

CHAPTER 21

HOT DIP GALVANIZING

by

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I. ABSTRACT

Hot dip galvanizing is a simple, but versatile process used to coat steel or iron in all shapes and forms with zinc. The process is applied to finished articles and also to semi-fabricated materials — sheet, strip, wire and tube.

Galvanizing after fabrication has the advantage of completely sealing edges, rivets and welds, so that there are no uncovered parts where rusting can start and penetrate recesses. Complete protection is given to what would be corrosion sites with other coating systems. The process is applicable to fabrication of geometrical shapes ranging from nuts and bolts to large tanks and structural members. With existing molten metal vessels 52 feet long and larger, structural members 90 feet long can be handled by double dipping. Since double dipping has occasionally been misused or misinterpreted, an explanation of this practice is covered in the text.

The ability to coat large pieces and to bolt or weld prefabricated sections after galvanizing allows almost any structure to be galvanized. Complex shapes and open vessels can be zinc coated inside and out in one operation. While wire, tubing and strip can be hot dip galvanized, the emphasis in this chapter is on geometric shapes, such as structurals.

The fundamental steps in the galvanizing process are:

- Soil and grease removal: hot alkaline or solvent cleaner is usually used to remove oil, grease, shop oil, and soluble paints. This will not, however, remove such things as epoxy, vinyl, asphalt, or welding slag. These soils must be removed by grit blasting, sand blasting or other mechanical cleaning not normally the responsibility of the galvanizer.
- Scale removal: accomplished by acid pickling or abrasive blasting.
- Fluxing and hot dipping: the hot dip galvanizing process consists after cleaning of fluxing the surface of an iron or steel article and immersing the articles in molten zinc. There the base metal and zinc react to produce several intermetallic compounds that usually form distinct layers on the iron or steel. When the reaction subsides after proper length of time, the article is withdrawn from the molten bath. As it emerges, it carries with it a layer of unreacted zinc that quickly freezes to cover the iron-zinc alloy layers with a bright lustrous metallic coating.

The material so processed has enough zinc on it as a surface film to give the desired coating for protection from corrosion. The amount of pickling of the material to be galvanized, proper regulation of the zinc kettle temperature, fluxing of the surface of the molten zinc and the position of the material as it is lowered into the zinc all are important factors. Each of these factors affects the quality of the coating produced.

Galvanizers have no time tables regulating the amount of pickling or the time that the material must be immersed in the molten zinc to insure proper alloying. The process of commercial galvanizing is a skill. Few pieces of structural steel being galvanized are the same size, shape or even of the same type material; therefore, the quality of the galvanizing depends on the skill of the craftsman performing the process. Once the steel has been properly prepared, the development of a galvanized coating is generally predictable for a given set of steel and operating conditions.

II. INTRODUCTION

Many methods have been employed to fight the expensive corrosion of steel. These include painting, cladding with a relatively thick layer of metal less susceptible to rust and developing special steel alloys to withstand highly corrosive conditions. One of the most widely used methods for protecting steel is to coat it with a relatively thin layer of some other metal.

Among the common metals used for this purpose are zinc, lead, tin, copper, nickel, chromium and aluminum. Because of its special advantages, zinc is used for protective coatings far more than any other metal. The principal reasons for its use are that it has inherent corrosion resistance; it is easy to apply (relatively low melting point, 787°F); it is relatively inexpensive and readily available; it has a hard, smooth surface which is comparatively resistant to abrasion; and it is highly amenable to continuous processing.

Zinc is one of the most versatile materials available for coating other metals. It can be applied as a metal by hot dip galvanizing, flake galvanizing, electrodeposition, thermal spraying or metallizing, mechanical or peen plating, sherardizing or cementation, brush scratching or rubbing, plasma arc spraying, shot blasting, vacuum metallizing and non-vacuum vapor condensation deposition. Zinc dust can also be used as a pigment in protective paints. Each of these methods of applying zinc coatings

has its specific reason for being and in certain applications is to be preferred. While there is always at least one process applicable to any particular set of circumstances, the processes are complementary rather than competitive, so that rarely are more than two to be seriously considered as the best choice for a particular job. Economic aspects are important factors in making the decision. Where there is little difference in cost, consideration should be given to the serviceability required.

Factors such as size, shape and complexity have to be taken into account in choosing the most suitable process for a particular application.

