

# Hot Dip Galvanizing Appearance: More than Meets the Eye

Aesthetics can be a highly subjective part of any protective coating specification and it is no different when it comes to hot dip galvanizing. However, unlike some other coating types, attempts at controlling the outcome can be particularly difficult due to nature of the galvanizing process and the numerous factors that influence appearance.

Over 30 different types of typical surface conditions that can occur on batch hot dip galvanized articles are discussed in detail in the Hot Dip Galvanizing Inspector Program run by the ACA, which about 120 participants from Australia, New Zealand and Indonesia have successfully completed since the course commenced in 2016. These surface conditions include everything from ash deposits to zinc splatter, but by far the most common point of contention where aesthetics is concerned is the initial appearance or colour of the galvanizing.

To understand the appearance of a batch hot dip galvanized coating, it is important to understand the basic process by which the coating is created on an article, usually steel. The process consists of two main steps, with the first being to thoroughly clean the article (typically by degreasing and acid pickling) followed by immersion in a bath of molten zinc. It is in the zinc bath where a metallurgical bond with the steel (iron) is formed creating zinc-iron alloy layers. This is generally followed by a quenching step to cool the article, which often contains an inhibitor to provide interim passivation of the zinc surface to prevent early oxidation.

## Initial Appearances

From the batch galvanizing process, there are four different initial appearances a coating can develop based on its formation; shiny, spangled, dull and mottled. Some galvanized articles may even develop more than one of these appearances across their surface.

Galvanized steel with a **shiny** appearance is the most commonly seen and has become what people expect to see when looking at newly galvanized steel (Figure 1). This shiny appearance is created by the solidification of unreacted zinc on top of zinc-iron alloy layers when it is withdrawn from the zinc bath (Figure 2).

A **spangled** appearance has the same general coating structure and lustre as the shiny appearance, with the only difference being how the zinc solidifies. For spangle to form, certain types of additional elements must be present in the zinc to allow the crystalline pattern to form. The concentration of these elements and the cooling rate of the article influence the size and shape of the crystal formation (Figures 3 & 4).

**Dull-grey** coatings on newly galvanized steel are seen by some as an inferior coating, but this is an inaccurate assumption. A dull-grey colouring as an



Figure 1 - A shiny new galvanized coating.

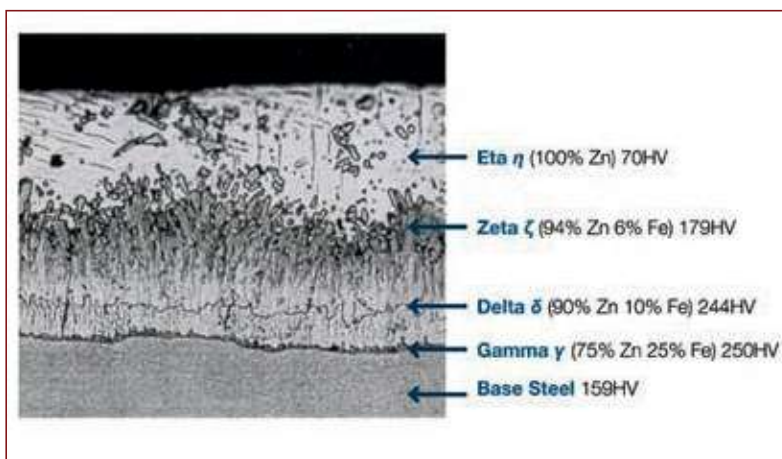


Figure 2 - Typical structure of shiny galvanized coating.



Figure 3 - Spangle pattern on galvanized poles.



Figure 4 - Large spangle pattern.



initial appearance is due to the coating structure being entirely made of zinc-iron alloy layers, with no top layer of zinc. While there is always zinc pulled up on top of the zinc-iron alloys when an article is withdrawn from the bath, it does not always just solidify in place as with shiny and spangled appearances. Sometimes, the zinc will continue to react with the base iron and be totally converted, leaving only zinc-iron alloy at the coating's surface (Figure 5 and Figure 6). These coatings are usually thicker than their shiny or spangled counterparts and in-turn will have a longer service life when placed in the same environment.

