INSPECTION

of hot-dip galvanized steel products

02

AMERICAN GALVANIZERS ASSOCIATION

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PURPOSE OF INSPECTION

Hot-dip galvanizing is one of the most economical, maintenance-free corrosion protection systems available. Like any other manufacturing process, hot-dip galvanized steel requires an inspection of the finished product to ensure compliance with applicable specifications. The inspection process requires a clear understanding of specification requirements and compliance measurement techniques to make an accurate assessment.

A key feature of hot-dip galvanized (HDG) products is durability, which yields decades of maintenance-free performance. For any environment, the time to first maintenance of HDG steel is directly proportional to the thickness of the zinc coating. To plan for this extended service life, the estimated time to first maintenance in atmospheric exposures can be seen in *Figure 1*.

Coating thickness is an important requirement in the specification and effectiveness of hot-dip galvanizing as a corrosion protection system. However, measuring coating thickness is only one of the many specification requirements in the inspection process. Other key requirements include adherence, appearance, and finish.

The difference between these specifications is the type of steel product covered by each. ASTM A123/A123M covers structural steel, pipe and tubing, flat/round bar, wire, reinforcing steel and assemblies of these steel products. ASTM A153/A153M includes small castings, nails, nuts, bolts, washers, and small parts centrifuged after galvanizing to remove excess zinc. And ASTM A767/A767M covers only reinforcing steel bars.

In Canada, the specification CSA G164 covers the requirements for all hot-dip galvanized articles, and ISO 1461 is the standard most commonly used in Europe. In all cases, the inspection of hot-dip galvanized steel is conducted at the galvanizing plant prior to shipment of the product.

The requirements for hot-dip galvanized coatings are found in three ASTM specifications;

- **A123/A123M *Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products***
- **A153/A153M *Specification for Zinc Coating (Hot-Dip) on Iron and Hardware***
- **A767/A767M *Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement***

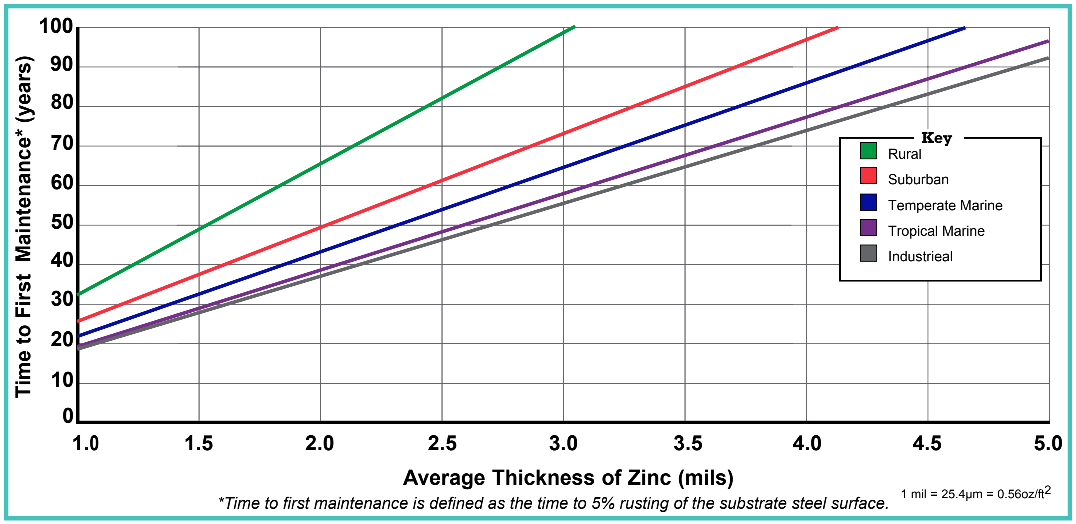


FIGURE 1: TIME TO FIRST MAINTENANCE OF HOT-DIP GALVANIZED COATINGS

ADDITIONAL RESOURCES

The American Galvanizers Association (AGA) offers a free online inspection course to train individuals on the proper inspection techniques and requirements for hot-dip galvanized steel products. Alternatively, the AGA offers a free app available in both the Apple and Google Play stores.

galvanizeit.org/inspection

Types of Inspection

There are a number of different inspections that can be conducted on hot-dip galvanized steel. The majority of these inspections happen immediately after the coating is applied and has cooled to ambient temperature, before it leaves the galvanizing facility, to verify the requirements of the specifications are met. However, once the hot-dip galvanized steel is being erected and after it is in place, ongoing field inspections are common. The next sections will review the various types of initial inspection as well as best practices for field inspection.

COATING MEASUREMENT

As mentioned, the most scrutinized element in the inspection of hot-dip galvanized steel is the coating thickness. The specifications provide minimum zinc coating requirements for a given material classes and measured steel thickness. The amount of coating can be specified by thickness or weight per surface area. The specifications include tables providing specific requirements for thickness or weight per surface area based upon the steel part type and the measured steel thickness.

The minimum coating requirements specified by ASTM for different classes of work are summarized in *Table 1* and *Table 1A* for ASTM A123/A123M, *Table 2* for ASTM A153/A153M (next page), and *Table 3* for ASTM A767/A767M (next page).

COATING THICKNESS GRADE

Coating Grade	mils	oz/ft^2	µm	g/m^2
35	1.4	0.8	35	245
45	1.8	1.0	45	320
50	2.0	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

TABLE 1A: COATING THICKNESS GRADES FROM ASTM A123/A123M

MINIMUM AVERAGE COATING THICKNESS GRADE BY MATERIAL CATEGORY ASTM A123/A123M

Material Category	All Specimens Tested [Steel Thickness Range (Measured), in (mm)]					
	<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 to <5/8 (≥6.4 to <16.0)	≥5/8 (≥16.0)
Structural Steel	45	65	75	75	100	100
Strip and Bar	45	65	75	75	75	100
Plate	45	65	75	75	75	100
Pipe and Tubing	45	45	75	75	75	75
Wire	35	50	60	65	80	80
Reinforcing Bar	-	-	-	-	100	100

TABLE 1: MINIMUM COATING THICKNESS FROM ASTM A123/A123M (SEE TABLE 1A FOR INFORMATION ON COATING THICKNESS GRADE)

