GalvInfoNote 11	Control of Coating Weight (Mass) for Continuous Hot-Dip Galvanized Sheet Products Rev 2.2 Sep-03

Introduction

Hot-dip galvanized sheet products are manufactured to exacting standards for coating thickness. Although we like to speak of coating thickness because the thickness is important to determine the expected life of the coating in any given application, the normal practice is to specify and manufacture to meet a given coating weight (inch-pound system) or coating mass (SI system). Since the density of the zinc coating is well-known, it is easy to approximate the thickness of a galvanized coating once the coating weight (mass) is determined. In this GalvInfoNote, we will discuss coating weight (mass) and how it is controlled.

Corrosion Performance

It has been well-established that, in most environments, the corrosion rate of a galvanized coating is approximately linear. That is, twice the coating gives approximately twice the product life before the onset of steel corrosion. For example, if a 1-mil thick (0.001 inch or 25.4 microns) coating provides a life of 20 years in a specific type of rural environment, a 2-mil thick coating (0.002 inch or 50.8 microns) would last approximately 40 years before the onset of rusting of the steel sheet. This type of behaviour – **the life of the product being a direct function of the coating thickness** – is relevant for almost all applications of galvanized sheet. Therefore, for most applications of galvanized sheet, it is important that:

1. the customer determine precisely what coating weight is needed for the intended application, and

2. the manufacturer of the galvanized sheet apply the amount of zinc coating that is ordered by the customer uniformly across the entire width of the sheet and on both surfaces.

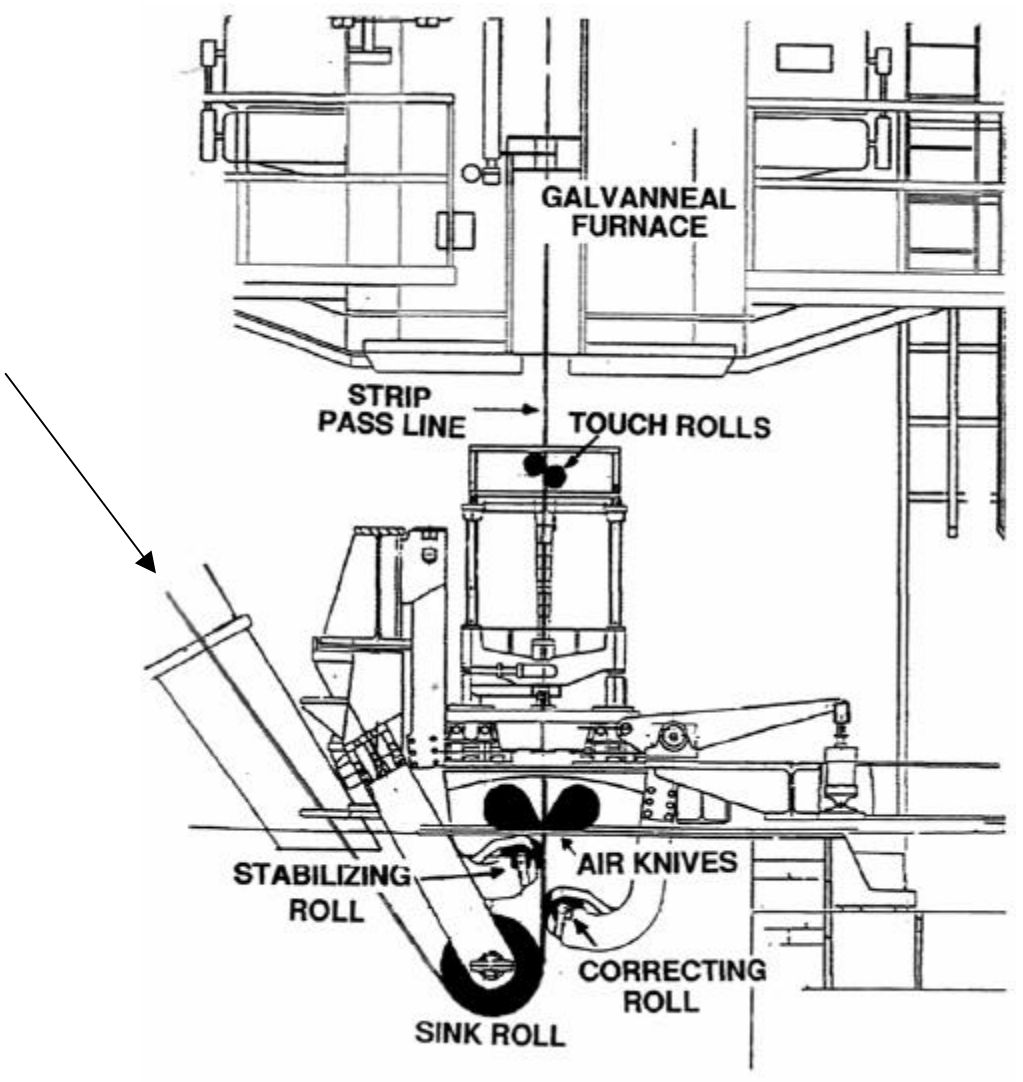
For the customer, it is important to answer the following two questions:

1. What is the corrosion rate in the environment that the product will be used?

2. What is the desired life of the product?

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, today's processing lines operate at high speeds. The sheet moves through the coating line (including exiting the zinc bath) at speeds up to 600 feet/minute and higher. At these speeds, very specialized equipment is required to ensure the correct coating thickness is applied to the sheet. The following diagram shows a general layout of the bath equipment, and strip pass-line, in a modern hot-dip coating line.