A **mottled** appearance consists of a dull-grey circular type pattern around areas with a shiny finish (Figure 7). It is also described as a cellular, web (spider web), or mechanical scale pattern and is often mistaken to be the result of cracks in the coating. This appearance occurs due to a partial presence of zinc-iron alloy layers at the surface of the galvanized coating (Figure 8), with the pattern believed to be due to the alloys being created at grain boundaries only and the remaining zinc solidifying without reacting. This appearance may occur in a localised area or extend over the entire surface of an article.

### Factors Influencing Initial Appearance

Why can't I specify the appearance I want? A simple question with a complicated answer. The commonly seen differences in initial appearance can rarely be controlled by the galvanizer, as it is highly dependent on the metallurgical reaction of the coating formation that occurs while immersed in the molten zinc. There are numerous factors that influence how a galvanized coating forms on any given piece of steel, with the four main factors affecting the initial appearance being steel composition (or chemistry), the surface condition of the article,

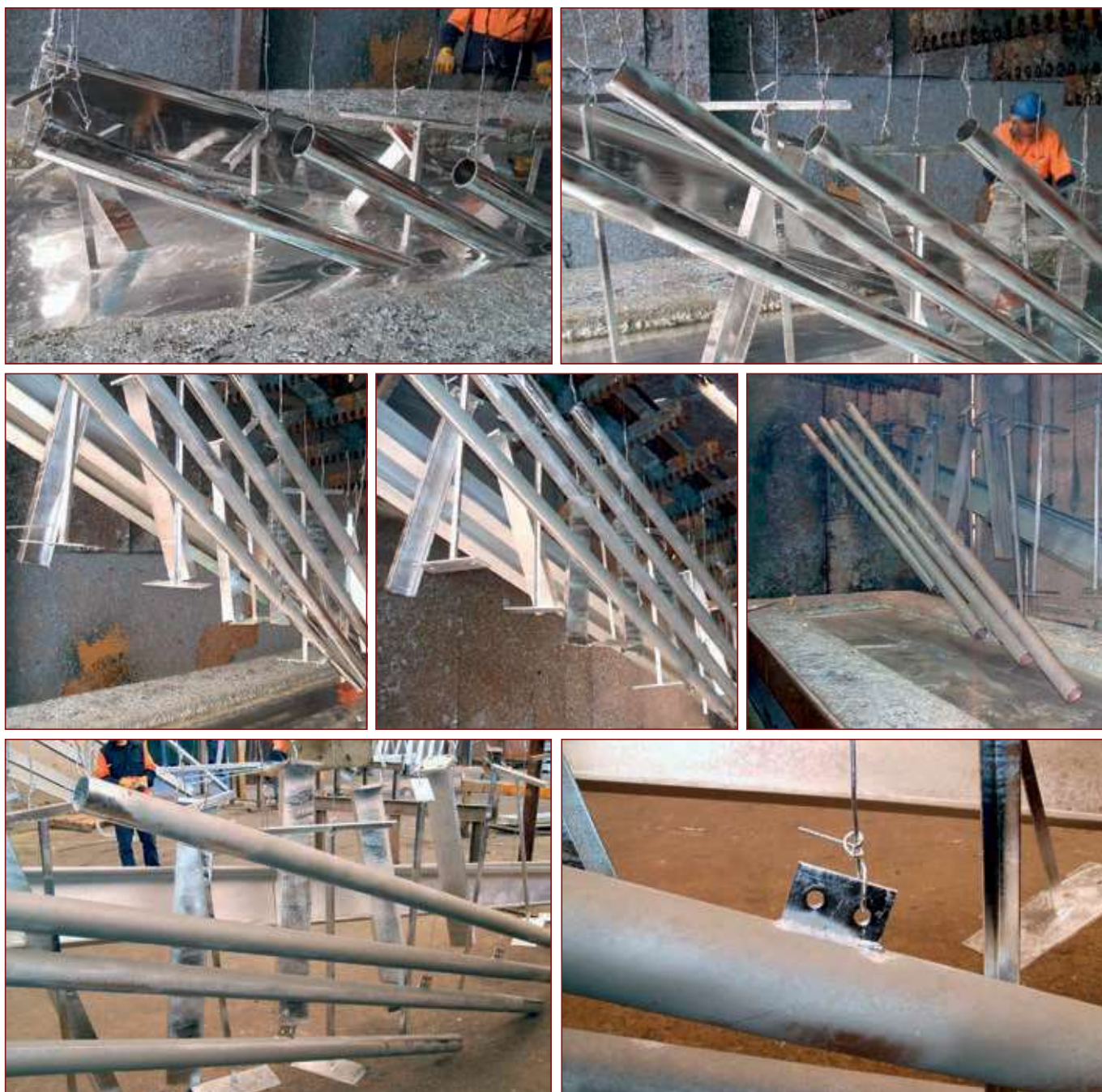


Figure 5 - Dull coating formed as reactive steel pipes are withdrawn from molten zinc.





Figure 6 - Micrograph of dull galvanized coating.



Figure 7 - Galvanizing with mottled appearance.



Figure 8 - Micrograph of galvanized coating with partial eta layer.

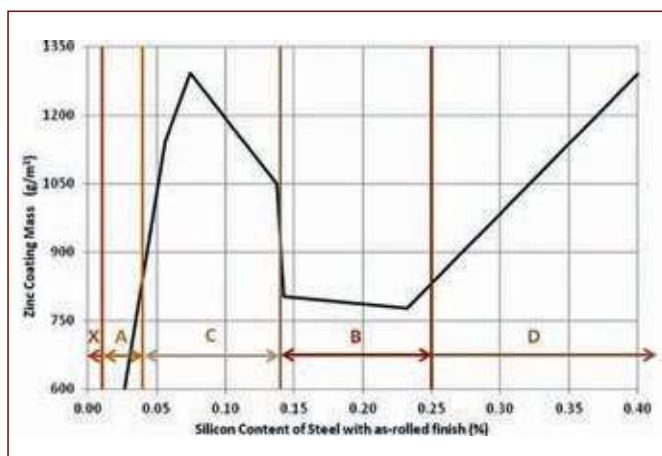


Figure 9 - Sandelin Curve.

its cooling rate and its design and fabrication, including venting and draining.

