GalvInfoNote	The Continuous Hot-Dip Coating Process for Steel Sheet Products
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Introduction

The continuous hot-dip coating process for steel-sheet products is a widely used practice, one that is employed in all corners of the globe today. The process was developed over fifty years ago for galvanizing (zinc coating), although the early practitioners would not recognize the process today. It has become a very sophisticated, technically advanced operation. Originally, the product was used for applications that did not demand a high quality finish or a high degree of formability. Today, the consuming industries are using hot-dip coated product for the most demanding surface quality applications; items such as automotive hoods, fenders and doors. Not only do these applications require a high degree of surface quality, but they also demand a high degree of formability. Hot-dip coated sheet is produced in thicknesses from 0.010 in. to 1.70 in. (0.25 mm to 4.30 mm) in widths up to 72 in. (1830 mm).

The Process – Basic Principle

As the name implies, hot-dip coating involves the application of a molten coating onto the surface of steel sheet in a continuous process. That is, the steel sheet is passed as a continuous ribbon, through a bath of molten metal at speeds up to 600 feet per minute. In the molten-metal bath, the steel strip reacts (alloys) with the molten metal to bond the coating onto the strip surface. As the strip emerges from the molten bath, it drags out excess metal, much like when an object is pulled rapidly from a container of water. Through the use of a gas-wiping process, a controlled amount (thickness) of coating, usually expressed as weight (mass) of coating[1] per unit area, is allowed to remain on the strip surface.

The Process Details

The most common type of continuous hot-dip coating processing line in use today consists of a series of steps, which may include the following sequential operations:

- An entry-end welder to join the trailing edge of one coil to the leading edge of the succeeding coil to allow the process to be continuous
- An alkaline cleaning section to remove the rolling oils, dirt, and iron fines (surface contaminants from the cold reduction process) that are on the sheet surface
- An annealing furnace that is used to heat the steel to high temperatures to impart the desired mechanical properties (strength and formability) to the steel sheet

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[1] *The precise amount of coating applied to the steel surface depends on the customer's requirement for a given application. For example, galvanized coatings can be applied at levels ranging from as low as 0.30 oz/ft^2 (90 g/m^2) to greater than 2.00 oz/ft^2 (600 g/m^2). Thin galvanized coatings provide sufficient corrosion protection for applications where the corrosion rate is low (interior electrical equipment, interior wall panels, computer equipment, etc.) while thick coatings are intended for applications where the corrosion rate is high (culverts and other outdoor articles for which a long life is desired).*

Similar considerations related to the corrosiveness of the application need to be made for the other types of hot-dip coatings. In all cases, one word of caution needs to be mentioned. The coating thickness may affect other properties of the coated-steel sheet product; thus, all application requirements need to be considered when selecting the specific coating weight. For example, does the part being made involve a large amount of forming? This may limit the thickness of the coating to avoid loss of coating adhesion. Is spot-welding involved? This may limit the acceptable maximum coating thickness for a given application.

- A bath of the molten coating metal being applied to the steel surface
- A cooling section to cool the strip and solidify the coating as it emerges from the bath
- A temper mill to impart the desired surface finish to the coated steel
- A tension leveler to flatten the strip to meet the end use requirements
- A treatment section to apply a clear, water-base treatment to the coating to prevent storage stains that can form on the coating surface when moisture is present (condensation and/or water infiltration originating from improper shipping or storage)
- An oiling section used most often to apply a rust-inhibitive oil; at times, used to apply a forming oil
- A recoiler to rewind the finished coil of steel that now has:
  - ✓ the desired steel strength and formability
  - ✓ an adherent, corrosion-resistant coating
  - ✓ the desired surface finish
  - ✓ a high level of flatness
  - ✓ a clear chemical treatment and/or oil to assist with preventing degradation of the coated-sheet appearance

The incoming steel is most often "full-hard" sheet coming directly from a cold reduction mill. The cold reduction mill is used to decrease the thickness of the hot-rolled pickled strip to the desired thickness. The cold rolling process makes the steel very hard with limited formability. For heavier sheet thicknesses, the product may be entered into the coating line directly after hot rolling and pickling. In either case, the sheet is uncoiled and welded to the tail end of the coil ahead of it in the processing line. Then, it is cleaned in a process that typically uses an alkaline liquid combined with brushing. From the cleaning section, the strip passes into the heating (annealing) furnace to soften the full-hard strip and impart the desired strength and formability to the steel.

