WELDING

& HOT-DIP GALVANIZING

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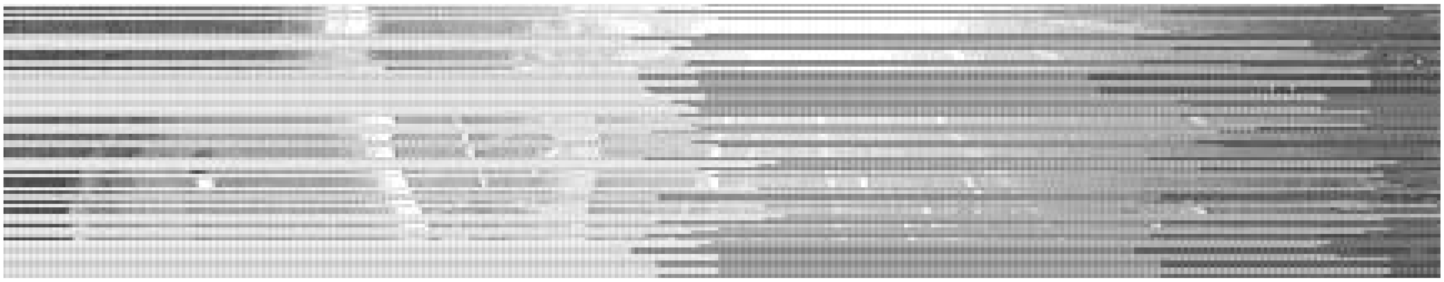


INTRODUCTION

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 that considerations for the galvanizing of welded black steel or for welding on galvanized steel must be integrated 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.

HOT-DIP GALVANIZING FOR CORROSION PREVENTION

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 prevention properties.

Galvanizing's primary component is zinc. This vital substance is silvery blue-gray in color and makes up an estimated 0.004% of the earth's crust, ranking 25th in order of abundance. It is essential for the growth and development of almost 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 blue-gray, it also can be "green." The zinc and galvanizing industries work to promote sustainable development by enhancing zinc's contribution to society and ensuring that 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 smelt zinc 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.

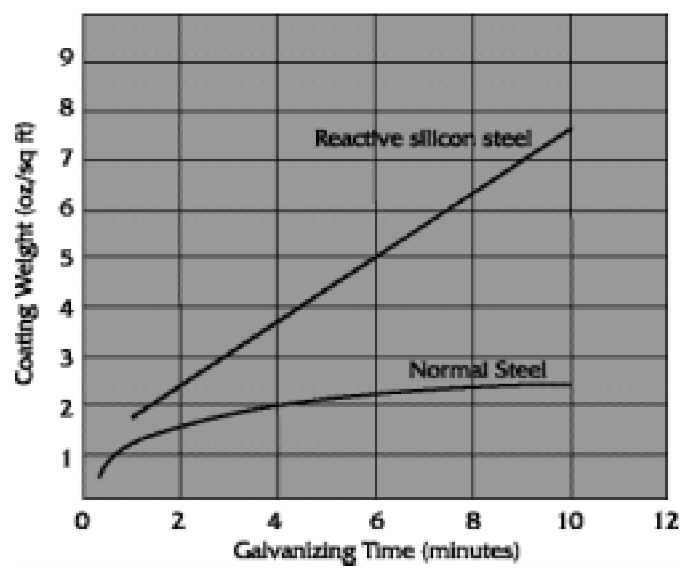
WELDING BEFORE HOT-DIP GALVANIZING

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

Weld Metal Chemistry

When there is a difference between the structural steel's chemistry and the weld filler material's chemistry, the galvanized coating on the weld can be thicker than the coating on the structural piece. The major difference between the weld metal and the structural steel is the amount of silicon in the weld rod. Excessive silicon in the steel or weld filler material can accelerate the growth of the hot-dip galvanized coating. Because some weld electrode metal contains nearly 1% silicon, the difference between the coating thickness on the weld metal and structural steel can be significant. Excessive silicon in the weld material to be galvanized causes an accelerated formation of the iron and zinc intermetallic layers that make up the hot-dip galvanized coating, greatly increasing coating weight (see 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

Figure 1



standards (such as American Society of Testing and Materials [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 two- to five-times the thickness of 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's becoming damaged in the weld area.

