INDUSTRIAL GALVANIZERS
SPECIFIERS MANUAL

A **valmont** COMPANY

CONTENTS

Industrial Galvanizers Corporation (IGC) 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 2.5 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 Fourth Edition have been revised to provide additional technical information related to the use of hot dip galvanized steel.

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.**

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Industrial Galvanizers has galvanizing plants in Brisbane QLD (2), Townsville QLD, Newcastle NSW, Sydney NSW, Port Kembla NSW, Melbourne VIC, and Launceston TAS. Additional special galvanizing facilities for galvanizing small parts (centrifuge plants) are located with the structural galvanizing facilities in Brisbane, Sydney and Melbourne.

Each plant provides transport services to customers with a fleet of table-top trucks and semi-trailers.

The sales staff at each plant location can provide advice on designing fabrications for galvanizing, and will provide design literature on request, free of charge.

Industrial Galvanizers also provides a comprehensive technical service through its web site at www.ingal.com.au. As well as having a large database of specific galvanizing and anti-corrosion design and specification information, the site has a contact facility where technical questions on project specific galvanizing issues can be dealt with directly by one of the division's technical authorities.

Industrial Galvanizers has developed a Corrosion Mapping System, which can also be accessed through the Industrial Galvanizers' web page. The Corrosion Mapping System allows accurate assessment of corrosivity (and the durability of galvanized coatings) using proprietary CSIRO atmospheric modeling technology to define the corrosivity of atmospheres at any location in Australia.

The strategic location of Industrial Galvanizers plants in major centers throughout Australia allows large and complex projects to be galvanized efficiently through one or more facilities simultaneously.

The Industrial Galvanizers plant have the capacity to handle very heavy fabrications (up to 20 tonnes) through large galvanizing baths; while plants in Sydney, Melbourne and Brisbane have specialised centrifuge plants designed to efficiently handle the galvanizing of small parts.

Most Industrial Galvanizers' sites have installed heavy lifting facilities that allow full loads of structural steel to be unloaded and loaded quickly.

Industrial Galvanizers Pinkenba Qld plant was the first to offer the Silver Bullet Service – overnight turnaround on steelwork to be galvanized.

This 10 tonne pole section was galvanized using the heavy lifting capacity of the Industrial Galvanizers' Newcastle plant.

In addition, the Industrial Galvanizers Melbourne plant has a specialised facility for hot dip galvanizing LPG gas bottles.

Each of these operations has experienced sales staff available to assist customers with the design of items for galvanizing, scheduling of work and co-ordination of special requirements for specific projects.

The company offers a range of special services to customers, including:

- The Silver Bullet Service – where urgent steel fabrications can be processed in less than 24 hours.
- Storage of completed work to match customer construction/distribution requirements.
- Packaging of galvanized product for transport and distribution.
- Coating Guarantees, typically 25-50 years, on specific projects.
- Custom Coating Packages – galvanized coating options above and beyond Australian Standards.
- On-line technical support – technical inquiries answered on the Industrial Galvanizers web site customer contact form.

Specialised centrifuge facilities are available in Industrial Galvanizers' plants in Melbourne, Sydney and Brisbane, to process large quantities of small parts for the manufacturing industry in those regions.

Complex items like this large cooling coil are technically difficult to galvanize, as heavy ballast is required to immerse the tubular assemblies that are full of air, into the molten zinc. Industrial galvanizers has developed special handling equipment to process

INDUSTRIAL GALVANIZERS LOCATIONS AND CONTACT DETAILS

Location and contact	Actual Bath dimensions metres l-w-d	Maximum lifting capacity	Maximum dipping length
Industrial Galvanizers (Sydney) 20-22 Amax Ave GIRRAWEEN 2145 Ph: 02 9636 8244 Fax: 02 499631 8615	12.5 x 1.8 x 2.6 6.7 x 1.2 x 1.6	6 tonnes Centrifuge only	20 metres
Industrial Galvanizers (Port Kembla) Lot 2, Shellharbour Rd PORT KEMBLA 2505 Ph: 02 42758888 Fax: 02 42758889	7.2 x 1.3 x 1.8	2 tonnes	11 metres
Industrial Galvanizers (Pinkenba) Cnr. Holt St. and Curtin Ave PINKENBA 4008 Ph: 07 3632 7700 Fax: 07 38597452	10.5 x 2.0 x 2.6	6.4 tonnes	18 metres
Industrial Galvanizers (Carole Park) Cnr. Boundary Rd and Cobalt St CAROLE PARK 4300 Ph: 07 3632 7700 Fax: 07 3718 2599	12.5 x 2.0 x 2.6 4.5 x 1.2 x 1.6	4.4 tonnes Centrifuge only	18 metres
Industrial Galvanizers (North Queensland) 9 Commercial Ave, Industrial Estate BOHLE 4818 Ph: 07 4774 8333 Fax: 07 4774 8444	9.5 x 1.6 x 2.1	4 tonnes	15 metres
Industrial Galvanizers (Newcastle) 312 Pacific hwy HEXHAM 2322 Ph: Ph: 02 4967 9099 Fax: 02 4964 8705	14.5 x 2.0 x 2.85	20 tonnes	19 metres
Industrial Galvanizers (Melbourne) 5 Lara Waym CAMPBELLFIELD 3082 Ph: 03 9358 6200 2866 Fax: 03 9358 6230	12.5 x 2.0 x 2.95 8.0 x 1.2 x 1.8	10 tonnes Centrifuge only	20 metres
Industrial Galvanizers (Tasmania) 2 Donald Ave PROSPECT VALE 7250 Ph: 03 6345 7500 Fax: 6344 7691	6.5 x 1.05 x 1.4	4 tonnes	9.5 metres

1. INTRODUCTION

With any applied coating, the quality of the surface preparation is the most important factor in determining whether the coating will perform for its expected design life. With paint coatings in particular, almost all failures are due to poor surface preparation. Longer maintenance free performance is being demanded of protective coatings, and environmental and heritage issues increasingly impact upon surface preparation technology. The specification and quality assurance of surface preparation thus require as much attention as the priming and top coating systems. There are no shortcuts to good surface preparation and the costs of premature failure render the savings associated with cheap surface preparation insignificant.

2. INITIAL SURFACE CONDITION

SURFACE PREPARATION

Rust is an oxide of iron formed by the action of air and water. It is voluminous and occupies one and three-quarter times the volume of the steel from which it originated. Rust forming under a paint coating, or through breaks in the coating, can burst through and may creep under the coating resulting in flaking so that repair is both difficult and costly.

Proper surface preparation is essential for the success of any protective coating scheme. The importance of removing oil, grease, old coatings and surface contaminants (such as mill scale and rust on steel, laitance on concrete and zinc salts on galvanized surfaces) cannot be over emphasised.

The performance of any paint coating is directly dependent upon the correct and thorough preparation of the surface prior to coating.

The most expensive and technologically advanced coating system WILL fail if the surface pre-treatment is incorrect or incomplete.

DEGREASING AND PRELIMINARY SURFACE PREPARATION

Organic Solvents

Aliphatic and aromatic solvents will remove most process oil and grease. It is not always appropriate to use these solvents because of fire, pollution or occupational health hazards. Statutory environmental requirements will generally require recovery of used solvents and solvent degreasing is best suited to controlled static manufacturing operations.

Detergent Degreasers

Spray or dip application is the best method for using detergent degreasers. There are many types of detergent degreasers. Many are alkaline and most require rinsing with clean water after application. Galvanizing plants use hot (70°C) caustic degreasing tanks for paint removal as well as degreasing. Containment of the detergent cleaning residues is a mandatory requirement as strict controls on such industrial waste products are now almost universal.

Steam Cleaning

Steam cleaning is well suited to small parts or machinery. Steam alone is unlikely to dislodge the lubricants used to grease working machinery. For more highly efficient steam cleaning of oil and grease from work¬ing machinery, a detergent is typically added. Operating conditions may be between 690-1,034 KPa and 60-71° C

These steel bridge railings have been abrasive blasted prior to coating but have flash-rusted, requiring further surface treatment prior to coating

Newer Methods

Among the newer methods available for grease and oil removal from working machinery are ice blasting, carbon dioxide pellet blasting, abrasive blasting with rubberized pellets, and blasting with a sodium bicarbonate slurry.

- **Ice Blasting** – Ice crystals generated within the blasting equipment are used as the abrasive media. Ice blasting is well suited to the removal of contaminants from softer substrates such as aluminium or brickwork that would be damaged by conventional abrasives.

- **Carbon Dioxide Blasting** - The principle of operation of this method involves solidification and erosion/abrasion of oil or grease from the structure. The operating conditions are typical of abrasive blasting with nozzle pressures at or near 550 KPa. Feed rates for the CO_2 are measured as a few kg per minute. The primary benefit claimed for this method is that the clean up required is very limited because the CO_2 sublimes to a gas after hitting the substrate, leaving only the removed oil and grease.

- **Rubber Pellet Blasting** - Blasting with pellets of rubbery polyurethane foam has been identified as a versatile method for a number of cleaning operations. Like CO_2 blasting, this method is said to dramatically reduce the need for clean-up of fractured abrasive. The principle involves the sponging of the oil or grease from the surface into pores on the foam pellets. The pellets change shape when they hit the metal surface, and grease or oil is squeezed into the pores of the rubbery foam. Operating conditions are quite mild, with nozzle pressures around 30-60 psi (200-400 kPa) being common.

- **Sodium Bicarbonate Slurry Blasting** - Several types of this method exist. A super-saturated slurry of baking soda in water is projected at the work piece with nozzle pressures of 85 -100 psi (586-690 kPa).

Rust and Scale Removal

The various methods of preparing steel for subsequent painting are given in Australian Standard 1627 Parts 0 to 10, issued by the Standards Association of Australia, with reference to pictorial standards depicted in Aust. Standard 1627.9 . It is strongly recommended that the appropriate Standard be stated to define clearly the degree of surface preparation required. Australian Standard 2312-2002, Guide to the Protection of Iron and Steel Against Exterior Atmospheric Corrosion also provides a comprehensive guide to surface treatment in Section 5 of that Standard.

It is essential to remove all oil, grease, drilling and cutting compounds and other surface contaminants prior to further surface preparation or painting of the steel. The most common method is by solvent washing, followed by wiping dry with clean rags. The wiping clean is critical, because if this is not carried out thoroughly the result of solvent washing will simply spread the contamination over a wider area. Proprietary emulsions, degreasing compounds and steam cleaning are also commonly used. Recommended procedures are described in Australian Standard 1627, Part 1 and in the above section of this article.

Processes like hot dip galvanizing use in-line pretreatment systems that remove all organic contaminants from the steel surface by immersion in a hot caustic solution prior to pickling off the mill scale and rust.

These galvanized conveyor frames are being brush-blasted prior to the application of a heavy-duty paint coating. This is a very effective surface treatment for painting over galvanized surfaces.

Hand Tool Cleaning

Hand tool cleaning is defined as a method of preparing new, corroded or previously painted steel surfaces prior to painting by removing loose mill scale, loose rust and loose paint by using hand wire brushing, hand sanding, hand scraping hand chipping or a combination of these methods. Preliminary cleaning of large deposits of oil or grease, soluble fluxes and fume deposits from areas adjacent to weld runs should be carried out by solvent or detergent cleaning, detailed in Australian Standard 1627 Part 1 or by fresh water washing as appropriate.

Three standards of surface preparation are defined:

Class 1:   is produced by "light wire brushing' to at least as good as Standard St 1 of AS1627.9.
Class 2:   is produced by "thorough scraping and wire brushing", and heavy rust scale first removed by hand hammering, The prepared surface to he at least as good as Standard St 2 of AS 1627.9.
Class 3:   is produced by "very thorough scraping and wire brushing", any heavy rust scale being first removed by hand hammering. The prepared surface to be at least as good as Standard St 3 of AS1627.9.

Hand tool cleaning should only be specified for normal atmospheric exposures and interiors when the painting system includes a primer of good wetting ability. Hand cleaning will not remove all residues of rust, nor will it remove firmly adherent mill scale, and particularly corrosive salts such as chlorides and sulfates.

These highway safety rail posts have suffered 100% failure of their powder coating because of inadequate pre-treatment of the hot dip galvanized surface to which they have been applied.

Power Tool Cleaning

When removal of rust and mill scale is required, other Australian Standards; Power Tool Cleaning 1627.2, Blast Cleaning 1627.4, or Pickling 1627.5 should be considered.

(a)   Power Tool Cleaning is defined as a method of preparing new, corroded or previously painted steel surface prior to painting by removing loose mill scale, loose rust, loose paint and all welding scale with power impact tools, power grinders, power sanders, power wire brushes or a combination of these tools. Tightly adhering mill scale and rust in deep pits will not normally be removed by this method of cleaning. Care should be taken not to polish the metal surface as this may reduce the key for subsequent coating.

(b)   All surfaces to be coated shall be cleaned by the use of power-driven tools according to Australian Standard 1627 Part 2. Reference is made to Pictorial Standards of original unpainted surfaces of Australian Standard 1627.9 and to painted surfaces with varying amounts of visible rust, the amount rated typified by the Reference Standards of Australian Standard 1580 Method 481,3.

(c)   Three standards of preparation are defined -

Class 1:   is produced by power wire brushes only
Class 2:   is produced by power impact tools followed by a light wire brushing
Class 3:   is produced by power impact tools or power sanders, followed by light wire brushing.

Flame Cleaning

Flame cleaning is affected by the use of high velocity, high temperature oxy-fuel gas flames over the surface to be treated. It is slightly more effective than power rod cleaning and covered by Australian Standard AS1627, Part 3. It is expensive and has inherent risks of fire and explosion, and of possible distortion to light gauge steel. It is generally used for cleaning corroded and previously painted steel.

Pickling

Pickling may be carried out by any of the methods using either acid, alkaline or electrolytic baths, or in combination, provided adequate precautions are observed to:

(a) Ensure sufficient inhibitor has been added to minimise attack on the base metal when pickling in acid solutions. NOTE: Hydrochloric acid is much less aggressive on the base steel than sulfuric and generally does not require an inhibitor if used at concentrations under 15%.

(b) Acid pickling or cathodic treatment methods are not used on steel having a tensile strength greater then 800 MPA. This precaution is necessary to prevent hydrogen absorption and subsequent embrittlement that may result in fracture due to hydrogen cracking.

The pickled steel must be thoroughly rinsed of residual acid and will require passivation treatment with phosphate or other appropriate medium to prevent re-rusting. This is not required for hot dip galvanizing as the steel is normally fluxed and galvanized immediately after pickling.

The hot dip galvanizing process uses chemical pretreatment. Close control of the pre-treatment chemistry ensures reliable galvanized coating application.

Blast cleaning

By far the most effective method for removal of mill scale, rust, and old coatings is through the use of abrasives such as slag, grit or shot transported by high pressure air. There are four commonly used grades of blast cleaning, and the approximate equivalents between the various International Standards are as follows:

Aust. Std 1627.4	US Spec SSPC NACE	British Std BS4232	Swedish Std SIS 05-5900
White metal	Class 3	SP-11 NACE -1	1st Quality Sa 3
Near white metal	Class 2 1/2	SP-3 NACE - 2	2nd Quality Sa 2 1/2
Commercial blast	Class 2	SP-2 NACE - 3	3rd Quality Sa 2
Brush blast	Class 1	NACE - 4	Sa 1

Australian Standard 1627.4 describes the correct practice to be followed in abrasive blast cleaning and details the various qualities of blast. All surfaces should be cleaned free of oil and grease before blasting. Australian Standard 1627 Part 9 provides pictorial representations of four different rust grades on steel that has been previously rusted as well as new steel. Pictorial representations are then given showing the appearance of each when blasted to any of the four classes of preparation.

The grade of blasting suitable for a particular coating specification depends on a number of factors, the most important of which is the type of coating system selected.

Prior to blasting, steelwork should be degreased and all weld spatter removed. If grease or oil is present on the surface it will appear to be removed by the blasting process, but this is not the case.

Although not visible, the contamination will still be present as a thin layer, and will affect the adhesion of subsequent coatings. The presence of residual chlorides on the surface of rusted steel will create a problem with subsequent coating operations, as the blasting will not remove these chlorides from the surface. Test procedures for chloride detection have been established and high-pressure water blasting after dry blasting may be required to reduce chlorides to acceptable levels. Weld seams and sharp edges should be ground down. This is because paint coatings tend to run away from sharp edges, resulting in thin coatings and reduced protection. Weld spatter is almost impossible to coat evenly, in addition to often being loosely adherent, and if not removed is a common cause of premature coating failure.

The profile or roughness obtained during blasting is important, and will depend on the abrasive used, the air pressure and the technique of blasting. Too low a profile may not provide a sufficient key for a coating, while too high a profile may result in uneven coverage of high, sharp peaks which will protrude through the applied paint film, possibly leading to premature coating failure, particularly for thin coatings such as blast primers. The following table gives a brief guide to typical roughness profiles obtained using various types of abrasive.

Type or Abrasive	Mesh Size	Max Height of Profile
Very fine sand	80	37 micrometers
Coarse sand	12	70 micrometers
Iron shot	14	90 micrometers
Typical non-metallic "copper slag"	75	100 micrometers
Iron grit No. G16	12	200 micrometers

Wet abrasive blasting
Wet abrasive blasting uses a slurry of water and abrasive rather than dry abrasive alone. This has the advantage that the hazards of dust and associated health problems are largely overcome. A further important advantage is that when wet blasting old, well rusted surfaces, many of the soluble corrosion products in the pits of the steel will be washed out, which will greatly improve

the performance of the following paint system. However, a disadvantage of this technique is that the cleaned steel begins to rust rapidly after blasting.

It is therefore common practice to include proprietary inhibitors in the blast water that will prevent this rusting for a sufficient time to allow painting to be carried out. In general, the use of very low levels of such inhibitors does not affect the performance of subsequent paint coatings for non-immersed steel work. The use of a moisture tolerant primer, which can be applied to wet blasted steel while it is still damp, can make the use of inhibitors unnecessary.

Where wet blasted surfaces have been allowed to corrode, they should be mechanically cleaned or preferably sweep blasted, to remove the corrosion prior to painting unless a surface tolerant paint has been specified.

High Pressure Fresh Water Cleaning
A number of factors influence the results obtained by high-pressure water washing. There are no recognised standards of surface cleaning - as exist for grit blasting - and it is difficult to predict the outcome of a cleaning procedure.

Pressures used range from 70kg/cm^2 to 2800kg/cm^2 (1000 psi to 40000 psi) and volumes of throughput also vary considerably.

High-pressure washing can also he used to clean corroded areas and has been used as an alternative to grit blasting. The result depends to a very large extent on the condition of the surface. Compact corrosion scale cannot be completely removed at a reasonable rate until pressures exceed 2100 kg/cm^2 (30,000 psi).

Vacuum Blasting
Vacuum blasting, which eliminates the dust hazard, has a relatively slow rate of cleaning, but is ideal for cleaning limited areas, such as welds and burn damage when open blasting may seriously damage the intact surrounding coating. The abrasive is driven by compressed air into a specially designed head held on the steel surface, where, as soon as it strikes the surface it is sucked back into the machine for separation of the dust and re-use of the abrasive.

Wet Blasting (Hydro blasting)

Water and abrasive are now more commonly used to clean surfaces. There are two main methods available:

(1) High pressure water + grit : this system is essentially a fan-jet washing type of equipment (approx.140kg/cm^2 with small amounts of abrasive present in the fan). It is useful for the controlled removal of particular coats of paint but a very slow method for total removal of paint to bare steel as the quantity of abrasive used is normally only 25% of that consumed by dry blasting.

(2) Abrasive blasting + water injection : the abrasive stream is shrouded in water by the injection of a small amount of water at the blasting nozzle. Production rates are similar to dry blasting.

The main advantages of these systems are that they cut down air pollution, compared to dry blasting, and eliminate contamination of nearby machinery by abrasive dust. Wet blasting has also proved an excellent tool when preparing old steel that is heavily contaminated with soluble salts, particularly chlorides.

The main draw back of wet blasting is that the steel exposed flash rusts on drying. This can be prevented by the introduction of a rust inhibitor in the water; these inhibitors are usually water soluble inorganic materials.

3. ABRASIVE CHARACTERISTICS

The highest quality applied paint coatings require the highest quality surface preparation, and a Class 2½ blast is a minimum requirement for maximum coating performance. The characteristics of the abrasive will influence the nature of the blasted surface and thus the ultimate performance of the coating.

The abrasive blast cleaning industry borrows heavily from the terminology of the geological sciences. The concept of relative hardness adopted by the abrasive industry is taken from a term from mineralogy called the "Mohs number" developed by Friedreich Mohs, a nineteenth century German mineralogist. His scale of hardness for 10 common minerals (talc is the softest rated at 1 and diamond is the hardest rated at 10) is widely used to set minimum limits on this property.

Abrasives for blasting generally have a hardness greater than 6.0 on the Mohs scale. Silica sand has a hardness of 7.0 and garnet has a Mohs number of 7.5. Diamond is arbitrarily set at 10.

Grain shape will influence the performance of the abrasive on the steel surface. Rounded or smooth grains have a peening effect on the steel. Angular or sharp edges grains will produce a sharper profile.

The shape of the abrasive grain affects the performance of the media. Very angular grains may tend to break down more readily than rounded grains, forming greater amounts of dust. More rounded grains may present a larger surface area for contact with the steel, resulting in surface profiles that are deeper than expected. Like the size and hardness of an abrasive, grain shape can influence materials consumption, waste minimization, dust generation, environmental compliance, and surface profile. All of these items significantly affect total project cost.

4. ABRASIVE BLASTING & OCCUPATIONAL HEALTH

The occupational health and safety risks associated with abrasive blasting are well established, although requirement may vary from state to state. Silica sand in not a permissible abrasive in many areas unless it is used under strict environmental control standards. The ethics of awarding contracts to low cost tenders who use cheap (silica sand) abrasives and do not comply with accepted OH&S industry standards are questionable.

Blast cleaning involves propelling abrasive media at speeds in excess of 175 km per hour and turning paint, rust, and substrate surfaces into a dust cloud consisting of many air-borne particles. In fact, if a particle size analysis of the air-borne particles generated from blast cleaning process is done, dust particles ranging in size from less than 1 micron to 1,000 microns could be found. One micron is 1/1000th of a millimetre. The smallest size particle that the unaided eye can see is generally accepted to be around 50 microns.

However, dust particles 10 microns and smaller are the only dust particles small enough to reach the deep inner regions of the lung. As particle size increases above 10 microns, particles are more likely to be arrested in the upper respiratory system and be either swallowed or expelled. (In the case of lead dust particles, this is one way for lead to be inadvertently ingested and be absorbed in the gastrointestinal system). Thus the dust particles that cannot be seen may be the most dangerous, not the big particles that are visible in most dust clouds.

Whether or not any of the air-borne dust particles are a potential health hazard depends not only on the size of the dust particles but also on the toxicity of the materials in the dust cloud and the amount of dust breathed into the respiratory system. This depends on the size of the dust particles in the work area and the concentration (total amount) of dust present. The toxicity of the particles in the dust cloud depends upon several other factors.

Air-borne dust generated from a blasting process may consist of broken down abrasive, pulverized surface coating, and abraded material from the object being blasted. The potential toxicity of each component in the dust cloud can be determined by reviewing material safety data sheets (MSDS) for the abrasive in use, and reviewing specific information on the chemical content of any old coatings being removed, as well as identifying the chemical make-up of the substrate or object being cleaned.

Some dusts are termed "nuisance" dusts. They produce little adverse effect to the body unless the airborne concentration is so high that it defeats the normal clearance mechanisms of the lungs. Other dusts are highly toxic to the body, such as dust from silica sand.

5. CONCLUSION

Almost all steel that is coated required some type of surface preparation and the quality of surface preparation is the single most important factor in determining coating reliability. 95% of all paint failures are caused by inadequate or poor quality surface preparation. The environmental responsibilities associated with maintenance painting and the impact of environmental legislation on paint technology will make adequate surface preparation even more important in the understanding of coating performance and the management of corrosion.

INTRODUCTION
Bolting of galvanized steel structures is the most common method of assembly. It is an obvious requirement that the bolts used in these connections are galvanized to the same standard as the structural steel. For reasons related to the galvanizing process, the durability of the galvanized bolts will rarely match that of the galvanized steel to which they are attached.

STANDARDS
There are a number of Australian Standards related to the fastening of structural steel and the requirements that need to be satisfied in designing these structures.

AS 4100:1998 Steel Structures, details the requirements for joint performance. There are no special requirements where the bolted connections rely on bolt bearing only and galvanized steel can be treated identically to uncoated or painted steel with bearing bolt connections.

Where friction grip connections are required, AS 4100 nominates a slip factor of 0.35 (coefficient of friction) for clean, as rolled surfaces with tightly adherent mill scale. In friction-bolted joints, all loads in the plane of the joint are transferred by friction between the mating surfaces.

Other current standards that are relevant to bolting of galvanized structures include:

1. AS 1214:1983 – Hot-dip galvanized coatings on threaded fasteners (ISO metric coarse series)
2. AS/NZS 1559:1997 – Hot-dip galvanized steel bolts with associated nuts and washers for tower contruction.
3. AS/NZS 1252:1996 – High-strength steel bolts with associated nuts and washers for structural engineering.

Bolted connections on electrical transmission towers have their own standard for xbolts in these critical galvanized structures.

The Sydney Olympic Shooting Centre is an excellent example of a significant bolted galvanized structure where fast erection and low long-term maintenance were a requirement of the design.

4. AS 1111.1:2000 – ISO Metric hexagon bolts and screws – Production grade C – Bolts.
5. AS 1111.2:2000 - ISO Metric hexagon bolts and screws – Production grade C – Screws
6. AS 4100:1998 – Steel structures
7. AS 4100:1999 – Supplement 1 -Steel structures commentary
8. AS 1237.1:2002 – Plain washers for metric bolts, screws and nuts for general purposes. General plan.
9. AS 1237.2 – Plain washers for metric bolts, screws and nuts for general purpose.Tolerances.
10. AS/NZS 1390:1997 – Cup head bolts with ISO metric coarse thread pitches.
11. AS 4291.1:2000 – Mechanical properties of fasteners made of carbon steel and alloy steel – Bolts, screws and studs.

FRICTION-GRIP BOLTED CONNECTIONS
The load in friction-bolted connection is dependent on the clamping force applied by the bolts and the slip factor of the mating surfaces.
Hot-dip galvanized coatings on structural steel require special treatment to ensure that the 0.35 design factor is satisfied. While the hot-dip galvanized coating is largely made up of zinc-iron alloys, the surface of the coating is pure zinc, which is relatively soft and malleable.

As a result, pre-tensioned bolts used in friction grip connections may be subject to relaxation of bolt tension. For this reason, the connecting surfaces of hot-dip galvanized structural elements can satisfy the slip factor requirements using three techniques.

These are:

1. Buffing the connecting surfaces during final inspection to roughen the surfaces and remove the thin layer of free zinc.
2. Modifying the cooling of the steel to produce a galvanized coating that is 100% alloy layer, characterised by a matt gray, rather than a shiny surface finish.
3. Brush abrasive blasting the connecting surfaces to remove some of the free zinc layer and profile the surfaces.