In the annealing furnace, the strip is maintained under a reducing gas atmosphere to remove any vestiges of oxides on the steel surface. The gas atmosphere is composed of hydrogen and nitrogen. This oxide-reduction step, iron oxide being converted to iron by reaction with the hydrogen, is very important to obtain complete wetting[2] of the steel surface during the short time that it is immersed into the coating bath.

The exit end of the furnace is connected directly to the molten coating bath by a "snout" to prevent any air from re-oxidizing the heated steel strip prior to it reacting and alloying with the molten coating metal. In the coating bath, the strip passes around a submerged roll and then exits the bath in a vertical direction. At the exit point, a set of gas knives (usually high pressure air), wipe off excess molten metal, leaving behind a closely controlled thickness of molten metal.

The coating is then cooled to allow the metal to freeze on the steel surface. Freezing of the coating, or solidification, has to be accomplished before the strip contacts another roll to avoid transferring the coating onto the roll. Thus, coating-process lines usually have a high tower above the coating bath, perhaps as high as 200 feet on some of the newer lines.

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[2]*Wetting is the term used to define the reaction between the steel surface and the molten coating metal. This reaction is very important to obtain complete coverage by the coating and good adhesion between the coating and the steel.*

Galvanneal is produced from galvanized by reheating the coated sheet above the wiping knives to alloy the zinc with the iron in the steel. See GalvInfoNote #5 for a detailed description of the galvannealing process.

After cooling to close to room temperature, the strip feeds into the exit end equipment - temper mill, tension leveler, chemical treatment section, oiler, and then is recoiled on an exit-end mandrel.

The continuous strip is sheared at the weld that was made at the entry end of the line to remove the weld as well as to maintain coil-to-coil identity.

Not all hot-dip coating lines have all of the above processing steps. For example, some do not include the aqueous cleaning stage, relying instead on “flame” cleaning in the entry end of the annealing furnace. Others might not have a temper mill; temper rolling is not necessary, and perhaps not desired, for some applications of hot-dip coated products.

Alternate Process (Flux Coating)

There is another hot-dip process that is used in some parts of the world, including the United States, which involves a significantly different approach. In this process, called the flux-coating process, the steel is annealed ahead of the coating line in a separate operation, either batch annealing or continuous annealing. Thus, the coating line does not have the large continuous annealing furnace that was mentioned above. In the flux-coating process, the steel is cleaned to remove oils, dirt, etc., and then pickled to remove the thin oxide coating that is present on the steel surface. After rinsing, the steel is then passed into an aqueous flux solution to apply a flux coating onto all areas of the steel surface.

When the flux-covered strip enters the coating bath, the chemical action of the flux behaves similar to the performance of fluxes used for soldering; that is, the flux reactions help to obtain rapid “wetting” of the molten coating to the steel surface. Recall that this wetting reaction is required to obtain complete coverage of the molten coating, and a good bond between the coating and the steel.

The remainder of the flux-coating process is essentially the same as that used in the process described above for the lines that have in-line annealing furnaces.

Some references to the flux-coating process refer to it as the “cold” process in contrast with the term “hot” process used to define the lines that have in-line annealing furnaces.

By far, the number of “hot” lines exceeds the number of “cold” lines.

See GalvInfoNote #17 for a more complete description of the flux coating process.

Summary

The hot-dip process for steel sheet is used today to make seven different types of hot-dip coated products, i.e., seven different coating metals. These coatings include:

- Galvanize (zinc)
- Galvanneal (zinc/8-10% iron alloy)
- Two alloys of zinc and aluminum
  - ✓ 55% aluminum/45% zinc alloy
  - ✓ 95% zinc/5% aluminum alloy
- Two aluminum based alloys
  - ✓ pure aluminum
  - ✓ aluminum/5-11% silicon alloy
- Terne coating (lead/3-15% tin alloy)

As of 2003, there are approximately 85 hot-dip lines in North America, each of which can apply one or more of the above coatings.

See GalvInfoNote #4, which describes the above coatings in more detail.