WELDING CONSIDERATIONS WITH HOT-DIP GALVANIZED STEEL

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ABSTRACT

Galvanizing has been in use for hundreds of years. Zinc forms a protective barrier between the steel and the environment.

Welding steel before and after galvanizing is common industrial practice. Galvanized steel can be satisfactorily welded by all commonly used welding processes.

When welding steels, before hot – dip galvanizing, normal welding practices can be followed with a few exceptions. The weld metal and base metal chemistry must be matched to ensure even galvanizing coating thickness and appearance. The weldment and surrounding areas must be made free from slag and spatter before galvanizing. The design of the structure must be adapted to be suitable for galvanizing.

During the welding of galvanized steel closer control of the welding conditions are needed than when welding uncoated steels. Welding procedures are simple and well established. The major differences between welding galvanized and uncoated steel are that when welding galvanized steel larger root openings are required as well as a reduction in the travel speed used during welding.

The mechanical properties of the welded joints in galvanized steel are not adverse affected by the galvanized coating. The mechanical properties are similar to those of uncoated steels.

The zinc will volatize during welding. The amount of welding fumes generated will be larger when welding galvanized steel than when welding uncoated steel. The zinc fumes could be hazardous if inhaled during. Adequate ventilation, local fume extraction and respiratory equipment should be used to ensure that welders are not exposed to the welding fumes.

1.0 INTRODUCTION

Zinc has been used to protect steel and iron for hundreds of years. Galvanizing is a simple coating of zinc over steel. It protects the steel from rusting by forming a barrier between the steel and environment, thus providing electrochemical protection as zinc is electrochemically more reactive than iron or steel. The zinc oxidizes to protect the steel near it even if it is scratched down to bare steel.

Some of the reported difficulties when welding galvanized steels are high levels of spatter and welding fumes, weld porosity and poor weld bead shape.

Galvanized steels are easily welded by all common welding processes. However to successfully weld galvanized steel closer control of the welding conditions is needed than when welding uncoated steels. These problems increase postweld cleaning costs, higher defect rate and rework as well as an overall reduction in productivity.

It is essential to understand that considerations for the galvanizing of welded steel or for the welding on galvanized steel must be integrated into the overall structural fabrication design.

The two scenarios i.e. welding on steel and then galvanizing the fabricated structure or galvanizing the material and then welding will be discussed in detail in subsequent paragraphs of this paper.

2.0 HOT – DIP GALVANIZING PROCESS

Though the process may vary slightly from plant to plant, the fundamental steps in the galvanizing process are:

- Soil & grease removal - A hot alkaline solution removes dirt, oil, grease, shop oil, and soluble markings.
- Pickling - Dilute solutions of either hydrochloric or sulfuric acid remove surface rust and mill scale to provide a chemically clean metallic surface.
- Fluxing - Steel is immersed in liquid flux (usually a zinc ammonium chloride solution) to remove oxides and to prevent oxidation prior to dipping into the molten zinc bath. In the dry galvanizing process, the item is separately dipped in a liquid flux bath, removed, allowed to dry, and then galvanized. In the wet galvanizing process, the flux floats atop the molten zinc and the item passes through the flux immediately prior to galvanizing.
- Galvanizing - The article is immersed in a bath of molten zinc at between 815-850 F (435-455° C). During galvanizing, the zinc metallurgically bonds to the steel, creating a series of highly abrasion-resistant zinc-iron alloy layers, commonly topped by a layer of impact-resistant pure zinc.

- Finishing - After the steel is withdrawn from the galvanizing bath, excess zinc is removed by draining, vibrating or - for small items - centrifuging. The galvanized item is then air-cooled or quenched in liquid.

The hot – dip galvanizing process is illustrated in Figure 1.

