

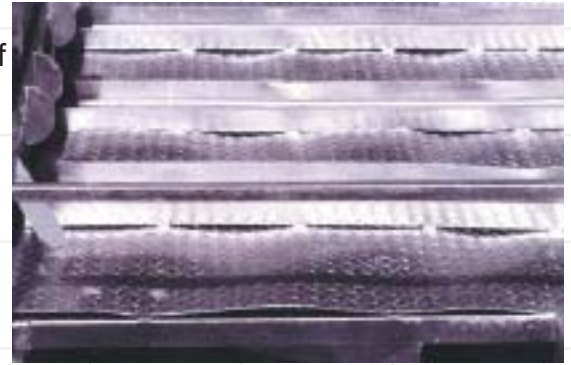
# 18. GALVANIZED COATING DEFECTS

## INTRODUCTION

Unlike many manufacturing processes, the hot dip galvanizing of fabricated steelwork involves many variables that can impact on the appearance and characteristics of the finished product.

Hot dip galvanizing is primarily an industrial protective coating process designed to provide a tough and durable protective coating for steel that will generally outlast the design life of the structure to which it is applied.

The variables inherent in the process can each affect the appearance of the galvanized product. Many of these variables are classified as 'coating defects'. Most are esthetic and do not affect the performance of the galvanizing as an anti-corrosion coating.



*Distortion of thin checker plate welded to heavier supporting members can be reduced by fixing the checker plate after galvanizing*

## FACTORS AFFECTING HOT DIP GALVANIZED COATINGS

The factors affecting hot dip the appearance and characteristics of hot dip galvanized coatings include:

- The size and shape of the item
- The steel chemistry
- The steel surface condition
- The design of the item with respect to
- The metallurgy of the galvanizing process.

The hot dip galvanizing process involves immersing steel items in molten zinc at 450°C after pre-treatment to remove organic materials, rust and mill scale. This hot dipping process, where the steel is immersed in the molten zinc for several minutes, gives the galvanized coating its unique characteristics.

## SIZE & SHAPE OF THE ITEM

Zinc freezes at 420°C, so there is very little superheat in the molten zinc as the item is withdrawn from the bath of molten zinc. Thicker sections will retain their heat longer and promote better drainage of the molten zinc from their surfaces than thinner sections.

The angle with which the work can be withdrawn from the bath will influence the drainage characteristics. One-dimensional items that are short enough to dip vertically will produce smoother and more uniform coatings than 2- or 3-dimensional items where some surfaces will be at shallow withdrawal angles from the molten zinc.

## THE STEEL CHEMISTRY

The rate at which molten zinc reacts with steel to form the galvanized coating is dependent on the steel chemistry. Pure iron has a very low reaction rate and for this reason, galvanizing kettles are manufactured from steel of this type.

Structural grades of steel always contains alloying elements, the most common of which are carbon, manganese and silicon. Sulfur and phosphorous are residual elements arising from the raw material used to make the steel, although some special steels have these elements added deliberately.

Of these elements, silicon and phosphorous have the most significant effect on the galvanized coating's characteristics, with silicon being the most common steel alloying additive affecting coating appearance.

High silicon levels (above 0.20%) may result in the galvanized coating have a duller or matt gray appearance, or a blotchy variable appearance.

High phosphorous levels (not normally found in structural steels) can give rise to dark gray or browning coatings that are prone to delamination from the steel's surface.

### STEEL SURFACE CONDITION

The surface condition of the steel will be reflected in the galvanized coating in two ways. Rougher surfaces have a higher surface area per unit of surface and thus generate thicker galvanized coatings. Hot rolled sections typically produce hot dip galvanized coatings 30-50% thicker than smooth, cold rolled surfaces.

Galvanized coatings on steel with gross surface defects such as pitting will conform to the defects and follow the surface profile of the steel.

While the coating will provide the same degree of protection from corrosion, the appearance may not be acceptable to the end-user and thus steel surface quality is an issue where the highest standards of surface appearance are required.

### DESIGN OF THE ITEM FOR GALVANIZING

The design of a fabrication is critical in determining the surface quality of the finished product. Unless the pre-treatment chemicals can penetrate to all surfaces of the item, the inaccessible surfaces will not be galvanized.

Conversely, if the molten zinc cannot completely drain from the work, zinc puddles will freeze in pockets and cause problems.

The techniques of designing for galvanizing are well understood by galvanizers and consultation in the design stage of fabrication will always result in a better quality outcome.

