Jurnal Kejuruteraan 34(4) 2022: 535-542
https://doi.org/10.17576/jkukm-2022-34(4)-01

A Review on Galvanizing Coating Defects: Causes and Remedies

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Received 12 May 2021, Received in revised form 10 October 2021
Accepted 10 November 2021, Available online 30 July 2022

ABSTRACT

Hot-dip galvanizing is an efficient technique to control the corrosion of substrates. Producing blemish-free coatings is a challenging task. Continuous work is done on galvanizing technology to achieve excellent surfaces; thus, flaws are encountered at intervals in all continuous galvanizing and galvannealed process. Most of each very small galvanized defect can appear like a draff particle, draff trapped actually a tiny lot of the blemishes found in hot-dipped galvanizing coatings. Also, almost all defects take place due to a roughed or mechanically dented surface, poor bath chemistry management, inadequate washing of the parts, and less maintained apparatus. Thus, the coated products, which are manufactured by galvanizers, have to develop the excellence of the line instrument, the heat treatment management, and the Zn bath in sequence to touching the hard and tough quality essential for automotive uses and applications. This review paper first discusses different types of galvanized coating defects, and then discusses different coating defects like Bare spot, Distortion, Dross, Touch marks, Dents, Rough Coating, Ash Deposit, Mechanical Damage, Blow out, Runs, Uncoated or Ungalvanized Surface, Reactive and Non-reactive steels welded together, Puddling and suggests possible remedial measures to be taken care; at the end, it summarize and concluded.

Keywords: Galvanizing; defects; corrosion; failure; galvanized product

INTRODUCTION

Quality of surface in some past years it has very great growth and advancement in hot dipping galvanized coating, it is still difficult to produce defect-less coatings for an automotive industry uses. Non-stop hot-dip galvanizing procedure poses joining, cleaning, annealing, and cooling of cold-rolling steel strip around 450ºC before hot dipping in molten Zn bath around 450ºC and post-treatment processes affecting, coiling, temper-rolling, air wiping and, also chromate passivation (Kim et al. 1989; Tang 1998).

The chemical reaction takes place around 450 ºC in continues galvanizing. As a result, intermetallic elements continuously appear in the bath, and Zn-Al oxide floats on the surface of the bath. The intermetallic particles and skimming from the surface can be easily withdrawn from the coating. About 0.18-0.20% Al is used in galvanizing bath and other elements such as 0.10-0.20% Pb while restricting Fe which is 0.30-0.40% max used for getting high-grade coating. Fluidity and also wettability of the Zn dissolve are improved by aluminum. Al was also used for improving the luster property of hot-dipped coatings and decrease the dross formation, by generating an oxide on the top of molten Zn. Pb also takes down surface tension and increases the fluidity of Zn the similar to the Al stimulate the growth of “spangles” on the galvanizing steel substrate. Excess Fe in the bath affects the fluidity of Zn and also influences looks appearance like dull and unpleasant coatings. Intermetallic compounds may progressively on the substrate of submerging hardware and then resulting in the low-quality coating. Unwanted contaminants and other undesirable impurities can be passed from the hardware substance to galvanized coatings (Komatsu et al. 1998).

The excellence of coating may be implicated by the quality of the steel surface. Defects on substrate caused due to mechanical damage. If surface contaminant not pulls out properly then imperative intervention with the coating method and resulting bare spots. Almost surface blemishes in hot-dipped galvanizing steel sheets formed by rough and mechanical damage surface, improper bath management, and insufficient pre-cleaning of surface and equipment preservation (Mahieu et al. 2000).

The appearance and property of hot-dip galvanized coatings include: The steel chemistry, Steel surface condition, the size and shape of the item, the design of the item with regards to the galvanized process [Tang & Goodwin 2001]. The area of steel surface/unit area has a vital effect on the zinc reaction with steel to produce a good galvanizing coating. Rough and mechanical damage substrates will be reacted much adversely than smooth and fine surfaces to produce denser very good and pleasant galvanized coatings with the product.