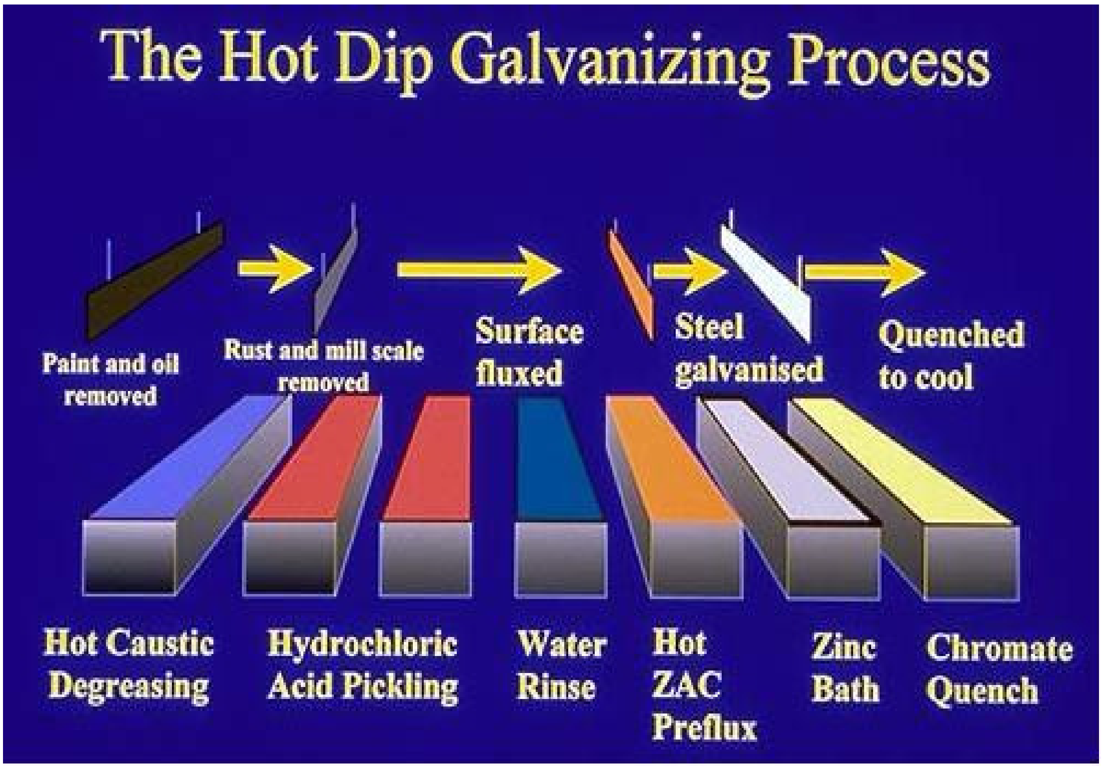


Figure 1. The Hot – Dip Galvanizing Process

3.0 WELDING BEFORE HOT – DIP GALVANIZING

To weld steels before galvanizing one would follow normal welding procedures using any of the common welding processes. The most common welding processes used are Gas Metal Arc Welding, Shielded Metal Arc Welding, Flux Cored Arc Welding and Braze Welding.

To achieve a high quality galvanized coating on welded areas after fabrication, some important issues have to be considered.

3.1 Hot – Dip Galvanizing Coating Thickness

If there is a significant difference in chemistry between the structural steel and the weld filler metal there could be a difference in coating thickness. Excessive silicon in the steel or the weld filler metal can accelerate the formation of the iron and zinc interlayers that make up the hot – dip galvanized coating(See Figures 2 and 3).

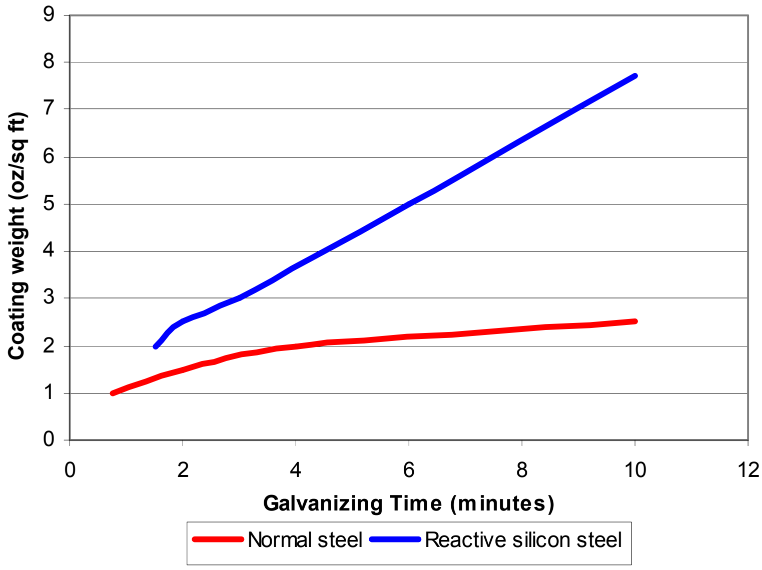


Figure 2. Galvanized coating as a function of galvanizing time.

