Hot-Dip Galvanizing for Corrosion Prevention

A Guide to Specifying and Inspecting Hot-Dip Galvanized Reinforcing Steel

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Corrosion Protection for Steel

Repairing damage caused by corrosion is a multi-billion dollar problem. Observations of numerous structures show that corrosion of reinforcing steel is either a prime — or at least an important — factor contributing to the staining, cracking, and/or spalling of concrete structures. The effects of corrosion often require costly repairs and continued maintenance during a structure's life.

When steel is exposed to an aggressive environment, or if the design details or workmanship are inadequate, corrosion of the reinforcement may become excessive, and the concrete may exhibit signs of distress.

Galvanized reinforcing steel is effectively and economically used in concrete where unprotected reinforcement will not have adequate durability. The susceptibility of concrete structures to the intrusion of chlorides is the primary incentive for using galvanized steel reinforcement. Galvanized reinforcing steel is especially useful when the reinforcement will be exposed to the weather before construction begins. Galvanizing provides visible assurance that the steel has not rusted.

This publication provides information on the design variables involved in specifying galvanized reinforcement. It also provides details on the specification and practices involved with galvanized reinforcement, as well as inspection details.
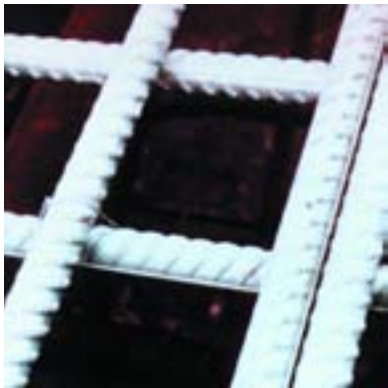
Galvanizing rebar helps prevent corrosion.

Steel Corrosion

Rust — iron's corrosion product — is the result of an electrochemical process. Rust 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). These differences in potential on the steel surface are caused by variations in steel composition/structure, the presence of impurities, uneven internal stress, and/or corrosive environments.

In the presence of an electrolyte, the differences mentioned above create corrosion cells, consisting of microscopic anodes and cathodes. Because of differences in potential within the cell, negatively-charged electrons flow from anode to cathode, and iron atoms in the anode area are converted to positively charge iron ions. The positively-charged iron ions (Fe^{2+}) of the

Corrosion of unprotected reinforcing steel creates hazards due to spalling concrete.

anode attract and react with the negatively-charged hydroxyl ions (OH^-) in the electrolyte to form iron oxide, or rust. Negatively-charged electrons (e-) react at the cathode surface with positively-charged hydrogen ions (H^+) in the electrolyte to form hydrogen gas. A simplified picture of what occurs in this corrosion cell is shown in Figure 1 (right).
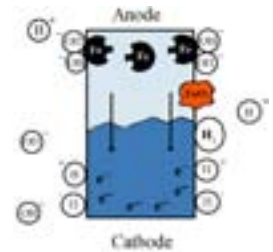

Figure 1: Corrosion cell.

Impurities present in the electrolyte create an even better conductive path for the corrosion process. For example, these impurities can be the constituents in which the steel is immersed or present in atmospheric contaminants, including sulfur oxides, chlorides, or other pollutants present in damp atmospheres or dissolved in surface moisture. Calcium hydroxide, present in hardened concrete, also acts as an electrolyte in the presence of moisture.

Under normal conditions, concrete is alkaline (pH of about 12.5) due to the presence of calcium hydroxide. In such an environment, a passivating iron-oxide film forms on the steel, causing almost complete corrosion inhibition. As the pH of the concrete surrounding the reinforcement is reduced by the intrusion of salts, leaching or carbonation, the system becomes active and corrosion proceeds.

The presence of chloride ions can affect the inhibitive properties of the concrete in two ways. The presence of chloride ions creates lattice vacancies in the oxide film, thus providing defects in the film through which metal ions may migrate more rapidly and permit pitting corrosion to proceed. Also, if the hydroxyl ion concentration is reduced — for example, by carbonation — the pH is lowered and the corrosion proceeds further. In the presence of oxygen, inhibition of iron corrosion occurs at a pH of 12.0. But as the pH is reduced, the corrosion rate increases. With reduction of pH to 11.5, the iron corrosion rate increases by as much as five times the rate at a pH of 12.0.

At an active anodic site, particularly in pits, the formation of positively-charged ferrous ions attracts negatively-charged chloride ions, yielding high concentrations of ferrous chloride. Ferrous chloride partially hydrolyzes, yielding hydrochloric acid and an acid reaction. These reactions reduce protection at the steel-concrete interface. At a corroding surface, the pH may be 6.0 or less.

As mentioned before, the anode and cathode areas on a piece of steel are microscopic. Greatly magnified, the surface might appear as the mosaic of anodes and cathodes pictured in Figure 2 (page 4), all electrically connected by the underlying steel.

Moisture in the concrete provides the electrolyte and completes the electrical path between the anodes and cathodes on the metal surface. Due to potential differences, a small electric current begins to flow as the metal is consumed in the anodic area. The iron ions produced at the anode combine with the environment to form the loose, flaky iron oxide known as rust.

Figure 2: Corrosion of steel.
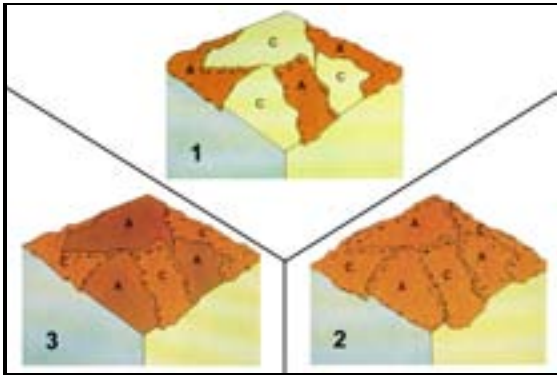
1. *Corrosion of steel is an electrochemical reaction. Minute differences in structure of the steel's chemistry create a mosaic pattern of anodes and cathodes containing stored electrochemical energy.*

2. *Moisture forms an electrolyte, which completes the electrical path between anodes and cathodes, spontaneously releasing the stored electrochemical energy. A small electrical current begins to flow, carrying away particles from the anodic areas. These particles combine with the environment to form rust. When salt or acid is added to the moisture, the flow of electric current and corrosion accelerates.*

3. *At this stage, the anodes are corroded and cathodes are protected. However, the instability of the metal itself causes the anodes to change to cathodes and the corrosion cycle begins again, resulting in uniform corrosion of the entire surface.*

As anodic areas corrode, new material of different composition and structure is exposed. This results in a change of electrical potentials and also changes the location of anodic and cathodic sites. The shifting of anodic and cathodic sites does not occur all at once. In time, previously uncorroded areas are attacked, and a uniform surface corrosion is produced. This process continues until the steel is entirely consumed.

