

2. Coating Processes and Surface Treatments

GalvInfoNote

2.3

Continuous Hot-Dip Galvanizing versus General (Batch) Galvanizing

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Introduction

There are two different processes for applying a zinc coating to steel by the hot-dip method. Both involve immersing the steel in a bath of molten zinc. Since zinc melts at 787°F [419°C], and must be further heated to a temperature of approximately 850°F [455°C] or higher for the galvanizing process to be effective, both operations are referred to in general as the “hot-dip” process.

One process involves the application of zinc onto a continuous ribbon of steel sheet as it passes through a bath of molten zinc at high speeds – hence, the term “continuous” hot-dip galvanizing. As a coil is processed through the coating line, another is welded to its trailing end. The process is truly “continuous”, as the line may operate for days without interruption. The other process involves the application of a zinc coating to the surface of steel parts after they have been fabricated. It is not continuous in that the parts are immersed as a discrete “batch” into the zinc bath; hence, the names “batch”, “after fabrication” or “general” galvanizing - terms that are used interchangeably. Parts as small as fasteners, to as large as bridge structural girders, are galvanized by the batch method.

Continuous Galvanizing

As briefly described above, the continuous galvanizing process applies a zinc coating to the surface of a continuous ribbon of steel sheet as it passes through a zinc bath. The coated sheet coils are either directly roll-formed or fed into stamping presses, or blanked/sheared and then formed into parts. The sheet thickness might be as thin as 0.010 inch [0.25 mm] or less, to as thick as 0.25 inch [6.3 mm]. The facilities in operation worldwide are typically “light-gauge”, “intermediate-gauge” or “heavy-gauge” coating lines. Product from light-gauge lines is used mostly for applications in the construction industry (roofing sheets, building sidewall panels, flashing, etc.) The largest application for product made on intermediate-gauge lines is automotive body panels. Product from heavy-gauge lines is used for culvert, automotive structural parts, grain bins, etc.

In this process, the steel sheet is passed through the molten zinc bath at speeds as high as 650 fpm [200] mpm. As the moving sheet exits the coating bath, it drags out molten zinc. The desired coating thickness is attained by the use of “gas knives”. These knives typically use air as the gas, and are directed at both sides of the sheet to remove excess zinc. The coated steel is then cooled and the zinc solidifies on the surface of the sheet.

The continuous galvanizing process for producing coated steel sheet involves a series of complex steps, one of which is to anneal the steel to soften it and make it more formable. More details about the continuous galvanizing process are given in GalvInfoNote 2.1.

One of the most important features of the continuous galvanizing process is the formation of a strong bond between the steel and its zinc coating. At the processing speeds used on continuous galvanizing lines the strip is only in the zinc bath for 2 to 4 seconds. During this brief time the molten zinc and steel must react to form a strong metallurgical bond by way of diffusion. The bonding region is an intermetallic compound, termed the “alloy layer”.

This thin alloy bonding zone, which is usually only 1 to 2 micrometers thick, is critical because after the coating is applied and the sheet cooled to room temperature, it is recoiled and shipped to customers for forming into the desired shape. For example, the sheet might be deep drawn to form a canister, it might be stamped into a car fender, or it might be roll-formed into a building roof panel. For the forming operation to be done successfully, the steel and zinc have to be well bonded to each other. If the bond zone is not formed, or not formed correctly, the steel and zinc would not “stick” together during the many critical forming steps that the coated sheet might undergo.

An adherent and formable bond zone requires that the alloy layer be thin and of the correct composition. This is because the intermetallic compound that the bond layer consists of is very hard and brittle, an inherent characteristic of such alloy layers. There is no metallurgical process that will make the bond zone soft and ductile. By producing a thin alloy layer of the correct composition, the coated steel sheet can be formed into many intricate shapes without loss of adhesion between the steel and zinc coating. If the alloy layer becomes too thick, or is of the wrong composition, cracks develop in it during forming and the steel and zinc coating may disbond when formed. A thin alloy layer of the correct composition can be bent and stretched without cracking and disbanding.