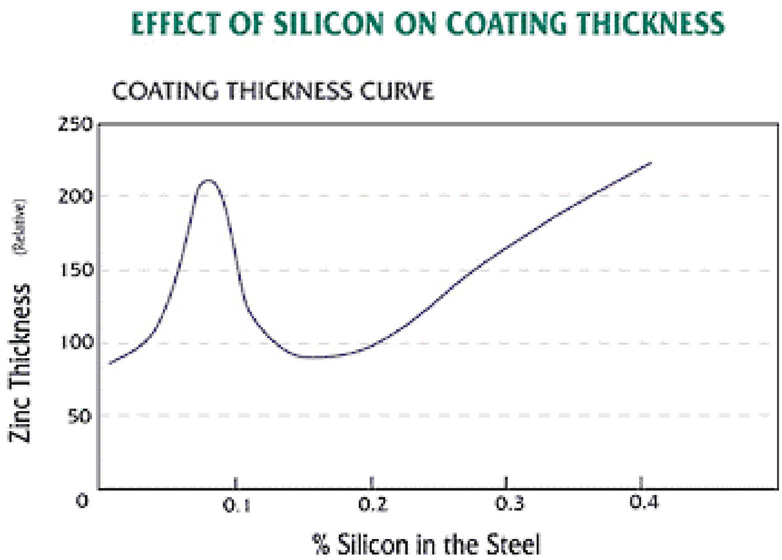


Figure 3. Effect of Silicon on galvanizing coating thickness.

From Figures 2 and 3 it is clear that the amount of silicon present either in the steel or the deposited weld metal significantly influences the final zinc coating thickness. Silicon increases the reactivity of the chemical reaction between iron and zinc.

Galvanizing forms a metallurgical bond between the zinc and the underlying steel or iron, creating a barrier that is part of the metal itself. During galvanizing, the molten zinc reacts with the surface of the steel or iron article to form a series of zinc/iron alloy layers. Figure 4 below is a photomicrograph of a galvanized steel coating cross-section and shows a typical coating microstructure consisting of three alloy layers and a layer of pure metallic zinc.

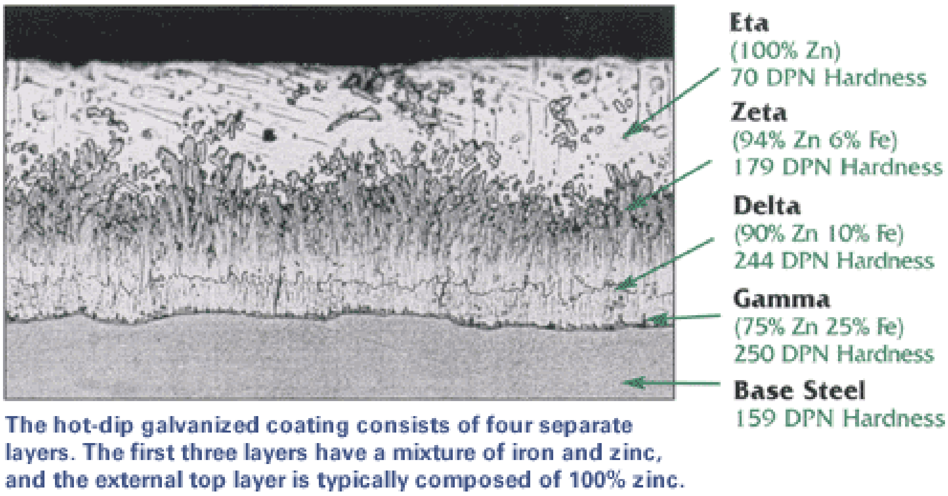


Figure 4. Typical galvanized coating.

Progressing from the underlying steel surface outward, these layers are:

- The thin Gamma layer composed of an alloy that is 75% zinc and 25% iron
- The Delta layer composed of an alloy that is 90% zinc and 10% iron
- The Zeta layer composed of an alloy that is 94% zinc and 6% iron
- The outer Eta layer that is composed of pure zinc

When the fabricated structure is immersed in the zinc bath for the minimum time to achieve a coating which meets the minimum thickness requirements of the standards such as ASTM A123 / A123M, then the coating on the high silicon material can be between 2 to 5 times the thickness of the surrounding coating. The thicker coating might detract from the appearance and be prone to be damaged more readily.