The corrosion products that form on steel have much greater volume than the metal that is consumed in the corrosion reaction. This increase in volume around the bare steel rebar exerts great disruptive tensile stress on the surrounding concrete. When resultant tensile stress is greater than the concrete tensile strength, the concrete cracks (Figure 3, below), leading to further corrosion. Corrosion cracks are usually parallel to the reinforcement and are quite distinct from transverse cracks associated with tension in the reinforcement caused by loading. As the corrosion proceeds, the longitudinal cracks widen and, together with structural transverse cracks, cause spalling of the concrete.
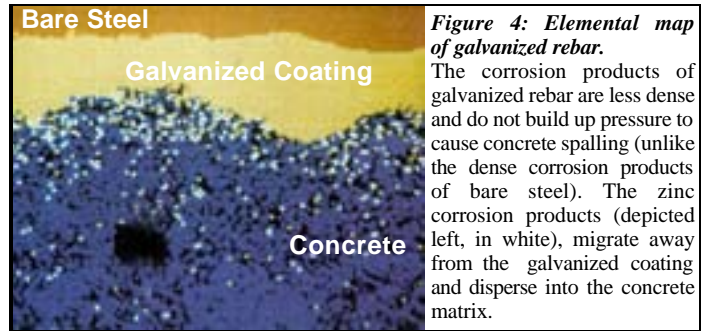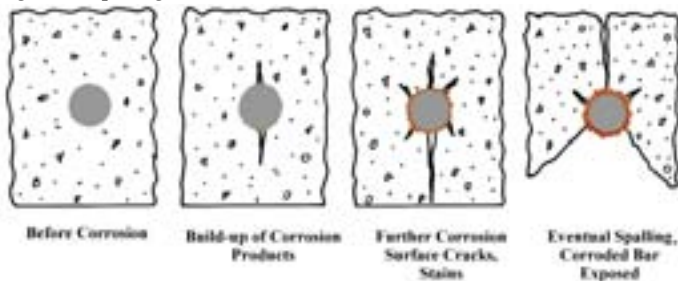
Figure 3: Spalling concrete.

| Before Corrosion | Build-up of Corrosion Products | Further Corrosion Surface Cracks, Stains | Eventual Spalling, Corroded Bar Exposed |

Figure 4: Elemental map of galvanized rebar. The corrosion products of galvanized rebar are less dense and do not build up pressure to cause concrete spalling (unlike the dense corrosion products of bare steel). The zinc corrosion products (depicted left, in white), migrate away from the galvanized coating and disperse into the concrete matrix.

How Zinc Prevents Steel Corrosion

The reason for the extensive use of hot-dip galvanized steel is the two-fold nature of the coating. As a barrier coating, galvanizing provides a tough, metallurgically-bonded zinc coating that completely covers the steel surface and seals the steel from the environment's corrosive action. Additionally, zinc's sacrificial action (cathodic) protects the steel even where damage or a minor discontinuity occurs in the coating.

It should be noted that the performance of hot-dip galvanized reinforcing steel in concrete is quite different than that of hot-dip galvanized steel in atmospheric conditions.

Barrier Protection

Zinc is characterized by its amphoteric nature and its ability to passivate due to the formation of protective reaction product films. Reaction of zinc with fresh cement leads to passivity by formation of a diffusion barrier layer of zinc corrosion products.

Cathodic Protection

Table 1 (page 5) shows the galvanic series of metals and alloys arranged in decreasing order of electrical activity. Metals toward the top of the table, often referred to as "less noble" metals, have a greater tendency to lose electrons than the more noble metals at the bottom of the table. Thus, metals higher in the series provide cathodic (or sacrificial) protection to those metals below them.

Because zinc is anodic to steel, the galvanized coating provides cathodic protection to exposed steel. When zinc and steel are connected in the presence of an electrolyte, the zinc is slowly consumed while the steel is protected. Zinc's sacrificial action offers protection where small areas of steel are exposed, such as cut edges, drill-holes, scratches, or as the result of severe surface abrasion. Cathodic protection of the steel from corrosion continues until all the zinc in the immediate area is consumed.

Both steel and chromated zinc are normally passive in the highly-alkaline environment of concrete. However, penetration of chloride ions to the metal surface can break down this passivity and initiate rusting of steel or sacrificial corrosion of the zinc. **The susceptibility of concrete structures to the intrusion of chlorides is the primary incentive for using galvanized steel reinforcement.**

Table 1: Galvanic series of metals.	
Corroded End *Anodic or less noble* *(Electronegative)* Magnesium Zinc Aluminum Cadmium Iron or Steel Stainless Steels (active) Soft Solders Lead Tin Nickel Brass Bronzes Copper Nickel-Copper Alloys Stainless Steels (passive) Silver Solder Silver Gold Platinum **Protected End** *Cathodic or more noble* *(Electropositive)*	**Arrangement of Metals in the Galvanic Series:** Any one of the metals and alloys listed, left, will theoretically corrode while offering protection to any other metal or alloy listed lower in the series, so long as both are electrically connected. (In actual practice, however, zinc is, by far, the most effective in this respect.)

Design

When galvanized steel is specified (see the AGA's publication, *Suggested Specification for Hot-Dip Galvanizing Reinforcing Steel*), the design requirements and installation procedures employed should be no less stringent than for structures where uncoated steel reinforcement is used. In addition, there are some special requirements to be observed when galvanized steel is used. The following suggestions are intended as a guide for designers, engineers, contractors, and inspectors. They are intended as a supplement to other codes and standards dealing with the design, fabrication, and installation of reinforced concrete structures, and deal only with those special considerations that arise due to the use of galvanized steel.

Steel Selection

The concrete reinforcing steel to be galvanized shall conform to one of the following ASTM specifications:

· A 615: *Specification for Deformed and Palin Billet-Steel Bars for Concrete Reinforcement;*
· A 616: *Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement;*
· A 617: *Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement;*
· A 706: *Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement.*

Detailing of Reinforcement

Detailing of galvanized reinforcing steel should conform to the design specifications for uncoated steel bars and to normal standard practice consistent with the recommendations of the Concrete Reinforcing Steel Institute (CRSI).

Overlapping lengths of hot-dip galvanized reinforcing steel are identical to uncoated steel reinforcement overlap lengths because of the equivalent bond strength to concrete.

Dissimilar Metals in Concrete

Another consideration when using galvanized reinforcement in concrete is the possibility of establishing a bimetallic couple between zinc and bare steel (i.e., at a break in the zinc coating or direct contact between galvanized steel and black steel bars) or other dissimilar metals. A bimetallic couple of this type in concrete should not be expected to exhibit corrosive reactions as long as the two metals remain passivated. To ensure this is the case, the concrete depth to the zinc/steel contact should not be less than the cover required to protect black steel alone under the same conditions.

Therefore, when galvanized reinforcement is used in concrete, it should not be coupled directly to large areas of black steel reinforcement, copper, or other dissimilar metal. Bar supports and accessories should be galvanized. Tie wire should be annealed wire — 16-gauge or heavier — preferably galvanized. If desired, polyethylene and other similar tapes can be used to provide insulation between dissimilar metals.

Galvanized steel can withstand exposure to chloride ion concentrations several times higher (at least four to five times) than the chloride level that causes corrosion in black steel reinforcement. While black steel in concrete typically depassivates below a pH of 11.5, galvanized reinforcement can remain passivated at a lower pH, thereby offering substantial protection against the effects of concrete carbonation.

These two factors combined — chloride tolerance and carbonation resistance — are widely accepted as the basis for superior performance of galvanized reinforcement compared to black steel reinforcement. The total life of a galvanized coating in concrete is made up of the time taken for the zinc to depassivate (which is longer than that for black steel, because of its higher tolerance to chloride ions and carbonation resistance), plus the time taken for the consumption of the zinc coating as it sacrificially protects the underlying steel. Only after the coating has been fully consumed in a region of the bar will localized corrosion of the steel begin.