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. Figure 2 indicates the material and chemistry for several welding rods that yield good coating appearance and thickness.

Figure 2

Welding Process	Weld Rod Material	Silicon Content
SMAW	Jetweld 2 (E6027)	0.25%
	Fleetwood 35 LS (E6011)	0.10%
	Fleetwood 7 (E6012)	0.30%
SAW	L60-860 (F6A2-EL12)	0.22%
	L61-80 (F7A2-EM12K)	0.35%
FCAW	NR-203NiC+ (E71T8-K2)	0.04%
	NR-311 (E70T-7)	0.07%

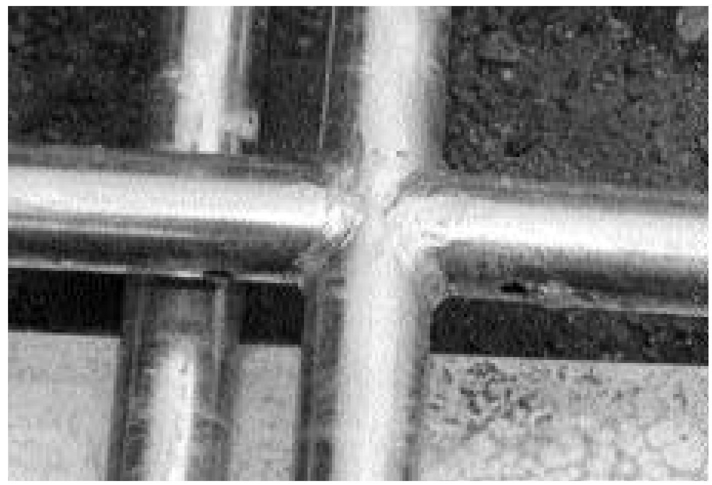
Weld Cleanliness

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 (see Figure 3). If a coated electrode is used during welding, all welding flux must be removed prior to galvanizing or the zinc coating will not adhere to the weld area (see Figure 4). Because weld flux and slag are insoluble in the chemical cleaning solutions used in the galvanizing process, they must be removed by other methods. Slag and flux must be removed by wire brush, flame-cleaning, chipping with a pick, grinding or abrasive blast-cleaning.

Design Considerations

On assemblies with contacting surfaces having a gap of less than 3/32" (2.5 mm), a full seal-weld must be used on all edges, depending on the size of the overlapped area. Zinc's viscosity prevents it from entering any space smaller than 3/32" (2.5 mm), resulting in ungalvanized surfaces (see Figure 5). Ungalvanized surfaces in tight spaces will corrode and bleed iron oxide onto the surrounding galvanized surfaces, making for an unsightly appearance.

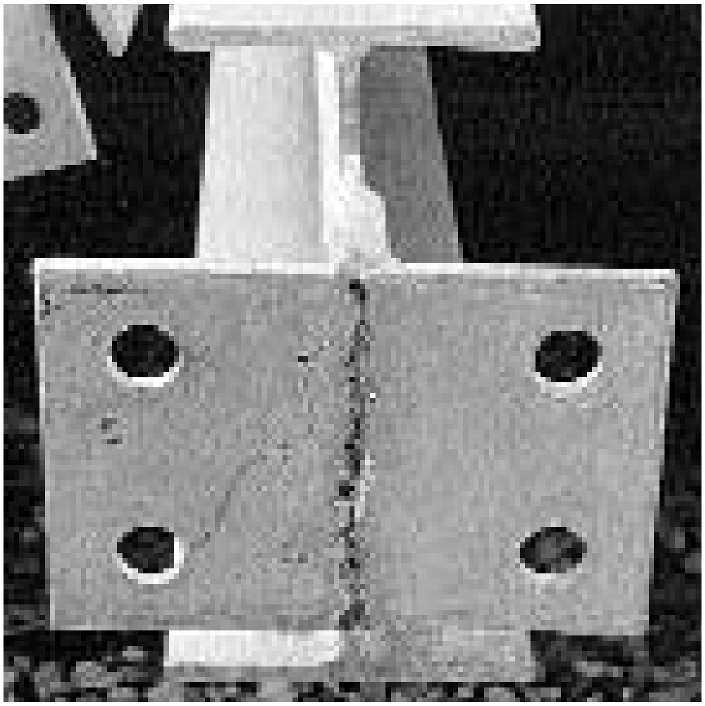
Figure 3



Cleaning solutions have lower viscosities, allowing them to enter these small gaps. Cleaning solution salts can be retained in these tight areas. Humidity encountered weeks or months later may wet these

Figure 4

Figure 5



salts and cause iron-oxide weeping. A second design consideration is to use equal or nearly equal thickness of assembly pieces, with symmetrical welds.