MINIMUM AVERAGE COATING THICKNESS BY MATERIAL CLASS– ASTM A153/A153M

		Minimum Weight of Zinc Coating, oz/ft²(g/m²) of Surface		Minimum Thickness, Mils (Microns)	
Class of Material		Average of Specimens Tested	Any Individual Specimen	Average of Specimens Tested	Any Individual Specimen
Class A -	Castings, Malleable Iron, Steel	2.00 (610)	1.8 (550)	3.4 (86)	3.1 (79)
Class B -	Rolled, Pressed and Forged Articles (Except those which would be included under Class C or D)				
B-1 -	5/8in (15.88mm) and over in Thickness and over 15in (381mm) in length	2.00 (610)	1.80 (550)	3.4 (86)	3.1 (79)
B-2 -	Under 5/8in (15.88mm) in Thickness and over 15in (381mm) in length	1.50 (458)	1.25 (381)	2.6 (66)	2.1 (53)
B-3 -	Any Thickness and 15in (4.76mm) and under in length	1.30 (397)	1.10 (336)	2.2 (56)	1.9 (48)
Class C -	Fasteners over 3/8in (9.52mm) in diameter and similar articles, washers 3/16in (4.76mm) and greater in thickness	1.25 (381)	1.00 (305)	2.1 (53)	1.7 (43)
Class D -	Fasteners 3/8in (9.52mm) and under in diameter, rivets, nails and similar articles, washers under 3/16in (4.76mm) in thickness	1.00 (305)	0.85 (259)	1.7 (43)	1.4 (36)

Note: Length of the piece, stated in Classes B-1, B-2 and B-3, refers to the finished dimensions of the piece after fabrication

TABLE 2: MINIMUM COATING THICKNESS FROM ASTM A153/A153M

MINIMUM COATING THICKNESS BY CLASS ASTM A767/A767M (REINFORCING BARS)

Coating Class	Mass of Zinc Coating, (g/m²) oz/ft² of Surface
Class I	
Bar Designation size No. 10 (3)	915 (3.00)
Bar Designation size No. 13 (4) & Larger	1070 (3.50)
Class II	
Bar Designation size No. 10 (3) & larger	610 (2.00)

TABLE 3: MINIMUM COATING THICKNESS FROM ASTM A767/A767M

Coating Thickness

Coating thickness refers to the thickness of the final hot-dip galvanized coating. Two different methods can be used to measure the coating thickness of hot-dip galvanized steel; a magnetic thickness gauge and optical microscopy. Utilizing a magnetic thickness gauge is a non-destructive, simple way to measure coating thickness. There are three different types of magnetic thickness gauges.

The **Pencil-Style Gauge** (*Figure 2*) is pocket-size and employs a spring-loaded magnet encased in a pencil-like container. Its accuracy depends on the skill of the inspector, thus the measurement should be made multiple times.

FIGURE 2: PENCIL-STYLE GAUGE

The **Banana Gauge** (*Figure 3*) measures coating thickness in any position, without recalibration or interference from gravity.

FIGURE 3: BANANA GAUGE

The **Electronic or Digital Thickness Gauge** (*Figure 4*) is the most accurate and easiest to use. Electronic gauges can also store data and perform averaging calculations.

FIGURE 4: DIGITAL THICKNESS GAUGE

The specification ASTM E376 *Practice for Measuring Coating Thickness by Magnetic-Field or Eddy Current (Electromagnetic) Examination Methods* contains procedures for measuring coating thickness as accurately as possible.

The other method to measure coating thickness, **optical microscopy** (*Figure 5*), is a destructive technique that exposes the edge of a coating under an optical microscope. The sample must be sectioned, then mounted and polished to show the exposed edge of the hot-dip galvanized coating. The calibrated eyepiece of an optical microscope can then determine the thickness of the coating. Since this technique destroys the part being measured, it is only used as a referee method for resolving measurement disputes.

Coating Weight

Coating weight refers to the mass of hot-dip galvanized coating applied to a product for a given surface area. Two different methods can be used to measure the coating weight of hot-dip galvanized steel. The first method uses a process called **weigh-galvanize-weigh**, and is only appropriate for single specimen samples. Weigh-galvanize-weigh measures the weight of a steel part after it has been cleaned, and again after it has been galvanized. This technique only measures the zinc metal added to the steel and will underestimate the total coating weight by up to 10 percent.

The second method is a destructive technique called **weigh-strip-weigh**, and again, is only appropriate for single specimen samples. Weigh-strip-weigh measures the weight immediately after a galvanized part is cooled, and again after the coating has been stripped off the part using an acid solution. The weigh-strip-weigh renders the part unusable as the coating is removed. The weights must then be divided by the surface area of the steel part to determine a value that can be compared to the specification requirements.

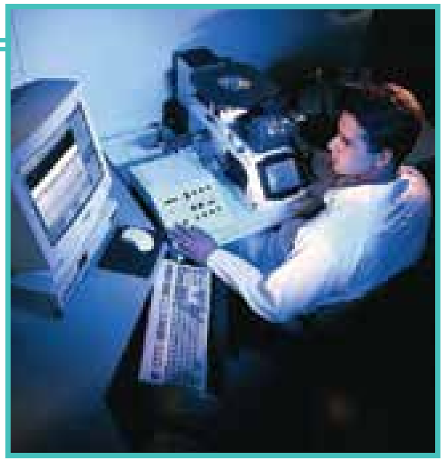


FIGURE 5: OPTICAL MICROSCOPY

VISUAL INSPECTION FOR FINISH & APPEARANCE

Several factors can affect the finish and appearance of hot-dip galvanized coatings. Some of these factors can be controlled by the galvanizers while others cannot. The inspection of finish and appearance is done with an unmagnified visual inspection, which is performed by fully observing all parts and pieces of a hot-dip galvanized product or assembly to ensure all specification requirements have been met. Visual inspection is done in order to observe surface conditions (both inside and out) and to check all contact points, welds, junctions, and bend areas. The visual inspection should be completed at the galvanizing facility before the part is shipped.

Different Appearances

The appearance of the hot-dip galvanized coating can vary from piece to piece, and even section to section of the same piece. Common appearances for hot-dip galvanized steel immediately after galvanizing include bright and shiny, spangled, matte gray, and/or a combination of these. There are a number of reasons for the non-uniform appearance; however, it is important to note appearance has no bearing on the corrosion protection of the piece. Furthermore, in time, after exposure to the environment, all galvanized coatings will take on a uniform, matte gray appearance, as seen in the *Case Study*.

CASE STUDY

Hot-dip galvanized (HDG) steel is specified because it provides maintenance-free corrosion protection for decades. However, some architects and engineers under-utilize HDG because of concerns about its appearance. Due to steel chemistry, fabrication processes, and other factors, the initial appearance of hot-dip galvanized steel can vary from bright and shiny to matte gray, or a mixture of both. Many specifiers erroneously equate the appearance of the coating with coating quality. It is important to note the durability of galvanized coatings is not determined by the appearance, but rather by the zinc coating thickness. Regardless of the external appearance of the coating initially, all galvanized pieces will protect steel from corrosion for decades. Additionally, as the galvanized steel weathers, initial variances in appearance will fade, producing a uniform, matte gray coating.