General Arrangement of the 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 excess zinc. Typically, 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"[1] to wipe off excess zinc and allow the desired amount to pass through the knives.

Gas-knife technology has become sufficiently good so that the coating thickness can be controlled within a narrow range. The exact degree of control depends on the thickness that is being applied. As shown in the above figure, the manufacturer can use a set of small rolls located immediately beneath the bath surface to

[1] Gas knives are simply high pressure/high velocity gas streams (in most cases air, but sometimes nitrogen) that impinge against the sheet surfaces. The gas streams are generated by blowers. The stream of gas 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 high speed gas jet acts as a knife, stripping the excess molten zinc and forcing it back in the direction of the coating bath surface.

keep the sheet uniformly distant from each orifice. This roll arrangement is very important to obtain the desired uniform thickness of coating on both sides of the sheet.

Range of Coating Weights (Masses) on Galvanized Sheet

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

Minimum Coating Thickness

The minimum thickness is limited simply by the amount of gas (volume and velocity) that is practical to use during manufacture. As the gas velocity and volume are increased, the coating thickness obviously decreases. The rate of decrease in coating thickness as the gas volume and velocity increase becomes limiting when the coating thickness gets down to about 0.00025 inch (about 6 microns). This is not an absolute number as the design of the gas knives and the processing speed impact the lowest coating thickness that is achievable. If the gas volume and velocity are increased further, the zinc exhibits a tendency to freeze at the gas knife location. If this occurs, there is obviously no further "wiping" action.

As described in more detail below, 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 gas velocity and volume need to be to achieve a specific coating thickness, therefore the thinnest coating achievable is influenced by the speed. Since the processing speeds used on coating lines are dictated usually 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. Thus, one should reasonably expect that the thinnest coatings might be applied to heavier-gauge strip. This is true except for one offsetting factor. As explained in GalvInfoNote #10, 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 gas knives. The longer the sheet is immersed in the bath, the thicker the alloy layer. Therfore, 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 processed to achieve the thinnest coatings.

Maximum Coating Thickness

The maximum coating thickness is limited by a number of issues, but clearly one is the amount of zinc that can be "dragged" from the bath. At low speeds, the amount of zinc being dragged out 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 product that is intended to be used for long times in service (culvert, for example), the end user often desires this product to have a thick coating. To accomplish this, the galvanized sheet producers will attempt to apply special practices for heavy-gauge sheet to achieve thicker coatings. One such special practice is to increase the surface roughness of the incoming steel sheet. This practice results in more zinc being dragged out at any given speed.

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 gas knives, there is a tendency for the molten coating metal to "sag" simply because of gravity as the strip travels upward toward the top roll above the coating pot. The coating immediately adjacent to the steel surface is "held" in place by surface tension between the molten coating and the "solid" alloy layer. 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. But, 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 affect the time before rusting of the steel sheet begins. *The coating needs to be uniformly thick to avoid localized early 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 inch or 50.8 microns) often have some amount of coating sags.

ASTM Coating Designations

Specifications such as A 653/A 653M, 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 A 653/A 653M.

In Table 1, the maximum coating thicknesses, G360 and G300, cannot be applied to all thicknesses of sheet. Also, the tendency for sags to develop in coatings this thick is high. On the other end of the range, the thinnest coating, G01, has no specified minimum thickness of coating. This designation clearly recognizes that there is a physical limit to the thinnest achievable coating thickness. Even a G30 coating at approximately 0.0003-inch or 7-microns thick, is beyond the thinnest designation that is achievable on some processing 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 gas-knife equipment, and
- the ability of the steel company to control sheet surface finish (surface roughness) on the incoming steel.

These and other reasons help to explain why producers develop very specific capability charts with respect to their coating weight (mass) capability for each of their processing lines. Typically, these capability limits have been developed on the basis of processing trials, 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.

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 coatings, aluminum-5 to 11% silicon coatings, 55%aluminum-zinc coatings, and 95%zinc-aluminum coatings – has coating-metal attributes that make the commercially available coating weight (mass) range a very specific defined window. If your 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. Much thicker coatings can be applied by the batch process. For batch-galvanized parts, the immersion time - the time the part is immersed into 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)
Inch-Pound	G360	3.60
	G300	3.00
	G235	2.35
	G210	2.10
	G185	1.85
	G165	1.65
	G140	1.40
	G115	1.15
	G90	0.90
	G60	0.60
	G40	0.40
	G30	0.30
	G01	No minimum
		Mass (g/m^2)
Metric	Z1100	1100
	Z900	900
	Z700	700
	Z600	600
	Z550	550
	Z500	500
	Z450	450
	Z350	350
	Z275	275
	Z180	180
	Z120	120
	Z90	90
	Z001	No minimum

* Source: ASTM Annual Book of Standards Volume 01.06

**Minimum coating weight (mass), total both sides of the sheet, triple-spot average. Refer to ASTM A 653/A 653M Specification 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 (masses from Z001 to Z1100). Batch hot-dip galvanizing can apply even thicker coatings.