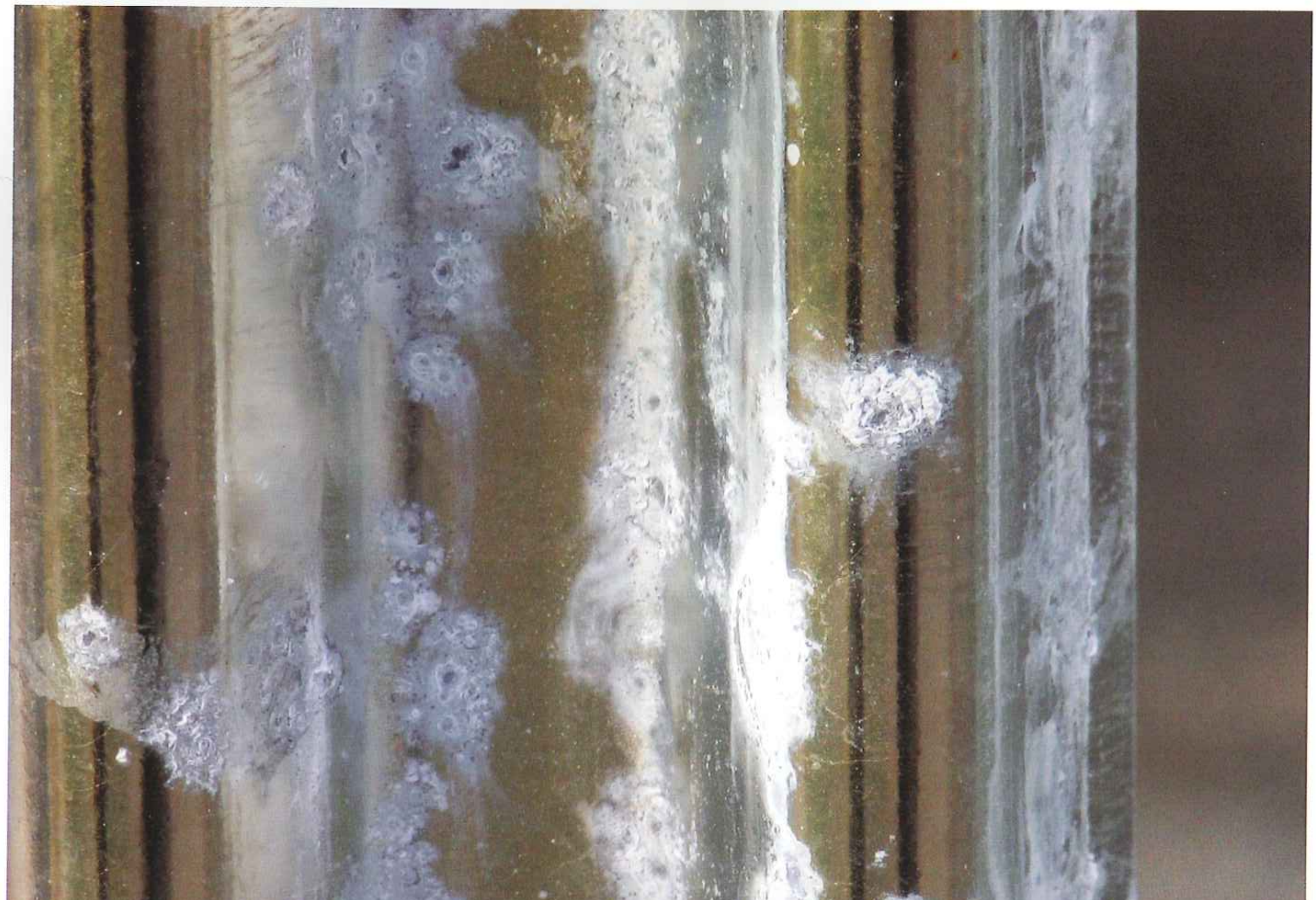
FEATURE ARTICLE

GALVANIZED COATING PROBLEMS & SOLUTIONS



Light white rusting has occurred on these galvanized steel security fence palings through storage in wet conditions. While unsightly, there has been little coating loss and durability is unaffected.