A great example of this transformation is the canopied walkway at Mark Twain Elementary in Riverside, CA. The galvanized canopies were installed in October of 2006, and the initial coating appearance varied (*left photo*) from bright and shiny to matte gray on the same beam. In June of 2009, the structure was revisited to examine the appearance and performance. The beams are now all uniformly matte gray with little to no visible difference in appearance (*right photo*). Additionally, as hot-dip galvanizing provides 75 years or more of maintenance-free corrosion protection, the beams show no signs of rust staining or corrosion damage. Hot-dip galvanized steel not only provides superior corrosion protection, but once in service will also sustain an aesthetically pleasing, uniform matte gray appearance for decades without maintenance. Preventing unsightly corrosion and rust staining, as well as costly maintenance will provide Mark Twain Elementary with a structure both easy on the eyes and the budget well into the future.

OCTOBER 2006

JUNE 2009

Steel Chemistry

The most common reason for galvanized steel to have different appearances is the chemistry of the steel pieces. There are two elements of steel chemistry which most strongly influence the final appearance; silicon and phosphorous. Both elements are catalysts to coating growth, and the thicker coating is responsible for the differing appearance.

Silicon is added during the steel-making process to deoxidize the molten steel. The recommended silicon composition for steel to be galvanized is either less than 0.04% or between 0.15% and 0.22%. Steels outside these ranges are considered reactive steels and can be expected to form zinc coatings thicker than average. The Sandelin Curve (*Figure 6)* compares the zinc coating thickness to the mass percentage of silicon in the steel.

In addition to producing thicker coatings, highly reactive steels tend to have a matte gray or mottled appearance instead of a typical bright coating. This difference in appearance is a result of the rapid zinc-iron intermetallic growth. This growth of the intermetallic layer is out of the galvanizer's control; however, if he is aware of the steel's composition beforehand, he can utilize some process controls to minimize the effect. *Figure 7* shows the differences between the alloy formations on steel with recommended silicon ranges (*left*) and those of reactive steels (*right*). Though the appearance and microstructure differ, the increased coating thickness can be beneficial in some respects as the time to first maintenance is linearly related to coating thickness.

Similar to silicon, the presence of phosphorus influences the reaction between molten zinc and steel. *Figure 8* shows steel with phosphorus levels over 0.04% which produces matte gray coating areas and a rough surface with ridges of thicker coating where there is increased intermetallic growth.

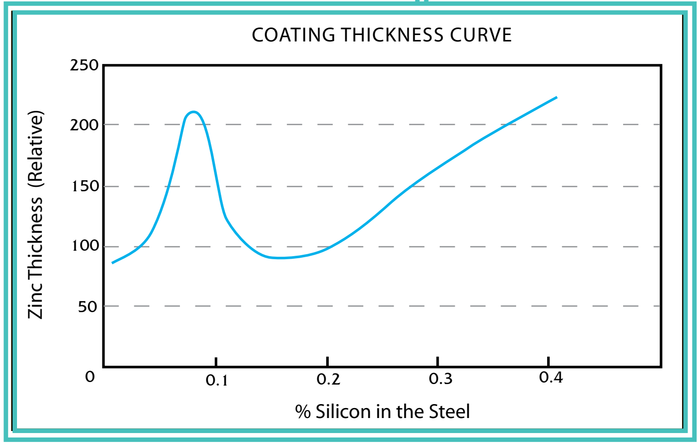


FIGURE 6: SANDELIN CURVE

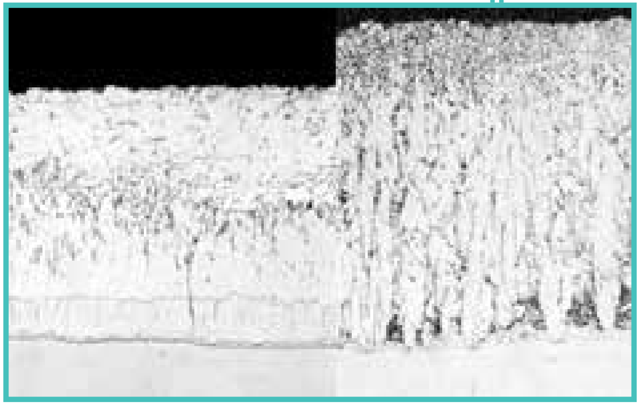


FIGURE 7: RECOMMENDED SILICON VS. REACTIVE STEEL

FIGURE 8: ROUGH COATING DUE TO PHOSPHOROUS LEVELS OVER 0.04% (ACCEPTABLE UNLESS HANDRAIL)

Figure 9 shows connected galvanized pieces with different appearances due to steel chemistry. This is often observed when connecting different types or thicknesses of steel, but can also occur on similar pieces. Another common place this is found is in welded areas, as the silicon content of the weld rod can influence appearance. Regardless of the appearance, all of these products have an equal amount of corrosion protection and meet the specification requirements.

FIGURE 9: SHINY VS. DULL (ACCEPTABLE)

Cooling Rate

A steel part with both dull and shiny coating can also be the result of a different cooling rate. In *Figure 10,* the outer edges of the product were cooled rapidly, allowing a free zinc layer to form on top of the intermetallic layers. The center of the product remained above 550 F longer and the metallurgical reaction between zinc and iron continued in the solid state, consuming the free zinc layer, resulting in a matte gray look. As the product weathers, the differences in appearance will become less noticeable and the overall color will turn a uniform, matte gray.

FIGURE 10: GRAY COATING DUE TO UNEVEN COOLING RATE (ACCEPTABLE)

FIGURE 11: GRAY COATING DUE TO PROCESSING (ACCEPTABLE)

Steel Processing

The fabrication and processing of the steel can also create a bright or dull appearance in galvanized products. The top rail in *Figure 11* has a winding pattern of dull gray areas corresponding to the process used during the making of the tube. The stresses in the steel from processing affect the intermetallic formation and can result in this striped look. The corrosion protection is not affected, thus these parts meet the specification.

Surface Conditions

When inspecting the finish of the hot-dip galvanized coating, a variety of surface conditions can be observed. Several factors can affect the finish of the galvanized coating – some of these factors can be controlled by the galvanizer while others cannot. The specification requirement for finish is the coating must be smooth, uniform, and continuous. There are many subjective interpretations for what that means; however, the key to whether surface conditions are acceptable or not relates to its effect on the long-term corrosion performance. If the surface condition will not lessen the long-term corrosion resistance of the piece, it is acceptable. On the other hand, if the condition compromises the life of the coating, it is cause for rejection.

If a hot-dip galvanized steel part has been rejected for any reason other than embrittlement, the part may be repaired and/or regalvanized and resubmitted for inspection. There are specific limitations to repairable areas, which will be discussed later in this publication. If the area does not meet the requirements for repair, the part can be stripped and regalvanized and then inspected again. It is important to note galvanizing does not change the mechanical properties of the steel, so there is no additional issue/concern with stripping and regalvanizing the part.

