



# Welding

**& Hot-Dip  
Galvanizing**



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# Welding



## Hot-Dip Galvanizing (HDG) for Corrosion Protection

As it becomes more common to specify hot-dip galvanizing (the metallurgical combination of zinc and steel) as the corrosion protection system for structural steel fabrications, it is essential to understand considerations for the galvanizing of welded black steel or for welding on galvanized steel and the need to integrate them into the overall structural fabrication design. Welding before and after galvanizing is common; the requirements are relatively simple for a designer to implement, resulting in superior corrosion protection.

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 reinforcing steel to playground equipment to professional sports stadiums to the artistic expression of today's sculptors – benefit from galvanizing's superior corrosion protection properties.

Galvanizing's primary component is zinc. This vital metal is silvery-gray in color and naturally found in the Earth's crust, ranking 27<sup>th</sup> in order of abundance. It is essential for the growth and development of all life. Between 1.4 and 2.3 grams of zinc are found in the average adult, and the World Health Organization has recommended a daily intake of 15 milligrams. Numerous consumer products, including cold remedies, sunscreens, diaper creams, and nutritional supplements, contain beneficial amounts of zinc, primarily in the form of zinc oxide.

Even though galvanized steel is gray, it can also be green. The zinc and galvanizing industries work to promote sustainable development by enhancing zinc's contribution to society and ensuring its production and use are in harmony with the natural environment and the needs of society, now and in the future.

Zinc, as it is used in galvanizing, is a healthy metal, completely recyclable. The energy used to produce zinc from ore is inversely related to the amount of zinc recycled. Galvanizing delivers incredible value in terms of protecting our infrastructure. Less steel is consumed and fewer raw materials are needed because galvanizing makes steel structures, bridges, roads, and buildings last longer. Over time, galvanizing helps maintain steel fabrications' structural integrity – galvanized structures are safer.

Additionally, because galvanized steel requires no maintenance for decades, its use in public construction is an efficient use of our taxes. Selecting galvanized steel for private projects makes a significant contribution to a company's profitability.

## Welding Before Galvanizing

To achieve a high-quality hot-dip galvanized coating on welded areas of fabrications, three important issues must be considered before galvanizing: chemical makeup of the weld metal, cleanliness of the weld area, and continuity of a seal weld.

### Weld Metal Chemistry

The galvanized coating coats almost any type of iron or steel, and the coating thickness primarily depends on the silicon content of the iron or steel part. The major difference between the weld metal and the structural steel is the amount of silicon in the weld rod. Excessive silicon in the weld filler material can accelerate the growth of the hot-dip galvanized coating. Because some weld rod metal contains nearly 1% silicon, the difference between the coating thickness on the weld metal and the surrounding structural steel can be significant. Excessive silicon in the weld material to be galvanized causes an

accelerated formation of the zinc-iron intermetallic layers that make up the hot-dip galvanized coating, greatly increasing coating weight (*Figure 1*).

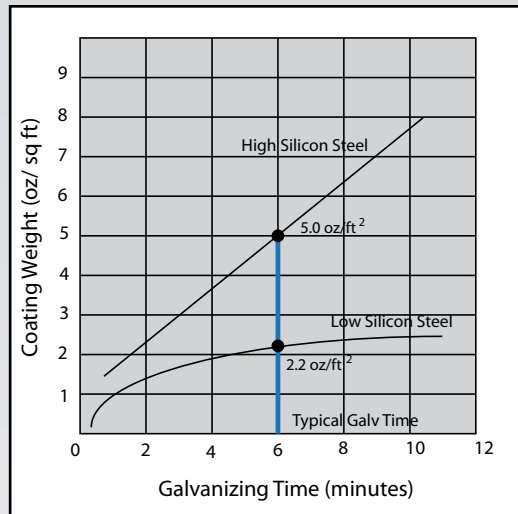


Figure 1

When the fabricated structure is immersed in the zinc bath long enough to achieve a coating that meets the minimum thickness of the galvanizing standards (such as ASTM A 123/ A 123M, *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*), the coating on the high-silicon weld metal can be more than two-times thicker than the surrounding coating. This thick coating on the weld detracts from the appearance of the fabricated structure and increases the possibility of the zinc coating becoming damaged in the weld area with further handling of the assembly or part.

For typical welding processes, such as shielded metal arc welding (SMAW), submerged arc welding (SAW) and flux-cored arc welding (FCAW), there are weld rod materials that will not cause excessively thick coatings as shown below (*Figure 2*).