TREATMENT OF FRICTION GRIP BOLTED SURFACES

To achieve a coefficient of friction exceeding 0.35 for the friction grip bolted connections on the galvanized structure, the following procedures are recommended.

1. Buffing the connecting surfaces to remove any surface irregularities and to roughen the surface. This should be done using an air grinder of a type equivalent to a Model SP-1222SD 125 mm high-speed grinder (max rpm 15,000). The grinder should be used with a flexible backing pad and 36 grit resin grinding discs. This process should not remove more than 10% of the galvanized coating. This proportion of the coating comprises the free zinc layer. The balance of the coating is made up of much harder zinc-iron alloys, which are not subject to plastic deformation. This ensures that bolt relaxation will not occur after torqueing of the friction grip bolts.

2. Whip blasting the connecting surfaces will roughen the surface to ensure that the design levels for coefficient of friction are satisfied. However, whip blasting will not remove zinc lumps and drainage spikes if they are present on the connecting surfaces.

Where the hot dip galvanizing process generates gray coloured coatings, the surfaces are deemed to comply with the 0.35 coefficient of friction minimum requirement for friction grip bolted connections.

The recommended specification for whip blasting (to prevent damage to the galvanized coating) is as follows:

(a) Use fine abrasives of a size which will pass through a test sieve of nominal aperture size 150 microns to 180 microns (80 to 100 mesh), e.g. ilmenite or garnet.
(b) Use a venturi nozzle which has an orifice diameter of 10 mm to 13 mm.
(c) Set the blast pressure at 275 kPa (40 p.s.i) maximum. Keep the venturi nozzle at a distance of 350 mm to 400 mm from the surface of the work piece and at an angle no greater than 45° to the surface.

DURABILITY OF FASTENERS

While structural steel is galvanized by immersing it in a molten zinc bath for periods up to 10 minutes, (depending on the section size) fasteners are hot dip galvanized in small batches in metal baskets using a centrifuge operation. After removal from the molten zinc, the baskets are spun at high revolutions to throw off the excess zinc and produce fasteners with clean threads.

For this reason, the minimum specified coating mass for structural bolts exceeding 8 mm in diameter is 390 g/m^2 or 55 microns in thickness. The process also allows this thickness to be closely controlled because of the standardised product being galvanized.

The minimum specified coating mass for steel over 6 mm in thickness is 600 g/m^2, or 85 microns in thickness. In practice, the hot-dip galvanized coating on hot rolled structural sections will comfortably exceed this minimum specification and will typically be in the order of 700-900 g/m^2 (100-125 microns in thickness).

As galvanized coating life is a function of the coating thickness, the bolts in any galvanized structure will always be the first to require maintenance. The condition of the galvanized coating on structural bolts will generally provide an indication of the remaining service life of the galvanized coating on the structure. If the galvanized bolts on a structure show signs of early corrosion, the likely remaining life of the coating on the structure should be in the order of an additional 30-50% of that on the bolts.

INTRODUCTION

The use of steel underground is not new. There are many applications where steel is used in the ground, from simple applications like signposts and fence posts, to engineered applications like piling and foundations. Over the past decade, new applications have been developed for steel foundation products. These products offer significant performance and cost advantages over traditional masonry and timber alternatives.

Alternative methods of installing steel utility poles for lighting and power distribution have been developed using direct embedded poles to reduce the installation costs and environmental impact of installation.

It is not practical to install expensive corrosion management technologies on many of these embedded steel products, as is the case for more critical infrastructure such as pipelines and tunnels. An understanding of the mechanism of corrosion will allow a predictable life to be designed into utility steel products that are to be used in-ground for new piers, piling and pole applications. This article has consolidated information from a number of authoritative sources to assist in evaluating the life of steel in-ground products.

STEEL CORROSION IN-GROUND

In the atmosphere, most materials have predictable modes of corrosion that are largely dependent on pollution levels, temperature and relative humidity. Once the important parameters are identified, the mechanism of metallic corrosion will then be common to all the products that are within that climatic zone.

In-ground situations are vastly different because of the wide local variations in soil chemistry, moisture content and conductivity that will affect the way coated or uncoated steel will perform in the ground.

Research into steel corrosion in soil started in the early years of the 20th century, when Melvin Romanoff began a study for the National Bureau of Standards that continued for over 40 years. Many other corrosion-in- soil research projects were undertaken concurrently or subsequently. Much of this activity has taken place in Australia sponsored by various road authorities and private enterprise companies such as BlueScope Steel

Galvanized steel poles have been direct buried for many years. BlueScope Steel's newly developed Sureline pole is designed for a minimum of 50 years in-ground service, using heavy galvanized coatings and membrane systems at the ground line.

and Ingal Civil Products, in evaluating in-ground corrosion performance on a range of products from culverts to piling.

Corrosion of metals in soil is extremely variable and while the soil environment is a complex one, it is possible to draw some conclusions about soil types and corrosion.

Any given soil will appear as a very heterogeneous electrolyte which consists of three phases:

- The solid phase made up of the soil particles which will vary in size and will vary in chemical composition and level of entrained organic matter.
- The aqueous phase which is the soil moisture - the vehicle which will allow corrosion to take place.
- The gaseous phase which consists of air contained in the soil's pores. Some of this air may dissolve in the aqueous phase.

THE SOLID PHASE

Soils are commonly classified according to the general size range of their particulate component. Sandy, silty and clay soils are thus identified from the predominant size range of their inorganic particles. Convention classifies particles over 0.07mm to around 2mm as sands, particles from 0.005mm to 0.07mm as silts and 0.005mm smaller as clays. Soils rarely exist with only one of these components present.

The various groups of sand, silt and clay make up the soil classifications on the basis of their particle size.

Clay soils are characterised by their ability to absorb water readily, the level of which is determined by the nature of the clay. For this reason, clay soils present a significantly higher corrosion risk than sandy soils. For this reason also, the nature of the soil on the surface may not reflect its nature below the ground.

THE AQUEOUS PHASE

Corrosion will only occur in the presence of moisture that contains ions that will transmit the electric current maintaining corrosion activity. There are several types of soil moisture. These are:

- free ground water
- gravitational water
- capillary water.

The free ground water is determined by the water table, which may range from near ground level to many metres below the surface. This is the least important factor in determining corrosion of buried steel as most installations are above normal water tables. Where high water tables bring ground water in contact with embedded steel, corrosion will progress as if the steel were in an immersed environment.

Gravitational water arises from rainfall or man-made irrigation and will soak into the soil at a rate determined by its permeability. This will increase the period of wetness of the steel's surface and this in turn will impact on the soil's corrosive effects, depending on the conductivity of the gravitational water. Where regular rainfall occurs, most soluble salts may be leached from the soil over time, which

INGAL Civil Products has been installing buried galvanized structures for over 60 years. Performance monitoring of installed structures has indicated significantly better performance than originally expected.

will reduce the corrosive effects of gravitational water. Gravitational water will ultimately end up in the water table.

Capillary water is water that is entrained in the pores and on the surfaces of the soil particles. The ability of soil to retain moisture is obviously important to plant growth. It is the capillary water that is the prime source of moisture in determining corrosion rates of steel in soil.

The fluctuations in water content in soil due to precipitation and evaporation cause a variation in oxygen content, as drier soils allow more oxygen access and oxygen concentration cell formation may be enhanced.

SOIL CHEMISTRY

Acid or alkaline conditions develop in the soils depending in their parent rock and the geological or man-made activity that may impact on them over time. Most soils are in the pH range of pH 5.0 to pH 8.0. Highly acidic soils are relatively rare, and generally occur in swamp soils or areas subjected to high accumulations of acidic plant material such as pine needles.

Soluble salts are essential to plant growth and are a major factor in corrosion. These salts may include salts of potassium, sodium, calcium and magnesium. Salts such as calcium and magnesium, while initially promoting corrosion, frequently act beneficially as their insoluble oxides and carbonates become corrosion inhibitors over time.

Bacteria in soil is another factor that is important in corrosion activity. Sulfates can promote rapid bacteriological corrosion of steel because of sulphate reducing bacteria. Hydrocarbon-using bacteria can also accelerate failure of organic coatings used underground.

Soil has to be able to conduct electricity to participate in the corrosion of buried steel. The resistivity of the soil is used as an important measure of soil corrosivity. The higher the resistivity, the more the resistance to current flow moving between anodic and cathodic regions of the steel.

Regions of moderate or high rainfall will commonly have low levels of soluble salts in the soil, while desert soils may have very high salt levels.

Some of the most aggressive soils in Australia are located in desert areas like the Simpson Desert clay pans, which have higher corrosion rates for galvanized coatings than many surf-side environments.

ESTIMATING SOIL CORROSIVITY

A great deal of case history data and specific research has been accumulated and this is invaluable in evaluating the potential for corrosion for various types of buried structures. While there is no easy answers, the German Gas and Water Works Engineers Association has developed a standard soil corrosivity assessment technique which rates the various factors that influence corrosion of steel in the ground detrimentally or beneficially. The sum of these factors gives an approximate corrosion rating.

TABLE 1
SOIL CORROSIVITY ASSESSMENT TECHNIQUE

Item	Measured value	Mark
Soil Composition	Calcareous, marly limestone, sandy marl, not stratified sand.	+2
	Loam, sandy loam (loam content 755 or less), marly loam sandy clay soil (silt content 75% or less)	0
	Clay, marly clay, humus	-2
	Peat, thick loam, marshy soil	-4
Ground Water	None	0
	Exist	-1
	Vary	-2
Resistivity	10,000 ohm.cm or more	0
	10,000 - 5,000	-1
	5,000 - 2,300	-2
	2,300 - 1,000	-3
	1,000 or less	-4
Moisture content	20% or less	0
	20% or more	-1
pH	6 or more	0
	6 or less	-2
Sulphide and hydrogen sulphide	None	0
	Trace	-2
	Exist	-4
Carbonate	5% or more	+2
	5 - 1%	+1
	1% or less	0
Chloride	100 mg/kg or less	0
	100 mg/kg or more	+1

TABLE 1 continued
SOIL CORROSIVITY ASSESSMENT TECHNIQUE

Item	Measured value	Mark
Sulphate	200 mg/kg or less 200 - 500 mg/kg 500 - 1000 mg/kg 1000 mg/kg or more	0 -1 -2 -3
Cinder and coke	None Exist	0 -4
Soil Rating	0 or above - Non-corrosive 0 to -4 - Slightly corrosive -5 to -10 - Corrosive -10 or less - Highly corrosive	

CORROSION CASE HISTORIES

While corrosion rates can be estimated using theoretical assessment, the one certainty is that in real life, the unexpected will always happen. For this reason, case history studies are very important for establishing performance benchmarks. Interest in the corrosion of steel buried structures has always been maintained, and a constant stream of information from a wide variety of sources is available.

There are two issues that determine the life of buried steel. The first is the life of the protective coating and the second is the corrosion rate of the steel. The item can be deemed to have failed when the steel loss is sufficient to prevent the steel performing its structural function.

Where polymer coatings are applied to buried steel items, most commonly pipelines, the failures are rarely caused by general deterioration of the coating. Localised failure due to holes in the coating, or pin holing, or large-scale corrosion related to electrolysis are common causes of failure in these installations.

Metallic coatings, specifically galvanizing, and to a lesser extent aluminium, fail through progressive consumption of the coating by oxidation or chemical degradation. The rate of degradation is approximately linear, and with galvanized coatings of known thickness, the life of the galvanized coating then becomes a function of the coating thickness and the corrosion rate.

Steel corrosion can be assessed similarly, although the body of case history evidence indicates that corrosion rates of steel in soil decrease with time as corrosion products block access of the corrodants to the steel surface. Studies of steel piling corrosion in the USA in severe environments have shown initial corrosion rates exceeding 100 microns per year in the first two years of service, falling to an average of 50 microns per year over the first 20 years to stabilise at 25 microns per year after that.

BlueScope Steel has done extensive testing of its steel piles over a number of years and has drawn the following conclusions based on case history measurements of piles in Victoria:

Corrosion rate of steel in undisturbed soil/compacted fill - 10-20 microns per year

Corrosion rates of steel in fill sites - low compaction   - 20-30 microns per year

Corrosion rates of steel in fill sites subject to tidal movement - 30-50 microns per year.

CORROSION RATES AND AUSTRALIAN STANDARDS

The use of corrugated steel culverts has been long established in Australia. A standard has been developed and the most recent revision, AS/NZS 2041:1-2011, contains a significant amount of useful information in its Appendix E on durability issues.

There are a number of informative tables in this Standard that address corrosion issues for a variety of coatings as well as the base steel. These tables base corrosion rates on soil resistivity and pH as well as soil classifications. These tables nominate corrosion rates for galvanized coating from around 3 microns per year in well drained soils with neutral pH to over 20 microns per year in undrained acidic (pH<4) soils.

Metal loss for steel is nominated at less than 10 microns per year in well-drained soils with high resistivity and pH greater than pH5, to 300 microns per year in poorly drained soils with low resistivity (usually related to chloride concentration). Reasonable averages derived from these tables for both zinc and steel in contact with soil are for zinc, 6-10 microns per year, and for steel, 20-30 microns per year.

DETERMINATION OF PRODUCT LIFE IN-GROUND

In designing steel products for use in soil, there is enough information available to make reasonable estimates of service life of the structure. For products like screw-in piles used for house foundations, and lighting and power poles, these considerations are important in determining their service life.

Often, the focus is simply on the performance of the protective coating. However, an understanding of the steel's performance allows a better outcome through the provision of a corrosion allowance over and above the structural requirements of the steel.

Taking the example of a screw-in pile used as a house foundation, the steel thickness needed to support the structure is in the order of 2.5-3mm in a square or circular hollow section pier. By using a pier with a wall thickness of 4.5-5 mm, with a heavy duty hot dip galvanized coating with a minimum coating thickness of 85 microns, inside and out, the durability expectations would be as follows, in a normal domestic building site environment:

Galvanized coating life :	
85 micron coating/ 6 microns/year = 12 years	
Steel corrosion allowance :	
2 mm at 30 microns per year	= 67 years
TOTAL	= 79 years

CONCLUSION

The use of steel in in-ground structural applications is on the increase, as the benefits of using well-engineered steel alternatives are recognised by engineers and specifiers. Given an understanding of the corrosion issues involved, it is possible to engineer an acceptable life for these buried structures.

The option of using high performance coatings in conjunction with additional steel is a reliable method of ensuring a long service life for these installations.

REFERENCES
1. BHP Steel Piling August 1973 pp 35-48.
2. AS/NZS 2041:1998 Standard for Buried Corrugated Metal Structures, pp 67-71.
3. Smith, T. Durability of Corrugated Galvanized Tunnel and Underpass Structures Lysaght Civil Products Report, August 1993.
4. Shrier, LL, Jarman RA, Burstein GT. Corrosion Vol 1, Third Edition - Metal/Environmental Reactions pp 2-73. Butterworth Heinemann, 1994.
5. Jeffrey, R. Corrosion Rates of Buried Galvanized Wires. Corrosion Management, May 1996 pp 8-12.

INTRODUCTION

In the 1970's and 1980's, serious problems started to manifest themselves in many reinforced concrete buildings after a relatively short service life. Poor workmanship, cost-cutting or just plain ignorance of good concrete practice were identifies as major factors in these premature failures. Costly remediation was required on many of these structures and the concrete industry received a lot of bad publicity based around the theme of `concrete cancer'.

This led to a review of industry standards and industry codes of practice within the concrete industry, to assist in raising the quality of concrete construction to a level that would provide acceptable durability.

The loss of durability and serviceability of reinforced concrete caused by the corrosion of reinforcement is enormously expensive and one of the primary reasons for the need for early remediation and repair, and even demolition, of concrete structures well before their design life (usually 30-50 years) has been reached. To counter the damaging effects of reinforcement corrosion, which include corrosion-induced cracking, rust staining and spalling of the concrete mass, a number of strategies can be employed to improve the durability of concrete and afford protection to the embedded steel.

CONCRETE BASICS

Reinforced concrete is a composite material that relies on the high compressive strength of concrete and the high tensile strength of steel for its mechanical performance. Steel has poor corrosion resistance and concrete has excellent anti-corrosion properties.

Concrete is a mineral aggregate glued together by a cement paste and consists of cement, fine aggregate (sand), coarse aggregate and water. These are mixed in the typical proportions of 1: 2: 2: 0.5 (cement, fine aggregate, coarse aggregate and water).

Cement itself is a complex mixture of calcium, silicon, aluminium, iron, magnesium, sodium and potassium oxides. The calcining (heating in a kiln) process drives off all water and fuses these metal oxides into more complex oxide combinations

Corrosing reinforcing bar has caused severe spalling of the concrete on this oceanfront dwelling.

(clinker). Additions such as gypsum (calcium sulfate) control the setting time of the cement.

The setting (or hydration) of cement occurs when water is added. In perfect proportion, about 25% by weight of water is required to fully hydrate cement. This is insufficient in practice as much of the water is captive in the pores of the cement and cannot migrate to where it is needed. For that reason, complete hydration is deemed to require 42% by weight of water – a water - cement ration of 0.42.

This additional water gives rise to pores in the concrete which can provide the major pathways for corrodents to enter the concrete mass. High water – cement ratios (over 0.50) will greatly increase the permeability of the concrete and subsequently reduce its durability.

A significant outcome of the hydration reaction is the formation of hydroxides, which raise the pH level of the cement to around pH 12.5 and provide an ideal passive environment for the reinforcing steel.

The characteristics of aggregates uses are also important in the performance of the cement. Australian Standards covering aggregate quality nominate factor such as particle size, shape,

surface texture, elastic modulus, porosity, chemical reactivity with cement paste and levels of contamination as being important in aggregate performance.

Chloride contaminated aggregates (sea sand) and soil contaminated aggregates can severely degrade the concrete's performance.

This also applies to the water used in the mix. The use of unsuitable water may result in staining of the concrete or corrosion of the reinforcing bar if chlorides are introduced to the mix in the water. Admixtures are also included to give the concrete specific properties such as rapid-cure, improved waterproofing and a number of other special characteristics. These are listed in detail in Australian Standard AS 1478.1-2000.

WHY CONCRETE FAILS

Reinforced concrete failure is almost always caused by the corrosion of the steel reinforcing bars. This occurs because the passivating film provided to the steel by the highly alkaline cement is destabilized by oxidation or contact with aggressive agents transported to the concrete surface by the environment to which it is in contact.

Access of corrodents to the reinforcing steel is usually a function of cracking or permeability.

All concrete cracks because it shrinks on cooling or is stressed beyond its design capacity. Most concrete cracks are small and the presence of the reinforcing steel restrains the concrete to minimise the formation of wide cracks. Structural cracks will occur after the concrete has hardened and may be due to overloading.

Non-structural cracks arise irrespective of the load applied to the structure and are usually the result of poor installation or design. It has been suggested that cracks less than 0.5 mm wide do not present a problem in normal exposures.

Permeability allows carbon dioxide and other acidic agents to move through the concrete surface and reduce its alkalinity to a level at which the reinforcing steel will become de-passivated and start to rust.

The Long Bay Gaol Hospital used galvanized reinforcing bar in all the concrete wall sections because of its proximity to the ocean, in eastern Sydney, NSW.

Galvanized reinforcing bar is widely used in the pre-cast concrete industry because the elements are almost always used as exposed facades and concrete cover is limited by design.

Permeability is almost directly related to the water-cement ratio of the original mix. At water-cement ratios of 0.70, concrete is over 10 times more permeable that concrete batched at a 0.50 water – cement ratio.

A serious, but less common cause of concrete failure is through leaching where the concrete is permeable and exposed to very soft water. The soft water leaches free calcium hydroxide out of the hardened cement gel, and subsequently results in the removal of the calcium silicates, aluminates and ferrites.

This phenomenon is manifested by the appearance of white calcium deposits on the surface of the concrete and can take the form of stalactites. Leaching at this level usually only occurs in underground car parks and tunnels, but when it is evident, it indicates a serious depletion of the concrete's strength.

CORROSION MECHANISMS

Many studies have been done on the corrosion of reinforcing bar in concrete. All corrosion is caused by electrochemical reaction. This requires an anode, a cathode and an electrolyte. All these things are present in reinforced concrete.

In most cases, reinforcing bar is used without any protective coating and relies on the passivation of its surface by the highly alkaline cement.

Unlike atmospheric corrosion of steel, which tends to be relatively uniform over the surface, the corrosion of reinforcing bar can be highly localised and small areas become depassivated and become small anodic areas influenced by large cathodic areas of adjacent passivated bars.

The presence of chlorides will result in the steel surface becoming depassivated at pH levels as high as pH 11.

IDENTIFYING THE PROBLEMS

Traumatic failure of concrete structures is very rare. Failures are usually signaled well in advance with visual warnings of deterioration. These will include:

1. Spalling
2. Cracking
3. Rust staining
4. Fretting (weathering)
5. Dampness
6. Efflorescence.

Very simple testing systems such as the use of a hammer or a chain drag can be used to detect delamination in horizontal structures such as bridge decks. A device called a Schmidt Hammer has been developed by the concrete inspection industry that works on a rebound system to determine the soundness of the concrete.

Instruments are available that can measure the depth of cover over the reinforcing bar. These cover meters can highlight potential problem areas.

Electrochemical methods (half-cell potential surveys) are one method of determining if corrosion currents exist in the embedded reinforcing bar. There is some reservations about the validity of this method in some types of concrete structures,

The corrosion of the reinforcing bar in this road bridge in North America has occurred because of poor rebar placement combined with the use of de-icing salts on the road.

although it is used in the USA to determine the condition of bridge decks subject to de-icing salt application in winter.

Other techniques such as linear polarisation resistance and resistivity of the concrete can be used, along with the measurement of depth of carbonation, in environments where other factors do not need to be considered.

REPAIR METHODS

While this review is not intended to deal with repair methods, the techniques used are well established by Australian Concrete Repair Association members and cover the following:

1. Crack repair
2. Patching and patching materials
3. Use of inhibitors
4. Recasting with new concrete
5. Shotcreting

For major structures, cathodic protection systems offer a high level of long-term protection. Cathodic protection is simply the application of a current to the reinforcing steel to override the corrosion currents.

This can be done using anodes or impressed current from a power source. Cathodic protection systems are best designed into the structure and their design and installation is a specialised area that requires a high level of technical expertise.

Cathodic protection technology can be used to desalinate chloride-contaminated concrete and re-alkalise concrete that has been affected by carbonation that has reduced the pH.

Major high-risk structures such as underwater tunnels and oil platform structures use cathodic protection systems to ensure their durability.

PREVENTING PROBLEMS IN THE FIRST PLACE
The best place to deal with concrete durability is at the design and construction stage where new concrete is being placed.

Concrete mix design will specify the relative amounts of cement, coarse aggregate, sand (fine aggregate), water and admixtures. The resultant concrete mix must have the following properties:

1. The wet concrete must be sufficiently workable to allow it to fill the forms and penetrate gaps between reinforcing steel and make 100% contact with the reinforcing steel.
2. The cured concrete must have the required design strength.
3. The cured concrete must be as free of cracks as possible.
4. The cured concrete must be impermeable to the environment to which it is exposed.

There are a number of Australian Standards that define requirements for concrete quality, including the Slump Test (AS 1012.3.1:1999) that indicates the shape of the aggregate use and more importantly, the amount of water in the mix.

The compressive strength of the cured concrete is the most commonly measured property of a concrete mix. Testing procedures for this property are defined in AS 1012.9:1999.

Two of the major factors affecting concrete strength and durability are the water-cement ratio of the mix and the level of compaction during installation. Poor compaction can reduce concrete performance by the same degree as a high water-cement ration. If both are combined in the same mix, the durability of the concrete will be severely compromised.

Reinforcing bar in routinely galvanized throughout Australia, where concrete durability is critical

Admixtures are incorporated in the concrete mix to modify its performance for specific construction purposes. The use of admixtures can improve durability but others may impact negatively.

Examples of admixtures include:

1. Air entraining admixtures. These compounds form very small bubbles in the concrete, which improves its resistance to frost attack and improves workability. Concrete strength is reduced by the use of these additives.
2. Set retarding admixtures. These are used when the curing speed needs to be delayed (e.g. in hot weather).
3. Set accelerating admixtures. These `rapid cure' additives are used to speed-up the concreting operations or may be used during cold weather were normal curing times may be prolonged. The high level of chloride ions in these admixtures (based on calcium chloride) has a detrimental effect on concrete durability through accelerated risk of reinforcing steel corrosion.
4. Water reducing and set modifying admixtures. These compounds maintain the workability of concrete at low water-cement ratios and can either advance otr retard the set, depending in the construction requirements.
5. Waterproofing additives. These additives reduce the water absorbing characteristics of concrete. They consist of pore filling materials and/or water repellent compounds.

Coatings and penetrants can also be used on the concrete surface that prevent or minimise access of corrodents to the concrete. There are five common forms of these materials used to improve concrete durability. These are:

1. Penetrants. These are usually solvent-borne hydrophobic compounds that restrict movement of water through the concrete surface.
2. Water-borne coatings. These are polymer emulsion (e.g. acrylic) that key to the surface and provide barrier protection to the concrete from the environment.
3. Solvent-borne coatings. These are organic coatings, predominantly two-pack systems, that polymerize on the concrete surface to produce heavy-duty, more abrasion resistant coatings.
4. Cementitious overlays. These are specially formulated renders applied to the concrete to reduce permeability, particularly to carbon dioxide.
5. Sheet membranes. These are used when the concrete needs to be isolated from aggressive chemicals and thermoplastic polymers that can be welded in-situ to provide a high integrity barrier are most commonly use.

GALVANIZING OF REBAR

Over the years, a growing body of evidence from both laboratory experiments and ongoing field surveys of existing structures has demonstrated that the galvanizing of steel rebar extends the service life of many types of reinforced concrete structures. Though the cost of galvanizing may significantly increase the price of the reinforcing steel itself - the actual costs depending on the nature of the product to be galvanized, the location of the galvanizing plant and the extra transportation and handling required - the overall premium for the use of galvanized rebar in mass concrete is a small proportion of total concreting costs. This premium reduces considerably in buildings and large constructions where the costs of services, facilities and fixtures are major project cost components.

Hot-dip galvanizing produces a tough and adherent coating on steel that resists abrasion and heavy handling, and which can be stored, handled and transported in much the same way as black steel. Other than following general guidelines when bending and fabricating galvanized steel,

no special precautions are required to protect the coating against mechanical damage. In the design and construction of reinforced concrete utilizing galvanized rebar, the same design parameters and construction practices are used that apply to conventional black steel reinforcement is used and best practice when using galvanized reinforcement is to use appropriately designed and placed concrete such as would normally be used in conventional construction.

Hot dipping involves the immersion of the steel bars in molten zinc at about 450°C and holding for a sufficient period to allow the development of a metallurgically bonded coating of zinc and zinc-iron alloys on the base steel. According to AS/NZS 4680, the minimum specified coating thickness on steel products greater than 5 mm thick is 84 microns, equivalent to a coating mass of 600g/m^2 of surface. In routine processing however, hot dipping results in coatings that would generally be at least 100-120 microns thick. Each successive layer of the coating from the steel substrate outwards contains a higher proportion of zinc and the zeta and delta alloy layers in particular are somewhat harder than ordinary steels. This feature, combined with good adherence, gives the coating its excellent abrasion and impact resistance.