TYPES OF GALVANIZED COATINGS DEFECTS

We can classify galvanized coating defects in major six types, based on their originated source and relevance (Saravanan & Srikanth 2018; Khode 2019; Kim & Chung 2000; Mondal e al. 2020; Azimia et al. 2012; Yu et al. 2020; Peng et al. 2021; Jin et al. 2020; Fang et al. 2020). Each type is discussed in details as:

DEFECTS ORIGINATED FROM STEEL SURFACES

Zn upwards surface defects, specifically that time when the steel sheet with stringent and harden situation. The defects form on steel sheets like steel slivers, scratches, hot strip mill mechanical flaws, surface damage, and mechanical damage during the cold rolling process and many others reason Zn-Fe alloy flares at the steel-coated boundary and not the same dendritic Zn crystal alignment. Temper rolling produces these sections additional significant as per a resultant of light reflectivity alterations. The small blemish types in the surface stick out and which are also known as dross (Saravanan & Srikanth 2018; Khode 2019). Various example of common flaws regards to the rough exterior of steel sheet surface features are Peel off and Exfoliation of Galvanized Coatings, Fines iron in Coating, bare spots, High Spots, and Intermetallic Growth at Mechanical Damage Surface, Substrate Scratches and Gouges, Coating Defect Origination from Rolling Scale on Steel surfaces, Tandem Rolling Scum in Galvannealed Coating (Azimia et al. 2012; Yu et al. 2020).

DEFECTS RELATED TO CHEMICAL CLEANING

The substrate contaminations on the cold rolling strip possess essential iron fines, oil, and dirt. Mostly hot-dipped galvanized coating outlines manufacturing exposes the quality of hot-dip galvanizing sheets for automotive industrial uses which have chemical pre-cleaning systems involving many of scrubber, water rinse container, electrolytic, etc. In specifications, electrolytic cleaning, isn't compulsory, on its surface, relatively 100 iron fines are used to clean the strip. Irregularly carries of iron particles in the Zn bath originating unwanted dross production and pick-up, even bare spots on the strip because of insufficient Zn wettability. It is noted that grease spots, Whether existence at strip surface, can't eliminate by alkaline cleaning process; they are convertible to carbonaceous residual at steel surface throughout annealing process and it grounds very low wetting of liquid Zn with steel and harmful galvanized coating adhesion; Such example of this type of defect is Grease on Galvanized sheets (Moon et al. 2012).

DEFECTS ORIGINATED FROM ANNEALING FURNACE

Constant hot-dipped galvanized process, in strip annealing, is practiced as well as to make softer the cold rolling strip with the prerequisite mechanical and other material goods, in the 2nd place to uncontaminated the strip substrates extricate from impurities before dipped in the liquid Zn bath. In the furnace, strip trips on rolls and go through different chemical responses. In furnace (direct fired), which is expose to immediate reheating in an atmosphere to be made it extra combustibles. Inappropriate controller of air and fuel proportion in the furnace may affect undesirable extraordinary levels of Carbon monoxide, it could because accumulations on strip (Ravi Shankar et al. 2009).

Throughout the constant line operation, the strip impurities which are accurately conserved in the furnace (direct fired) atmosphere is preserved. Nonetheless, at intermittent process states like during an extended line stopping, a very extreme strip corrosion process may occur. In this case, a part of the resultant FeO is carried by the strip into the snout, thus, contaminated liquid and molten Zn in the snout. Whether this contaminated molten Zn will not drove out, then it may cause bare spots in the galvanized coating. Such examples are defects due to Improper Furnace Atmosphere Control, Grease Seepage/ Carburization of very Low Carbon Steel within Galvannealed Coatings, Hearth-Roll Pickup on Galvanized Sheet, and Entrapped Argon Gas in a Galvannealed Coating (Saravanan & Srikanth 2018).

DEFECTS RELEVANT TO ZN BATH

Poor Zn bath practices formed a large range of coating problems and defects. In more addition, high strip immersions temperature in aggregation with a small snout dew point may affect Zn vaporation rapidity, and when the Al free Zn steam condensed on sheet already arrival in Zn container, Zn-Fe alloy bursts occurred which seems like blemishes and elevated ridge plugs in the coating. Inappropriate control of aluminum is combining with excess molten Zn temperature and Fe variation tends to form a drossy bath. On the upper side of the strip, dross has a higher tendency to pick up on sinker, it instigating stripy ZnFe alloy outbreaks, particularly on ultra LCS (low carbon steels) (Mondal et al. 2018).

Substantial and massive dross pickup may create dimples in the strip. These Irregularities could be sorted by introducing specific and proper Zn bath management. Here few examples of Zn bath regards coating problems and defects are Low Aluminum content lead to very poor and bad Adhesions in hot-dipped galvanized Sheet, Coated Surface Contamination/ Discoloration, Entrapped Dross Particles, Dross in Galvannealed Coating, Zinc Dust on Galvannealed Coating, Zinc Oxide in Snout, In-Situ Grown Zn-Fe Crystallites (Yang et al. 2013).

