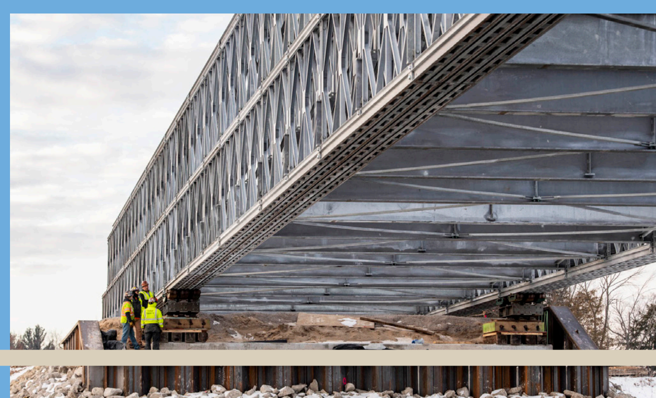


Hot-Dip Galvanizing Specification

S8.3—2022

American Association of State Highway and Transportation Officials
AASHTO

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AASHTO/NSBA STEEL BRIDGE COLLABORATION

American Association of State Highway and Transportation Officials

National Steel Bridge Alliance

Preface

These Specifications are a standard developed by the AASHTO/NSBA Steel Bridge Collaboration. The goal of the Collaboration is to achieve steel bridge design and construction of the highest quality and value through standardization of steel bridge design, fabrication, construction, inspection, and long-term maintenance. Each standard represents the consensus of a diverse group of professionals.

It is intended that owners adopt and implement Collaboration documents in their entirety to facilitate the achievement of standardization. It is understood, however, that local statutes or preferences may prevent full adoption of the document. In such cases owners should adopt these documents with the exceptions they feel are necessary.

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HOT-DIP GALVANIZING SPECIFICATION

Introduction

These Specifications are intended for adoption by owners for galvanizing bridges and other highway structures. Unless otherwise noted, all references to galvanizing in these Specifications refer to the hot-dip galvanizing process. Other zinc coating processes include mechanical galvanizing (a mechanical process commonly used for fasteners), electroplating (which is an electrical process), and metalizing (thermal spray).

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SCOPE AND RESPONSIBILITIES

1.1—SCOPE AND RESPONSIBILITIES

This Specification covers bridge members and other transportation structures, including expansion joints; drains and scuppers; camera, light, sign, and signal support structures; bridge railing; stairs; walkways; bearings; and ballast plates. The Specification does not cover fasteners or reinforcing steel.

The owner, general contractor, fabricator, and galvanizer must communicate to ensure a shared understanding of the project requirements before the project starts, which may include having a prefabrication meeting.

The fabricator of the component to be galvanized is responsible for preparing the project for galvanizing in accordance with this Specification. This preparation is distinct from the surface preparation steps done by the galvanizer in the hot-dip process.

The entity contracting the galvanizer (usually the fabricator) shall convey project requirements for maintaining traceability, coating thickness limitations superseding this Specification or ASTM A123/A123M, and any special treatments required by the contract.

The galvanizer shall have a documented and implemented quality management system that is internally audited on a regular basis.

C1.1

One key to providing the best design for the hot-dip galvanizing process is communication among the owner, general contractor, fabricator, and galvanizer. Opening the lines of communication early in the development of design details can eliminate potential costly pitfalls later in the process.

The fabricator or owner may choose to call a prefabrication meeting after award to discuss any questions and ensure common understanding of acceptance criteria, special provisions, hold points, venting needs, and notification for inspections. The meeting typically includes the owner, general contractor, and fabricator. Other subcontractors, such as the galvanizer or duplex coating applicator, may be included. It can be very helpful to address coating issues at the prefabrication meeting, or hold a separate prefabrication meeting to address coatings topics.

Special treatments may include non-galvanized areas, aesthetic appearance, and smoothness. Also, if any other coatings will be applied on the galvanizing, this can affect other choices made in the galvanizing process.

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Section 3:

DEFINITIONS

Duplex coating system—galvanizing further coated with liquid or powder coatings constitute duplex coatings systems.

Fabricator—the entity fabricating and preparing the steel assemblies that will be sent to the galvanizer.

Fully weathered galvanized steel—galvanized steel that has developed a stable surface, consisting mainly of zinc carbonate. It often takes up to two years to achieve a fully weathered surface.

Galvanizer—entity performing the galvanizing process, including surface preparation, and who may provide surface preparation for and application of painting.

Newly galvanized steel—per D6386, steel within 48 hours of galvanizing, and free of fine white powder indicating zinc oxide or zinc hydroxide.

Painter/powder coater—entity preparing the galvanized surface (unless prepared by the galvanizer) and applying a liquid coating or powder coating

Partially weathered galvanized steel—galvanized steel more than 48 hours after galvanizing, or exhibiting a fine white powder indicative of zinc oxide or zinc hydroxide but not meeting the definition of fully weathered galvanized steel

Pickling—a step in the preparation of steel surfaces for galvanizing whereby the steel is held in an acid tank to remove iron oxide or scales, exposing bare steel to permit the galvanized coating to form upon immersion in a molten zinc bath.

Prominences—localized elevated points on a galvanized surface that can be excessive deposits of zinc, or dross (zinc, iron, intermetallic particle) or other debris covered by zinc.

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SECTION 4:

BASE METAL

4.1—MATERIAL CONSIDERATIONS

4.1.1—Heat-Treated Steels

Steels that are heat-treated in the temperature ranges of the galvanizing kettle shall not be galvanized. Galvanizing of structures composed of HPS 70W or HPS 100W should be avoided.

C4.1.1

Bath temperatures, which are usually 840 degrees F (450 degrees C), may adversely affect the final properties of materials thermally treated to enhance strength, such as ASTM A709/A709M HPS 70W and HPS 100W. High-carbon steels (over 0.8 percent carbon), such as 4140, pickled too long or at too high a temperature may result in elevated hydrogen concentration and brittle behavior.

Research (Bennett et al., 2021) indicates that liquid-metal-assisted cracking (LMAC) affected a wide range of steels commonly used in highway structures. HPS100W exhibited a high propensity for LMAC as well as increased interaction with other aggravating factors that could be present during galvanizing. Although HPS 70W and HPS 50W were not included in the study, their chemical compositions are more similar to HPS 100W than to the other grades included in the study (ASTM A572/A572M Grades 50 and 65, and ASTM A36/A36M). Therefore, HPS 70W and HPS 50W are considered to likely also be at increased risk of LMAC. Feldmann et. al found that where LMAC is a concern, dipping the structure as fast as possible may be helpful, and it is recommended that special controls or limits to the chemistry of the galvanizing bath should be identified.

4.1.2—Weathering Steel

When galvanizing structures composed of weathering steel, preblasting is required.

C4.1.2

Weathering steels (e.g., ASTM A709/A709M Grade 50W) can effectively be galvanized but doing so is discouraged since they are more likely than non-weathering grades to have silicon levels above desirable limits and heavy galvanizing buildup. If weathering steel is to be galvanized, preblasting is recommended to help control heavy buildup unless material test reports (MTRs) demonstrate that the steel is non-reactive.

4.1.3—Steel Chemistry and Reactivity

Consider practices to manage reactivity of steel to be galvanized.

C4.1.3

This Specification does not have any requirements related to steel reactivity. Steel reactivity varies, and galvanizing reactive steel is normal. However, reactivity affects galvanizing; therefore, language describing reactivity is provided here for guidance.

Steel with a silicon content less than 0.02 percent is considered non-reactive and produces thinner galvanized coatings that may not meet thickness requirements. Reactivity of steel with silicon content between 0.02 percent and 0.04 percent or between 0.15 percent and 0.22 percent and manganese content less than 1.35 percent is considered optimal. Other compositions, especially for silicon, are considered highly reactive and may cause high build-up of zinc layers, potentially leading to flaking and a darker coating. This darker coating is not prohibited by this Specification but can be an aesthetic concern.

Mills frequently meet the optimal criterion for plate but specifying the steel chemistry is not recommended because doing so may add cost and delay delivery, especially for smaller quantities that may not be ordered directly from a mill. Service centers may have material satisfying the desired range in stock if requested. Section 3 of ASTM A385/A385M discusses steel chemistry for galvanizing steel and is a good reference. Phosphorus content can also affect the reactivity of steel, but the typical levels in structural steels usually have insignificant effects unless silicon is high.

Cross-frames and diaphragms often use rolled shapes, which were silicon-killed, potentially resulting in reactive chemistry and excessive coating thickness. Galvanizing thickness on reactive steels may exceed 20 mils, above which certain problems are more likely (see Article 6.2.2). Fabricators may discuss this with the galvanizer and agree to order steel with desirable chemistry; use normal acquisition methods and select the least reactive compositions; or blast-clean cross-frames and diaphragms before galvanizing (see Article 7.1).

To help avoid excess coating thickness but improve uniformity when highly reactive steels are to be galvanized, abrasive blasting per SSPC-SP 6/NACE No. 3 prior to galvanizing can be used to slightly roughen the surface and reduce the tendency to develop thick coatings. Blasting helps reduce thickness because the zinc-iron intermetallic grains grow perpendicular to the anchor profile surface, interfering with each other and limiting growth (see Section 7). Preblasting non-reactive steel increases surface area which can increase coating thickness and help in achieving the minimum required thickness. A profile is not specified or required for SSPC-SP 6/NACE No.3 blast cleaning, but research on profile effects is underway. Preblasting steel could be mandated by the contract or mutually agreed between the fabricator and galvanizer

The galvanizer may request MTRs from the fabricator. Knowing material chemical composition and configuration in advance can help the galvanizer prevent chipping and flaking that can occur if the coating is too thick and can also help with control of liquid-metal-assisted cracking.

When steel is produced for a galvanized application, the goal is to obtain a silicon level that's within one of the optimal ranges mentioned above. As lighter gauge (roughly ≤ 0.75-in.) hot-rolled steels (both hot-strip mill and plate) are often used for surface-critical applications, and higher silicon levels can result in a rougher surface texture, they are typically produced without an intentional silicon alloying addition. However, during steelmaking, silicon will revert from the slag into the molten steel, and silicon in alloys used for chemistry treatment can increase the heat; as a result the silicon content is almost always greater than 0.02 percent. Because of both surface quality and galvanizing considerations, light gauge steels are typically produced to an aim maximum silicon of 0.04 percent. If the heat is intended for a galvanizing application requiring a 0.04 percent maximum, additional measures to meet this requirement will be taken during steelmaking, but it is difficult to consistently meet this silicon criteria. However, for virtually all these heat chemistries, the silicon will be less than 0.06 percent. If the galvanizer can closely collaborate with the producing mill, they can accommodate this silicon level to produce an acceptable galvanized surface, as is mentioned in ASTM A385/A385M Section 3.2.

Heavier gauge (roughly > 0.75 in.) hot-rolled steels are typically produced with a silicon range of 0.15 percent to 0.22 percent regardless of whether or not they will be galvanized. As this range is obtained by adding silicon as an alloy, it is much more consistently achieved than the optimal 0.02 percent to 0.04 percent silicon range used for galvanizing lighter gauges. Rolled beams and shapes are typically silicon killed, so if a galvanizing-compatible chemistry is desired, a silicon range of 0.15 percent to 0.22 percent should be able to be specified from the producing mill.

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Section 5:

SHOP DRAWINGS AND HANDLING

5.0—SHOP DRAWINGS AND HANDLING

Shop drawings shall include provisions for sufficient drain and vent holes in accordance with ASTM A385/A385M to permit safe galvanizing. If contract documents do not provide for adequate venting and draining, the fabricator shall contact the owner to coordinate addition of the openings. Limits of faying surfaces for slip-critical connections shall be clearly delineated.

The fabricator, general contractor, and galvanizer shall coordinate any modifications needed to the element to accommodate lifting and handling during galvanizing. Follow requirements of AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code* for use of temporary welded attachments. Any additional holes, whether for bolts or for lifting equipment, need approval by the engineer.

C5.0

Owners may not understand the physical requirements for galvanizing, such as providing drainage openings for pockets formed by intersecting elements. The fabricator, often with the assistance of the galvanizer, may need to suggest details to the owner for the process to be successful. The American Galvanizers Association (AGA) publishes guidance for detailing, including the size and placement of drains and vents.

Pick points allowing galvanizing operations without damaging elements are essential. Smaller elements may need bolted-on attachments or additional holes to provide appropriate lifting points.

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Section 6:

PRODUCT DETAILS

6.1—PRODUCT IDENTIFICATION

Identification of each piece or lot shall be maintained during the surface preparation and galvanizing process. Like pieces may be processed as a lot without marking individual elements, provided the identity of the lot is maintained and the pieces are either kept as a lot for shipping or re-marked after galvanizing. Members fabricated for specific locations, such as beams drilled in assembly, shall have their identity and orientation maintained throughout the galvanizing process by tags or other methods not obscured by galvanizing.

Welding shall not be used for marking members unless allowed by contract.

C6.1

Owners may specify a method of permanent marking, but this Specification does not recommend a permanent marking methodology. Keeping marks on individual pieces may not be necessary when galvanizing like pieces that are in lots.

Low-stress die marks may not show through galvanized coating, so tags designed for immersion during galvanizing or other methods may be preferred.

Owners' specifications may allow or require welded marking on a specific area of ancillary items such as railing posts.

6.2—GALVANIZING THICKNESS AND SURFACE CRITERIA

The coating shall meet the thickness and surface criteria of ASTM A123/A123M, and the additional requirements noted in this section.

6.2.1—Minimum Allowable for Individual Measurements

The minimum for each individual coating thickness spot measurement shall not be less than two coating grades below that required for the appropriate material category and thickness. ASTM A123/A123M Section 6.1.3 exempting deficient individual measurements shall not apply.

C6.2.1

ASTM A123/A123M designates thickness categories as "grades." For thickness evaluation, ASTM A123/A123M defines material to be evaluated as lots and then defines how the lot is sampled based on the articles in the lot. Under ASTM A123/A123M, the overall thickness average must meet the minimum requirement of the grades, and individual specimen averages may be below the minimum by one thickness grade. However, in ASTM A123/A123M, there is no minimum requirement for individual readings, meaning that an individual measurement can approach zero under ASTM A123/A123M provided the required averages are met. Therefore, this specification goes further than ASTM A123/A123M to avoid allowing areas with particularly low readings by stating that no individual measurement may be more than two grades below the grade applicable for the category.

It is important to have an adequate zinc layer thickness (including in repaired areas) to provide the expected corrosion performance. Corrosion in bridges can occur wherever the protective coating thickness or continuity is compromised, so galvanizing repairs need to produce an uninterrupted coating with the necessary corrosion protection.

When coatings satisfy ASTM A123/A123M average thickness requirements, but individual spot measurements are deficient, the extent of the deficiency shall be determined by additional measurements at the low reading in accordance with the examination criteria in SSPC-PA 2.

- If all three gauge readings that comprise a spot measurement per SSPC-PA 2 show coating thickness of at least 80 percent of the required grade, the thickness is satisfactory and no repair is needed.
- If any of the additional three gauge readings are less than 80 percent of the required grade, additional spot readings radiating from the initial reading shall be taken in accordance with SSPC-PA 2 criteria to determine the extent of deficient thicknesses.
- If areas with deficient thickness comprise no more than 5 percent of the total area, coating shall be added to bring the coating up to thickness requirements in accordance with ASTM A780/A780M or an owner-approved renovation procedure to bring them into conformance.
- If areas with deficient thickness exceed 5 percent of the total area, the general contractor and owner shall be contacted to determine acceptable remedies.

The requirement for further investigation of low-thickness areas is intended to avoid rejecting the coating due to local low spots.

Sometimes material may arrive at the site with areas that have flaked off. This does not necessarily mean that the coating thickness is insufficient in the flaked area, and the thickness in those areas should be measured to determine whether there is cause for concern.

There may be cases of flaking where remaining galvanizing satisfies minimum requirements but has questionable appearance. When such aesthetic concerns arise, the purpose and visibility of the condition should be considered. Most owners have customary expectations for renovation of flaked areas for aesthetics.

Shipping, handling, and bolt tensioning can cause local flaking. When these occur, it is preferable to repair these conditions in the field.

In general, coatings for renovation of galvanizing are specified by ASTM A780/A780M based on corrosion resistance and not because of their appearance.

The owner, fabricator, and galvanizer and subsequent coater should agree on the final appearance and smoothness of galvanized products. This may be defined by project-specific requirements related to the product's initial appearance and smoothness, including corrective actions for non-compliance. This activity should be reviewed during the contracting process to ensure bidders are aware of requirements and responsibility for potential additional costs

Areas exposed to direct weathering, wet conditions during pre-erection storage, and road salt may discolor sooner than protected areas.

6.2.2—Maximum Galvanizing Thicknes

There is no maximum thickness. However, adhesion on coatings exceeding 20 mils [500 μm] shall be verified both visually (no spider cracks, flaking, or other delamination) and by testing for adhesion per ASTM A123/A123M (stout knife).

Galvanizers shall document remedial actions taken to address areas that fail the stout knife test.

C6.2.2

A coating of 20 mils is not inherently defective, but it is about the point at which problems can occur with coating adherence or delamination.

With a significant difference in material thickness, such as a thick flange and thin web, the time in the tank is determined for the thicker material to reach the temperature of molten zinc (about 840 degrees F [450 degrees C]). This dwell time may result in much heavier coating on the thinner material.

Pull-off tests are not suitable for adhesion testing because usually the dolly pulls off and this leaves adhesive stuck to the coating.

If there is disagreement between the owner's representative and the galvanizer's inspector about the results of the stout knife test, an alternate test can be proposed. The alternate method of testing and required results should be agreed upon by the involved parties before use.

6.2.3—Measurement and Inspection

Plate girders and rolled beams have many surfaces to check for coating thickness. The following example inspection plan applies to I-shaped primary members.

- Sample members from each lot shall be chosen in accordance with ASTM A123/A123M.
- For members up to approximately 65 feet (20 m) long, sample members shall be divided into three specimen areas.
- Measurements shall be performed near each end of the member and near the center of the member. In the case of progressive dipping, the overlap/interface shall be chosen for one of these areas.
- Longer members shall be divided into four specimens, measuring as above plus one additional interior location.
- For each specimen, a minimum of five measurements shall be taken on surfaces that represent the coating based on the uniformity observed.
- Thermal-cut edges shall be given a close visual inspection for flaking.

C6.2.3

A plan for measurement locations should be used for each member type on the project. The lot sampling plan from ASTM A123/A123M is applied to all smaller items. Other large shapes may require specific inspection and sampling plans in the special provision. The owner is encouraged to give direction on the sampling plan for larger shapes and longer shapes. Consider stiffener plates and other attachments separately from main plates of the member.

Rolled beams generally have uniform coating thickness since the webs and the flanges have the same chemistry and are relatively close in thickness and, therefore, the coating growth takes place across the steel surface at similar rates. In the case of plate girders, the flanges could be much thicker than the web plates, causing the flanges to take longer to come to the temperature needed for the coating to start growing. This temperature difference, as well as the steel chemistry differences between the flange plates and the web plates, can result in coating thickness differences on the part.

Galvanizing tends to be much more uniform than spray-applied coatings because galvanizing is not dependent upon spray technique. Generally, this uniformity is apparent and, therefore, choosing representative areas to evaluate is straightforward.

Coverage on cut edges can be problematic. However, thickness readings cannot be taken on such edges effectively, so a visual inspection must suffice.

6.3—FAYING SURFACES

Galvanized faying surfaces shall be free of runs, globules, and other prominences preventing sound contact with mating material.

Any high spots shall be reduced to be no more than $\frac{1}{16}$ in. [2 mm] above the surrounding surface and not more than 0.25 in.^{2} [160 mm.^{2}] in surface area.

C6.3

The maximum thickness of galvanizing at a slip-critical faying surface is not specified by ASTM A123/A123M or in the Specification for Structural

Such high spots shall not be within 3 in [75 mm] of other high spots. Removal shall leave zinc thickness satisfying Section 6.2.

Joints Using High-Strength Bolts (RCSC, 2020). The commentary in the Specification for Structural Joints Using High-Strength Bolts says thicknesses over 15 mils [380 μm] on each mating surfaces may creep under sustained bolt tension, reducing clamping force and slip resistance. Research (DeWolf and Yang) has found that thickness exceeding 10 mils [250 μm] may lead to creep and loss of bolt tension. However, to address this concern, the *AASHTO LRFD Bridge Design Specifications* (Forthcoming) have adopted a 20 percent reduction in allowable clamping force. Therefore, no limit on faying surface thickness is required. Further information regarding faying surfaces is available in the Specification for Structural Joints Using High-Strength Bolts commentary. Fabricators and erectors may need to further reduce the high spots or perform additional snugging, to achieve firm contact between the plies during high-strength fastener installation and tightening.

Use of a class C slip coefficient is recommended for the design of faying surfaces on galvanized structures. If a higher slip class is specified and the means of achieving the higher class is not shown in the plans, the means of achieving the higher class should be discussed among the fabricator, the galvanizer, and the designer.

Slip-critical galvanized faying surfaces shall not be power wire-brushed, and hand wire-brushing shall only be used to remove visible debris and heavy oxidation, without causing a smooth surface.

Wire-brushing is prohibited because it can polish the galvanizing and thus reduce surface friction.

6.4—BOLT HOLES

After galvanizing, ensure that bolts can readily pass through the bolt hole. Bolt holes may be reamed and touched up if needed.

C6.4

Galvanizing builds up inside bolt holes, and this can make it difficult to install bolts, particularly when ¾ in. or ⅞ in. galvanized bolts are used. Reaming reduces excess coating thickness but does not completely remove the coating. Alternatively, the general contractor or fabricator may request the use of larger holes to compensate for the buildup of galvanizing and to eliminate the need for reaming. Increasing the hole size reduces the design slip capacity and may also reduce the bearing capacity of the connection and therefore must be approved by the engineer.

For non-slip-critical connections, oversized holes (either ⅛ in. or 3⁄16 in. [3 or 5 mm] over nominal bolt diameter) may be specified (and accounted for in the design, with engineer approval) for use with ¾ in. or ⅞ in. [20 or 22 mm] bolts.

Per Article 6.13.2.4.2 of the *AASHTO LRFD Bridge Design Specifications* (2020), standard holes for 1 in. [25 mm] and larger bolts are ⅛ in. [3 mm] larger than the bolt's nominal diameter. Experience has shown the ⅛ in. [3 mm] to be adequate to install galvanized bolts in as-galvanized members without significant reaming.

6.5—FIELD-APPLIED SHEAR STUDS

When the contract requires field installation of studs after galvanizing, stud locations shall be masked to prevent zinc adhering to the stud location during the galvanizing process, or stud locations shall be ground to bare steel. Masking shall not be applied within 1 in. [25 mm] of the flange edge. Masking materials shall be the choice of the galvanizer.

C6.5

Some states allow shop-applied studs and may put them in arrangements that reduce the trip hazard and still permit form placement.

Three options exist to prevent galvanizing at field-applied stud locations:

1. Apply masking at each stud location or each row of studs.
2. Mask the entire top flange area that will have studs applied in the field, except for 1 in. (25 mm) at each edge.
3. Grind zinc away as needed for stud attachment after galvanizing.

Masking for studs is better than removing galvanizing because the labor to remove the coating is high and removal is difficult. Masking may be applied by the fabricator or the galvanizer, and if by the galvanizer, masking may be applied before or after cleaning. The fabricator should coordinate with the galvanizer to agree to an effective approach for designating areas to be masked.

Further considerations include the following:

- Blasting removes a larger area than desired and creates residue that needs to be removed.
- Grinding removes coating in specific locations, but unless rust is allowed to form, it is very difficult to distinguish remaining zinc from underlying steel in the ground area.
- Chemical removal methods present time and contamination problems.

6.6—CUT EDGES

If cut edges prove problematic because of hardness, grind to remove hardness down to Vickers 275.

C6.6

Thermal-cut edges that satisfy the requirements of AASHTO/AWS D1.5M *Bridge Welding Code* are suitable for galvanizing regarding roughness, notches, and gouges. However, thermal cutting can leave a thin hardened surface layer, particularly on thicker flanges, such as 2-½ in. and thicker. For thinner material, the cutting process heats the edges so that excessive hardness does not develop. When such hardness occurs, it can sometimes be seen as visible discoloration.

Hardness can result in flaking coating on corners and edges, particularly on thicker pieces, which have greater coating thickness due to longer dwell times. In certain conditions, hardness can also result in LMAC.

Hardness can be removed by grinding; such grinding is typically done by the fabricator. This specification does not require the grinding of all thermal-cut edges because not all cut edges are too hard, depending upon the cutting process, cutting practices, and thickness of material.

Abrasive blasting prior to galvanizing also helps control hardness and flaking.

ASTM A143/143M requires that after cutting, the cut surface of flame-cut copes "be ground to remove notches, grooves, and irregular surface features to leave the surface smooth" to avoid stress raisers that could initiate cracking during the rapid expansion and contraction associated with immersion and extraction from molten zinc.

"Smooth" is not defined in ASTM A143/143M but conveys the intent of a surface free of visually significant irregularities. A finish not rougher than 250 µin (6 µm) is suggested.

More information is available at: https://galvanizeit.org/knowledgebase/article/cut-edges.

6.7—COPES

Copes shall have a minimum 1-in. radius and shall receive a close visual inspection. The Galvanizer shall inspect copes in connection plates and girder webs for cracks after galvanizing. Cracks that penetrate beyond the coating shall be repaired following AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code* requirements.

C6.7

Cope cracking is a recurring issue on copes with small radii. If cracks occur, they must be repaired by welding (following the applicable welding specifications and any needed approvals on the project). Using a minimum 1-in. radius is intended to avoid these cracks, although smaller radii have also been used successfully.

A minimum radius of 1 in. (25 mm) or larger is required by ASTM A143/A143M for copes. The AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code* also requires a 1-in. radius for all reentrant corners.

Although cracks are not likely with use of a 1-in. minimum radius, if cracking does occur, another method that has had fairly good success at minimizing the cracking at the edges of the flame-cut cope is to weld a bead along the sides of the cope in the area where the flame cutting was done before hot-dip galvanizing. This approach is suggested by ASTM A385/A385M. The welding operation will reheat the area and may relieve some of the residual stress near the cope edges. The weld bead will not eliminate all incidents of cracking but will greatly reduce the likelihood of cracking. Residual compressive stress induced by welding in the area of the cope reduces the likelihood of cracking during the galvanizing process (Lindsley). See Figure C6.7-1. Use of this technique, as with any other introduced weld, requires the engineer's approval. Use of a larger radius is generally preferable.

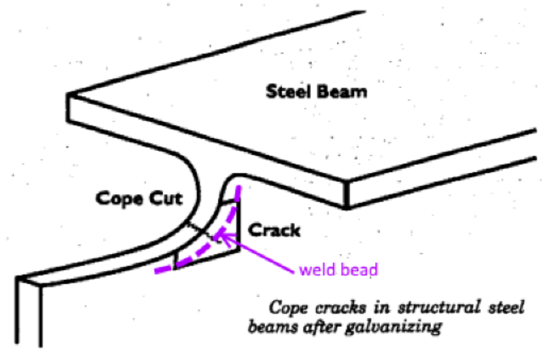

Figure C6.7-1. Coped Beam End with Corner Radius and Weld Bead

6.8—SHEARED EDGES

Sheared edges shall be finished (ground, machined, etc.) sufficiently deep (1⁄32 in. to 1⁄8 in. [1 mm to 3 mm]) to remove all tears and micro-cracks that may be susceptible to crack formation during the thermal cycles of the hot-dip galvanizing process. This shall be completed by the fabricator before shipping to the galvanizer.

C6.8

Shearing is no longer as common as it once was in fabrication, but it may still be used.

6.9—SINGLE DIP

Single dip shall be used whenever possible. Progressive dipping is acceptable.

C6.9

"Single dip" is completely immersing the part in the zinc bath. "Progressive dipping" is immersing the part in the zinc bath in multiple dips because the part is too large for a single dip. Progressive dipping is usually two dips but can be as many as four.

Progressive dipping is not preferred, but it is not prohibited. For product that is longer than the galvanizing kettle, it is necessary. The AGA's progressive dip calculator is a Microsoft Excel-based tool that can be used to confirm whether an article of known dimensions can be progressive dip galvanized within a galvanizing kettle of known dimensions. It can be downloaded for free from galvanizeit.org.

An overlap area results when progressive dipping is done. In the overlap area, the free zinc from the first dip melts off during the second dip but the alloy layers of iron zinc remain because, once formed (in the first dip), they have high melting points (about 1500 degrees F or about 800 degrees C). The presence of these alloy layers from the first dip causes a difference in thickness and appearance in the overlap area. Although overlap areas are noticeable at the time of dipping, the overlap area will fade as the coating ages. Overlap areas are not deleterious to the girder, to the corrosion protection of the girder, or to the coating. After aging, the overlap area will not be visible, but if the initial appearance of the overlap is a concern for an owner, the contract specifications should include requirements to treat and otherwise reduce the visibility of the overlap.

In progressive dipping, part of the component being dipped is in the zinc bath and part of it is out of the bath, resulting in a thermal gradient. Such thermal gradients can contribute to distortion and can also cause expansion of existing cracks, including cracks that may not have been visible before dipping. This tends to be more of an issue with complex components and less so with symmetric components like rolled I-beams. Residual stresses in the part can exacerbate such distortion.

Dipping, whether single or progressive, is usually done with the girder web vertical rather than with the girder web horizontal. Dipping with the girder web being horizontal is less common. This can be done, but skill using the technique is required to avoid local build-up and achieve a satisfactory coating.

Section 7:

SURFACE PREPARATION BEFORE GALVANIZING

7.1—PREBLASTING

Abrasive blasting per SSPC-SP 6/NACE No. 3 is required for built-up plate girders and rolled beams prior to galvanizing.

C7.1

Preblasting helps control coating thickness, particularly when reactive steels are used and there are significant variations in component thicknesses, such as webs compared to flanges, facilitating good workmanship. When steel is reactive, silicon exacerbates the growth of zinc/iron crystals, resulting in excess thickness. When material is preblasted, the anchor pattern causes the zinc/iron crystals to grow into each other and arrest thickness. Rust that occurs after pre-blasting but before galvanizing is not a concern because the rust does not affect the anchor pattern and is readily re-moved during the pickling process.

Further information about reactive steels may be found in Section 4.1.

7.2—REMOVAL OF MARKINGS

Markings and stickers from fabrication or shipping that will interfere with galvanizing adhesion shall be removed prior to beginning the galvanizing process.

C7.2

Paint stick, grease pencil, and other substances that will not be removed by the caustic bath or acid pickling must be removed to ensure uniform galvanizing coating. Special treatments intended to prevent adherence of galvanizing (threaded holes, post-galvanizing weld zones, etc.) should remain. When stickers are removed, this must include all the sticker adhesive because it will also preclude adhesion.

The best practice in fabrication is to use water-soluble markers for marking steel to be galvanized. Water-soluble markings and chalk stick do not need to be removed prior to galvanizing because the galvanizing process will remove these markings. More information about markers for product to be galvanized is available from the AGA at https://galvanizeit.org/design-and-fabrication/fabrication-considerations/marking-parts.

7.3—WELD CLEANING

Welding byproducts (e.g., slag, silicon deposits, spatter, or other residues) shall be removed by the fabricator prior to the galvanizing process.

C7.3

Slag, spatter, smoke residue, and welding flux residues are chemically inert in normal pickling solutions. Thus, they will not be removed by cleaning techniques used for galvanizing and must be removed at the time of fabrication to avoid degrading the final coating. Tightly adhering spatter will get some zinc coverage in galvanizing but not enough for long-term performance; insufficient coverage can result in pinpoint rusting.

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Section 8:

DISTORTION

8.0—DISTORTION

Distortion that occurs during galvanizing that prevents installation or the intended use of the product shall be unacceptable. Final distortion shall not exceed the following criteria:

- Applicable fabrication dimensional tolerances in the contract documents
- Applicable tables of ASTM A6/A6M for rolled shapes and unwelded plates

C8.0

Steel assemblies and subassemblies fabricated by welding, such as built-up structural members, bracing, expansion joints, etc., that are hot-dip galvanized after fabrication, are subject to warpage and distortion of the assembly due to the heating and cooling integral to the galvanizing operation.

Elements bent to tight radii (less than limit of five times thickness per the *AASHTO LRFD Bridge Construction Specifications* (2017)) should be carefully inspected before galvanizing for corner or outer-face fractures which could exacerbate their condition.

When distortion correction is needed, galvanizers should coordinate this with the fabricator. Correction should be by cold methods to help protect the coating.

Research (Bennett et al., 2021) indicates that dipping and extracting as quickly as practical and maximizing dipping angle both minimize distortion.

8.1—STIFFENING AND BRACING

Elements susceptible to galvanizing-induced distortion that would prevent their intended use shall have permanent or temporary bracing installed before galvanizing. Bracing may consist of clamps, bolted-on items, or connections to similar opposite-hand elements. Temporary bracing shall be removed after galvanizing, and contact areas shall be repaired in accordance with ASTM A780./A780M

Plate girders shall have sufficient bracing to resist lateral deformation during galvanizing. Bracing may include permanent welded stiffeners, temporary bolted stiffeners using field splice bolt holes, or other temporary bracing within 3 feet of girder ends.

C8.1

Temporary bracing may be needed to avoid distortion during galvanizing. Such bracing is usually based on the galvanizer’s knowledge and not shown on the design plans or shop drawings. The expectation is for the fabricator or galvanizer to clamp or bolt on bracing for lightweight, non-symmetric assemblies that would be prone to distortion and discuss strategies with the designer.

Although they may twist, it is not common for typical rolled beams or plate girders to need special bracing to resist lateral deformation. The need sometimes arises on lightweight plate girders. Thin plate girder webs with different flange sizes and few welded stiffeners are vulnerable to lateral distortion (rotation of unstiffened areas about the longitudinal neutral axis). Use of stiffeners or any other welded or permanent addition requires approval of the engineer. Angles can be temporarily bolted to field splices during galvanizing and then removed after cooling. The fabricator should discuss tolerances and limitations on temporary attachments with the galvanizer to determine the best approach.

Elements that were deformed (bent, straightened, curved, etc.) by force, heat, or their combination before galvanizing may distort during galvanizing due to the release of residual stresses from that previous work.

For multiple items, a “first article” observation point (i.e., verify the success of the stiffening approach for control of distortion before proceeding with the next pieces) after galvanizing should be performed to verify the stiffening or bracing system for galvanizing.

Asymmetric members and elements created by bending shall be braced to maintain their required geometry.

Two examples of asymmetrical members that can be problematic are:

- a curved "T" section—the galvanizing process may straighten the member if it is not braced; and
- a curved beam with stiffeners on one side only—the beam may tend to straighten during galvanizing, potentially fracturing the stiffener-to-web welds and distorting the beam.

8.2—THICKNESS RATIO AND SYMMETRY

Significant thickness differences between adjoining elements affect galvanizing-induced distortion and galvanizing thickness, and asymmetric assemblies are more susceptible to galvanizing-induced distortion. If problems are anticipated, these should be raised with all parties before fabrication.

C8.2

For designs including galvanizing, designers should discuss potential problems with significant thickness differentials and asymmetric assemblies with galvanizers or the AGA. Preferably this is done in the design phase of the job and not in construction.

As thickness ratios increase between member elements, distortion issues increase. For example, consider the 3:1 rule: if the ratio of the flange thickness to the web thickness exceeds 3, this is considered detrimental for geometric stability during galvanizing. Including additional bracing stiffeners (beyond design requirements) may reduce distortion.

The mismatch in thickness of the baseplate thickness to the pole wall is very significant in high-mast light towers, and cracking at pole-to-base-plate welds has resulted in additional non-destructive examination requirements. Research performed under NCHRP 10-94 showed a strong trend indicating that increased ratios of transverse plate thickness to tube thickness corresponded with significantly greater stress and strain demands during galvanizing, and an increased risk of liquid-metal-assisted cracking. Therefore, this competing criterion should be balanced with design for fatigue in structures that are to be hot-dip galvanized. One way in which the transverse plate to tube thickness ratio can be controlled without adversely affecting fatigue performance is to utilize a thicker pole section near the base. This also helps to lower stresses at the handhole detail. It is recommended that multisided poles be designed to have a ratio of base plate thickness to pole thickness equal to or less than 6.0.

Cracking has occasionally occurred in galvanized multi-sided poles at the top of pole-to-base-plate welds crossing the formed bends in the pole. This is due to the thickness differential between the base-plates and the poles, as well as stress concentrations at the bends. The difference in expansion and contraction between these elements during the thermal cycle puts stress on the weld, causing cracks, particularly at the formed bends in the pole. See further discussion in C4.1.

8.3—WELDING

Except for planned field-welded connections, all welding shall be completed before galvanizing.

C8.3

If welding is to be done after the galvanizing process, the galvanizing should be kept off the area to be field-welded by masking during galvanizing. Galvanizing can also be removed from an intended weld zone by grinding in the field, but this is less preferable because it is difficult to verify that galvanizing has been removed.

Use of ultrasonic impact treatment (UIT) after galvanizing is sometimes specified to mitigate fatigue effects. UIT introduces residual compressive stress at the toe of the weld, which helps prevent crack initiation. Galvanizing temperatures remove the residual compression benefits of the process, so UIT is done after galvanizing. After UIT, surfaces can be repaired in accordance with ASTM A780/A780M except that zinc-rich solders ("hot stick") and zinc-based solders containing tin should not be used.

Temporary welds shall not be used without the owner's documented approval.

Removing temporary welds after galvanizing creates significant coating damage, so temporary welds should be avoided.

8.4—CORRECTION

If distortion during galvanizing exceeds applicable tolerances, the fabricator shall submit a proposal to the owner for correction, use as-is, modification to allow use of the item, or replacement. After distortion correction, damaged galvanizing shall be repaired per ASTM A780/A780M except that solders containing tin shall not be used.

If the item will be duplex-coated and zinc-rich paint is used per ASTM A780/A780M, the zinc-rich paint shall be compatible with the subsequent coating. The final condition on faying surfaces shall satisfy any applicable requirements.

C8.4

If damage to the galvanizing due to repair of distortion is significant, the fabricator and galvanizer may choose to re-galvanize the part instead of repair by ASTM A780/A780M. However, in using this approach, there is a significant risk of simply reintroducing the same distortion unless additional bracing is used.

Compatibility can be established by the coating manufacturer. Alternatively, a test piece can be made to demonstrate satisfactory adhesion, and to also demonstrate that there will not be an outgassing problem.

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SECTION 9:

FINAL GALVANIZED SURFACE CONDITIONS

9.1—GENERAL

Exposed galvanized surfaces shall meet the requirements of ASTM A123/A123M.

9.2—AESTHETIC AND PEDESTRIAN CONTACT AREAS

Surfaces subject to direct human contact or close observation in service shall be free of

- protrusions over ⅛ in. [3 mm] above the surrounding surface,
- anomalies capable of injuring flesh or snagging material, and
- visually apparent variations detracting from the intended use of the product.

After corrections, the surface shall be inspected to verify that the remaining zinc thickness satisfies the contract.

Renovations shall leave zinc thickness satisfying Article 6.2.

9.3—SPECIAL SURFACE REQUIREMENTS

When special surface treatments are defined by descriptions or pictures in the contract or physical specimens provided by the engineer, the final product finish shall satisfy those requirements. Areas not satisfying these criteria shall be remediated to meet the standards.

C9.3

The owner may establish final surface condition criteria for project-specific aesthetic, function, or safety considerations. These should be clearly communicated to the galvanizer in the purchase order. Standards defining the criteria may include pictorial or physical specimens in addition to written, measurable criteria. For physical specimens, the size and shape may depend on variations in the fabricated elements, the frequency of application (e.g., common railing or project-specific detail), and the range of acceptable conditions. A full test article of a product may be appropriate for multiple projects, while a much smaller specimen may be adequate for a project-specific detail.

The as-galvanized and delivered condition compared to a long-term weathered condition for galvanizing needs to be understood by the owner's inspectors and representatives.

Roughness may be the primary consideration rather than color or appearance. Special conditions may be specified for both the appearance and smoothness of pedestrian railing.

Smoothness should be expressed in a quantifiable way, but establishing a measurable value is difficult. If a fingernail can catch on the coating, that is not smooth. Use of “smooth” is inappropriate for structural items and should be reserved for items such as handrails that are intended to be touched. Pictures and physical specimens are suggested as a mediation tool for the parties involved.

9.4—HANDLING AND STORAGE OF GALVANIZED PRODUCTS

Galvanized products shall be stored off the ground and not in standing water. Handling shall avoid damage to the galvanized coating, including raising burrs or upsetting the galvanizing at lift points.

C9.4

It is preferable to avoid using dunnage that stains the galvanizing. However, such stains are not detrimental to the performance of the coating and can be cleaned easily.

Use of uncoated chains or banding in direct contact (i.e., without cushioning) should be avoided. Uncoated chains and banding may cause staining, which is not detrimental but may raise appearance concerns.

Section 10:
DUPLEX COATINGS

10.0—DUPLEX COATINGS

C10.0

The general contractor is ultimately responsible for the final product and needs to ensure the obligations of subcontractors (fabricator, galvanizer, and painter) are clearly defined in their agreements. The need for special conditioning for duplex coatings should be clearly communicated to the galvanizer in the purchase order. The following section addresses preparation of the galvanized surface for the coating; application of the coating will be per the coating specification.

10.1—PREPARATION FOR DUPLEX COATING

Product to receive duplex coatings shall meet the post-galvanizing requirements of ASTM D6386 (for liquid coatings) or ASTM D7803 (for powder coatings).

After any surface treatment, the galvanizing shall meet the thickness criteria of Article 6.2 and the specified finish requirements.

C10.1

Smoothing, which includes the removal of prominences, should be the responsibility of the galvanizer, and further surface preparation should be the responsibility of the painter.

Appropriate preparation of galvanizing for duplex coating is addressed in ASTM D6386. If other surface preparation for duplex coating is specified which is not appropriate for the galvanized coating (such as blast cleaning that is too aggressive and will remove the galvanizing), this should be brought to the attention of the owner for the owner's consideration.

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Section 11:

QUALITY

11.1—QUALITY CONTROL

The galvanizer shall conduct quality control to ensure all contract requirements are met, including, at a minimum, the following activities:

- Verify the identification and condition of material received for galvanizing, including proper venting and drain holes, absence of deleterious material, and absence of damage.
- Ensure proper cleaning, handling, and galvanizing procedures are used.
- Maintain traceability of each item through the process.
- Satisfy contract requirements for coating thickness, and ensure no areas are missing galvanizing.
- Avoid post-galvanizing treatments that would affect subsequent coating.
- Ensure the surface condition is appropriate for the intended use of the product.
- Ensure conformance with distortion limitations, treatment of fastener holes, and special handling.

11.2—QUALITY MANAGEMENT SYSTEM

The galvanizer shall maintain a quality management system that addresses the following items. The extent of documentation and self-audit method for effectiveness is determined by the galvanizer, subject to the owner's approval.

- Management
  - ○ Management review
  - ○ Equipment and facilities
- Galvanizing order review
  - ○ Order review document record
  - ○ Communicating requirements throughout the organization
  - ○ Required documents
  - ○ Document control, including retention period
- Purchasing
- Material identification and traceability

C11.2

An effectively implemented quality management system is a key indicator of a galvanizer's ability to control their quality processes and consistently deliver quality product. The AGA offers a Quality Assurance Manual that the galvanizer can use as a guide for developing their own manual.

- Galvanizing process control
  - Frequency of testing tank contents including the zinc bath
  - pH/acid strength (limits)
  - Temperature limits
  - Iron content
  - Zinc purity
  - Metal contamination

The presence of some alloys commonly added to the galvanizing bath has been shown to aggravate occurrences of LMAC. In particular, tin (Sn) has been shown in multiple studies to aggravate LMAC in extremely small quantities and thus, should not be added to galvanizing baths in any quantity. Lead (Pb) and bismuth (Bi) are common alloy additions to galvanizing baths. When used in typical quantities in combination (<1 percent Pb, <0.1 percent Bi), these alloys corresponded with only a slight increased sensitivity to LMAC. However, it should be noted that galvanizing with pure zinc (e.g., Special High Grade zinc) provided less risk in terms of LMAC.

- Inspection
  - Receipt inspection
  - In-process inspection
  - Final inspection
  - Inspection equipment
  - Qualification of QC inspectors
  - Inspection records
- Calibration
  - Identification of master and controlled gauges
  - Records of calibration
- Addressing nonconformances
  - Product nonconformance
  - Process nonconformance
  - Assessing nonconformances
  - Reinspection of nonconforming work
- Corrective action
  - Identification and recording
  - Resolution and review
  - Assessing effectiveness
  - Process non-conformance, including root cause analyses, application, and follow-up
- Handling and delivery
- Reporting
- Training and qualification of personnel
  - Inspectors (AGA qualification or equivalent)
  - Process personnel
  - Training documentation
- Internal audit

One source of inspection training is AGA Inspection Training, available at https://galvanizeit.org/inspection-course.

- ○ Personnel
- ○ Planning
- ○ Recording
- ○ Review
- ○ Frequency

Each area should be reviewed at least annually.

Internal auditors should be trained to assess process-based systems, as defined by ISO 9001. To maintain independence, an auditor should not audit their own departments. Executive management may audit all areas.

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