Coating Failures on Galvanized Mast Arms
By Paul Vinik, MSChE, P.E., Florida Department of Transportation and Richard A. Burgess, B.S, M.S, KTA-Tator, Inc.

The next time you pull up to an intersection with traffic signals look for the mast arms that support them. Are the arms galvanized, concrete, aluminum, or painted? Painted mast arms may have had the coating system applied directly to blast cleaned steel or over hot-dip galvanized steel (a duplex system). This article discusses the failure of coatings applied to galvanized mast arms for the Florida Department of Transportation (FDOT); analysis of the failure, including key background information on galvanizing; the findings; and the approach FDOT implemented to correct failing galvanized mast arms exhibiting corrosion.

Florida Experience
FDOT identified 60 coated and galvanized steel mast arms in the Jacksonville, FL, area as having paint (coating) peeling from galvanized steel. Consultants were engaged to investigate the failures in 2004. Nearly two-thirds of the mast arms under investigation were in service for only two years. Records indicated that six of the failed mast arms were included in construction projects from 1997 through 2001.

The Investigation
Clearly, the performance was significantly less than expected. Initial examination of the mast arms in November 2004 found that the failed coating systems had intact blisters filled with corrosion products (without free moisture) and the same type of corrosion products were present where the coating had cracked and peeled. The corrosion products under the coating film were typically soft and pasty. Exposed corrosion products easily crumbled and contained zinc and iron. Examples of the conditions, shown in Figs. 1, 2, and 4, demonstrate the degree of failure and that these failures were clearly visible to the traveling public. Several surface conditions are shown in Figs. 3, 5 (p. 22), 6 (p. 22), and 7 (p. 23).

Factors in the Analysis
Understanding how hot-dip galvanizing corrodes and how to prevent corrosion was essential to the analysis.

Hot-dip galvanizing of steel results in a shiny metallic zinc surface and several alloyed layers with the lower layers having decreasing zinc content. The finish is often spangled as a result of alloy and cooling properties, but spangling becomes less obvious as the surface weathers and changes color.1 From the time steel is removed from the molten zinc bath, the zinc surface can be classified into one of three aging stages: newly galvanized, partially weathered, or weathered.

Newly galvanized surfaces are essentially zinc metal. However, zinc is relatively reactive, and chemical changes occur quickly at the surface. Zinc reacts with oxygen in the air, forming zinc oxide, ZnO. Thus, even newly galvanized structures will have some ZnO present on the surface. Over time, a surface reaction between moisture and ZnO forms zinc hydroxide, Zn(OH)₂. Zn(OH)₂ reacts with carbon dioxide (CO₂) in the air to form basic zinc carbonate (ZnCO₃).

A partially weathered zinc surface consists primarily of
zinc oxide and zinc hydroxide with lesser amounts of zinc carbonate. The zinc oxide and hydroxide yield porous films that provide little protection to the zinc surface. ZnO and Zn(OH)₂ continue to form as long as oxygen and moisture are available. Zinc carbonate content in the film typically increases until the film covers the surface, and the surface film takes on a dull gray color.

Depending on climate and exposure, the full weathering process can take from six months to two years. Zinc carbonate, insoluble in water, forms a very protective film at the surface. Even so, the galvanizing can still corrode. Airborne pollutants, particularly sulfur dioxide (SO₂), that contribute to acidic moisture can dissolve the ZnCO₃ layer, exposing metallic zinc and allowing corrosion to continue. Consequently, galvanizing performs best under neutral atmospheric conditions. Even so, the zinc-rich surface will eventually be depleted in aggressive environments in as little as a month but can last for decades in mild environments. As the zinc surface layer is lost, the zinc-iron alloy layers will be exposed and corrode. The corrosion products change color, from white-gray to a pale rust, and then to deeper shades of rust, as the iron (steel) substrate is exposed.

Coating Galvanizing

Organic coatings are used to protect galvanizing and steel from aggressive environments and to provide color as well as extend service life in milder environments. Coating manufacturers and trade associations such as the American Galvanizers Association (AGA),2 SSPC: The Society for Protective Coatings (SSPC),3 and NACE International (NACE)4 provide guidance for preparing and coating galvanized structures. ASTM International5 (ASTM) addresses the use of coating to repair new galvanizing in ASTM A 780, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings, and ASTM D 6386, Standard Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting. The latter document includes recommended practices for preparing new galvanizing, partially weathered galvanizing, and weathered galvanizing.

Surface Preparation

Removing grease, oil, and dirt is necessary before painting any surface, including galvanizing. Additional requirements for galvanizing include avoiding water quenching and chromate treatment to protect against white storage stain, which frequently follow the galvanizing process.6 If these practices cannot be avoided, the surface films they create must be removed because they inhibit coating adhesion. Surface smoothing of the galvanizing is also necessary, particularly where liquid zinc run-off or other galvanizing byproducts are present. Otherwise, the rough surface texture, like rough welds on steel, contributes to discontinuities in the subsequently applied coating film. Further, unlike steel where tightly adhered rust (iron oxides) may be allowed to remain,7 the oxide and hydroxide corrosion products of zinc are weak and loosely adherent. They must be removed physically and/or by surface treatments (chemical etching, conversion coating) before applying organic coatings.