DEFECTS ORIGINATED FROM AIR JET WIPING

At that time of air-jet wiping to the regulator and maintain the layer depth, jet lines can procedure. Mainly longitudinal bands with a tinier and little denser and finer coating than the nearby region result from air jet disturbances because of blocking of knife slot with Zn dirt or deflecting of air-jet because of Zn atom precipitate on knife lip. Other conspicuous coating problems and flaws formed very quickly later air-jet wiping is coatings sags and ripple.

Sags tend to occur in the heavyweight coat on denser strip gauges and ripple in the dainty coat on thinner gauges, most in glance-free coatings which don't solidify speedy in the upper leg. Smooth sheet substrate, high strip and temperature of molten Zn, very much strip tremors and fractures of rust layer on molten Zn coating surface contributes to this all faults. Such defects are Caterpillar defects in Galvanized Coating and Dents.

DEFECTS REGARD TO TEMPER ROLLING

Because of the sliding or transverse friction at the middle of hard and stringent working roll surface and soft Zn coating on the sheet, Zn picks up on working roll and subsequently deposit on strip substrates throughout rolling, especially on standalone temper mills uniform with wet rolling, which is very common defects and difficulty. Though working roll polished and wet rolling solution performance has been industrialized to encounter these defects [Saravanan & Srikanth 2018].

But the no. of defects in hot-dip galvanizing are discussed on the basis of causes and remedies are individual. So, the defects are briefly discussed below with causes and remedies.

GALVANIZING COATING DEFECTS AND REMEDIES

Bare spots

During dipping, the defects are not coated portion is caused due to incorrect wetting. Proper wetting involves that all oxide mill, scale and rust, cleaning solutions, and oils may be escaped, exposed clean steel substrate. In baths having Aluminum in extra amount around 0.2% galvanizers normally formed exposing-quality hot-dipped galvanizing coatings. Coatings formed in the bath like shiny and preferred.

The requirement of surface spotless become more critical for very good wetting, at high levels of bath Al. Frequently, small not coated portions could be find in coating, as in Figures.1(a) and (b). High-strength steels like TRIP steels and dual-phase possess alloying elements like Mn, Cr, Al and Si which could segregate the steel substrates and convert them into oxide during the thermal process. As resultant repeated turn in a difficultly.

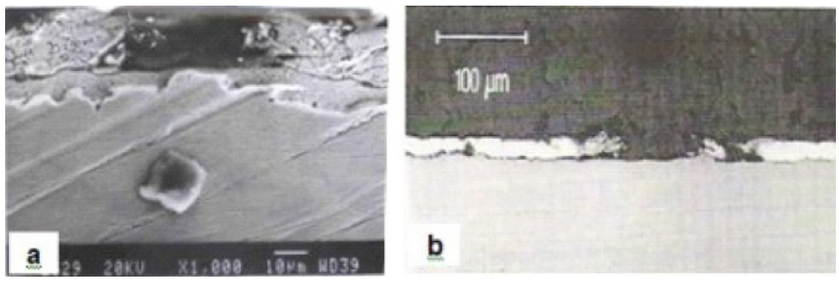

FIGURE 1. Bare spots galvanizing coatings. [a] SEM micrograph photo and [b] Optical micrograph photo [Saravanan & Srikanth 2018]

Whether the time between galvanizing and fluxing is dryer temperature is much higher, the barrier protection by flux may be mislaid. It is not covered by a rustic look appearance in non-galvanized products, which could result in coating discontinuities after galvanizing. To minimize it one should reduce over-drying and control temperature and dry; maintain the content of the Al of bath below 0.007% [Saravanan & Srikanth 2018].

Distortion

Distortion is a very common defect in galvanizing. It is the undesirable warped that intermittently turn into evident after galvanizing. The galvanizing practice takes place at liquid Zn temperature around 450° C. For treating steel it is lower at end of stress relief temperature. Any other inherent welding and rolling stress in fabrication, which seems to release. It results in a dimensional-based change, like distortion defect (Tang & Goodwin 2001).

