Disclaimer

GALVAINIZATION[1]

1.0 HOT DIPPED GALVANIZING

Hot-dip galvanizing after fabrication is one of the most widely used methods of corrosion protection. The final step in the hot-dip galvanizing process is inspection to ensure compliance with specifications. Interpretation of inspection results must be made with a clear understanding of the causes of various coating conditions and their affects on the ultimate objective of providing corrosion protection.

1.01 GENERAL DESCRIPTION[2]

The purpose of hot-dip galvanizing is to protect the steel from corrosion. The length of time this protection can reasonably be expected to last before minimal maintenance is required is called its “service life.” The Galvanizing service life is directly related to the thickness of the protective zinc coating: the thicker the coating the longer the service life (Figure 1). Thus, coating thickness is the single most important inspection check to determine the quality of a galvanized coating.

Coating thickness, however, is only one item of inspection. Coating uniformity, adherence and appearance also are evaluated. Additionally, embrittlement and other defects arising from fabrication and design are inspection concerns.

While minimum standards must be satisfied in all these areas, their relative importance varies according to the end-use of the finished product. For example, the end-use requirement for galvanized structural steel in an isolated area differs from that for a thin-gauge product used in a decorative application. Understanding the individual requirements of the product and the capability of the hot-dip galvanizing process is essential for proper inspection.

Inspection of the galvanized product is most effectively and efficiently conducted at the galvanizer’s plant. Here, questions and concerns can be raised and dealt with quickly and efficiently - speeding up the inspection process and resulting in a time savings that is an asset to the overall project.

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[1] Adapted from American Galvanizers Association Guide and other internet based vendor sites then revised for CCPW application

[2] Photo from www.nkcoatings.com

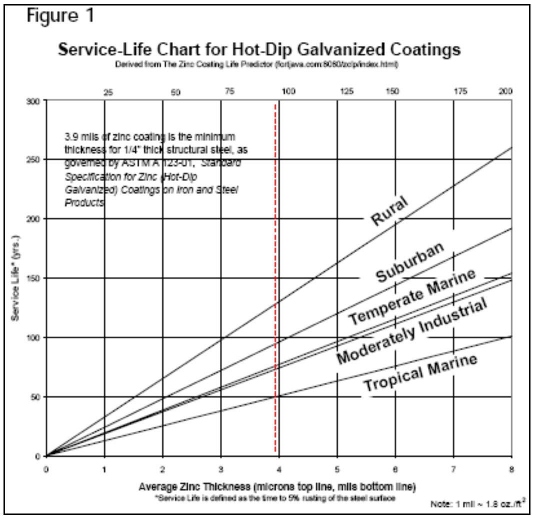
Figure 1

Service-Life Chart for Hot-Dip Galvanized Coatings

Derived from The Zinc Coating Life Predictor (fortjava.com:8080/zclp/index.html)

*Service Life is defined as the time to 5% rusting of the steel surface

Note: 1 mil ~ 1.8 oz./ft^2

Figure 1- Service Life

1.02 TESTING

To properly evaluate hot-dip galvanized coatings, it is essential that selected specimens be representative of the inspection lot. The sampling and testing method shall be that as described in the Regional Transportation Commission of Southern Nevada (RTCSN).

The inspection lot is a collection of galvanized articles of the same kind that:

- Were galvanized at approximately the same time,
- Were galvanized in the same manner,
- Were galvanized in the same galvanizing kettle, and
- Are being submitted for acceptance as a group.

1.03 THICKNESS AND UNIFORMITY

The thickness of the galvanized coating is the primary factor in determining its service life. The thicker the coating, the longer the corrosion protection lasts.

The factors affecting coating thickness are a combination of several variables, some of which the galvanizer can control and some of which are beyond the galvanizer's control. The chemical composition of the steel plays the biggest role in determining the thickness of a galvanized coating. During the galvanizing process, a complex metallurgical reaction takes place creating a series of zinc-iron alloy layers. These layers contain varying amounts of zinc and iron, depending on the proximity to the base steel. The layers closest to the base steel contain more iron and less zinc than the layers farther away.

depicts the zinc-iron alloy layers as seen in a typical after-fabrication, hot-dip galvanized coating. Normally, the alloy-layer growth tapers off as the steel reaches the bath temperature. When the item is removed from the bath, a free zinc layer forms which gives the galvanized coating its familiar shiny, silver appearance.

However, certain steel compositions tend to accelerate the growth of the zinc-iron alloy layers so that the galvanized coating has a matte finish with little or no pure zinc outer layer as illustrated in Figure 3*.* Steel containing carbon in excess of 0.25 percent, phosphorus in excess of 0.04 percent, or manganese in excess of about 1.35 percent have been shown to create these heavy coatings. This coating also tends to be thicker than traditional bright, shiny galvanized coatings. The galvanizer has no control over this reactive silicon-killed steel condition, which is illustrated in Figure 4*.* These thicker coatings frequently have a dark gray, matte appearance due to the lack of a free zinc layer capping the alloy layers. A silicon level greater than 0.30 percent is particularly influential in producing heavier zinc-iron alloy layer coatings.