Newly galvanized steel (for painting purposes) is defined as not having received a surface treatment after galvanizing and the galvanizing occurred within 48 hours.8 Even so, steps are recommended to ensure zinc corrosion products (ZnO and Zn(OH)₂) are removed from the surface. When abrasive blast

Editor's Note: This article is based on a paper the authors gave at PACE 2008, January 27-28, Los Angeles, CA. PACE is the joint conference of SSPC: The Society for Protective Coatings and the Painting and Decorating Contractors of America.
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cleaning is used to texture the surface and remove the corrosion products, coating application should occur within 60 minutes if conditions favor formation of zinc salts. Partially weathered galvanizing should be evaluated for the presence of a (chromate) surface treatment and wet storage stain (white zinc salts consisting primarily of Zn(OH)₂). Once these issues are addressed, the partially weathered steel can be prepared in the same manner as newly galvanized steel—again with consideration of conditions favoring zinc corrosion. On the other hand, a weathered basic ZnCO₃ surface is suitable for painting without extensive preparation provided other interference materials are removed.

**Coatings and Application**
The most commonly used coating techniques for hot-dip galvanized mast arms are spray and electrostatic powder coating or brush and roller application of liquid coating and fluidized bed powder coating may also be used. Many generic coating types can be successfully applied to properly prepared galvanized steel.

Some resins, however, such as alkyds, oils and epoxy esters are not suitable because they may react with the alkaline salts that form on zinc surfaces. While often quite adequate in a dry environment, these coatings are quite susceptible to failure in wet, damp, or humid environments.

Polyamide epoxy is probably the most popular industrial coating applied directly to newly hot dip galvanizing. Once primed, the surface can be overcoated with a primer-compatible finish coat, commonly polyurethane. Powder coatings include epoxy, polyurethane, and polyesters. Use of surface treatments such as conversion coatings may be recommended by the coating manufacturers. The performance of a duplex system is generally understood to be related to isolating the reactive zinc metal surface from the environment. Yet, the combination of coating system dry film thickness (DFT), the specific product formulations selected, and overall system permeability may not yet have had sufficient discussion and may warrant further investigation.

Weathered galvanizing is more easily coated than new or partially weathered galvanizing. Some coating manufacturer data sheets recommend allowing galvanized steel to weather for several
months before coating because at this stage, application of coatings to galvanizing carries the lowest risk, but the substrate does require some degree of cleaning. Unfortunately, it is commonly not the most practical time. Weathered and aged galvanized steel exhibiting red rust is commonly coated with a zinc-rich organic coating.

Florida Requirements for the Masts
FDOT 2004 Standard Specification for Road and Bridge Construction (Standard Specification) Section 649—Steel Stain Poles, Steel Mast Arm and Monotube Assemblies—requires galvanizing components in accordance with ASTM A 123, Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products, using methods suitable for painting. Surface preparation of all galvanized surfaces is to be done in accordance with ASTM D 6386 followed by solvent wiping in accordance with SSPC-SP 1, Solvent Cleaning, and application of either a two-coat liquid paint system or a powder coat system.

The specified liquid paint system is an epoxy primer (4.0 to 6.0 mils DFT) and aliphatic polyurethane finish (2.0 to 4.0 mils DFT). The electrostatically applied urethane or triglycidyl isocyanurate (TGIC) polyester powder coat system requires a minimum DFT of 2.0 mils. The powder is to be cured by heating the coated structure to 350 F to 400 F.
Thus, it appears the galvanizing process itself may have been contributory to the exterior coating failure.

The findings in the Jacksonville mast pole coating failure investigation suggest a systematic, process problem was the root cause.

**FDOT Approach to Resolution**

**Issues and Economic Considerations**

FDOT inspected mast arm structures in Jacksonville and Orlando, FL, in September 2004 and reported an estimated failure rate of 15 to 20%. Based on the September inspections and November 2004 investigations, it was estimated that up to 3,000 of the roughly 15,000 coated galvanized mast arms in the state may have failed. A series of important issues was identified while developing an approach to resolving the problem with existing structures and future structures.

Findings of the Investigation

The finding of zinc corrosion products indicates the cause of failure was related to inadequate surface preparation, which left zinc oxide and hydroxides on the galvanized surface. Zinc corrosion products are voluminous, as much as 500 times that of the zinc metal consumed. Thus, even though other surface contaminants can also compromise adhesion, the development of large and irregular blisters filled with zinc corrosion products (Figs. 5 and 6, p. 22) showed an ongoing corrosion process, not an interfering bond-breaker.