In hot dip galvanizing, thoroughly cleaned steel or iron is immersed in molten zinc and withdrawn to provide a smooth, even coating that frequently has a crystalline, "spangled" appearance. The galvanized coating is applied by various means: hand-dipping of fabricated items of irregular shapes, either singly, e.g. for items such as structural beams, or in baskets for coating nails, bolts and similar products; intermittent or semi-continuous mechanical dipping of pipe; and a highly automated dipping that enables steel strip and wire to be galvanized by passing continuously through molten zinc. Coatings produced by the third method are quite uniform in thickness and are very ductile.

In the hot dip galvanizing operation the steel is first cleaned of all foreign material before immersion in the zinc bath. This is generally accomplished by removing grease, oil and other foreign contaminants either by alkaline or solvent degreasing and thorough rinsing, then by acid pickling or blast cleaning and fluxing which further cleans and activates the surface. One type of continuous galvanizing surface preparation is effected by gas pickling in an atmosphere which reduces and eliminates the oxide film generally found on exposed steel. The steel is then immersed in the molten zinc which readily "wets" the clean surface of the base metal and fuses with it to form the coating. The thickness of the coating is largely determined by the temperature of the bath, time of immersion, fluidity of the bath, the rate of withdrawal from the bath, and the thickness and weight of the article. On withdrawal from the bath, coating thickness of strip sheet, wire and pipe is further controlled by mechanical means. This text, however, will concentrate on hot dip galvanizing after fabrication.

The process is very versatile and has been used to protect articles ranging in size from very small to very large. This size range, together with the ability to bolt (friction grip or conventional using galvanized bolts) or weld prefabricated sections after galvanizing, enables almost any structure to be galvanized. Of particular interest to the process industries is the fact that tubes, open vessels and complicated shapes can be galvanized inside and out in one operation. All types of plain carbon and some low alloy steels can be galvanized, as well as iron and steel castings.

III. SURFACE PREPARATION

While a clean surface is necessary for the successful application of any coating to a base metal, it is especially so for applying a zinc coating by hot dip galvanizing to steel. Because the molten zinc fuses with the base metal to form a metallurgical bond with it, the steel surfaces must be practically surgically clean to allow the reaction to take place completely. The molten zinc cannot bond to the steel if anything foreign is present.

Surface preparation, in general, requires a number of steps. Cleaning is necessary to remove dirt or grime accumulated during shipping, storage or manufacture. Removal of paint or similarly adherent materials requires other means to be discussed later. Degreasing with an organic solvent or hot alkali solution removes oils or similar organic materials.

A. PICKLING

Since pickling is considered fully in another chapter of this Manual, only those aspects pertinent to hot dip galvanizing will be mentioned here. While the previous surface preparation procedures aim toward complete removal of dirt, grime, grease and other contact contaminants, scale has to be removed by pickling or blasting.

For pickling, suitably diluted sulfuric or hydrochloric acid is used. The time required for pickling will depend upon the surface condition and nature of the steel and the thickness of the scale. Usually 10 to 15 minutes of immersion is sufficient.

Immersion time should be as short as possible to minimize hydrogen absorption and undesirable attack on the work surface. Inhibitors are recommended to minimize attack on the metal. They lower acid consumption, reduce hydrogen absorption, decrease acid fuming and help prevent "burned" work. In addition, they improve general working conditions around the pickle tank.

If an effective inhibitor is used, no harm results from leaving the material for a prolonged period in the pickling acid. If no inhibitor is used, hydrogen evolved when the iron dissolves in the acid is liable to be absorbed by the steel and may cause embrittlement or give rise to a blistered coating when the material is dipped in the molten zinc bath.

Hydrofluoric acid is required to properly prepare surfaces contaminated with silica from sand molds or welding rods.

Scale removal must be complete to obtain high quality zinc coatings. Scale, if not removed, will result in uncoated or roughly coated areas. Although scale removal is mandatory, overpickling will yield abnormally heavy zinc coating and occasionally poor adhesion of the galvanized coating.

Small articles are pickled in baskets or crates of wood, monel metal or other suitable acid-resistant material. Sheets are held in acid-resisting frames and are

often agitated mechanically, while pipes are raised and lowered at an angle inclined to the horizontal to ensure adequate movement of the acid through them.

B. WASHING

Except when the pickling acid (hydrochloric acid) serves also as a flux, an undesirable practice, the work must be thoroughly washed after pickling. The first rinse is best done in warm water because the iron salts dissolve more easily. But a warm rinse must be kept slightly acid (pH 3-4) to prevent hydrolysis of the ferric salts formed by atmospheric oxidation; in the absence of acid, ferric hydroxide would be deposited on the steel. The warm, slightly acid rinse needs to be followed by a second dip in cold running water to complete the removal of iron salts. It is suggested that only cold water should be used for rinsing, and that the quantity should be kept small, again to reduce hydrolysis.