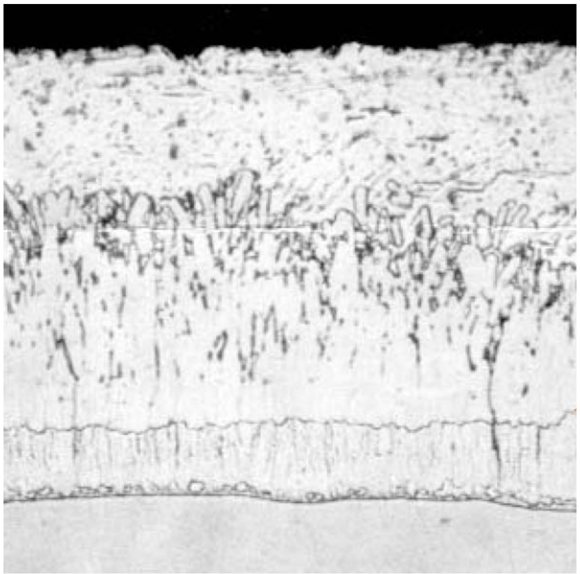

Figure 2- Typical zinc/alloy layer

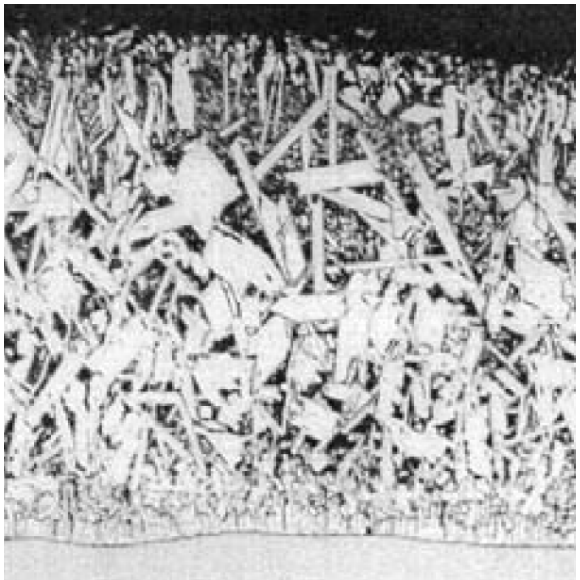

Figure 3 – Irregular zinc/iron alloy layers

The surface condition of the steel also influences the thickness and smoothness of the galvanized coating. Non-reactive steels that have been abrasively cleaned prior to galvanizing can have coating thicknesses 50 to 100 percent greater than steels only chemically cleaned.

In reactive steels, the opposite effect can be seen with steels that have been abrasively cleaned. The coating thickness on these steels is generally lower than expected. The appearance, however, remains a matte gray with occasional roughness.

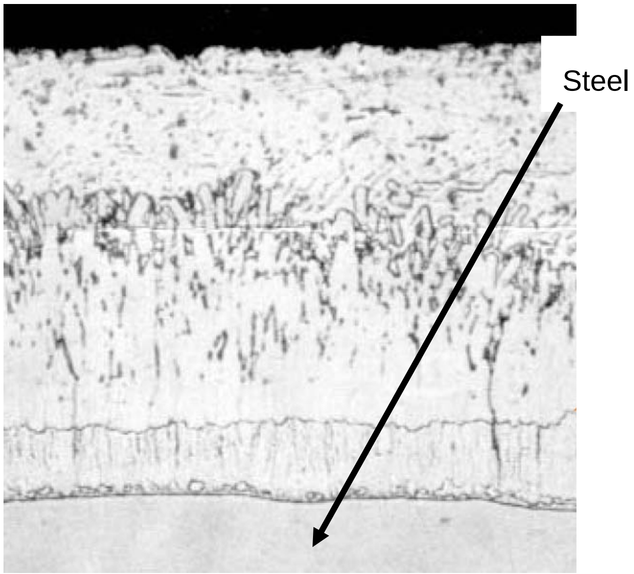

Figure 2- Typical zinc/alloy layer

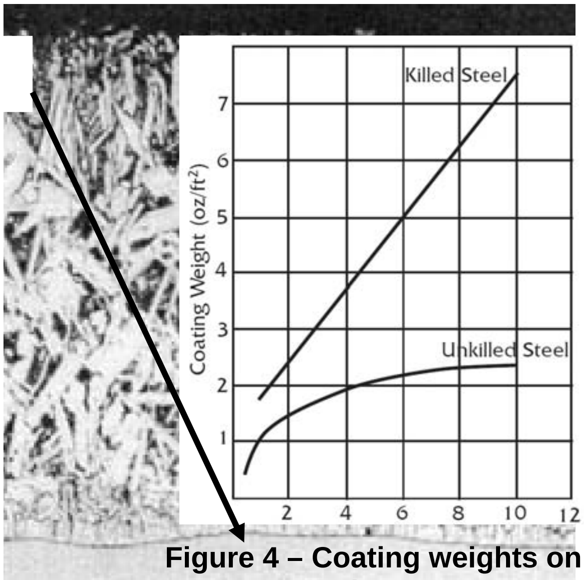

Figure 4 – Coating weights on reactive steel

Figure 3 – Irregular zinc/iron alloy layers

The mass, the shape and the amount of cold working of the piece also affect coating thickness and uniformity. When a fabricated article has both heavy and light sections, differences in coating thickness between the sections may result. Since immersion time varies according to the relationship of the surface area of an item to its weight, the galvanizer has little control over this situation. Variables the galvanizer can control are bath temperature and withdrawal rate. Because formation of the zinc-iron alloy layers is a diffusion process, higher bath temperatures generally produce heavier alloy layers. Like many diffusion processes, the reaction proceeds rapidly at first and slows down as the alloy layers become thicker.

The thickness of the outer zinc layer largely depends on the rate of withdrawal from the zinc bath and the drain-off of excess zinc. A faster rate of withdrawal causes an article to carry out more zinc. This results in a heavier coating.

When hot-dip galvanizing fabricated articles, local differences in the drain-off, because of the shape of the article and the angle at which different surfaces leave the bath, will generally result in some variation in coating thickness. Specifications for hot-dip galvanizing recognize that variations in coating thickness are inherent in the process. The minimum thickness of the zinc coating is always specified as an average thickness of specimens tested and a minimum weight for any individual specimen.