The corrosion of the steel reinforcement in this concrete power pole has cause it to split from end to end.

It is generally most economical to process straight lengths of reinforcing bar with all fabrication being done after galvanizing. During fabrication, the tendency for cracking and flaking of the coating in the area of the bend increases with bar diameter and the severity and rate of bend. The use of large bend diameters, typically 5-8X the bar diameter, can minimize damage to the coating. Some cracking and flaking of the coating at the bend is not uncommon, and should not be the cause for rejection provided such damage is in accordance with the specification. Should repairs be required, an organic zinc rich paint containing a high proportion of metallic zinc (90% minimum) in the dry film is generally used.

As an alternative to post-galvanizing fabricating, bars bent to special shapes (ties, stirrups etc) or complete sections such as prefabricated column forms or pre-casting cages can be galvanized. This offers the distinct advantage of little or no fabrication-related damage to the coating.

ZINC IN CONCRETE

Zinc is an amphoteric metal that reacts with both strong acidic and strong basic solutions, the attack being most severe below pH 6 and above pH 13. At intermediate pH ranges, the rate of attack on zinc is very slow due to the formation of protective surface layers. When embedded in concrete, zinc is passivated for pH values between about 8 and 12.5, again due to the formation of a protective surface film of corrosion product that is relatively insoluble below pH 12.5. While zinc reacts with wet cement, this reaction effectively ceases once the concrete has hardened and the barrier layer of calcium hydroxyzincate has formed. Hydrated concrete is strongly alkaline with a pH in excess of pH 12.2 due to the presence of a saturated solution of $Ca(OH)_2$ filling the pore space.

Corrosion of steel in concrete is usually caused by either a natural reduction in the pH of the concrete through reaction with acidic gases such as carbon dioxide – the carbonation effect, and/or the presence of chloride ions above certain threshold levels at the depth of the reinforcement. Chlorides accumulate in concrete due to salt contamination of concrete-making materials, exposure to the marine environment or saline ground waters, or the use of de-icing salts as is especially common in the snow-belt states of the USA.

Black steel in concrete typically de-passivates below pH 11.5, or higher in the presence of chlorides, leading to the onset of corrosion, zinc remains passivated to about pH 9.5 thereby offering substantial protection against the effects of carbonation of the cover concrete. Zinc can also withstand exposure to chloride ion concentrations several times higher than causes corrosion of black steel.

The corrosion protection thus afforded by galvanizing is due to the combined effects of a substantially higher chloride threshold than black steel in concrete, and a complete resistance to the effects of carbonation of the concrete. The presence of the protective zinc alloy coating delays the initiation of the corrosion process, although the extent of this depends on the quality of the concrete and the severity of the exposure.

When very high chloride levels build up in concrete, such as may occur in poor quality concrete in severe marine exposure conditions, the life of the zinc coating may be somewhat reduced. It is important to note however that the life of the galvanized rebar in these conditions would still be significantly longer than that of black steel in equivalent concrete and exposure conditions.

This issue of the chloride tolerance of galvanized steel has been widely studied. Recently, comparative accelerated corrosion studies in chloride-contaminated concrete have revealed the improved corrosion behavior of galvanized reinforcement over black steel. Under identical exposure conditions, galvanized reinforcement resisted chloride levels in concrete at least 2.5 times higher than for black steel and delayed the time to the onset of corrosion of the underlying steel by some 4-5 times. These results have been confirmed in other investigations where it has been demonstrated that galvanizing had a higher chloride threshold relative to bare steel and the delayed onset of corrosion.

Considerable work has also been done to identify the nature of zinc corrosion products and the effect of these on the integrity of the concrete. A number of minerals have been identified in the corrosion products including zinc oxide and zinc hydroxide. A unique feature of these corrosion products is that they are friable (loose, rather than blocky) minerals

and they migrate well away from the bar and into the adjacent concrete matrix where they fill voids and micro cracks. As a result, these products cause very little disruption to the surrounding matrix and this helps maintain the integrity of the concrete itself. This behavior should be contrasted to the situation encountered when black steel in concrete corrodes. Iron corrosion products are extremely bulky and precipitate at the steel-concrete interface causing the build up of tensile stresses sufficient to crack the cover concrete.

APPLICATIONS OF GALVANIZED REINFORCEMENT

The rationale for the use of galvanized steel in concrete centres on the concept that the coating provides a safeguard against early or unexpected corrosion of the reinforcement. The coating itself should not be used as the primary or sole means of corrosion protection, rather it should be used in conjunction with an adequate cover of a dense impermeable concrete suited to the type of structure and the exposure conditions. There is a premium to be paid for this additional protection, above that provided by the concrete mass, but the advantage is that premature, and possibly whole-of-life, costly cycles of repair and remediation to the structure can be avoided.

Particular circumstances where the galvanizing of reinforcement is likely to be a cost-effective and sound engineering decision include:

• light-weight pre-cast cladding elements and architectural building features;
• surface exposed beams and columns and exposed slabs;
• prefabricated building units such as kitchen and bathroom modules and tilt-up construction;
• immersed or buried elements subject to ground water effects and tidal fluctuations;
• coastal and marine structures;
• transport infrastructure including bridge decks, roads and crash barriers; and
• high risk structures in aggressive environments.

 Throughout the world, galvanized reinforcement

has been successfully used in a variety of types of reinforced concrete buildings and construction applications. Some examples include:
• bridge decks, pavements and crash barriers;
• coastal bridges and highway structures;
• cooling towers and chimneys;
• tunnels, water storage tanks and treatment facilities;
• docks, jetties and offshore platforms;
• sea walls and coastal balustrades;
• paper mills, water and sewerage treatment works; and also
• processing facilities and chemical plants.

COATING REINFORCING STEEL

While its proponents state that reinforcing bar needs no protection in good quality concrete, the plethora of failures due to rebar corrosion indicates that the added assurance of applying a protective coating to the rebar may be a good investment in long-term concrete durability.

The predominant coating options for reinforcing bar are hot dip galvanizing and epoxy coating. There has been much debate, particularly in the USA, regarding the merits of each coating system.

The major end-use for coated reinforcing bar in the Northern Hemisphere is in bridge decks where de-icing salt is used on the roads during winter.

A number of significant structures such as the Sydney Opera House and Parliament House in Canberra have made extensive use of galvanized reinforcing bar in Australia, as have the sewerage outfall tunnels in Sydney.

The use of galvanized reinforcing bar has been more prevalent in Australia, as the epoxy coated rebar industry here is insignificant compared to that in the USA.

A great deal of research has been undertaken by the Federal Highways Administration in the USA in assessing coated reinforcing bar performance. Dr.Stephen Yeomans, from the University of NSW Australian Defence Academy spent a period on secondment to the USA for the Commerce Technology Administration National Institute of Standards and Technology.

A complete copy of his report on this research project (funded by the International Lead Zinc Research organization – Project ZE 341) was published in two parts in 'Corrosion Management' in November 1993 and February 1994.

The conclusions in this report condense the galvanizing versus epoxy issues as follows:

1. Epoxy coating provides excellent corrosion protection to reinforcing steel provided the coating remains intact. If the coating is severely damaged, such as at cut ends, corrosion occurs to a similar extent to that for black steel in equivalent circumstances and corrosion progresses along the bar under the adjacent coating.

2. Patch repairs to cut ends of epoxy coated bar did not substantially delay corrosion of the steel substrate compared to the corrosion of un-coated black steel in equivalent concrete and exposure conditions.

3. Results indicate that holes and points of minor damage in a fusion bonded (epoxy) coating are responsible for the large negative half-cell potentials measured for epoxy coated reinforcement. General corrosion of the uncoated steel would be expected at such potentials, though there was little evidence of corrosion of the epoxy-coated reinforcement. This suggests that the half-cell measurements to assess the corrosion of the epoxy coated bar in concrete are unreliable.

4. Galvanized reinforcement can tolerate chloride levels in concrete at least 2.5 times higher than those causing corrosion in black steel under equivalent concrete and exposure conditions.

5. Galvanizing provides sacrificial protection to steel in concrete, the period over which the zinc layers dissolve effectively delaying the onset of corrosion of the steel substrate. The distance over which the exposed steel is protected at the cut ends is in the order of 8 mm.

6. Results indicate that the total period over which the galvanizing delays the onset of corrosion of reinforcing steel in concrete is in the order of 4-5 times that for corrosion of black steel in equivalent concrete and exposure conditions.

7. Half-cell potential measurements of galvanized steel in concrete may provide an opportunity to continuously assess the performance of the reinforcement and predict remaining life of the zinc coating in service, but further study is needed.

SUMMARY

Well-designed and constructed concrete structures have a well-established reputation for durability. However, the fact that failures have occurred reflects that the variables occur in the construction process. The nature of concrete renders it a very costly proposition to repair.

At the specification end, options exist to ensure that the durability of concrete structures can be best assured by the use of protective coating systems on the concrete surface, and more importantly, on the reinforcing bar.

INTRODUCTION

The durability of metal structures is determined by the environment to which the structures are exposed, and the way that the metals or their protective coatings respond to that environment.

The way that metallic coatings such as zinc-based coatings protect the base steel is quite different to the mechanism of applied paint coatings.

Zinc coatings, specifically hot dip galvanized coatings are metallurgically alloyed to the base steel and form what is essentially a composite material. They deteriorate through surface oxidation when exposed to moisture and corrodents such as chlorides and sulfates.

Paint coatings, in the other hand, depend on the condition of the surface to which they are applied (surface preparation), the performance of the primer used to promote adhesion, and the resistance of the topcoat to the atmospheric or service conditions to which the coating is exposed.

Paint coatings can be formulated to deal with a wide range of service conditions, while zinc-based coatings have clearly defined performance boundaries that will set the appropriateness of their use.

Paint coating may fail due to loss of adhesion for various reasons, degradation due to ultra violet light exposure or undercutting corrosion of the steel adjacent to damaged areas. The paint film itself may still be in good condition except that it no longer provides an effective barrier for the steel.

Galvanized coatings fail by being consumed from the surface through some form of oxidation. In any given environment, this oxidation progresses at a steady rate for the life of the coating. In a stable environment, the rate of corrosion is also stable.

By defining the expected rate of corrosion in any given environment, the service life of galvanized (and any zinc-based) coating can be determined. This is the basis of the Industrial Galvanizers Corrosion Mapping System.

THE DEVELOPMENT OF THE CORROSION MAPPING SYSTEM

The CSIRO's Manufacture and Infrastructure Technology Division has compiled a large body of research on environmental conditions affecting the corrosion of metals, and has used the data from this research to develop corrosivity models that can be applied on a geographically large-scale.

Previously, coupon testing of corrosion parameters at specific sites was the standard method of measurement of corrosivity. This is time-consuming and costly and also defines performance over a limited time span. Detailed corrosion maps of Newcastle, NSW, Melbourne, VIC, and parts of South Australia have been developed using coupon exposures and in Newcastle, for example, the closure of two major metallurgical industries has changed the corrosion landscape significantly.

Industrial Galvanizers Corporation and CSIRO entered into a research agreement in 2000 to develop a web based system that would allow the corrosivity of specific locations throughout Australia to be determined, based on time of wetness, chloride deposition rates and orientation of the surface being assessed.

This joint venture resulted in the web-based Corrosion Mapping System (CMS) being set up on the Industrial Galvanizers web site (www.ingal.com.au), with additional modules dealing with in-ground performance of galvanized steel and environmental sustainability factors associated with materials of construction.

Also included in the Industrial Galvanizers CMS is a module to assist in the determination of the corrosivity of soils with respect to buried metal structures, as well as a sustainability of materials calculator for environmental assessment of materials.

HOW THE CMS WORKS

The CMS allows the user to locate a position in Australia using an interactive map or by entering known co-ordinates.

Once the location is identified, the CMS will then deliver the corrosivity data for the site. For ocean-side locations, further refinement of the corrosivity data can be implemented by defining the exact distance from the coastline in metres, up to I km.

The data from the above actions can then be further refined to take into account the effect of the item's position in its service environment. The position may be classified as exposed, partly sheltered or sheltered.

Where airborne chlorides are present, these qualifications are important, as sheltered (not washed by rainwater) areas may be subject to chloride accumulation that will significantly increase corrosion rates. The CMS accounts for these higher rates of corrosion.

If refinement of corrosivity data is required, further assessment can then be done in-house, by Industrial Galvanizers trained staff. This second-level assessment evaluates local topographical data : coastal forms (cliffs, etc) height above sea level, prevailing winds, vegetation and the built environment.

SUMMARY

The large-scale corrosivity modeling that has been built into the CMS by CSIRO allows assessment to be made of the durability of steel and galvanized coatings throughout Australia. Industrial Galvanizers' experience in assessing the performance of galvanized steel in a wide range of applications and environments over the past 30 years, using carefully documented case-histories, combined with its CMS, allows the company to offer its industry leading Coating Guarantees to customers seeking assurance of the long term durability of their steel structures.

NAVIGATING THE INGAL CORROSION MAPPING SYSTEM

1. Go to the Industrial Galvanizers Web Site at www.ingal.com.au
2. Scroll down to the CORROSION button and select CORROSION MAPPING
3. Select NEW USER and register.
4. The CMS will load.
5. Follow on-screen instructions to find specific location. The corrosion data for the location will be displayed.

INTRODUCTION

Hot dip galvanized coatings are always costed on the basis of the weight of steel galvanized, with the items being weighed after galvanizing. For contract galvanized products, an agreed price per unit may be negotiated to facilitate invoicing and minimise repetitious handling in the galvanizing process.

The price is quoted on a $/kg basis for smaller projects or a $/tonne basis on larger tonnages. These costs will be highly variable and will be determined by the ease of handling through the galvanizing process, and the mass that can be processed in a given time, along with the zinc pick-up on the item.

SURFACE AREA PER TONNE

While variable such as the design of the item and its steel chemistry and surface condition will influence zinc pick-up, the main factor in this part of the cost equation is the surface area of the item.

The density of steel is 7.85 t/m^3, and this factor can be used to derive a simple equation to calculate surface area per tonne for steel based on its average section thickness. This equation is:

$$\text{Surface area per tonne} = \frac{255}{\text{Section thickness in mm}}$$

Mass per square metre of steel can also be calculated using the following formula:

Mass per square metre in kg = Section thickness in mm x 7.85

When comparing the cost of hot-dip galvanized coatings with other industrial coating systems, it may be necessary to convert the cost per tonne to cost per square metre. This will produce a cost comparison that will allow the competitive position of alternative coatings to be easily compared. This may not be as obvious if assessed on a cost per tonne basis.

For example, light (3 mm) steel fabrications may have a galvanizing cost of $1200/tonne or $1.20/kg. This equates to a cost per m^2 of 1200/85 = $14.00/m^2. This is a very low cost for a high performance steel coating.

On the other hand, heavy (16 mm thick) sections may have a galvanizing cost of only $600/tonne. This equates to a cost per m^2 of 600/16 = $37.50/m^2.

Fabrications like this large frame require double dipping, which is typically 30% higher cost than single dipping because of the extra time in handling.

The mass of steel items that can fi t on a galvanizing jig is a major factor in costing. These small items have a high cost factor because of the low dip weight and large amount of handling required in processing them.

WEIGHT INCREASE AFTER GALVANIZING

Traditionally `white weight' rather than 'black weight' has been used to calculate galvanizing cost. Some clients have questioned this method based on the assumption that the galvanizer might put more zinc on the work to raise the price.

No galvanizer wants to give away zinc that costs $2300/tonne for the cost of galvanizing which is typically 1/4 of that cost.

The zinc pick-up can be a factor when the mass of steelwork needs to be accurately calculated for engineering dead-load calculations or for safe load limits for transport.

A factor of 6% is commonly used to estimate zinc pick-up for the purposes of calculating the cost of zinc in the galvanizing equation. This takes into account the amount of zinc consumed per tonne of steel processed, which covers zinc consumption on jigs and handling equipment, as well as the zinc coating.

The physical zinc pick-up on the steel is better calculated by measuring the coating thickness (in microns), and proportioning it against the average steel section thickness (in microns).

Thus an 8 mm (8000 micron) section with 100 microns of coating on each surface will have a coating mass representing approximately 200/8000 or 2.5%. There are other factors that make exact assessment difficult. A 2 mm section with a 65 micron coating on each surface will have a physical zinc pickup of 4.3%

New structural steelwork may have 20-50 microns of mill scale on the surface. This mill scale is removed by acid pickling in the pretreatment process and not be accounted for in the conversion of the steel from 'black' to 'white'.

Zinc usage accounts for approximately 33% of the cost of hot-dip galvanizing and is the most volatile cost input in the galvanizing process, as it is priced in $US as a world commodity and fluctuates with both $US and market price movements in commodity process. Since 2005, the zinc price has fluctuated from $1800/tonne to almost $6000/tonne.

EFFICIENCY FACTORS

The major cost-determining factor in hot dip galvanizing is the efficiency with which the fabricated steel can be moved through the galvanizing process. Most Industrial Galvanizers structural galvanizing baths in Australia are 10 – 12.5 meters in length and contain over $1 million worth of zinc. This must be kept molten at all times.

The galvanizing costs are thus based on the number of dollars that have to be earned by the galvanizing bath per hour to recover its fixed and variable costs. For this reason complex or light fabrications (trailers, 3-D shapes) may cost much more than simple structural sections (columns and beams) that are the same weight.

Items that are longer or wider than the galvanizing bath, that require double-end dipping will incur a cost penalty over similar single-dipped items.

Where large volumes of standardised light fabrications are to be processed, special jigging or handling systems can be developed in consultation with Industrial Galvanizers to facilitate handling of the work through the process, with significant cost savings.

Large and simple structural members such as this universal beam can be galvanized at lower cost because of the ease of handing, the signifi cant mass and relatively low zinc pick up on the heavy section.
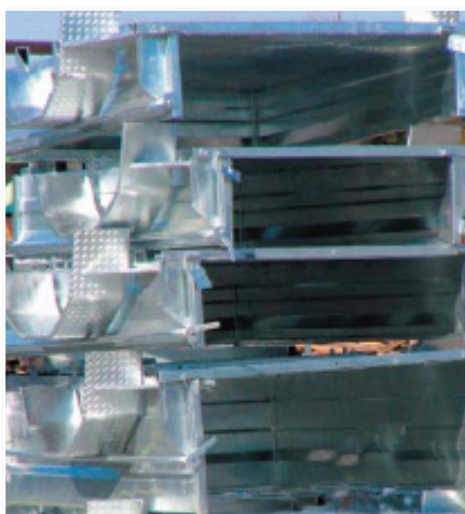
Box trailers have a very high surface area per tonne (about 200 m2) and have a low mass compared to their volume, dictating a relatively high galvanizing cost per tonne but a low coating cost per m2.

SUMMARY

Compared with other high-performance anti-corrosion coatings for steel, hot-dip galvanizing offers a very cost-competitive option on a $/m^2 comparison. Even on thicker sections, the cost per square metre for hot dip galvanized coatings is rarely more than $45/m^2. As steel sections become thinner, the competitive position of hot dip galvanizing is further enhanced, as its cost does not increase in proportion to surface area. An additional benefit on thicker structural sections is that the galvanized coatings will be thicker that that required by the Standard (AS/NZS 4680:2006), and this will further enhance the durability of the item in service.

Fabrications that are designed for galvanizing will be able to be processed most efficiently, and this will be reflected in lower processing costs.

INTRODUCTION

Industrial Galvanizers offers several coating options to serve the needs of specific projects.

Hot dip galvanizing is an industrial coating process intended to improve the durability of fabricated steel products, the coating is a result of a metallurgical reaction between steel and molten zinc.

Traditionally, when hot dip galvanized coatings are specified, AS/NZS 4680:2006 Hot-dip galvanized (zinc) coatings on fabricated ferrous articles is referenced. This standard defines minimum requirements for coating mass (thickness) and appearance. The galvanizing process has defined these minimum thickness standards based on a range of steel section thicknesses. Unlike applied coatings such as paint, where specific or additional thickness can be applied if required, the process rather than the supplier defines the thickness of hot dip galvanized coatings.

The surface finish is also process controlled to a large degree. A steel fabrication is submerged in a molten zinc bath and then withdrawn at a rate and in an orientation designed to allow the molten zinc to drain off the steel as uniformly as possible. Variations in the steel's surface condition, steel chemistry and the design of the fabrication will determine the appearance of the galvanized coating.

The development of the Industrial Galvanizers' Custom Coating Packages has been in response to requests for hot dip galvanized coatings that exceed the basic requirements of AS/NZS 4680:2006.

GALVANIZED COATING CHARACTERISTICS

Unlike other zinc-based protective coatings, hot-dip coatings predominantly consist of zinc-iron alloys that are crystalline in appearance. The surface of the coating is covered by a layer of zinc that freezes on the surface as the steel is withdrawn from the bath.
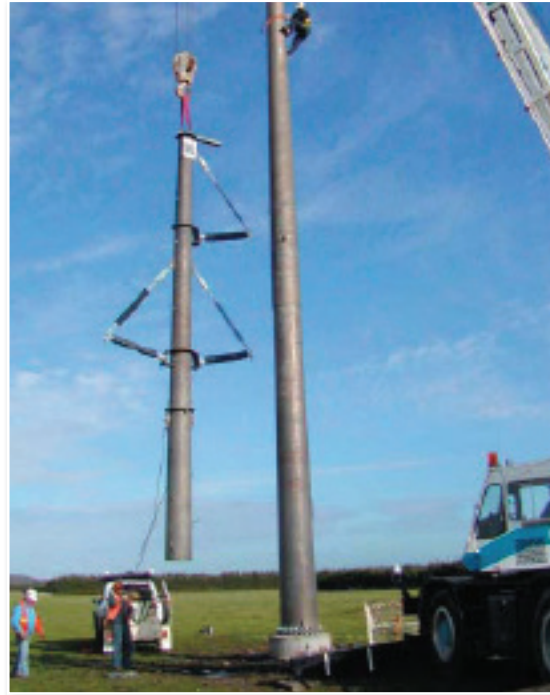
This transmission pole made by INGAL EPS for Hydro Tasmania has an INGAL Matt galvanized coating to reduce the visual impact this large structure.

The thickness of the zinc alloy layers determines the final thickness of the galvanized coating. The alloy layer thickness is determined by a number of interrelated factors. These are:

• The steel's sections thickness
• The steel chemistry
• The galvanizing bath temperature
• The time that the steel is immersed in the molten zinc
• The alloy additions to the zinc bath.

Other processes associated with hot-dip galvanizing operations can affect the appearance of the final product and its suitability for additional processing e.g. painting or powder coating.

It is possible for the galvanizer it take these issues into account when processing specific items, to produce a galvanized coating that may be thicker, shinier or duller than a standard coating.

DURABILITY OF GALVANIZED COATINGS
The anti-corrosion performance of zinc-based coatings is largely a function of the thickness of the coating in any given environment. The rate at which zinc corrodes is approximately linear so by doubling the coating thickness, the coating life will also be doubled.

09. CUSTOM COATING PACKAGES – SPECIAL GALVANIZED COATING OPTIONS

The following table has been reproduced from the Australian Standard and indicates the minimum spot and average galvanized coating thicknesses required for various steel sections to comply with the standard.

TABLE 1 REQUIREMENTS FOR COATING THICKNESS AND MASS FOR ARTICLES THAT ARE NOT CENTRIFUGED

Article thickness mm	Local coating thickness minimum µm	Average coating thickness minimum µm	Average coating mass minimum g/m²
51.5	35	45	320
>1.5 <3	45	55	390
>3 <6	55	70	500
>6	70	85	600

NOTE: 1 g/m² coating mass = 0.14 µm coating thickness

In practice, hot dip galvanized coatings will almost always exceed the minimum specified thickness, particularly on hot-rolled structural sections.

CUSTOM COATING PACKAGES

Custom coating packages are offered by the Industrial Galvanizers. Not all plants offer all options, as plant size and material handling characteristics will determine the individual plant's capabilities.

The Coating Packages include:
1. HDG – Australian Standard AS/NZS 4680 compliant coating
2. HDG Plus – Over-standard coating. 2X over for hot rolled sections and 1.5X over for cold rolled sections. Provides extra-long life in heavy-duty applications.
3. SSQ – Australian Standard AS/NZS 4680-compliant coating. Special surface quality to meet specific customer requirements for overcoating or appearance.*

The Sydney Olympic Tennis Centre was specified INGAL SSQ – Special Surface Quality – for this important sporting facility.

Each of these Coating Packages can be supplied with a performance guarantee on the coating, which is typically in the range of 10-25 years, depending on the exposure conditions. This guarantee provides the client with an assurance that the hot dip galvanized coating will protect the steel from corrosion for the term of the guarantee, and any liability for maintenance during the guarantee period lies with Industrial Galvanizers.

Because of the logistics involved in providing these packages, Industrial Galvanizers can only make them available on specific projects and not on general galvanized products.

* Not available all locations. Conditions apply.

More details on each of these Custom Coating Packages are as follows:

HDG

This specification complies with current Australian and international (ISO) hot dip galvanizing standards for items galvanized after fabrication. Negotiated long-term coating performance guarantees are available with INGAL HDG specifications.

HDG Plus

INGAL HDG Plus exceeds Australian and International (ISO) standard minimum coating thickness requirements by a minimum of 50% for cold-formed sections and 100% for hot rolled sections. This specification guarantees a minimum average coating mass on cold-formed sections of 900 g/m2 (130 microns thickness) and 1200 g/m2 (170 microns thickness) on hot rolled sections.

The differing steel characteristics produced by the steel section's manufacturing processes account for the different minimum extra coating mass.

Galvanized coating life is proportional to its thickness, and the additional thickness provided by INGAL HDG Plus significantly increases coating life proportionately.

HDG SSQ*

INGAL SSQ (Special Surface Quality) offers specifiers the option of nominating surface quality requirements above and beyond the obligations listed in AS/NZS 4680. Depending on the specifiers requirements, details such as steel chemistry, design of the product and handling of the products through the galvanizing process are negotiated to ensure a managed outcome. Where items are to be painted after galvanizing, the INGAL HDG SSQ process insures a smoother surface better suited to the application of architectural paint finishes.

INGAL HDG SSQ has been specified on a number of major projects, including the award-winning Olympic Tennis Centre at Homebush Bay in Sydney.

An INGAL HDG Plus coating was specified for this indoor pool/ leisure centre structure in the Hunter valley, NSW. The heavier galvanized coating proportionately increases maintenance free life in this humid environment.

COATING GUARANTEES

Each of the above Custom Coating Packages comes with the option of a negotiated performance guarantee. Guarantees are currently in place with clients such as the NSW Roads and Traffic Authority for major projects such as the M5 East Motorway and the Western Ring Road for periods from 25 to 40 years, and on other landmark projects in Melbourne such as the MCG grandstands and the Eastlink Motorway.