Galvanizing protects the steel during in-plant and on-site storage, as well as after it is embedded in the concrete. In areas where the reinforcement may be exposed due to thin or porous concrete, cracking, or damage to the concrete, the galvanized coating provides extended protection. Since zinc corrosion products occupy a smaller volume than iron corrosion products, the corrosion that may occur to the galvanized coating causes little or no disruption to the surrounding concrete. Tests also confirm that zinc corrosion products are powdery, non-adherent, and capable of migrating from the surface of the galvanized reinforcement into the concrete matrix, reducing the likelihood of zinc corrosion-induced spalling of the concrete (Yeomans).

Fabrication
Bending Bars

Hooks or bends should be smooth and not sharp. Cold-bending should be in accordance with the recommendations of CRSI. When bars are bent cold prior to galvanizing, they need to be fabricated to a bend diameter equal to or greater than those specified in Table 2 (below). Material can be cold bent tighter than shown if it is stress-relieved at a temperature from 900º F to 1050º F (482º - 566º C) for one hour per inch (2.5 cm) of bar diameter before hot-dip galvanizing.

Table 2: Minimum suggested bend diameters.

Minimum Finished Bend Diameters - Inch - Pound Units			
Bar No.	Grade 40	Grade 50	Grade 60	Grade 75
3, 4, 5, 6	6*d*	6*d*	6*d*	---
7, 8	6*d*	8*d*	8*d*	---
9, 10	8*d*	8*d*	8*d*	---
11	8*d*	8*d*	8*d*	8*d*
14, 18	---	---	10*d*	10*d*

d = nominal diameter of the bar

When galvanizing is performed before bending, some cracking and flaking of the galvanized coating at the bend may occur. The speed at which the article is bent also may affect coating integrity. The galvanized coating is best maintained at slower bend speeds. According to ASTM A 767, *Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*, some cracking and flaking of the galvanized coating in the bend area is not cause for rejection. Any flaking or cracking can be repaired as described in ASTM A 780, *Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.*

Storage and Handling

Galvanized bars may be stored outdoors without a degradation in corrosion performance. Their general ease of storage makes it feasible to store standard lengths so that they are available on demand. Another important characteristic of galvanized reinforcing steel is that it can be handled and placed in the same manner as black steel reinforcement, due to galvanized steel's great abrasion resistance (please refer to the AGA's *Field Handling Guide: Hot-Dip Galvanizing vs. Fusion Bonded Epoxy* for additional information).

Standard-size reinforcing steel, both straight and fabricated, can be galvanized in advance and easily stored until needed.

Installation
Welding

Welding galvanized reinforcement does not pose any problems, provided adequate precautions are taken. Steps include utilizing a slower welding rate and maintaining proper ventilation (the ventilation normally required for welding operations is considered adequate). More details are outlined the AGA's *Welding and Hot-Dip Galvanizing* publication.

Local Repair of Coating

Local removal of the galvanized coating in the area of welds, bends, or sheared ends will not significantly affect the protection offered by galvanizing, provided the exposed surface area is small compared to the

Despite improper treatment, the abrasion-resistant galvanized coating requires no special handling.

adjacent surface area of galvanized steel. When the exposed area is excessive and gaps are evident in the galvanized coating, the area can be repaired in accordance to ASTM A 780.

Removal of Forms

Because cements with naturally low-occurring levels of chromates may react with zinc and retard hardening and initial set, it is important to ensure that forms and supports are not removed before the concrete has developed the required strength to support itself. Normal form removal practices may be utilized if the cement contains at least 100 ppm of chromates in the final concrete mix or if the hot-dip galvanized bars are chromate-passivated according to ASTM A 767, Section 4.3.

The Hot-Dip Galvanizing Process

The hot-dip galvanizing process consists of three basic steps: surface preparation, galvanizing, and inspection. Each of these steps is important to obtain a quality galvanized coating (Figure 5, page 7).

Surface Preparation

It is essential for the steel surface to be clean and uncontaminated in order to obtain a uniform, adherent coating. Surface preparation is usually performed in sequence by caustic (alkaline) cleaning, water rinsing, pickling, a second water rinsing, and fluxing.

The caustic cleaner removes organic contaminants including dirt, water-based paint markings, grease, and oil. Next, scale and rust are removed by a pickling bath of hot sulfuric acid (150º F / 66º C) or room-temperature hydrochloric acid. Water rinsing usually follows both caustic cleaning and pickling.

Surface preparation can also be accomplished using abrasive cleaning as an alternate to, or in conjunction with, chemical cleaning. Abrasive cleaning is a mechanical process in which shot or grit is propelled against the material by air blasts or rapidly-rotating wheels.

Figure 5: The hot-dip galvanizing process.

Surface Preparation

Caustic Cleaning — Rinsing — Pickling — Rinsing — Flux Solution

Galvanizing

Molten Zinc Bath

Inspection

Cooling and Quality Assurance
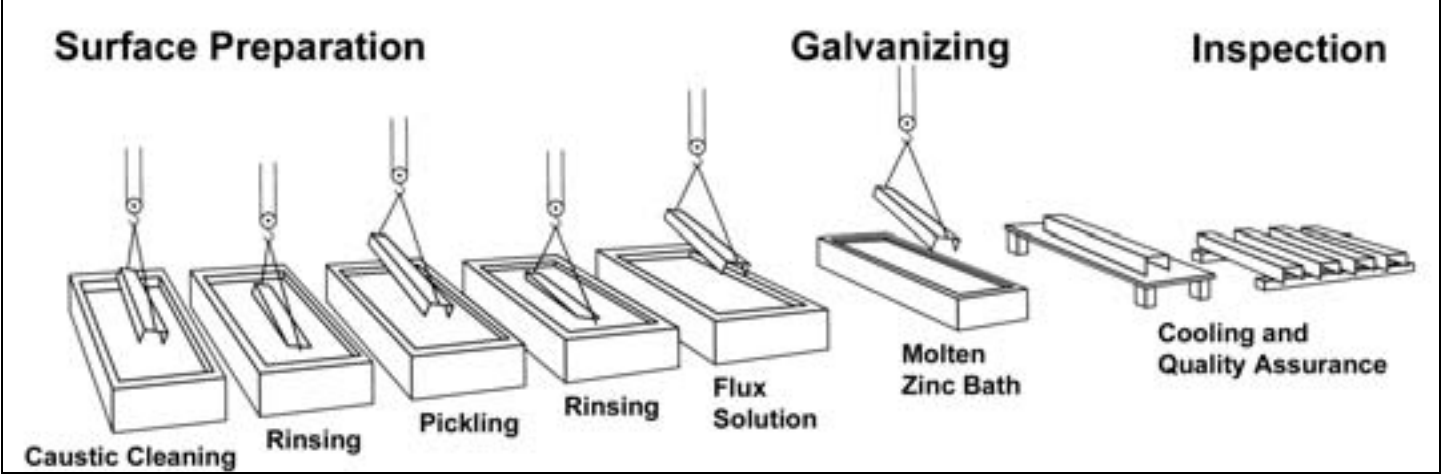
The final cleaning of the steel is performed by a flux, an aqueous solution of zinc ammonium chloride that prevents any oxidation of the newly- cleaned steel and promotes good zinc adhesion to the steel.
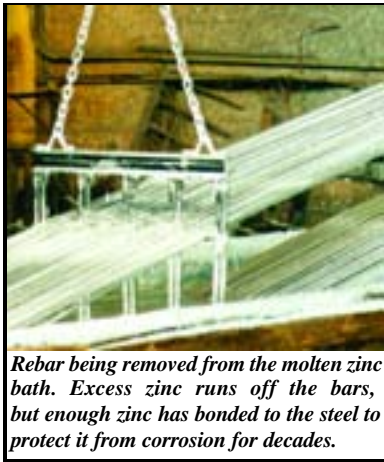
Galvanizing

Rebar being removed from the molten zinc bath. Excess zinc runs off the bars, but enough zinc has bonded to the steel to protect it from corrosion for decades.