For the common welding processes there are weld filler materials readily available, which are low in silicon and suitable for welding steels before galvanizing. It typically is best to use filler metal which has a deposited weld metal silicon content of less than 0.3%.

3.2 Weld Cleanliness

The weld cleanliness can significantly affect the quality and appearance of the galvanized coating around the welded area.

All slag must be removed prior to galvanizing. Galvanizing does not adhere properly to the slag. The flux and slag are normally insoluble in the cleaning solutions used in the galvanizing process. Thus any slag has to be removed either by wire brushing, chipping, grinding or abrasive blast cleaning.

All weld spatter has to be removed from the steel surface before galvanizing. If the weld spatter is not removed it results in an uneven, unsightly surface and in some instances the spatter might drop off leaving an ungalvanized area.

3.3 Design

During the design of the structure use equal or near equal thickness of parts with symmetrical welds as far as practically possible. When welded pieces of dissimilar thickness are galvanized, distortion can occur as a result of residual stress induced during fabrication and thermal stress as a result of the hot-dip process.

Contacting surfaces with a gap smaller than 2.5 mm needs to have a full seal weld. The viscosity of zinc prevents it from flowing into spaces less than approximately 2.5mm. Thus ungalvanized areas could exist which will corrode and bleed iron oxide onto the surrounding areas.

Cleaning solutions have lower viscosities than the molten zinc. The cleaning solutions can enter smaller gaps and the salts can be retained in these areas. If humid conditions exist weeks or even months later the salts may become wet and cause iron oxide bleeding onto the surrounding areas. This results in poor coating surface appearance.

4.0 WELDING AFTER HOT – DIP GALVANIZING

Welding galvanized steel requires more preparation and control than when welding uncoated steel. Some points to consider are discussed below.

After welding the uncoated areas have to be protected against corrosion.

4.1 Preparation of the Area to be Welded

If at all possible the area to be welded must be made free from zinc. The galvanized coating should be removed at least 25 mm to 75mm from either side of the intended weld zone. All sides of the workpiece should be cleaned.

Zinc will vaporize during the welding process and a large volume of gas will evolve. The gas or fume has to be able to escape easily into the atmosphere and not be forced through the liquid metal joint. If the fume is forced through the liquid metal joint, porosity will most likely occur.

4.2 Welding Processes

All the common welding process can be used to join galvanized steel. Some of the most common welding processes will be discussed below.

4.2.1 Oxyfuel Gas Welding

Preparation for welding is similar to that used when welding normal steel. Use a neutral flame and the forehand welding technique when welding galvanized steel. The forehand welding technique implies that the flame point in the direction of travel with the filler rod preceding the flame

Figure 5. Basic Oxyfuel Welding Process.

If the galvanized coating has not been removed a low travel speed will ensure that the zinc is volatilized and removed from the area of the joint. The galvanized coating will be removed for approximately 6 mm on either side of the welded joint. The coating will be partly damaged and can be affected up to 25 mm on either side of the welded joint.

Weaving with the flame should be minimized in order to reduce the amount of damage to the zinc coating adjacent to the weld joint.. Remelting of the joint to improve the bead profile should not be done as it would result in additional loss of the galvanized coating.

Normal copper coated mild steel rod in accordance with AWS A5.2 can be used as a filler metal.

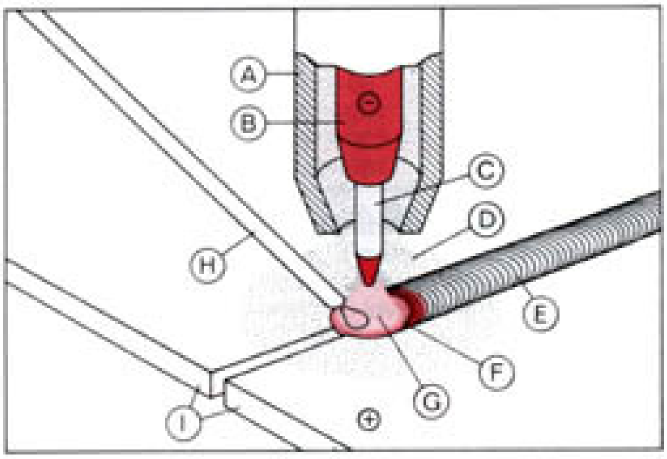
4.2.2 Gas Tungsten Arc Welding

Gas Tungsten Arc welding (GTAW or TIG) of galvanized steel is not recommended. GTAW should only be used if al of the galvanized coating has been removed for at least 75 mm on either side of the area to be welded. The GTAW process is illustrated in Figure 6.