SUMMARY

Industrial Galvanizers is unique in the hot-dip galvanizing industry, worldwide, in offering a range of additional coating options to the specifiers. These options add to the already well-established reputation of hot-dip galvanized coatings as the most durable and predictable method of protecting steel from corrosion.

* Not available all locations. Conditions apply.

INTRODUCTION

One of the most important characteristics of zinc (galvanized) coatings on steel is the ability of the zinc to protect adjacent steel from corrosion. The electrical potential between zinc and steel ensures that zinc will act as an anode to adjacent exposed steel and prevent its corrosion.

All continuously galvanized products are dependent on the cathodic protection of their galvanized coatings to protect them from localised corrosion, as the galvanized coatings on all of these products are 'damaged' during the manufacturing process. They are cut, formed or punched after being manufactured from sheet, wire, or hollow and open sections to feed the next stage of the manufacturing process.

The degree of protection provided by the zinc coating to the exposed cut edges will be determined by:

1. The thickness of the material.
2. The mass of zinc available in the coating adjacent to the exposed steel.
3. The nature of the environment to which the product is exposed.

The cut edge corrosion phenomenon is almost always ignored in Standards and specifications. **Australian Standard AS/NZS 4680:2006 Hot dip galvanized coatings on fabricated ferrous items,** is a good example of this. The requirement to repair damaged areas on items galvanized after fabrication is clearly defined in the Standard, where the maximum permissible un-coated areas are nominated in terms of area.

In other standards associated with continuously galvanized products, there is no such requirement for repair of cut edges on sheet, tube, or wire products that are galvanized prior to fabrication. This is particularly relevant with cold-formed structural sections (purlins, channels) used for commercial construction, where the exposed steel per unit of surface exceeds the maximum allowable repairable area in the hot dip galvanizing standard.

Pre-galvanized products rely on cathodic protection to prevent corrosion on their cut edges. Thicker sections such as these heavy purlins are on the borderline and corrosion is visible on installation.

HOW FAR DOES GALVANIC PROTECTION EXTEND?

For many years, the only type of product reliant on galvanic protection of its cut edges was hot dip galvanized sheet used for roofing and cladding. The base steel used for these applications is very thin, typically 0.5-0.7 mm in thickness and thus the surface area of bare steel exposed is negligible.

Development in continuous manufacturing and coating of pipe and open structural sections, as well as heavier (up to 3.2 mm) sheet has resulted in a wide range of products being developed that have significant areas of exposed steel between the coated surfaces.

The other factor common to all galvanized products is the coating's ability to protect any exposed steel in the event of damage to the coated surface. While the ability of galvanized coatings to cathodically protect adjacent exposed steel has been evaluated empirically for over 100 years, few attempts have been made to quantify this phenomenon.

Work done in by X.G.(Gregory) Zhang of the Cominco Product Technology Centre, Mississauga, Canada, has allowed a more scientific approach to be taken.

EXPERIMENTAL RESULTS

The Cominco research by Gregory Zhang was aimed at determining the consumption rate of zinc as a barrier coating along with its galvanic protection of the exposed steel. Samples were prepared to simulate various zinc/steel combinations and included a number of degrees of separation, using zinc and steel strips of various thicknesses embedded in epoxy resin mounts. The samples were subjected to testing in the following environments:

- ASTM standard salt spray test
- full immersion test
- cyclic wet-dry humidity tests
- actual atmosphere exposure test.

After testing in each corrosion environment, the samples were evaluated with an optical microscope. Each sample was inspected for areas of rusted and non-rusted steel surface based on both colour and depth of corrosion. Brown to dark brown discoloration on the steel surfaces was used to define the range of galvanic protection provided by the zinc.

CONCLUSION

In atmospheric exposure conditions, the Cominco report concludes that cathodic protection afforded to exposed steel by a zinc (galvanized) coating will be about 2 mm. This will vary somewhat depending on exposure conditions, and while rusting may occur outside this area, partial galvanic protection will cover a much larger area and significantly moderate the rate of steel corrosion in this area. The thin (0.2 mm) lateral surface of the zinc coating will be subject to galvanic corrosion in protecting the adjacent exposed steel while the rest of the zinc coating will corrode normally.

Very thin (<0.5 mm) sections used for roofing and cladding are well protected on their cut edges because of the proximity of the zinc-based coating on each face of the sheeting.

INTRODUCTION

The successful hot dip galvanizing of fabricated steelwork is heavily dependent on its design. To be satisfactorily galvanized, the fabrication must be immersed in a series of pre-treatment baths to prepare the surface for galvanizing, and then be immersed in a bath of molten zinc.

If the pre-treatment chemicals and the molten zinc cannot get access to all surfaces of the fabrication, it will not be galvanized in areas that are not accessible.

Fabrication techniques can also either create or alleviate problems in the galvanizing process.

Industrial Galvanizers technical sales staff are available to advise on design, and will assist with design detailing prior to fabrication to ensure that a high quality hot-dip galvanized coating is applied to customers' projects.
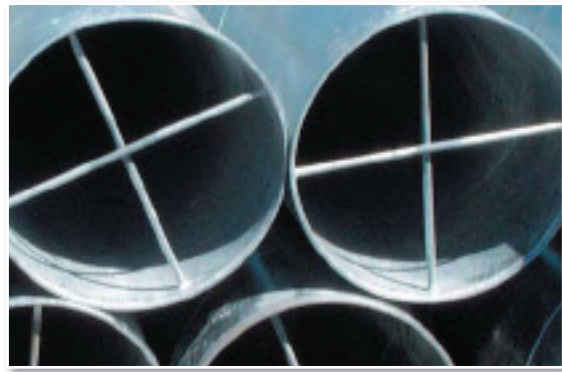
The cross bracing in this tin-walled spiral welded pipe p;revents the ends from sagging under their own weight during galvanizing.

IMPORTANT DESIGN FACTORS

There are a number of fundamental considerations when designing a steel fabrication for hot-dip galvanizing. The key issues are:

- The molten zinc will not react with the steel to form the galvanized coating unless the surface of the steel is perfectly clean.
- The hot-dip galvanized coating will not form unless the zinc can intimately contact the steel.
- The hot-dip galvanized coating will not form unless the steel is heated to 450-455°C.
- Items larger than the galvanizing bath in two dimensions cannot be galvanized.
- The density of steel is 7850 kg/m^3. The density of molten zinc is 6620 kg/m^3. If a hollow section traps 18% of its internal volume as air, it will not sink in the molten zinc.
- Steel sections of differing section thickness heat up and cool down at different rates. Unbalanced sections causing differential heating and cooling will increase the risk of distortion.
- Structural grades of steel lose 50% of their yield strength at galvanizing temperatures. The design of the fabrications for galvanizing must take this into account to prevent sagging or bending under self-loads.
- Overlapping surfaces should be fully sealed. Large overlapping surfaces exceeding 400 cm^2 should be provided with vent holes.
- The size of the item that can be galvanized will be governed by the size of the galvanizing bath. Long items can be galvanized by double-end dipping but items large than the galvanizing bath in two dimensions cannot be galvanized.

For standard fabrications, a basic set of design rules should be applied.
These design steps do not add to the fabrication cost but will ensure a good quality outcome.
These are;

- Gussets and stiffeners should be cropped.
- End plates or base plates on columns. Universal sections should have vent/drain holes in the corners of the web/flange connection and hollow sections should have vent/drain holes in the internal extremities.
- Outward facing channels and angles in fabricated frames eliminate the need for vent and drain holes, contrary to inward facing sections.
- Terminating bracing short of adjacent flanges eliminates the need for cropping or vent holes.

VENTING AND DRAINING RULES

One of the most common issues in designing fabrications for hot dip galvanizing is ensuring that fabrications are vented and drained correctly. All steel to be galvanized needs to be immersed in molten zinc and the zinc needs to be able to flow freely into and out of all hollow sections and corners.

The flow of molten zinc into, off, and out of the fabrication is one of the most important factors in determining the final quality of the coating. Inadequate venting and draining can cause the following galvanized coating defects:

- Misses in the coating caused by air locks preventing molten zinc contacting the steel surface.
- Puddling of zinc in corners, wasting zinc and interfering with subsequent assembly
- Ash trapped on zinc surface causing surface defects
- Irregularities in surface appearance caused by erratic immersion and withdrawal because of the item floating or trapping zinc internally
- Thick zinc runs on surface caused by zinc freezing during draining
- Steel is only about 15% heavier than zinc. A relatively small amount of air trapped inside a hollow section will prevent the section from sinking in the molten zinc
- Any water trapped inside a hollow section will expand 1750 times its original volume as steam and generate pressures as high as 50 MPa (7250 psi), enough to distort the product or cause a catastrophic explosion.

Good design for galvanizing on this cable spool produces a high quality result. All hollow sections are well ventilated and drained, as is the flange rim.

By lifting long items in chains connected to cleats or lifting lugs allows steep withdrawal angles and avoids chain touch marks on the fabrication.

BASIC VENTING RULES

- No vent hole should be smaller than 8 mm
- The preferred minimum size is 12 mm
- About 200 grams of zinc ash will be produced for each square metre of steel surface galvanized This ash is a powder and will not pass through small openings. Venting large internal areas required larger vent holes to allow ash to escape
- Hollow vessels require 1250 mm² of vent hole for each cubic metre of enclosed volume This means that a 40 mm² diameter hole is required for each cubic metre of volume
- Hollow sections such as tube, RHS and SHS require minimum vent hole area equivalent to 25% of the section' diagonal cross section
- Vent holes should be at the edges of hollow sections

BASIC DRAINING RULES

- No drain hole should be less than 10 mm
- Preferred minimum drain hole size is 25 mm
- Large hollow sections (tanks, pressure vessels) require a 100 mm diameter drain hole for each cubic metre of enclosed volume
- Drain holes should be at the edges of hollow sections.
- Hollow sections such as tube, RHS and SHS require minimum drain hole area equivalent to 25% of the section' diagonal cross section. The preferred design option is to leave the ends of tubes, RHS and SHS open.

TABLE OF VENT AND DRAIN HOLE SIZES FOR VARIOUS HOLLOW SECTIONS – RECOMMENDED MINIMUMS

Circular Hollow Section Nominal bore mm	Rectangular Hollow Section Size mm	Square Hollow Section Size mm	Vent Hole Diameter mm Single	Double
8				8
10				10
15				10
20		13x13		10
25		16x16		10
32		19x19		10
40	38x19	25x25		10
50	38x25	32x32	12	2x10
65	64x38, 76x38	51x51	16	2x12
80	76x51, 89x38	64x64	20	2x14
100	102x51, 102x76	76x76	25	2x18
	127x51, 127x64	89x89	25	2x18
125	27x76, 152x76	102x102	32	2x22
150	152x102	127x127	38	2x27
200	203x102, 203x152	152x152	50	2x35
250	254x152	203x203	63	2x45
300	305x203	254x254	75	2x54
350	305x254	305x305	88	2x63
400			100	2x70

TABLE OF VENT AND DRAIN HOLES FOR TANKS AND PRESSURE VESSELS

Capacity - litres	Single drain hole diam mm.	Double drain hole diam. mm	Vent hole diam. mm
500	80		25
1000	115	2x80	40
1500	140	2x100	45
2000	160	2x115	55
2500	175	2x125	60
3000	200	2x140	70
3500	225	2x150	75
4000	225	2x160	80
4500	240	2x170	85
5000	250	2x175	90
5500	265	2x185	95
6000	280	2x200	100
7000	300	2x220	110
8000	325	2x225	115
9000	350	2x240	120
10000	350	2x250	125

AVOIDING DISTORTION

When steel sections or fabrications are immersed in molten zinc, their temperature is raised to that of the molten zinc which is typically 455°C. The rate at which the steel will reach this temperature across its entire surface will depend on:

- the thickness of the sections used in fabricating the item
- the rate at which the item can be immersed in the molten zinc
- the total mass of the item
- the dimension of the item - large items exceeding bath dimension require double-dipping

Large and complex fabrications can be hot dip galvanized by double dipping. This large spiral staircase is half-way through the dipping process.

At galvanizing temperatures, there is no change to steel's metallurgical micro-structure and the galvanizing process is not hot enough to have any affect on the mechanical properties of the steel after galvanizing.

However, at galvanizing temperatures, the yield strength of steel is lowered by approximately 50%. If the adjacent steel is not at the same temperature and any stresses exist, the weaker area will be subject to movement by the stronger area. There is a responsibility on the designer, the fabricator and the galvanizer to co-operate in ensuring that distortion risks are minimised or eliminated.

This pipe bracing has been correctly designed with multiple vent and drain holes at each end of the hollow sections.

USE DESIGN AND FABRICATION TECHNIQUES TO AVOID DISTORTION

- Design and fabricate sections of uniform steel thickness.
- Use symmetrical designs where possible, and avoid asymmetrical designs where cleats or plates are welded to one side only of a beam or RHS section.
- Avoid designs that require fabrications with a large surface area of thin plate to be double-dip galvanized.
- During fabrication use balanced or staggered welding techniques to avoid uneven locked-in stresses.
- If cutting a plate to size, ensure all sides are cut using the same technique.
  Guillotine is the preferred cutting technique.
- Ensure that the structural design of the item is sufficient to support its own weight at 50% of the steel specified yield strength. Consider temporary bracing if potential to yield exists.
- Ensure that venting and draining holes are adequate. This will allow the item to be immersed and withdrawn from the molten zinc as quickly as possible.
- During fabrication, accurately pre-form parts to avoid force or restraint during welding.
- Consider (or consult your galvanizer) the hanging requirements for the hot dip galvanizing process. This will ensure the fabrication is adequately supported throughout the process.
- The faster the fabrication can be immersed in the zinc, the more uniformly it will be heated to galvanizing temperature and the risk of distortion will be significantly reduced.
  This will be determined by its overall design, venting and draining characteristics and ease of handling.

ITEMS THAT ARE PRONE TO DISTORTION

Most steel sections and fabrications that are hot dip galvanized never give rise to distortion problems. However, certain types of products have a high risk of losing dimensional stability during the galvanizing process. Some examples are:

- Thin (6 mm and under) flat sheet and plate will almost always ripple or buckle unless it is ribbed or corrugated. Flat steel sheet used for box trailer floors will always buckle when the trailer is galvanized. The ribbed sections

Large fabrications can be galvanized by double-end dipping as long as they do not exceed galvanizing bath size in two dimensions.

of the same thickness (1 mm) used for the side sections will rarely buckle.

- Long lengths of light wall pipe (spiral or seam welded) or other long, thin sections can be prone to bending during the galvanizing process. As the yield strength of the steel is halved at galvanizing temperature, long lengths of light section can bend or distort under their own weight. This can be avoided by designing dipping equipment that supports the product or by adequate hanging or support points along the length of the section.
- Floor plate welded to heavier structural framework render the fabrication prone to distortion because of differential expansion and contraction of the plate and structural sections. The framework and the plate should be galvanized separately and then mechanically fixed.
- Welded beams with a flange to web thickness ratio of greater than 2:1, particularly long beams that need to be double-dipped, may present a risk of distortion. Web depths exceeding 800 mm should also be treated with caution, particularly where web thickness is 10 mm or less. Your galvanizer should be consulted at the design stage to ensure satisfactory processing of these types of products as the handling of the sections through the galvanizing process is critical to achieving satisfactory result.
- Fabrications containing large areas of asymmetrical welds (e.g. crane beams). The welding stresses built into these fabrications will significantly increase the risk of distortion as the temperature of the galvanizing process will stress relieve the fabrication.

In most cases, distortion risks can be minimised or designed out of fabrications in consultation with the galvanizer.

CLEARANCES FOR MOVING PARTS

The surface tension of molten zinc is such that it will not flow feely in or out of gaps of 1 mm or less. When moving parts are incorporated into fabricated assemblies to be subsequently galvanized, a clearance of at least 2 mm should be provided.

If the parts are galvanized separately, a smaller clearance of 1 mm can be used.

DESIGN FOR HANDLING

All items to be galvanized must be able to be suspended or supported through the galvanizing process. Small or short items are suspended by wire or hooks from the galvanizing head frames. Smooth items such as tube may require holes to allow wiring up of the items.

Long sections such as beams, columns or large pipes are best provided with lifting lugs to avoid chain marks on the galvanized surface. To best support long slender items during galvanizing the location of lifting lugs can be advised by the galvanizer.

Where regular quantities of standard products are to be galvanized, special galvanizing jigs can be designed to facilitate productivity and ensure uniform quality.

SUMMARY

Good design for galvanizing is also good anti-corrosion design, as the fabrications will facilitate the good drainage of the items in service if they are exposed to the elements.

Consultation with Industrial Galvanizers' technical sales staff at the design stage will also ensure that items can be galvanized most efficiently and at the lowest cost.

These usiversal beams have been masked on the top flange to prevent the galvanized coating forming. This has been implemented by the galvanizer to allow shear studs to be welded to the beams on site. The galvanized coating interferes with the resistance welding of these connections.

3-D fabrications made up of complex hollow sections require careful design detailing to ensure they can be successfully hot dip galvanized, because of the venting and draining requirements of the individual elements.
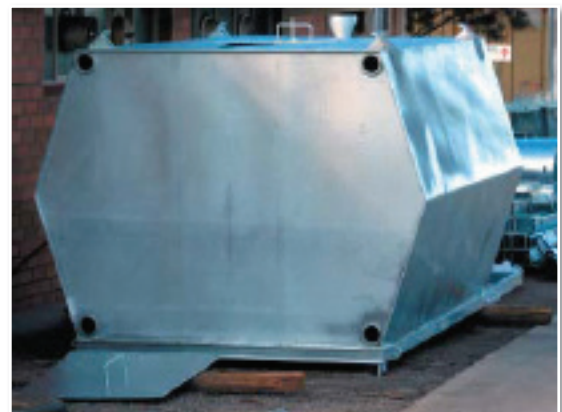
Large hollow vessels such as this water tank require large vent and drain holes to ensure that molten zinc can flow in and out. A tank of this size would hold nearly 15 tonnes of molten zinc.
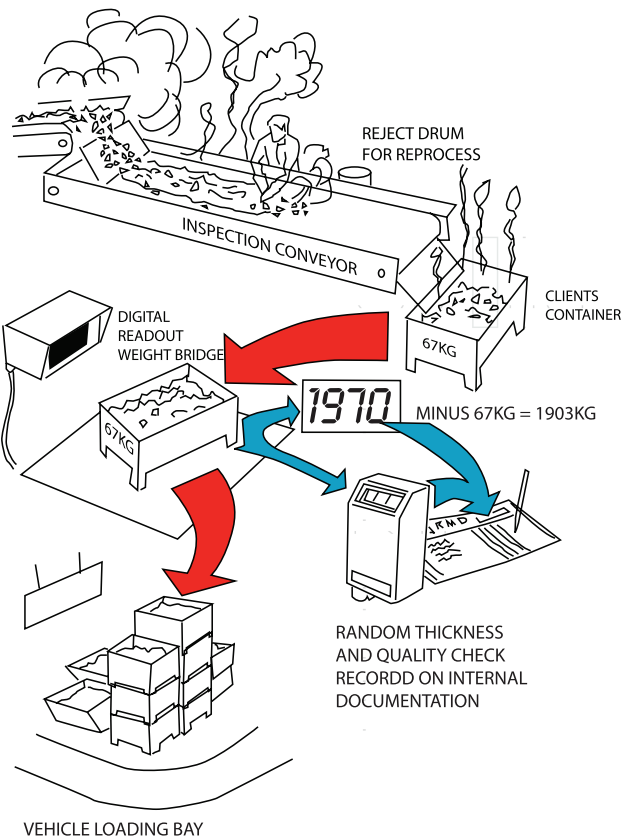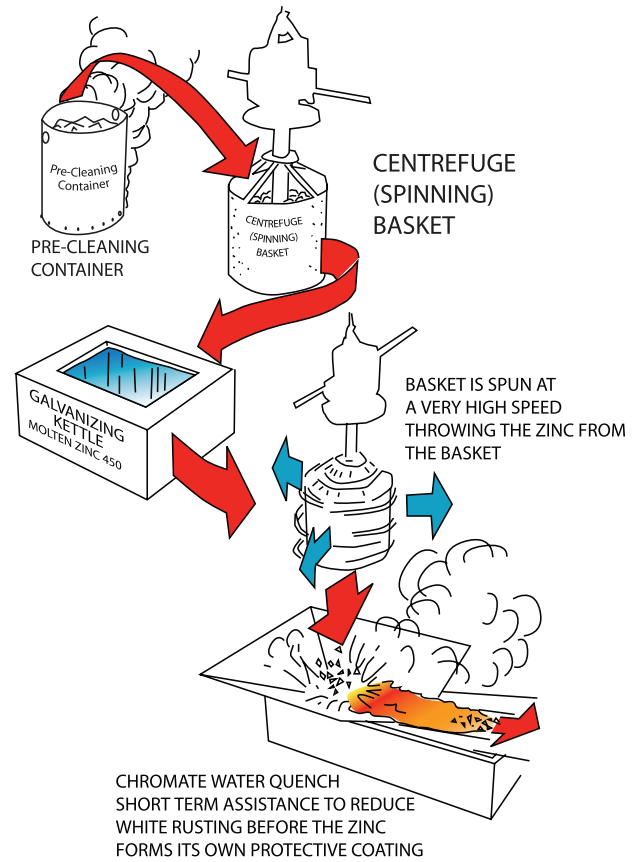
1. Hot Dip Galvanizing
2. Centrifuge processing of small parts
3. End plate design
4. The Sandelin Diagram
5. Welding and weld metal
6. Zinc drainage off large items
7. Orientation and surface finish
8. Venting and draining of structural sections
9. Design detailing
10. Design details for angle fabrications
11. Detailing complex fabrications
12. Zinc buildup and clearances
13. Draining larger hollow sections
14. Pipe spools and other 2-D and 3-D hollow section fabrications
15. Venting and draining of handrails
16. Vent and drain hole size
17. Back-to-back sections
18. Minimising distortion in thin sections
19. Design for fence panels and balustrade
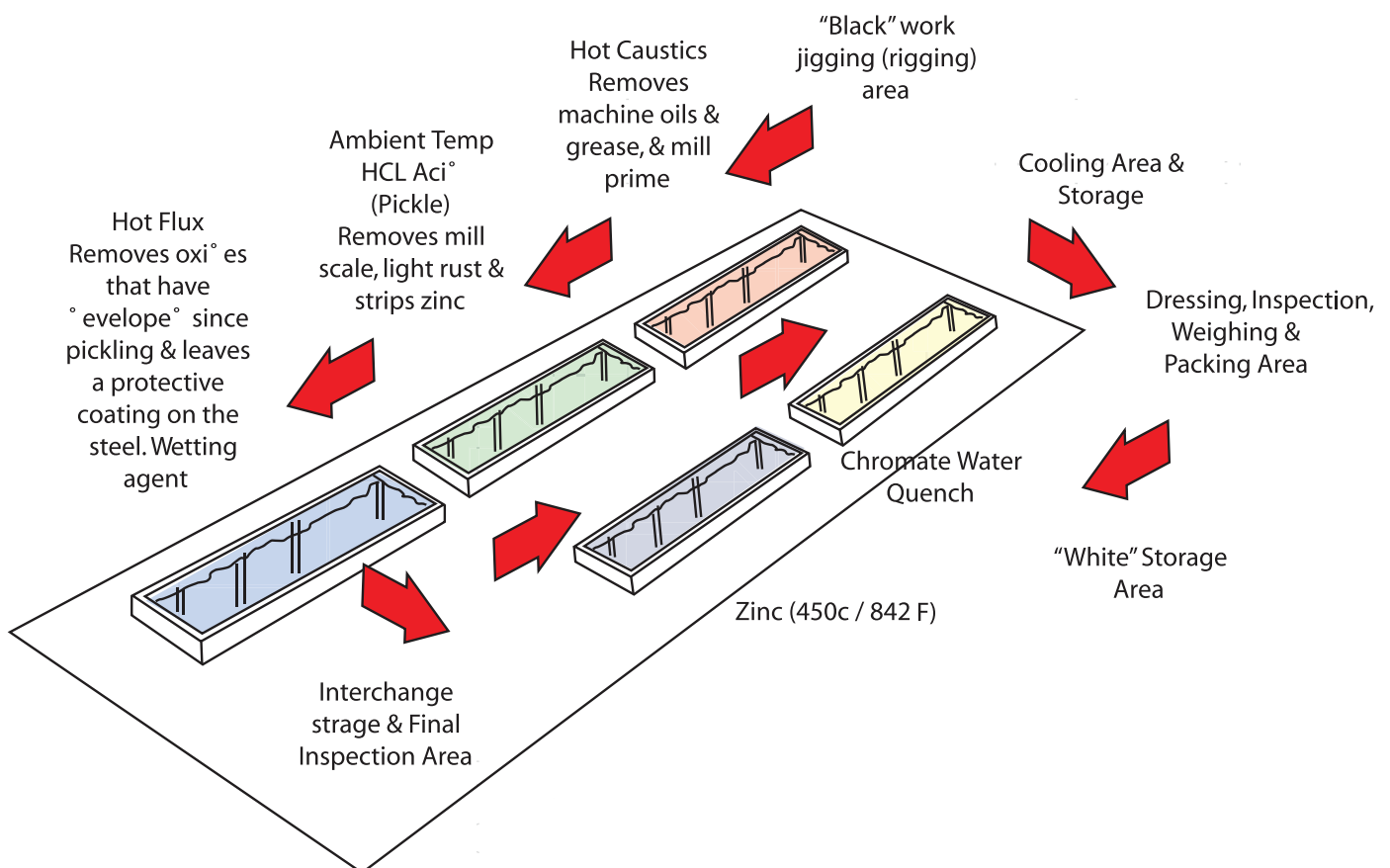
1. Hot Dip Galvanizing: The hot dip galvanizing process involves at least 5 operations. Plant design and layout will determine the maximum size of fabrications that can be galvanized.

67kg Clients Container

Pre-Cleaning Container

HOT CAUSTIC
REMOVES MACHINE OILS GREASE & MILL PRIMERS

HCL ACID (PICKLE) AMBIENT TEMP.

REMOVES LIGHT RUST & MILL-SCALE. PICKLES STEEL TO A CLEAN FINISH.