The following is a review of surface conditions that can be present after galvanizing, including an overview of the cause of the condition and whether it is acceptable or rejectable according to the specifications.

Bare Spots

Bare spots, uncoated areas on the steel surface, are a surface defect that can occur because of inadequate surface preparation. Bare spots may be caused by welding slag, sand embedded in castings, excess aluminum in the galvanizing kettle, or lifting devices that prevent the coating from forming in a small area. In order to avoid bare spots, (*Figure 12*), the galvanizer must ensure the surfaces are clean and without rust after pretreatment. Small bare spots can be repaired in the galvanizing shop. If the size of the bare spot or total number of spots causes rejection, the parts may be stripped, regalvanized, and then re-inspected for compliance to the specifications.

FIGURE 12: BARE SPOTS (REJECTABLE)

FIGURE 13: BLASTING DAMAGE (REJECTABLE)

Blasting Damage

Blistered or flaking areas on the surface of the galvanized product can occur due to blasting damage prior to painting of the galvanized steel. It is caused by incorrect abrasive blasting procedures creating shattering and delamination of the alloy layers in the zinc coating. Blasting damage (*Figure 13*) can be avoided when careful attention is paid to preparation of the product for painting or powder coating. In addition, blast pressure should be greatly reduced according to ASTM D6386 *Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Paint.* More information about proper surface preparation of hot-dip galvanized steel for painting or powder coating can be found in the American Galvanizers Association's (AGA) *Preparing Hot-Dip Galvanized Steel for Paint or Powder Coating* instructional DVDs and guide booklets. Since blasting damage is induced by a post-galvanizing process, the galvanizer is not responsible for the damage.

FIGURE 14: CHAIN AND WIRE MARKS (ACCEPTABLE UNLESS BARE STEEL IS EXPOSED)

Chain & Wire Marks

Another type of surface defect occurs when steel is lifted and transported using chains and wires attached to overhead cranes. Lifting devices can leave uncoated areas on the finished product that will need to be renovated. Superficial marks (*Figure 14)* left on the galvanized coating from the lifting attachments are not grounds for rejection unless the marks expose bare steel; in such a case, the galvanizer must repair the bare areas before the part is acceptable. One potential way to avoid these types of marks is to design permanent or temporary lifting points in the fabrication.

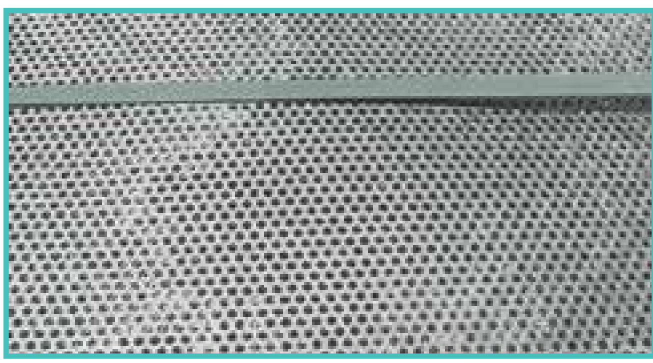


FIGURE 15A: CLOGGED HOLES < 1/2IN (ACCEPTABLE), HOLE SIZE ≥ 1/2 IN (ACCEPTABLE AFTER CLEANING)

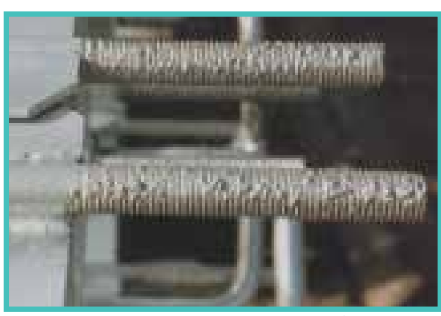


FIGURE 15B: CLOGGED THREADS (ACCEPTABLE AFTER THREADS ARE CLEANED)

Clogged Holes & Threads

Clogged holes are caused by molten zinc metal not draining adequately and partially or completely filling holes with zinc. Molten zinc will not drain easily from holes less than 3/32" (3mm) in diameter due to the viscosity of zinc metal. A good example is the screen shown in (*Figure 15a*). Clogged holes can be minimized by making all holes as large as possible; regardless, clogged holes less than 1/2" (12.7mm) in diameter are not a cause for rejection, unless it prevents the part from being used for its intended purpose.

Similarly, clogged threads are caused by poor drainage of the threaded section after the product is withdrawn from the galvanizing kettle. Clogged threads, (*Figure 15b*), can be cleaned by using post-galvanizing cleaning operations such as a centrifuge or by heating them with a torch to approximately 500 F (260 C) and then brushing them off with a wire brush to remove the excess zinc. Clogged threads must be cleaned and free of excess zinc before the part will meet the specification.

Delamination & Peeling

Delamination or peeling creates a rough coating on the steel where the zinc has come off. There are a number of causes for zinc peeling. Many thick galvanized parts take a long time to cool in the air and continue to form zinc-iron layers after they have been removed from the galvanizing kettle. This continued coating formation leaves behind a void between the top two layers of the galvanized coating. If there are many voids formed, the top layer of zinc can separate from the rest of the coating and peel off the part. If the remaining coating still meets the minimum specification requirements, then the part is acceptable. If the coating that remains on the steel does not meet the minimum specification requirements, then the part must be rejected and regalvanized. If delamination (*Figure 16*) occurs as a result of fabrication after galvanizing, such as blasting before painting, then the galvanizer is not responsible for the part acceptance.

FIGURE 16: DELAMINATION (ACCEPTABLE IF MINIMUM THICKNESS LEVELS ARE MET)

Distortion & Warpage

Warpage and distortion are caused by the thermal changes steel parts or assemblies encounter during the hot-dip galvanizing process. Steel parts or assemblies are susceptible to warpage and distortion through residual stress in the part from fabrication or from asymmetrical designs. *Figure 17* shows checkered plate which is asymmetrical due to the fabrication of the checkers on one side of the part. This can also happen to designs that combine thick and thin steel components together into an asymmetrical assembly. The thinner section reaches the zinc bath temperature quickly and expands while the thick portion of the assembly increases temperature slowly preventing the thinner parts from expanding, causing significant stress within the assembly. Best practice to avoid warpage and distortion dictates fabricating parts with similar steel thickness and/or temporary bracing. For more on minimizing distortion, please see the AGA's publication *The Design of Products to be Hot-Dip Galvanized after Fabrication.* Many distorted items can be manually formed or laid flat after galvanizing to bring the part to an acceptable final condition.