If the zinc layer cannot be removed prior to welding the GTAW electrode will be contaminated by the zinc and result in erratic arc behaviour and poor weld quality. Electrode contamination can be reduced by :

- Using a torch angle of 70° instead of the normal 80° angle.
- Increase the gas flow rate from approximately 7 l/min to 12 l/min.

These changes have the effect of flushing the zinc vapour from the arc area.



Schematic representation of GTA-welding

A Gas cup
B Electrode holder
C Non-consumable tungsten electrode
D Shielding gas
E Finished weld
F Weld pool
G Arc
H Filler wire
I Parent metal

Figure 6. Gas Tungsten Arc Welding Process

4.2.3 Shielded Metal Arc Welding

Shielded Metal Arc Welding (SMAW or 'stick' welding) of galvanized steel can be easily achieved. The SMAW process is illustrated in Figure 7.

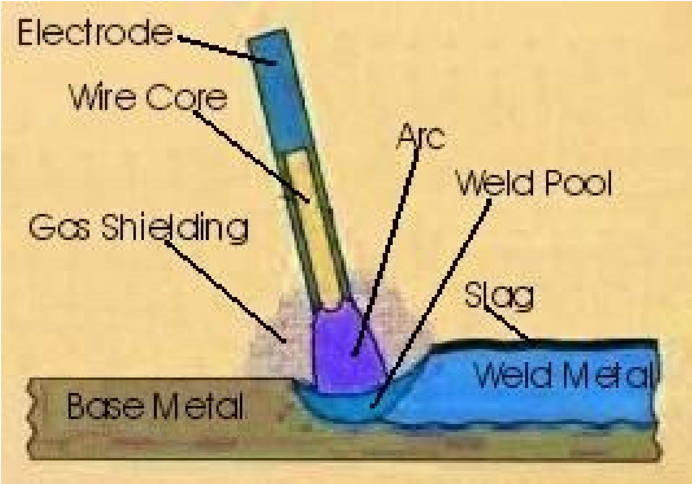


Figure 7. Shielded Metal Arc Welding Process

A short arc length is recommended for welding in all positions. Using a short arc length results in better control of the weld pool and prevents intermittent excess penetration or undercutting.

Welding speed should be reduced compared to that of normal uncoated steel. The speed reduction should be in the order of 30% to ensure acceptable welds. The lower travel speed ensures a higher heat input that will assist to remove zinc in front of the weld as well as from the weld pool.

The electrode angle must be reduced to approximately 30 ° and a whipping motion of the electrode back and forth is required to move the molten zinc pool away from the weld.

Care must be taken to ensure that larger root openings are used for butt welding. The larger root opening facilitates full penetration and drainage of liquefied zinc. Typically root openings should be increased by 30 – 50%.

The root pass can be deposited and subsequently removed by gouging from the reverse side and rewelded. This is common practice to ensure weld integrity in critical applications.

SMAW is only recommended for material thicker than 1.6 mm as the risk of burnthrough increase with the decrease in steel thickness.

4.2.4 Gas Metal Arc Welding

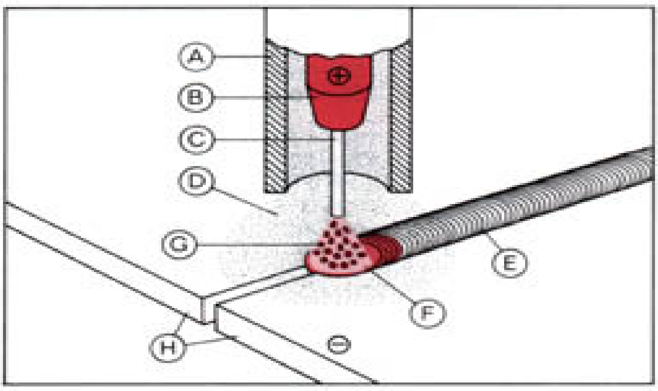
The Gas Metal Arc Welding (GMAW) process can be used to produce satisfactorily welds in galvanized steel. The GMAW process is illustrated in Figure 8.

