GalvInfoNote	Control of Coating Weight [Mass] for Continuous Hot-Dip Galvanized Sheet Products
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Introduction

Hot-dip galvanized sheet products are manufactured to exacting coating thickness standards. It is the coating thickness that determines coating life in any given application, even though the normal practice is to specify and manufacture to coating weight (inch-pound system) or coating mass [SI system] per unit area. The reason for this is explained In GalvInfoNote 1.1. Since the density of zinc is well known, it is easy to calculate the thickness of a galvanized coating once the coating weight [mass] is determined. This GalvInfoNote explains how coating weight [mass] is controlled.

Corrosion Performance

It is well established that, in most environments, the corrosion rate of a galvanized coating is approximately linear. Twice the coating thickness gives approximately twice the product life before the onset of steel corrosion. For example, a 1-mil thick (0.001 in.) [25.4 μm] coating provides a life of 30 years in a rural environment, and a 2-mil thick coating (0.002 in.) [50.8 μm] lasts about 70 years before the onset of rusting of the steel sheet. This relationship – **the life of the product being a linear function of the coating thickness** – is relevant for almost all applications of galvanized sheet. It is important, therefore, that:

1. The customer ascertain and order the coating weight [mass] needed for the intended application, and
2. The manufacturer of the galvanized sheet produces the correct coating thickness uniformly across the entire width of the sheet and on both surfaces.

For the customer, it is important to have the following two questions answered:

1. What is the corrosion rate in the environment that the product will be used?
2. What is the desired life of the product?

The answers will then dictate what coating weight [mass] is required. Refer to GalvInfoNote 1.6 for additional reference information on selecting the appropriate coating weight [mass].

Controlling the Coating Weight [Mass] During Coating

Modern coating lines are very capable of controlling the thickness of the coating to meet end-user needs. As noted in GalvInfoNote 2.1, these lines operate at high speeds – as fast as 650 fpm [200 mpm]. At these speeds, very specialized equipment is required to ensure the correct coating thickness is applied to the sheet. Figure 1 shows a general layout of the bath equipment, and strip pass-line, in a modern hot-dip coating line.