C. BLAST CLEANING

Grit, shot or sand blasting are not commonly employed as methods of surface preparation for hot dip galvanizing. Acid pickling is less expensive and more practical; where it can be employed, it is generally used. In the past, blasting was confined mainly to cleaning of ferrous castings or heavily rusted articles. It is especially applicable to ferrous castings, since their complex and irregular surfaces require excessive pickling time which can result in uneven, heavy galvanized coatings. Also, castings do not respond to the conventional chemical cleaning process employed by most galvanizers, primarily because of burned-on sand from the casting operation.

Blast cleaning precludes hydrogen embrittlement, a condition that can result from acid pickling. Its peening action has a tendency to minimize or eliminate stresses that might be induced by severe cold work during fabrication. Unlike acid pickling, it removes only surface contamination and does not attack the steel.

Very thick galvanized coatings can be obtained by deliberately roughing the surface of work by blast cleaning. Also, it eliminates some problems of disposing of acid waste.

D. FLUXING

After thorough washing, the work is dipped in a flux solution. Fluxing is mandatory to dissolve any oxide film that has formed on the steel after pickling and galvanizing, and to absorb any remaining impurities on the metal surface, all to ensure that clean steel or iron contacts the molten zinc. It also acts as a preheating and drying medium to permit wet material to be immersed into the galvanizing bath with a minimum of spattering. Reducing oxidation of the molten zinc surface greatly lowers zinc ash formation, minimizing bath degradation. Proper fluxing reduces the cost of galvanizing as well as heat loss. The flux, of course, facilitates wetting of the steel by the

molten zinc. Spowers, a notable galvanizing authority, recommends a flux solution of zinc ammonium chloride of composition $\text{ZnCl}_2 \cdot 3\text{NH}_4\text{Cl}$. Proprietary fluxes consist of zinc ammonium chloride with the addition of a wetting agent.

The solutions may be made up from the ammonium and zinc salts in correct proportion and wetting agents. Flux baths contain 20-30% by weight of the salts, and are normally operated at temperatures around 50°F (10°C), though they may be left cold.

Pickling leaves a film of dissolved iron salts on the surface of the iron or steel. Whether or not these are washed off the surface depends on which galvanizing techniques is used.

There are a number of different processes. These include the so-called Old Dry Process, in which the salts from a hydrochloric acid pickle are dried on the work and act as a flux, the Wet Process, where work is usually taken directly from the rising tank to the galvanizing bath that has a blanket of molten flux floating on the zinc, and the Dry Process, in which the pickled work is rinsed, immersed in a tank of flux and then dried. It coats the works with a thin layer of salt that protects the steel from air until it is galvanized. Generally this is required for complex parts. Pickling plus flux assures the fabricator that the entire surface of the work is covered with a fresh layer of flux leading to a better and more consistent finish. Work that has been pickled and dried should be galvanized without delay as the flux coating picks up moisture from the air and also tends to oxidize.

The fresher and more fluid the flux, the greater is its effectiveness and the more readily is it dispelled from the surface of the steel. Because of local chilling action before it enters the bath, the steel invariably carries with it some salt. Time must be allowed for the steel to reach the temperature of the bath and for the article to be held in the zinc bath until bubbling subsides and a preliminary inspection has shown a continuous coating of zinc has formed.

E. DRYING

After fluxing and draining, the work is dried in a low temperature oven. In the case of plates, spacers are sometimes used to improve drying. Heat can be supplied conveniently by passing the flue gases from the galvanizing bath through separate compartments forming the sides of the oven. Products of combustion containing sulphur must not enter the oven or come in contact with the work before dipping. The temperature of the oven should not exceed 300°F (149°C), since the flux may decompose if it is heated too strongly in drying. Iron salts can also be formed during drying by interaction between the flux and the metal surface, thus, the drying temperature and time should not exceed what is necessary to produce a degree of dryness that avoids splashing during the subsequent galvanizing dip. In an oven with a sufficiently high draught, rapid drying can be done at 212°F (100°C).

IV. DIPPING PROCEDURES

A. START-UP OF A NEW KETTLE

Slab zinc should be stacked vertically on edge in the pot to insure the best contact of the zinc slabs with the kettle walls. Additional rows of vertically stacked zinc should also be set on edge, from kettle walls toward the center. Some space should be left, usually near the center of the kettle, for thermal expansion and moisture release. This vacant space may be filled with water to insure fairly uniform heating of the entire contents of the kettle up to 212°F (100°C). To avoid overheating, the temperature should be raised very slowly until melting starts. As the zinc slabs melt and the pool of liquid zinc increases, the rate of heating may be increased gradually.