FIGURE 2. Distortion (Tang & Goodwin 2001)

Thin plates are many possibilities to distort and it causes due to quick different heating and cooling of products. To control this one should use sections of similar thickness; use

symmetrical designs; use the correct and precise minimum bend radii and Stiffen non-supported thin wall sections; use staggered welding techniques and make use of temporary braces on thin-walled sections like troughs, angles edging and cylinders. Components can be straightened out after hot-dip galvanizing [ASTM A 780].

Dross

Dross formed during the process of hot-dipped galvanizing in form of Zn-Fe crystal (around 95% Zn and 5% Fe) with a high melting point compared to metal in Zn mud bath. Dross trapped in the hot-dipped galvanized coating may be given the rough look. It is also particles of Fe and Zn alloy produce during the process. Excessive Fe fines carry on incoming strip substrate could easily lead to form a dross particle inner side of the Zn tank. Figure.3 (a) characterize the visual look of dross, which can be simply misguided as coated over a "scratch" defect. Figure.3 (b) characterize the SEM substrate look of dross pick-up after then polishing.

It is uninvolved by galvanizer and precipitate in the bottommost. Dross deposits from the lowermost of the Zn bath surrounded the edges of production. The dross is associated with coating, which prevents drainage of the Zn in the middle portion (Khode 2019).

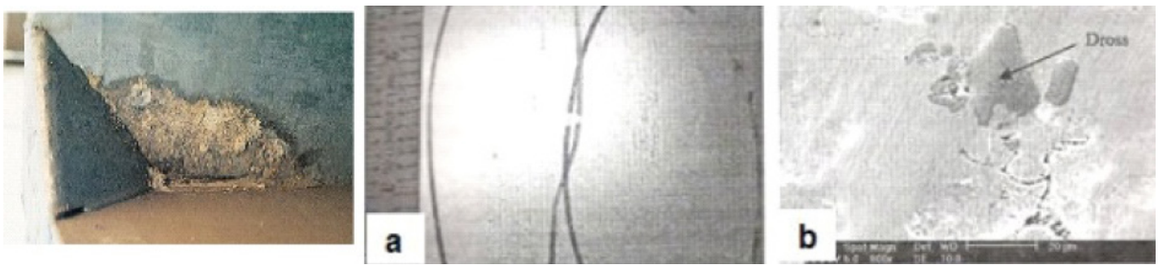

FIGURE 3. Different types of drosses (Khode 2019)

Dross contains a similar Fe-Zn alloy as coating; it will offer the same oxidation resistance as a common hot-dipped galvanizing coating (Tang 1998). The presence of dross addition in the coating is non-harmful to coating performance as corrosion resistance of Zn dross matches with the hot-dipped galvanizing coatings (Tang & Goodwin 2001).

Touch Marks

The Zn in the hot-dipped bath should have been the free entrance to all work-piece substrates. Objects that come in the hot galvanizing bath shouldn't be in constricted interaction with each other. For reducing wire marks, Jigging wire should also be attached loosely. Where the module has been rested on dipping apparatus, a non-coated portion of a touch mark can appear [Inspection of hot-dip galvanized steel products- American Galvanizers Association]. It can be controlled by decrease connection among the work-piece and jig contact; tiny modules could be centrifuged (Khode 2019).

FIGURE 4. Touch marks (Khode 2019)

Dent

The coating is more thin compare to the nearest coating, but it is incompletely missed. These tinny spots are formed by damage to producing coating as it passes from the air knife and the small-spangle rig. Typically, Representation of dent defects in Figures.5 (a) and (b). The dents are created due to impingement of droplets, patenting much likely from small-spangle rigs. The dent can see in Figure.5 (b) which is less in contour. The flowing lines, which are recorded on flanks of dents and also recommended that the wiping jet is disturbed due to solid particles. A very close investigation of the cross-section portion with appropriate coating sample exposed the number of Fe fines in the hot-dipped coating. When hot-dipped galvanizing coating was passed through the air knife, the solid particles are apparently a Fe fine is driven away from the coating by air pressures.