The material to be coated is immersed in a bath of molten zinc maintained at temperatures over 800º F (430º C). A typical bath chemistry used in hot-dip galvanizing is 98% pure zinc. The immersion time in the galvanizing bath will vary, depending upon the dimensions and chemistry of the material being coated; materials with thinner sections galvanize more quickly than those with thicker sections.

Surface appearance and coating thickness are the result of many process parameters, including steel chemistry, variations in immersion time and/or bath temperature, rate of withdrawal from the galvanizing bath, removal of excess zinc by wiping, shaking or centrifuging, and control of the cooling rate by water quenching or air cooling.
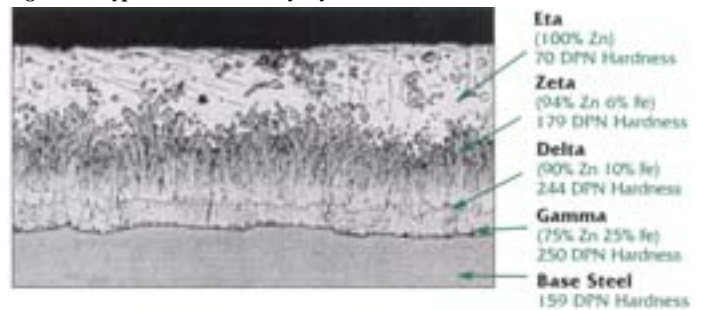
The AGA has developed procedures for galvanizing reinforcing steel to ensure the galvanized coating will meet not only the minimum coating weights for galvanized reinforcement specified in ASTM A 767, as seen in Table 4 (page 9), but also the other requirements of the standard.

Physical Properties of Hot-Dip Galvanized Coatings

Metallurgical Bond

Hot-dip galvanizing is a factory-applied coating that provides a combination of properties unmatched by other coating systems because of its unique metallurgical bond with the steel.

Figure 6: Typical zinc-iron alloy layers.

Eta (100% Zn) 70 DPN Hardness
Zeta (94% Zn 6% Fe) 179 DPN Hardness
Delta (90% Zn 10% Fe) 244 DPN Hardness
Gamma (75% Zn 25% Fe) 250 DPN Hardness
Base Steel 159 DPN Hardness

The photomicrograph in Figure 6 (above) shows a section of a typical hot-dip galvanized coating. The galvanized coating consists of a progression of zinc-iron alloy layers metallurgically bonded to the base steel at around 3600 psi. The metallurgical bond formed by the galvanizing process ensures that no underfilm corrosion can occur. Epoxy coatings, on the other hand, merely overcoat the steel with a penetrable film. As illustrated in Figure 7 (below), once the epoxy film is broken and the bare steel is exposed, corrosion begins as if no protection existed.

Figure 7: Barrier protection only.

What happens at a scratch on barrier coatings: The exposed steel corrodes, forms a pocket of rust, and lifts the coating from the metal surface, forming a blister. This blister will continue to grow toward complete coating failure.

What happens at a scratch on galvanized steel. The zinc coating sacrifices itself to protect the steel; this action continues as long as there is zinc in the immediate area.

7

Because of its unique, tough coating, galvanized steel requires no special handling at the work-site. The intermetallic layers of the galvanized coating are harder than the base steel, so galvanized rebar is extremely resistant to damage from abrasion.

Impact and Abrasion Resistance

The ductile outer zinc layer provides good impact resistance to the bonded galvanized coating. The micrograph mentioned in Figure 6 (previous page) shows the typical hardness values of a hot-dip galvanized coating. The hardness of the zeta, gamma, and delta layers is actually greater than that of the base steel and provides exceptional resistance to coating damage from abrasion.

Corner and Edge Protection

Corrosion often begins at the corners or edges of products that have not been galvanized. Epoxy coatings, regardless of application method, are thinnest at such places. The galvanized coating will be at least as thick, possibly thicker, on edges and corners as on the general surface. This provides equal or extra protection to these critical areas (see Figure 8, above).
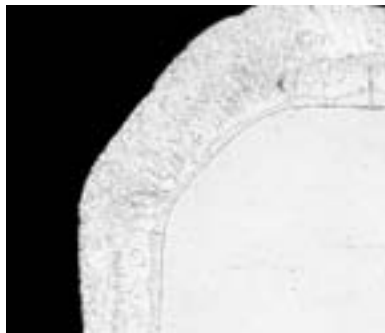

Figure 8: Full corner protection.

Complete Coating

Because galvanizing is accomplished through total immersion, all surfaces of the article are fully coated and protected, including areas inaccessible and hard to reach with brush-on or spray-applied coatings. Additionally, the integrity of any galvanized coating is ensured because zinc will not metallurgically bond to unclean steel. Thus, any uncoated area is immediately apparent as the work is withdrawn from the molten zinc. Adjustments are made on the spot, when required, so a fully-protected item is delivered to the job site.

Mechanical Properties of Hot-Dip Galvanized Steel

Ductility and Yield/Tensile Strength

Ductility and strength of reinforcing steel are important to prevent brittle failure of reinforced concrete. Studies on the effect of galvanizing on the mechanical properties of steel reinforcing bars have demonstrated that the tensile, yield, and ultimate strength, ultimate elongation, and bend requirements of steel reinforcement are substantially unaffected by hot-dip galvanizing, provided proper attention is given to steel selection, fabrication practices and galvanizing procedures.

The effect of the galvanizing process on the ductility of steel bar anchors and inserts after being subjected to different fabrication procedures has also been investigated. The results demonstrate conclusively that, with correct choice of steel and galvanizing procedures, there is no reduction in the steel's ductility.

Fatigue Strength

An extensive experimental program examining the fatigue resistance of galvanized steel reinforcement shows that deformed reinforcing steel, exposed to an aggressive environment prior to testing under cyclic tension loading, performs better when galvanized.

Bond Strength

Good bonding between reinforcing steel and concrete is essential for reliable performance of reinforced concrete structures. When protective coatings on steel are used, it is essential to ensure that these coatings do not reduce bond strength. Studies on the bonding of galvanized and black steel bars to Portland Cement concrete have been investigated. The results of these studies indicate:

1. Development of the bond between steel and concrete depends on age and environment;

2. In some cases, the time required for developing full bond-strength between steel and concrete may be greater for galvanized bars than for black, depending on the zincate/cement reaction;

3. The fully developed bond strength of galvanized and black deformed bars is the same. As depicted in Table 3 (below), the bond strength of galvanized bars is greater than for similar black bars.