Figure 2: Typical weld results

Welding Process	Welding Rod Material	Silicon Content
SMAW	Jetweld 2	0.30%
	Fleetwood 35 LS	0.11%
	Fleetwood 7	0.33%
SAW	L61 - 860	0.34%
FCAW	NR 203 NiD	0.04%
	NR 311	0.07%
	NR 431	0.21%

Table 1

Table 1 indicates the material and chemistry for several welding rods that have been tested by the AGA and produce coatings comparable to low silicon steel.

## Weld Cleanliness

When welded structures are hot-dip galvanized, the weld area's cleanliness significantly affects the quality and appearance of the galvanized coating around the weld (*Figure 3*). If a coated electrode is used during welding, all welding flux and slag must be removed prior to galvanizing or the zinc coating will not adhere to the weld area (*Figure 4*). Chemical cleaning solutions used in the galvanizing process cannot remove weld flux and slag. Slag and flux must be removed by wire brush, flame-cleaning, chipping with a pick, grinding or abrasive blast-cleaning prior to the galvanizing process. Slag not removed from the steel surface will cause a bare spot in the coating.



Figure 3 ✓

Figure 4 ✗

## Seal Welding Before HDG

On assemblies with contacting surfaces having a gap of less than 3/32" (2.5 mm), a full seal-weld can be used on all edges, depending on the size of the overlapped area (*Figure 5*). Zinc's



Figure 5



viscosity prevents it from entering any space smaller than 3/32" (2.5 mm), resulting in ungalvanized surfaces. Ungalvanized surfaces in tight spaces will corrode and bleed iron oxide onto the surrounding galvanized surfaces, making for an unsightly appearance. Cleaning solutions have lower viscosities, allowing them to enter these small gaps. Cleaning solution salts can be retained in these tight areas and humidity encountered weeks or months later may wet these salts and cause iron-oxide weeping.

A second design consideration is to use equal or nearly equal thickness of assembly pieces, with symmetrical welds (Figure 6). During galvanizing, the assembly is heated to the molten zinc bath temperature – more than 815 F (435 C) – and then cooled to ambient temperature. When welded pieces of dissimilar thickness are galvanized, one of the pieces will often have a high stress induced in the fabrication process and/or by the galvanizing temperature changes. If the stress is high enough, distortion of the assembly, or in extreme cases, a fracture of the weld or of the stressed piece in the assembly can occur. Galvanizing welded fabrications is a common method of protecting a structure from corrosion.



Figure 6

## Welding Before HDG Summary

A high-quality hot-dip galvanized coating, even over welded areas, is achieved by properly selecting a weld metal, thoroughly cleaning the slag from the weld area, and using good design practices.

## Welding After Galvanizing

Many commonly practiced welding and cutting techniques can be used on galvanized steel (see American Welding Society's (AWS) specification D-19.0, *Welding Zinc Coated Steel*). Welding on galvanized steel can be necessary if the final structure is too large to be dipped in a galvanizing bath or for structures that must be welded in the field.

## Preparation of Weld Area

AWS D-19.0, *Welding Zinc Coated Steel*, calls for welds to be made on steel free of zinc in the area to be welded. Thus, for galvanized structural components of a fabrication, the zinc

coating should be removed at least one to four inches (2.5-10 cm) from either side of the intended weld zone and on both sides of the workpiece. Grinding back the zinc coating is the preferred and most common method; burning the zinc away or pushing back the molten zinc from the weld area can also be used.

## Weld Metal Chemistry

Because the galvanizing has already taken place, selection of weld material is less critical. It is important to avoid zinc in the weld and proper preparation of the area to be welded as previously described assures a quality weld.

## Welding Methods

The three methods of manual/semi-automatic welding detailed here are more flexible than resistance or laser welding, which are not used on batch galvanized assemblies. All three manual/semi-automatic methods benefit from the removal of zinc from the areas to be welded, but zinc removal is not an absolute requirement.

### Gas Metal Arc Welding (GMAW)

Particularly suited to welding of thinner materials, gas metal arc welding (GMAW), also known as CO<sub>2</sub>, is a convenient and versatile semi-automatic welding process (Figure 7). The presence of the zinc coating has no effect on weld mechanical properties, although it may produce some appearance changes due to weld spatter. Arc stability is excellent and generally unaffected by the galvanized coating.