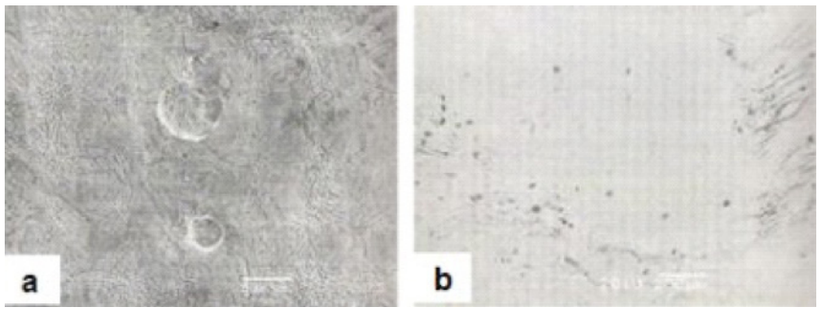

FIGURE 5. Different types of dents (Khode 2019)

Rough Coatings

It caused due to irregular substrate and coating on corroded steel surfaces could be hot-dipped galvanizing adequately. A coating can reproduce the texture of the substrate. Some other reasons that rough substrates contain uneven pickling, cold working, higher galvanized temperature, and extended submergence in liquefied Zn. Irregular, heavyweight coating refers to a hot-dipped galvanizing workpiece that shows rough substrates. It can be added coatings have a general irregular surface and grooves type substrate configuration, the effect that "Tree barked effect" happen by variation in steel substrate examination. An uneven surface can create thick coating and result in long-time serviced life. The thick coating formed can supply great erosion preservation except when coating tendency to flaked off (Khode 2019).

FIGURE 6. Rough Damage (Khode 2019)

Ash Deposits

Zn ash could grow during the hot-dipped galvanizing process as immersion in Zn. The ash is produced which skimmed off. The surface of the molten Zn before elimination of workpiece from hot galvanizing process bath. Sometimes, ash is entrapped inside areas and stick to the outside of the coating as work is taken out from galvanizing bath [Komatsu et al. 1998]. Zn oxide deposit could be taken place when the component is plunging or take off (Khode 2019). The coating is commonly in one piece beneath the ash deposit. To control it ash has to be removed and the coating thickness is evenness to the specification required [Tang 1998].

FIGURE 7. Ash Deposits (Tang 1998)

Mechanical Damage

In mechanical handling and transportation damage may occur, specifically in a thick coating, which has the tendency to be brittleness in nature. The main causes of it are using of chains, wire ropes, dropping and dragging of components on the hard and stringent substrate; it can cause mechanical damage. It is primarily appropriate with thicker and brittleness coatings. It can prevent by warned tags, highlighted loss and thicker coating can possibly damage if manhandling, it shall attach by galvanizer before the component was conveyed. The usage of nylon lifting slings is suggested (Tang & Goodwin 2001).

FIGURE 8. Mechanical Damage [Tang & Goodwin 2001]

Blow Out

Molten Zn at galvanizing temperature is 30° C directly more than freezing point. Molten metal viscosity is limited to its ability that penetrated tiny crevices and cavity and also gaps <1 mm in width don't allow to penetrate by molten Zn. The problem was held near the non-sealing welding area and vented hole. It is likely to stain wept ceasing.

Most fabrication components have during the pre-treatment process and overlapped substrate, pre-treatment chemicals will be penetrated on these overlaps and it may be not drained out due to surface tension hold fluid at the place. When the work-piece enter the hot galvanizing bath, any kind of moisture present in the cavity or crevices will speedy boiled and eject steam and pre-treatment resides on an adjacent substrate of work. This impurity interferes with Zn ability to react with the steel and non-covered parts adjacent to these `blow out defects' will happen [Tang & Goodwin 2001]. To control it preheat item before the immersion in Zn and both should take dry out the overlapped area as soon as possible (Khode 2019).

FIGURE 9. Blowouts (Khode 2019)

Runs

It is a localized thicker part of Zn which occurred on the surface of hot dipped galvanizing elements. The efficacy causes when Zn to freeze on the substrate of galvanized elements during the taken out from Zn bath. Except they affect the intended use of steel part, then there is no any requirement to remove. Whether runs are non-preventable because of the design of manufactured items, but it will affect with intended application and they could be buffed (Khode 2019).

FIGURE 10. Runs (Khode 2019)

Uncoated or Ungalvanized Surfaces

Residuals are presence like grease, oil, and paint on the steel substrate and non-accurate position vent holes which can result in confined non-galvanized portion in continuation hot-dipped galvanizing coating. Flaws after galvanizing process could be different colors like grey or black to brown color. Sand on mill scale or cast iron on steel substrate is much cause due to process used in roll product. Localized and non-galvanized areas nearer the weld part could be triggering by the weld slug deposits, weld undercut, and weld porosity. Deposit of oxide and residual from welding not affected to normal pickling not involved before the work is pickled and hot-dipped galvanizing.