When measurements are made to determine the thickness distribution of a large galvanized article, a sufficient number of readings, not less than five and preferably 10, should be taken at each end and in the middle of the article being examined. The requirements are specified in the RTCSN. Usually, the end of an article that leaves the bath last will carry a thicker coating.

This is particularly so towards the edge, where at the time of drainage the last few drops of the zinc tend to collect as a result of surface tension.

Figure 5 – Appearance of reactive and non-reactive steels after galvanizing

1.04 THICKNESS MEASURING

There are several methods to determine the weight or thickness of the zinc coating on a galvanized article. The methods of testing chosen will most likely are dictated by the size, shape and number of pieces to be tested. Some test methods are non-destructive; other methods are destructive, since they require the removal of the zinc coating or sectioning of the coated material.

1.04.01 Magnetic Thickness Measurements

The thickness of the coating may be determined by magnetic thickness gauge measurements in accordance with ASTM E 376. Usually a minimum of five readings shall be taken for each specimen. The average of the thickness values taken for each specimen shall be not less than one coating thickness grade lower than the value listed in the appropriate specification. If these coating thickness measurements are made on an article with different thicknesses of steel, the values in the appropriate specification apply to each thickness of steel on the article.

1.04.02 Stripping and Weighing Method

The average weight of a zinc coating may be determined by stripping an entire piece in accordance with ASTM A 90; alternatively, the average coating weight may be determined by stripping test pieces from the representative part, each with a measurable area of coated surface as specified. The weight of coating obtained at each location shall not be less than the value listed in the appropriate specification.

The average weight of coating for the item shall be the average of the values obtained in the three locations and shall not be less than the value listed in the appropriate specification. If these coating weight measurements are made on an article with different thicknesses of steel, then the values in the appropriate specification shall apply to each thickness of steel on the article.

1.04.03 Weighing Before and After Galvanizing

The average weight of the zinc coating may be determined by weighing the articles before and after galvanizing, subtracting the first weight from the second, and dividing the result by the determined surface area. The first weight shall be determined after pickling and drying, the second after cooling to ambient temperature. The weighing before and after galvanizing method does not take into account the weight of iron reacted from the article that is incorporated into the coating. It may thus underestimate coating weight by as much as 10 percent. Steel reactivity will affect the extent of underestimation.

1.04.04 Microscopy

The thickness of the coating may be determined by cross sectional and optical measurement in accordance with ASTM B 487. This method requires the use of an optical microscope with a calibrated eyepiece.

The thickness determined by this method is a point value. No less than five such measurements are made at locations on the test article and are as widely dispersed as practical so as to be representative of the whole surface of the test article. The average of no less than five such measurements is the specimen coating thickness. The microscopy method is a destructive test and may be appropriate for smaller articles, but would not be practical for larger articles.

1.05 THICKNESS TESTING GAUGES

There are a number of simple magnetic gauges that can be used to give a quick and convenient measurement of the zinc coating thickness. These magnetic gauges give reliable thickness readings provided they are properly calibrated against non-magnetic coatings of known thickness and the manufacturer’s instructions are observed.

The most commonly used magnetic gauges provide readings based on magnetic attraction between the gauge and the base steel. Two instruments of this type are magnetic balance gauges and pull-off gauges.

1.05.01 Magnetic Balance Gauges

These gauges are based upon the variation in the force of attraction between two ferromagnetic bodies as a function of the distance between them. Coating thickness measurements are taken by placing the rubber magnet housing on the coating’s surface with the gauge held parallel to the surface. The scale ring of the gauge is turned forward to bring the magnetic tip into contact with and perpendicular to the coating surface. The scale ring is slowly turned by hand until the spring tension on the magnet just overcomes the attractive force between the magnet and substrate of the galvanized item. At this point, the magnetic tip breaks loose from the coated surface and the inspector stops rotating the scale ring. The break in contact is shown by an indicator and can also be heard and felt. Since the strength of the magnetic attraction relates to the thickness of the coating between the magnet and substrate, the spring tension required to equal

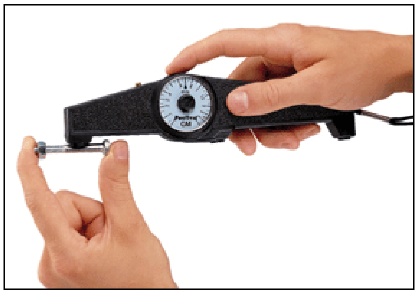

Figure 6 – Magnetic Balance[3]

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[3] www.defelsko.com

this force is measurable. The scale ring has been calibrated in units of coating thickness (mils or microns).

This type of gauge has the advantage of being able to measure coating thickness in any position, without recalibration and without interference from gravity, because the pivot arm is balanced. The typical accuracy of the magnetic balance type gauges is plus or minus 10 percent of the indicated readings.

1.05.02 Pull-off Magnetic Gauges

These gauges are also based on magnetic attraction to the underlying steel. They are primarily intended for use in the field as a rough guide to determine if the coating is within the thickness specification.

To take a measurement with a pull-off gauge, the magnet end of the gauge is placed vertically on the surface of the coating. The gauge is drawn away, thus extending a spring. The reading is taken on the scale at the lowest point where the magnet breaks from the coated surface. Before each use, the hemispherically tipped magnet should be carefully inspected for dirt, small steel particles, tacky paint film and tip-wear. Wear on the magnet will alter the calibration of the gauge. The typical accuracy of a pull-off gauge is plus or minus 15 percent, provided the gauge is used within a true vertical plane. If the gauge is used in a horizontal or overhead position, more error will be inherent.

Figure 7 – Pull-off gauge

Besides accuracy limitations, the pull-off type gauge has other disadvantages: the inspector’s eye must record the coating thickness as the magnet breaks away from the coating, and erroneous readings will result if the magnet is allowed to slide over the coating prior to breakaway.