In summary, it is very important for the steel and zinc to form a proper bonding zone, and that this zone is thin. The producers of hot-dip galvanized sheet readily accomplish this by focusing on two primary control points:

1. The addition of a controlled amount of aluminum (approximately 0.15 to 0.20%) to the molten zinc coating bath, and
2. Control of the steel sheet temperature at the point where it enters into the molten zinc and control of the temperature of the zinc coating bath.

The impact of the addition of aluminum to the zinc coating bath used for continuous hot-dip sheet galvanizing is covered in detail in GalvInfoNote 2.4. It is a complex issue that needs to be discussed as a specific topic.

Nevertheless, when the process is properly controlled, the coated steel sheet made by the continuous hot-dip galvanizing process is a well engineered product; one that is being used for the manufacture of many sophisticated end products.

General (Batch or After Fabrication) Galvanizing

The second hot-dip process involves the application of zinc onto a “fabricated” shape. This means the steel is shaped into the final product; a structural beam, a large diameter pipe, or a small fastener, and then dipped into molten zinc to apply the zinc coating. These items are coated either one at a time or, in the case of small parts, as a number of parts contained in a “basket”. Hence, the terms “batch” or “after fabrication” are used to describe this process.

In a sense, the general or batch process is the same as the continuous process in that the objective is to apply an unbroken coating of corrosion resistant zinc onto the surface of steel. However, these two methods have many differences.

The typical batch process involves three steps prior to the immersion of the part(s) into the molten zinc bath:

- Caustic cleaning
- Pickling
- Fluxing

Caustic cleaning involves the use of a hot alkali solution to remove organic contaminants such as oils and greases. These surface contaminants need to be removed prior to pickling so that the surface can be “wetted” by the pickling solution.

Pickling involves the immersion of parts into an acid solution (typically heated sulphuric acid or ambient temperature hydrochloric acid) to remove surface scale or rust (both oxides of iron). The term “scale” is typically used to describe the oxides of iron that form at high temperatures such as during hot rolling, annealing in air, or welding. Rust is the product of corrosion of the steel surface when it gets wet. Both types of iron oxide need to be removed prior to the application of the zinc coating.

Fluxing involves the application of a special chemical coating onto the surface of the steel part. This “flux” serves the same purpose as fluxes used during soldering operations. The fluxing chemical (zinc ammonium chloride) is designed to chemically remove the last vestiges of oxides just as the steel is being immersed into the molten zinc, and allow the steel to be wetted by the molten zinc. Fluxing can be either “dry” or “wet”. Dry

fluxing involves immersion of the steel part into an aqueous solution of the flux. Upon removal, the flux solution is dried prior to immersion into the zinc bath. (Note that there is a continuous galvanizing process that uses dry fluxing. It is described in GalvInfoNote 2.7). In wet fluxing, a blanket of liquid (molten) zinc ammonium chloride is floated on top of the molten zinc bath. The part to be coated is then immersed through the molten flux as it is being introduced into the coating bath. (Wet fluxing works because zinc ammonium chloride has a melting point below that of molten zinc and is less dense than molten zinc, thereby floating on the bath surface).

As with continuous galvanizing, the application of the zinc coating in batch galvanizing involves immersion of the steel into a bath of molten zinc. However, in contrast with the continuous process wherein the steel is immersed for a very brief time, the batch process requires that the part be immersed for much longer times, typically measured in minutes, not seconds. There are two reasons for needing longer immersion times. One is to allow the part to reach the bath temperature. Immersion of a relatively cold thick-walled large pipe, for example, results in a skin of zinc freezing onto its surface when it is first immersed. For the coating to bond metallurgically to the steel, the pipe has to reach the bath temperature to “remelt” the zinc. After this, additional time is required to develop the iron/zinc alloy bond zone.

Unlike the continuous process, where the alloy layer has to be kept very thin to accommodate subsequent forming into the final shape, for batch-galvanized parts the alloy layer can be allowed to grow much thicker. In fact, a thicker alloy bond layer is often desired to provide a longer life to the final product, i.e., a longer time before the onset of rust. Like zinc itself, the alloy layer is galvanically protective to the steel part and a thicker alloy layer means longer life. Yes, the alloy layer is hard and brittle, but since the part is already fabricated, there will be no additional forming that can crack the alloy. The brittle alloy layer is not deleterious. It will not result in coating damage during shipment and subsequent handling at the jobsite. A representative photomicrograph of the alloy layer that forms while the steel is immersed in the bath is shown in Figure 1. As can be seen in this photo, the alloy layer is as much as 50% of the total coating thickness and it actually consists of two or more distinct zinc/iron layers. Each of these distinct layers combines to form the “total” alloy layer zone. Each layer actually has a specific amount of iron and zinc. The layer closest to the steel has the highest iron content while the layer immediately adjacent to the pure zinc outer layer has the lowest iron content. The composition and properties of these alloy layers are shown on Table 1.