Once galvanized baths have been started up, they are usually maintained hot throughout their operating life because solidification of the zinc in the bath may cause warping and fracture of the bath walls. The design should allow the pot to be changed without difficulty when a new one is required.

For "wet" galvanizing, a fresh fluid blanket of flux should cover the end of the kettle where the material being dipped enters the zinc. Zinc ammonium chloride or ammonium chloride flux is used and maintained in an active condition by the frequent addition of small portions of fresh flux. Accumulation of heavy, pasty flux immediately above the molten zinc should be removed frequently. Items are withdrawn at the opposite end of the galvanizing kettle through a clean zinc surface. The work is immersed in the galvanizing bath with tongs or by the aid of suitable overhead tackle, or automatically. When large parts are being galvanized, they should be pre-heated before dipping. Parts should be immersed only until they reach the temperature of the bath. Flux patches can be avoided by withdrawing the finished work through a portion of the bath surface from which the flux and oxide coating has been skimmed back.

When immersed in the galvanizing bath, iron and steel are immediately wetted by the zinc and react to form iron-zinc layers. At normal galvanizing temperatures of 835-855°F (446-457°C), the rate of reaction is very rapid at first with a 'boiling-off' action. The main thickness of coating forms during this initial period. Subsequently, reaction slows down and the coating thickness does not increase greatly if the article is immersed in the bath for a much longer time. The normal period of immersion is a minute or two, but longer for work that is particularly heavy or requires draining from internal spaces.

Galvanizing proceeds until a "normal" coating develops. As the work is removed from the bath, some molten zinc is taken out on top of the alloy layers, the whole coating being metallurgically bonded to the base metal. Thus, the galvanized product has a coating made up of two major parts: the zinc-iron alloy layer, which is the portion that forms in the kettle and is influenced by the steel chemistry, immersion time, and galvanizing bath

temperature, and a covering of bath metal which gives the galvanized product its characteristic bright, shiny appearance.

If the coating consists of zinc-iron reaction products only, it has a matte gray finish. The free zinc portion of the coating varies in thickness and in the percentage of total coating weight, depending upon the speed of the withdrawal and the wiping practice, if any. There is no real line of demarcation between the steel and the zinc, but a gradual transition through a series of iron-zinc alloys that provides a metallurgical bond.

B. SIZE OF KETTLE

The capacity of the kettle should exceed what is necessary to accommodate the material being handled: the articles have to be heated to the temperature of the zinc during immersion, and unless the bath has sufficient heat content and ample heating surface areas, high rates of heating which shorten the life of the pot are required. A formula for estimating the permissible throughput of a galvanizing bath is that the weight of steel galvanized per hour should not exceed one-twentieth of the weight of zinc in the bath. If this formula is adhered to, rapid temperature fluctuations can be avoided.

The real limiting factor is, however, the temperature of the bath wall. Zinc melts at 787°F (419°C) and in the molten state attacks all ferrous metals, the rate of attack depending primarily upon the temperature and becoming rapid about 878°F (479°C). The galvanizing bath should, therefore, be run at the lowest possible temperature and hot spots must be avoided. Hot spots can be prevented if the bath is very uniformly heated, and temperature carefully controlled.

C. WITHDRAWAL RATE

Rate of withdrawal from the spelter also influences formation of spots. Steel strip of known spotting tendencies was galvanized under identical immersion time and temperature. Samples withdrawn rapidly revealed considerably less spotting because zinc did not drain so rapidly from the surface, resulting in a heavier coating which froze before it had opportunity to diffuse into the base metal to form a spot. Slow withdrawal was accompanied by deposition of 1.012 ounces of zinc per square foot with bad spotting compared to 1.258 ounces per square foot for rapid withdrawal with little spotting.

The rate of withdrawal controls the thickness of the coating between quite wide limits; the faster the rate, the heavier the coating. Thus, for control of thickness and elimination of waste, a multi-speed, power driven hoist is advisable for most large work. Five feet per minute has proved a convenient and satisfactory withdrawal rate for many types of larger work.

In addition to the speed of withdrawal, the free zinc portion of the coating will be influenced by the temperature of the bath. For a given withdrawal speed, the amount of free zinc that mechanically attaches itself to

the existing work will decrease as the temperature increases. This is due to a slight change in the fluidity of the zinc and also to the improved drainage that results from the higher temperature metal.