1.05.03 Electronic Thickness Gauge.

This uses a temperature-compensated magnetic transducer to measure the magnetic flux changes that occur when the probe (a magnet) is separated from the coated Pull-off gauge ferrous substrate. The output signal from the probe is proportional to the reduced amplitude and displayed to show coating thickness. These battery-powered instruments have typical accuracies of plus or minus 5 percent and have the advantage of not requiring recalibration with probe orientation.

To avoid possible sources of error in the use of magnetic instruments, certain precautions should be taken:

- Follow the manufacturer’s instructions. The instrument should be frequently recalibrated against non-magnetic film standards of known thickness.
- Never expose any magnetic gauge to strong AC or DC fields because the magnet will change, affecting the calibration of the gauge.

- The base steel should be backed up with similar material if thinner than the critical thickness for the magnetic gauge, or the instrument should be recalibrated on a substrate of similar thickness.
- Readings should not be taken near an edge, hole or inside corner.
- Readings should not be taken on curved surfaces without proper recalibration.
- The test surface should be free from dirt, grease, oxides and corrosion products.
- Test points should be chosen to avoid obvious peaks or irregularities in the coating.
- A sufficient number of readings should be taken to obtain a true average.

Figure 8 – Electronic gauge[4]

ASTM E 376 and CSA G 164-M provide guidance for use of these instruments and factors affecting their accuracy.

1.05.04 Metallographic Examination

Where the galvanized coating microstructure and thickness are of interest, microscopic examination is a reliable tool. This very accurate method uses a small polished and etched cross-section specimen of the galvanized work to provide information about the relative thicknesses of the alloy and the free zinc layers that comprise the galvanized coating.

Important disadvantages of this technique are that specimens are required to be cut from the galvanized article, coating thickness provided only applies to a very limited area, it does not indicate the variation in coating distribution on the article, and it is necessary to examine a number of specimens to determine the average coating thickness on the galvanized article.

1.06 COATING ADHERENCE

The hot-dip galvanized coating should be sufficiently adherence to withstand handling consistent with the nature and the thickness of the coating in normal use of the article, without peeling or flaking. Bending or forming, other than straightening after hot-dip galvanizing, are not considered to be normal handling.

When certain grades of steels or very heavy steel sections are galvanized, thicker-than-normal coatings may occur. The galvanizer has little control over this because these thicker coatings are a function of the steel's chemical composition or the longer immersion time required for massive items. Heavy galvanized coatings are more brittle than thin coatings; consequently, application and interpretation of the standard adherence test must take this

Figure 9 - Flaking

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[4] www.defelsko.com

into account.

1.06.01 Testing for Adherence

One method is recognized for testing galvanized coatings for adhesion: the stout knife test. While it is not a true measure of the adhesive strength of the metallurgical bonding of the galvanized coating to the base steel, it serves as an indicator of the adherence properties of the coating.

This simple but effective test is conducted by prying the galvanized coating with the tip of a sharp knife. Considerable pressure is exerted in a manner tending to remove a portion of the galvanized coating. If the coating flakes off or delaminates in advance of the knife point it is non-adherent. If the coating separates at the point it is adherent.

Removal of small particles of coating is not considered failure. This test is detailed in ASTM A 123 and A 153, and in CSA G 164-M.

Figure 10 – Test for Adherence

1.06.02 Testing for Chromate Finishes

In some cases, post-galvanizing chromate treatments are specified for the prevention of wet storage stain. The presence of chromate film on the surface of the galvanized coating is usually visible as a light yellow tint on the surface.

ASTM B 201 describes a test method for determining the presence of chromate coatings.

1.06.03 Embrittlement Testing

Embrittlement of galvanized steel is very rare and usually is the result of using high-strength steel. The design of the product and selection of the proper steel for its suitability to be fabricated and galvanized without embrittlement are the responsibility of the designer and fabricator. Good communication among the designer, fabricator and galvanizer can reduce the likelihood of encountering embrittlement.

As noted in the AGA publication “The Design of Products to be Hot-Dip Galvanized After Fabrication”, the hot-dip galvanizing process produces no significant changes in the mechanical properties of the structural steel commonly galvanized throughout the world.

In the rare case when embrittlement testing is specified, ASTM A 143 and CSA G 164-M designate the appropriate test method to be used.

1.07 APPEARANCE

The ability of a galvanized coating to meet its primary objective of providing corrosion protection should be the chief criteria in evaluating its overall appearance and in determining its suitability. The basic finish requirements of the galvanized coating are that it be relatively smooth, continuous and free from gross surface imperfections. Smoothness is an ambiguous term; the product’s end use must be the determining factor in setting tolerances for smoothness. The galvanized coating should be continuous to provide optimum corrosion protection.

Figure 11 – Chain marks

Handling techniques for galvanizing may require the use of chain slings, wire or other holding devices to lower material into the galvanizing kettle, if suitable lifting features are not available on the item. Chains, wires (Figure 11) and special jigs used to handle the items may leave a mark on the galvanized item. These marks are not necessarily detrimental to the coating, nor are they cause for rejection unless they have exposed the base metal. If considered necessary, these areas can be easily touched up using the procedures described in ASTM A 780. Differences in the luster and color of galvanized coatings do not significantly affect corrosion resistance. The presence or absence of spangle has no affect on coating performance. The well-known spangled effect found on galvanized products is a crystallization process that is dependent upon the zinc bath chemistry, the rate of cooling, the method of pickling, the steel chemistry, and the thickness of the coating. Dull gray or patchy matte gray galvanized coatings give a service life equal to bright or spangled coatings since the service life depends on the zinc coating thickness. Variations in coating appearance or finish are important only to the extent that they will affect corrosion performance or the intended use of the article. The primary function of the galvanized coating is corrosion protection.