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INTRODUCTION

Hot dip galvanized coatings (HDG) on fabricated steel have traditionally been applied as industrial coatings with the aim of providing durable, long-term protection from corrosion. As the benefits of the performance of HDG coatings have been more widely recognised, they have been increasingly specified for more architectural applications, where appearance as well as durability is important.

There are a number of characteristics of the HDG process that give rise to variations in the appearance of the galvanized coating, along with its metallurgical characteristics, that can compromise the appearance of the finished product if a smooth and uniformly shiny coating is the client's expectation.

This article examines some of the common causes and effects of galvanized coating defects and variations, along with possible solutions.

THE GALVANIZERS' CHALLENGE

Hot dip galvanizing is a metallurgical process involving a reaction between molten zinc alloy (usually containing small amounts of aluminium, sometimes nickel and lead) and steel. The reaction takes place once the steel reaches the galvanizing temperature of 455°C.

Zinc-iron alloys form on the steel's surface and this reaction will ultimately determine the thickness of the galvanized coating, influenced by how long the steel remains in contact with the molten zinc, its surface condition and its chemistry. The relatively long immersion time in the molten zinc (typically 5-10 minutes) is the reason why HDG coatings are much thicker than those applied to sheets, strips and tubes by continuous processes, where immersion times are measured in seconds.

The challenges faced by the galvanizer are;

- The shape size and design details of the fabrication are usually not known until it is delivered for processing
- The condition of the steel (clean, mill-scaled, rusty, painted) is unknown until it is delivered for processing
- The steel chemistry is unknown and several different grades and types of steel section may be included in a single fabrication

In the 21st Century, most Australian galvanizing operations have galvanizing baths large enough to accommodate structural steel fabrications. Within the Industrial Galvanizers Group, both in Australia as well as the USA and Asia, bath sizes are typically between 10 -14 m with depths up to 2.6 m and widths around 1.8 m. In some regional centres, small galvanizing kettles service the local markets.

Any fabrication that exceeds the galvanizing bath size in one dimension can generally be double-end dipped. If the fabrication exceeds the bath size in two dimensions it cannot be hot dip galvanized. The shape and size of a fabrication will dictate how it has to be handled through the galvanizing process. This handling orientation will then determine what venting and draining details are required to prevent air locks or zinc puddling.

Because the pre-treatment processes associated with hot dip galvanizing are all chemical immersion processes, the same venting and draining principles apply, as the pretreatment chemicals need to contact all surfaces of the fabrication to ensure adequate surface preparation.

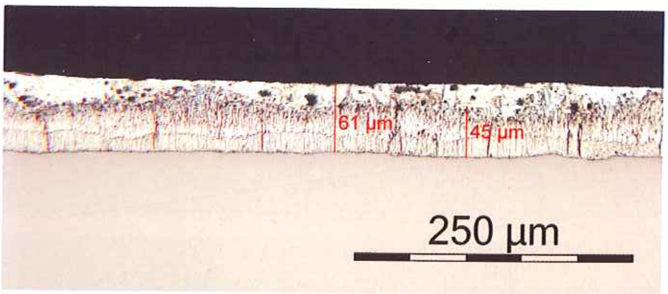
The surface condition of the steel will influence the appearance of the coating. Hot rolled sections will not produce a smooth and shiny galvanized surface like cold-rolled sections that are free of mill scale prior to galvanizing. Steel that is rusty will also reflect surface variations through the galvanized coating to a greater degree than steel that has not been subject to corrosion.

INVISIBLE ISSUES

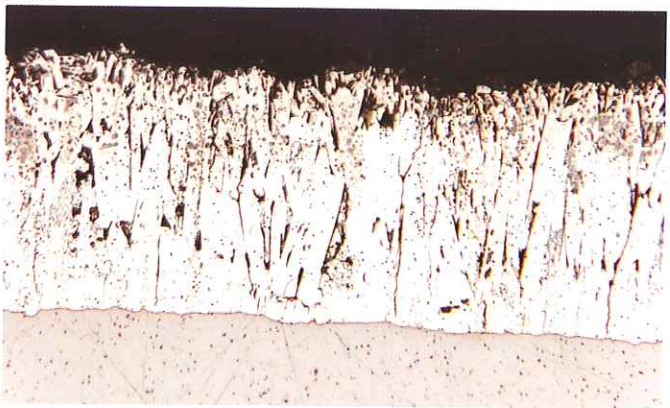
All steel sections will be subject to 'invisible' variations arising from the steelmaking and production processes, that can affect the appearance of a hot dip galvanized coating. The major factor is related to steel chemistry. Most structural grades of steel are alloys of iron containing carbon (C) , phosphorous (P), Manganese (Mn), silicon (Si) and sulfur (S) and aluminium (Al), as alloying or residual ingredients, as well as small amounts of nickel (Ni), copper (Cu), chromium (Cr), molybdenum (Mo), titanium (Ti), niobium (Ni) and vanadium (Va).