When the coating is completed, the submerged parts are moved to the flux-free area of the kettle, which should be cleaned of oxide with a skimmer. Then the work should be withdrawn with a slow, steady pull. The work is held over the bath for a short time and allowed to drain. Shaking the piece will facilitate draining. At this time, parts should be inspected for uncoated spots, which usually appear black. If such spots appear, they may be eliminated by dusting the spot area with a pinch of sal ammoniac (NH_4Cl) and reimmersing in the bath.

D. DROSSING

Galvanizing baths should be freed from dross at weekly or somewhat longer intervals. The bath should be allowed to stand for three hours before drossing to allow the dross to settle, at a temperature sufficiently low to minimize the quantity of iron actually dissolved in the zinc.

E. TUBE GALVANIZING

Unfabricated tubes generally used for electrical conduits are usually galvanized by the manufacturer who has a galvanizing plant designed for semi-automatic handling. The protective coating forms on the inside as well as on the outside of the tube. Normal practice is to smooth and then to blow steam under pressure through the inside of the tube to remove molten zinc and leave a smooth bore. Consequently, the coatings on unfabricated tube are usually thinner than those on tubular fabrications.

F. PIPE ASSEMBLIES

While the surface must be thoroughly cleaned to produce the galvanized coating, pipe commonly presents two special cleaning problems. The "mill coating" (varnish, lacquer and similar materials) applied by the manufacturer is normally removable at the galvanizing plant at extra cost. However, because some formulations, both foreign and domestic, are extremely difficult to remove with common cleaning solutions, blasting may be required. Removing this mill coat at the galvanizing plant can be avoided by ordering uncoated pipe from the supplier. Welding mill-coated pipe burns and carbonizes the varnish in the surrounding heated areas. This "soot" requires blasting or other mechanical removal. The burned coating could be removed when blasting to remove weld flux, but if welding has been done with an uncoated rod, any blasting or other hand cleaning is expensive and highly impractical. Most pipe is galvanized by the steel producer. Such pipe is used as electrical conduit.

G. CENTRIFUGING

Centrifuging or spinning is a common practice used to control the thickness of the free zinc portion of galvan-

ized coatings. It works effectively on small parts such as nuts and bolts that are galvanized in a wire mesh basket or perforated cage. After removal from the galvanizing bath, this basket is immediately placed in a low speed centrifuge to get rid of excess zinc on screw threads and other areas and to prevent the articles from sticking together. High centrifuging speeds are not required. Small thick parts, castings or forgings, are usually quenched in water to make the coating set quickly.

Slow delivery to the centrifuge spinner or low to medium spin speeds require heating the spinner. Labor savings are possible using a spinner as it eliminates hand wiping or hand shaking. A spinner generally assures more consistent coating thickness and conserves zinc. Limited production, high production and automatic centrifuges are available.

H. DOUBLE-DIP PROCESS MISUNDERSTOOD

Double-dipping in the galvanizing trade is not dipping a product in the molten bath, withdrawing and reimmersing it in the bath. Double-dipping means immersing one-half of a structural in molten zinc, withdrawing, and then dipping the other half in the bath. Thus, an item 85-90 feet or even larger can be galvanized. Should the length be such that the center portion would not be galvanized, that area can be zinc coated by thermal spraying.

I. EMBRITTLEMENT

To prevent embrittlement during galvanizing, all malleable castings should be heated to 1,200 to 1,500°F (649-816°C) and water quenched. The holding time and the temperature of the quench water are not important.

J. APPEARANCE OF ZINC COATINGS

Varying with different types of steel, the rate of alloying is determined by composition of the base material.

With some compositions of the steel base, the rapid reaction between zinc and steel produces coatings consisting entirely of (or almost entirely) zinc-iron compound. These may be gray, with matte surface, and are usually thicker with ordinary steel compositions. This condition may be planned, as with pole line hardware using higher silicon steels to secure unusually heavy coatings, or it may be the unexpected result of the use of certain low-alloy, high strength steels for their increased elastic strength. Where undesirable appearance or reduced adhesion of the coating accompanies such excessive growth, the galvanizer may be able to modify his operations to relieve, in part, this condition. Some of these fast growing coatings consist of an intimate mixture of zinc-iron compound with zinc of the composition of the bath, and as such are two phase materials with potential difference of several tenths of a volt between the constituents. This may adversely affect corrosion resistance in wet exposure, and is usually accompanied by reduced adhesion of the coating. Such structures are termed diffuse alloy.