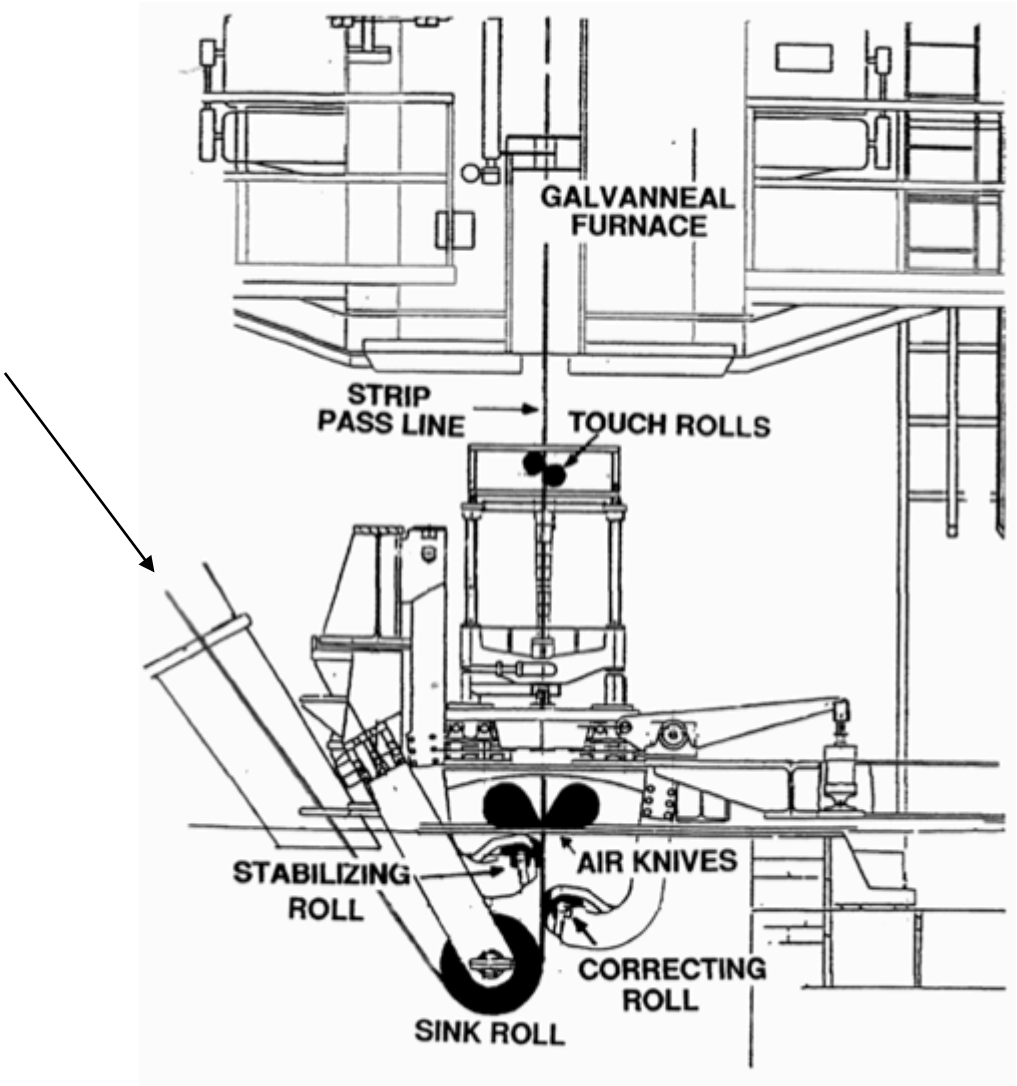


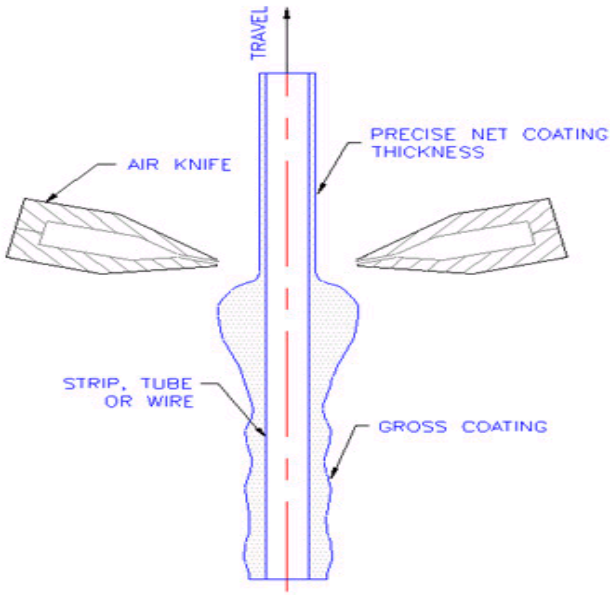
Figure 1 General Arrangement of Coating Bath Equipment in a Continuous Hot-Dip Coating Operation

In this arrangement, the sheet is exiting the bath at high speeds, and as it exits, it drags out more zinc than is needed for the coating. The higher the line speed, the more zinc is dragged out of the bath. The thickness of zinc on the sheet is then controlled by using “gas knives” to wipe off excess zinc while allowing the desired amount to pass through the knives.

Typical gas knives employ low-pressure/high-volume gas streams (in most cases air, but sometimes nitrogen) that impinge against the sheet surfaces. Blowers generate the pressurized air. The air flows from the blower through piping up to a position parallel and adjacent to the strip. It is then allowed to escape through a precisely designed and machined slot opening or orifice that is placed about ½ inch or less from the traveling strip. The resulting air jet acts as a knife, stripping the excess molten zinc and forcing it back in the direction of the coating bath surface. Pressure/volume is the principal control parameter, although height above the bath, distance to the strip, angle of the knives, and knife orifice gap are also controlled.

Automatic coating weight [mass] control systems using artificial intelligence technology have been installed on many lines to produce consistent coating thickness with low standard deviation. The degree

of control required depends on the thickness that is being applied. The thinner the coating the more control required. As shown in Figure 1, the manufacturer can use a set of small rolls located immediately beneath the zinc bath surface to keep the sheet stable and uniformly distant from each knife orifice. This, or a similar, roll arrangement is very important to obtain the desired uniform thickness of coating on both sides of the sheet. Figure 2 is a cross-section schematic of an air knife operation. In addition to flat sheet or strip, this technology is also used when coating wire or tubing.