### 1. Steel composition (chemistry)

Certain elements in the steel, in particular silicon (Si) and phosphorus (P), affect the reactivity of the iron with molten zinc. The extent of the reactivity is dependent on the concentration of each element and this relationship was first described by Sandelin in 1940 (Figure 9). It is now summarised in Table 9.1 of AS/NZS 2312.2 "Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings - Hot dip galvanizing". The compositions that cause a prolonged or faster rate of reaction between the iron and molten zinc while the steel is submerged are known as 'reactive steels.' These steels usually result in mottled or dull appearances as well as having thicker coatings.

### 2. Surface condition

The condition of the article's surface contributes to the initial appearance of galvanizing. On a macro level, the surface of the galvanized coating typically matches or amplifies the

article's contours. A good example is if the steel suffered from pitting corrosion before being galvanized, the coating will follow the corroding pits. On a micro level, the surface profile affects the reactivity of the steel with the zinc. A rougher surface with a higher surface area will generally result in increased reactivity and higher potential for a dull or mottled appearance, while smoother surfaces are less reactive and more likely to have a shiny appearance.

### 3. Cooling rate

The thickness of the steel will affect the cooling rate of the steel when it is withdrawn from the molten zinc, with thicker steel retaining heat longer and hence more likely to develop mottled or dull coatings. On large pipes or hollow sections, a difference in appearance can occur across the article due to cooling rate. When the article is being lowered into the quench, straight from the zinc bath, the bottom surface cools quickly and the steam generated from the quench solution travels up and around the top of the section, so it remains at a higher temperature for longer. As a result, the bottom surface retains a shiny pure zinc layer while the zinc and steel on the top half of the member

continues to react, converting the zinc and leaving a dull zinc-iron alloy layers at the surface (Figure 10).