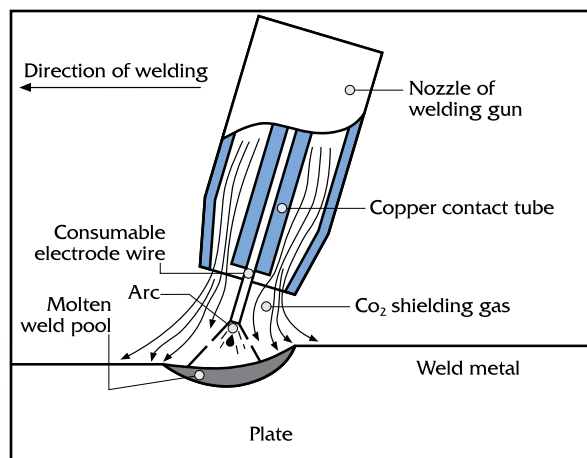


Figure 7

There may be a reduction in welding speed because the galvanized coating must be burned off ahead of the weld. The use of a 100% CO<sub>2</sub> weld shield gas is acceptable for galvanized steel and there are no advantages to using more expensive shielding gas combinations. Penetration of the weld in zinc-coated steels is less than for uncoated steels. Therefore, slightly wider gaps must be provided for butt-welds.

The major difference between welding zinc-coated steel and welding uncoated steel using the GMAW process is the need for higher heat input to remove the zinc from the weld pool and lower welding speeds to burn off as much of the zinc coating ahead of the weld bead.

Typical welding conditions for CO<sub>2</sub> welding of butt-joints on hot-dip galvanized steel are available in AWS D19.0, Tables 5.5 through 5.12.

## Shielded Metal Arc Welding (SMAW)

This most common of the manual processes uses flux-covered electrodes. The conditions necessary for Shielded Metal Arc Welding (SMAW) or Manual Metal Arc Welding (MMAW) are similar to those used on uncoated steel. However, the speed of the welding may be slower because the angle of the electrode is reduced to about 30° and a whipping motion of the electrode back and forth is required to move the molten zinc pool away from the weld (*Figure 8*).

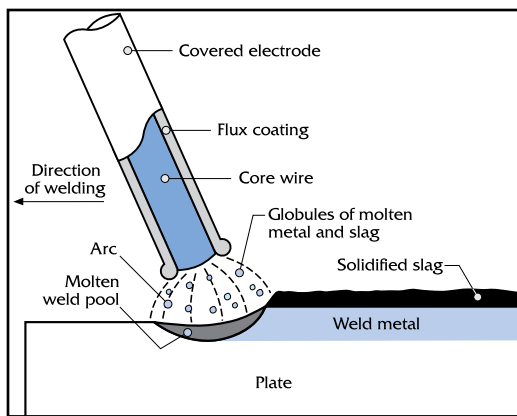


Figure 8

The major difference between welding zinc-coated steel and welding uncoated steel using the SMAW process is the root opening must be increased to give full weld penetration. The amount of spatter formed when SMAW is used is slightly higher than for welding on uncoated steel.

Typical SMAW conditions for the root pass in butt-welds on batch galvanized steel are available in AWS D19.0, Tables 6.2 through 6.5.

MMAW is recommended for galvanized steels of 1/2" (1.27 cm) thickness or greater. In general, welders can use the same procedures for galvanized steel as for uncoated steel, although the following should be noted:

- The electrode should be applied slower than normal, with a whipping action that moves the electrode forward along the seam in the direction of the weld and then back into the molten zinc pool.

- Weaving and multiple weld beads should be avoided, as should excessive heat injection into the joint. Excess heat may damage the adjacent zinc coating.
- A short arc length is recommended for all positions to give better control of the weld pool and to prevent either intermittent excessive penetration or undercutting.
- Slightly wider gaps are required in butt-joints in order to have complete penetration.
- Grinding off edges prior to welding give the best quality weld joint. It also reduces fuming from the galvanized coating. Welding procedures will then be the same as for uncoated steel.

Electrodes similar to those used for arc welding uncoated steel may be used. The major difference when MMAW galvanized steel compared to uncoated steel is the need for higher heat input to remove the zinc from the weld pool and lower welding speed to burn off as much of the zinc from the leading edge of the pool. This may result in greater fluidity of the slag and increased splatter.

## Oxyacetylene

Preparation for oxyacetylene fusion welding is similar to that for welding uncoated steel. Because low travel speed is necessary to bring the joint edges to the fusion temperature, the extra heat causes the zinc coating to be affected over a much greater area than other welding processes. Best results are obtained when the filler rod is moved back and forth, producing a ripple weld.

