	In shop factory-controlled; no special requirement	ASTM B695	0.2 to 4.2 mils[c]/ 0.2 to 4.2 mils	Small parts 8"-9" and under 1 lb	<1 hr
Electrogalvanizing	In shop factory-controlled; no special requirement	ASTM A879	0.28 mils[b]/ 0 to 0.28 mils	Sheet steel	<1 hr
Zinc Plating	In shop factory-controlled; no special requirement	ASTM B633	0.2 to 1.0 mils[c]/ 0.2 to 1.0 mils	Small parts	<1 hr

[a] Range based on ASTM, ISO, and CSA minimum thicknesses for all grades, classes, etc., encompassed by the specifications.
[b] Total for both sides of sheet.
[c] Range based on ASTM minimum thicknesses for all grades, classes, etc., encompassed by the specifications.
[d] Dependent on sealer top coat

Table 3: Zinc Coatings and Applications

oatings

COVERAGE CONSISTENCY	BOND TO SUBSTRATE STEEL	ABRASION RESISTANCE/ HARDNESS	FINISH/ APPEARANCE	EXPOSURE CONDITIONS
100% edges, corners, and interior ≥ flat surfaces	Metallurgical ~3,600 psi	Intermetallic layers 179-250 DPN	Varies Matte, gray, shiny, spangle, or combination	Interior/exterior
Uniform thickness Controlled by air knife	Metallurgical ~3,600 psi	~70 DPN	Controlled Minimum to highly spangled	Interior or mildly corrosive conditions
Inconsistent, based on operator skill Tends to thin at edges and corners Interior surfaces are uncoated	Mechanical 400-600 psi	Soft and not abrasion resistant	Smooth finish Color to suit specifier	Interior/exterior
Inconsistent based on operator skill	Mechanical ~1,500 psi	~70 DPN	Matte gray Rough	Interior/exterior
Inconsistent Thinner at edges, corners, and recesses	Mechanical 400-600 psi	75 DPN	Matte gray Rough compared to electroplated	Interior/exterior
100% coverage	Mechanical 300-500 psi	~70 DPN	Smooth finish Shiny, unless passivated	Interior
100% coverage	Mechanical 300-500 psi	75 DPN	Smooth finish Dull gray to shiny Controlled by additives	Interior

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We acknowledge the assistance of the following who supplied illustrations for use in this booklet:

Figure 2: Teck Metals Ltd.

Figure 3: Adapted from drawing courtesy Nordisk Förzinkningsförening, Stockholm, Sweden from *Rust Prevention by Hot Dip Galvanizing.*

Figure 6: Xstrata Canada Corp.

Figure 7: Lester Coch, Tru-Plate Process, Inc., Jericho, New York from the *Economics of Mechanical Plating,* April 1978.

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