1.08 BARE SPOTS

Because of zinc's sacrificial action, small localized flaws are somewhat self-healing and have little effect on the service life of the coating. Where considered necessary, such spots may be repaired using one of the repair methods indicated in ASTM A 780. Any un-repairable, uncoated areas should be rejected. Some of the causes of bare spots on galvanized steel are described below.

1.08.01 Inadequate Surface Preparation

Thorough preparation of the steel is the foundation of good galvanizing. Remnants of paint, oil, grease, scale, or rust are the most common causes of uncoated spots. Such residues are not wetted by the molten zinc and, therefore, prevent normal coating reactions.

Figure 12 – Inadequate preparation

1.08.02 Welding Slag

Slag deposits from welding (Figure 13) are resistant to normal pickling acids and must be completely removed before the work enters the galvanizing process. Grinding or grit-/sand-blasting are strongly recommended for this purpose and are more effective than hand-chipping and wire-brushing. The removal of welding slag is the fabricator's responsibility, unless other arrangements have been made.

1.08.03 Rolling Defects in Steel

These defects may be broadly classified as discontinuities in the steel that have been closed and elongated during rolling but have not bonded. Examples are laminations, laps and folds, and nonmetallic impurities rolled into metal surfaces. Defects of this type are sometimes detected before or after pickling, but may not become apparent until opened by the heat of the galvanizing bath. Minor flaws in the steel may be removed by local grinding, but little reclamation is possible where the steel surface is seriously defective.

Figure 13 - Slag

1.08.04 Sand Embedded in Castings

This condition (Figure 14) can result in localized bare areas. Since sand and other surface inclusions are not removed by conventional acid pickling, abrasive cleaning is generally required to provide a clean surface for galvanizing castings. This abrasive cleaning is typically done at the foundry before the parts are sent to the galvanizer.

Figure 14 – Improper cleaning

1.08.05 Oxidized Steel

If the time between fluxing and galvanizing is prolonged or the drying temperature is too high, the corrosion protection afforded the cleaned steel by a pre-flux may be lost. This is indicated by a rusty appearance on the un-galvanized article. The appearance of the galvanized coating is similar, in extreme cases, to that resulting from under-preparation.

1.08.06 Excess Aluminum

A condition sometimes referred to as “black spots” may occur if the aluminum content of a galvanizing bath on which a flux blanket is used becomes too high. Minimal trouble should be experienced if the aluminum content of the bath is maintained below approximately 0.01 percent, which is well above the range needed to brighten the coating.

1.08.07 Articles in Contact

The zinc in the galvanizing bath should have free access to all parts of the surface. Articles entering and passing through the galvanizing bath should not be in tight contact with each other.

1.09 GENERAL ROUGHNESS

A rough coating (Figure 15) is usually caused by excessive growth or unevenness of the alloy layers. This condition is attributable to the steel’s chemical composition or its original surface condition. Since the irregularity of the alloy layers tends to increase with their thickness, heavy coatings are usually rougher than lighter ones. Where a heavy coating results, some degree of roughness may be unavoidable. The importance attached to surface

Figure 15 - Rough

roughness varies with the nature of the product. For certain articles, such as tube and pipe, which are sold largely on the basis of visual appeal, a smooth appearance may be essential. Also, where one surface is required to mate with another, such as pole line insulator caps, a rough coating may be detrimental to the intended product function or assembly. Such cases are the exception, however. In most instances, the degree of roughness is not critical.

Provided it is within reason and adhesion is good, the material should be accepted.

Figure 16 – Dross protrusions

1.10 DROSS PROTRUSIONS

Dross (Figure 16) is the zinc-iron alloy that settles to the bottom of the zinc bath. Dross inclusions in the coating resulting from agitation of the dross layer can produce surface protrusions. Because dross has a corrosion rate similar to zinc's, it has little effect on the normal life of the coating and its presence in the form of finely dispersed pimples is not seriously objectionable.

However, extensive dross inclusions are normally grounds for rejection since they tend to make the coating more susceptible to mechanical damage and may cause premature discoloration of the surface upon weathering.

1.11 LUMPINESS AND RUNS

Figure 17 – Lumpiness & Runs

The coating's surface uniformity is controlled primarily by the drainage of the zinc as the work leaves the galvanizing bath. A lumpy and uneven (Figure 17) coating will result when the rate of withdrawal is too fast or when the bath temperature is too low to allow molten zinc to drain back into the bath as the item is removed. Excessive zinc may also occur because of delayed drainage from bolt holes, folds, seams and other pockets where zinc collects, and is a direct consequence of product design. The additional zinc, though wasteful, is clearly not detrimental except in those instances where a smooth finish is essential. A similar effect may result when articles are withdrawn in contact with each other.

1.12 FLUX INCLUSIONS

Flux inclusions (Figure 18) occur when the wet galvanizing process is employed. In the wet process, a layer of zinc-ammonium chloride is floated on top of the molten zinc. The material to be galvanized passes through the flux immediately prior to immersion in the zinc bath. The flux is carefully pushed to the side in order for the item to be removed. Flux inclusions may originate in several ways. Stale kettle flux, for example, tends to adhere to the steel instead of separating cleanly from the surface as the work is dipped. This may occur even with active flux if residual grease, scale, or other surface contaminants, which resist the cleansing action of the flux blanket, are present.

In both instances, the inclusions are often associated with bare spots in the coating. Resulting black spots formed by the included flux particles are distinguishable from dirt smuts, splash marks and other less harmful types of surface contamination by their characteristic tendency to pick up moisture.