FIGURE 17: DISTORTION (ACCEPTABLE)

Drainage Spikes

Drainage spikes or drips are teardrops of zinc along the edges of a product. These are caused when steel products are removed from the galvanizing kettle, and the zinc does not flow freely back into the kettle (*Figure 18*). Drainage spikes are typically removed during the inspection stage by a buffing or grinding process. Comprised of excess zinc, drainage spikes and drips will not affect corrosion protection, but are potentially dangerous for anyone who handles the parts. Therefore, these spikes must be removed before the part can be accepted.

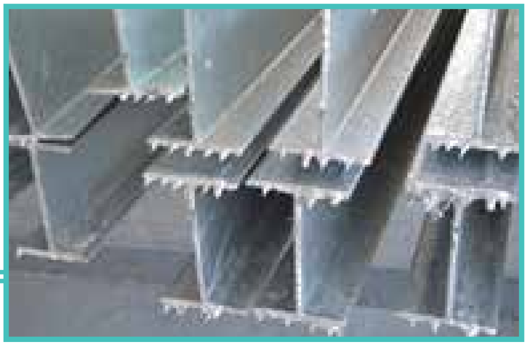


FIGURE 18: DRAINAGE SPIKES (ACCEPTABLE AFTER REMOVAL OR FILING)

Dross Inclusions

Dross inclusions are a distinct particle of zinc-iron intermetallic alloy that can become entrapped or entrained in the zinc coating (*Figure 19*). Dross inclusions may be avoided by changing the lifting orientation or redesigning the product to allow for more effective drainage. If the dross particles are small and completely covered by zinc metal, they will not affect the corrosion protection; and thus, are acceptable. If there are gross dross particles (large inclusions) that prevent the full galvanized coating from forming on the steel, then the particles must be removed and the area repaired.

FIGURE 19: DROSS INCLUSIONS (ACCEPTABLE UNLESS LARGE, AND IF REMOVED, A BARE SPOT IS EXPOSED)

Excess Aluminum In Bath

Galvanizers are required to have a bath of 98% pure zinc, according to the product specifications ASTM A123, A153, and A767, while the remaining 2% is comprised of additives at the galvanizer's discretion. One common additive is aluminum, which improves the aesthetic of the coating. When excess aluminum is in the galvanizing bath, it can create black marks or bare spots on the surface of the steel, which can be seen immediately upon withdrawal from the bath (*Figure 20*). Bare spots due to excess aluminum in the bath can be repaired if only small areas are evident; however, if this condition occurs over a signification portion of the part, it must be rejected, stripped, and regalvanized.

FIGURE 20: EXCESS ALUMINUM IN GALVANIZING BATH (REJECTABLE)

Flaking

When heavy coatings (12 mils or more) develop during the galvanizing process, flaking can result. Excessively thick coatings generate high stresses at the interface of the zinc/iron intermetallic layers which causes the zinc coating to become flaky and separate from the steel surface (*Figure 21*). Flaking can be avoided by minimizing the immersion time in the galvanizing kettle and cooling of the galvanized steel parts as quickly as possible, and/or if possible using a different steel grade. If the area of flaking is small, it can be repaired and then accepted; however, if the flaking area is larger than allowed by the specifications, the part must be rejected and regalvanized.

FIGURE 21: FLAKING (REJECTABLE)

Flux Inclusions

Flux inclusions are created by the failure of the flux to release during the hot-dip galvanizing process, preventing the coating from forming. Because no coating grows under the inclusion, the area must be repaired prior to acceptance. If the area is small enough, it can be cleaned and repaired with touch-up, but if the flux inclusion covers a large area, the part must be rejected. Flux deposits on the interior of a hollow part, such as a pipe or tube, (*Figure 22*) cannot be repaired and thus must be rejected. Parts rejected for flux deposits may be stripped of their zinc coating and then regalvanized to provide an acceptable coating.

FIGURE 22: FLUX INCLUSIONS FROM INTERIOR OF PIPE (REJECTABLE)

Oxide Lines

Oxide lines are light colored film lines on the galvanized steel surface created when a product is not removed from the galvanizing kettle at a constant rate (*Figure 23*). The inconsistent rate of withdrawal may be due to the shape of the product or the drainage conditions. Oxide lines will fade over time as the entire zinc surface weathers (oxidizes). Strictly an aesthetic condition, oxide lines have no effect on the corrosion performance; and therefore, are not a cause for rejection of hot-dip galvanized parts.

FIGURE 23: OXIDE LINES (ACCEPTABLE)

Products In Contact/Touch Marks

Another surface defect can occur if steel parts come in contact with one another or are stuck together during the galvanizing process. This can occur when many small products are hung on the same fixture, creating the chance products may become connected or overlapped during the galvanizing process (*Figure 24*). The galvanizer is responsible for proper handling of all steel parts in order to avoid defects from products in contact.

A similar type of surface defect, touch marks are damaged or uncoated areas on the surface of the product caused by galvanized products resting on one another or by the material handling equipment used during the galvanizing operation. Touch marks (*Figure 25*) may be cause for rejection, but may be repaired if their size meets the specification requirement for repairable areas.

FIGURE 24: PRODUCTS IN CONTACT (ACCEPTABLE UNLESS BARE SPOT)

FIGURE 25: TOUCH MARKS (REJECTABLE)

FIGURE 26: ROUGH SURFACE CONDITION/ STEEL SURFACE CONDITION (ACCEPTABLE)

Rough Surface Conditions

Rough surface condition or appearance is a uniformly textured appearance over the entire product (*Figure 26*). The cause for rough surface condition could be the steel chemistry or the preparation of the surface by mechanical cleaning, such as blasting before the part reaches the galvanizer. Rough surface condition can actually have a positive effect on corrosion performance because a thicker zinc coating is produced; and therefore, rough coatings are usually not cause for rejection. However, one of the few situations where rough coating is cause for rejection is on handrails, as it impacts the intended use of the product and should be smoothed prior to use.

FIGURE 27: RUNS (ACCEPTABLE)

Runs

Runs are localized thick areas of zinc on the surface that occur when zinc freezes on the surface of the product during removal from the zinc bath (*Figure 27*). Runs are not cause for rejection unless they affect the intended use of the steel part. If runs are unavoidable due to the design of the product, but will interfere with the intended application, they can be buffed.

FIGURE 28: RUST BLEEDING (ACCEPTABLE)

Rust Bleeding

Rust bleeding appears as a brown or red stain that leaks from unsealed joints after the product has been hot-dip galvanized (*Figure 28*). It is caused by pre-treatment chemicals that penetrate an unsealed joint. During galvanizing of the product, moisture boils off the trapped treatment chemicals leaving anhydrous crystal residues in the joint. Over time, these crystal residues absorb water from the atmosphere and attack the steel on both surfaces of the joint, creating rust that seeps out of the joint. Rust bleeding can be avoided by seal welding the joint where possible or by leaving a gap greater than 3/32" (2.4mm) wide in order to allow solutions to escape and zinc to penetrate during hot-dip galvanizing. If bleeding occurs, it can be cleaned up by washing the joint after the crystals are hydrolyzed. Bleeding from unsealed joints is not the responsibility of the galvanizer and is not cause for rejection.