HOT FLUX

LEAVES A DRYCOAT WHICH PROTECTS THE STEEL SURFACE AFTER REMOVING OXIDES FORMED AFTER THE PICKLE PROCESS

Pre-Cleaning Container

PRE-CLEANING CONTAINER

CENTREFUGE (SPINNING) BASKET

CENTREFUGE (SPINNING) BASKET

GALVANIZING KETTLE MOLTEN ZINC 450

BASKET IS SPUN AT A VERY HIGH SPEED THROWING THE ZINC FROM THE BASKET

CHROMATE WATER QUENCH SHORT TERM ASSISTANCE TO REDUCE WHITE RUSTING BEFORE THE ZINC FORMS ITS OWN PROTECTIVE COATING

REJECT DRUM FOR REPROCESS

INSPECTION CONVEYOR

CLIENTS CONTAINER

67KG

DIGITAL READOUT WEIGHT BRIDGE

67KG

1970

MINUS 67KG = 1903KG

RANDOM THICKNESS AND QUALITY CHECK RECORDD ON INTERNAL DOCUMENTATION

VEHICLE LOADING BAY

2. Centrifuge processing of small parts. Hot dip galvanizing of small parts is done using the centrifuge process, where the pre-treated parts are galvanized in baskets that are spun at high revolutions after withdrawal from the molten zinc to remove excess zinc from their surfaces.
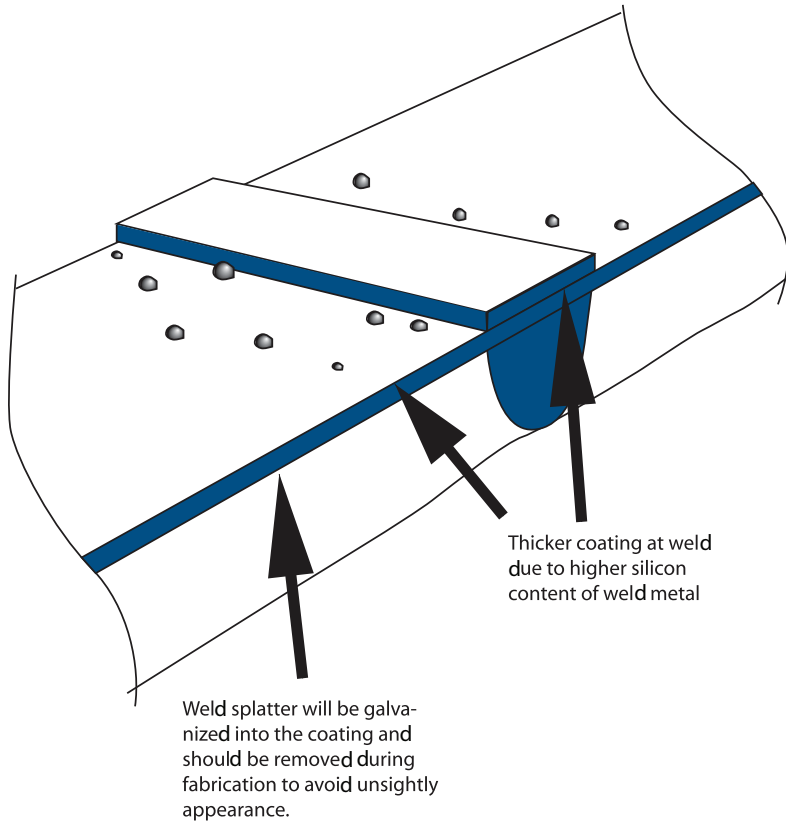
options for venting and draining end plates
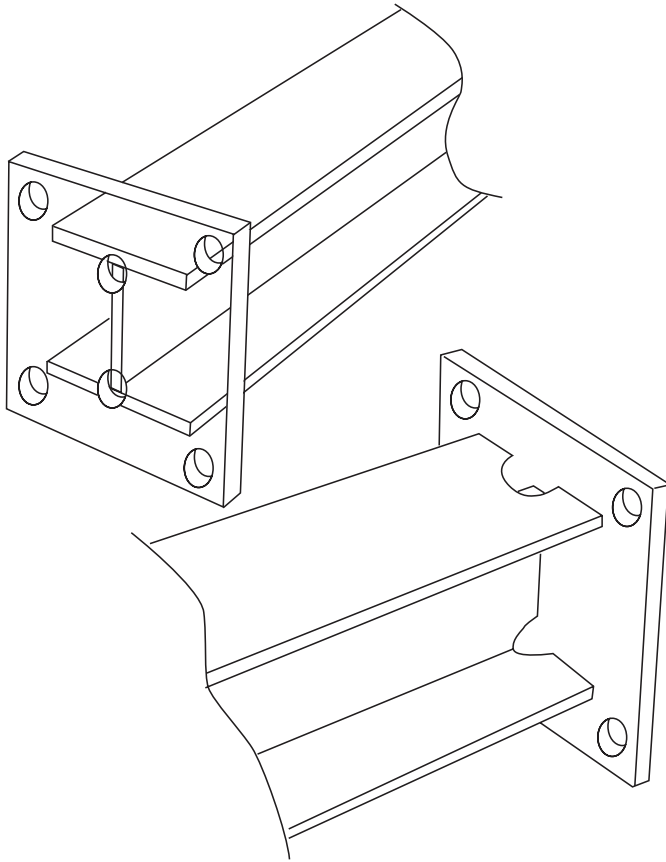
3. End plate design. Base plates and end plates need to be designed for adequate venting and draining. Simple detailing during fabrication, as shown here, will produce good galvanizing results.

Effect of silicon content of steels on galvanized coating mass and appearance
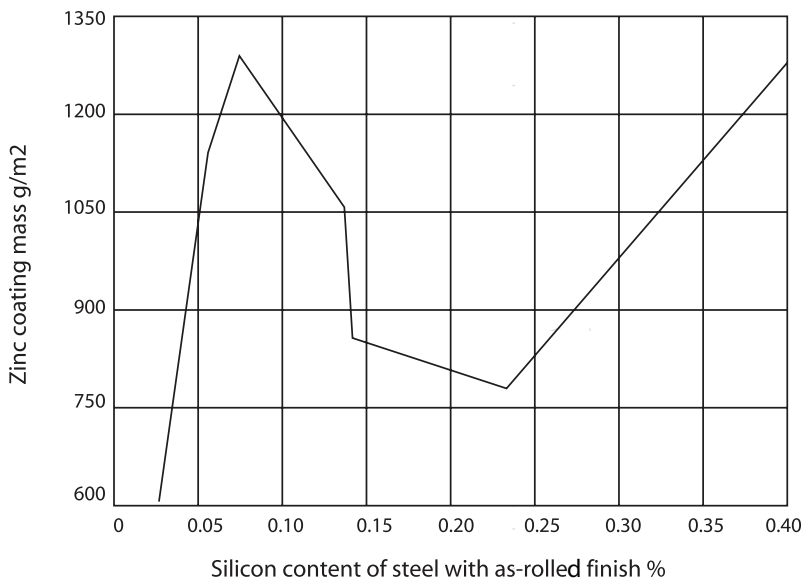
4. The Sandelin Diagram. Steel chemistry determines the rate at which the steel will react with the molten zinc alloy in the galvanizing bath to form the galvanized coating. Silicon is the most significant reactive alloying element in structural steels. This graph shows the reaction rate of steel with zinc at various steel silicon levels, and will give an indication of the likely galvanized coating characteristics of a steel of known silicon composition.

Thicker coating at weld due to higher silicon content of weld metal

Weld splatter will be galvanized into the coating and should be removed during fabrication to avoid unsightly appearance.

5. Welding and weld metal. Weld metal composition and welding techniques can affect the finished appearance of fabrications. Weld metal is normally high in silicon content and will react with the molten zinc alloy at a higher rate that the parent metal. Weld areas ground flush prior to galvanizing may thus appear raised above the metal surface after galvanizing. Weld splatter will not be removed in the pre-treatment process and will be galvanized on the surface, creating an unsightly appearance.

Zinc drips off causing spikes (dags) and a very rough surface

6. Zinc drainage off large items. The angle with which large fabrications can be withdrawn from the bath will determine the effectiveness of the drainage of excess zinc from its surfaces.

natural drain to one point
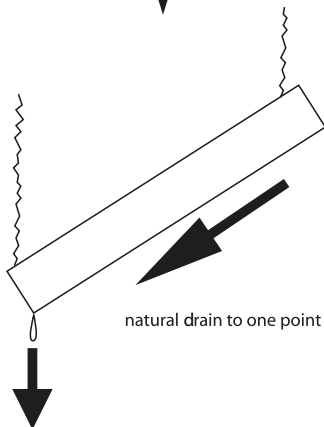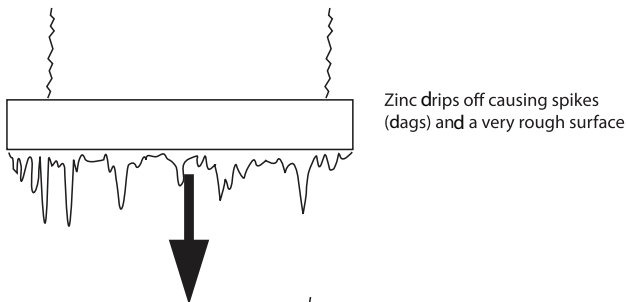
size of fame and head height of hoists affect quality of drain

Combination of good drainage angles

combination of good and bad drainage angles

multiple hanging points for best drainage angles
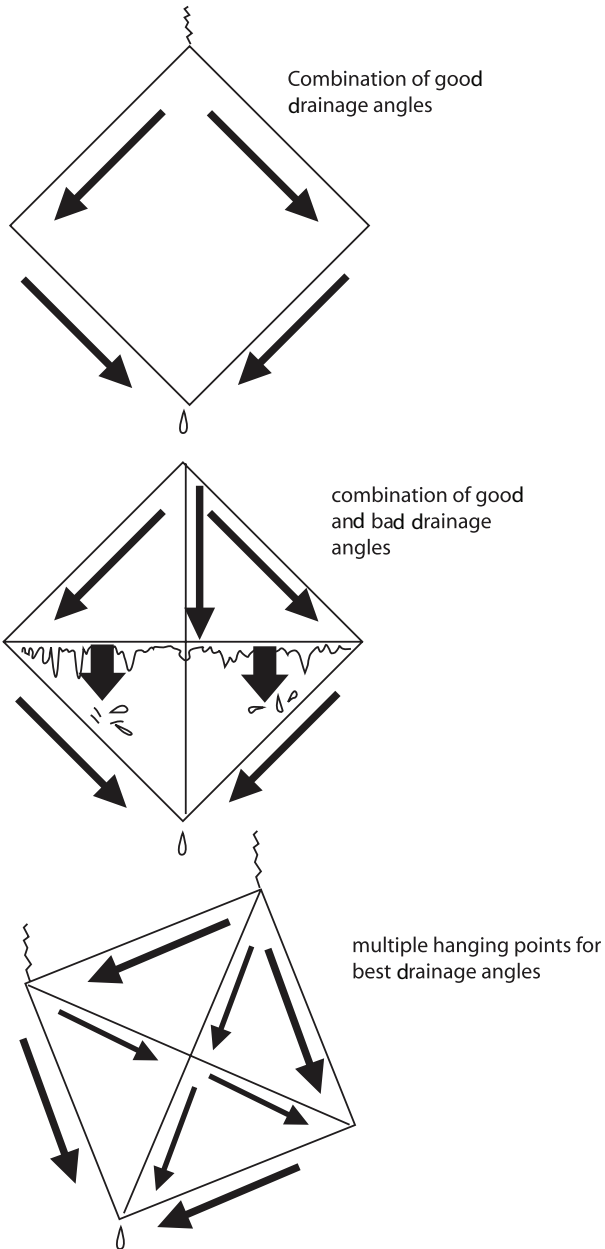
7. Orientation and surface finish. The steeper the angle at which a fabrication can be withdrawn from the galvanizing bath, the smoother the finish is likely to be. The flatter the surface is with respect to the molten zinc, the more drips, drainage spikes and feathers will occur on the edges. Provision of lifting points to allow the optimum orientation will produce the most consistent surface finish.

On immersion, the air travels up the under-side surfacres causing air pockets at each plate
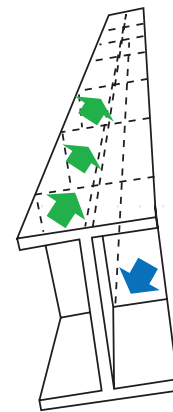
On withdrawal, zinc travels or flows down the upper surfaces, pooling at each plate

There will always be air or zinc traps even on channels.

8. Venting and draining of structural sections. Beams, columns and channels that contain gussets, splice plates or stiffeners in their design will not galvanize satisfactorily unless both zinc and air can get free access to all surfaces of the sections. Cropping of gussets and stiffeners fabricated into these sections will ensure a good galvanizing outcome.

leave space between cleats and wall of unit

UB's, UC's, RSC's Cleats, Gussets strengtheners crop or drill corners

UB. UC, RSC frames

crop or drill holes at each connection

crop or drill all corners

9. Design detailing. Simple detailing will ensure that adequate venting and draining of fabricated assemblies will deliver a good quality hot dip galvanized finish.

angles

crop plates before welding
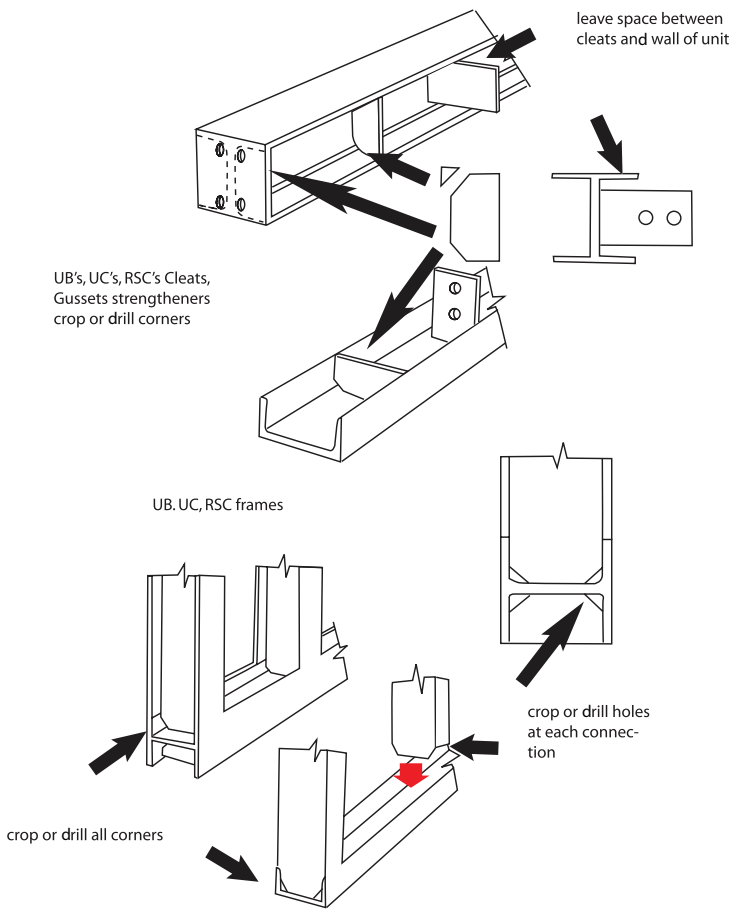
10. Design details for angle fabrications. 1-, 2-, or 3-dimensional angle fabrications need to be designed to consider their venting and draining characteristics during hot dip galvanizing. Using outward facing angles, rather than conventional inward-facing angles, in 3-D fabrications can eliminate the need for any special venting or draining requirements.

angle fabrications

zinc or air trap

hole or cut corners

air pockets

zinc pockets

zinc surface

49

JIG HOLE

AIR TRAP

VENT HOLE

DRAIN HOLE

ZINC TRAP

CROP ALL GUSSETS
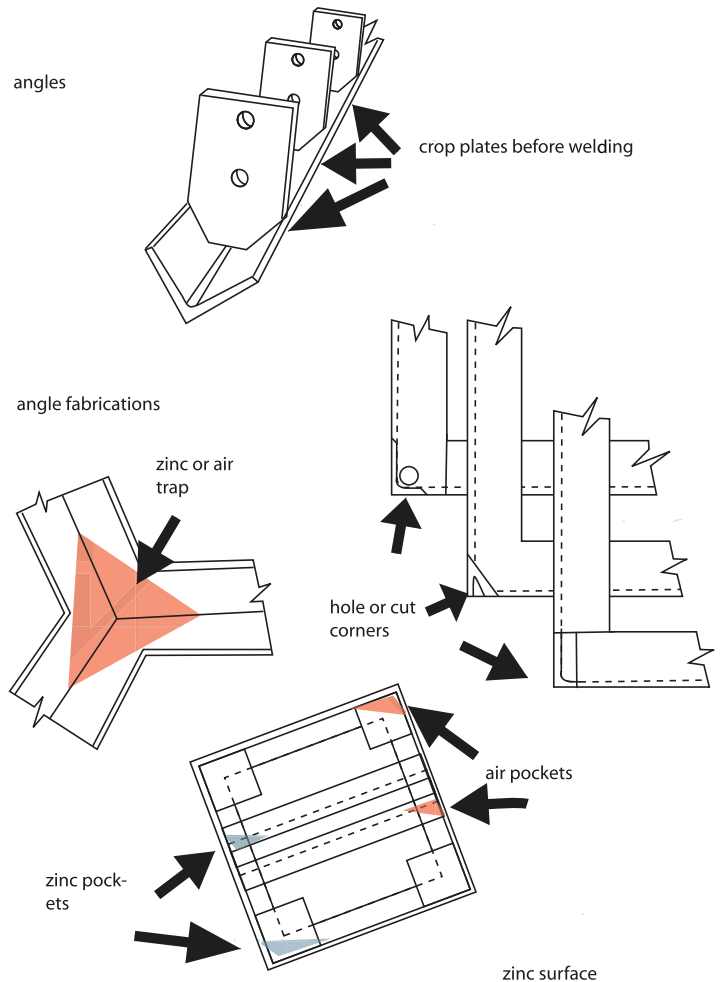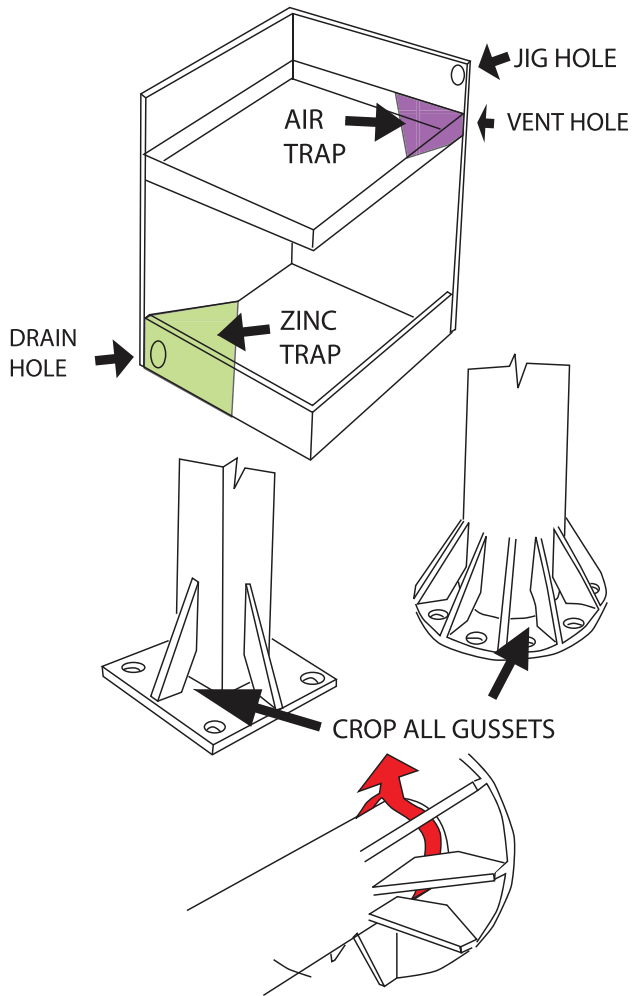
11. Detailing complex fabrications. For complex fabrications, advice should be sought from the galvanized to ensure that adequate lifting points, and venting and draining requirements are incorporated into the fabrication.

12. Zinc buildup and clearances. The surface tension and fluidity of molten zinc will result in thickening of the galvanized coating at low points on solid and hollow circular sections. Where clearances for the fitting of mating parts is requires, this thickness variation needs to be accommodated in the design, particularly on internal surfaces of hollow sections where removal of excess zinc is difficult.
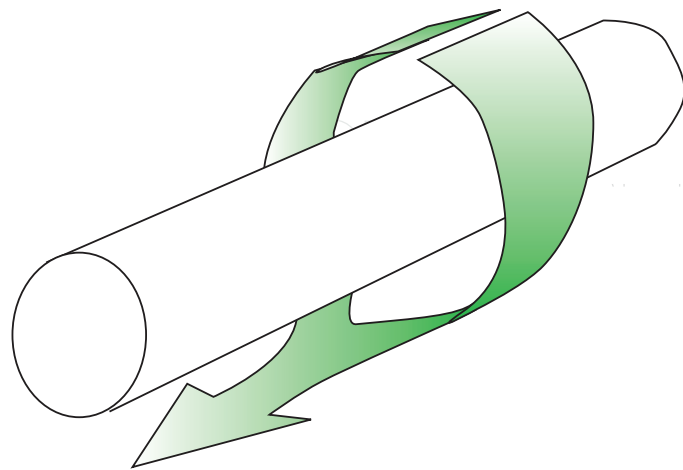
zinc will flow around and down circular units. leaving drainage runs along units

OPEN END OR DRAIN HOLE AT THE CORRECT POSITION AND SIZE

IF NO LUG IS POSSIBLE OPPOSITE HOLEING WILL BE REQUIRED FOR JIGGING

CENTRE HOLE DRAINAGE IS NOT RECOMMENDED

ZINC

RESIDUAL ZINC

ZINC RUN

SUGGESTED DESIGN FOR FLANGED HOLLOW SECTIONS
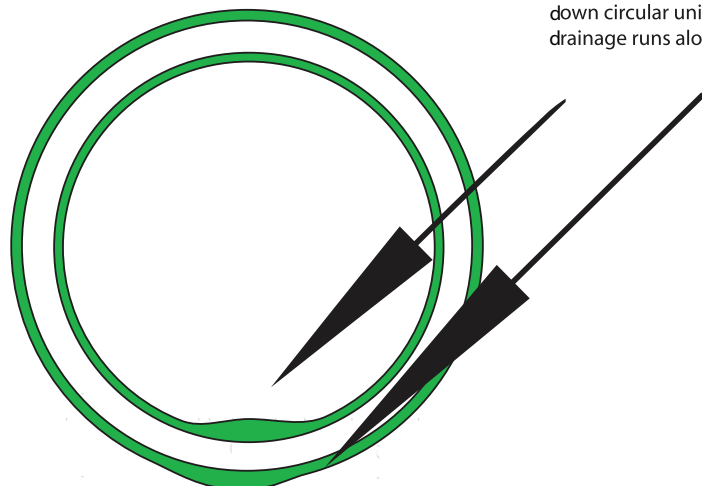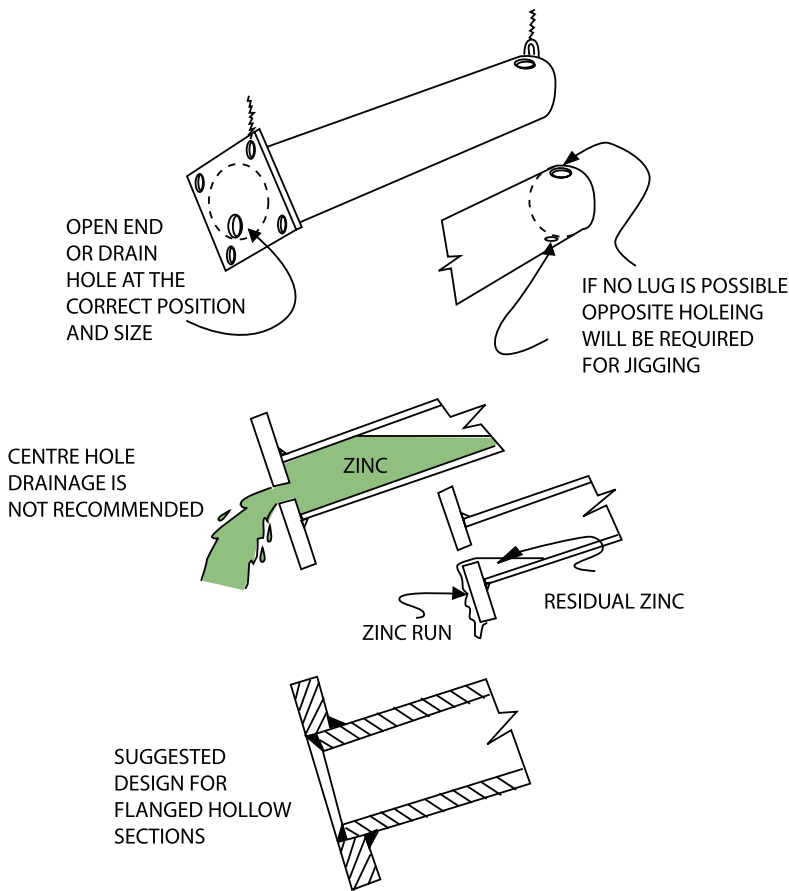
13. Draining larger hollow sections. Larger hollow sections used for structural applications have a significant internal volume so venting and draining of base plates and end plates needs to accommodate the flow of larger volumes of pre-treatment chemicals and molten zinc. The location of drain holes in base plates and end plates will be determined by the orientation of the section during galvanizing.

VENT HOLE PREVENTS AIR TRAPS AND RESULTING UNGALVANIZED INTERNAL AREAS OR EVEN FLOATATION

AIR

LARGER OPENING FOR FASTER FLOW OF ZINC INTO UNIT

AIR

14. Pipe spools and other 2-D and 3-D hollow section fabrications require careful detailing to ensure safe and satisfactory galvanizing. Moisture trapped inside the fabrication is an explosion hazard, and air trapped inside will prevent the item from sinking into the molten zinc.