GMAW is suitable for thin and thick material. It is particularly suitable for thin material (<1.6mm) when using pulse technology.

The advantages of using an Argon – CO_2 mixture compared with 100% CO_2 normally obtained on uncoated steel, is no longer evident when welding galvanized steel. Spatter increase when welding galvanized steel compared to uncoated steel, regardless of the gas mixture used. Thus using 100% CO_2 is sufficient. However if an Argon – CO_2 mixture is currently used no change is needed.

The welding torch gas nozzle needs to be cleaned more frequently as a result of increased spatter build-up.

Lower welding speeds (20 – 25% reduction) are necessary to allow the galvanizing to burn off at the front of the weld pool. The speed is dependant on the welding position and the thickness of the galvanized coating.



Schematic representation of GMA-welding

A Gas cup
B Electrode holder
C Filler wire
D Shielding gas
E Finished weld
F Weld pool
G Arc
H Parent metal

Figure 8. Gas Metal Arc Welding Process.

For fillet welds it is common to increase the current by 10A. The increased heat input helps to burn away the galvanize coating at the front of the weld pool. A small gap needs to be left to allow the zinc vapour to escape. Double fillet welds are troublesome as for the second fillet weld there is no escape route for the zinc vapour. This can result in root porosity.

4.2.5 Gas Metal Arc Braze Welding

Gas metal arc braze welding is an extension of the GMAW process. It uses a filler metal with a lower melting point than the steel to be welded. The joint does not rely on capillary action or on intentional melting of the parent metal. It is used extensively for sheetmetal components in the automotive industry.

The low heat input minimizes damage to the coating on the underside of the parent metal and minimize the level of distortion of sheetmetal.

The welding current is critical to the weld joint quality. High current can cause inclusion of too much iron from the base metal in the weld metal, resulting in an increase risk of transverse cracking. Low current can lead to uneven deposits and lack of fusion.

Typical parameters for a 1mm diameter wire would be a current of 110 – 130 A and voltage of 14 – 15 V.

5.0 RECONDITIONING OF WELD – DAMAGED SURFACES

If severe damage has occurred to the galvanized coating during welding or when the welded area will be exposed to corrosive conditions then the protective coating has to be restored.

Restoration of the area should be done in accordance with ASTM A780 ‘ Standard practice for Repair of Damaged and Uncoated Areas of Hot – Dip Galvanized Coatings’.

Suitable materials to restore the protective coating are zinc rich paints, zinc – based solder or zinc metal spray.

6.0 PROPERTIES OF WELDED JOINTS

Studies performed by the International Lead Zinc Research Organization have shown that the tensile, bend and impact properties of welds on galvanized steel are equivalent to the properties of welds on uncoated steel.

The fracture toughness of welds are unaffected by galvanized coatings.

The fatigue strength of welds made on galvanized steel is comparable to that of welds made on uncoated steel.

7.0 SAFETY AND HEALTH

All welding processes produce fumes and gases to a greater or lesser extent. During welding the zinc is vapourized. The zinc vapour reacts with oxygen in the air to form zinc oxide. Inhaling zinc fumes causes a condition know as metal fume fever. It typically begins 4 hours after exposure and full recovery happens within 48 hours. The typical symptoms are fever, chills, thirst, headaches and nausea.

If welding is carried out in accordance with normal industrial practice with provision for adequate ventilation and air circulation, the fumes will cause no inconvenience.

Welders should be taught that even when welding uncoated materials to keep their heads out of the fume plume.

When welding galvanized steel in confined spaces the welder must be protected by using breathing apparatus or have full local extraction.

Figure9. Localized Fume Extraction.

Exposure limits are defined in specification SANS 10238. It is recommended that SANS 10238 be consulted before welding.

8.0 CONCLUSION

Welding of galvanized steel can be done using any of the conventional welding processes.

Welding of galvanized steel requires certain precautions to ensure a quality weld and acceptable appearance.

Given the choice, welding should be done as much as possible before galvanizing.

9.0 REFERENCES

1. AWS Welding Handbook, 8^{th} Edition, Vol 4, p118 - 155

2. Welding & Hot – Dip Galvanizing, American Galvanizers Association, p3 – 9

3. AWS D19.0, Welding Zinc Coated Steel,