FIGURE 29: SAND EMBEDDED IN CASTING (REJECTABLE)

Sand Embedded In Castings

Sand inclusion defects occur when sand becomes embedded in castings and creates bare spots on the surface of the galvanized steel (*Figure 29*). Sand inclusions are not removed by conventional acid pickling; therefore, abrasive cleaning must be done before the products are sent to the galvanizer. Because this defect leaves bare spots, it must be cleaned and repaired, or the part must be rejected, stripped, and regalvanized.

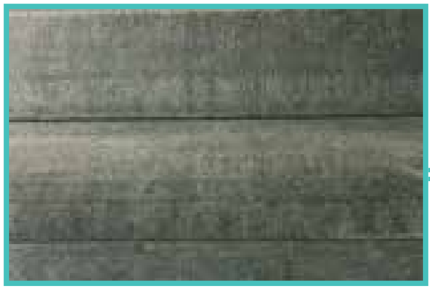


FIGURE 30: STRIATIONS (ACCEPTABLE)

FIGURE 31: FISH BONING (ACCEPTABLE)

Striations & Fish Boning

Striations are characterized by raised parallel ridges in the galvanized coating, which can be caused by the chemical composition of the steel. Striations, (*Figure 30*) are related to the type of steel that was galvanized, and while the appearance is affected, the performance of the corrosion protection is not; therefore, striations are acceptable.

Fish-boning, (*Figure 31*) similar to striations, is an irregular pattern over the entire surface of the steel part, which is caused by differences in the surface chemistry of a large diameter steel piece and variations in the reaction rate between the steel and molten zinc. These surface conditions do not affect the corrosion resistance and are acceptable.

Surface Contaminants

Contaminants on the steel surface not removed by pretreatment will create an ungalvanized area where the contaminant was originally located. Paint, oil, wax, lacquer, or other contaminants chemical cleaning cannot remove cause this; thus, surface contaminants *(Figure 32)* should be mechanically removed prior to the galvanizing process. If they cause bare areas on the final product, they must be remedied. If the area meets size limits in the specification, it may be repaired; however, if the area is too large, the part must be rejected and regalvanized.

FIGURE 32: SURFACE CONTAMINANT (REJECTABLE)

Weeping Weld

Weeping welds stain the zinc surface at welded connections on the steel. Caused by entrapped cleaning solutions that penetrate the space between the two pieces, weeping welds can be avoided by providing a 3/32” (2.4mm) or larger gap between the two pieces when welding them. This will allow the zinc to penetrate the gap. The weld must then be made with gaps instead of continuous weld bead, actually making a stronger joint when the process is complete. Weeping welds *(Figure 33)* are not the responsibility of the galvanizer and are not cause for rejection.

FIGURE 33: WEEPING WELD (ACCEPTABLE)

FIGURE 34: WELDING BLOWOUT (REJECTABLE)

Welding Blowouts

Welding blowout is a bare spot around a weld or overlapping surface hole caused by pre-treatment liquids penetrating the sealed and overlapped areas that boil out during immersion in the molten zinc. Blowouts cause localized surface contamination and prevent the galvanized coating from forming. In order to avoid welding blowouts *(Figure 34)*, check weld areas for complete welds to ensure there is no fluid penetration. In addition, products can be preheated prior to immersion into the galvanizing kettle in order to dry out overlap areas as much as possible. Bare areas caused by welding blowouts must be repaired before the part is acceptable.

FIGURE 35: WELDING SPATTER (REJECTABLE)

Welding Spatter

Welding spatter appears as lumps in the galvanized coating adjacent to weld areas due to spatter left on the surface of the part from fabrication *(Figure 35)*. To avoid bare spots in the coating, welding residues should be removed prior to hot-dip galvanizing. Welding spatter appears to be covered by the zinc coating, but the coating does not adhere well and can be easily removed, leaving an uncoated area or bare spot. If this defect occurs, the area must be cleaned and properly repaired, which may require regalvanizing.

Wet Storage Stain

Wet storage stain is a white, powdery surface deposit on freshly galvanized surfaces. Wet storage stain is caused by newly galvanized surfaces being covered by moisture, such as rain, dew, or condensation, and having no air flow over the surface. Water reacts with the zinc metal on the surface to form zinc oxide and zinc hydroxide. Wet storage stain is most often found on stacked and bundled items, such as galvanized sheets, plates, angles, and bars. It can have the appearance of light, medium, or heavy white powder on the galvanized steel product *(Figure 36)*.

One method to avoid wet storage stains is to passivate the product after galvanizing by using a quench solution. Another precaution is to avoid stacking products in poorly ventilated, damp conditions. Light or medium wet storage stain will weather over time in service and is acceptable. In most cases, wet storage stain does not indicate serious degradation of the zinc coating, nor does it necessarily imply any likely reduction in the expected life of the product; however, heavy wet storage stain should be removed mechanically or with appropriate chemical treatments before the galvanized part is put into service. Heavy wet storage stain must be removed or the part must be rejected and regalvanized.

The galvanizer is responsible for following best practices for avoiding wet storage stain on parts stored at the galvanizing facility. When those best practices are followed, the galvanizer is not responsible for wet storage stain developed at his facility, during transit, or storage at the job site prior to use. For more information on avoiding and/or removing wet storage stain, please see the AGA's publication *Wet Storage Stain*.

FIGURE 36: WET STORAGE STAIN [LIGHT (1) OR MEDIUM (2) IS ACCEPTABLE, HEAVY (3) IS REJECTABLE]

Zinc Skimmings

Oxidized zinc on the bath surface, zinc skimming deposits, are usually caused when there is no access to remove the zinc skimmings during the withdrawal of the steel from the galvanizing kettle. Zinc skimmings on the molten zinc surface are then trapped on the zinc coating. Zinc skimming deposits (*Figure 37*) are not grounds for rejection as long as the zinc coating underneath is not harmed during their removal and it meets the necessary specifications.

FIGURE 37: ZINC SKIMMINGS (ACCEPTABLE)

Zinc Splatter

Zinc splatter is defined as splashes and flakes of zinc that loosely adhere to the galvanized coating surface. Zinc splatter is created when moisture on the surface of the galvanizing kettle causes molten zinc to "pop" and splash droplets onto the product. These splashes create flakes of zinc loosely adherent to the galvanized surface (*Figure 38*). Zinc splatter will not affect the corrosion performance of the zinc coating and thus is not cause for rejection. The splatter does not need to be cleaned off the zinc coating surface, but can be if a consistent, smooth coating is required.