CORRCT VENT HOLE

INCORRECT VENT HOLE

TRAPPED ZINC SLOSHES OUT AND RUNS SOLIDIFY DURING COOLING CAUSING HEAVY, UNSIGHTLY BUILDUP FROM INCORECTLY POSITIONED HOLE

CORRECT DRAIN HOLE

ZINC

(A) OPTIONAL HOLE POSITION

PREFERRED FILL / DRAIN HOLE POSITION

(B) VENT HOLE

FILL / DRAIN HOLE

(C) VENT HOLE

PREFERRED VENT HOLE POSITION

(D) OPTIONAL HOLE POSITION

(E) OPEN END FILL / DRAIN FACILITY
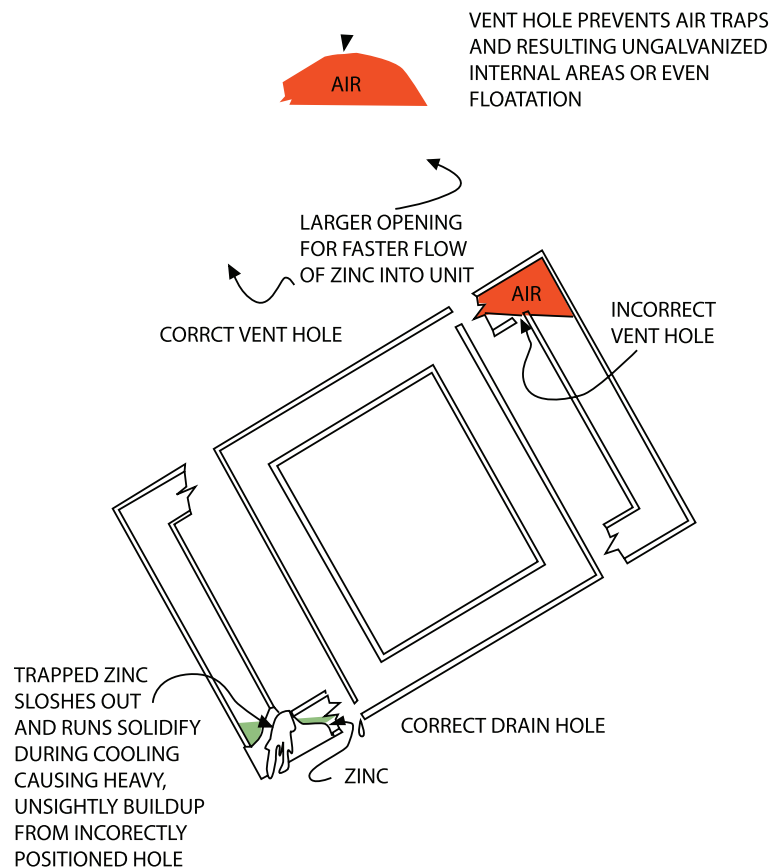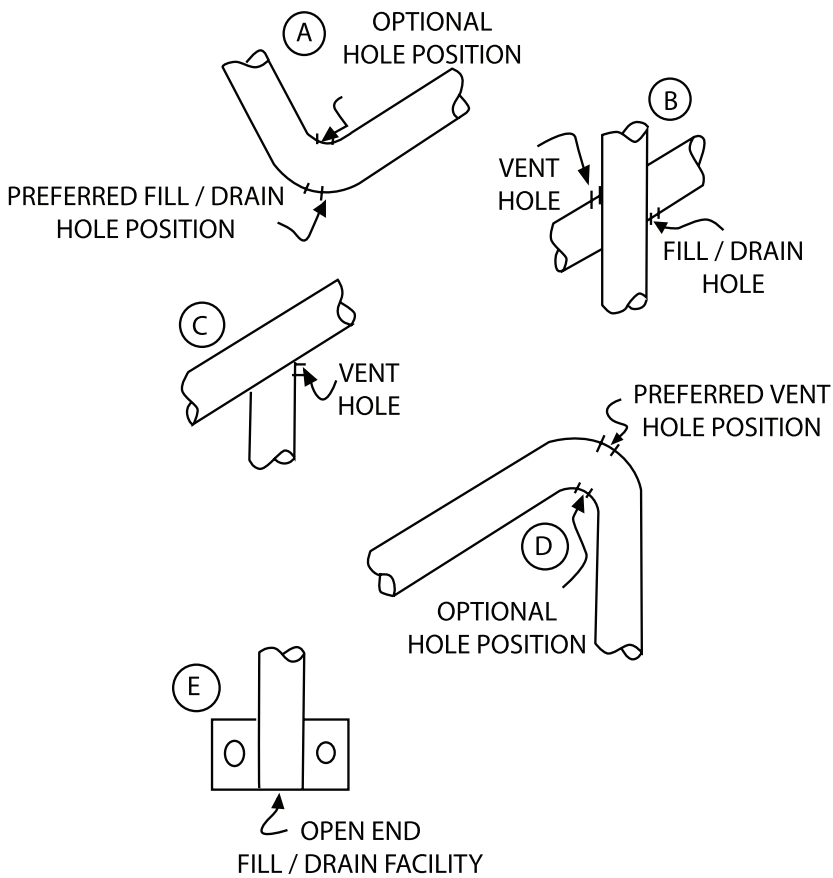
15. Venting and draining of handrails. Stanchions and handrails fabricated from hollow sections need to be vented and drained on the underside or inside to prevent ingress of rainwater and hazards to the pedestrians using the handrails.

VENT AND DRAIN HOLES TOO SMALL!

16. Vent and drain hole size. Vent and drain holes that are too small in hollow sections increase immersion time and may cause unsightly excessive zinc drainage runs as the zinc freezes during the draining period.

VENT AND DRAIN HOLE SIZE. VENT AND DRAIN HOLES THAT ARE TOO SMALL IN HOLLOW SECTIONS INCREASE IMMERSION TIME AND MAY CAUSE UNSIGHTLY EXCESSIVE ZINC DRAINAGE RUNS AS THE ZINC FREEZES DURING THE DRAINING PERIOD.

SPACE MATING SURFACES?

DO NOT FORGET TO VENT AND DRAIN HOLLOW SECTIONS

AVOID WELDING UNITS BACK TO BACK

SUGGESTED FABRICATION
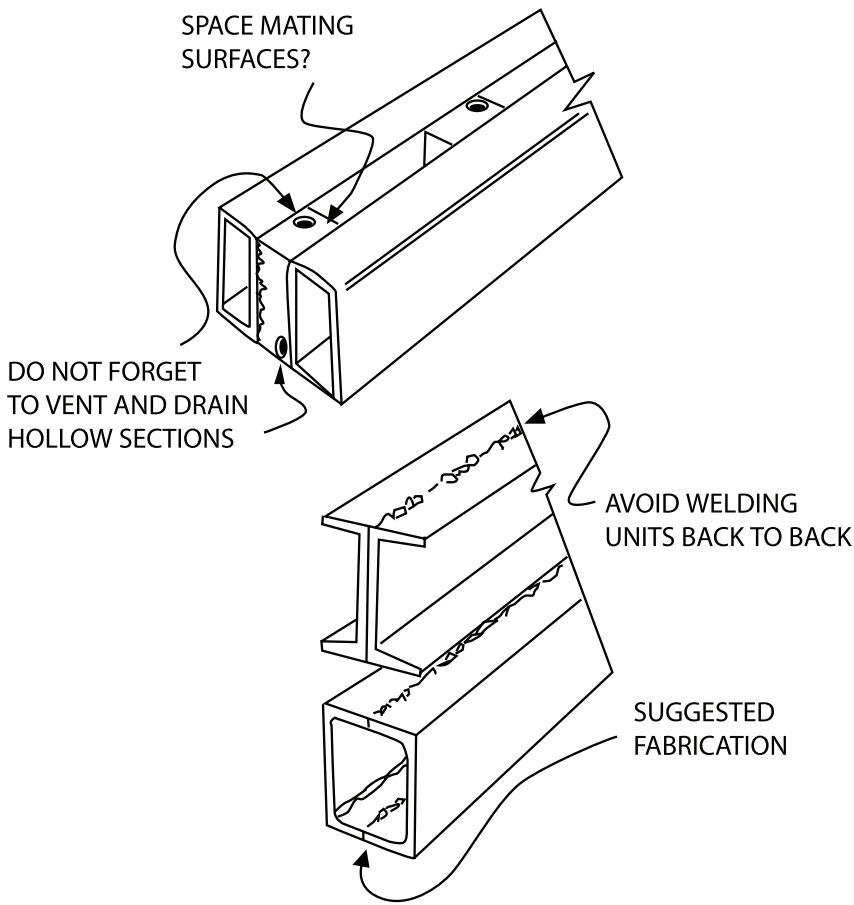
17. Back-to-back sections. Where back-to-back angle or channel fabrications need to be hot dip galvanized, welding to create large overlapping surface areas should be avoided. The use of packers between the sections, or using channels toe-to-toe will ensure a good galvanizing outcome.

18. Back-to-back sections. Where back-to-back angle or channel fabrications need to be hot dip galvanized, welding to create large overlapping surface areas should be avoided. The use of packers between the sections, or using channels toe-to-toe will ensure a good galvanizing outcome.
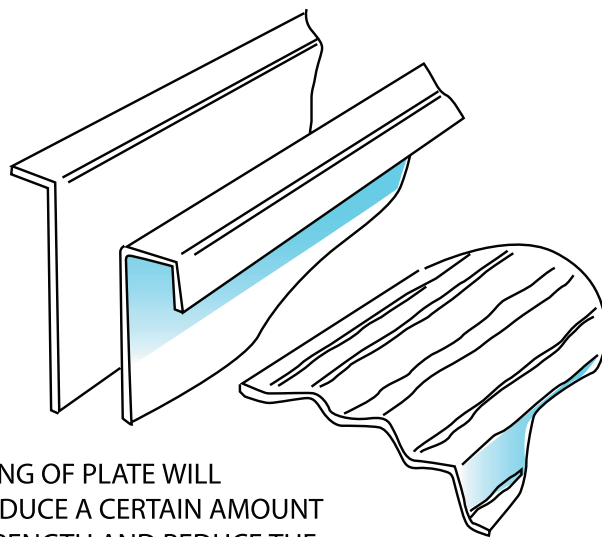
FOLDING OF PLATE WILL INTRODUCE A CERTAIN AMOUNT OF STRENGTH AND REDUCE THE POSSIBILITY OF DISTORTION
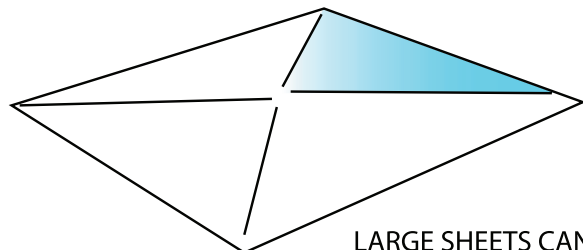
LARGE SHEETS CAN BE BREAK PRESSED WHICH WILL REDUCE THE DISTORTION TO SMALLER AREAS

allow for free flow of zinc and air between internal walls
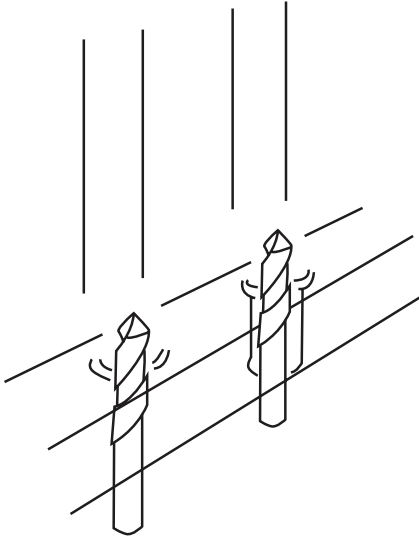
Drill up through the bottom of the lower horizontal unit into the uprights

min 10mm
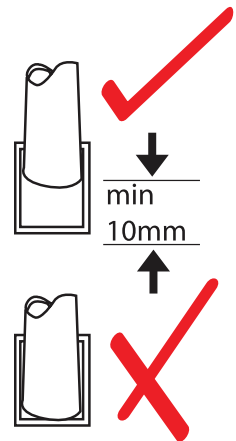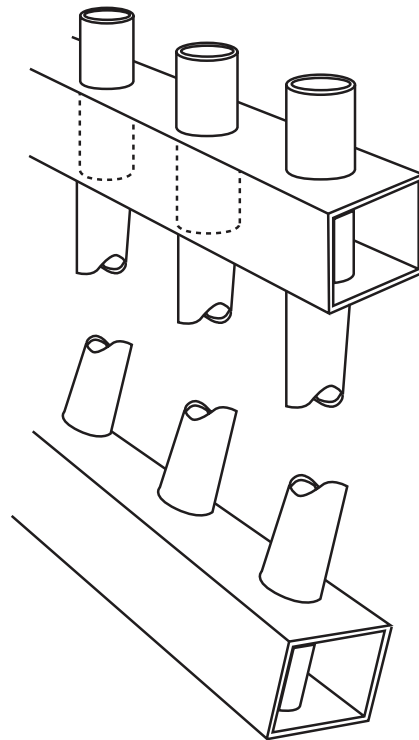
19. Design for fence panels and balustrade. Where hollow sections are used in the fabrication of fence panels and balustrades to be hot dip galvanized, the pre-treatment chemicals and molten zinc must be able to flow freely into and out of the fabrication. Venting and draining on the underside of fence panels and balustrade will not effect their appearance and will not allow weather to enter the panels.

13. DEWPOINT TABLES

One of the most critical aspects of applied coating quality, as well as corrosivity of atmospheres is the dew point, or the point at which a steel surface becomes wet with condensation. For reference, this Dew Point Table lists Dew Point over a range of relative humidities and air temperatures.
To allow a practical safety margin, steel substrate temperature should be at least 3°C above the Dew Point. The Dew Point is the temperature of an air-water vapor mixture at which condensation of water vapor starts, as at that point, the air becomes saturated.

Some solvent-based paints are water intolerant and should not be applied unless the surface is at the specified level above the Dew Point. Some other coatings, which are moisture cured, cannot be applied in conditions of low humidity and high temperature as this affects their curing.

The Dew Point is an important factor in corrosion of metals as it is a major determinant of Time of Wetness. Moisture is required to allow any electrochemical corrosion processes to occur, and is thus one of the most significant criteria used for corrosion modeling.

AIR TEMP. °C	DEW POINT IN °C AT RELATIVE HUMIDITY LISTED								
	50%	55%	60%	65%	70%	75%	80%	85%	90%
16	5.6	7.0	8.3	9.5	10.5	11.6	12.5	13.5	14.4
17	6.5	7.9	9.2	10.4	11.5	12.5	13.5	14.5	15.3
18	7.4	8.8	10.2	11.4	12.4	13.5	14.5	15.4	16.3
19	8.3	9.7	11.1	12.3	13.4	14.5	15.5	18.4	17.3
20	9.3	10.7	12.0	13.3	14.4	15.4	16.4	17.4	18.3
21	10.2	11.6	12.9	14.2	15.3	16.4	17.4	18.4	19.3
22	11.1	12.5	13.8	15.2	16.3	17.4	18.4	19.4	20.3
23	12.0	13.5	14.8	16.1	17.2	18.4	19.4	20.3	21.3
24	12.9	14.4	15.7	17.0	18.2	19.3	20.3	21.3	22.3
25	13.8	15.3	16.7	17.9	19.1	20.3	21.3	22.3	23.2
26	14.8	16.2	17.6	18.8	20.1	21.2	22.3	23.3	24.2
27	15.7	17.2	18.6	19.8	21.1	22.2	23.2	24.3	25.2
28	16.6	18.1	19.5	20.8	22.0	23.2	24.2	25.2	26.2
29	17.5	19.1	20.5	21.7	22.9	24.1	25.2	26.2	27.2
30	18.4	20.0	21.4	22.7	23.9	25.1	26.2	27.2	28.2

INTRODUCTION

From time to time, galvanizers are asked about galvanizing special steels or unusual steel sections that are outside the normal range of steels processed on a day-to-day basis through jobbing galvanizing operations. While these steels can present problems for galvanizers, it is sometimes possible to deal with these problems in the design of the components or through modifications to the hot dip galvanizing process.

In addition, steelmaking processes may vary from time to time, or steel may be sourced from imports that have variable chemistry because of the nature of the raw materials used in their manufacture in their country of origin.

GALVANIZING ALLOY STEELS

While high strength alloy steels are rarely used for structural applications, they are sometimes used as performance-critical components in assemblies or as individual manufactured items. There are three factors that effect the ability of steel to be galvanized. These are:

1. The chemical composition of the steel
2. The strength rating of the steel (the yield strength in MPa)
3. The steel's section thickness*

* This is a factor in that it determines the immersion time of the steel in the molten zinc.

When a request is received to galvanize an unusual type of steel, the chemical composition is first checked. Most special steels contain carbon (C), phosphorous (P), manganese (Mn), silicon (Si), sulfur (S), chrome (Cr), nickel (Ni) and may also contain copper (Cu), Vanadium (Va) and other elements that are used to give the steel particular performance characteristics.

WHAT IS IN ALLOY STEELS?

While there are hundreds of different types of special steels, there are generic chemistries that fit particular applications and these are useful in determining what is likely to happen when these steels are hot dip galvanized. The following list is a guide to the most prominent alloying elements likely to be in these special steels that will have an effect on their ability to be galvanized:

1. Spring steels. These steels contain high levels of silicon which can be up to 2.0%.
2. Tough steels. These steels contain high levels of manganese which may be over 1.0%
3. Hard steels. These steels contain high levels of carbon which may be over 1.0%
4. Free machining steels. These steels contain high levels of sulfur
5. Electrical steels. These steels contain high levels of phosphorous
6. Stainless steels. These steels contain high levels of nickel and chrome
7. Cast iron and steel. These items may have high carbon content, non-metallic inclusions or casting sand fused to the surface.
8. Very low alloy steel. These steels contain very low levels of alloy additions and are largely pure iron – similar to the steel from which galvanizing baths are manufactured. This type of steel has a very low reaction rate with zinc, and can cause problems in producing galvanized coatings that comply with Australian Standards. It is most frequently found in products that are formed from low-strength (under 350 MPa) steel coil.

This fracture in high-strength Bisalloy plate resulted from hydrogen embrittlement induced by the acid pickling process. High strength steels such as this can be satisfactorily galvanized by mechanically cleaning the surface and avoiding the acid pickling pre-treatment stage in the galvanizing process.

The galvanizing characteristics of these steels are as follows:

1. High silicon steels will produce thick galvanized coatings that may be brittle because the steel reacts very rapidly with the zinc. The effects of high silicon content can be minimised by keeping immersion time in the zinc as short as possible. This becomes increasingly difficult as section thickness increases.

2. High manganese steels will produce brownish coloured coatings that may be brittle and easily damaged in handling compared to galvanized coatings on conventional steels.

3. High carbon steels can be successfully galvanized as long as their yield strength is within an acceptable range (see note below).

4. High sulfur steels are used for high-speed machined components (threaded fasteners, sockets etc) and should not be galvanized. The high sulfur steel can be severely eroded in the galvanizing process, rendering threaded items unserviceable.

5. High phosphorous steel are rarely encountered in galvanizing operations but are unsuitable for galvanizing. They react rapidly with the zinc to form thick, dark coatings that are easily damaged and may delaminate from the surface.

6. Stainless steels can be galvanized but are susceptible to liquid metal embrittlement and can fracture under load after immersion in molten zinc. Stainless steels are only galvanized incidentally if they are attached to mild steel assemblies.

7. Cast iron and steel will normally galvanize satisfactorily, but moulding sand fused to the surface will not be removed by the pre-treatment process. Cast items may require abrasive blasting prior to delivery to the galvanizing plant to remove these refractory surface contaminants.

8. Very low alloy steel has a very low reaction rate with zinc, and can cause problems in producing galvanized coatings that comply with Australian Standards. It is most frequently found in products that are formed from low-strength (under 350 MPa) steel coil.

STEEL STRENGTH AND GALVANIZING

High strength steels (over 800 MPa [115,000 psi] yield strength) are susceptible to hydrogen embrittlement arising from the pickling process in galvanizing. Pickling should be avoided for steels in this strength range.

These heavy coil springs have been successfully galvanized following special handling of this high silicon material.

STEEL SIZE AND GALVANIZING

While all conventional steel structural sections can be galvanized, from time to time, unusual sections arise that may present problems. Very thick sections over 100 mm in thickness may be difficult to galvanize acceptably in a conventional galvanizing bath. The mass of these items per unit of volume is very high, and as the zinc in the galvanizing bath is only about 35 degrees above its freezing point, the zinc freezes around the item when it is immersed, and may form a layer of frozen zinc 50 mm or more in thickness.

This zinc has to be re-melted and then the item itself heated up by the zinc bath to bath temperature for the galvanized coating to form. This sequence of events may interfere with the performance of the flux on the surface of the item and cause uncoated areas on the surface. These defects can be minimised by pre-heating the item or operating at higher galvanizing bath temperatures, which requires special galvanizing bath design.

CONCLUSION

It is possible to successfully galvanize many difficult steels, particularly spring steels or wear resistant steel (Bisalloy) which are the type most likely to turn up for galvanizing. As long as the sections can be abrasive blasted rather than pickled, an acceptable galvanized coating can be produced on these steels that will not affect their performance.

INTRODUCTION

A hot-dip galvanizing plant is a service operation, in that products manufactured elsewhere are delivered, largely in an unscheduled manner, by a large number of diverse clients, with an expectation that the finished product will be available in less than a week from the time of delivery.

Steel fabrications that are required to be hot-dip galvanized come in an infinite variety, from small parts to large or complex structural sections. Each item has to be evaluated by the galvanizer to determine how it will best be handled through the galvanizing process.

One consignment of steel may need to go via three separate routes through the galvanizing process because of its specific handling requirements. To ensure that each order is processed efficiently, and is collated correctly on exiting the galvanizing process, the delivery documentation and the communication between galvanizer and customer needs to a high standard.

DOCUMENTATION

On delivery, the work should be accompanied by documentation containing the following information:

- Customer contact details
- Quotation number if appropriate
- Order number for the work
- Detailed description of each item
  (e.g. 6 off 250 x 250 x 9 SHS   1450 mm long)
- Any special requirements for inspection,
  packaging or delivery.

IDENTIFICATION

Each item or batch needs to be clearly identified by permanent marking (stamping or welded mark numbers) or my marking with an **approved type** of marking paint. Using incorrect types of marking paint will result in galvanizing defects as the chemical pre-treatment may not remove the wrong type of paint. At this point, the item is tagged with an embossed metal tag indicating the Factory Order Number allocated to the job. This tag remains attached to the item or part of a batch.

Items are individually tagged for identification. The metal tag remains attached throughout the galvanizing process.

On major projects involving quantities of scheduled steelwork, arrangements can be made to mark individual items with clearly visible mark numbers after galvanizing (using black marking pens) to facilitate sorting and erection on site.

PROJECT ADMINISTRATION

On major construction projects, fabricated steel may be sourced from a number of fabricators, with the galvanizing plant controlling the scheduling and dispatch of loads to the construction site. Industrial Galvanizers has managed a number of large projects of this nature, involving up to 6,000 tonnes of fabricated structural steel.

Close liaison between the project managers and Industrial Galvanizers' operations is essential to ensure that documentation and processing is done in accordance to the construction requirements. Special process documentation, including bar coding systems, has been implemented on specific projects, permitting close control of tracking items through the process.

LOADING AND PACKAGING

Industrial Galvanizers' aim is to return the finished galvanized products to its customers in good condition. The regular processing of manufactured products can be facilitated through the use of purpose built containers or stillages for transporting product to and from the galvanizing plant.

Special arrangements can be negotiated for items to be packed for final shipment at the galvanizing plant and this is currently done for a number of customers around Australia. Arrangements can also be made to store finished work to reduce transport and handling costs.

TRANSPORT

Each Industrial Galvanizers plant has its own fleet of delivery vehicles, including table-tops and semi-trailers. Pick-up and delivery services can be negotiated or included within the galvanizing cost for customers.

For long-haul transport, Industrial Galvanizers can assist clients with transport arrangements.

STORAGE OF GALVANIZED WORK

The storage of work following galvanizing is the responsibility of the customer. It is important that stored galvanized work is stacked so that each item is well ventilated and can adequately drain rainwater from its surfaces.

Poor storage of finished product can give rise to white storage staining (white rust) which is caused by rapid corrosion of the freshly applied galvanized coating by pure water (rain or condensation) in badly drained or ventilated conditions. Severe white rusting can occur very quickly, particularly in warm, humid conditions and may result in the coating becoming unserviceable prior to installation.

The use of hardwood dunnage may also cause tannin staining of the galvanized coating if the stacked work is wet during storage. While this does not affect durability, the dark brown staining that occurs may be aesthetically unacceptable and is difficult to remove.

Documentation accompanying fabricated steel deliveries for galvanizing should detail all items in the consignment. The galvanizers describes and tags items after delivery to track items through the galvanizing process.

Clearly marked items make processing of loads easier for both client and galvanizer. The correct type of strippable marking paint should be use to ensure removal in the pre-treatment process prior to galvanizing.

INTRODUCTION

There are few industrial activities in which environmental considerations are not looming large in both the way products are manufactured, and their long-term environmental impact.

Work health and safety, management of effluents and residues and greenhouse issues are becoming very important in driving specifications and the selection of materials.

In areas such as OH&S and waste management, government involvement in setting and administering standards has driven the agenda in most jurisdictions. In the areas of material sustainability and greenhouse management, the participation by industry has been largely voluntary.

ENVIRONMENTAL ISSUES FOR COATINGS

The fundamental environmental issues for coatings are:

- Is the coating itself environmentally acceptable - what does it contain?
- Is its manufacturing process environmentally acceptable?
- Is its application process environmentally acceptable?
- What are its long-term effects on the environment?
- Can it be recycled?
- Can the manufacture meet its carbon footprint obligations in the future.

Paint coatings have long been subject to scrutiny in all of these areas, and the paint industry has worked hard on its technology to provide coatings that comply with increasingly stringent regulations.

TOXICITY OF PAINT PIGMENTS

Red lead pigment in paint has been used as a rust inhibitor for centuries and is still used in some areas in maintenance painting in industrial situations, e.g. bridges and process plants. The reason for this is that oleoresinous red lead materials have had an unrivalled anticorrosive performance on compromised surfaces. Lead chromate pigments have been also been used, particularly in bright yellows and red colours, in decorative paint coatings.

Environmental controls are much more stringent where maintenance painting is required, even for non-hazardous coating. This navigation tower required full containment for its refurbishment.

Intact dried paint containing lead, in an industrial environment, represents little if any health hazard. Hazards arise during application, especially spray, but the main hazard occurs during removal of lead based paints. In construction projects, this removal may occur when welding, burning or abrasive blasting is performed on painted steel.

During burning and welding processes the temperature generated is high enough to vaporise the lead. Abrasive blasting of the coating generates very fine airborne particles, which present a serious hazard to workers and the public in close vicinity. Lead is a poison that serves no known useful function in the body. In large enough doses it can kill in a matter of days. Exposure to smaller doses over long periods of time can cause severe damage to the blood-forming, nervous, urinary and reproductive systems. Children born to parents who have been exposed to excessive lead levels have a greater chance of having birth defects, mental retardation, behavior disorders or dying during the first year of life.

Lead is a particularly insidious poison because severe, permanent damage can be done before any symptoms are felt, unless very large doses are involved. Removal of lead paints represents a significant cost penalty. Disposal of hazardous waste together with the problem of containment and capture is a difficult and expensive proposition. It is estimated that this could increase cleaning and painting costs between five and ten times more than normal.

Isocyanates

Isocyanates, in monomeric form, are used to manufacture pre-polymers that are in turn used in paint manufacture, specifically in polyurethane coatings that have a variety of end uses, for example as durable finishes or elastomers.

Most paints present some form of health hazard, but isocyanates have particular hazards and careful precautions must be taken by paint applicators to avoid these. Isocyanate containing coatings are safe to handle provided all precautions as specified on the Health and Safety Data Sheets are taken. In the case of two pack isocyanates, as well as the protective clothing worn for all paints; the precautions include the use of air fed hoods when spraying for this type of material.

Isocyanate monomers which are used to make pre-polymers (resins) are the largest contributors to ill health effects because of the small molecular size and hence volatility. Very small amounts remain together with larger less volatile pre-polymer molecules in paint. All the unreacted 'free' isocyanate represents a hazard particularly when sprayed.

Isocyanates are particularly hazardous to the respiratory system and atmospheric over-exposure can lead to varying conditions of ill-health. In mild cases, the afflicted may suffer irritation of the eyes, nose and throat. There may be a tightening of the chest and coughing. In more severe cases the symptoms experienced can be acute bronchial irritation and difficulty in breathing. The onset of such respiratory effects may be delayed for several hours after exposure.