FIGURE 11. Uncoated Surfaces (Khode 2019)

To control it removal of paint and grease is a necessary step before hot-dipped galvanizing. Tick some marks with the pen for short-term identification. These ungalvanized regions can occur in line arrangement on channels, angles, or other rolling products. It can look on CI (cast iron) products. Deposit of weld slags should be taken out by fabricators it means of abrasion blast cleaning. It could be distant by appropriate wire brushing and chipping. Shielded arc welding defends slick welding which is favors for the module which is a hot-dipped galvanizing coating [ASTM A 780].

Non-Reactive and Reactive Steels Welded Together

Determinations to raise the galvanized coating depth on minimum reactive steel can be resulting in unfortunately thicker and brittleness coating on much reactive steel. Alteration in the coating depth and its carried by a mixture of one or more reactive Si killed steel and high P results in thick galvanized coating and very less reactive Al killed steel results in galvanized coating depth lower than that requirement in specifications. The thickness of resultant coating on reactive steel may be much thicker, results in an inelastic coating more prone to damage. To prevent it select same steel for fabrication any part. If necessity, agree to take a request by any galvanizer when thin coating is possible (Khode 2019).

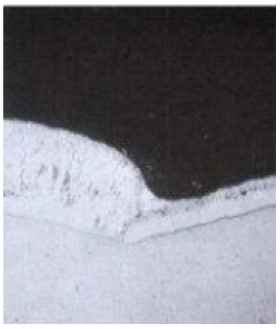

FIGURE 12. Non-Reactive and reactive steel welding together (Khode 2019)

Puddling

It happened due to poor and bad drainage also Design problems are the primary cause of puddling and it can be eliminated with the help of good design. With except bleeding and blowouts and where the galvanizing coating was absent, many of that hot-dipped galvanized defects

haven't had any influence on the durability of coating (Khode 2019).

FIGURE 13. Puddling (Khode 2019)

All these defects are non-avoidable in hot-dip galvanized common products and some of these are tolerable as long as they don't interfere with the assembly of the functional items and present safety from hazardous in handling and maintaining service.

SUMMARY

In this review paper, most of the hot-dipped galvanized defects are analyzed and discuss with aid of some research papers, websites, and many other sources. The defects are discussed with different research papers with the origin of the defects it means clauses, defects occurred in which environment and some factors which are implicated the galvanized product and other factors simultaneously. The next discussion about the remedies and solutions for combat different types of defects are occurring.

Therefore, primarily defects are discussed and Classified galvanized coatings defects with causes and their combating remedies which depends upon its beginning, the surface defects faced in galvanized and galvannealed sheet products. Then it can be divided into 6 types which are thoroughly discussed before such as Defects originating from steel substrate, Defects originated from annealing furnace, Defects associated with chemical cleaning, Defects regards to Zn Bath, Defects discovered from air jet wiping and Flaws regards to temper rolling. These are discussed before thoroughly.

The main and primary defects which are discussed thoroughly with cause and combating solutions in before which are Bare spot, Distortion, Dross, Touch marks, Dents, Rough Coating, Ash Deposit, Mechanical Damage, Blow out, Runs, Uncoated or Ungalvanized Surface, Reactive and Non-reactive steels welded together Puddling.

CONCLUSIONS

It is structurally difficult to produce fully defect-less and free from blemish galvanized and galvannealed coatings for many applications and other uses like expose automotive industrial section. Coating defect and difficulty are petite, and also apparatuses or instrumental to analyses their original nature isn't easy and accessible to line operators. Almost all defects are the outcome of quality of component surface, inadequate sheet surface pre-cleaning, poor and improper bath chemistry management, and inadequate and inappropriate instrument preservation.

Manufacturing of defect-free expose-quality of galvanizing coating pre-requisite steels with high and good surface excellence. Steels should be microscopically smooth and flat with unrestricted mechanical damage or destruction. The cleaning portion must work very effective manner, otherwise, it will create wetting, it may become challenging problems in the hot-dipped galvanizing coating. It is assumed that when all these newly-developed and upgraded steels turn out to be the mainstream for the component, manufacturing blemish less hot dipped galvanized coatings may turn into even more interesting and also for economical for industrialists. Where pathetic and aesthetic issues are present and involved, then hot dipped galvanizing coatings only process to deliver a superb level of quality within the fewer limits of the procedure.

ACKNOWLEDGEMENT

The authors would like to thank to Gujarat Technological University for supporting this research.

DECLARATION OF COMPETING INTEREST

None

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