Table 3: Bond between concrete and reinforcing steel.
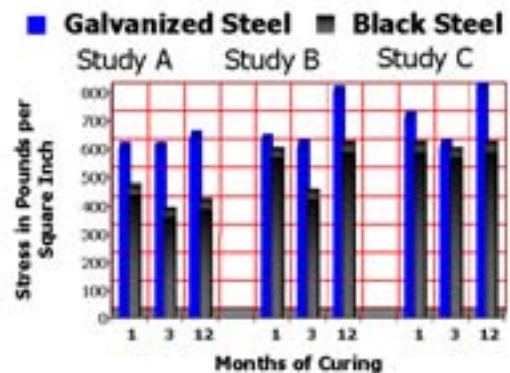
Zinc Reaction in Concrete

During curing, the galvanized surface of steel reinforcement reacts with the alkaline cement paste to form stable, insoluble zinc salts accompanied by hydrogen evolution. This has raised the concern of the possibility of steel embrittlement due to hydrogen absorption. Laboratory studies indicate that liberated

*Because of the bond strength between galvanized steel and concrete, galvanized rebar is used successfully in a variety of applications to provide reliable corrosion prevention.*

The concrete in this photo was in service for almost 20 years in a salt-water, marine environment, and required a jackhammer to break the bond between it and the galvanized rebar!

hydrogen does not permeate the galvanized coating to the underlying steel and the reaction ceases as soon as the concrete hardens.

Most types of cement and many aggregates contain small quantities of chromates, which passivate the zinc surface to minimize the evolution of hydrogen during the reaction between zinc and the concrete. If the cement and aggregate contain less chromate than will yield at least 100 ppm in the final concrete mix, the galvanized bars can be dipped in a chromate solution or chromates can be added to the water when the concrete is mixed.
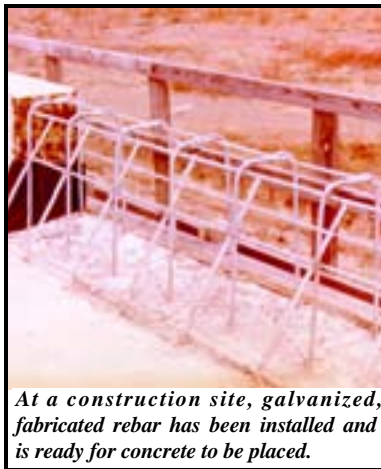
At a construction site, galvanized, fabricated rebar has been installed and is ready for concrete to be placed.

Inspection

Once the reinforcing steel has been galvanized, the product must be inspected to ensure compliance with specification requirements. The standard specification for hot-dip galvanized reinforcing steel is ASTM A 767. This specification covers individual bars, as well as groups of bars. When the bars are fabricated into assemblies prior to galvanizing, the standard specification for hot-dip galvanized assemblies, ASTM A 123, *Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*, applies. In Canada, for either bars or assemblies, the standard specification for hot-dip galvanized articles is CSA G 164, *Galvanizing of Irregularly Shaped Articles*.

Inspection of the hot-dip galvanized product, as the final step in the galvanizing process, can be most effectively and efficiently conducted at the galvanizer's plant. Here, questions can be raised and answered quickly, inspection hastened and time saved, which is turned into an asset for the overall project.

Coating Thickness

The thickness of the galvanized coating is the primary factor in determining the service life of the product. The thicker the coating, the longer it provides corrosion protection. For steel embedded in concrete, the relationship is approximately linear. For example, the service life is doubled or tripled if the weight of the zinc coating is doubled or tripled.

Table 4: ASTM A 767 - Mass (weight) of zinc coating.	
Class	**Mass of Zinc Coating** min gm/m² (oz/ft²) of Surface Coating
Class 1	
Bar Designation Size No. 3	915 (3.00)
Bar Designation Size No. 4 & larger	1070 (3.50)
Class 2	
Bar Designation Size No. 3 & larger	610 (2.00)

Table 5: Conversion from zinc coating weight to zinc coating thickness.

Coating Weight		Coating Thickness	
oz/ft²	gm/m²	mils	microns
1.00	305.2	1.70	43
1.50	457.8	2.55	65
2.00	610.3	3.40	86
2.50	762.9	4.25	108
3.00	915.5	5.10	130
3.50	1068.1	5.95	153

The minimum coating mass or weight requirements for reinforcing bars from ASTM A 767 are summarized in Table 4 (above). The conversion of these weights into thickness values is shown in Table 5 (above). The minimum coating thickness requirements for reinforcing bar assemblies from ASTM A 123 are summarized in Table 6 (below). The conversion of these grades into thickness and weight numbers is shown in Table 7 (page 10).

The galvanized coating thickness can be determined via several methods. The size, shape, and number of parts to be tested likely dictates the method of testing. Some test methods are non-destructive, while others require removal of the zinc coating or sectioning of the test article, thereby destroying the test article.

Table 6: ASTM A 123 - Coating thickness requirements.
Minimum Average Coating Thickness Grade by Material Category

Material Category	<1/16 (<1.6)	1/16 to <1/8 (1.6 to <3.2)	1/8 to 3/16 (3.2 to 4.8)	>3/16 to <1/4 (>4.8 to <6.4)	≥1/4 (≥6.4)
				All Specimens Tested Steel Thickness Measurement in Inches (mm)	
Structural Shapes	45	65	75	85	100
Strip	45	65	75	85	100
Pipe & Tubing	45	45	75	75	75
Wire	35	50	60	65	80

Table 7: ASTM A 123 - Coating thickness requirements.				
Minimum Coating Thickness by Grade*				
Coating Grade	**mils**	**oz/ft²**	**mm**	**g/m**
35	1.4	0.8	35	2.45
45	1.8	1.0	45	3.20
50	2.4	1.2	50	355
55	2.2	1.3	55	390
60	2.4	1.4	60	425
65	2.6	1.5	65	460
75	3.0	1.7	75	530
80	3.1	1.9	80	565
85	3.3	2.0	85	600
100	3.9	2.3	100	705

* Conversions in this table are based on the metric thickness value equivalents from the next earlier version of this specification, using conversion factors consistent with Table x.21 in ASTM A 653 (see back cover), rounded to the nearest 5 μm x 0.03937; oz/ft² = μm x 0.02316; g/m² = μm x 7.067.

Magnetic Thickness Measurements

The thickness of the coating can be determined by magnetic thickness gauge measurements in accordance with ASTM E 376, *Practice for Measuring Coating Thickness by Magnetic-Field of Eddy-Current (Electromagnetic) Test Methods.* To find the specimen coating thickness, a minimum of five randomly located readings must be taken to represent, as much as practical, the entire surface area of the bar. After specimen coating thicknesses have been determined for three bars, the average of those three bars is the average coating thickness for the size lot. If the lot size is large, more than three samples may be needed, as dictated in Section 7.3 of ASTM A 123.

Stripping Method

The average coating weight can be determined by stripping specimens taken from sample bars in accordance with ASTM A 90, *Test Method for Weight (Mass) of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings*. Cut one specimen from each end of the bar and a third specimen from the center of the bar. The average coating weight for the bar is derived from the averages of the specimen coating weights obtained for each of the three pieces. This method is a destructive test and is not appropriate for assemblies of reinforcing steel.