Isocyanate-free technology is now available to provide coatings with a performance similar to that of polyurethanes, such as durability, weathering and colour and gloss retention, without the degree of risk of respiratory disease and sensitisation associated with 2-pack isocyanate paints. The Sydney 2000 Olympic Stadiums were finished in a 2-pack isocyanate- free catalysed acrylic coating.

Other pigments and binders

Restrictions have been placed on a number of other paint technologies including coal tar and chromate pigmented paints because of the negative WH&S

EPA requirements on some repainting projects require full filtration of the extracted air.

implications of these materials. From a performance point of view, these coating systems, along with lead pigments, are excellent technology for their design applications, but environmental criteria have overridden technical performance.

V.O.C.'S

The global problems attributed to Volatile Organic Compounds, (VOCs), arise from the use of solvents in many industrial processes with the paint industry playing a very significant part. In Europe and the US, paint and the painting industries have been targeted as a key area to receive legislative attention. Estimates in Australia alone are that in excess of 80,000 tonnes of VOC's are released into the atmosphere annually with the existing technology.

The environmental impact of any substance is related to how it is released into its surroundings. In the case of volatile materials (including solvents), they evaporate into the air and are then oxidised by photo degradation. This results in the three main air pollution problems of ozone layer depletion, a photochemical smog and global warming.

Ozone Layer Depletion

The ozone layer in the upper atmosphere absorbs harmful UV irradiation which would otherwise promote skin cancers in human beings and animals and damage agricultural crops and marine organisms. The depletion of ozone in this region (18-40 km above ground), was first noted about 20 years ago but ozone levels are difficult to measure and it is only more recently that the evidence has been universally accepted.

Halogenated substances (including chlorinated solvents) are the main cause of this effect. They have a longer life than hydrocarbon solvents once released into the atmosphere, which allows them to reach the higher atmospheric layers. They are then decomposed by UV light to form halogen reactive groups which act as catalysts to the break down of ozone to form oxygen, so removing the ozone protective layer.

Photochemical Smog
Although hydrocarbon solvents rarely reach the upper atmosphere, they are retained in the lower atmosphere where they cause damage. They actually react under the influence of UV light with nitrogen oxides that are particularly dominant in the atmosphere of industrial and large built-up areas, to promote the concentration of ozone otherwise known as 'photochemical smog'. Whilst in the upper atmosphere, ozone is protective, its presence in the lower atmosphere causes acute human respiratory disorders such as asthma, especially in young children, and severe irritation of the eyes. In addition, the ozone has a damaging effect on agricultural crops.

Global Warming
The sun's radiation warms the earth's surface, which in turn heats the atmosphere by the emission of infra-red radiation. Higher molecular weight gases, including those attributable to solvent emissions into the atmosphere, absorb and trap some of this infrared radiation that would otherwise reach outer space. The result is an increase in the earth's atmospheric temperature, an effect known as global warming or the 'greenhouse effect'.

INDUSTRY ACTION
The international paint industry has been active in developing coating systems that eliminate or reduce the environmental impact of the older technologies. More water-based systems are now available that offer levels of performance equivalent to some solvent-based systems.

Low VOC or solventless systems are now readily available, and other technologies are emerging using inorganic or hybrid organic-inorganic coatings that offer superior technical performance. Unfortunately, in many developing countries, many older technologies such as lead-based paints are still used, as are many high VOC materials.

Galvanized coatings slowly weather away, with the zinc ending up in the soil. Most soils are zinc deficient and this has no negative environmental impact in most instances. All protective coatings prolong the life of steel and make an energy saving contribution as a result.

International protocols for greenhouse reduction will ultimately have an impact and bring developing country standards up to those of the industrialised countries.

METALLIC COATINGS
Zinc is used almost exclusively as the metallic coating for protecting steel from corrosion. It is applied by various technologies, ranging from electroplating through continuous galvanizing to after fabrication galvanizing. All these processes have differing environmental impacts and produce coatings with varying levels of durability.

Zinc, being a reactive metal high in the electrochemical series of metals, does not exist in nature as a metal, but, like most metals, is present as a mineral, frequently in concert with lead and other less abundant metals. As a result, the production of zinc metal requires that its ores be mined, milled, smelted and refined to produce zinc metal. Once in this form, zinc then takes its place in the manufacturing process and ends up as a coating (e.g. galvanizing), as an alloying metal (in brass), as a pigment (zinc dust), as a chemical, (e.g. zinc oxide used in rubber manufacture, fertilizer and medicine) or as a product itself (e.g. zinc die castings, zinc sheeting).

These operations produce a stream of secondary zinc waste products (e.g. zinc drosses and oxides, scrap, zinc rich waste acid solutions) which are then subject to secondary processing operations to recover zinc and other components of commercial value for subsequent return to the material cycle.

ZINC AS AN ENVIRONMENTALLY SUSTAINABLE COATING MATERIAL

The issue of environmental sustainability is becoming increasingly significant at all levels of our society. It is not only on the political agenda as 'green' candidates represent an increasing proportion of the political landscape at local, state and federal level, but is also a high priority for the design professions and their clients in the 21st Century.

A simple method of rating materials is to compare them on the basis of their Gross Energy Requirements (GER.). This accounts for all the energy used in mining, smelting, refining and forming the material. For metals in particular, another factor called Gibbs Free Energy (GFE) is a measure of the energy required to convert the ores to the metal. Nature always seeks equilibrium at the lowest energy levels and the GFE makes all metals intrinsically unstable. Their stored energy constantly seeks an opportunity to get out. The GER and the GFE are not necessarily related. Some metals like copper have high GER requirements because of the nature of their ores, and low GFE requirements because of the nature of the material.

The following table illustrates this relationship:

Material	Mineral	Gross Energy Requirement (MJ/kg)	Gibbs Free Energy (MJ/kg)
Aluminium	Al_2O_3	270	29.00
Copper	Cu_2S	115	0.70
Zinc	ZnS	70	3.00
Steel	Fe_2O_3	35	6.60
Lead	PbS	30	0.45

It can be seen from this table that in the context of protective coatings for steel, zinc has double the GER of steel but has less than half the GFE.

Although using more heat energy, powder coating are solventless and have zero ZOC's, significantly reducing their environmental impact.

Zinc, when used as a component in a protective coating for steel is by its nature, sacrificial. All zinc used as a protective coating for steel will be returned to the environment as it oxidises or corrodes sacrificially to prevent corrosion of the steel. Protective coatings of all kinds work on the principle that a small amount of coating can protect a large amount of steel.

On hot dip galvanized products, for example, the galvanized coating mass is typically about 5% of the mass of the steel that it is protecting. If unprotected, the steel would corrode at rates typically 20 times faster than zinc. Using adequate protective coatings systems on steel to delay the escape of its Gibbs Free Energy as long as possible is thus a major factor in determining environmental sustainability.

ZINC IN COATINGS - WHERE DOES IT GO?

Zinc is the most widely used metal for the protection of steel from corrosion as well as being present in a range of other manufactured products and in the natural environment. About 10 million tonnes of zinc metal are produced annually, of which about 20% is from recycled material and the rest from mining and refining.

From this, about 50% goes into coatings for corrosion prevention, 20% goes into brass, about 10% goes zinc chemicals with about half of this used for tyre manufacture), while the balance is consumed for products such as sheeting, dry cell batteries and diecastings.

As coatings and tyres are consumable products, it is logical to assume that the zinc in these products will eventually end up dispersed into the environment. Is this a health hazard? Does it represent a risk to the natural environment?

The important issue from an environmental point of view is that of where the zinc ends up after it becomes a corrosion product. Does it migrate far from its original source? Does it accumulate? Research on these subjects is starting to provide a better understanding of the behavior of zinc leached from coatings.

The International Lead-Zinc Research Organization (ILZRO) has undertaken research on the leaching of zinc from galvanized coatings on transmission towers. This research concluded that even in aggressive acid rainfall zones, zinc concentrations in soil were at background levels within 6-9 metres of the tower base. Research continues in this area.

ZINC AS A SUSTAINABLE MATERIAL

Compared to other base metals zinc occupies a favorable position as an environmentally sustainable material. Energy consumption for primary zinc production is 25-50% higher than that of steel and only about 20% of aluminium.

About 20% of zinc used is recovered as scrap and this is likely to increase to over 60% as recovery process technology improves.

The galvanizing of steel as sheet, wire, tube and fabrications offers very good corrosion resistance on steel and greatly increases its life. On average, about 70 kg of zinc (which consumes 250 kWh of energy to produce) is consumed to prolong the service life of 1 tonne of steel as sheet, which consumes about 2900 kWh of energy to produce, by a factor of between 3x and 5x. At the end of its service life, the galvanized material can still be recycled, except for the zinc lost through corrosion and run-off.

As weathering occurs with these zinc-based coatings, the zinc is consumed in two ways. These are:

1. Oxidation of the zinc and physical removal of the zinc oxide products by washing or erosion.
2. Electrochemical dissolution of the zinc adjacent to exposed steel when an electrolyte (water) is present.

These zinc corrosion products are transported into the surrounding environment. It is their impact in this context that determines their viability as coatings for the foreseeable future. The rate at which zinc moves into its surrounding environment from the weathering of coatings is obviously determined by coating life.

CONCLUSION

The protective coatings industry internationally is well aware of the major environmental challenges facing the industry into the 21st Century. These are:

1. Minimising energy usage in the mining, processing and production of coatings raw materials and in the processes that utilise coatings.
2. Minimising effluents and contamination entering the ecosystem (rivers, groundwater, and the atmosphere) from the weathering and rehabilitation of coatings.
3. Responsible planning and operation of mining and processing sites, including rehabilitation of mine-sites.
4. Optimising the recycling of zinc coated materials, including galvanized scrap steel.
5. Development of by-products to ensure maximum usage of available zinc in a form that meets international standards of occupational health and safety and are free of long-term toxicity risks.
6. Technological improvement to enhance the durability of coatings and extend the service like of the material to which they are applied.
7. Reducing the carbon footprint of the industry producing the protective coating products to levels that are internationally acceptable.

INTRODUCTION

Zinc is the most widely used metal for the protection of steel from corrosion as well as being present in a range of other manufactured products and in the natural environment. About 13 million tonnes of zinc metal are produce annually, of which about 20% is from recycled material and the rest from mining and refining.

From this, about 70% is used for coatings for corrosion prevention, 15% goes into brass, about 5% goes into rubber tyres (as zinc oxide) while the balance is used for zinc chemicals, dry cell batteries and diecasting.

As coatings and tyres are consumable products, it is logical to assume that the zinc in these products will eventually end up dispersed into the environment. Is this a health hazard? Does it represent a risk to the natural environment?

HOW MUCH ZINC MIGRATES INTO THE ENVIRONMENT?

Emissions of zinc from point sources (factories, sewage treatment) have decreased dramatically since the 1970's to a level expected to be reduced by more than 80% by the early 21st Century.

Significant decreases from diffuse sources (coatings, run-off from zinc coated products) have also occurred in developed countries, particularly in Northern Europe, due to dramatic reduction in sulfur dioxide emissions, again since the 1970's. Acid rainfall arising from high sulfur dioxide levels has not been such a problem in Australia as has been the case in the Northern Hemisphere, where environmental controls have reduced sulfur dioxide emissions by up to 90% in some industrialised regions.

It is estimated that in Sweden, where a major study has been done in the 1990's, zinc gets into the environment from the following sources and in the following volumes:

Source	Tonnes/year
Corrosion and run-off	400t
Tyre wear	150t
Asphalt wear	50t
Brake lining wear	50t
Sewage	50t
Landfills and mining activities	400t
Sundry sources	50t

Zinc is the 24th most common element in the earth's crust and is always present naturally at various levels depending on local soils and other environmental factors. In Sweden the average zinc concentration in soil is around 60mg/kg. In Australia, with its ancient soils, very low zinc levels occur in many areas that contributes to the infertility of these soils for cropping, in particular.

The Swedish investigators have estimated that about one quarter of the zinc that ends up in the waterways and lakes comes from natural sources while the balance derives from human activity.

An interesting observation made by the researchers is that the atmospheric deposition of zinc in the forested areas of the country from industrial activity has contributed to maintaining the zinc levels in the humus layer in forest soils. As pollution controls continue to reduce the atmospheric zinc levels, there is now a risk of zinc deficiency becoming an issue in the future in Sweden's forest soils. In Australia, where 95% of the continent is not subjected to industrial activity of any kind, zinc in soil levels are generally very low.

ZINC REQUIREMENTS FOR PLANTS, ANIMALS & HUMANS

In human and plant biology, there are both essential, non-essential and toxic metals. These individual characteristics may not apply to all organisms and at all concentration levels, and even the most beneficial compounds may be toxic if their biological uptake is excessive.

Zinc is one of the essential metals and plays a central role in the function of a number of proteins in living organisms. Zinc participates in many vital biochemical reactions such as detoxification, maintenance of DNA and RNA genetic codes, protein synthesis and particularly in reproductive functions.

Many plants are prone to zinc deficiency that dramatically reduces their fertility and productivity. The higher up the food chain, the greater the organism's ability to regulate its zinc intake and even in high natural zinc environments, mammals (including humans) and birds do not accumulate zinc in their tissues.

It appears from research done to date, that the life forms most susceptible to toxic effects from zinc are lower forms of plant life (micro-organisms, algae). This phenomenon is used deliberately through the addition of zinc oxide pigment to paint to inhibit fungal growth on painted surfaces.

It is for this reason also, that zinc is used in many ointments and medications, particularly for the treatment of skin disorders.

While the research is incomplete, current findings indicate that levels of five times the background zinc level may have detrimental impact of these lower plant life forms.

While zinc is often classified with the so called 'heavy metals' such as lead and cadmium when environmental standards are discussed, zinc is in fact one of the most beneficial metals. There would be 'no life without zinc' to quote Prof. Heinrich Vahrenkamp from the Institute of Inorganic and Analytical Chemistry, University of Freiburg, Germany from a paper of the same title presented at International Zinc Day, 1994.

The human body contains about 2.5g of zinc and more than 200 enzymes are known that require zinc to function correctly. This is a far higher number than any of the other metals essential to healthy body functions. (e.g. iron, magnesium, calcium, sodium and trace metals such as copper). Zinc has been identified as essential in wound healing, digestion, reproduction, kidney function, breathing, diabetes control, inheritance functions, tasting and skin health.

High levels of zinc are not required in humans or plants and they do not accumulate zinc, with one or two notable exceptions. Oysters have 10 times as much zinc as the next highest source (red meat), and a small flower, silene vulgaris can accumulate up to 3% of its dry weight of zinc. Some plant species can tolerate very high levels of zinc, and vulgar knotgrass (polygonum) has been found to extract over 300 kg of zinc per hectare per year from zinc contaminated soils.

In humans, zinc is found in the highest concentrations in the reproductive system and lowest in the nerves and brain. Mother's milk, sperm and ova have very high concentrations of zinc and humans require around 20 mg/day of zinc, which is available in a normal balanced diet with a supply of fruit, vegetables, cereals, red meat and seafood.

The most dramatic effect of zinc deficiency is on the reproductive system in humans, particularly in the Middle East. Extreme growth retardation in adolescents and the skin disease, acrodermatitis enteropathica, which is a very painful and potentially lethal condition, have both been immediately cured by simply adding zinc supplements to severely zinc deficient diets.

Zinc in soil is vital for cereal crops and the well being of a wide range of vegetation. For this reason, zinc compounds are widely used as additives in fertilizers. Excess levels of zinc in soils can produce reduction in yields and unhealthy plant growth just as zinc deficiency will detrimentally affect similar plants.

All of the oxidised zinc residues produced throughout Australia by Industrial Galvanizers galvanizing operations, along with the zinc residues of most other Australian zinc users, are processed into zinc oxide for the fertilizer or chmical industry.

CONCLUSION

Zinc is such an important industrial material, particularly in respect to making steel a durable construction product, that any constraint on its use would have a costly and dramatic impact on almost every aspect of manufacturing, building and construction.

It is unfortunate that zinc is almost always mentioned in conjunction with those other 'heavy metals' of ill environmental repute, cadmium and lead, and up-to-date quality research is the best way to clarify the real issues related to zinc and its impact on the environment.

The information referring to zinc usage in the Northern hemisphere in this article was derived from the following publication:

Zinc in Society and in the Environment - an Account of the Facts on Fluxes, Amounts and Effects of Zinc in Sweden, by Lars Landner and Lennart Lindström. Published by Swedish Environmental Research Group (MFG), Fryskta, Sweden 1998 160 pp.

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 aesthetic and do not affect the performance of the galvanizing as an anti-corrosion coating.

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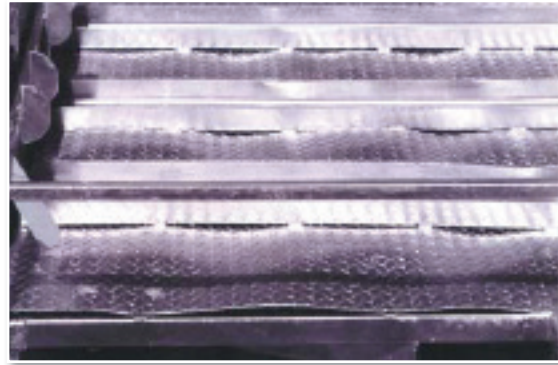
Distortion of thin checker plate welded to heavier supporting members can be reduced by fixing the checker plate after galvanizing

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.

Drainage spikes will always occur where edges are parallel to the molten zinc surface. These are removed by grinding of filing during the inspection process.
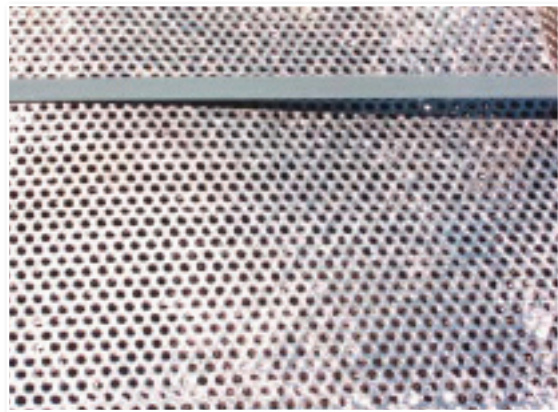
Blinding of small holes (6mm or under) will occur because of the surface tension of the molten zinc. This can be minimised by detailed attention to the item as it emerges from the molten zinc.

THE METALLURGY OF THE GALVANIZING PROCESS

Many of the surface imperfections that are characteristic of hot dip galvanized coatings are a function 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.
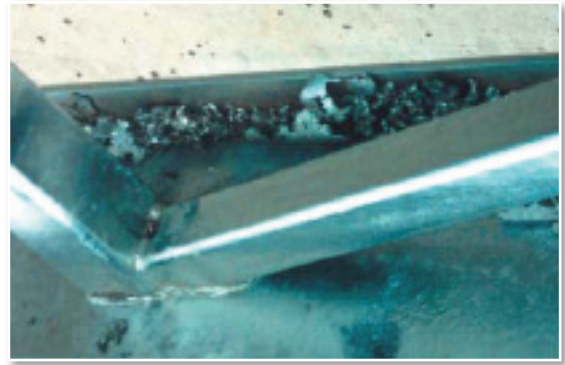
Blinding of small holes (6mm or under) will occur because of the surface tension of the molten zinc. This can be minimised by detailed attention to the item as it emerges from the molten zinc.

• 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.

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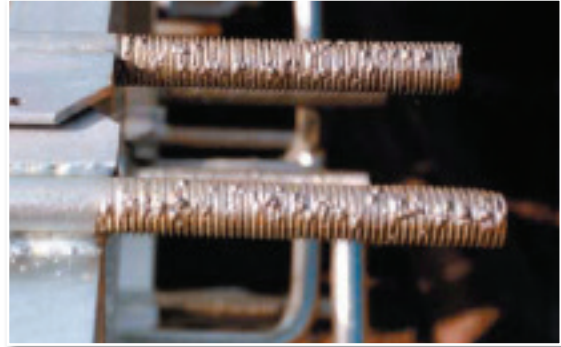
Threaded items will usually require post-galvanizing treatment to clean the threads of zinc. This can be done by reheating the threads to galvanizing temperature (450oC), then removing the excess zinc by wire brushing.

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.

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.

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.

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 whole 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 stain-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, and fabricators and manufacturers who abide by established practices and use appropriate steel grades rarely experience problems.
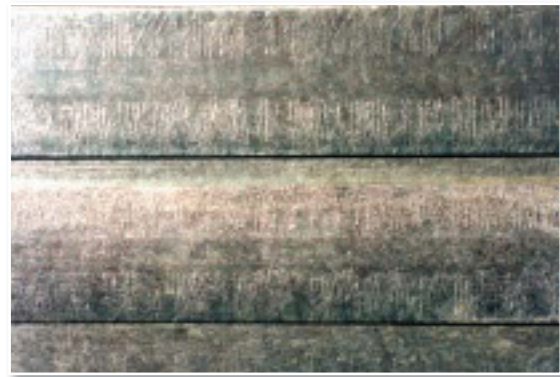
These lateral striations are a result of surface stresses in the steel section cause by the rolling process reacting at a higher rate with the molten zinc than the surrounding steel.

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.

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.

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.

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 Hercalloy chain is caused by exposing this 1200 MPa steel to pickling acid. These types of steels should not be galvanized.

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 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 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

This miss in the galvanized coating is caused by surface contamination by residual oxides not removed in the pickling process.
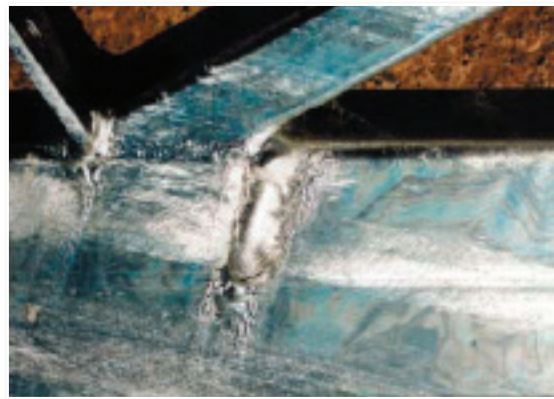
Zinc run caused by zinc freezing while draining from flat RHS surface. Durability is enhanced but thick runs may interfere with connecting surfaces

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.

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 staining of the work and highlight the lack of a galvanized coating, and a potential
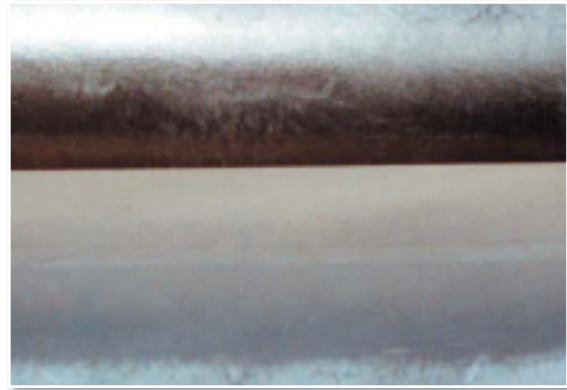
The gray coating on these pipes is a result of high silicon content of the steel, making it more reactive and converting all the coating to zinc-iron alloy. These gray coatings are typically thicker than shiny galvanized coatings on similar sections.
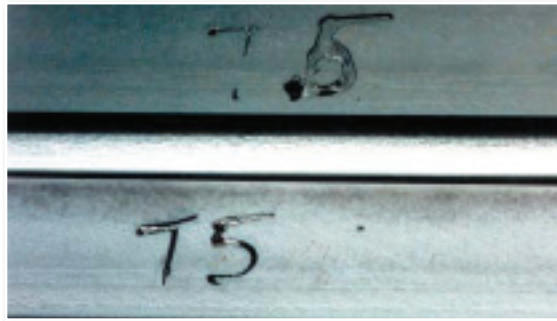
This miss in the galvanized coating is caused by surface contamination by an incorrect type of marking paint that is resistant to removal by pre-treatment chemicals.

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.

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.

*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.*

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 more zinc or zinc-rich residues, may increase coating life 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.

However, an understanding of the issues of design, steel composition and the hot dip

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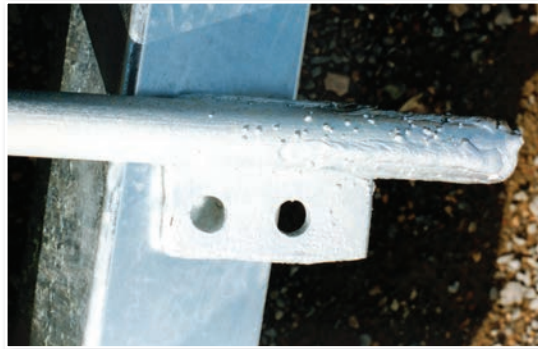
Weld splatter left on the steel will be galvanized along with the work, resulting in a rough and pimply appearance.

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.

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.

INTRODUCTION

All conductive elements (all metals) have different electrical potentials. These electrical potentials put each metal in a hierarchy of activity, with the most active metals at the top of the lists, and the least active at the bottom. This order of electrochemical activity is called the Galvanic Series.

A metal higher in the Galvanic Series will corrode preferentially to a metal below it in the Series. The greater the distance apart the metals are in the Galvanic Series, the higher the current that will flow between them if they are connected in the presence of an electrolyte (a conducting solution; usually water-containing dissolved salts).

Some metals like aluminium and zinc develop tough oxide films. These films give them exceptionally good corrosion resistance, although they are among the most active metals.

The position of zinc on the Galvanic Series, above most other metals, means that it will corrode preferentially if it contacts any of these metals and moisture is present. This characteristic of zinc is an important part of its exceptional performance in protecting steel from corrosion.

Many steel products are galvanized using continuous galvanizing processes. These semi-fabricated steel items (columns, beams, angles etc.) are subject to further processes like slitting, cutting, drilling, punching and welding.

This leaves the steel uncoated on cut edges and other areas damaged by processing. The galvanic protection provided by the adjacent zinc coating provides these steel products with their anti-corrosion performance, otherwise rapid corrosion would occur on these exposed areas.

A counter example occurs with chrome-plated steel. Chromium is below steel in the Galvanic Series. When a chrome plating is breached to expose the steel substrate, rapid corrosion of the steel will occur as the presence of chromium will accelerate the rate of steel corrosion. In addition, copper plating is often used in the decorative chrome plating process and copper is also highly cathodic to steel.

Reference to the Galvanic Series is important when selecting metals that will be in contact. Their relative positions in the Galvanic Series will determine whether corrosion occur at the point of contact. For this reason copper should never be allowed in contact with steel, zinc or aluminium, nor should run-off from copper cladding be allowed to contact these other metals, as quite serious galvanic corrosion may result.

Similar care must be taken with stainless steel in contact with either mild steel or galvanized or Zincalume™ coated steel.

An often-overlooked material in the Galvanic Series is graphite – the only non-metal listed. It is lowest in the series, and thus can cause serious electrochemical corrosion problems with a range of other metals. Some rubber sealing products have high graphite content and can cause electrochemical corrosion problems.

Earlier versions of self drilling roofing screw washers were made from this material and resulted in the premature failure of the coated steel roofing and cladding on which they were used. The effect of graphite can also be observed on galvanized or Zincalume™ roofs near wood or oil fire chimney outlets. The carbon (graphite) deposits falling on the roof will accelerate the corrosion of the roofing.