Source: www.coatingcontrol.com

Figure 2: Schematic of Air Knife Operation

Range of Coating Weights [Masses] on Galvanized Sheet

There are limitations to the minimum/maximum coating thickness that can be applied to continuous galvanized sheet products.

Minimum Coating Thickness

The minimum thickness is limited primarily by the amount of air (pressure and volume) that is practical to use during manufacture. As the air pressure and volume are increased, or the strip to knife distance is decreased, the coating thickness will decrease. The rate of decrease in coating thickness as the knife parameters are adjusted becomes limiting when the coating thickness gets down to about 0.00025 inch [6.4 μm]. This is not an absolute number as the design of the air knives and the processing speed govern the lowest coating thickness that is achievable. If the air pressure and volume are increased further, or the knives are moved too close to the strip, the zinc exhibits a tendency to freeze at the air knife location. If this occurs, there is obviously no further “wiping” action.

The speed of the sheet when it exits the coating bath has a large influence on the volume of zinc that needs to be wiped off. The higher the sheet speed, the higher the air pressure and volume needed to obtain a specific coating thickness, therefore the thinnest coating achievable is influenced by line speed. Since the processing speeds used on coating lines are usually dictated by the annealing furnace design, it is common for thin gauge sheet to be processed at high speeds and for thick gauge sheet to be processed at lower speeds. It is reasonable to expect that the thinnest coatings might only be possible on heavier gauge strip. This is true except for one offsetting factor. As explained in

GalvInfoNote 2.4, the sheet and coating metal react to form an alloy layer during the time that the sheet is immersed in the coating bath. This alloy layer is solid and cannot be wiped off by the air knives. The longer the sheet is immersed in the bath, the thicker the alloy layer. Therefore, heavy gauge sheet, being processed at lower speeds, is immersed in the coating bath longer than light gauge sheet, and typically has a thicker alloy layer. Since the alloy layer is a part of the final total coating thickness, it is not necessarily true that heavy gauge sheet can be coated with the thinnest coatings.

Maximum Coating Thickness

The maximum coating thickness is limited by a number of factors, but clearly one is the amount of zinc that can be "dragged" from the bath. Since it is governed by the surface tension of the liquid zinc, the amount of zinc being dragged at low speeds is less than at high speeds, so it is difficult to achieve a thick coating on heavy gauge sheet. *Remember, heavy gauge sheet is usually processed at lower line speeds because of the limitations of the annealing furnace.* Since heavy gauge sheet is often a product that is expected to be in corrosion-free service for many years (corrugated steel pipe, for example), the product needs to have a thick coating. To accomplish this, galvanized sheet producers apply special practices to heavy-gauge sheet to achieve thicker coatings. One such practice is to increase the surface roughness of the steel substrate. The rougher surface results in more zinc being dragged out at any given speed, and provides more "holding power" to prevent the liquid zinc from running back down the sheet before it freezes.

Besides being limited by the amount of zinc that is dragged out of the coating bath, there is another practical limitation. If the coating is too thick after it passes through the air knives towards the top roll above the coating pot, there is a tendency for the molten coating metal to "sag" simply because of gravity. The coating immediately adjacent to the steel surface is "held" in place by surface tension between the molten coating and the solid alloy layer on the smooth or rough steel sheet. Also, the outer surface of the molten coating has a "solid" but very thin layer of oxide. This oxide layer attempts to hold the molten coating in position until it has totally solidified. However, as the thickness of the molten layer increases, there is a tendency for the coating to "break through" the oxide layer, and as a result local sagging can occur. This results in a non-uniform coating thickness on the sheet surface, one that can be unsightly as well as affecting the time before rusting of the steel sheet begins. *The coating needs to be uniformly thick to avoid localized uneven onset of red rust.*

The practical maximum thickness depends on many specifics of the particular coating line, but realistically, coatings thicker than about 2 mils (0.002 in.) [50.8 μm] often have coating sags.

ASTM Coating Designations

Specifications such as A653/A653M, the ASTM Standard that covers continuous hot-dip galvanized sheet products, take into account the limitations that were discussed in the previous sections on minimum/maximum coating thickness. Table 1 at the end of this GalvInfoNote contains the coating designations that are recognized in A653/A653M.

In Table 1, the maximum coating thicknesses, G360 and G300, can only be applied to thicker sheet (for most producers, approximately 0.060" [1.5 mm] and heavier), and the tendency for sags to develop in coatings this thick is high. In fact, coating designations of G115 [Z350] and heavier typically have minimum sheet thickness to which they can be applied. This limitation varies by producer as explained in the next section.