The main issues to be addressed in designing for galvanizing to minimise defects are as follows:

1. The item needs to be suspended during galvanizing. The provision of lifting lugs to eliminate touch marks from wire or chains is an example of design improving quality.
2. The item needs to be have adequate venting and draining provisions to ensure the smooth flow of zinc into and out of the item.
3. The dimensions of the item need to comfortably fit within the bath dimensions to allow adequate withdrawal angles. Double dipping of the item will frequently produce a better quality than single dipping an item that can be barely submerged in the bath.

### THE METALLURGY OF THE GALVANIZING PROCESS

Many of the surface imperfections that are characteristic of hot dip galvanized coatings are a function



*Drainage spikes will always occur where edges are parallel to the molten zinc surface. These are removed by grinding or filing during the inspection process.*



*Blinding of small holes (6mm or under) will occur because of the surface tension of the molten zinc. This can be minimised by detailed attention to the item as it emerges from the molten zinc.*

of the metallurgy associated with the process.

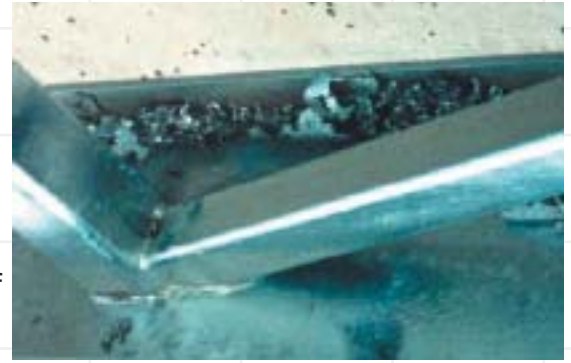
Prior to galvanizing, the steel is chemically pre-treated and at the final stage, is immersed in a zinc ammonium chloride (ZAC) preflux solution. This process puts a thin film of ZAC crystals on the steel surface.

When the steel is immersed in the molten zinc bath, a number of reactions take place. These are:

1. The preflux is activated by the molten zinc and performs a final cleaning action on the steel surface. Oxidation products are produced by this reaction that contain a combination of zinc chloride and zinc oxide. These oxidation products are lighter than zinc and float to the surface. This is called zinc ash.
2. When the steel reaches galvanizing bath temperature, the zinc reacts with the steel to form a series of zinc-iron alloys. Some of these zinc-iron alloy crystals float off the surface of the steel and enter the zinc bath.
3. The zinc bath becomes saturated with iron in solution, either from work entering the bath or from the steel galvanizing kettle. This saturation level is typically about 250 parts of iron per million at galvanizing temperature.
4. Over time, these zinc-iron crystals coalesce and sink to the bottom of the zinc bath. This forms a mushy layer called 'dross'. The dross is periodically removed by scooping it from the bath with special equipment. Zinc dross is crystalline and has a much higher melting point than zinc (650°C versus 420°C).
5. The molten zinc surface is constantly oxidising, and this oxide film is always present on the zinc surface to a greater or lesser degree.

In the process of galvanizing a steel fabrication, the presence of ash and dross may have the following effects on the appearance of the hot dip galvanized coating:

- If the item comes in contact with the dross layer in the bottom of the bath, the dross can get caught in or on the work and form a rough, lumpy deposit.
- If areas of the item are inaccessible for skimming, ash may stick to the surface of the galvanizing as it is withdrawn from the bath.
- If the rate of withdrawal varies or stops during the extraction of the galvanized item from the bath, tide marks (oxide lines) may appear on the surface of the galvanizing causing variations in the shiny appearance of the coating.
- With smooth-surfaced work such as tanks or large diameter pipes, dross crystals floating in the bath may be caught up on the galvanized coating. These 'dross pimples' give the coating a gritty appearance.



*Blinding of small holes (6mm or under) will occur because of the surface tension of the molten zinc. This can be minimised by detailed attention to the item as it emerges from the molten zinc.*

### STEEL DEFECTS AND THEIR EFFECTS ON GALVANIZED COATINGS

Hot dip galvanized coatings, as described above, are not 'coatings' in the conventional sense, but



alloys that form on the steel to make the galvanized steel item a composite material.

As such, galvanized coatings, unlike paint coatings are not very effective at covering up defects in the steel, and are more likely to highlight steel surface quality problems.

Steel, like most manufactured products, can be prone to a variety of common defects, most of which are associated with the casting, rolling and manufacturing processes.

The surface area of the steel per unit of area has a significant effect on how the zinc reacts with the steel to form the galvanized coating. Rough surfaces will react more vigorously than smooth surfaces to form thicker galvanized coatings.