Figure 7 (p. 23) shows the surface beneath coating removed adjacent to peeling paint. The spots of pinpoint red rust among the white corrosion products indicate that lower, iron-containing layers of galvanizing and/or the steel substrate were corroding. The pattern was consistent with overblast damage from aggressive blast cleaning. An additional indication of inadequate surface preparation was high zinc edges from drip lines and zinc runoff.

The applied coatings consisted of a polyamidoamine epoxy primer and aliphatic acrylic polyurethane finish coat. Intercoat adhesion was good and system thickness was generally within the specification requirements. The topcoat appeared to be free of defects. However, the texture of the back surface of the primer suggested that abrasive blast cleaning may have been performed but was not uniform.

Quality control data from the galvanizing process was not readily available for review so a retrospective evaluation of the exterior galvanized surfaces was not fruitful. However, boroscope examinations of the unpainted interior surfaces found the galvanizing was not preventing corrosion of the steel substrate. Thus, it appears the galvanizing process itself may have been contributory to the exterior coating failure.

The findings in the Jacksonville mast pole coating failure investigation suggest a systematic, process problem was the root cause.
Technical Considerations
The immediate technical considerations included identifying existing failed poles.

Risk of catastrophic failure
Risk to the motoring public
Defining failure and degree of failure
Impact on mast arm service life
Resources required to identify failed units
Remediation of failed units
Interfacing with vendors to eliminate future failures on new structures

The potential economic impact of galvanized mast arm coating failures is significant, not only to the State of Florida but to the vendors as well. Each of the mast arms represents an investment of $50,000—a potential collective financial impact of up to $150 million.

Currently, any structures failing in less than 820 days fall under the latent defect clause of the standard specifications and must be repaired or replaced by the contractor. Structures older than 820 days are being handled on a structure-by-structure basis.

FDOT implemented a revised Section 649 of the Standard Specifications in June of 2007 to address future structures. This revised specification has no new direct instructions regarding materials or methods to paint a structure. However, it does require that the contractor designate a “responsible party” for the adhesion and color retention of the structures. The responsible party must also provide a five-year warranty that starts at project final acceptance and covers any repairs required for adhesion or color. The responsible party can be the contractor or the fabricator. When the responsible party is the fabricator, it must be pre-approved by the Department and be listed on the Pre-qualified Fabricators of Painted Galvanized Steel Strain Poles, Monotube, and Mast Arm Assemblies List. In addition, the fabricator must provide an annual bond based on the number of structures provided to FDOT the previous year.

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and the procedures/protocols for remediation and establishing performance criteria to differentiate failing from non-failing poles.

Options for remediation of existing mast arms could range from in-situ cleaning and repainting to replacement. A statewide repair procedure for correcting failing structures, summarized below, was issued in April 2006.

- Identify failed mast arms by the presence of failed coating.
- Inspect the interior surface for steel corrosion.
- Replace the structure if interior corrosion is present.
- Repaint the structure if interior corrosion is not present.
- Repaint the structure in the field or in a shop as follows:
  - Pressure wash with 5000 psi
  - Abrasive blast SSPC-SP 10 (exception: leave good zinc)
  - Apply organic zinc primer and poly-siloxane finish per manufacturer’s requirements

Changes made to prevent future failures included implementing a revised qualified product list (QPL) in April 2007. Standard Specification Section 649 revision established color and coating adherence requirements and preparation of coupon standards.

Briefly, a coating failure has occurred when color degradation is greater than $8\Delta E'$ or coating delamination is greater than 100 square inches.

**Conclusion**

Vendor resistance to the 5-year bonding requirement was anticipated, but vendors have elected to participate. There are clear incentives for them to improve quality control to minimize the number of mast arm coating failures that occur. This is expected to increase the unit cost to the state to some degree. The full impact of these changes is not fully known at this time. However, it is expected that the state will receive an improved product, and the industry in general will likewise benefit.

**Notes**

1. Surface treatments may be used to prevent discoloration but are not recommended when galvanizing will be painted.
3. SSPC: The Society for Protective Coatings 40 24th Street, 6th Floor Pittsburgh, PA 15222-4656.
4. NACE International, 1440 South Creek Drive Houston, TX 77084-4906.
5. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.
6. The galvanizer should be advised that the pieces are to be painted.
7. SSPC Surface Preparation Standards such as SSPC-SP 2- Hand Tool Cleaning, SSPC-SP 3-Power Tool Cleaning, SSPC-SP 7- Brush Off Blast Cleaning.
8. ASTM D 6386, Section 5.1.
9. Mark B. Dromgool PCS Managing Director, KTA-Tator Australia Pty Ltd, Personal communication.

Paul Vinik, state chemical materials engineer at FDOT’s State Materials Research Park, works in Gainesville, FL. He is an instructor for SSPC’s BCI, C1, and C2 courses.

Richard Burgess, a senior coatings consultant with KTA-Tator, Inc. (Pittsburgh, PA), is the editor of the F-Files series.
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