FIGURE 38: ZINC SPLATTER (ACCEPTABLE)

ADDITIONAL
INSPECTION TESTING

In addition to coating measurements and a visual inspection of the appearance and finish, there are a few other tests that may be conducted on hot-dip galvanized steel. These tests are typically only done when there is a question or concern about a specific part.

Adherence Test

Testing zinc coating adherence is achieved using a stout knife and smoothly running it along the surface of the steel without whittling and gouging, as detailed in the ASTM specifications A123/A123M and A153/A153M.

Embrittlement Test

When there is suspicion of potential embrittlement of a product, it may be necessary to test a small group of the products to measure the ductility according to the protocol in specification A143/A143M *Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement*.

Bending Test for Reinforcing Steel

The hot-dip galvanized coating on a steel reinforcing bar must withstand bending without flaking or peeling when the bending test is performed in accordance with the procedure in A143/A143M. Rebar is commonly bent cold prior to the hot-dip galvanizing process. When bending prior to galvanizing the fabricated bend diameter should be equal to or greater than the specified value in A767/A767M.

Passivation Testing

The specification to determine the presence of chromate on zinc surfaces is ASTM B201. This test involves placing drops of a lead acetate solution on the surface of the product, waiting five seconds, and then blotting it gently. If this solution creates a dark deposit or black stain, there is unpassivated zinc present. A clear result indicates the presence of a passivation coating.

SAMPLING
METHODS

When conducting an inspection of hot-dip galvanized steel, it would be impractical to test every single piece for coating thickness. Therefore, a sampling protocol has been adopted by ASTM to ensure high quality products. To properly evaluate hot-dip galvanized coatings, randomly chosen specimens are selected to represent the lot. The inspection quantities are determined by the lot sizes and are detailed in the ASTM specifications A123/A123M, A153/A153M, and A767/A767M.

For products whose surface area is equal to or less than 160in^2 (1032cm^2), the entire surface of the tested product constitutes a single specimen. Products containing multiple material categories or steel thickness ranges and products with surface areas greater than 160in^2 (1032cm^2) are considered multi-specimen products. The minimum number of specimens required for sampling is based on the total lot size (number of pieces) and is defined in the ASTM specifications.

For single specimen articles, specimens are randomly selected and a minimum of five widely dispersed measurements are taken over the surface area of each specimen to represent the average thickness. The average value of the five coating thickness measurements must be greater than or equal to one grade below the minimum average coating thickness for the material category. The average coating thickness of the lot (all specimens tested) must meet the minimum coating thickness for the material category.

For multi-specimen products, the product's surface area is subdivided. For parts greater than 160in^2 (1032cm^2), three continuous local sections with equivalent surface areas constitutes a specimen. Each specimen (subsection) must have five widely dispersed readings just as for single specimen articles. For fabrications with more than one material category or steel thickness, the fabrication will contain more than one specimen. Each specimen's (subsection) average thickness measurement values must be greater than or equal to one grade below the minimum average coating thickness for the material category, and the overall sample (three subsection averages) must meet the minimum average coating thickness for the material category.

IN FIELD

INSPECTION

Inspection of hot-dip galvanized steel products does not end once they are accepted at the galvanizer's facility or job site. During the erection process, and once in place, any good corrosion protection strategy includes periodic inspection and maintenance to ensure the protective coating is performing as expected. When inspecting hot-dip galvanized steel in the field, the inspector should be aware of potential accelerated corrosion areas and aesthetic surface conditions and whether they are a concern.

When inspecting a galvanized coating in the field, the primary concern is the number of years remaining before the coating will need to be touched-up or replaced. Fortunately, estimating the remaining time to first maintenance for hot-dip galvanized coatings in atmospheric exposures is relatively simple. For a ballpark estimation, use a magnetic thickness gauge to take a coating thickness measurement and check the thickness value against the AGA's *Time to First Maintenance Chart* (*Figure 1*, page 3).

Visual Observations

In addition to taking coating thickness measurements, the galvanized coating can be visually inspected for signs of accelerated corrosion in specific areas. Thickness measurements should be taken in these areas to ensure adequate zinc coating remains or if touch-up should be performed. Corrosion-prone areas to inspect further include:

Crevices

When corrosive elements such as water penetrate crevices, the limited air flow can create differences in potential creating anodic and cathodic areas which can lead to corrosion. Some common areas include: overlapped areas, mated sections between fasteners, and areas where the galvanized coating is butted up against another surface such as wood, concrete, or asphalt. When possible, crevices should be avoided during the design process.

Dissimilar Metals in Contact

When dissimilar metals are in contact, galvanic corrosion can occur. Zinc, which comprises the galvanized coating, is high on the Galvanic Series of Metals; and therefore, will preferentially corrode to almost any other metal with which it is in contact. When possible, preventing dissimilar metals from being in contact should be addressed during the design process. Electrically isolating dissimilar metals from one another stops galvanic corrosion and can be accomplished by using plastic or rubber grommets between the dissimilar metals or by painting the cathode. When the surface area of the cathode is much larger than the anode, galvanic corrosion can quickly consume the anodic material.

Areas Where Water Pools

Flat areas can collect water and other corrosive elements and can have higher corrosion rates than vertical surfaces. Visually observing galvanized steel's flat areas and taking coating thickness measurements will ensure adequate corrosion protection remains. When possible, areas that collect water can be addressed by providing drain holes to prevent moisture from pooling on the surface for long periods. If drain holes do exist, inspect the drain holes of the galvanized steel for corrosion and touch-up when necessary.

Previously Touched-Up Areas

Areas of hot-dip galvanized steel previously touched-up either after the initial coating or erection often corrode more quickly than the surrounding zinc coating and should be inspected visually and tested with a magnetic thickness gauge. These areas may be touched-up when necessary using the instructions listed in the *Touch-Up and Repair* section of this publication to extend the service life of the part.

Common Appearance Issues

During your visual inspection of galvanized steel in the field, you may observe a few common appearance issues as well. Most are surface or aesthetic conditions and not cause for concern; however, others may require attention and/or maintenance. The most common appearance issues on galvanized steel after being in service for a number of years include:

Brown Staining

Often mistaken for corrosion, brown staining is a surface condition created when loose iron in the zinc-iron alloy layers oxidizes. As previously noted in this publication, sometimes hot-dip galvanized coatings form without a free zinc layer (eta), leaving intermetallic layers on the surface. Also, as galvanized steel weathers, the free zinc layer will be consumed and can lead to this phenomenon. Brown staining forms when free iron in the intermetallic layers reacts with moisture in the environment and oxidizes, discoloring the surrounding zinc coating. To distinguish between red rust and brown staining, simply test the area with a magnetic thickness gauge. If the gauge reading shows a coating thickness, it is brown staining and the corrosion performance of the galvanized coating is not affected. As brown staining is simply an aesthetic concern, touch-up is not necessary in the stained area.