Hot rolled surfaces with mill scale may have 30 to 50% more surface area per unit than smooth, cold rolled surfaces. Abrasive blasting will artificially increase surface roughness and is a way to deliberately increase coating thickness for heavy duty applications.

Galvanized coatings are totally unlike paint films in the way in which they conform to sharp edges or corners. The surface tension effects with paint films tend to thin the paint film out over corners and edges.

Hot dip galvanized coatings,, on the other hand, tend to be thicker on edges and corners because the crystals in the alloy layer can flare out and have more room to grow around the corner radius.

For this reason, hot dip galvanized coatings may exaggerate the appearance of defects where rolling defects cause sharp ridges on the steel surface.

Small particles or slivers of steel can be rolled into the steel's surface, and these may be almost invisible to the naked eye. However, when the steel is pickled and the surrounding oxide is removed from these shells and scales, as they are called, the galvanized coating can take on a pimply appearance as the zinc reacts more quickly with these small, loosely attached steel slivers.

The manufacturing operations performed on some steel sections can also show up in the form of visual defects, the most common of these being striations. These are narrow (typically about 1-2 mm wide) longitudinal raised lines in the coating usually running the full length of the section.

The most common cause of striations is stress lines on the surface of the steel caused by cold working of the section. Heavy gauge rod will sometimes show a spiral striation pattern arising from the rod or wire being passed through a roller/straightener prior to final manufacture.

Welded sections will frequently have much thicker coatings in the weld areas. While this is rarely a problem on structural steel sections, it can cause aesthetic problems on high quality fabrications such as wrought iron and security doors, where the welds have been ground flush and the item is to be painted after galvanizing.

This phenomenon is caused by the differing chemistry of the weld metal compared to the parent metal. Most weld metals contain high levels of silicon, and the higher silicon in the weld metal will result in thicker (sometimes 3-4X as thick) galvanized coatings.



*Threaded items will usually require post-galvanizing treatment to clean the threads of zinc. This can be done by reheating the threads to galvanizing temperature (450oC), then removing the excess zinc by wire brushing.*

A reverse of this phenomenon can occur where heavier steel sections (over 12mm) are flame-cut. The edges of flanges of welded beams are a common example

The flame cut edges of these heavy plate sections will frequently show a wide variation in coating thickness from zone to zone in the flame-cut area.

This is caused by irregular oxidation of some of the constituents in the steel on the surface, giving the flame cut surface a variable metallurgy compared to the parent metal. The zinc coating in these flame cut areas may appear as a series of sharply defined plateaus, with low thickness coatings where significant oxidation has taken place, and normal coating thickness, typically well over the minimum standard required, in less affected areas.

### EMBRITTLEMENT

Embrittlement of steel as a result of the hot dip galvanizing process is rarely encountered with structural grades of steel. However, the use of higher-strength steel grades or inappropriate fabrication techniques can lead to embrittlement problems with galvanized steel.

There are three types of embrittlement encountered in the hot dip galvanizing process. These are:

1. Hydrogen embrittlement
2. Strain-age embrittlement
3. Liquid metal embrittlement

Hydrogen embrittlement is most commonly encountered and affects susceptible steel whose yield strength is above 800 MPa.

Hydrogen atoms from the acid pickling process penetrate the grain boundaries of these high strength steels and can cause brittle fractures under certain conditions. Many high strength steels can be galvanized and standard pre- or post-galvanizing treatments are available to eliminate the risk of hydrogen embrittlement.

Consultation with the galvanizer is essential where fabrications involving the use of high-strength steel are involved.

Strain-age embrittlement is caused by excessive cold working of the steel prior to galvanizing. The heat of the galvanizing process accelerates the embrittlement, so susceptible steels present a long-term embrittlement risk, even if they were not galvanized. Localised heating of severely cold worked steels through welding may also precipitate strain-ageing failure.

Bending steel through too tight a radius, re-bending already cold worked steel, or hole punching through thick sections are all manufacturing processes that can give rise to strain-age embrittlement problems.

Many manufacturing standards for products such as re-bar address this issue within the standard,



*The fracture of Bisalloy wear plate is a result of Hydrogen embrittlement arising from the pickling process. High strength (over 800 MPa) steel is susceptible to this type of embrittlement.*



*These lateral striations are a result of surface stresses in the steel section cause by the rolling process reacting at a higher rate with the molten zinc than the surrounding steel.*

and fabricators and manufacturers who abide by established practices and use appropriate steel grades rarely experience problems.