The majority of these elements have little influence on the metallurgy of the galvanizing process, with the exception of silicon and phosphorous. Each of these elements, individually or in combination, increase the reaction rate between the steel and the molten zinc to a point where at higher levels, their presence can give rise to very thick galvanized coatings.

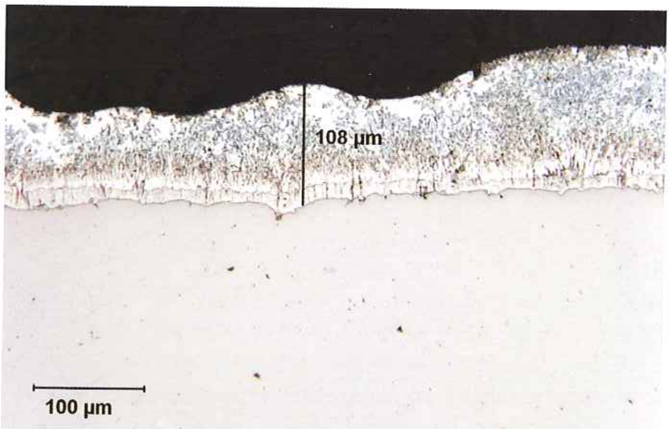
Extremely severe and nearly total delamination of the galvanized coating on these relatively small tube fabrications is a result of very reactive steel high in both silicon and phosphorous.



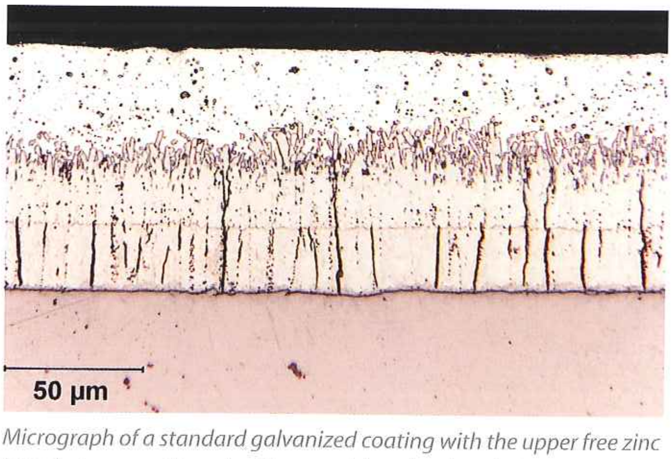
Steel with very low silicon content reacts more slowly with the molten zinc, producing thinner than normal coatings, as shown in this micrograph. The coating's alloy layer is 45 microns for a total thickness of 60 microns, about 25% thinner than standard.



Micrograph of a galvanized coating on very reactive steel. This coating will have a dull gray appearance.



Micrograph of a galvanized coating subject to striations. The variations in the galvanized coating are not reflected on the steel's surface.



Micrograph of a standard galvanized coating with the upper free zinc layer being smooth and uniform and the alloy layer being compact.

A significant amount of research has been done by the galvanizing industry and its affiliates into the effects of silicon and phosphorous levels on the galvanized coating. As long as the steel chemistry is known, the galvanizer can at least predict the outcome of galvanizing this reactive steel with a degree of confidence.

A factor called the silicon equivalent is used to determine steel reactivity to molten zinc. This factor is derived from the silicon content of the steel added to 2.5 times the phosphorous content. If the resulting number exceeds 0.25%, it is likely that the hot dip galvanized coating will be thick, fragile and possibly unsightly. High silicon/phosphorous levels can result in the galvanized coating being wholly or partly matt gray in appearance, rather than having a typically shiny appearance.