Weighing Bars

The average coating weight can be determined by weighing the bars before and after galvanizing. The first weight is determined after pickling and drying, the second after the hot-dip galvanized bar has cooled to an ambient temperature. The coating weight is the difference between the two weights divided by the surface area of the bar. This method does not take into account the weight of iron reacted from the bar that is incorporated into the coating, so the coating weight can be underestimated by as much as 10%. Base metal reactivity affects the extent of underestimation. This method is only appropriate for assemblies if the assemblies' surface area can be obtained.

Microscopy

The average coating weight can be determined using cross-sectioned samples and optical microscopy in accordance with ASTM B 487, *Test Method for Measurement of Metal and Oxide Coating Thickness of Microscopial Examination of a Cross Section*. The thickness of a cross-sectioned sample is determined by optical measurement. The average coating thickness is obtained by averaging five thickness measurements on widely dispersed cross-sections along the length of the bars, so as to represent the entire surface of the bar. The average coating thickness must then be converted to coating weight. This test method is destructive and is not appropriate for assemblies of reinforcing steel.
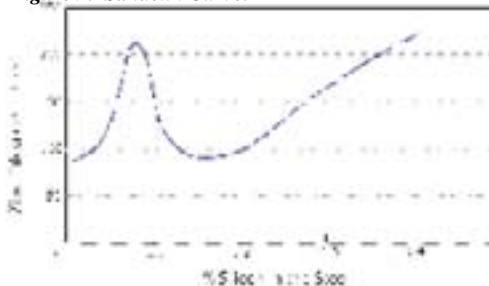
Sampling Statistics

For determining the average coating weight, three random samples must be tested from each lot. A "lot" is defined as all bars of one size furnished to the same hot-rolled reinforcing bar specifications that have been galvanized within a single production shift. It is essential for selected specimens to be representative of the inspection lot. Because inspection lot sizes can be very small, statistical sampling plans, such as those covered in ASTM B 602, *Test Method for Attribute Sampling of Metallic and Inorganic Coatings*, may not be valid. However, such a statistical sampling plan is recommended for large lots.

Factors Affecting Coating Thickness

There are several factors that affect the coating thickness. The only two that are readily manageable by the galvanizer are the temperature of the zinc bath and the withdrawal rate of the reinforcing bar from the zinc bath. To a lesser degree, the roughness of the surface affects the coating thickness. Therefore, parts that have been over-pickled and are rough on the surface can develop thicker zinc-iron layers.

There are two conditions that are uncontrollable by the galvanizer that significantly affect the outcome of the finished galvanized coating. The first is the silicon and phosphorous content of the reinforcing steel. Certain levels of silicon and phosphorous tend to accelerate the growth of the zinc-iron alloy layers so that the coating continues to grow for the entire time the reinforcing steel is immersed in the zinc bath. The Sandelin Curve (Figure 9, below) shows the coating thickness produced by steels with different silicon levels by immersing them in zinc baths for the same amount of time. There are two regions where the coating can become very thick, between 0.05% and 0.14%, and over .25% silicon. The growth of coatings in these two regions of silicon concentration produces very thick and brittle coatings characterized by a matte gray surface, indicating a predominately zinc-iron intermetallic coating with little or no free-zinc outer layer.

Figure 9: Sandelin Curve.

Hot-dip galvanized coatings more than 12 mils (305 microns) thick can be susceptible to damage from rough handling. These thick coatings may experience flaking of the outer free zinc layer in areas where external stress is put on the bars. In more extreme cases, the coating can fracture at the interface between separate zinc-iron intermetallic layers, leaving only a fraction of the original coating thickness.

The second factor affecting coating thickness is the blend of various bar sizes in a reinforcing steel assembly. Different size bars will develop a zinc coating at a different rate. Larger bars must be kept in the zinc bath for a longer time in order to develop the minimum required thickness. In an assembly with different size bars, smaller ones tend to have thicker-than-normal coatings due to the need to keep larger bars in the bath for the required time.

Coating Appearance

ASTM A 123 and A 767 require that the zinc coating have no bare spots and be free of blisters, flux spots, inclusions, and large dross inclusions. The same specifications also state that a matte gray finish is not in and of itself a cause for rejection. The matte gray finish is a sign of accelerated growth of the zinc-iron inter-metallics due to steel with high levels of silicon. Cold-working may also result in this appearance. The ability of a galvanized coating to meet its primary objective of providing corrosion prevention should be the chief criteria in evaluating its overall appearance and in determining its suitability.

The galvanized coating must be continuous to provide optimum corrosion prevention. Handling techniques for galvanizing require the use of chain slings, wire racks, or other holding devices to lower material into the zinc bath. Chains, wires, and special fixtures used to
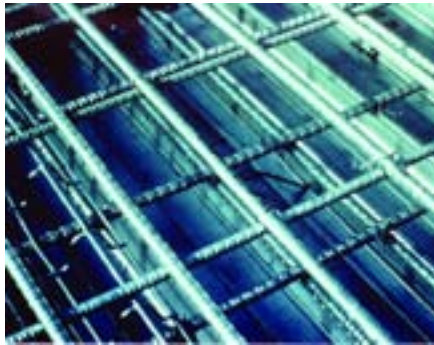
ASTM standards require the zinc coating to be free of major imperfections.

handle pieces may leave a mark on the galvanized item. These marks are not necessarily detrimental to the coating and are not a cause for rejection, unless they have exposed the bare steel or created a handling hazard for erection personnel. If needed, these areas can be adequately repaired according to ASTM A 780.

The surface roughness of the reinforcing steel after galvanizing also depends on the amount of silicon in the reinforcing steel. Often a matte gray coating will have a rough surface; this does not affect the performance of the reinforcing steel or the galvanized coating as the rebar is embedded in concrete.

Visual Inspection Guide

A visual inspection should be performed at the galvanizer's facility to ensure compliance with the coating appearance requirements. The following coating conditions may occur:

Bare Spots

Gross uncoated areas should be rejected. Small bare areas may be repaired according to ASTM A 780. Some of the causes of bare spots are:

1. Incomplete surface cleaning:
Remnants of paint, oil, grease, scale, or rust cause uncoated areas; the molten zinc does not bond to such residues.

2. Welding slag:
In assemblies that have been welded, slag deposits from welding procedures are resistant to the normal cleaning solutions used in the galvanizing process and must be mechanically removed.

3. Over-drying:
If the time between prefluxing and galvanizing is too long, or the drying temperature is too high, the steel may rust due to evaporation of the preflux and the zinc will not bond to these rusted areas.

4. Excess aluminum:
If the aluminum concentration in the zinc bath exceeds 0.01%, there may be an occurrence of dark areas on the coating surface.

5. Articles in contact:
The zinc in the galvanizing bath should have free access to all parts of the surface; articles should not be in contact throughout the galvanizing process.

Dross Protrusions

Dross is the zinc/iron alloy that forms in the galvanizing kettle. Dross usually settles on the bottom of the kettle and, if stirred up from the bottom, can attach to steel being galvanized. The galvanized coating will commonly form around the dross particles, although rough surfaces may result. This is not cause for rejection unless safe handing is compromised or removal due to handling will leave a spot under the dross article.

Blisters and Slivers

Blisters and slivers sometimes form as a result of surface and/or subsurface defects in the steel being galvanized. The possibility of this occurrence can be minimized by the communication among the galvanizer, fabricator, and steel supplier throughout the design phase of the project.