Liquid metal embrittlement is specific to certain types of steels that are infrequently encountered in the galvanizing process. The most susceptible are many grades of stainless steel that from time to time, are attached to mild steel assemblies as fittings or components.

The molten zinc penetrates the grain boundaries of these steels and fracture under load may result. If the use of stainless steel components is required, mechanical attachments after galvanizing is strongly recommended.

### **DISTORTION**

Distortion in galvanizing is one of the most common causes for concern, In practice, a small proportion of fabricated items are prone to distortion during the galvanizing process.

Some items will always represent a high risk of distortion, and the galvanizer is well aware of the types of steel sections that are prone to distortion.

There are three significant causes of distortion with steel sections. These are:

1. The thickness and shape of the section being galvanized.
2. The design of the fabrication with respect to location of welds, symmetry and fabrication stresses present prior to galvanizing.
3. The way the work is handled during the galvanizing process.

It is the heat of the galvanizing process and the manner it is transferred and withdrawn from the steel during processing that determines the dimensional stability of an item being galvanized.

The work has to be heated from around ambient temperature to 450°C almost instantaneously as it enters the molten zinc.

Not all of the item is heated at the same time as it has to be lowered into the bath at a rate that is safe for the operators and consistent with the ability of the molten zinc to flow over and into the item.

At the galvanizing temperature, steel loses 50% of its yield strength, and regains it as it cools down. Much research has been done on the effect of the galvanizing process on steel strength, and this has revealed that there is no measurable loss, and in most cases, there is a slight increase, in yield strength after galvanizing.



*The 'white rust' on these galvanized flat bar sections has been caused by their being wet in the bundle. Galvanized coatings require good ventilation when newly applied to allow the passive oxide films to develop.*



*Dross pimples on this pipe spool arise from dross crystals being stirred up from the bottom of the galvanizing bath by long or deep items. Appearance is unsightly but durability is unaffected.*



*Hydrogen embrittlement failure of Herculloy chain is caused by exposing this 1200 MPa steel to pickling acid. These types of steels should not be galvanized.*



Thin plate sections are most prone to distortion, and this is caused by the rapid differential heating and cooling of the sections, and its relative weakness as a thin section.

Thin steel that has been processed into hollow sections or cold-formed structural shapes is much more stable and is routinely galvanized without problems. Corrugating thin sheet will also largely eliminate the tendency to distort.

Fabrications that are asymmetrical, or have significant welding on one side of the section are in a highly stressed state due to the heat effects of the welding processes. Hot dip galvanizing will stress relieve these sections and distortions may result, typically cambering or sweeping of beam sections.

Fabrications containing elements of significantly different section thickness are another potential problem area, and high stresses can be generated during the heating and cooling cycle that may cause distortion due to differential heating and cooling.

Platforms with checker plate welded to structural framing are a common problem area that can be avoided by galvanizing the thin and thick sections as separate elements.

The galvanizer has the responsibility to handle the work in a way that will reduce the risk of distortion. Locating lifting points located at the optimum points to support the fabrication so that its own unsupported weight does not contribute to it bending or sagging during galvanizing is a galvanizers' responsibility.

The way the item is immersed in the molten zinc and the post galvanizing quenching process may also have an influence on the dimensional stability of the finished product. Competent galvanizers should be aware of these issues and be prepared to advise the client on design details that can minimise distortion problems.

Where distortion is unavoidable, particularly with products such as waste bins and trailers, clients are now prepared to accept the appearance of the thin metal plate sections because of the dramatic increase in service life provided by the coating.

The acceptance of unavoidable distortion during hot dip galvanizing will thus always be a trade-off between appearance and performance. Only the client can decide.

### PICKLING CORROSION

Hydrochloric acid is used for pickling steel prior to galvanizing. Some galvanizers add inhibitor to the acid but most operate at acid concentration levels of around 10%.

At this level, the acid will efficiently attack and dissolve rust and mill scale but will not react with the base steel at a very high rate.

The exception is with high sulfur steel. The main application for these types of steel is for small part manufacture of machined



*This miss in the galvanized coating is caused by surface contamination by residual oxides not removed in the pickling process.*



*Zinc run caused by zinc freezing while draining from flat RHS surface. Durability is enhanced but thick runs may interfere with connecting surfaces*

components.

The sulfur is added to the steel to weaken its grain structure so that during high speed machining operations, the chips break off in short sections and facilitate the machining operations.

These steels are used for non-critical components such as threaded fittings and repetition machined steel non-stressed components.

From time to time, threaded fitting such as sockets, spigots, nipples and bushes are welded into fabricated assemblies.

Attack by the acid on these threaded components can quickly dissolve the threads and render the item unserviceable.

The corrosion of the threaded area may also be caused by zinc attack in the galvanizing bath, but it is largely a function of acid attack during the pickling process.

### **BLOWOUTS AND BLEEDING**

Molten zinc at galvanizing temperature is only about 30 degrees above its freezing point. The viscosity of the molten metal limits its ability to penetrate small cavities and crevices, and gaps less than 1 mm in width may not allow penetration by the molten zinc.

Many fabricated items have overlapping surfaces, and during the pre-treatment process, pretreatment chemicals will penetrate these overlaps and may not drain out because of surface tension holding the liquor in place.

When the item enters the galvanizing bath, any moisture trapped in these crevices will rapidly boil and eject steam and pretreatment residues onto the adjacent surface of the work.

This contamination interferes with the zinc's ability to react with the steel and uncoated areas adjacent to these 'blowouts' will result.

Another defect arising from unsealed overlapping surfaces is the 'bleeding' which occurs out of the overlap after galvanizing.

This is commonly referred to as 'acid staining'. Hydrochloric acid vaporises at below 200 degrees C so there is never any acid residues left in or on the item after galvanizing.

The staining that occurs is caused by flux residues that have been desiccated by the heat of the galvanizing process, re-hydrating from contact with atmospheric moisture.

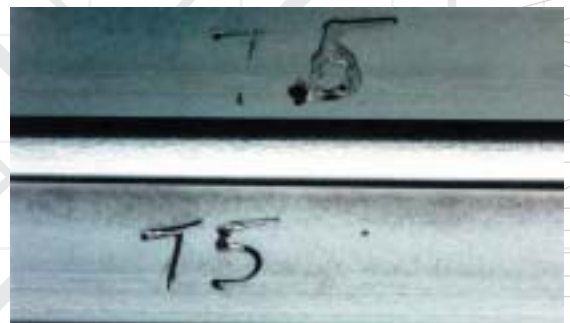
The brown liquor bleeding from overlaps is not particularly aggressive to zinc but causes unsightly



*Flux staining has occurred on unsealed vent holes in overlaps on this fabrication. The stains are caused by iron salts, that have penetrated the overlap during pre-treatment, re-hydrating with atmospheric moisture.*



*The gray coating on these pipes is a result of high silicon content of the steel, making it more reactive and converting all the coating to zinc-iron alloy. These gray coatings are typically thicker than shiny galvanized coatings on similar sections.*



*This miss in the galvanized coating is caused by surface contamination by an incorrect type of marking paint that is resistant to removal by pre-treatment chemicals.*



staining of the work and highlight the lack of a galvanized coating, and a potential for corrosion, in the uncoated overlap area.

### FLAKING

Flaking of galvanized coatings can occur on reactive steels which produce thick alloy layers in the galvanizing process.

On thick reactive steel, coating thicknesses in the order of 300-500 microns may be produced. These alloy layers are very hard and inflexible and differential expansion or contraction of the steel can cause areas of the alloy layers to shear off the steel surface.

Localised flaking can occur with these types of coatings if there are subject to impact or point pressure from lifting slings or handling equipment. Flaking can be minimised by quick cooling of the work after it exits the galvanizing bath but may be aggravated by slow air-cooling.

Modification of standard galvanizing practice in handling reactive steel sections prone to flaking will generally minimise the risk of delamination of heavy coatings after galvanizing, but careful design is required to ensure that the items can be immersed and withdrawn from the molten zinc as quickly as possible.

### WHITE RUST

Zinc is a reactive metal, relying on the development of inert complex carbonate oxide films for its excellent atmospheric corrosion resistance.

When freshly galvanized steel is exposed to pure water (rain, dew, condensation), the zinc will react with the water to form zinc hydroxide, a characteristically bulky white deposit.

If the zinc surface remains wet and cannot get access to good air circulation (the main source of carbon dioxide to form the stable oxide films), the water will continue to react with the zinc and can severely damage the coating at worst and result in unsightly staining at best.

Most galvanizers post-treat items with a chromate solution integral with the quenching process. This provides a short-term passivating film on the zinc surface that will prevent white rusting in the event of wet weather.

The main white rusting problems arise where galvanized work is stacked or packed in tightly nested bundles, where water can be trapped and air circulation is poor.

Additional post-treatments that provide more durable protection from white rust over time can be arranged in consultation with the galvanizer, usually at an additional small cost.



*The textured surface on this steel angle results from the rough as-rolled surface of the base steel, usually cause by excessive mill-scale on the steel section in the hot rolling process.*



*Fishbone striations on large diameter pipes arise from surface stresses in the steel causing different zinc-steel reaction rates on the pipe surface.*



*Thin, flat sheet will always buckle in the galvanizing process. Corrugating or ribbing of these type of sections will significantly reduce the likelihood of distortion during galvanizing.*

Exposure to sea water will also rapidly promote white rust, and for this reason, it is recommended that galvanized products such as boat trailers be washed down with fresh water after each salt water immersion.

Leaving salt water to dry on the surface will accelerate the consumption of the galvanized coating as the chlorides will strip the stable carbonate film from the surface.

### **PINHOLING**

On some fabrications, particularly welded beams and heavier sections that have been assembled using submerged arc welding techniques, the weld areas may show evidence of a series of small pinholes along the weld bead. These pinholes are generally less than 1mm in diameter.

The small size of the pinholes, combined with the thickness of the galvanized coating on the weld metal (typically 200 microns or more) means that they have no measurable effect on coating performance.

The cause of this phenomenon has been attributed to small particles of sub-arc welding slag powder being fused into the weld surface. These refractory particles are not affected by the pre-treatment processes and remain on the surface throughout the galvanizing process and form small barriers to the galvanized coating's formation.

### **PUDDLING, DROSS & SPLATTER**

Puddling caused by poor drainage, dross caught in an item, and splatter from the zinc bath ending up in or on the surface of the galvanized item are processing issues. Some of these, such as removal of splatter, are dealt with the inspection/QA stage. Design issues are the main cause of puddling and can only be eliminated by good design.

### **CONCLUSION**

With the exception of blowouts and bleeding, and where the galvanized coating is missing, most galvanizing defects have no effect on the coatings' durability. In fact, many 'defects', because they result in thickening of the coating or deposition of much more zinc or zinc-rich residues, coating life may be increased significantly.

For example, a dull or mottled galvanized coating may be 2X or 3X as thick as a standard shiny coating that complies with the relevant standard. The thicker gray coatings will thus have a coating life 2X or 3X as long as the standard coating.

Where aesthetic issues are involved, hot dip galvanized coatings can only deliver a level of quality within the limitations of the process.



*Where jigs are used to support large items in the galvanizing processes, touch marks will occur where the galvanized coating adheres to the jig at the point of contact.*



*Weld splatter left on the steel will be galvanized along with the work, resulting in a rough and pimply appearance.*



*This small RHS section has severe galvanized coating delamination arising from very high phosphorous levels in the steel, creating a thick, fragile coating almost 1000 microns in thickness.*

However, an understanding of the issues of design, steel composition and the hot dip galvanizing process will go a long way to ensure that hot dip galvanized coatings on structural fabrications can be produced to a standard that will satisfy architectural applications.







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# 01 - SPECIFIERS MANUAL – THIRD EDITION

Industrial Galvanizers Australian Galvanizing Division (IGAG) operates nine galvanizing plants around Australia, ranging in size from large structural galvanizing facilities to specialised small plants designed to process small parts.

The Australian Galvanizing Division has galvanized in excess of 2 million tonnes of steel products in Australia since its first plant was commissioned in 1965 and is recognized for its ability to handle complex and difficult projects, as well as routine contracts.

This experience has been collated in the Specifiers Design Manual, to assist those involved in the design of steel products and projects to better understanding the galvanizing process and allow the most durable and cost-effective solutions to be delivered to these products and projects. All sections of this Third Edition have been completely updated and additional sections have been included to provide additional technical information related to the use of hot dip galvanized steel.

In addition to its Australian Galvanizing operations, Industrial Galvanizers Corporation has a network of manufacturing operations in Australia, as well as galvanizing and manufacturing businesses throughout Asia and in the USA.

The company's staff in all these locations will be pleased to assist with advice on design and performance of hot dip galvanized coatings and products. Contact details for each of these locations are located elsewhere in this manual.

This edition of the Industrial Galvanizers Specifiers Manual has been produced in both html and .pdf formats for ease of access and distribution and all documents in the Manual are in .pdf format and can be printed if paper documents are required.

The Specifiers Manual is also accessible in its entirety on the company's web site at [www.ingal.com.au](http://www.ingal.com.au).

Additional copies of the Specifiers Manual are available on CD on request.

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