Most Australian-made steel are relatively low in phosphorous and silicon levels are controlled to ensure that few galvanizing problems arise. On the other hand, some steelmaking processes use aluminium rather than silicon as the de-oxidising agent and steel with very low silicon content will have very low reactivity with molten zinc. Galvanizing kettles are made from this very low silicon steel for that very reason.

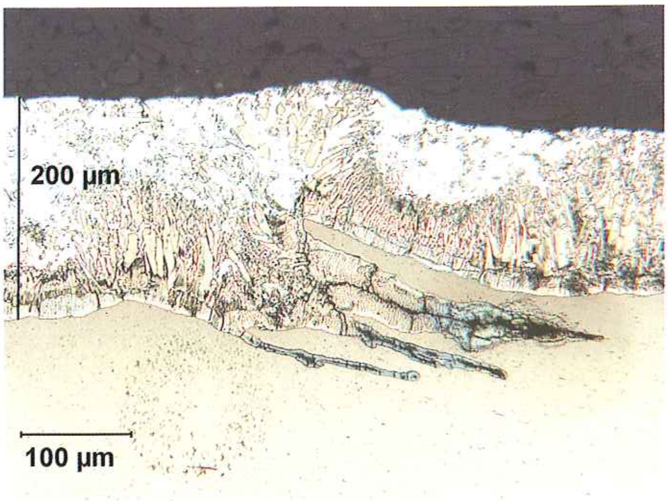
This type of steel will produce a smooth and shiny galvanized coating, but may struggle to produce a coating whose thickness will comply with Australian and international standards. As long as the galvanizer is aware of the chemistry of this type of steel, the hot dip galvanizing process can be modified to accommodate the lower reaction rate of the steel and produce a compliant galvanized coating.

Another phenomenon arising from the steel manufacturing process is the presence of stressed areas on the 'skin' of the steel arising from its being cold-worked in forming or rolling. The reaction between the molten zinc and the steel involves only a few microns of the steel's surface.

The stressed areas will have a different (usually higher) reaction rate that the adjoining unstressed area, and this will give rise to striations that usually run longitudinally along the section.

From time to time, particularly on large diameter pipes and other products manufactured from heavy rot rolled coil of plate, a phenomenon called 'fish-boning' may occur with the galvanized coating. This gives the coating a ribbed appearance with areas of different coating thickness running in roughly parallel lines down the surface of the section.

This is caused by the surface of the steel being activated by corrosion, which is caused by rainwater running over the surface of the steel section during prolonged outside storage prior to galvanizing. The pattern in the galvanized coating will closely match the pattern formed by areas of



Galvanized coating roughness, as shown in this micrograph, is a result of surface defects in the steel (shells and scales) that are not readily visible prior to galvanizing.

heavier corrosion arising from the water draining off the steel surface. This occurs although all the rust and corrosion products are removed from the steel's surface during the acid pickling process. It is an aesthetic issue and has no effect on coating durability.

DISTORTION

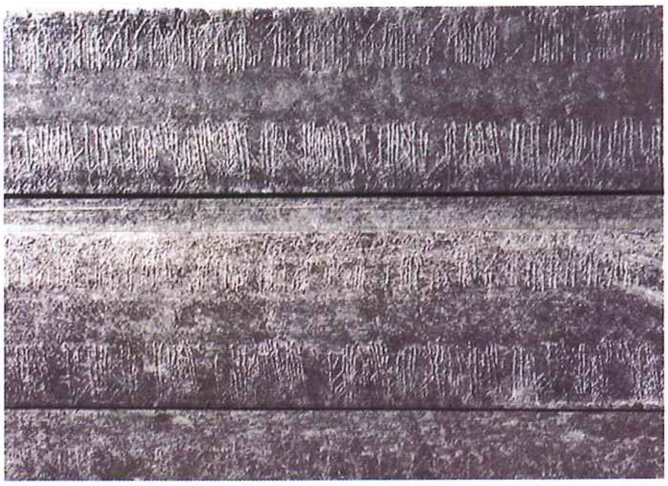
The dimensional stability of a fabrication during the galvanizing process, or lack thereof, has in the past been seen as detrimental to the specification of hot dip galvanized coatings. In the 21st Century, distortion during galvanizing is much less of an issue as both galvanizers and designers have a far greater understanding of the factors causing distortion in the galvanizing process.