During galvanizing, the assembly is heated to the molten zinc bath temperature – more than 815 F (435 C) – and then cools 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. A high-quality hot-dip galvanized coating, even over welded areas, is achieved by properly selecting a weld metal, thoroughly cleaning the weld area, and using good design practices.

WELDING AFTER HOT-DIP GALVANIZING

All 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 is usually 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 that is 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 also are effective.

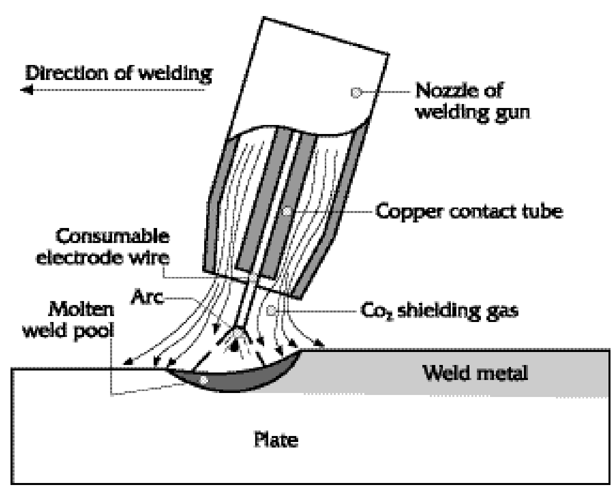
Weld Metal Chemistry

Because the galvanizing has already taken place, selection of weld material is less critical. Most of the materials used for touchup of the weld area will adhere and cover the weld and any damaged area around the weld (see "Touch-up of Weld Area").

Welding Methods

Four methods of manual/semi-automatic welding are detailed below. More flexible than resistance or laser welding, which usually are in-line processes on galvanized sheet, all four manual/semi-automatic methods benefit from the removal of zinc from the areas to be welded, but it is not an absolute requirement.

Figure 6 - Diagrammatic Illustration of CO_2 Welding



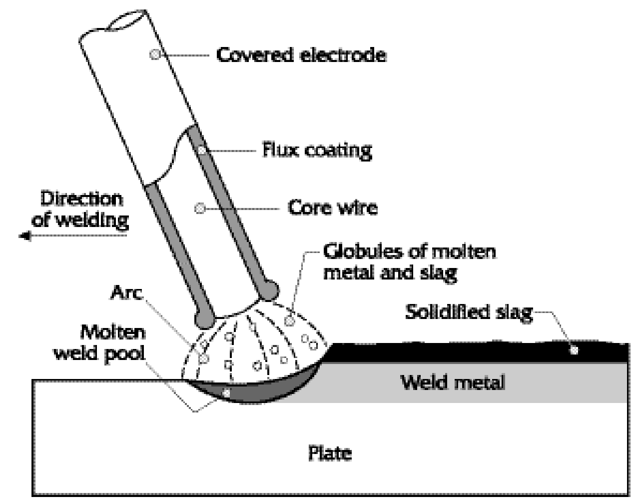
1. Gas Metal Arc – Particularly suited to welding of thinner materials, gas metal arc welding, (GMAW) also known as CO_2, is a convenient and versatile semi-automatic welding process (see Figure 6 on the previous page). The presence of the zinc coating has no effect on weld mechanical properties, although it may produce some appearance changes due to weld spatter. Arc stability is excellent and generally unaffected by the galvanized coating. 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_2 weld shield gas is acceptable for galvanized steel. 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 at the weld area as possible.

Typical welding conditions for CO_2 welding of butt-joints on batch galvanized steel are available in AWS D19.0, Tables 5.5 through 5.12.