Flux Inclusions

Zinc ammonium chloride, or "flux," may adhere to steel being galvanized. Flux inclusions are not cause for rejection, assuming the underlying coating is sound and the flux deposits are removed.

Lumps and Runs

Areas of thicker coating, sometimes resulting from fast withdrawal rates or lower zinc bath temperatures, are not detrimental to coating performance.

Zinc Skimming

Zinc skimmings are the oxide film that develops on the surface of the molten zinc. Zinc skimmings picked up from the surface of the bath during withdrawal have no detrimental effect on corrosion prevention performance and are not cause for rejection.

Gray or Mottled Coating Appearance

Exposed zinc-iron alloy layers not covered by a layer of free zinc result in a matte gray or mottled coating. This may happen over the entire coating or in isolated areas. Steel chemistry contributes to this occurrence. Because coating appearance does not affect the corrosion prevention provided, mate gray or mottled coatings are not cause for rejection.

Brown Staining

If coatings with exposed intermetallic layers (zinc-iron alloy layers) are exposed to the environment, brown staining may appear. This results from the interaction between iron in the intermetallic layer and the atmosphere. Coating performance is not affected.

Rust Staining

If galvanized coatings come into contact with bare steel (such as chains used in transportation, etc.), there may appear to be rust staining on the galvanized steel surface. This is actually a superficial occurrence; the staining may be cleaned off before end-use.

Wet Storage Stain

The naturally-occurring formation of a tenacious, abrasion-resistant zinc carbonate patina provides yet another component to the protection afforded by galvanizing. The formation of this patina depends on the galvanized steel being exposed to freely-circulating air.

Stacking galvanized articles closely together for extended periods of time — thereby limiting access to freely-circulating air — can lead to the formation of a white, powdery product commonly called "wet storage stain."

Wet storage stain is often superficial, despite the possible presence of a bulky, white product. In the vast majority of cases, wet storage stain does not indicate serious degradation of the zinc coating, nor does it necessarily imply any like reduction in expected service-life.

If wet storage stain does form, the affected objects should be arranged so that their surfaces dry rapidly. Once dry, most stains can be easily removed by brushing with a stiff, nylon bristle brush. If the affected area will not be fully exposed in service, or if it will be subjected to an extremely humid environment, even superficial white films should be removed with a stiff, **nylon** bristle brush.

Galvanized Reinforcing Steel Testing

In addition to visual inspection, different properties and characteristics of hot-dip galvanized rebar may also be tested. These tests may need to be performed on specific lots of steel to ensure that they meet relevant standards, or on trial lots before they are put into end-use. Accredited labs experienced with the individual test procedures should perform these tests.

Bond Strength Test

The bond of the hot-dip galvanized reinforcing bar to the concrete can be tested according to ASTM A 944, *Test Methods for Comparing Bond Strength of Steel Reinforcing Bars to Concrete Using Beam-End Specimens*. The bond strength relies heavily on the deformation of the bar and not as much on the actual bond between the zinc and the concrete. For plain bars with no deformation, the bond between the zinc and the concrete becomes very important. Pullout strength of hot-dip galvanized reinforcing steel has been tested many times, and the values of bond strength are equivalent to, or better than, black steel bond strength, as illustrated in Table 3 (page 8).

Chromate Finish Test

If chromate coating is required, the existence of chromates may be verified using the method described in ASTM B 201, *Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces*. Because chromate conversion coatings will weather away fairly quickly, bars chromated after galvanizing may exhibit no chromate by the time they are embedded in concrete. The formation of zinc carbonate will begin as the chromate weathers away.

Embrittlement Tests

Higher-strength bars that have had considerable cold working may be susceptible to embrittlement during the galvanizing process. Guidelines for fabricating bars to be hot-dip galvanized are provided in ASTM A 143, *Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement*, and ASTM A 767. When embrittlement is suspected, ASTM A 143 designates the appropriate test method to determine the presence of embrittlement.

Accelerated Aging Test

Efforts have been made in many zinc-coated steel applications to develop the correct test method to determine a proper accelerated lifetime. One test for corrosion prevention system is ASTM B 117, *Practice for Operating Salt Spray (Fog) Apparatus*. ASTM Committee G-1 on Corrosion of Metals has jurisdiction over the salt spray standards B 117, and G 85-02, *Standard Practice for Modified Salt Spray (Fog) Testing*. The committee passed the following resolution regarding the use of B 117:

"ASTM Committee G-1, on the Corrosion of Metals, confirms that results of salt spray (fog) tests, run according to ASTM standard designation B 117, seldom correlate with performance in natural environments. Therefore, the committee recommends

that the test not be used or referenced in other standards for that purpose, unless appropriate, corroborating, long-term atmospheric exposures have been conducted.

"ASTM B 117 and B 368, Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (CASS Test), are best used as quality-control tests assuring that the day-to-day quality of products and manufacturing processes are optimized. There are a number of other corrosion tests which can be used for predicting performance in service."

Extensive use of hot-dip galvanized reinforcement, including this surrounding wall, was specified for a hospital in Australia. Galvanizing will help keep corrosion from creating severe spalling problems in this structure, located in the coastal city of Katingal, home to a highly-corrosive marine environment.

Salt spray tests cannot accurately test zinc-coated steel because they accelerate the wrong failure mechanisms. Without a proper wet/dry cycle, the zinc coating cannot form patina layers; the absence of a patina layer allows constant attack of the zinc metal and gives a very low prediction of the zinc coating lifetime. Additionally, because the corrosion rate of zinc embedded in concrete is significantly less than that of zinc in atmospheric conditions, and has never been subject to long-term analysis, correlation to salt spray test results is impossible.

Field Performance Examples of Galvanized Reinforcement

Bermuda

Hot-dip galvanized reinforcing steel in concrete has been used extensively since the early 1950s. One of the first installations occurred in the construction of the Longbird Bridge in Bermuda by the US Navy in 1953. Galvanized steel was used to reinforce the bridge deck in the construction of an 18-foot long, single-approach span concrete bridge.

The Bermuda marine environment is highly corrosive as exhibited in a 1978 inspection of bridges and quays conducted by Construction Technology Labs. This inspection included the Longbird Bridge and showed chloride levels in the concrete up to 4.3 kg/m3 (7.3lb/yd3). During this inspection, a low chloride

Watford Highway - Bermuda.

ion gradient across the concrete cores indicated that significant chlorides were already in the concrete at the time of placing (most likely from salt water used to mix the concrete). The internal chloride concentration, combined with salt spray from the nearby ocean, produce an extremely corrosive environment.

According to this inspection, the galvanized coating had only been slightly affected by corrosion, as 98% of the initial zinc (galvanized) coating remained intact.

A later inspection of the galvanized reinforcement in the Longbird Bridge was conducted in response to the Bermuda Ministry of Works and Engineering's unilateral specification of hot-dip galvanized reinforcement. In this report, evidence of zinc coating integrity was found on exposed sections of rebar during repairs made in 1984, after 30 years of exposure to extremely high chloride levels.