Most steel fabrications have welding stresses built into them simply from the fabrication process. The temperature at which steel is galvanized (455°C) is well below the transition temperature for steel (about 750°C) but is high enough to normalise (stress relieve) the steel. Normal structural steel grades (250-350 MPa tensile) lose about 50% of their tensile properties at galvanizing temperature.

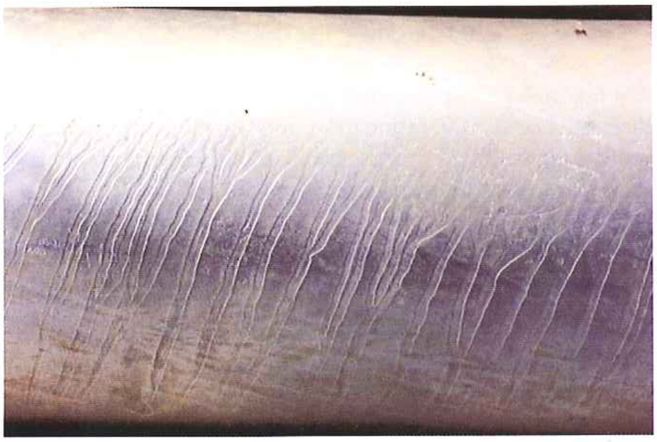
The steel rapidly regains its full strength at temperatures not much below 400°C, so differing steel sections that may have different cooling rates will generate tensile stresses in the fabrication that may exceed the strength of some of the components to resist. Distortion may result.

Large, light sections such are large diameter thin wall pipes may simply not be able to support their own weight when heated to 455°C and experience a 50% loss of their ambient temperature tensile properties. Such sections will require bracing during the galvanizing process to prevent their sagging out of shape.

Variations in galvanized coating appearance such as this are caused by the steel being in a reactive range due to its silicon content, causing some or all the free zinc on the coating's surface to be converted to zinc-alloy. These coatings are thicker than standard galvanized coatings.

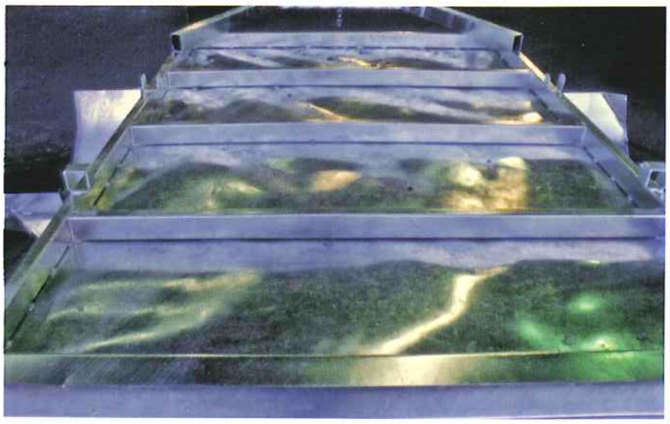


Lateral stress striations on this beam flange are caused by surface cold-working of the section during processing. The stressed areas galvanize at a different rate to the adjacent areas.



"Fishboning" of a galvanized coating on large pipes is a result of rust activation of the pipe surface during storage in wet conditions. While unsightly, durability is unaffected.

Some buckling of the plate used in the sides and bottom of this dumper bin has occurred, but is acceptable to the client because of the significant (up to 5x) service life of galvanized bins over painted items.



Distortion of this thin sheet used for a trailer floor cannot be avoided in the hot dip galvanizing process, but could be minimised by galvanizing the floor separate to the frame.

In most cases, distortion can be avoided or minimised by appropriate design and modifications to the galvanizing process to eliminate or reduce the distortion stresses. These techniques can include rapid immersion and withdrawal from the molten zinc to minimise the temperature differential across the fabrication, and the elimination of the chromate quenching process by air cooling the fabrication, to again minimise thermal stress across the fabrication.