Flux deposits picked up from the bath's surface as the work is withdrawn do not warrant rejection if the underlying coating is sound and the flux is removed.

Figure 18 - Flux

1.13 ASH INCLUSIONS

Zinc ash (Figure 19) is the oxide film that develops on the surface of the galvanizing bath. As with flux, ash may be burnt on the steel during dipping or picked up from the top of the bath during withdrawal. Ash inclusions can occur on work that is cumbersome and requires slow withdrawal from the bath. This ash has no adverse effect on service life.

Zinc ash that is not detrimental to the appearance of the finished product or that does not interfere with the product's function is not cause for rejection. Gross oxide lumps due to improper skimming of the exit surface of the bath can reduce the effective thickness of the coating and are unacceptable.

Figure 19 - Ash

1.14 MATTE GRAY OR MOTTLED COATING

This condition (Figure 20 and Figure 21) develops during cooling and is caused by lack of a free zinc layer on the coating surface. It usually appears as a localized dull patch or spider web-like area on an otherwise normal surface; although in extreme cases it may extend over the entire surface of the steel. It is not cause for rejection unless specifically stated and agreed to by the galvanizer and the fabricator.

A matte gray coating is most frequently found on heavy sections that cool slowly, with certain types of steel, such as those with relatively high silicon or phosphorus content, or severely cold-worked steel, all of which may exhibit abnormally rapid alloy growth.

Where the condition is caused by the nature of the base steel, the galvanizer has no control over its occurrence. Galvanizers generally do not have prior knowledge of steel's chemical composition. A lower galvanizing temperature and shorter immersion time followed (if the type of product is suitable) by rapid quenching in water to arrest the alloy growth may be successful in marginal cases. However, such measures are not always effective and matte areas in the coating may be unavoidable.

Figure 20 – Matte or mottled

Due to the steel's chemical nature, these coatings are often thicker than the bright galvanized coatings and provide service life in proportion to the increased thickness. After exposure, these coatings may take on a light yellow to brown dusty appearance as the alloy layers weather. The appearance of this light residue colored by the iron content of the corrosion-resistant layers should not be considered a sign of failure.

1.15 RUST STAINS

These are caused by seepage from joints and seams after galvanizing or by material being stored under or in contact with rusty steel. Rust stains of this type are superficial and should not be confused with failure of the underlying coating. Rust stains caused by seepage from an assembly can indicate a need for a modification of the design. Surface rust stains are not cause for rejection of the galvanized product.

Figure 21 – Mottled spider-web effect

1.16 WET STORAGE STAIN

Wet storage stain is the buildup of zinc oxide and zinc hydroxides on the galvanized surface. As the name implies, wet storage stain occurs when the steel is exposed to a humid or moist environment without access to freely circulating air. Tightly stacked or nested galvanized items are particularly vulnerable to wet storage stain, especially if they are stored as unopened bundles for more than a few weeks.

Although in extreme cases the protective value of the coating may be impaired, attack is often superficial, despite the relative bulkiness of the zinc hydroxide. Where the surface staining is light and smooth without growth of the zinc oxide layer, as judged by lightly rubbing fingertips across the surface, the staining will gradually disappear and blend in with the surrounding zinc surface as a result of normal weathering in service. If the affected area is not fully exposed in service or is subject to a humid environment, wet storage stain must be removed, even if it is superficial, to allow formation of the basic zinc carbonate film, which normally contributes to the corrosion resistance of the galvanized coating.

Medium to heavy buildup of white corrosion product must be removed; otherwise, the essential protective film of basic zinc carbonates cannot form in affected area. Light deposits can be removed by brushing with a stiff bristle (not wire) brush. A coating thickness check should be performed on the affected areas to ensure that sufficient zinc coating remains after the removal of the wet storage stain.

In advanced stages of wet storage stain, the typical white or gray corrosion product may blacken. When this occurs, a significant amount of coating has been lost to corrosion and the service life is decreased. In extreme cases where heavy white deposits or red rust have formed as a result of prolonged storage under poor conditions, corrosion products must be removed and the damaged area repaired as detailed in ASTM A 780.

Figure 22 – Wet storage

Where the affected area is extensive; or when the wet storage stain would impair the use of the article for its intended service, re-galvanizing may be necessary. Unless present prior to shipment from the galvanizer, the development of wet storage stain is not cause for rejection.

The Contractor or Agency must exercise proper caution during transportation and storage to protect against wet storage stain. More information on wet storage stain can be found in the AGA Publication, “Wet Storage Stain”.

1.17 TOUCH-UP AND REPAIR

Occasionally during the hot-dip galvanizing process, bare spots or minor imperfections may occur that, if allowed to go un-repaired, will allow base metal corrosion. Sometimes after leaving the galvanizer’s plant, the coating is damaged during shipping or by welding during field erection. If the area of renovation is less than or equal to 1" (25mm) in its narrowest dimension and the total area is less than ½ of 1% of the surface area to be coated on the article, or 36 square inches (22,500 mm^2) per ton of piece weight, whichever is less, as allowed by ASTM A 123 Standard Specification for Zinc (Hot- Dip Galvanized) Coatings on Iron and Steel Products, the area may be repaired. If the area to be repaired exceeds those limits, the material must be re-galvanized.

As cited above, ASTM A 123 specifies the maximum area that can be repaired, but ASTM A 780-00 Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings addresses most other areas relevant to repair, including preparation, coating thickness, composition of repair material and measurement.

1.18 SURFACE PREPARATION

Regardless of what repair method is chosen, it is critical that whether wire brushing, grinding or mild blasting is used to prepare the area, the undamaged surrounding galvanized area is disturbed as little as possible. For newly galvanized steel, this may mean light wire brushing of the bare areas and only high-pressure water washing of the surrounding galvanized area.