### 4. Design and fabrication, including venting and draining

The influence of design and fabrication on appearance generally relates to the adequacy of the venting and draining along with variations in section thicknesses and fabrication methods.

If vent and drain holes are too small, it will take more time for the zinc to flow around and/or into the article when being dipped as well as more time to flow out during withdrawal. This also increases the time taken to cool the article and in turn can affect the surface appearance.

Ideally, thickness variations in fabrications should be minimised to help avoid distortion but this also helps to limit variations in initial appearance due to different cooling rates.

Another factor related to design and fabrication that affects appearance is when steels of significantly different chemical composition are used in the one article (Figure 11). This can



Figure 10 - A partially shiny and dull galvanized coating resulting from the effect of cooling rate.



Figure 11 - Steels with significantly different steel composition used in the same fabrication.

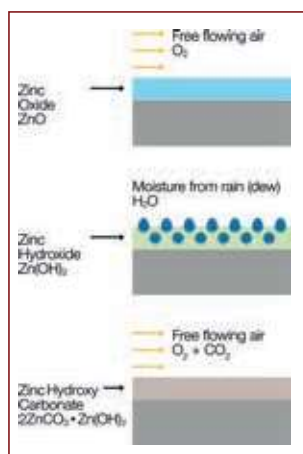


Figure 12 - Schematic of zinc patina formation.



Figure 13 - Galvanized handrail.



Figure 14 - Galvanized guardrail.



Figure 15 - Galvanized light pole.

lead to completely different initial appearances between adjacent areas, despite the whole article being dipped at the same time.

### Appearance Over Time

All metals oxidise in the atmosphere and create a passive film on their surface. For zinc, this natural passivation process results in a noticeable change to its appearance and generally occurs in three stages, as shown in Figure 12. The result of this process is the formation of a relatively insoluble zinc carbonate film, known as the patina, which has a matte, light grey colouring. Everyday examples of commonly galvanized objects where this light grey appearance of the patina can generally be observed include handrails (Figure 13), street sign posts, roadside guardrails (Figure 14), and light poles (Figure 15).

The development of the zinc patina happens over time and the speed of change will vary depending on the exposure environment. At the extremes, it can happen in as little as a couple of days or take as long as a few years, but for most common exposures in Australia and New Zealand it will develop over a few weeks or months.

Another appearance one may come across, usually on older galvanized coatings, is what's commonly referred to as bronzing. For a typical shiny coating (whose structure is shown in Figure 2), bronzing will start after the eta layer is consumed and corrosion of the top alloy layer (zeta) starts. As there is a small percentage of iron in the alloy layers, small amounts of iron oxide (rust) are formed on the surface coating, creating a 'bronze' or 'rusty' appearance. This appearance can be confused with rusting of the base steel, however there is always a significant amount of galvanized coating remaining on top of the base steel. One method for determining the difference between bronzing and corrosion of the base steel is to take coating thickness measurements of the area.

As initial dull coatings don't have an eta layer and their coating structure consists solely of zinc-iron alloy layers, it is likely bronzing will occur relatively early in the coating's service life. This can also be the case with articles that are centrifuged or 'spun' after withdrawal from the zinc bath. The thickness of the eta layer for centrifuged articles will often be reduced, as much of the zinc

withdrawn from the bath will be spun off. In service, with a reduced eta layer, the alloy layers will be reached sooner than a 'typical' coating, hence bronzing of the coating will occur earlier.

As the alloy layers with higher iron content are exposed bronzing becomes more pronounced, but research has shown the corrosion rate of the galvanized coating is essentially unchanged if a zinc patina has formed.

### Summary

Irrespective of whether the initial appearance is shiny, spangled, dull or mottled, it doesn't affect the corrosion protection offered by the coating and over time the appearance of the galvanized coating will change as it naturally weathers. Facts worth remembering when next writing a specification or designing a galvanized structure where aesthetics is to be a focal feature.

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