WHITE STORAGE STAINING

White storage staining, or white rust, is a perpetual problem for not only hot dip galvanizing, but all galvanized coatings. It is also a politically difficult issue, as responsibility for the problem does not normally rest with the galvanizer. Galvanized items can be rendered unserviceable by severe white rusting caused by faulty storage and may require re-galvanizing.

The surface of galvanized coatings is almost 100% zinc. It is the durability of the zinc that provides the outstanding anti-corrosion performance for steel, yet zinc is a relatively 'reactive' metal. It is the stable oxides that form on the zinc's surface that determine its durability, and these oxides are formed progressively as the zinc is exposed to the atmosphere. Carbon dioxide in particular is a contributor to the formation of these stable oxides.

With newly galvanized steelwork, the zinc's surface has been subjected to little oxidation and is at its most vulnerable. For this reason, galvanizers use a chromate passivation process in conjunction with their galvanizing operations to provide protection to the galvanized coating during the 'youth' period of the coating. This passivation coating provides short-term protection to the zinc to give the stable oxides time to form on the surface.

Pure water (H_2O) contains no dissolved salts or minerals and zinc will react quickly with pure water to form zinc hydroxide, a bulky white and relatively unstable oxide of zinc. Where freshly galvanized steel is exposed to pure water (rain, dew or condensation), in an oxygen deficient environment, the water will continue to react with the zinc and progressively consume the coating. The most common condition in which white rust occurs is with galvanized products that are nested together, tightly packed, or when water can penetrate between the items and remain for extended periods.

There are a number of simple steps that can greatly reduce or eliminate the formation of white rust. These are:

- Keep the packed work dry
- Pack the items to permit air circulation between the surfaces
- Stack the packed items to allow water to drain out.
- Treat the surface with proprietary water repellent or barrier coatings to prevent moisture contact with galvanized surface

The following treatments are recommended to deal with white rust on galvanized products.

Light White Rusting

This is characterised by the formation of a light film of white powdery residue that frequently occurs on freshly galvanized products during periods of heavy rain. It is particularly evident on areas that have been buffed or filed during quality assurance operations. These treatments remove the passivated surface from the galvanizing and expose unoxidised zinc to attack from rainwater. Provided the items are well ventilated and well drained, white rust rarely progresses past this superficial stage. It can be brushed off if required but will generally wash off in service with normal weathering. No remedial treatment is generally required at this level.

Moderate White Rusting

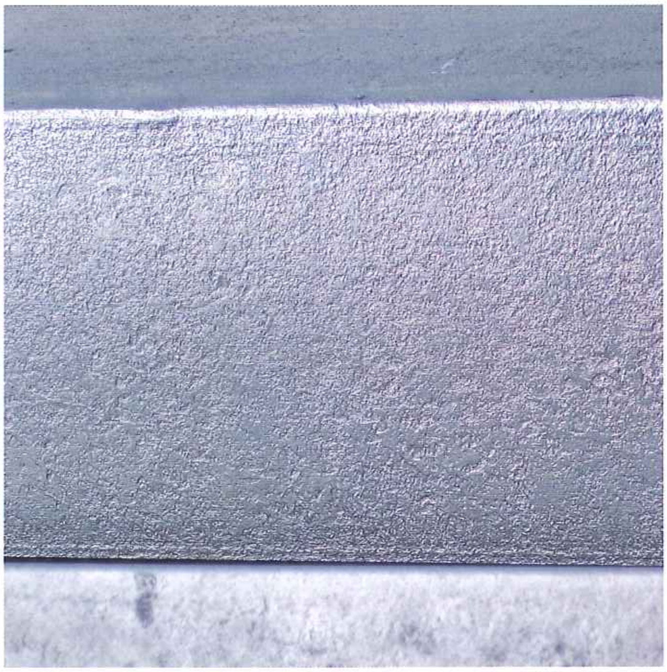
This is characterised by a noticeable darkening and apparent etching of the galvanized coating under the affected area, with the white rust formation appearing bulky. The galvanized coating thickness should be checked to determine the extent of attack on the coating. In the majority of cases, less than 5% of the galvanized coating will have been removed and thus no remedial work should be required, as long as the appearance of the affected area is not detrimental to the use of the product and the zinc hydroxide residues are removed by wire brushing. If appearance is unacceptable, the white rust affected area can be treated as follows:

- Wire brush the affected area to remove all white corrosion products
- Using a cloth pad, wet with aluminium paint, rub the surface with the pad to apply a thin film of aluminium paint to the affected area to blend it with the adjacent unaffected galvanized surfaces

Severe White Rusting

This is characterised by very heavy oxide deposits. Items may be stuck together. Areas under the oxidised area may be almost black of show signs of red rust. A coating thickness check will determine the extent to which the galvanized coating has been damaged. Remedial treatment to reinstate the coating should be undertaken as follows:

- Wire brush or buff the affected area to remove all oxidation products and rust if any
- Apply one or two coats of approved epoxy zinc-rich paint to achieve required dry film thickness of 100 microns minimum



Rough textured galvanized surface on the flange of this hot-rolled beam is a result of the condition of the original rough steel surface.

Severe white rusting of these corrugated hot dip galvanized sheets, intended for an architectural application, was caused through being stored in packs during very wet weather over the Christmas holiday shutdown period.

Careful handling has allowed these large panel frames to be satisfactorily hot dip galvanized with no distortion problems. Fast Immersion, slow cooling and proper stacking contribute to a good result.

Chemical Removal of White Rust

Zinc hydroxide dissolves readily in weak acidic solutions. A research project was undertaken by the American Galvanizers Association in 2007 to evaluate white rust removal methods. A number of commercially available cleaning products were evaluated, along with generic solutions. Due to the tests being done in the USA, a number of these products may not be available locally.

Of the generic products that can be used to successfully remove white rust deposits from galvanized steel, white vinegar was found to be very effective and environmentally benign. Application can be done with a nylon brush (a dishwashing brush can be used) and any residues can be rinsed off with clean water after treatment.

A commercial product that is also available in Australia that was also found to be effective, is CLR Clear, which has been widely advertised as a scale and stain removal product. Its application is similar to that of white vinegar, although the manufacturer's safety recommendations should be adhered to in the use and disposal of the product.

APPEARANCE VERSUS PERFORMANCE

The immersion of irregularly shaped fabrications into a bath of molten zinc will result in the formation of a coating which is unlikely to be particularly smooth and uniform, and may also give rise to other coating issues that can be classified as defects or anomalies. These defects or anomalies can include:

- Drips, runs and drainage spikes
- Misses in the coating because of air locks, poor surface preparation or surface contamination
- Puddling of zinc in corners
- Touch marks in the coating from jigs and handling equipment
- Blinding or restriction of holes and perforations
- Thick or mottled coatings
- Striations or significant adjacent coating thickness variations
- Flaking or delamination of the galvanized coating

Some of these anomalies are unavoidable and arise from steel chemistry characteristics, design details or, in the case of touch marks, the need to handle the work safely through the galvanizing process.

In most instances, the less aesthetically appealing the galvanized coating, the longer it is likely to last, as gray or mottled galvanized coatings are usually caused by more reactive steel developing thicker alloy layers and thus, thicker coatings.

Where the base steel is exposed, appropriate touch up will be required. The industry standard is to use an approved high quality epoxy zinc-rick paint, applied to at least the equivalent thickness of the existing galvanized coating.

Another example of rust activation of the steel surface caused by fabrications being stored outside during rainy periods. The patterns in the break-down of the mill scale is reflected in the raised areas of the galvanized coating in the differentially rusted zones on the steel surface.

Where maximum durability is required, the thicker the galvanized coating applied, the better. However, there is a practical limit, because the alloy layers in the galvanized coating that make up the majority of the coating are metallurgically quite different in their mechanical properties than both the base steel and the free zinc that is on the surface of the coating.

Once the thickness of a hot dip galvanized coating exceeds about 250 microns, the coating is likely to become more fragile and susceptible to mechanical damage, and in the worst case, subject to delamination from the steel's surface.

If a fabrication is required to be galvanized to an 'architectural' standard, close attention needs to be given to the design detailing and steel chemistry to minimise or eliminate touch marks, drainage runs and variations in coating appearance due to steel chemistry. These parameters are well understood within the galvanizing industry.

Experienced galvanizers are well versed in the causes and effects of their process, and are always willing to work with specifiers, designers and fabricators to ensure that the hot dip galvanized coating that they supply satisfies the needs of their clients.