## Touch-up of Weld Area

Any welding process on galvanized surfaces damages the zinc coating on and around the weld area. Restoration of the area should be performed in accordance with ASTM A 780, *Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings*, which specifies the use of paints containing zinc dust, zinc-based solders, or sprayed zinc. All touchup and repair methods are capable of building a protective layer to the thickness required to provide corrosion protection.

The restored area of the zinc coating will have no effect on the overall lifetime of the part. Repair materials and their coating thickness have been chosen to give comparable lifetimes to the coating minimums required by ASTM A 123/A 123M, *Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*. There may be some visual differences between the original hot-dip galvanized coating and the restored area, but over time, the natural weathering of the galvanized coating can blend the two appearances or can accentuate the different appearances depending on the choice of repair materials.



## Quality of Welded Joints

AWS D19.0 recommends removing all zinc from the weld area prior to welding because burning through the zinc slows the welding process, generates zinc fumes (see “Health & Safety” next column), and creates an unsightly burn area around the weld.

However, as studies performed by the International Lead Zinc Research Organization (ILZRO) have shown, the tensile, bend and impact properties of welds on galvanized steel are equivalent to the properties of welds on uncoated steel.

## Fracture Toughness

In the same study as mentioned above, ILZRO established the fracture toughness properties of welds are unaffected by the presence of galvanized coatings.

## Fatigue Strength

The fatigue strength of arc welds on galvanized steel is equivalent to welds on uncoated steel made by CO<sub>2</sub> welding as shown in Figure 9.

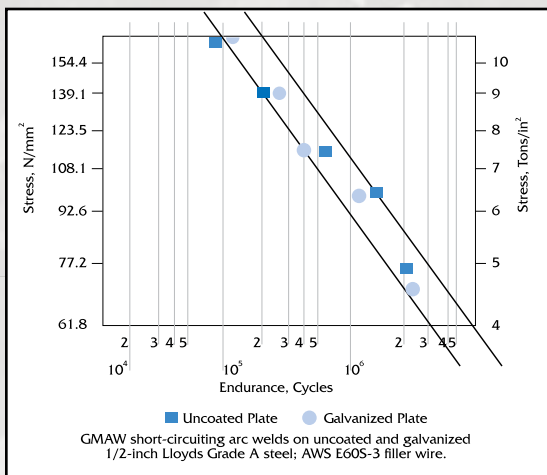


Figure 9

## Porosity

The extent of weld porosity is a function of heat input and the solidification rate of the weld metal. Not always possible to eliminate, porosity affects the fatigue strength and cracking tendencies of welds.

When welds are subject to fatigue loading, welds on galvanized steel should be made oversized to reduce the influence of any weld metal porosity or zinc inclusions. When evaluating the effect of porosity on the fatigue strength of a fillet weld, it is

necessary to consider both the function of the joint and the weld size.

When a fillet weld on galvanized steel is large enough relative to plate thickness to fail by fatigue from the toe of the weld in the same manner as in uncoated steel, the presence of porosity in the weld does not reduce the fatigue strength of the joint. Where the dimensions of the weld are just large enough to cause fatigue failure from the toe in a sound weld, a weld containing porosity at the root may fail preferentially through the throat of the weld. Intergranular cracking of fillet welds containing porosity, sometimes referred to as zinc penetrator cracking, does not significantly affect the strength of non-critical joints. For more critical stress applications, it is advisable to carry out procedural tests on materials and samples.

## Health & Safety

All welding processes produce fumes and gases. Manufacturers and welders must identify the hazards associated with welding coated and uncoated steel and workers must be trained to maintain work practices consistent with Occupational Safety and Health Administration (OSHA) regulations. In general, welding on steel with the zinc coating ground away from the weld area will produce lead and zinc oxide emissions below OSHA permissible exposure limits (PELs). When welding directly on galvanized steel is unavoidable, PELs may not be surpassed in open area, but may be exceeded in confined areas and every precaution, including high-velocity circulating fans with filters, air respirators and fume-extraction systems suggested by AWS, should be employed.

Fumes from welding galvanized steel can contain zinc, iron, and lead. Fume composition typically depends on the composition of materials used, as well as the heat applied by the particular welding process. In any event, good ventilation minimizes the amount of exposure to fumes. Prior to welding on any metal, consult ANSI/ASC Z-49.1, *Safety In Welding, Cutting and Allied Processes*, which contains information on the protection of personnel and the general area, ventilation and fire prevention.

## Welding After HDG Summary

With proper preparation of the weld area, selection of a suitable welding material and process, and careful touch-up of the weld area, welding on galvanized steel provides an excellent product for use in myriad applications, from bridges, towers, and grating to handrail, trusses, and guardrail.





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