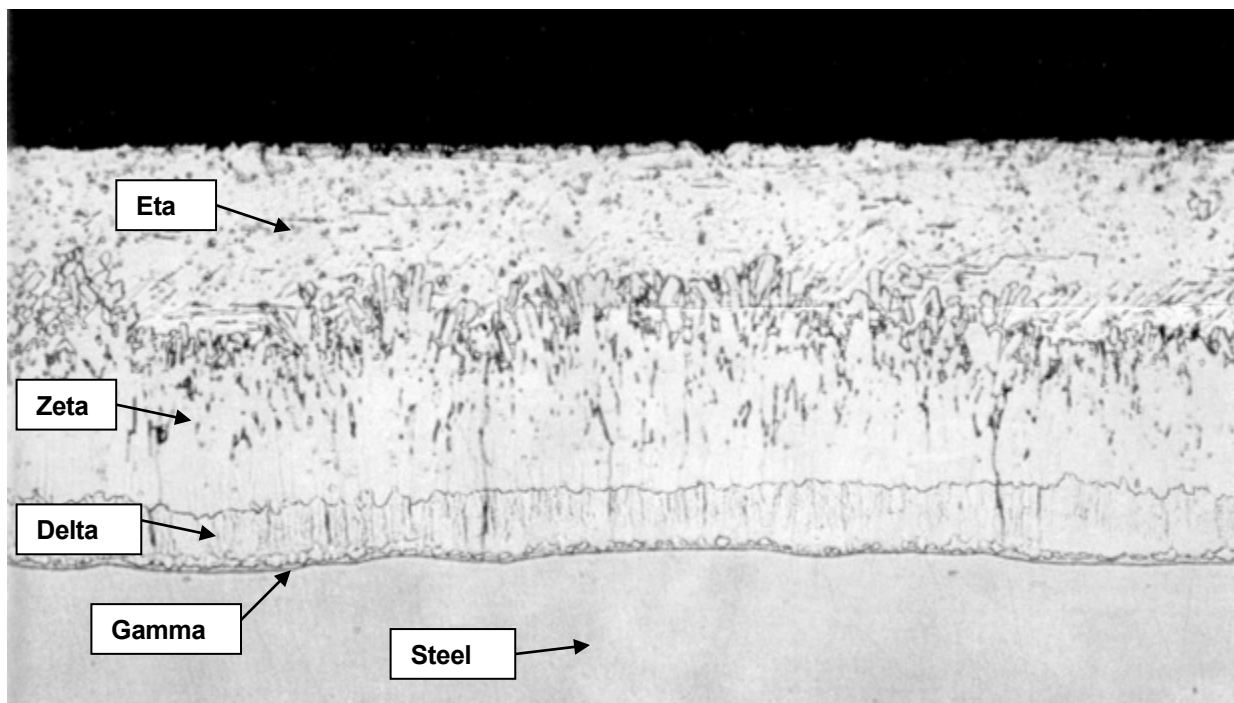


Figure 1: Cross-section of a batch hot-dip galvanized coating.

Remember, the alloy layer grows by an intermixing diffusion reaction between the atoms of the steel and zinc. This is a time dependent process, and for most steels, a longer immersion time provides a thicker alloy layer. In fact, for batch galvanized parts, additional immersion time is often needed to achieve the final required thickness of the protective coating (the thickness is a combination of the alloy layer and the pure zinc outer coating metal).