Wet Storage Stain

As addressed earlier in this publication, improper storage and tight stacking of galvanized products can lead to the development of wet storage stain or zinc oxide and hydroxide build-up on the surface (*Figure 36*, page 13). If galvanized products are going to be stored before erection, it is important to properly vent the bundle to avoid the development of wet storage stain. For more information, see the AGA's publication *Wet Storage Stain*. Another common area for this to occur is on surfaces where snow is piled on the piece and left to melt or in areas where water pools for extended periods without drying. Wet storage stain occurs most often during the first month after galvanizing.

Weeping Welds

Weeping welds (*Figure 33*, page 12) were previously discussed in this publication, and though they can be seen immediately after galvanizing, they often occur after the steel is in service. As reviewed earlier, weeping welds are mostly a cosmetic concern; however, corrosion can be accelerated in the area where the liquids and rust bleeding are leaking. To clean and seal weeping welds, you can wash away the oxides on the outer area and apply epoxy or caulk to the area to prevent water from penetrating the crevices in the future.

Bare Spots

The galvanized coating can be compromised during delivery, handling, erection, and while in use. Some cathodic protection is offered to bare areas of the steel by the surrounding galvanized coating, but these areas can still rust if the area is too wide or corrosive elements frequently attack the steel. Research has shown the galvanized coating offers cathodic protection to bare areas between 1mm - 5mm wide depending on the electrolyte that electrically connects the galvanized coating to the bare area. Bare areas should be touched-up in accordance with the procedures outlined in this publication and specified in ASTM A780.

TOUCH-UP AND REPAIR

The touch-up and repair of hot-dip galvanized steel coatings is important to maintain uniform barrier and cathodic protection, as well as ensure longevity. Although the hot-dip galvanized coating is very resistant to damage, small voids or defects in the coating can occur during the galvanizing process or due to improper handling of the steel after galvanizing. Touch-up and repair of galvanized steel is simple, whether newly galvanized or in service for years. The practice is the same, but there are more restrictions to the allowable repairs on a new product than one that has been in service.

The main restriction in the specification for repairing newly galvanized material in the plant is the size of the area which is outlined in the product galvanizing specifications (A123, A153, and A767). According to those specifications, the allowable surface area for repair is no more than ½ of 1% of the accessible surface area on that article, or 36in^2 (22,500 mm^2) per ton of piece-weight, whichever is less. If a part does not pass inspection, and the repair area is larger than this minimum, the part can be stripped and regalvanized, then resubmitted for approval.

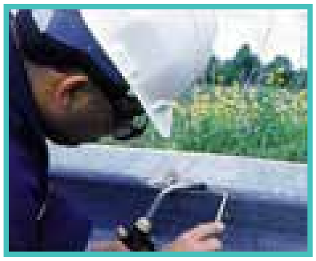
When it comes to repairing galvanized steel in the field, there is no limitation to the size that can be repaired. The zinc coating is difficult to damage, and field fabrication that requires removal of the coating should be minimized as much as possible. As noted before, the cathodic protection of the coating will provide some protection to uncoated areas, but the best practice for longevity is to touch-up any bare areas.

The specification to follow for touch-up and repair of hot-dip galvanized steel, whether immediately after galvanizing or once it is in the field is ASTM A780 *Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.* This specification details how to use the various repair methods as well as the required coating thickness each application. Touch-up materials are required to meet a coating thickness of at least 2.0mils (50.8µm) for one application, and the final coating thickness of the repair area is dictated by the material used to do the repair, outlined below.

Touch-Up & Repair Methods

ASTM A780 includes three acceptable methods of touch-up and repair of hot-dip galvanized steel:

Zinc-Based Solders



Soldering with zinc-based alloys is achieved by applying zinc alloy in either a stick or powder form. The area being repaired needs to be preheated to approximately 600F (315C). The acceptable material compositions of solders used for repair are included in the specification.

The final coating thickness for this repair must meet the specification requirement for the material category of the steel part being repaired with a maximum thickness of 4 mils (100 µm). The thickness should be measured by any of these methods in A123/A123M that are non-destructive. Zinc-based solder products closely match the surrounding zinc and blend in well with the existing coating appearance.

Zinc-Rich Paints

Zinc-rich paint is applied to a clean, dry steel surface by either a brush or spray. Zinc-rich paints should contain either between 65% to 69% metallic zinc by weight or greater than 92% metallic zinc by weight in dry film. Paints containing zinc dust are classified as organic or inorganic, depending on the binder they contain. Inorganic binders are particularly suitable for paints applied in touch-up applications of undamaged hot-dip galvanized areas.

The coating thickness for the paint must be 50% more than the thickness of the galvanized coating for the material class, but not greater than 4.0 mils (100µm), and measurements should be taken with a suitable gauge.

Zinc Spray (Metallizing)

Zinc spray, or metallizing, is done by melting zinc powder or zinc wire in a flame or electric arc and projecting the molten zinc droplets by air or gas onto the surface to be coated. The zinc used is nominally 99.5% pure or better.

The renovated area must have a zinc coating thickness at least as thick as that required in ASTM A123/A123M for the material category. For best results, thickness measurements for the metallized coating should be taken with either a magnetic or an electromagnetic gauge.

INSPECTION SUMMARY

Inspection of hot-dip galvanized steel is fairly simple, and most effectively and efficiently conducted at the galvanizing facility where questions can be asked and answered quickly. A visual inspection will easily identify any uncoated areas or surface conditions to further analyze, and once that is complete, coating thickness measurements should be taken in accordance with the sampling procedures outlined. The purpose of inspecting hot-dip galvanized steel is to ensure conformance to the specification requirements, and although differences in appearance and finish may be present, they are not cause for rejection unless they will affect the long-term corrosion protection.

RELATED ASTM SPECIFICATIONS

ASTM A123/A123M	*Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*
ASTM A153/A153M	*Specification for Zinc Coating (Hot-Dip) on Iron and Hardware*
ASTM A767/A767M	*Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*
ASTM A780	*Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings*
ASTM A143/A143M	*Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement*
ASTM A384/A384M	*Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies*
ASTM A385	*Practice for Providing High-Quality Zinc Coatings (Hot-Dip)*
ASTM B6	*Specification for Zinc*
ASTM B201	*Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces*
ASTM B960	*Standard Specification for Prime Western Grade - Recycled (PWG-R) Zinc*
ASTM D6386	*Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Paint*
ASTM D7803	*Practice for Preparation of Zinc (Hot-Dip Galvanized) Coating Iron and Steel Product and Hardware Surfaces for Powder Coating*
ASTM E376	*Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods*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