For steel with long-term exposure, the bare or damaged areas may require sand blasting and only a mild caustic solution washing of the surrounding galvanized area.

1.18.01 Touch-up and Repair Methods

There are three accepted repair methods:

- Spraying the bare spot or damaged area with metallic zinc (metallizing),
- Application of paint containing zinc dust, and
- Coating the affected area with zinc solder.

1.19 METALLIZING (ZINC SPRAYING)

Metallizing is the melting of zinc powder or zinc wire in a flame or electric arc and projecting the molten zinc droplets by air or gas onto the surface to be coated. The zinc used is nominally 99.5% pure or better; the performance of wire versus powder is the same. Zinc-aluminum alloys can also be used. The application equipment may limit the concentration of aluminum.

1.19.01 Surface Preparation

According to ASTM A 780, the surface to be reconditioned shall be blast cleaned to SSPC-SP5/NACE No. 1 white metal and be free of oil, grease, weld flux residue, weld spatter and corrosion products. The blast cleaning must extend into the surrounding undamaged galvanized coating.

1.19.02 Application

Zinc spraying of the clean, dry surface by skilled workers should take place as soon as possible after preparation (within four hours) and prior to development of visible oxides. Spraying in horizontal overlapping lines yields a more uniform thickness than the cross-hatch technique. The zinc coating can be sealed with a thin coating of low viscosity polyurethane, epoxy-phenolic, epoxy, or vinyl resin. For details of the application sequence and procedures, consult ANSI/AWS C2.18-93.

Zinc spraying can be done either in the galvanizer’s plant or on the job site, but the transport of blasting and metal spraying equipment to the job site may make it uneconomical compared to other touch-up and repair methods.

If high humidity conditions exist during spraying, adhesion may be degraded.

1.19.03 Performance Characteristics

- **Coating Thickness:** The renovated area shall have a zinc coating thickness at least as thick as that specified in ASTM A 123/123M for the thickness grade for the appropriate material category. When blast cleaning is not available, wire brushing to expose bare steel is allowed. Thickness measurements should be taken with either a magnetic, electromagnetic or eddy current gauge.
- **Corrosion Resistance:** The usual criterion for determining the expected service life of zinc coatings is thickness: the thicker the coating, the longer the service life. This is acceptable when comparing coatings produced by the same process. However, because zinc sprays have a coating density less than hot-dip galvanized coatings, 1.9 mils of zinc spray are needed to provide the same amount of zinc as 1.7 mils of hot-dip galvanized coating. However, performance equivalency should not be inferred from this. Exposure conditions will determine true performance.
- **Coating Appearance:** The surface of the sprayed zinc coating on the repair area should be free of lumps, coarse areas and loose particles. Touchup and repair by metal spraying of a surface area surrounded by galvanized steel 18 months or older delivers an excellent color match. Some sprays with aluminum additives may also be a good match for newly galvanized, bright surfaces. Uniformity of the coating is largely dependent on the skill of the worker.
- **Adhesion:** Adhesion of the zinc spray to the base metal is by mechanical means and is dependent on the quality of surface preparation and cleaning. The higher the surface profile, the better the mechanical bond. Adhesion values of 1000 psi are typical. The temperature of the zinc upon impact with the base metal is not high enough to result in the alloy coating produced by hot-dipping.
- **Abrasion Resistance:** Abrasion resistance of zinc spray coatings is moderate compared to hot-dip galvanized surfaces.

- **Mechanical Properties:** The relatively low temperature of application has no adverse effect on the steel properties. Metallizing does improve some properties such as surface frictional coefficients and corrosion fatigue resistance.
- **High Temperature:** Sprayed zinc coatings are suitable for constant exposures up to approximately 390 F (200 C) and short-term exposure at higher temperatures.

1.20 ZINC RICH PAINT APPLICATION

Touch-up using zinc-rich paint is the spray or brush application of zinc and usually organic binder pre-mix to a clean, dry steel surface. Zinc dust paints must contain between 65% and 69% zinc by weight or greater than 92% metallic zinc in dry film. Paints containing zinc dust are classified as organic or inorganic, depending on the binder. Inorganic binders are particularly suitable for paints applied in touch-up applications around and over undamaged hot-dip galvanized areas.

1.20.01 <u>Surface Preparation</u>

According to ASTM A 780, the surface to be reconditioned shall be blast cleaned to SSPC-SP10/NACE No. 2 near white metal for immersion applications and SSPC-SP11 bare metal for less aggressive field conditions.

When blasting or power tool cleaning is not practical, hand tools may be used to clean areas to be reconditioned. In all cases, the surface must be dry, free of oil, grease, weld flux, preexisting paint and corrosion byproducts. The blast cleaning must extend into the surrounding undamaged galvanized coating.

1.20.02 <u>Application</u>

Paints containing zinc dust may be applied by brush or spray on a clean, dry surface by skilled workers. Painting should take place as soon as possible after preparation and prior to development of visible oxides. Spraying or brushing should be in a single application of multiple passes according to the paint manufacturer’s written instructions. Proper curing of the repaired area must occur before the article is returned to service. Zinc painting can be done in the galvanizer’s plant or on the job site and is the easiest repair method to apply because limited equipment is required. If high humidity and/or low temperature conditions exist during zinc painting, adhesion may be adversely affected.