"The advantages and benefits of galvanized reinforcement in Bermuda's environment has been proved beyond doubt in practice. It's expected the that Ministry of Works and Engineering will continue to specify hot-dip galvanized reinforcement exclusively on all of its projects for a long time to come. It is hoped that other countries and organizations can benefit from Bermuda's positive experience with galvanized reinforcement"
— N.D. Allan, B.Sc. (Hons.) M.I.C.E., C. Eng.
Ministry of Works & Engineering, Bermuda

The unmatched corrosion protection that hot-dip galvanized steel provides when protecting reinforcing materials in concrete has caught the eye of many state DOTs and highway authorities. The NY State Thruway Authority, Penn DOT, and the Florida DOT have all made extensive use of galvanizing's ability to protect bridges from corrosion.

New York State Thruway Authority

The New York State Thruway Authority (NYSTA) has recently begun to specify hot-dip galvanized rebar for all of its current and future bridge decks. The thruway consists of over 600 miles of toll roads comprising major sections of Interstates 87, 84, and 90, with sections connecting to other interstate highways and toll roads to four neighboring states and Canada. Most of the NYSTA's 810 bridges are installed in fresh water environments, with the exception of a few that are close to the Atlantic Ocean and qualify as located in a marine environment. In addition to the close proximity to water, the bridges undergo freeze-thaw cycles, and have heavy exposure to deicing salts and industrial pollution, all adding up to a highly-aggressive corrosive environment. The need to protect these bridges from corrosion became a major concern to the thruway authority during the early 1960's when maintenance and inspection revealed extensive corrosion to previously installed bridge decks that incorporated bare steel reinforcement in the concrete.

Based on an FWHA endorsement and research conducted by numerous states, the New York Bridge Authority had seemingly solved its corrosion problem by implementing the use of epoxy-coated rebar in bridge decks during the early 1980s. In as little as ten years, doubts began to rise regarding the protection provided by these epoxy-coated systems. Within another four years, cracks began to appear in these bridge decks, at which time the thruway authority decided to utilize hot-dip galvanized rebar as its corrosion protection method of choice.

Another concern regarding the performance of epoxy-coated reinforcing steel arose during the NYSTA's pursuit to find an alternative corrosion protection system. Epoxy coatings were exhibiting inferior bonding to the concrete. When removing sections of concrete from epoxy-coated rebar during a repair of an improperly designed pier, the concrete was easily broken away from the epoxy-coated rebar. By specifying hot-dip galvanized rebar, this problem was eliminated due to the superior bond developed between the galvanized rebar and concrete.

> *"At this time, the NYSTA feels that it's on the right track by specifying galvanized reinforcing, unilaterally. We are getting materials of the specified quality, and we feel our contractors have readily adjusted to galvanized reinforcing and are giving us good installations.*
> *— Robert F. Grimm,*
> *Materials Engineer*
> *- New York State Thruway Authority*

The cathodic and barrier protection provided by hot-dip galvanized rebar has reduced repair costs incurred in handling the rebar in the field. Epoxy-coated rebar was getting damaged in the field due to rough handling at some of the New York bridge installations during the 1980s. Epoxy coatings only supply barrier protection for the underlying steel. If epoxy coatings become damaged during handling or installation, the barrier becomes broken and the corrosion protection for the rebar has been compromised. The superior bond strength and hardness properties of hot-dip galvanized coatings make it tough to damage under any material handling conditions, and if damaged does occur, the exposed bare steel will be protected by the sacrificial cathodic action of the surrounding zinc.

Life cycle cost analysis was performed by the NYSTA to compare the costs of galvanized and other competing coating systems. Initially, the cost of hot-dip galvanized rebar was slightly greater than epoxy coatings and bare steel on a per pound basis. However, the amount of rebar required for an epoxy-coated rebar installation is far greater than for black or galvanized rebar. Lap splices are significantly increased when specifying epoxy coated rebar. This fact alone brings the initial cost of specifying hot-dip galvanized rebar to an extremely competitive position. On a life cycle cost analysis, the maintenance-free hot-dip galvanized rebar is unmatched.

Pennsylvania DOT

The Pennsylvania DOT has specified galvanized reinforcement for decades. One such bridge, the Athens Bridge, was built in 1973 and is an eleven-span, four-lane, divided bridge that uses only hot-dip galvanized reinforcing bars.

The Athens bridge deck was inspected eight years after installation to ensure that hot-dip galvanizing was protecting the bridge from corrosion. Concrete cores were drilled and an analysis of chloride contamination and coating thickness was conducted. The chloride levels found in the cores exhibited concentrations between 1.8 to 7.9 lbs/yd^3 of concrete,

Athens Bridge - Pennsylvania.

where the high end of these concentrations is well above the threshold for active corrosion to occur on bare steel. Despite these extremely corrosive conditions, the coating thickness measurements indicated galvanized coatings in excess of 15 mils (approximately three times the coating thickness required on newly-galvanized rebar according to ASTM A 767). In all instances, the galvanized rebar showed no signs of corrosion.

The Athens Bridge was later inspected in 1991 and 2001, and the analysis generated similar results. No sign of active corrosion on the galvanized reinforcement was found and coating thickness measurements reported were in excess of ten mils. These current coating thicknesses indicate an estimated 40-plus years of additional maintenance-free corrosion protection.

Table 8: Bridge inspection summary.

Location	Installed	Inspection Date	Chlorides (lb/yd³)	Zinc Coating Thickness mils	Zinc Coating Thickness 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 Street 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.

It is estimated that over 500 galvanized bridges use hot-dip galvanized steel for corrosion protection. Inspections on these bridges are continually conducted in order to evaluate the performance of the galvanized reinforcement. Table 8 (page 14) is a brief summary of some of the more recent inspections that have

Tioga Bridge - Pennsylvania.

been made. The table verifies the outstanding performance of hot-dip galvanized rebar. With concerns arising over the performance of epoxy-coated reinforcement in concrete and the desire to produce bridges that last 100 years, hot-dip galvanizing is more than an alternative to epoxy-coated reinforcement but rather the premier corrosion protection system. The current inspections being done on existing bridge decks all report that hot-dip galvanized steel is performing extremely well and estimates have shown that most hot-dip galvanized reinforced bridge decks will provide at least 75 years of maintenance-free corrosion protection in the most severe environments.

Additional Resources

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ASTM and CSA Specifications*

ASTM A 90
Test Method for Weight (Mass) of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

ASTM A 123
Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products

ASTM A 143
Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement

ASTM A 615
Specification for Deformed and Palin Billet-Steel Bars for Concrete Reinforcement

ASTM A 616
Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement

ASTM A 617
Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement

ASTM A 653
Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process

ASTM A 706
Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

ASTM A 767
Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement

ASTM A 780
Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings

ASTM A 944
Test Methods for Comparing Bond Strength of Steel Reinforcing Bars to Concrete Using Beam-End Specimens

ASTM B 117
Practice for Operating Salt Spray (Fog) Apparatus

ASTM B 201
Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces

ASTM B 386
Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (CASS Test)

ASTM B 487
Test Method for Measurement of Metal and Oxide Coating Thickness of Microscopial Examination of a Cross Section

ASTM B 602
Test Method for Attribute Sampling of Metallic and Inorganic Coatings

ASTM E 376
Practice for Measuring Coating Thickness by Magnetic-Field of Eddy-Current (Electromagnetic) Test Methods

CSA G 85-02
Standard Practice for Modified Salt Spray (Fog) Testing

CSA G 164
Galvanizing of Irregularly-Shaped Articles

*For more information or copies of the specifications listed above, contact: