



Design Guide

The Design of Products to be Hot-Dip Galvanized after Fabrication



Table of Contents

Introduction	2
Communication among Design Engineer, Architect, Fabricator, & Galvanizer	3
Materials Suitable for Galvanizing	3
Combining Different Materials and Surfaces	5
Size & Shape	6
Process Temperature & Heat	7
Mechanical Properties of Galvanized Steel	
Strain-age Embrittlement	
Hydrogen Embrittlement	
Minimizing Distortion	9
Allowing for Proper Drainage	10
Tubular Fabrications & Hollow Structural	10
Cleaning	
Venting	
Handrail	
Rectangular Tube Truss	
Pipe Truss	
Pipe Columns, Pipe Girders, Street Light & Transmission Poles	
Box Sections	
Tapered Signal Arm	
Proper Venting & Drainage of Enclosed & Semi- Enclosed Fabrications	15
Precautions for Overlapping & Contacting Surfaces	17
Welding Procedures & Welding Flux Removal	18
Threaded Parts	19
Moving Parts	20
Additional Design Considerations	21
Masking	
Marking for Identification	
Post Galvanizing Considerations	22
Storage	
Cleaning Galvanized Steel	
Dissimilar Metals	
Temperature of Use	
Related Specifications	24





Introduction

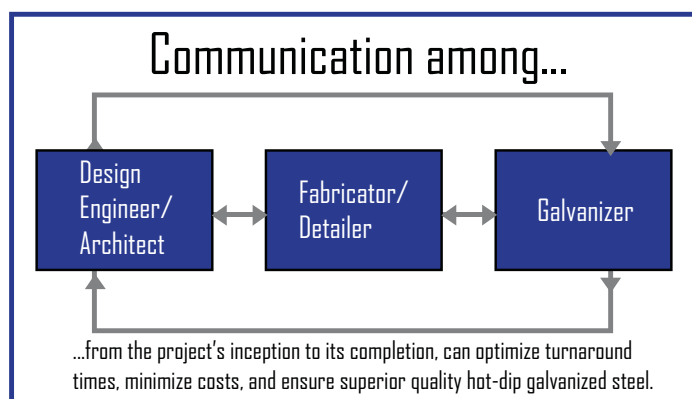
The galvanizing process has existed for more than 250 years and has been a mainstay of North American industry since the 1890s. Galvanizing is used throughout various markets to provide steel with unmatched protection from the ravages of corrosion. A wide range of steel products – from nails to highway guardrail to the Brooklyn Bridge's suspension wires to NASA's launch pad sound-suppression system – benefit from galvanizing's superior corrosion protection properties.

The uses of hot-dip galvanized steel continue to evolve, and new markets are emerging all the time. As with all materials and coatings, there are certain practices which yield better quality finished products. In order to meet the expectations and demands of many different markets, it is important to be cognizant of these best design practices for steel to be galvanized. Often no or only minor adjustments to the design are necessary, and worth the extra time and/or effort up front to alleviate certain future headaches related to the utilization of other coating systems.



Communication among Design Engineer, Architect, Fabricator, & Galvanizer — — —

Corrosion protection begins at the drawing board, and regardless of what protection system is specified, it must be factored into the product's design. Similarly, all corrosion protection systems require certain design details and proper planning to ensure the highest quality coating. For hot-dip galvanizing, a total immersion process in molten zinc, the design engineer will want to ensure all pieces are fabricated suitably for the process. Most design principles necessary for success throughout the galvanizing process are easily and readily followed, and in most cases, ensure maximum corrosion protection. Incorporating these design practices along with those listed in ASTM A 385 *Practice for Providing High Quality Zinc Coatings (Hot-Dip)*, will not only produce optimum quality galvanized coatings, but also help reduce costs and improve turnaround times.



One key to providing the best design for the hot-dip galvanizing process is communication between the architect, engineer, fabricator and galvanizer. Opening the lines of communication early in the design process can eliminate potential costly pitfalls later in the process. A few discussion topics good to cover while the project is being designed include:

- Steel Chemistry and Surface Condition
- Size & Shape
- Process Temperature/Heat
- Venting & Drainage
- Welding
- Threaded Parts/Connections
- Post Galvanizing Design/Use

Understanding these aspects of the galvanizing process and how they can affect the coating and finished product's outcome will help ensure everyone's expectations are met.

Materials Suitable for Galvanizing — —

Most iron-containing (ferrous) materials are suitable for hot-dip galvanizing. Plain carbon steel (under 150 ksi/1100 MPa) and low alloy materials, hot-rolled steel, cold-rolled steel, cast steel, ductile iron, cast iron, castings, stainless steel, and even weathering steel can be and are galvanized for enhanced corrosion protection. However, the material's chemical composition influences the characteristics of the galvanized coating.

During galvanizing, the iron in the material reacts with the molten zinc to form a series of zinc-iron alloy layers, which are covered by a layer of iron-free zinc. For most hot-rolled steels, the zinc-iron alloy portion of the coating will represent 50-70% of the total coating thickness, with the free zinc outer layer accounting for the balance (*Figure 1*).

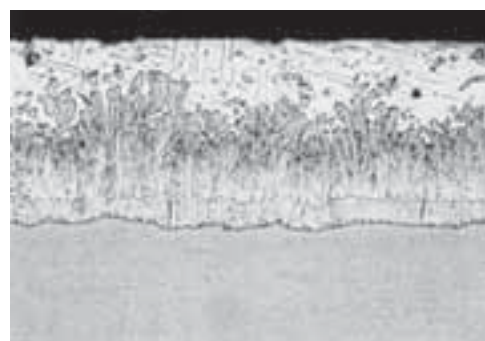


Figure 1: Typical zinc-iron alloy layers

Steel compositions vary depending on strength and service requirements. Trace elements in the steel (silicon, phosphorus) affect the galvanizing process as well as the structure and appearance of the galvanized coating. Steels with these elements outside of the recommended ranges are known in the galvanizing industry as highly reactive steel, and may produce a coating composed entirely, or almost entirely, of zinc-iron alloy layers (*Figure 2*).

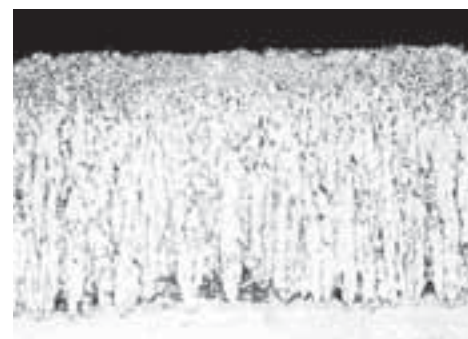
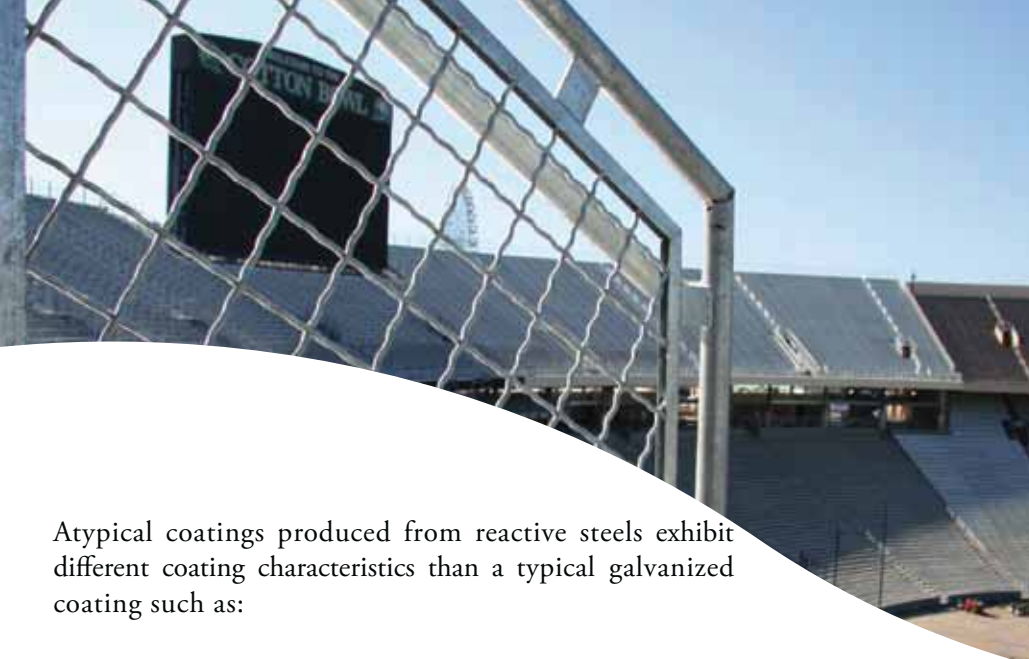


Figure 2: Atypical zinc-iron alloy layers





Atypical coatings produced from reactive steels exhibit different coating characteristics than a typical galvanized coating such as:

Appearance: The atypical galvanized coating may have a matte gray appearance and/or rougher surface due to the absence of the free zinc layer. The free zinc layer present on typical coatings imparts a shinier finish to a galvanized coating.

Adherence: The zinc-iron alloy coating tends to be thicker than a typical galvanized coating. In the rare situation where the coating is excessively thick, there is the possibility of diminished adhesion under external stress (thermal gradients, sharp impact).

Reactive steels are still galvanized on a regular basis, and it is important to note differences in appearance have no effect on the corrosion protection afforded by the galvanized coating. The performance of the coating is based on the thickness of the zinc; therefore, often the duller (and thicker) coatings produced by reactive steels last longer. Furthermore, all galvanized coatings as they weather over time will develop a uniform matte gray appearance.

It is difficult to provide precise guidance in the area of steel selection without qualifying all steel grades commercially available. However these guidelines discussed will assist you in selecting steels that provide good galvanized coatings.

- Levels of carbon less than 0.25%, phosphorus less than 0.04%, or manganese less than 1.35% are beneficial
- Silicon levels less than 0.04% or between 0.15% - 0.22% are desirable

Silicon may be present in many steels commonly galvanized even though it is not a part of the steel's controlled composition, because silicon is used in the steel deoxidation process and is found in continuously cast steel. Both silicon and phosphorous act as catalysts during the galvanizing process, resulting in rapid growth of zinc-iron alloy layers.

And even when both elements are individually held to desirable limits, the combined effect between them can still produce an atypical coating of all or mostly zinc-iron alloy layers. When possible, your galvanizer should be advised of the grade of steel selected in order to determine whether specialized galvanizing techniques are suggested.

Castings

High-quality castings and forged parts are also commonly and successfully galvanized. The quality of the galvanizing is strongly influenced by the quality of the casting. As with all steel to be galvanized, cleanliness is very important to achieve completely galvanized cast iron or steel parts. However, conventional cleaning processes employed by galvanizers do not adequately clean castings because sand and other



Steel Casting



surface inclusions are not removed by chemical cleaning. Thorough abrasive cleaning is the most effective method for removing foundry sand and impurities. The preferred way to clean the casting is by abrasive blasting, either grit-blasting or a combination of grit and shot. Cleaning is traditionally performed at the foundry before shipment to the galvanizer.

Sound, stress-free castings with good surface finishes will produce high-quality galvanized coatings. The following design and preparation rules should be applied for castings to be galvanized:

- Avoid sharp corners and deep recesses
- Use large pattern numerals and generous radii to facilitate abrasive cleaning
- Specify uniform wall sections. Non-uniform wall thickness in certain casting designs may lead to distortion and/or cracking. Cracking results from stress developed as the temperature of the casting is increased during galvanizing. Uniform wall sections and a balanced design lowers stress.

Combining Different Materials & Surfaces –

Varying surface conditions, different fabrication methods, or ferrous metals with special chemistries, when combined, make it difficult to produce coatings with uniform appearance. This is because different parameters for pickling (immersion time, solution concentrations, temperatures) and galvanizing (bath temperatures, immersion time) are required for:

- Coatings such as paint, lacquer, etc. on the steel
- Excessively rusted surfaces
- Machined surfaces
- Cast steel
- Malleable iron
- Hot-rolled steel
- Cold-rolled steel
- Cast iron, especially with sand inclusions
- Pitted surfaces
- Steel containing excess carbon, phosphorus, manganese, or silicon



Varying steel chemistries create visually different coatings, as illustrated by this pipe assembly

Many coatings such as paint and lacquer cannot be removed from the steel with the chemical cleaning process used in the galvanizing facility. As perfectly cleaned steel is required for the metallurgical reaction to occur in the galvanizing kettle, these contaminants need to be removed mechanically from the surface prior to sending the fabrication to the galvanizer.

The use of old along with new steel, or castings with rolled steel in the same assembly, should be avoided (*Figure 3*). Where assemblies of cast iron, cast steel, malleable iron, or rolled steel are unavoidable, the entire assembly should be thoroughly abrasive-blasted prior to pickling to give the best chance for producing a consistent galvanized coating appearance.

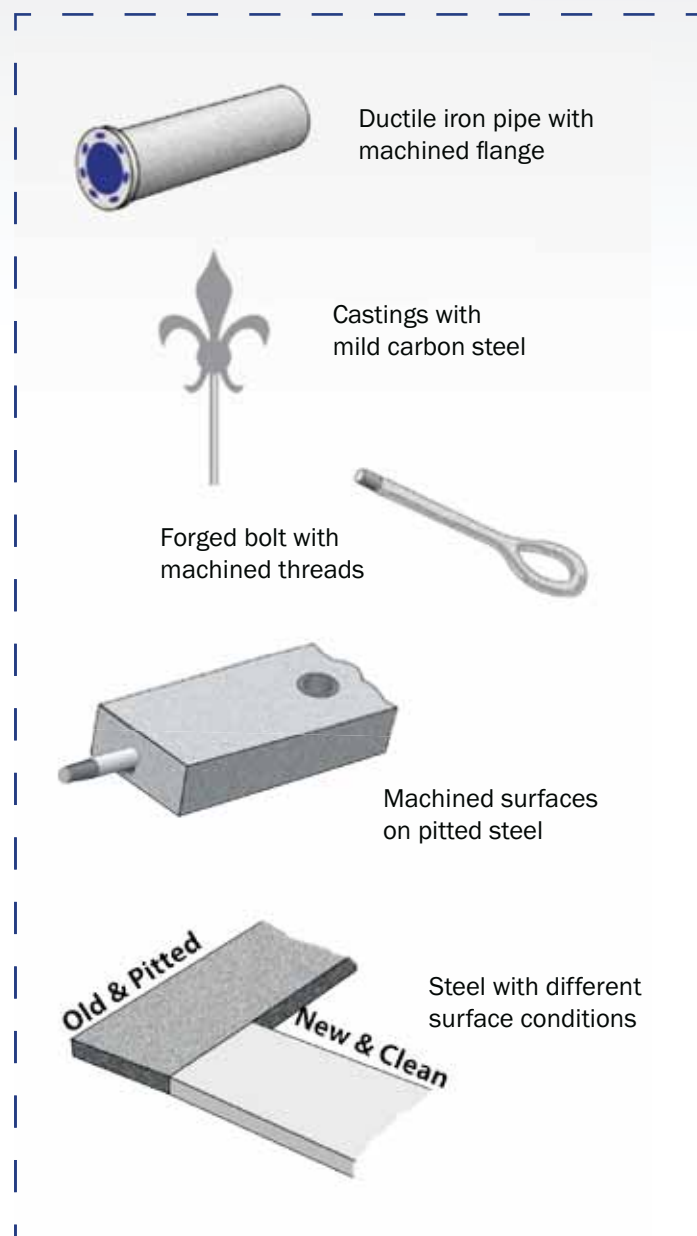


Figure 3: Results will not be consistent with a combination of these type of metals or finishes

Similarly, excessively rusted, pitted, or forged steels should also not be used in combination with new or machined surfaces because the difference in required pickling time for sulfuric acid pickling baths can cause over-pickling of the new or machined surfaces. Where this combination is unavoidable, a thorough abrasive blast cleaning of the assembly (normally before any machining is done) provides a more uniform galvanized coating.

If abrasive blast cleaning is used to prepare a surface for galvanizing, a coating thicker than normal will be produced for low silicon steel. Abrasive cleaning roughens the steel surface and increases its surface area, resulting in increased reactivity with the molten zinc.

The best practice when combining different materials and surfaces is to galvanize separately and assemble after galvanizing. This will help facilitate efficient turnaround times in the process, eliminate over-pickling, and allow the pieces to be matched for appearance. Whether run through the galvanizing process joined or separately, the differences in appearance on assemblies containing steels with varying surface condition do not affect the corrosion protection. Furthermore, after aging in the environment, all surfaces will exhibit a uniform matte gray appearance.

Size & Shape — — — — —

Another important consideration during the design process is the size and shape of the fabrication. Because hot-dip galvanizing is a total immersion process, the design must take into consideration the capacity of the galvanizing kettle; therefore, it is wise to verify kettle constraints with

your galvanizer early in the design process. Almost any component can be galvanized by designing and fabricating in modules suitable for available galvanizing facilities. The average kettle length in North America is 40 feet (13m), and there are many kettles between 50-60 feet (15.24 m - 18.28 m). Kettle dimensions and contact information for all member galvanizers are available at www.galvanizeit.org/galvanizers.

Large structures designed in modules or sub-units to accommodate the galvanizing kettle often provide additional savings in manufacturing and assembly because they simplify handling and transportation. The sub-units can be connected after galvanizing by field-welding or bolting. Alternatively, if an item is too large for total immersion in the kettle, but more than half of the item will fit into the kettle, the piece may be progressively dipped. Progressive dipping is accomplished by dipping each end of the article sequentially to coat the entire item. **Consult your galvanizer before planning to progressively dip.**

Considering size and shape, as well as weight, is also important due to material handling techniques used in galvanizing plants. The steel is moved through the process by the use of hoists and overhead cranes. Small items, less than 30" (76 cm) in length, are frequently galvanized in perforated baskets. The baskets are then centrifuged or spun to throw off excess zinc, delivering smoother coatings. Fasteners, small brackets, and clips typify work handled in baskets.



Progressive dipping - galvanizing oversized pieces



A perforated basket filled with bolts is placed in a centrifuge to spin off excess zinc





Large assemblies are usually supported by chain slings or by lifting fixtures. Special jigs and racks are also commonly used to simultaneously galvanize large numbers of similar items. Providing lifting points where possible will reduce or eliminate chain or wire marks that can be left on an item when no lifting points are present. If no lifting points are provided, any marks, which are usually fully galvanized, can be touched up if desired for aesthetic reasons. It is also good practice to discuss the weight-handling capacity with the galvanizer to ensure capacity or the best places to put lifting points.

In addition to lifting points, large pipe sections, open-top tanks, and similar structures may benefit from temporary bracing to maintain their shape during handling.

Process Temperature/Heat — — — —

During the hot-dip galvanizing process, steel is heated to approximately 830 F (443 C) for the galvanizing reaction to occur. Every time steel is heated and cooled, stress is added to the fabrication. Therefore, there are some design considerations to be aware of to help reduce any issues with the heating of the galvanizing process.

Mechanical Properties of Galvanized Steel

The hot-dip galvanizing process produces no significant changes in the mechanical properties of the structural steels commonly galvanized throughout the world. The mechanical properties of 19 structural steels from major industrial countries were investigated before and after galvanizing in a four-year research project of the BNF Metals Technology Centre, UK, under the sponsorship of the International Lead Zinc Research Organization (ILZRO). Steels conforming to ASTM Standard Specifications A 36 and A 572 Grade 60 and Canadian Standards Association (CSA) Specifications G 40.8 and G 40.12 were included in this study.

The BNF report, *Galvanizing of Structural Steels and Their Weldments* (ILZRO, 1975), concludes “. . . the galvanizing process has no effect on the tensile, bend or impact properties of any of the structural steels investigated when these are galvanized in the ‘as manufactured’ condition.”



Hot-dip galvanizing cold-worked steel is very successful when following suggested guidelines

Strain-Age Embrittlement

Many structures and parts are fabricated using cold-rolled steel or cold-working techniques. In some instances, severe cold-working may lead to the steel becoming strain-age embrittled. While cold-working increases the possibility of strain-age embrittlement, it may not be evident until after galvanizing. This occurs because aging is relatively slow at ambient temperatures, but more rapid at the elevated temperature of the galvanizing bath.

Any form of cold-working reduces steel's ductility. Operations such as punching holes, notching, producing fillets of small radii, shearing, or sharp bending (*Figure 4*) may lead to strain-age embrittlement of susceptible steels. Cold-worked steels less than 1/8-inch (3 mm) thick that are subsequently galvanized are unlikely to experience strain-age embrittlement. Since cold-working is the strongest contributing factor to the embrittlement of galvanized steel, these tips (*next page*) are recommended to reduce the incidence of strain-age embrittlement.

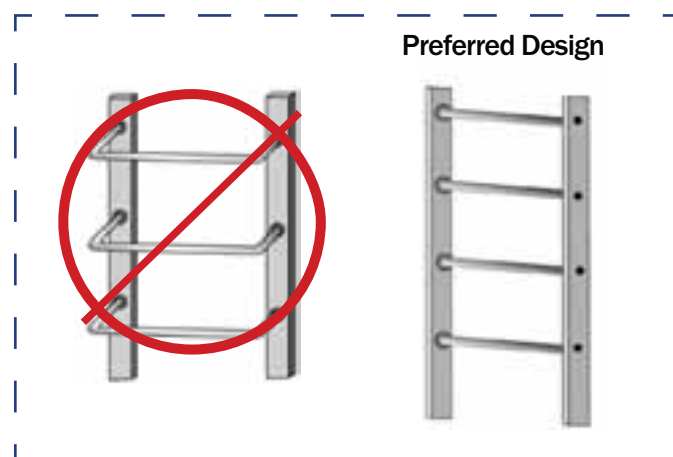


Figure 4: Avoid severe cold-working



Tips to Reduce Strain-Age Embrittlement

- Select steels with carbon contents below 0.25%
- Choose steels with low transition temperatures since cold-working raises the ductile-brittle transition temperature and galvanizing (heating) may raise it further.
- Specify aluminum-killed steels; they show less susceptibility to strain-age embrittlement.
- For steels with a carbon content between 0.1% and 0.25%, maintain a bending radius of at least three times (3x) the section thickness. If bending is required to be less than 3x, the material should be stress-relieved at 1100 F (595 C) for one hour per inch (2.5 cm) of section thickness.
- Avoid notches – they increase stress. Notches may be caused during shearing or punching operations. Flame-cutting or sawing is preferred, particularly for heavy sections.
- Drill, rather than punch, holes in material thicker than 3/4-inch (19 mm). If holes are punched, they should be punched undersize and then reamed an additional 1/8-inch (3 mm) overall or drilled to size. Material between 1/4- and 3/4-inch (6.5 - 19 mm) thick is not seriously affected by cold punching if the punching is done under good shop practice. Material up to 1/4-inch (6.5 mm) thick that has been cold-worked by punching does not need stress-relieving before galvanizing.
- For steel sections with edges greater than 5/8-inch (16 mm) thick subject to tensile loads, cut using normal shop procedures. Edges of sections up to 5/8-inch (16 mm) thick may be cut by shearing.
- In critical applications, the steel should be hot-worked above 1200 F (650 C) in accordance with the steel manufacturer's recommendations. Where cold-working cannot be avoided, stress-relieve the part.

ASTM A 143, *Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement*, and CSA Specification G 164, *Hot-Dip Galvanizing of Irregularly Shaped Articles*, provide guidance on cold-working and stress-relieving procedures. However, it is best to avoid severe cold-working of susceptible steels. If there is concern with possible loss of ductility due to strain-age embrittlement, advise your galvanizer. A sample quantity of the cold-formed items should be galvanized and tested before further commitment.

Hydrogen Embrittlement

Hydrogen embrittlement is a ductile to brittle change that occurs in certain high-strength steels. Hydrogen embrittlement can occur when the hydrogen released during the pickling process is absorbed by the steel and becomes trapped in the grain boundaries. Normally, at galvanizing temperatures, hydrogen is expelled from the steel.

Although hydrogen embrittlement is uncommon, precautions should be taken to avoid it, particularly if the steel involved has an ultimate tensile strength exceeding 150,000 psi (1050 MPa). If high-strength steels are to be processed, grit-blasting instead of acid-pickling is recommended in order to minimize the introduction of gaseous hydrogen during the pickling process.



Minimizing Distortion

Some fabricated assemblies may distort at galvanizing temperature as a result of relieving stresses induced during steel production and in subsequent fabricating operations. For example, a channel frame with a plate should be galvanized separately and bolted later rather than welded together before galvanizing, or it can be welded after galvanizing.

Guidelines for minimizing distortion and warpage are provided in ASTM A 384, *Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies*, and CSA Specification G 164, *Hot Dip Galvanizing of Irregularly Shaped Articles*.

Tips for Minimizing Distortion

To minimize changes to shape and/or alignment, design engineers should observe the following recommendations:

- Where possible, use symmetrically rolled sections in preference to angle or channel frames. I-beams are preferred to angles or channels.
- Use parts in an assembly that are of equal or near equal thickness, especially at joints (Figure 5).
- Use temporary bracing or reinforcing on thin-walled and asymmetrical designs (Figure 6).
- Bend members to the largest acceptable radii to minimize local stress concentration.
- Accurately pre-form members of an assembly so it is not necessary to force, spring, or bend them into position during joining.
- Continuously weld joints using balanced welding techniques to reduce uneven thermal stresses. Pinholes from welding are very dangerous in items to be galvanized and must be avoided. Staggered welding techniques to produce a structural weld are acceptable. For staggered welding of 1/8-inch (4 mm) or lighter material, weld centers should be closer than 4 inches (10 cm).
- Avoid designs that require progressive-dip galvanizing. It is preferable to build assemblies and subassemblies in suitable modules so they can be immersed quickly and galvanized in a single dip. In this way, the entire fabrication can expand and contract uniformly. Where progressive-dip galvanizing is required, consult your galvanizer.

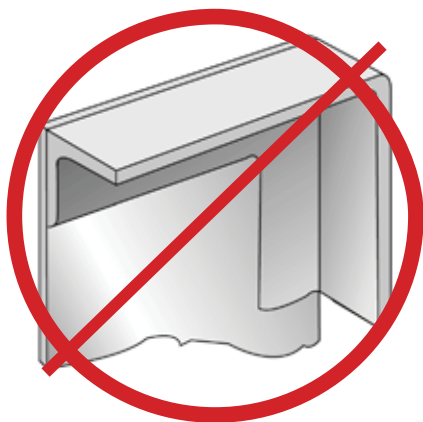


Figure 5: Avoid uneven thickness at joints

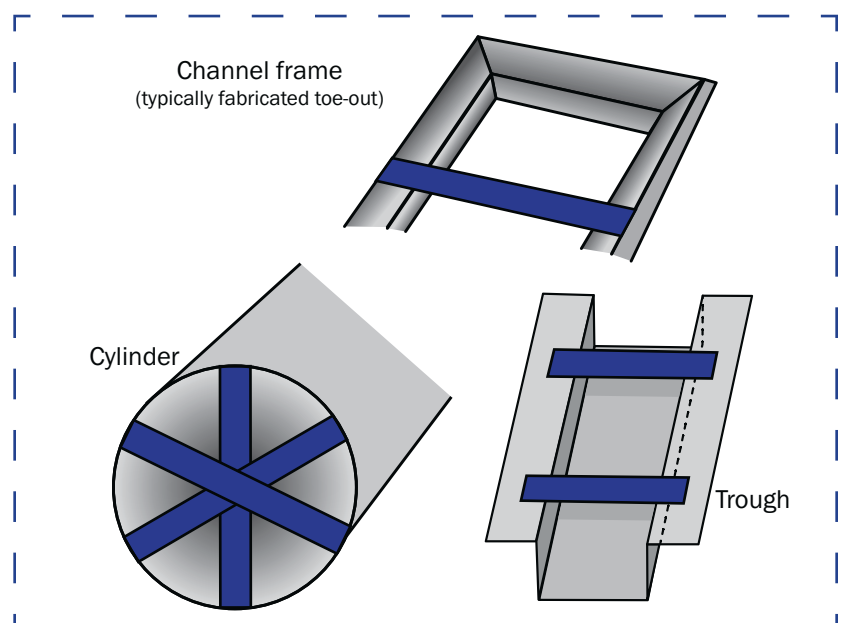


Figure 6: Temporary Bracing

Allowing for Proper Drainage — — — —

For effective galvanizing, cleaning solutions and molten zinc must flow without undue resistance into, over, through, and out of the fabricated article. Failure to provide for this free, unimpeded flow can result in complications for the galvanizer and the customer. Improper drainage design results in poor appearance, bare spots, and excessive build-up of zinc. All of these are unnecessary and costly, and another example of why communication throughout the project is key.

A few common fabrications where drainage is important are gusset plates, stiffeners, end-plates, and bracing. Following these best design practices will help ensure the highest quality coatings:

- Where gusset plates are used, generously cropped corners provide for free drainage. When cropping gusset plates is not possible, holes at least 1/2-inch (13 mm) in diameter must be placed in the plates as close to the corners as possible (*Figure 7*).

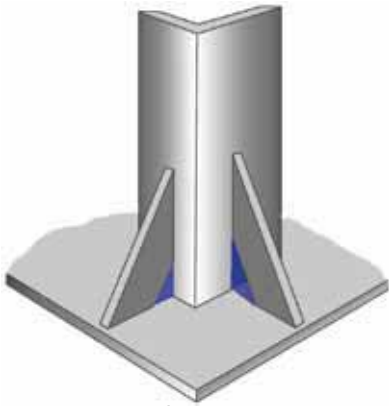


Figure 7: Cropped bracing

- To ensure unimpeded flow of solutions, all stiffeners, gussets, and bracing should be cropped a minimum of 3/4-inch (19 mm) (*Figure 8*). Provide holes at least 1/2-inch (13 mm) in diameter in end-plates on rolled steel shapes to allow molten zinc access during immersion in the galvanizing bath and drainage during withdrawal.

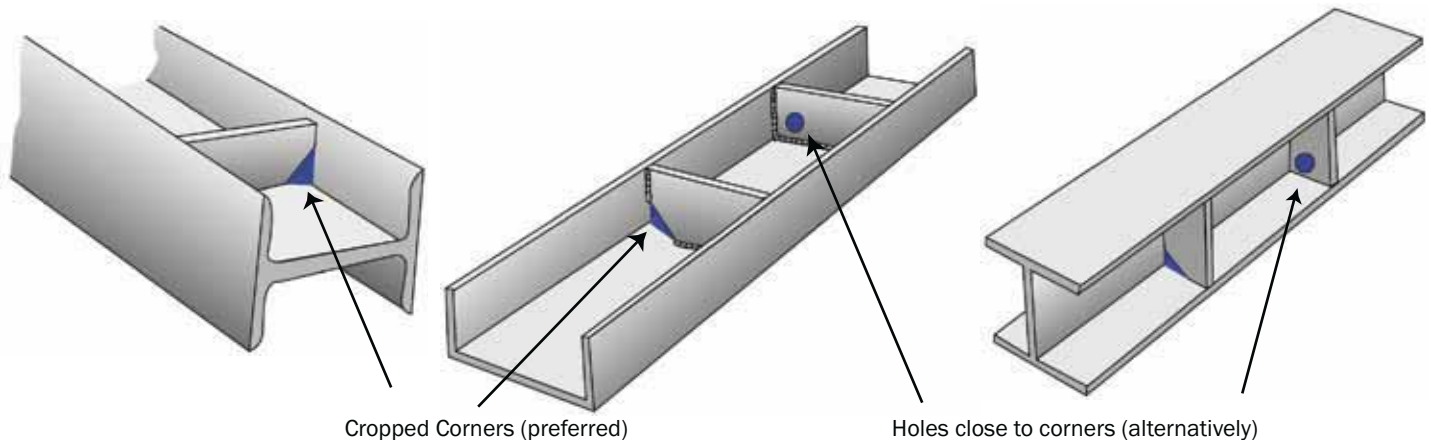


Figure 8: Cropped gusset plate corners

Alternatively, holes at least 1/2-inch (13 mm) in diameter can be placed in the web within 1/4-inch (6 mm) of the end-plate. To facilitate drainage, end-plates should have holes placed as close to interior corners as possible (*Figure 9*).

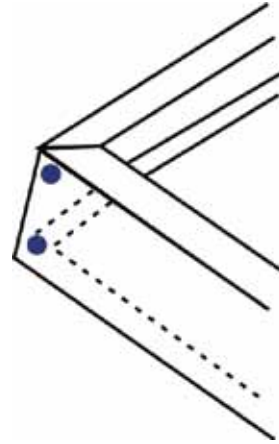


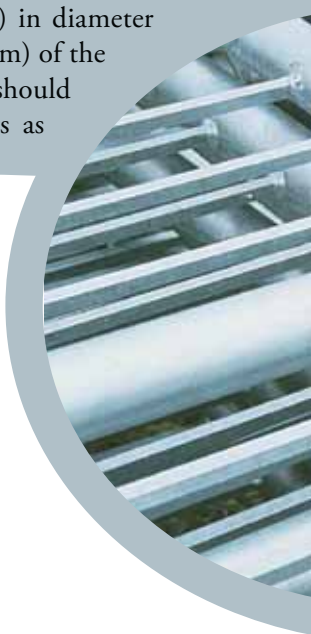
Figure 9: Holes in end-plate

Tubular Fabrications & Hollow Structural

Tubular assemblies (handrails, pipe columns, pipe girders, street light poles, transmission poles, pipe trusses, sign bridges) are commonly galvanized because corrosion protection is afforded to the interior and exterior of the product. To provide an optimal galvanized coating, hollow products require proper cleaning, venting, and draining.

Cleaning

As with all steel, pipe and other hollow materials must be thoroughly cleaned before the molten zinc will metallurgically bond with the steel. Pipe can present two special cleaning challenges. First, the mill coating (varnish, lacquer, and similar materials) applied by pipe manufacturers requires extra time and effort to remove at the galvanizing plant. Some galvanizers do not have the capability to remove this coating. Some organic mill coating formulations, both foreign and domestic, are





extremely difficult to remove with common cleaning solutions, so blasting may be required. Ordering uncoated pipe avoids costly attempts to remove these mill coatings. In some cases, it may be more cost effective to substitute tube for pipe.

Second, welding around mill coatings burns and carbonizes the varnish in the surrounding areas and cannot be removed by the normal cleaning process at a galvanizer. This soot must be removed by blasting or other mechanical cleaning methods prior to delivering steel to the galvanizing facility.

Venting

The primary reason for vent and drain holes is to allow air to be evacuated, permitting the object to be completely immersed into cleaning solutions and molten zinc. Proper hole sizing and location make it safer to galvanize and provide the optimal finish. The secondary reason is to prevent damage to the parts. Any pickling solutions or rinse waters that might be trapped in a blind or closed joining connection will be converted to superheated steam or gas and can develop a pressure of up to 3,600 psi (1,100 MPa) when immersed in molten zinc. Not only is there risk of damage to the fabrication being galvanized, but there also is risk of serious hazard to galvanizing personnel and equipment.

When the fabrication is lowered into the cleaning solutions and zinc, air and frothy fluxes must be allowed to flow upward and completely out. Cleaning solutions and molten zinc must be allowed to flow in and completely wet the surfaces. Then, when the structure is raised from the bath, no solutions should be trapped inside. Consequently, ample passageways allowing unimpeded flow into and out of the part must be designed into assemblies. Proper galvanizing results when the inside and outside of a product are completely cleaned and zinc-coated.

Items are immersed and withdrawn from the galvanizing kettle at an angle; thus, the vent holes should be located at the highest point and drain holes at the lowest. All sections of fabricated pipe-work should be interconnected with full open-tee or miter joints. Each enclosed section must be provided with a vent hole at each end.

Most galvanizers prefer to visually identify venting from the outside, in order to verify the adequacy of the venting as well as to determine that venting has not been mistakenly omitted.

Some galvanizers may hesitate to process complicated pipe assemblies unless all venting is visible on the outside and readily accessible for inspection (*Figure 10*).

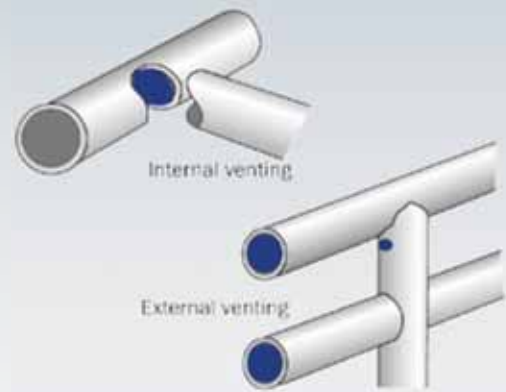


Figure 10: Venting

Base-plates and end-plates must be designed to facilitate venting and draining. Fully cutting the plate provides minimum obstruction to a full, free flow into and out of the pipe. Since this is not always possible, using vent holes in the plate often provides the solution.

Vent holes are frequently left open but can be closed with drive caps or plugs after galvanizing. Various methods of venting are acceptable (*Figure 11*), but the subsequent plugging of these holes should be kept in mind, where necessary or desired.

It is recommended tubular structures be completely submerged in one dip into the galvanizing kettle. This minimizes potential internal coating problems that, because of the size and shape of the item, may be difficult to discover during inspection.

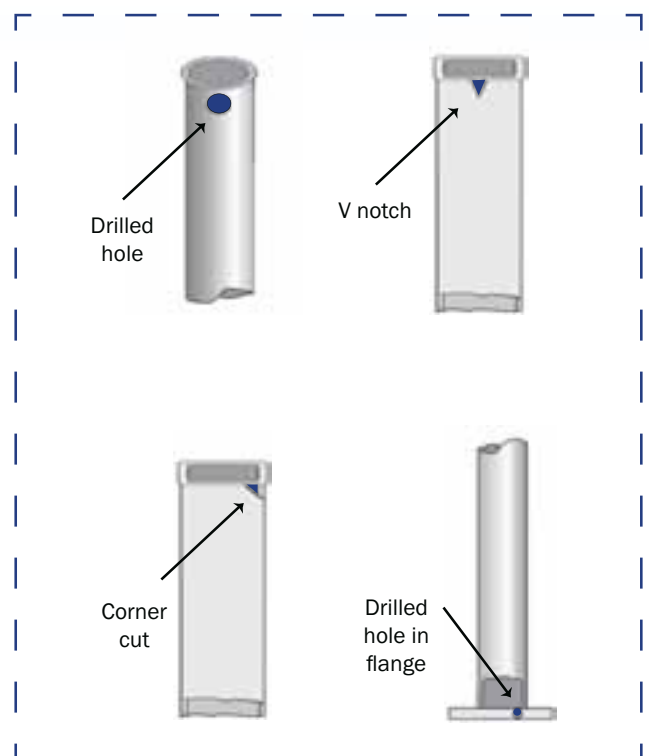


Figure 11: Vent hole options

The following drawings illustrate recommended designs for tubular fabrications and hollow structures. The vent dimensions are the minimum required.

Handrail (Figure 12 & 13):

Figure 12 illustrates the most desirable design for fabrications of handrail for galvanizing. It shows internal venting as well as the minimum amount of external vent holes.

- 1 External vent holes must be as close to the weld as possible and not less than 3/8-inch (9.5 mm) in diameter.
- 2 Internal holes should be the full I.D. of the pipe for the best galvanizing quality and lowest galvanizing cost.
- 3 Vent holes in end sections or in similar sections must be 1/2-inch (13 mm) in diameter.
- 4 Ends should be left completely open. Any device used for erection in the field that prevents full openings on ends of horizontal rails and vertical legs should be galvanized separately and attached after galvanizing.

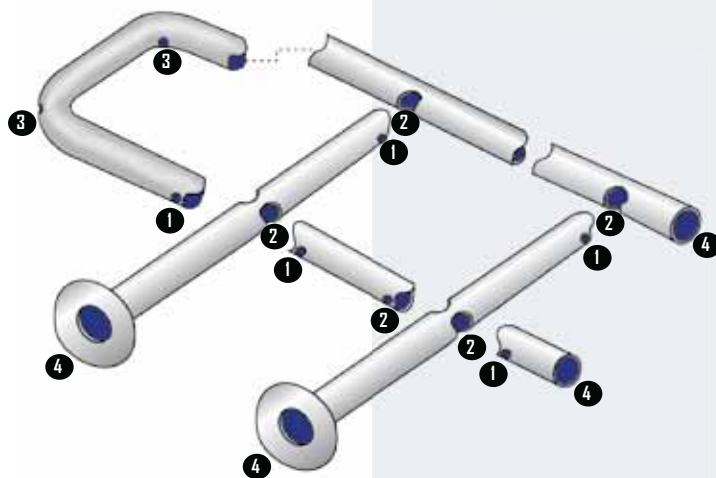


Figure 12: Vent holes should be visible on the outside of any pipe assembly to provide internal vent verification

Figure 13 illustrates an acceptable alternative if full internal holes (the full I.D. of the pipe) are not incorporated into the design of the handrail.

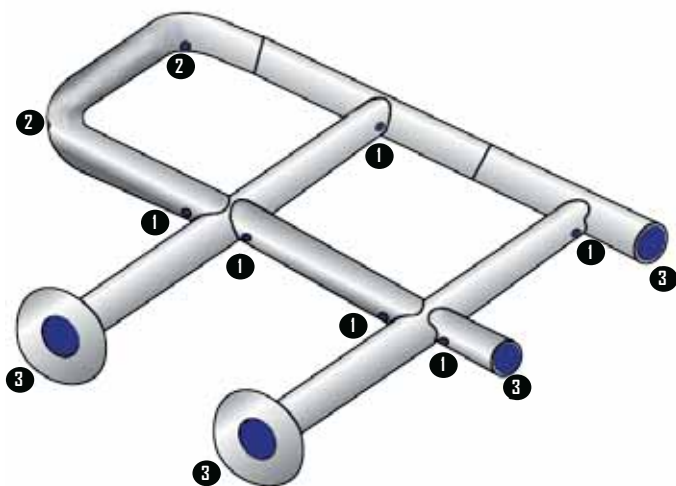


Figure 13: External vent holes should be visible on the outside of pipe assemblies

- 1 Each external vent hole must be as close to the welds as possible and must be 25% of the I.D. of the pipe, but not less than 3/8-inch (10 mm) in diameter. The two holes at each end and at each intersection must be 180° apart and in the proper location as shown.
- 2 Vent holes in end sections or in similar sections must be 1/2-inch (13 mm) in diameter.
- 3 Ends should be left completely open. Any device used for erection in the field that prevents full openings on ends of horizontal rails and vertical legs should be galvanized separately and attached after galvanizing.

Rectangular Tube Truss (Figure 14):

Vertical Sections

Hole locations for the vertical members should be as shown in Figure 14 on Examples A and B.

Each vertical member should have two holes at each end, 180° apart in line with the horizontal members. The size of the holes preferably should be equal, and the combined area of the two holes at either end of the verticals should be at least 30% of the cross-sectional area.

End Plates - Horizontal

- 1 The most desirable fabrication is completely open.
- 2 From Figure 14, if $H + W = 24"$ (61 cm) or larger, the area of the hole, plus clips, should equal 25% of the area of the tube ($H \times W$).
 - If $H + W =$ less than 24" (61 cm) but more than 16" (41 cm), the area of the hole, plus clips, should equal 30% of the area of the tube.
 - If $H + W =$ less than 16" (41 cm) but more than 8" (20 cm), the area of the hole, plus clips, should equal 40% of the area of the tube.
 - If $H + W =$ less than 8" (20 cm), leave it open.

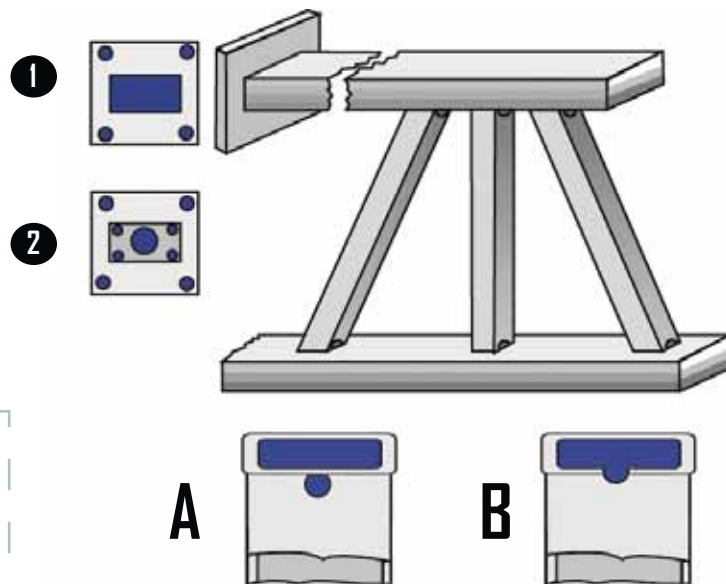


Figure 14: Holes at either end of the rectangular tube trusses should be completely open

Pipe Truss 3" (7.6 cm) & Larger (Figure 15):

Vertical Sections

Hole locations for the vertical members should be as shown in Examples A and B in Figure 15.

Each vertical member should have two holes at each end and 180° apart in line with the horizontal members as indicated by the arrows. The size of the holes preferably should be equal and the combined area of the two holes at either end of the verticals (Areas C and D or Areas E and F) should be at least 30% of the cross-sectional area.

End Plates - Horizontal

- 1 The most desirable fabrication is completely open with the same hole diameter as the tube's inner diameter.
- 2 Equal substitutes would have openings as shown and would be at least 30% of the area of the inside diameter.

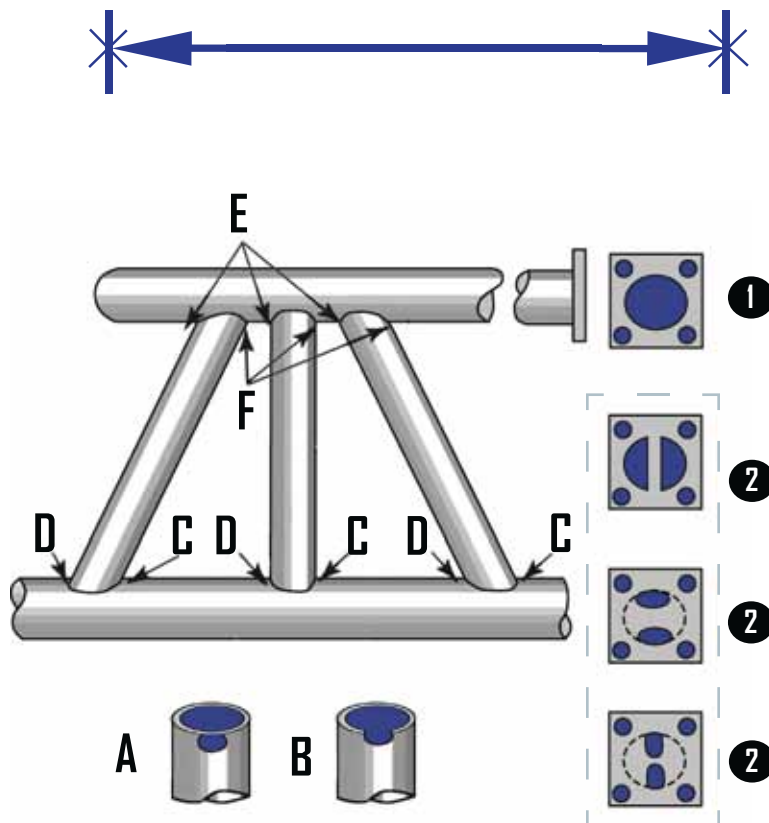


Figure 15: Venting and draining holes should be the same size as the tubing, or one of these four possible alternatives

Pipe Columns, Pipe Girders, Street Light, & Transmission Poles (Figure 16):

(With base plates and with or without cap-plates)
Location of Openings

- 1 The most desirable fabrication is to have the end completely open, with the same diameter as the section top and bottom.
- 2 This is an equal substitute if the full opening is not allowed.
- 3 This is an equal substitute if the full opening is not allowed.
- 4 This is an equal substitute if the full opening is not allowed.
- 5 This must be used when no holes are allowed in the cap- or base-plate: two half-circles 180° apart and at opposite ends of the pole.

Dimensions (Figure 16)

Openings at each end must be at least 30% of the I.D. area of the pipe for pipe three inches and greater and 45% of the I.D. area for pipe smaller than 3" (7.6 cm). Allow 30% of the area of the I.D. for hole sizes at each end.

- 1 End completely open
- 2 Slot A = 3/4-inch (19 mm), Center hole B = 3 inches (7.6 cm) in diameter
- 3 Half circle C = 13/4-inch (4.5 cm) radius (example of sizes for a 6 inch (15 cm) diameter section)
- 4 Oval opening = 13/4-inch (4.5 cm) radius
- 5 Half circle D = 15/8-inch (1.9 cm) radius

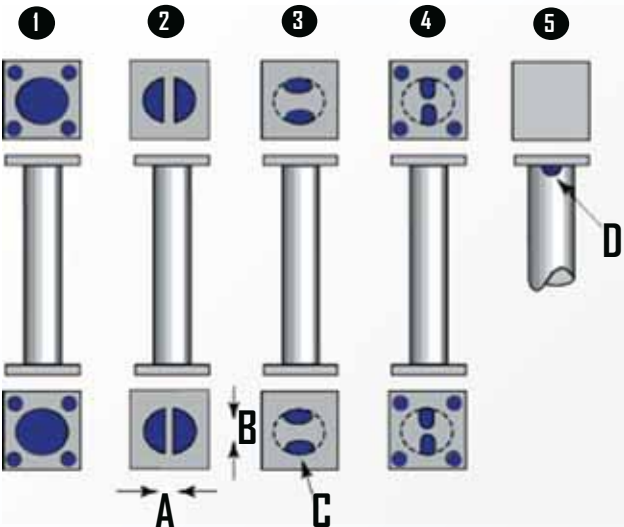


Figure 16: Pipe columns, pipe girders, street light poles and transmission poles

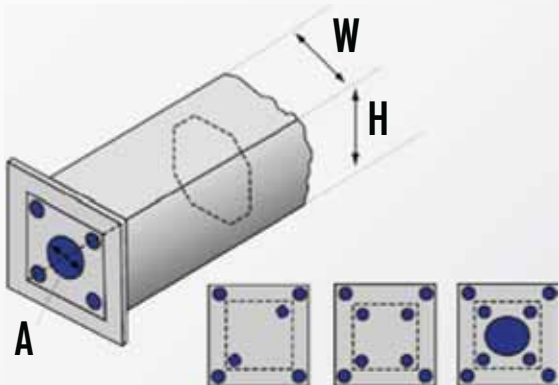


Figure 17: Box sections

Box Sections (Figure 17):

Figure 17 shows the location of holes and clipped corners, which must be flush. Using the following formulas, Table 1 shows typical sizes of holes for square box sections only. For rectangular section, calculate the required area and check with your galvanizer for positioning of openings.

- Internal Gussets – space at a minimum of 36 inches (91 cm)
- Box Sections

- $H + W = 24"$ (61 cm) or larger, the area of the hole, plus clips, should equal 25% of the cross-sectional area of the box ($H \times W$).
- $H + W =$ less than 24" (61 cm) but greater than 16" (40.6 cm), the area of the hole, plus clips, should equal 30% of the cross-sectional area of the box.
- $H + W =$ less than 16" (40.6 cm) but greater than or equal to 8" (20 cm), the area of the hole, plus clips, should equal 40% of the cross-sectional area of the box.
- $H + W =$ under 8" (20 cm), leave completely open, no end-plate or internal gusset.

Table 1

Box Size (H + W)	Holes A-Dia.
48" (122 cm)	8" (20 cm)
36" (91 cm)	6" (15 cm)
32" (81.3 cm)	6" (15 cm)
28" (71 cm)	6" (15 cm)
24" (61 cm)	5" (12.7 cm)
20" (50.8 cm)	4" (10.2 cm)
16" (40.6 cm)	4" (10.2 cm)
12" (30.5 cm)	3" (7.6 cm)

Tapered – Signal Arm (*Figure 18*):

The small end “A” should be completely open.

Pole Plate End

- 1 The most desirable fabrication is to have the end completely open.
- 2 For acceptable alternatives, the half-circles, slots, and round holes must equal 30% of the area of the I.D. of the pole end of the tapered arm for 3” (7.6 cm) and larger I.D.s. The opening must equal 45% of the area of the pole end of the tapered arm if the I.D. is less than 3” (7.6 cm).

Internal gusset-plates and end-flanges should also be provided with vent and drainage holes. In circular hollow shapes, the holes should be located diametrically opposite each other at opposite ends of the member.

In rectangular hollow shapes, the four corners of the internal gusset-plates should be cropped. Internal gusset-plates in all large hollow sections should be provided with an additional opening at the center. Where there are flanges or end-plates, it is more economical to locate holes in the flanges or plates rather than in the section.

Proper Venting & Drainage of Enclosed & Semi-Enclosed Fabrications

Tanks and enclosed vessels should be designed to allow cleaning solutions, fluxes, and molten zinc to enter at the bottom and air to flow upward through the enclosed space and out through an opening at the highest point. This prevents air from being trapped as the article is immersed (*Figure 19*). The design must also provide for complete drainage of both interior and exterior details during withdrawal. The location and size of fill and drain holes are important. As a general rule, the bigger the hole the better the air and zinc flow.

When both internal and external surfaces are to be galvanized, at least one fill/drain hole and one vent hole must be provided. The fill/drain hole should be as large as the design will allow, but at least 3” in diameter for each cubic yard (10 cm in diameter for each cubic meter) of volume. The minimum diameter is 2” (5 cm). Provide vent holes of the same size diagonally opposite the fill/drain hole which allows the air to escape.

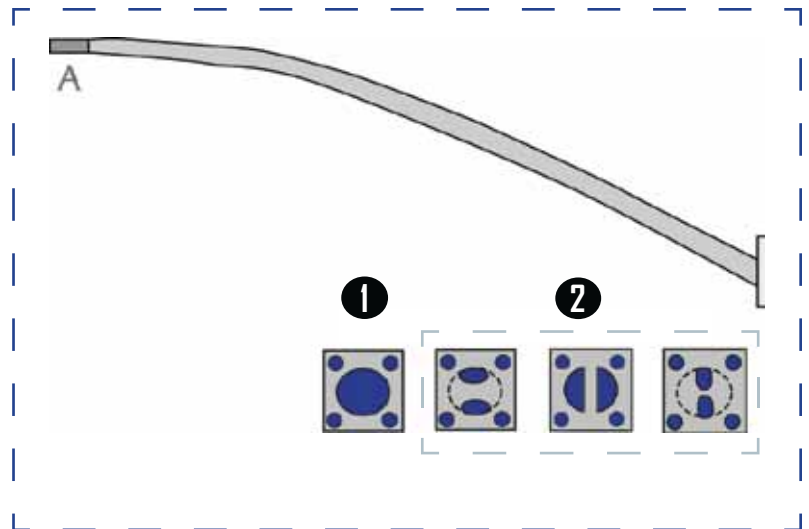


Figure 18: Tapered - signal arm

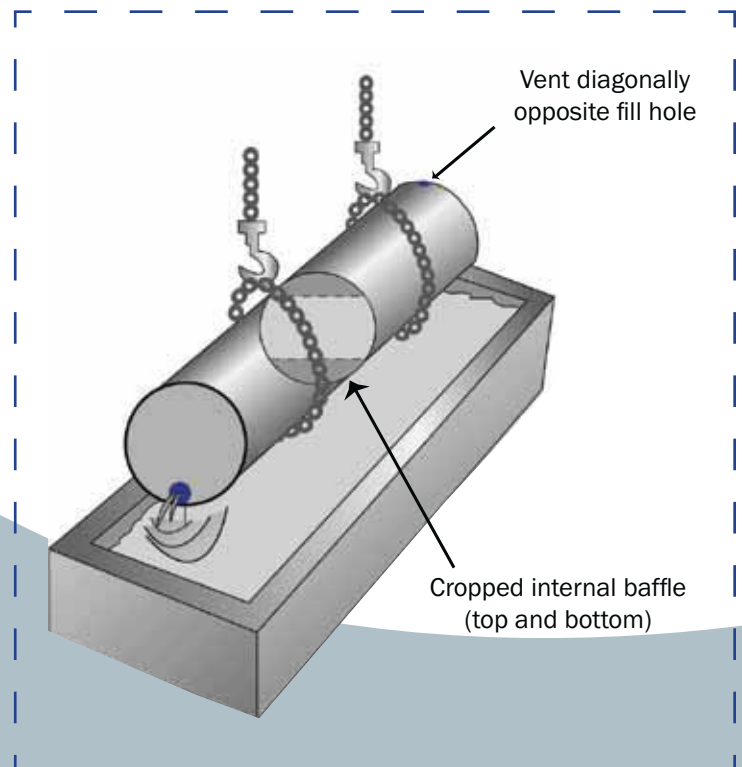


Figure 19: Venting of enclosed fabrications

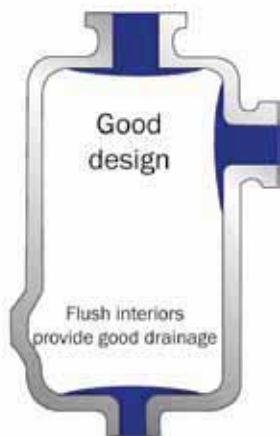


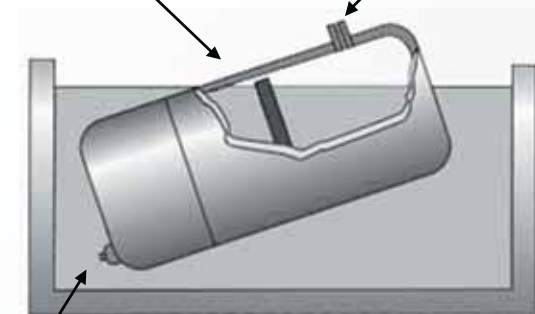
Figure 18: Venting of tanks and vessels



Figure 19: Improper venting

Internal baffles
cropped top and bottom

Vent hole



Fill/drain hole

Figure 20: Tank

Vent pipes connect
interior to the
atmosphere

Flanges should be
finished flush inside

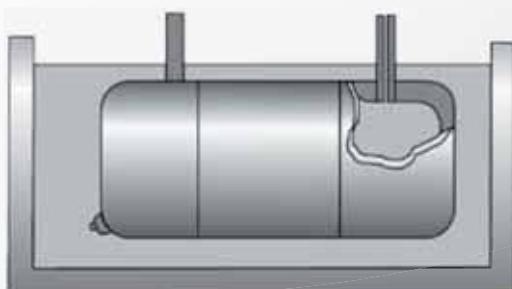


Figure 21: Tank

In tanks, internal baffles should be cropped on the top and bottoms or provided with suitable drainage holes to permit the free flow of molten zinc. Manholes, handholes, and openings should be finished flush inside to prevent trapping excess zinc (*Figures 18-20*). Openings must be placed so the flux on the vessel can float to the surface of the bath. These openings also prevent air-pocket formations that may keep solutions from completely cleaning the inside of the vessel.

Items such as vessels or heat exchangers galvanized on the outside only must have snorkel tubes, or extended vent pipes. These openings provide an air exit from the vessel above the level of molten zinc in the galvanizing kettle (*Figure 21*). Consult your galvanizer before using these temporary fittings, because special equipment is needed.

Communication with your galvanizer, including review of the drawings of enclosed or partially enclosed vessels before fabrication, is critical. Galvanizers may recommend changes that would provide a better galvanized product, and the least expensive time to make any changes that may be warranted is before fabrication.

Precautions for Overlapping & Contacting Surfaces

When designing articles to be galvanized after fabrication, it is best to avoid narrow gaps between plates, overlapping surfaces, back-to-back angles, and channels, whenever possible (*Figure 22*).





When overlapping of contacting surfaces cannot be avoided and the gap is 3/32-inch (2.5 mm) or less, all edges should be completely sealed by welding. The viscosity of the zinc keeps it from entering any space tighter than 3/32-inch (2.5 mm). If there is an opening, less viscous cleaning solutions will enter but zinc will not. Trapped solutions may cause iron oxide to weep out of the joint later on.

Additional challenges resulting from tightly overlapping surfaces include:

1. Cleaning solutions that may be trapped will flash to steam when the part is immersed in the galvanizing bath. This steam can wash the flux off of the part near the gap, causing bare areas adjacent to the lap joint.
2. Cleaning solution salts can be retained in these tight areas due to the impossibility of adequate rinsing. The galvanized coating may be of good quality in the adjacent area, but humidity encountered weeks or even months later may wet these salts. This will cause unsightly rust staining to seep out onto the galvanized coating.
3. Cleaning solutions will not effectively remove oils and greases trapped between surfaces in close contact. Any residual oil and grease will partially volatilize at the galvanizing temperature. This will result in an unsatisfactory zinc coating in the immediate area of the lap joint.

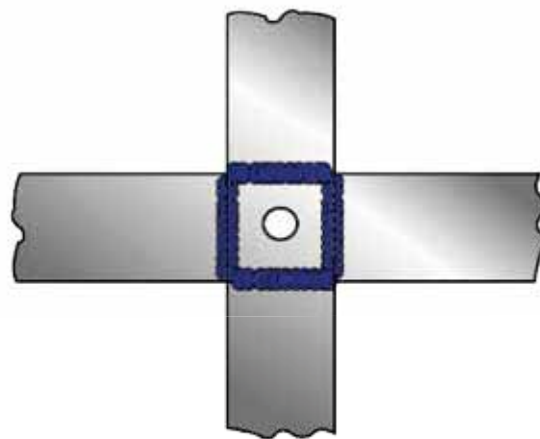
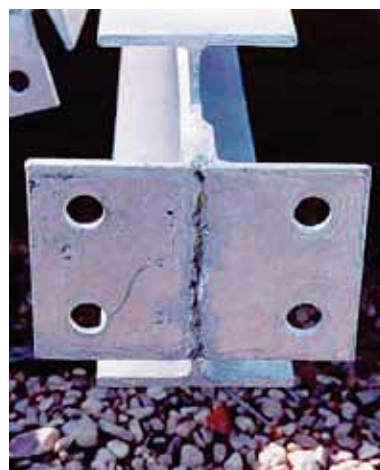


Figure 22: Overlapping Surfaces



Failure to seal weld small spaces may result in iron oxide weeping and staining

It is important to contact your galvanizer before constructing any piece that will include overlapping surfaces. The trade-off between a completely sealed weld joint that may undergo expansion and cracking when subjected to galvanizing temperatures and a skip-welded joint that may experience weepage and staining later becomes a very difficult choice. Your galvanizer's experience can be very beneficial to assist you in making this decision.

When a weld joint is completely sealed, there must be no weld imperfection or pinholes. The penetration of moisture into the sealed cavity could cause significant safety hazards during the hot-dip galvanizing process as the sealed air will greatly expand when the part reaches the galvanizing temperature. This gas expansion can cause the molten zinc to splash out of the bath and endanger galvanizing workers.

If the area of a seal-weld overlap is large, there should be vent holes through one or both sides into the lapped area. This is to prevent any moisture that gets in through a pinhole in the weld from building up excessive pressure while in the galvanizing bath. This venting becomes more important the greater the area. Consult your galvanizer or the AGA publication *Recommended Details for Galvanized Structures* for vent size and quantity. Vent holes can be sealed after galvanizing. Seal welding is not mandatory but prevents trapped moisture, which can result in internal rusting and weepage.

Where two bars come together at an angle, a gap of at least 3/32-inch (2.5 mm) after welding must be provided to ensure the area is wetted by the molten zinc (*Figure 23*). An intermittent fillet weld may be used. This can be on one side of the bar only, or where necessary, an intermittent staggered fillet weld may be employed on both sides so that a pocket is not formed. This type of welding, however, may not be suitable for load-bearing members.

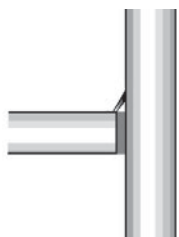


Figure 23: 3/32-inch (2.5 mm) gap after welding

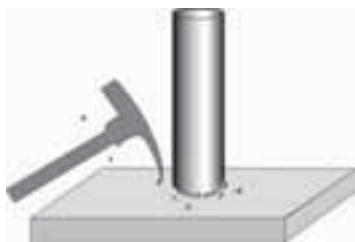


Figure 24: Chipping away weld flux residues

Welding Procedures & Welding Flux Removal

When welded items are galvanized, the cleanliness of the weld area and the metallic composition of the weld itself influence the galvanized coating's characteristics. Galvanized materials may be easily and satisfactorily welded by all

common welding techniques. The specific techniques can best be obtained from the American Welding Society (www.aws.org or 800-443-9353) or your welding equipment supplier. Additional information about welding galvanized steel may be obtained from the AGA.

Several welding processes and techniques have been found to be successful for items to be galvanized:

- In welding, an uncoated electrode should be used when possible to prevent flux deposits on the steel or product.
- Welding flux residues are chemically inert in the pickling solutions commonly used by galvanizers; therefore, their existence will produce rough surfaces and coating voids. If a coated electrode is used, all welding flux residues must be removed by wire brushing, chipping, grinding, pneumatic needle gun, or abrasive blast cleaning (*Figure 24*).
- Welding processes such as metal inert gas (MIG), tungsten inert gas (TIG), or carbon dioxide (CO₂) shielded are recommended since they essentially produce no slag. However, there can still be small flux-like residues that need to be chipped off.
- In the case of heavy weldments, a submerged arc method is recommended.
- If none of these welding methods is available, select a coated rod specifically designed for "self-slagging," as recommended by welding equipment suppliers.
- Choose a welding rod providing a deposited weld composition as close as possible to the parent metal. The composition and compatibility will yield a more uniform galvanized coating appearance.

Welding rods high in silicon may cause excessively thick and/or darkened galvanized coatings to form over the weld. In smooth products welded together with high-silicon weld rods, the coating over the weld material will be thicker than the surrounding coating, causing a bump in an otherwise smooth product. A very low-silicon rod should be used.

Threaded Parts — — — — —

Hot-dip galvanized fasteners are recommended for use with hot-dip galvanized subassemblies and assemblies. Galvanized nuts, bolts, and screws in common sizes are readily available from commercial suppliers. Bolted assemblies should be sent to the galvanizer in a disassembled condition. Nuts, bolts, or studs to be galvanized also should be supplied disassembled.

Because hot-dip galvanizing is a coating of corrosion-inhibiting, highly abrasion-resistant zinc on bare steel, the original steel becomes slightly thicker. When talking about tapped holes and fasteners, the increased thickness is important.

Bolts are completely galvanized, but internal threads on nuts must be tapped oversize after galvanizing to accommodate the increased diameter of the bolts. While chasing or retapping the nuts after galvanizing results in an uncoated female thread, the zinc coating on the engaged male thread will protect both components from corrosion. For economy, nuts are usually galvanized as blanks and the threads tapped oversize after galvanizing (*Figure 25*).

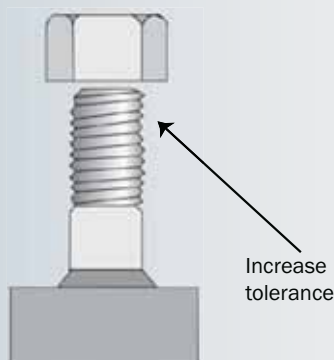


Figure 25: Overtapped nut

To remove excess zinc and produce smoother coatings, small parts, including fasteners, are centrifuged in special equipment when they are removed from the galvanizing bath. Items too long or too large to centrifuge, such as long threaded rods, may be brushed while hot to remove any excess zinc from the threads. Studs welded to assemblies may have to be cleaned after the assembly has cooled. This requires reheating with an acetylene torch and brushing to remove excess zinc. Alternatives to welded studs should be considered when possible.

Masking to prevent galvanizing threads on pipe or fittings is very difficult. The recommended practice is to clean and tap after galvanizing. Anchoring devices (such as threaded rods and anchor bolts) sometimes are specified to be galvanized in the threaded areas only or in the areas to be exposed above ground. This can be more expensive than galvanizing the complete unit because of the additional handling required. Complete galvanizing can be specified for items to be anchored in concrete. Research has proven the high bond-strength and performance of galvanized steel in concrete.

Tapped through-holes must be retapped oversize after galvanizing if they are to contain a galvanized bolt after assembly. Tapping of all holes after galvanizing is recommended to eliminate double-tapping costs and the possibility of cross-threading. Oversizing holes according to American Institute of Steel Construction (AISC) guidelines is usually sufficient for clearance holes to account for the zinc coating's thickness.

Table 2 shows the recommended overtapping for nuts and interior threads as detailed in ASTM A 563, *Specification for Carbon and Alloy Steel Nuts*. On threads over 1 1/2-inches (38 mm) it is often more practical, if design strength allows, to have the male thread cut 0.031-inches (0.8 mm) undersize before galvanizing so a standard tap can be used on the nut.

Table 2

Overtapping Guidelines for Nuts & Interior Threads	
Nominal Nut Size (inches) and Pitch	Diametrical Allowance (inches)
0.250-20	0.016
0.312-18	0.017
0.375-16	0.017
0.437-14	0.018
0.500-12	0.018
0.562-12	0.020
0.625-11	0.022
0.750-10	0.024
0.875-9	0.024
1.000-8	0.024
1.125-7	0.024
1.250-8	0.024
1.250-7	0.027
1.375-8	0.027
1.375-6	0.027
1.500-8	0.027
1.500-6	0.050
1.750-5	0.050
2.000-4.5	0.050
2.500-4.5	0.050
2.500-4.5	0.050
2.750-4	0.050
3.000-4	0.050
3.250-4	0.050
3.500-4	0.050
3.750-4	0.050
3.750-4	0.050
4.000-4	0.050
* For metric overtapping allowance see ASTM A 563M, section 7	

Manufacturers of threaded parts recognize special procedures must be followed in their plants when certain items are to be galvanized. Following are some examples:

- Low carbon bars are recommended since high carbon or high silicon cause a heavier, rougher galvanized coating on the threads.
- Hot-formed heading or bending requires cleaning at the manufacturing plant to remove scale before threading. Otherwise, over-pickling of threads will result during scale removal.
- Sharp manufacturing tools are mandatory. Ragged and torn threads open up in the pickling and galvanizing processes. Worn tools also increase bolt diameters. Frequent checking is necessary on long runs.
- Standard sized threads are cut on the bolt, while standard sized nuts are retapped oversize after galvanizing.

Hinges should be galvanized separately and assembled after galvanizing. All hinges to be galvanized should be of the loose-pin type. Before galvanizing, any adjacent edges should be ground to give at least 1/32-inch (0.8 mm) clearance (*Figure 27*). The pin holes can be cleared of excess zinc during assembly. After hinges are galvanized, it is recommended an undersized pin be used to compensate for the zinc picked up during galvanizing. If desired, the pin holes in the hinges may be reamed 1/32-inch (0.8 mm) after galvanizing to permit the use of regular-size pins. On hinges, all adjacent surfaces must be ground 1/32-inch (0.8 mm) on both pieces to allow for thickness increases. Grinding both pieces is necessary.

At times, moving parts must be reheated in order for them to work freely. Although heating may cause discoloration of the galvanized coating near the reheated area, this discoloration does not affect the corrosion protection of the galvanized surface.

Moving Parts

When a galvanized assembly incorporates moving parts (such as drop-handles, shackles, and shafts), a radial clearance of not less than 1/16-inch (1.5 mm) must be allowed to ensure full freedom of movement after the addition of zinc during galvanizing (*Figure 26*). Whenever possible, work should be designed so that hinges can be bolted to frames, covers, bodies, and other items after galvanizing.

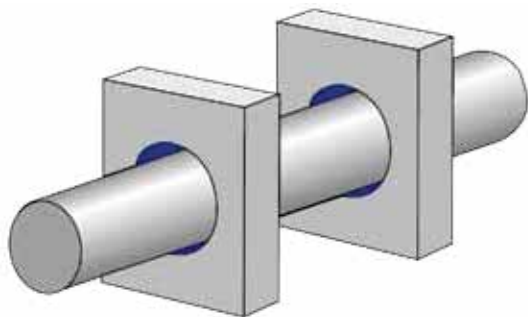


Figure 26: Shaft

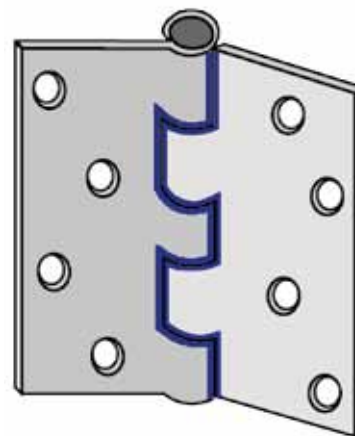


Figure 27: Hinge





Detachable metal tags or water-soluble markers should be specified for temporary identification. Alternatively, barcode tags are manufactured to survive the hot-dip galvanizing process and easily maintain identification.

Where permanent identification is needed, there are three suitable alternatives for marking steel fabrications to be hot-dip galvanized. Each enables items to be rapidly identified after galvanizing and at the job site (*Figures 28 & 29*).

Additional Design Considerations

Masking

During the galvanizing process, all surfaces are cleaned and coated with zinc. For some purposes, intentionally ungalvanized areas are required. Masking, treating a portion of the steel surface so the area remains ungalvanized, may be performed to accomplish this. Masking is not an exact science; thus, additional work may still be required to remove unwanted zinc. In most cases, it may be easier to grind off the zinc coating after galvanizing than to the mask the material.

There are four major categories of masking materials:

- Acid-resistant, high-temperature tapes
- Water-based pastes and paint-on formulations
- Resin-based, high-temperature paints
- High-temperature greases and thread compounds

The AGA is conducting a masking study to identify other common products that can be used effectively in the hot-dip galvanizing process. Masking can also be done at the fabricator's shop to correctly locate the area to be free of coating.

Marking for Identification

Identification markings on fabricated items should be carefully prepared before galvanizing so they will be legible after galvanizing, but not disrupt the zinc coating's integrity. Cleaning solutions used in the galvanizing process will not remove oil-based paints, crayon markers or oil-based markers, so these products should not be used for applying addresses, shipping instructions, or job numbers. If these products are used, ungalvanized area may result.

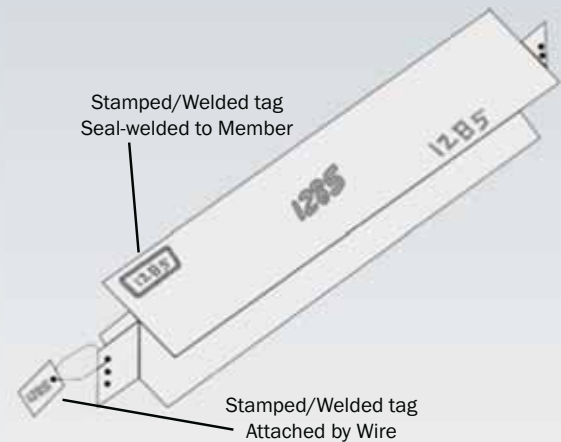


Figure 28: Permanent identification

Stamp the surface of the item using die-cut deep stencils or a series of center punch-marks. These marks should be placed in a standard position on each of the members, preferably toward the center. They should be a minimum of 1/2-inch (13 mm) high and 1/32-inch (0.8 mm) deep to ensure readability after galvanizing. This method should not be used to mark fracture-critical members.

A series of weld beads may also be used to mark letters or numbers directly onto the fabrication. It is essential that all welding flux be removed in order to achieve a quality galvanized coating (*Figure 29*).

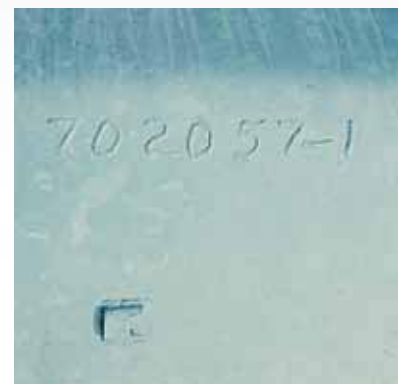


Figure 29: A series of weld beads may be used to identify the fabrication

Deep stenciling a steel tag (minimum #12 gauge) and firmly affixing it to the fabrication with a minimum #9 gauge steel wire is another option for identification (*Figure 30*). The tag should be wired loosely to the work so that the area beneath the wire can be galvanized and the wire will not freeze to the work when the molten zinc solidifies. If desired, tags may be seal-welded directly to the material.



Figure 30: Tag for identification affixed with a minimum #9 gauge steel wire

Post-Galvanizing Considerations

Once the fabrication has been successfully galvanized, there are a few additional considerations to take into account regarding storage and use. These best practices will ensure your galvanized project will provide maintenance-free corrosion protection as anticipated.

Storage

Zinc, like all metals, begins to corrode naturally when exposed to the atmosphere. However, zinc corrosion products actually form a tenacious, abrasion-resistant patina which helps to provide hot-dip galvanizing with its long service life. The formation of this patina depends on the galvanized coating being exposed to freely circulating air. Stacking galvanized articles closely together, or nesting, for extended periods of time, thereby limiting access to freely circulating air, can lead to the formation of a white powdery product known as wet storage stain.



Poles with wet storage stain



To minimize the possibility of wet storage stain, these storage guidelines should be followed:

- Provide adequate ventilation between stacked pieces and avoid nested stacking
- Elevate and separate articles stacked outdoors with strip spacers (poplar, ash, spruce); and during shipping if there is the likelihood of condensation
- Incline parts to allow for maximum drainage
- Prevent uncovered material from being left at in-transit loading points where it may be exposed to rain, mist, condensation, or snow
- Thoroughly dry small items that are quenched and stored in containers and include a dehumidifying agent in the sealed containers
- Store galvanized material under cover in dry, well-ventilated conditions, away from doorways open to the environment
- Treat with passivating agent
- Maintain a low humidity environment



Galvanized guard rail stored with wood spacers to avoid wet storage stain

Wet storage staining is often superficial, despite the possible presence of a bulky white product. In the vast majority of cases, wet storage stain does not indicate serious degradation of the zinc coating, nor does it necessarily imply any likely reduction in the product's service life. If wet storage stain does form, the objects should be arranged so that their surfaces dry rapidly. Once dry, most stains can be easily removed by brushing with a stiff bristle (not wire) brush. If the affected area will not be fully exposed in service, or if it will be subject to an extremely humid environment, even superficial white films should be removed with a stiff-bristle brush. This allows for the successful formation of galvanized coatings' protective zinc carbonate patina.

Cleaning Galvanized Steel

Once in service, galvanized surfaces may need to be cleaned to remove graffiti or other contaminants. There are a number of products that can be used to successfully clean hot-dip galvanized steel without damaging the coating. Contact the AGA for more details.

Follow these easy steps to clean the surface:

1. Use suitable personnel protective equipment
2. Apply cleaning product
3. Let sit for appropriate time
4. Wipe off with clean cloth

Dissimilar Metals

When zinc comes into contact with another metal under atmospheric or aqueous conditions, the potential for corrosion through a bimetallic couple exists. The extent of corrosion will depend upon the position of the other metal relative to zinc in the galvanic series (*Figure 31*), the relative surface areas of the two metals in contact, and the conductivity of the electrolyte on the surface of the two metals.



Figure 31: Galvanic Series of Metals

Under atmospheric conditions of moderate to mild humidity, contact between a galvanized surface and aluminum or stainless steel is unlikely to cause substantial galvanic corrosion. However, under very humid conditions, the galvanized surface may require electrical isolation through the use of paint or joining compounds. You should always consult your galvanizer or the AGA when designing a project with galvanized steel in contact with other metals.

Temperature of Use

Hot-dip galvanized steel provides uninterrupted corrosion protection in a wide variety of temperatures. However, some extreme temperatures can affect the coating. Cold temperatures have little effect on the galvanized coating. On the other hand, constant exposure to temperatures above 390 F (200 C) will cause the coating to separate and is not recommended. Short times at temperatures above 390 F do not effect the galvanized coating.



American Society for Testing and Materials

Related Specifications

ASTM A 36	Specification for Carbon Structural Steel
ASTM A 123	Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
ASTM A 143	Practice for Safeguarding against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
ASTM A 153	Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
ASTM A 384	Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel seml As
ASTM A 563	Specification for Carbon and Alloy Steel Nuts
ASTM A 572	Specification for High-Strength Low-Alloy Columbium - Vanadium Structural Steel
ASTM A 767	Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
ASTM A 780	Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
ASTM B 6	Specification for Zinc
ASTM D 6386	Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting
ASTM E 376	Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Test Methods

Canadian Standards Association

G 40.8*	Structural Steel with Improved Resistance to Brittle Fracture
G 40.12*	General Purpose Structural Steel
G 164	Galvanizing of Irregularly Shaped Articles

Further Reading & Related Materials

Hot-Dip Galvanizing for Sustainable Design

American Galvanizers Association; Centennial, CO; 2009

Hot-Dip Galvanizing for Corrosion Protection

American Galvanizers Association; Centennial, CO; 2006

Recommended Details for Galvanized Structures

American Galvanizers Association; Centennial, CO; 2010

The Inspection of Hot-Dip Galvanized Steel Products

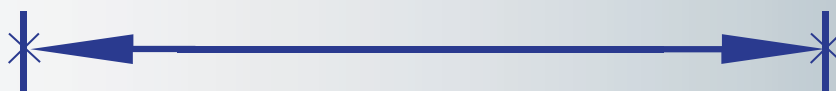
American Galvanizers Association; Centennial, CO; 2008

Hot-Dip Galvanized Fasteners

American Galvanizers Association; Centennial, CO; 2009

Welding & Hot-Dip Galvanizing

American Galvanizers Association; Centennial, CO; 2009







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