Table 1: Composition and Properties of Alloys Layers in Batch Hot-Dip Galvanize

Layer	Alloy	Iron, %	Melting Point		Crystal Structure	Alloy Characteristics
			°C	°F		
Eta (η)	Zinc	0.03	419	787	Hexagonal	Soft, ductile
Zeta (ζ)	FeZn ₁₃	5.7-6.3	530	986	Monoclinic	Hard, brittle
Delta (δ)	FeZn ₇	7.0-11.0	530-670	986-1238	Hexagonal	Ductile
Gamma (Γ)	Fe ₃ Zn ₁₀	20.0-27.0	670-780	1238-1436	Cubic	Thin, hard, brittle
Steel Base Metal	Iron	99+	1510	2750	Cubic	-----

As a result of the ability to accommodate long immersion times, the final thickness of the coating (pure zinc + alloy layer) on batch galvanized parts is often considerably thicker than the coating on continuous galvanized sheet product – at least the thickness can be much thicker if desired/required. This is one major difference between the batch galvanizing process and the continuous galvanizing process.

There are production issues that often need to be considered with respect to the maximum alloy layer thickness that can be achieved during batch galvanizing. As the alloy layer thickens, its rate of growth slows down because diffusion through the thickening alloy layer takes longer, resulting in a practical limit to the final thickness. Also, for some steel compositions, the uniformly thickening alloy bond does not form on the surface. Instead, the alloy grows to a certain thickness and then begins to spall off the steel surface. When this type of behaviour is experienced, the practical maximum coating thickness is less than when the alloy continues to grow as a compact layer.

Zinc Bath Composition for General (Batch) Galvanizing

Historically, the zinc bath used for general galvanizing contained between 0.5 and 1.0% lead. The lead had two effects. First, it caused the formation of the typical, attractive large spangled surface, which through the years was “the way to identify galvanized coatings”. Second, the lead was beneficial to accommodate “free drainage” of excess zinc as the part was removed from the zinc bath. In some instances today, bismuth is being substituted for lead to achieve free drainage of the excess zinc. Alloys that contain bismuth for use by the general galvanizing industry are available today from a number of zinc suppliers.

Another alloying addition to zinc that is receiving some attention today as a way to further improve the coating performance is the addition of nickel to the galvanizing bath. The influence of nickel is important with respect to the development of the zinc/iron alloy layer, especially when galvanizing high silicon-containing steels. This development is still quite new and the metallurgical aspects related to the addition of small amounts of nickel are still being discovered.

The addition of 0.15 to 0.20% aluminum to the coating bath – a required addition to the bath when continuous galvanizing – is not a typical practice for general galvanizing. In general galvanizing, the development of a thick alloy layer is important to the achievement of the required coating thickness. Aluminum acts as an inhibitor and interferes with this action.

Part Thickness

Another difference in the two processes, batch vs. continuous, relates to the thickness of the steel that can be galvanized without experiencing “heat distortion” of the steel. In the continuous process, very thin steel can be coated. The reason that this can be accomplished is that during continuous galvanizing, the steel sheet is held under some amount of tension while being processed. Tension needs to be applied to “pull” the ribbon of steel through the coating line, and to maintain the flatness of the sheet. Distortion of the sheet can occur during exposure to the high annealing temperatures. Tension prevents distortion, and allows a controlled, even application of zinc onto very thin sheet, which otherwise would not be possible if it were off flat.

In the batch process, the products immersed into the coating bath are not constrained by the application of outside forces. The part has to be designed to be dimensionally stable during the exposure to the bath temperature. This is accomplished by using both thicker steels and part design principles that prevent heat-generated distortions. Also, temporary bracing can be used for thin-walled parts to minimize distortions caused by the heating. Stated simply, it is not easy to batch galvanize fabricated parts made from thin steel sheet, nor is it easy to continuous galvanize heavy steel plate.

For more extensive information on the after fabrication general galvanizing process, visit The American Galvanizers Association at www.galvanizeit.org/.

Summary

Both continuous and batch galvanizing processes have been in use for many years. Both processes provide a corrosion resistant zinc coating that has been a proven value-added method for protecting the steel substrate in a multitude of applications. Through the years, both processes have undergone advances in technology that continue to expand the markets for galvanized steel.

The two processes described in this GalvInfoNote are generally applicable to different spectrums of steel thickness. Yes, there is some overlap in that thick steel can be continuous galvanized and thin steel can be batch galvanized, but to a large extent, the two processes are complementary and allow the protective nature of zinc to be used for a wide range of steel products.

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