2. Shielded Metal Arc – This most common of the manual processes uses flux-covered electrodes. The conditions necessary for SMAW 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^o and a whipping motion of the electrode back and forth is required to move the molten zinc pool away from the weld (see Figure 7).

Figure 7 - Diagrammatic Illustration of Shielded Metal-Arc Welding



The major difference between welding zinc-coated steel and welding uncoated steel using the SMAW process is that 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.

SMAW is recommended for galvanized steels of 1/2" (33 mm) thickness or greater galvanized steel pieces. In general, SMAW 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 SMAW on 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.

3. 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.

4. Friction – Friction welding is generally used for making butt-welds in which one component of circular cross-section is rotated relative to and in contact with another component to produce heat at the interface. Once sufficient heat is generated, the relative rotation of the parts is stopped and pressure is increased to complete the weld. Friction welding is often used for attaching shear connectors to steel beams for the anchoring of concrete in concrete/steel structures. Flat-ended studs, whether uncoated or galvanized, cannot be welded to galvanized plate because the zinc coating's alloy layers appear to act as a low friction-bearing surface and insufficient heat is developed for welding. This may be circumvented by using pointed studs with a point having a 120º angle. Conditions for welding pointed studs are available in AWS D19.0.

TOUCH-UP OF WELD AREA

Any welding process on galvanized surfaces destroys the zinc coating on and around the weld area. Restoration of the area should be performed in accordance with ASTM A 780, *Standard 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 by ASTM A 780.

The restored area of the zinc coating will have no affect 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, *Standard 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 and the repair material yield a similar appearance.

QUALITY OF WELDED JOINTS

It is recommended in AWS D19.0 to remove all zinc from the weld area prior to welding because burning through the zinc slows the welding process, generates zinc fumes (see "Safety & Health," on the next page) 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

Tests establish that the fracture toughness properties of welds are unaffected by the presence of galvanized coatings.

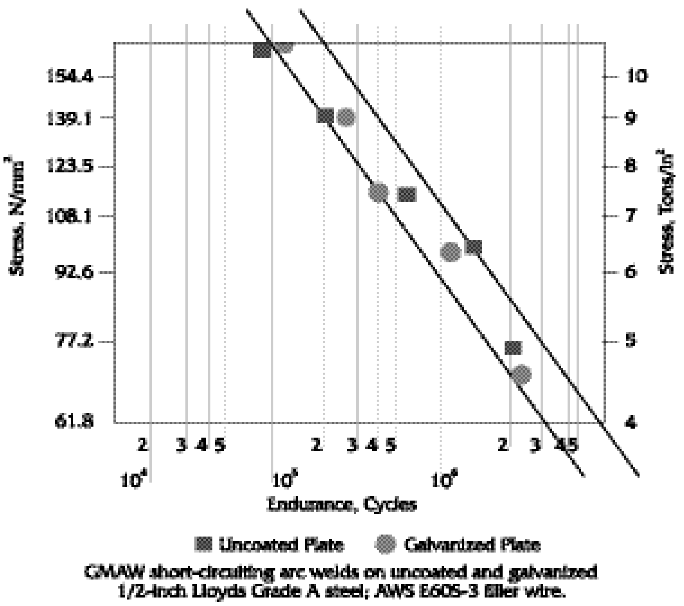
Fatigue Strength

The fatigue strength of arc welds on galvanized steel is equivalent to welds on uncoated steel made by CO2 welding as shown in Figure 8.

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.

Figure 8 - SN Curves Showing Fatigue Tests on Cruciform Joints



When welds are subject to fatigue loading, welds on galvanized steel should be made oversized to reduce the influence of any weld metal porosity. 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 toplate 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.

SAFETY & HEALTH

All welding processes produce fumes and gases to a greater or lesser extent. Manufacturers and welders must identify the hazards associated with welding coated and uncoated steel and workers must be trained to maintain work practices within Occupational Safety and Health Administration (OSHA) regulations. In general, welding on steel with the zinc coating ground back away from the weld area will produce lead and zinc oxide emissions below OSHA permissible exposure limits (PELs) for zinc and lead. When welding directly on galvanized steel is unavoidable, PELs may be exceeded 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.

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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