On the other end of the range, the thinnest coating, G01, has no specified minimum thickness. This designation clearly recognizes that there is a physical limit to the thinnest achievable coating thickness. Even a G30 coating at approximately 0.0003 in. [7 μm] thick is beyond the thinnest designation that is achievable on some coating lines when processing the sheet at high speeds.

Producer Capability

The preceding discussion highlights the importance of determining the specific coating thickness needed for a given application. It also shows that there are some very definite limitations to the thickest and thinnest coatings achievable by the continuous hot-dip process.

Each continuous hot-dip production line has specific capabilities with regard to the thickest and thinnest coatings that can be applied uniformly. These limitations depend on some very specific features of the line including:

- The processing speed for any specific sheet thickness/width combination,
- The design of the air knife equipment, and
- The ability of the steel company to control sheet surface finish (surface roughness) on the incoming steel. A rough steel surface is needed for thicker coatings, but such a surface is not possible on thin sheet that requires a relatively smooth surface.

These and other reasons are why producers have very specific limits with respect to their minimum and maximum coating weight [mass] capability for each of their coating lines. Typically, these capability limits have been developed on the basis of experience, and they take into account the needs of the end-user community with respect to coating thickness uniformity and coating appearance. Issues such as forming, welding, and corrosion performance all are very dependent on the application of a uniform coating thickness. To find out what coating weights [masses] are produced as a function of sheet thickness, it is necessary to contact the intended galvanize producer.

Other Types of Hot-Dip Coatings

The other types of continuous hot-dip-coated sheet products have limitations much like galvanized coatings with respect to coating thickness. The capability range is somewhat different because of differences in the density and viscosity of the specific liquid coating alloy, but each type of product - pure aluminum coated, aluminum-5 to 11% silicon alloy-coated, 55% aluminum-zinc alloy-coated, 95% zinc-aluminum alloy-coated, and zinc-aluminum-magnesium alloy-coated – has coating metal attributes that make the commercially available coating weight [mass] range a very specific defined window. If an application involves one of these other products, recognize that it is still important to have a uniformly thick coating, and the commercially available range of coating weight [mass] has been established taking into account many of the same parameters as those discussed here.

Batch-galvanized parts are made in a very different manner than continuous galvanized sheet product, and as a result, the range of commercially available coating thickness is very different than for sheet product. The batch process can apply much thicker coatings. For batch-galvanized parts, the immersion time - the time the part is submerged in the molten coating bath – is much longer than that for continuous-galvanized sheet. The manufacturer takes advantage of this to allow the alloy layer to grow quite thick, if desired. Since the alloy layer provides good galvanic protection to the steel part, it is a vital component of the coating life. Thus, items such as transmission towers can be batch galvanized to provide sufficiently thick coatings to last for more than 50 years without maintenance.

Table 1 Coating Designations for Hot-Dip Galvanized Sheet Products*

Units	Coating Designation	Minimum Coating** Weight (oz/ft^2)
	G01	No minimum
	G30	0.30
	G40	0.40
	G60	0.60
	G90	0.90
	G115	1.15
Inch-Pound	G140	1.40
	G165	1.65
	G185	1.85
	G210	2.10
	G235	2.35
	G300	3.00
	G360	3.60
		Mass (g/m^2)
	Z001	No minimum
	Z90	90
	Z120	120
	Z180	180
	Z275	275
	Z350	350
SI (Metric)	Z450	450
	Z500	500
	Z550	550
	Z600	600
	Z700	700
	Z900	900
	Z1100	1100

* Source: ASTM Annual Book of Standards Volume 01.06

**Minimum coating weight [mass], total both sides of the sheet, triple-spot average. Refer to Specification ASTM A653/A653M for additional requirements pertaining to single spot and per side requirements.

Summary

The life of galvanized sheet is a direct function of the coating thickness. To determine what coating weight [mass] to order, the customer needs to know both the desired life of the product and the corrosion rate of the environment it will be exposed to. Modern coating lines have excellent capability in controlling the thickness of all hot-dip zinc and zinc-alloy coatings. For continuous hot-dip galvanized products, coating weights available range from G01 to G360 [Z001 to Z1100]. Batch hot-dip galvanizing can apply even thicker coatings.