1.20.03 <u>Performance Characteristics</u>

- **Coating Thickness:** The renovated area shall have a zinc coating thickness of 150% of that specified in ASTM A 123 for the thickness grade for the appropriate material category, but not more than 4 mils. Thickness measurements should be taken with either a magnetic, electromagnetic or eddy current gauge.
- **Corrosion Resistance:** Zinc-rich paints contain greater than 65% zinc in the dry film condition. High concentrations of zinc may provide cathodic protection in addition to barrier protection. Exposure conditions will determine true coating corrosion protection performance. Inorganic zinc-rich paints are more effective than organic in terms of delivering corrosion protection.
- **Coating Appearance:** The surface of the painted coating on the repair area should be free of lumps, coarse areas and loose particles. Touch-up and repair materials are formulated to deliver an excellent color match for both newly galvanized, bright finish

coatings and for matte gray, aged galvanized organic coatings do. This is a major advantage when the coating is applied to corners, edges and rough surfaces. However, when inorganic coatings are applied too thickly, mud-cracking may occur. Uniformity of the coating is largely dependent on the skill of the worker.

- **Adhesion:** Bond strength for paints containing zinc dust are on the order of a few hundred psi. Adhesion of the paint is largely a function of the cleanliness of the surface being repaired. There is no alloying when applying the paint; the bond is simply mechanical.
- **Abrasion Resistance:** Abrasion resistance of zinc-containing paint coatings is minimal compared to hot-dip galvanized surfaces. The limited ductility of paints containing zinc dust gives them poor impact resistance.
- **Mechanical Properties:** Some paints containing zinc dust provide enough friction resistance to allow them to be used on faying surfaces, delivering a coefficient of friction equal to or greater than the 0.5 values obtained by sandblasting steel surfaces.
- **High Temperature:** Inorganic coatings provide effective service at temperatures up to 700 F (370 C). Organic zinc-rich paints do not have the temperature resistance of inorganic zinc-rich paints and are limited to service temperatures of 200 to 300 F (90 to 150 C).

1.21 SOLDERING WITH ZINC-BASED ALLOYS

Soldering with zinc-based alloys is defined as applying zinc alloy in stick or powder form to the area to be repaired that has been preheated to approximately 600 F (315 C). Common solders used for repair include zinc-tin-lead, zinc-cadmium and zinc-tin-copper alloys.

1.21.01 Surface Preparation

According to ASTM A 780, the surface to be reconditioned shall be wire brushed, lightly ground or mild blast cleaned. All weld flux and spatter must be removed by mechanical methods (if wire brushing or light blasting is inadequate). The cleaned area should be preheated to 600 F (315 C) and at the same time wire brushed. Care should be exercised to not burn the surrounding galvanized coating.

1.21.02 Application

Solders are the most difficult of the three repair methods to apply. Caution must be taken while heating the bare spot to prevent oxidizing the exposed steel or damaging the surrounding galvanized coating. Solders are molten when applied, thus the resultant coatings are inherently thin. When the repair has been completed, remove the flux residue by rinsing with water or wiping with a damp cloth. Solders are typically not economically suited for touch-up of large areas because of the time involved in the process and because heating large areas to the same temperature are very difficult.

1.21.03 Performance Characteristics

- **Coating Thickness:** The renovated area shall have a zinc coating thickness at least as much as that specified in ASTM A 123 for the thickness grade for the appropriate material category, but not more than 4 mils. Thickness measurements should be taken with either a magnetic, electromagnetic or eddy-current gauge. Operator skill is particularly important to ensure consistent coating thickness across the repair area.

- **Corrosion Resistance:** Because of the relatively thin film of zinc that can be applied, long-term performance tests of zinc-based solders indicate they do not perform as well as metallizing or painting with zinc. Some cathodic and barrier protection is provided by solders.
- **Coating Appearance:** If solder material chemistry is chosen to match the galvanized coating, solders can deliver a very good color match.
- **Adhesion:** Because there is heating of the surface to be repaired to 600 F (315 C) there may be some alloy layer development between the base metal and the zinc. Thus, bond strength for solders is very good.
- **Abrasion Resistance:** Based on tests performed according to ASTM D 968 “Determination of Abrasion Resistance by the Falling Sand Method”, abrasion resistance of solders is minimal compared to hot-dip galvanized surfaces and even metallized surfaces.
- **Mechanical Properties:** Solder materials have little or no effect on the mechanical properties of the underlying steel. Solders in general have a smooth surface and very low coefficients of friction so they should not be used in the area of faying surfaces.
- **High Temperature:** Solders can withstand constant temperature exposure of approximately 550 F (285 C); the surrounding galvanized steel coating performs well only to constant temperature exposure of about 390 F (200 C).

1.22 REPAIR METHOD SELECTION CONSIDERATIONS

1.22.01 Performance

The touchup and repair method chosen should be made after considering the specific requirements of the application and the performance characteristics of each of the three touch-up methods. Corrosion protection should always be the primary consideration, but certain uses and conditions may warrant selection on the basis of one of the other performance characteristics. Comparative performances are listed on

1.22.02 Economics

The location of the article to be repaired, the size of the area and the skill level of the repair labor are the three primary determinants for economic consideration.

Table 1 – Comparison of Repair Performance

	Metallizing	Zinc Dust Paints	Zinc-based Solder
Corrosion protection			
Barrier	Very Good	Good	Fair
Cathodic	Excellent	Poor	Fair
Coating appearance	Very Good	Very Good	Good
Adhesion	Very Good	Poor	Very Good
Abrasion resistance	Fair	Poor	Poor
Mechanical properties	Good	Good	Poor
High temperature	Good	Good	Very Good
Relative Rating Total **1 = poor** **5 =excellent**	3.6 Very Good	2.7 Good	2.4 Fair

Table 2 – Economic Comparison

	Metallizing	Zinc Dust Paints	Zinc-based Solder
Equipment/materials	$$$	$	$$$
In-plant	$	$	$
Field Applied	$$$	$	$$$
Preparation	$$	$	$$$
Small touch-up area	$$	$	$$
Large tough-up area	$$	$	$$$
Skill level	$$$	$$	$$$
Relative Total	$$+	$+	$$$-