The Galvanic Series diagram shows the differences in electrical potential between materials. The further apart they are in the Series, the greater the potential and the greater the corrosion current that can operate between them.
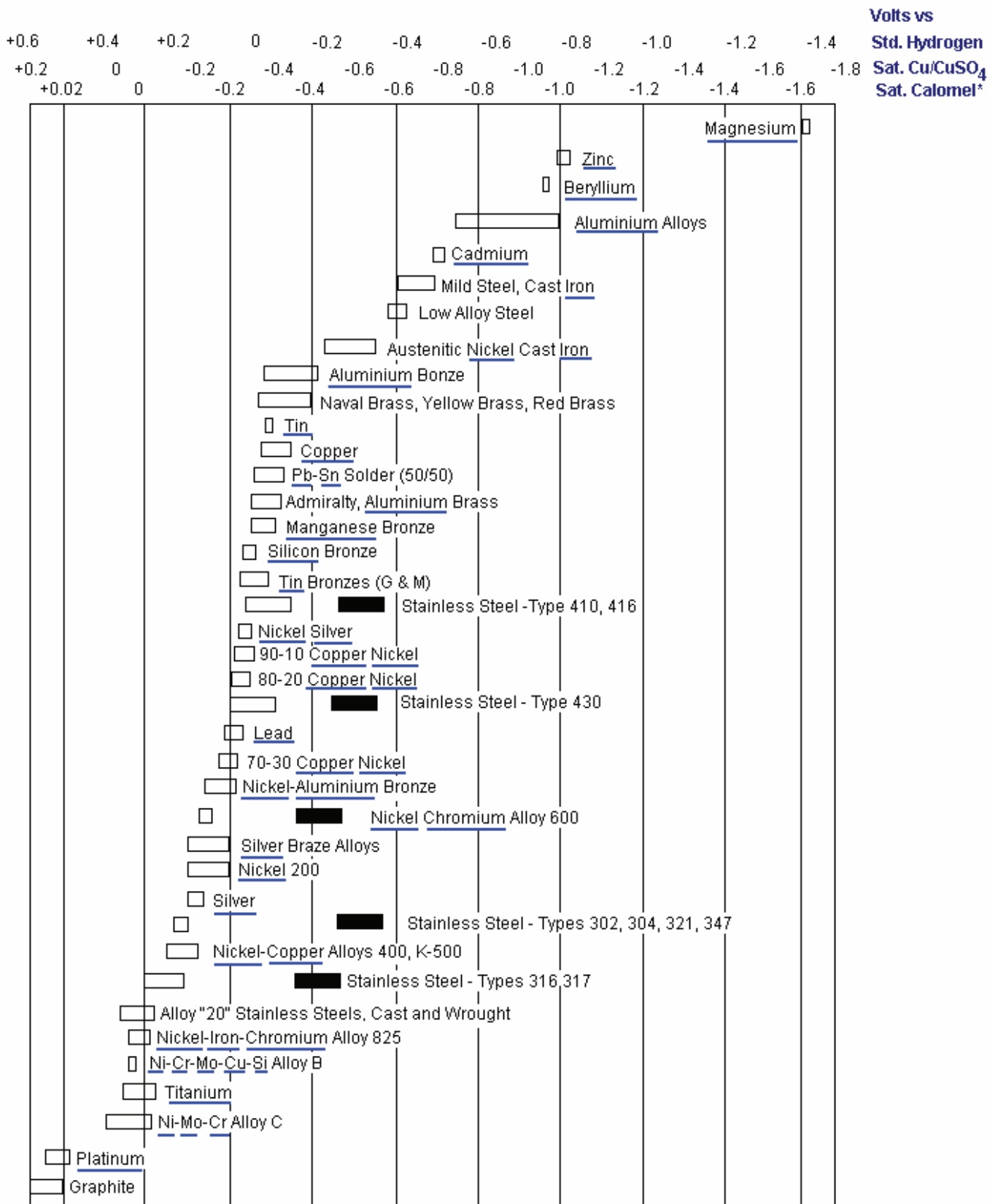
This glossary of galvanizing terms provides a brief description of the meaning of commonly encountered words associated with galvanized coatings and the galvanizing process.

More detailed information on many of these descriptors is available elsewhere in this manual.

Acid pickling	Hydrochloric acid at 10% concentration is used to remove rust and mill scale from the steel surface prior to galvanizing
Air lock	An area where air is trapped in a fabrication and prevents the molten zinc from contacting the steel's surface, causing an uncoated area on the work.
Alloy layer(s)	The hot dip galvanized coating consists of a series of zinc-iron alloy layers that make up typically 80% of the coating thickness. These alloy layers are coated with a layer of zinc. The zinc-iron alloys are much harder than zinc with excellent abrasion resistance.
Ash	Zinc oxidation products formed by the molten zinc reacting with oxygen in the air, and oxidation products arising from the flux reaction form on the surface of the molten zinc. This ash is skimmed off and recycled.
Bare spots	Defects on the steel surface that have not galvanized because of poor design or poor pretreatment
Beam work	Beams or head frames are used to support steelwork on wire or hooks to allow it to be handled through the galvanizing process.
Blowout(s)	Areas adjacent to unsealed overlapping surfaces that have been affected by pre-treatment solutions boiling out of the overlap area.
Brush blasting	Galvanized steel needs to be lightly abrasive blasted prior to painting. Brush blasting required the use of fine abrasive media at relatively low pressure (less than 40 psi) to prevent damage to the galvanized coating.
Cathodic protection	Zinc is higher in the electrochemical series than iron, and will corrode sacrificially to prevent the corrosion of adjacent exposed steel. Pre-galvanized products (sheet, tube and wire) rely on this feature of the galvanized coating to protect the cut edges of products processed from these sections. Also called `galvanic protection'.
Caustic degreasing	All steel products are degreased in a hot caustic solution as the first stage of the pretreatment process for galvanizing. The acid pickling will not be effective unless all organic contamination, grease and oil is removed from the steel's surface.
Centrifuge work	Small parts that cannot be efficiently handled individually are centrifuged or spun to remove excess zinc and allow them to be processed in bulk in baskets. Nails, washers, bolts and chain are typical centrifuge products
Chain work	Large or complex steel fabrications that need to be handled individually are suspended on chains for galvanizing. These products include large pipes, box and boat trailers and heavy items.
Chromate quenching	After galvanizing, the steel item is cooled by quenching in a water bath containing a low concentration of sodium dichromate. The sodium dichromate solution creates a passivation film on the galvanized surface.

Clearances	Where galvanized components have to fit together (e.g. hinged items), galvanized bolts), sufficient clearance must be allowed to accommodate the galvanized coating on each surface.
Coating mass	Galvanized coatings are generally specified in terms of coating mass, in g/m^2, on the surface of the steel. For ease of measurement, the thickness of a galvanized coating is measured in microns (μ) using non-destructive techniques, One micron in thickness approximates 7 g/m^2 in coating mass.
Coating thickness	The hot dip galvanized coating thickness is determined by galvanizing bath chemistry, steel chemistry, steel surface condition and steel section thickness. Australian Standard AS/NZS 4680:2006 defines minimum acceptable coating thickness for a range of steel sections.
Continuous galvanizing	Sheet wire and tube sections are galvanized using a continuous process associated with the manufacturing of the product. The galvanized coating is almost 100% pure zinc and applied to a maximum thickness of about 30 microns.
Corrosion rate	Galvanized (zinc) coatings oxidize progressively over time. This loss of metal from the surface is deemed to be the corrosion rate and is consistent over time. It is measured in μ/year. A typical corrosion rate for galvanized coatings is 1-2 μ/year.
Degreasing	First pre-treatment stage in the galvanizing process using a hot caustic soda bath to remove organic contaminants and paint from the steel surface.
Delta layer	The thickest alloy layer in the galvanized coating containing about 5% zinc. Reactive steels increase the delta layer thickness.
Distortion	Some steel sections will distort during galvanizing due to differential heating and cooling or inbuilt welding stresses.
Double-dipping	Fabricated items longer or wider than the galvanizing bath in one dimension can be galvanized by double dipping, where one side or end of the fabrication is galvanized first. The fabrication is then rotated or turned over allowing the second section to be galvanized.
Draining	Fabricated items immersed in molten zinc must be designed and to allow the zinc to freely drain from internal and external surfaces and must be suspended correctly during the galvanizing process.
Dressing	After galvanizing, the coating is inspected and irregularities are removed by dressing the surface by buffing or filing.
Dross	Steel reacting with molten zinc for small zinc-iron crystals in the galvanizing bath. These are heavier than zinc and settle to the bottom of the galvanizing kettle where they are periodically removed.
Duplex coating	When galvanized surfaces are painted or powder coated, these are called duplex coatings. Duplex coating systems enhance the appearance or durability of the steel being protected.

Electroplating (Electo-galvanizing)	Zinc is deposited on a clean steel surface from a zinc chemical solution to form a thin, bright zinc coating. Electroplated zinc coatings are not suitable for exterior exposures as they contain very little zinc – typically less than 10 µ in thickness.
Embrittlement	Some high strength or severely cold-worked steels are susceptible to embrittlement in the galvanizing process. This can be caused by hydrogen embrittlement from the acid pickling, or the heat of the process with severely cold worked (strain aged)) steel.
Etch priming	Some galvanized coating primers contain acid etching components to improve adhesion. These are application critical products that require experience in their application.
Flux staining	After galvanizing crevices and overlaps that are not sealed may show signs of brown staining bleeding out of the crevices. This is the result of iron-rich flux residues being trapped in the crevices absorbing moisture.
Fluxing	A hot zinc ammonium chloride preflux solution is use to condition the cleaned steel prior to its immersion in the molten zinc.
Galvanizing	Applying a protective coating of zinc to steel by immersing the cleaned steel in molten zinc. The zinc and steel react to form the galvanized coating.
Galvanizing alloy	Galvanizing baths are alloyed with small amounts of other metals such as aluminium, nickel or lead to improve the fluidity and resistance to oxidation of the zinc.
Gamma layer	The zinc-iron alloy layer closest to the steel's surface in the galvanized coating. It contains about 10% iron and is the hardest layer in the coating.
Gray coatings	Some steels produce a matt gray galvanized coating. These coatings are 100% alloy layer and contain no free zinc. They tend to be thicker than standard shinier galvanized coatings.
Hydrogen embrittlement	High strength (over 800 MPa) steel is susceptible to hydrogen embrittlement arising from hydrogen in the acid pickling solutions penetrating the steel surface.
Jig	A specially designed fixture for holding fabricated items during the galvanizing process to improve quality and productivity.
Magnetic thickness testing	Non-destructive measurement of galvanized coatings is usually done with electronic instruments that measure the distance from the surface of the coating to the steel surface that is magnetic. Any non-magnetic coating over steel can be measured with these instruments.
Metallising	Zinc wire or powder is applied to an abrasive blast cleaned steel surface through a gas flame that melts the zinc. Metallising is used to repair large damaged areas of galvanized coating.
Normalising	The heat of the galvanizing process is insufficient to affect steel properties by performs a stress relieving (normalizing) function.

Passivation	Galvanized items are quenched in a weak sodium dichromate solution to passivated the fresh galvanized surface and allow it time to develop its protective oxide layer.
Pimples	Small lumpy inclusions may sometimes occur in galvanized coatings, caused by dross stirred up from the bottom of the galvanizing kettle.
Reactive steel	Some grades of steel will react more quickly with molten zinc. This is usually caused by steel chemistry, particularly silicon and phosphorous content.
Silicon steel	Steel high in silicon will give rise to thicker coatings that may be gray in appearance.
Spangles	Crystalline formations on the surface of the galvanized coating caused by the presence of lead and other alloying elements in the galvanizing bath.
Strain-ageing	Steel that has been severely cold-worked by bending of punching is susceptible to strain-age embrittlement. The onset of this type of embrittlement is accelerated by the heat of the galvanizing process.
Venting	All hollow sections must be vented to allow molten zinc to freely enter and leave the fabrication, and allow condensation or moisture to escape.
White rust	Bulky white oxide deposits will form on galvanized coatings if they are stored in damp, poorly ventilated conditions. This oxidation product is zinc hydroxide.
Zeta layer	The outer alloy layer in a galvanized coating containing about 3-4% iron. This sometimes merges with the delta layer, depending on the steel chemistry.

INTRODUCTION

Asset owners are becoming increasingly aware of the need to prolong the maintenance-free life of their buildings, plant and equipment. This has led to their project managers passing responsibility for materials performance on the suppliers, over and above what would be considered normal warranty periods.

With protective coatings, in particular, there has been an increasing demand for long-term guarantees on the coating's performance. This is driven by the financial imperative that building (coating) maintenance adds no value, particularly on manufacturing or infrastructure projects.

For this reason, Industrial Galvanizers introduced a Coating Guarantee program that provides a simple and sustainable performance guarantee of hot-dip galvanized coating performance on specific projects.

HOW THE COATING GUARANTEE WORKS

There is no practical upper limit on the term of an Industrial Galvanizers Coating Guarantee. While 10-25 years is the most common coating guarantee range nominated by project managers, guarantee periods of 50 years or more can be supported on specific projects given the location and environmental conditions to which the hot-dip galvanized coating will be exposed.

Once a client has expressed interest in having an Industrial Galvanizers Coating Guarantee raised on a project, the location and operating conditions to which the hot-dip galvanized coating is to be exposed are subject to review by Industrial Galvanizers staff. This includes the preparation of an Environmental Evaluation Report (EER) and may also include a site audit, depending on the scope of the project.

This information is forwarded for review and detailed analysis. This analysis includes reference to the Corrosion Mapping System to determine regional rates of corrosion for hot-dip galvanized coatings, followed by detailed topographical analysis based on local Geosciences Australia maps.
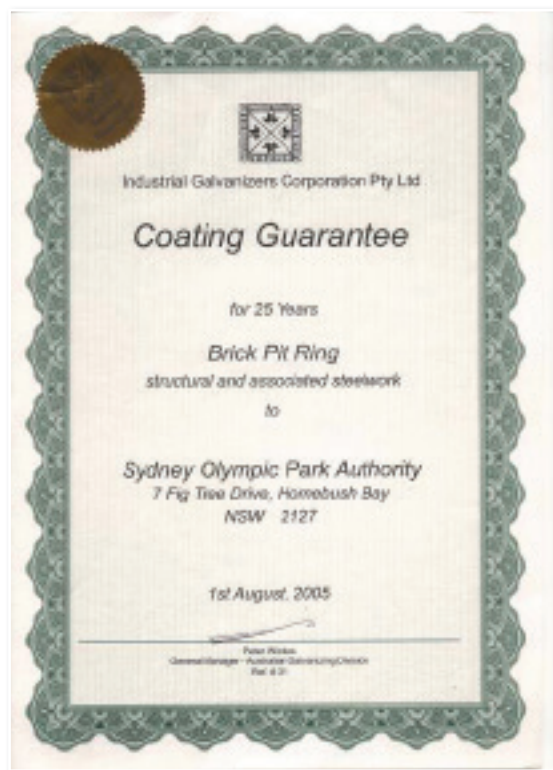
Industrial Galvanizers introduced formal coating guarantees on major projects, such as this 25 year guarantee on the galvanized coatings use on the Brick Pit Ring project at Homebush Bay, for the Sydney Olympic park Authority.

This analysis allows topographical features such as height above sea level, prevailing wind direction, classification of locality (urban, rural, industrial, marine) and other factors that will influence the durability of hot-dip galvanized coatings.

This analysis allows approximate corrosion rate to be established for hot-dip galvanized coatings. This corrosion rate can then be applied to the hot-dip galvanized coating, based on the coating thickness that will result from the hot-dipping of the sections involved in the project.

The coating thickness may vary from section to section, based in steel chemistry, method of manufacture and steel section thickness. This outcome can be predicted with a high degree of accuracy based on Industrial Galvanizers experience in processing over 100,000 tonnes of fabricated steel annually.

By combining the calculated rate of corrosion with the minimum average galvanized coating thickness of the project steelwork, a Coating Guarantee period can be established that becomes the offer to the client.

On negotiated acceptance of the Coating Guarantee offer in principle, the formal documentation is generated and forwarded for approval.

In some circumstances, the coating guarantee may not be approved.

EXCLUSIONS

Coating Guarantees may contain some exclusions to accommodate conditions that may affect the durability of the hot-dip galvanized coating that are outside the parameters determining the normal service life of the coating.

These logical exclusions include exposure to corrosive chemicals, mechanical damage, electrochemical corrosion through contact with incompatible materials and prolonged contact with certain chemicals. It will also define some housekeeping issues that are the responsibility of the operator.

CLIENT OBLIGATIONS

It is essential that clients who wish to avail themselves of a coating Guarantee advise Industrial Galvanizers of the requirement for a galvanized coating guarantee prior to the project's commencement.

It is contrary to the strict protocols associated with the provision of these binding warranties to provide galvanized coating guarantees retrospectively.

In addition, it is not Industrial Galvanizers' policy to issue coating guarantees on small quantities of steelwork because of the costs involved in the processing and administration of individual Coating Guarantees.

The galvanized steelwork supplied by Industrial Galvanizers to the M5 East Motorway project for the NSW Roads and Traffic Authority in 2003 has a 25 year coating guarantee

SUMMARY

Since the commencement of the Industrial Galvanizers Coating Guarantee program, a large number of project-specific guarantees have been issued. These have ranged from less than 10 years (at the clients nomination) to 50 years on a number of infrastructure projects.

INTRODUCTION

The concept of life cycle costing is not a new one. Standards Australian produced its first AS/NZS Standard in 1999 ; **AS/NZS 4536 - Life cycle costing – An application guide**.

In any life-cycle costing assessment, the initial cost of the coating is an important component in doing any long-term cost analysis, as is the need to determine the likely maintenance free life of the coating and the future costs of maintenance.

A BIT OF HISTORY

Protective coating costs on most projects are a relatively small component of the total project cost; typically less than 2%. On a major steel project containing, say, 1000 tonnes of structural steel, the cost of a basic protective coating system may be in the order of $500/tonne, a high performance coating system may be $1000/tonne, and a special super-durable specification may cost $1500/tonne.

This equates to an additional project cost of $500,000 - $1,500,000. If a project accountant applied a net present value analysis to this in the 1980's, when interest rates exceeded 15% and company taxation was well over 40%, the option of using the cheaper coating and expensing accelerated maintenance costs would seem a sound financial decision.

However, in the 21st Century, company tax is only 30% and interest rates are lower, so the Tax Office no longer subsidises maintenance costs to the same degree. In addition, expensed maintenance costs hit the balance sheet at a level that exceeds any interest benefits from the original saving.

Also, the labour costs of the 1980's did not include the on-costs of superannuation, higher workers compensation and other statutory obligations for employers. Nor were the WH&S and environmental obligations anything like they are today.

It is thus very difficult to foretell the distant future for the purposes of life-cycle costing for protective coatings, and conditions in 2035 will have changed as much in that 25-year cycle as they did between 1950, 1975 and 2000.

The maintenance painting of structures in public or environmentally sensitive areas required costly containment systems to meet EPA requirement. The cost of repainting this tourist observation tower in Newcastle, NSW exceeded its initial installation cost after only 12 years.

The other reality faced by asset owners, particularly of infrastructure assets, is that their service life is often far longer that originally anticipated. Many power distribution and transport structures are now well over 50 years old and are subject to numerous maintenance cycles to maintain their functionality.

The other issue with maintenance coatings is that they add very little value to a business. They make no contribution to efficiency or productivity.

For this reason, the selection of an appropriate protective coating system for steel, be it paint, galvanizing, or a combination of both should be based on the performance of the coating over time rather than its initial cost.

FACTORS IN THE COST OF A COATING
Australian Standards such as AS/NZS 2312:2002 – Guide to the protection of iron and steel against atmospheric corrosion contains comprehensive guidelines related to coating selection versus environmental condition to provide an estimated service life for a range of coating systems.

MATERIAL SELECTION
The choice between materials of construction will usually be a `steel versus concrete decision', with a proportion of projects being a composite of both.

The decision may be based on familiarity of a designer of working with one material or another, the form of the structure, its location and most importantly, its installed cost.

While the protective coating costs are a relatively small component of the total projects cost, they can be a significant proportion of the structural steel cost. In addition, steel simply cannot be used (with a few exceptions) without protective coatings and these coatings will have a defined life that will determine future maintenance costs.

While steel and fabrication costs are volatile, benchmark costs obtained in mid-2012 indicate that the cost components are approximately as follows for standard medium structural steel:

Medium structural steel cost: $1200/t
Fabrication cost: $3000 - $5000/t

COATING COSTS FOR NEW STEELWORK
The cost of coating new steelwork is made up of a number of factors. These are:

1. The type of steel – size, shape, section.
2. The quantity of steel
3. The location of the project with respect to the coating provider, the fabricator and the site.
4. The regional cost of labour
5. The material cost (paint components/zinc/ chemicals)
6. The cost of surface preparation (abrasive blasting/chemical/mechanical)
7. The cost of application – number of coats, plant capability, processing time
8. Logistic costs – inspection, loading, transport, erection
9. Post erection costs – remediation of handling damage, on-site completion.

For applied coatings (paint, metallising) the surface area of the steelwork and the complexity of the fabrication will be the most significant factors influencing the cost. Logically, thin steel sections with high surface area per tonne will absorb more labour and materials than heavy structural sections.

For example, a 3 mm thick steel section has a surface area per tonne of over 80 m², while a 10 mm section has a surface area of 25 m² per tonne.

Industrial facilities like this coal treatment plant at Teralba, NSW process 800 tph of coal 24 hours/day, 7 days/week. The cost of down-time for coating maintenance is a bigger factor than coating cost.

For process-applied coatings (hot dip and continuous galvanizing, powder coating), material costs and fixed costs are important, making the profitability of these processes very volume sensitive.

TYPICAL MATERIAL COSTS
Many of the materials incorporated in coatings are traded as commodities with supply and demand affecting prices above and beyond normal inflationary variations. The following indicative prices are for generic materials used in coating in mid-2008, in commercial quantities

Zinc	$3.00/kg
Zinc dust	$4.00/kg
Red oxide zinc phosphate	$10.0/litre
Epoxy primer	$10-12.00/litre
High build epoxy	$14.00/litre
Urethane – standard grade	$12.00/litre
Urethane GP3 grade	$25+/litre
Polysiloxane	$35+/litre
Acrylic – water based	$8.00/litre
Acrylic – catalysed	$12.00/litre

PAINT COATINGS
The true material cost of paint coatings is determined by how much of what is in the can ends up on the steel surface. This is determined by the volume solids in the paint, the applied thickness of the coating and the coating efficiency (over-spray losses).

Low volume solids will result in higher losses due to solvent evaporation. Simple solid structures (beams, tanks) will experience higher coating efficiencies that open structures (pipe work and trusses)

One litre of paint, applied to a wet film thickness of 100 microns will theoretically cover 10 m^2 of surface. In practice, the same paint applied to a dry film thickness of 100 microns, to medium structural steel by airless spray will cover approximately 5 m^2.

All paint suppliers have product safety data sheets for each of their paints. These documents list technical specifications for the paint, including volume solids, recommendations for wet and dry film thickness requirements and theoretical coverage.

In addition to the paint cost, most solvent-based spray applied coatings require the addition of thinners, (typically around 30% by volume) which becomes a component of the paint material cost.

An important point to note is that the paint cost is a relatively small proportion of the applied system cost. Based on a typical practical coverage rate of $5.00/$m^2$, the cost differential between a basic industrial epoxy or urethane and a high performance urethane or polysiloxane is in the order of $3.00-$4.00/m^2.

The most significant single cost in paint coatings is surface preparation. Abrasive blasting is almost mandatory to ensure acceptable performance for industrial paint systems.

Fabricated steelwork is usually abrasive blasted with chilled iron shot, in a chamber that allows recovery and recycling of the blasting media. Abrasive blasting standards are defined in Australian Standard AS 1627.4. Class 2 ½ Blast is most commonly specified for industrial coating, with Class 3 (the highest level) being a requirement for specialised coatings such as zinc metal spray.

Abrasive blasting costs vary regionally, but generally fall in the $15.00 - $20.00/$m^2$ range. Large automated blasting facilities using wheelabrador equipment to process columns, beams and plates can significantly reduce this cost.

Where galvanized coatings are to be painted, Class 1 or whip blasting is generally specified. This involves using less aggressive media such as garnet or illmentite, at typical cost ranging from $10.00 - $15.00/$m^2$, depending on the complexity of the fabrication.

Chemical preparation (pickling, phosphating) is rarely used as a method of preparing fabricated steel for painting, and is confined to process applied coatings such as powder coating and galvanizing.

Powder coating costs are usually charges on a `window area' basis rather than surface area, as the area the item takes up on the powder coating line is the main factor in its cost of processing. For standard grades of polyester powder, powder coating costs are typically $15.00 - $20.00/$m^2$, although large quantities of uniform manufactured product that can be loaded to high line efficiencies can be powder coated at lower cost.

With all costs included (labour, overheads, margins) indicative industrial painting costs for commonly specified systems are:

1. Basic wire brush/Class1 blast and ROZP prime ---> $12.00/$m^2$
2. Class 2 ½ blast + inorganic zinc primer ---> $25.00/$m^2$
3. Class 2 ½ blast + inorganic zinc primer + epoxy topcoat ---> $35.00/$m^2$
4. Class 2 ½ blast + inorganic zinc primer + urethane ---> $45.00/$m^2$

NOTE: These are indicative average prices only and will vary regionally and depending on the design of the items being painted.

GALVANIZED COATINGS
The parameters governing the cost of galvanized coatings are quite different to those determining paint costs.

Continuously applied galvanized coatings applied to sheet, wire and tube are applied in facilities with high capital and operating cost, with large volumes of steel being able to be processed very efficiently.

For this reason, the galvanized coating cost component of these products is relatively small and

driven by the material (zinc) cost. In addition, these technologies apply relatively thin zinc coatings – usually less than 30 microns per side for a material cost of about $0.75/m^2 of surface.

Hot dip galvanized coatings applied to fabricated steelwork are priced on the basis of the tonnage that can be processed through the galvanizing bath. Surface area is thus not as significant in galvanizing costs. Thin sections that can be loaded into galvanizing jigs at high loading density will attract a relatively low galvanizing cost, while 3-D structural fabrications containing heavy universal sections may be more costly to process.

Hot dip galvanized coatings are almost always costed on a $./tonne basis. Typical galvanizing costs per tonne will range from $650/tonne for heavy, simple elements such as columns and beams in large project quantities, to $1500/tonne for light fabrications. Items requiring double-end dipping will usually attract a premium cost and small one-off fabrications (boat trailers, wrought iron, anchors etc) for non-account customers will be charged around $2000-$2500/tonne.

The cost per square metre for hot dip galvanizing reduces quite significantly as sections become thinner. The following examples illustrate this:

Medium structural steel – 10 mm average thickness

Galvanizing cost:	$700/tonne
Surface area per tonne:	25 m^2/tonne
Cost/m2:	$28/m^2

Light fabrications - 3 mm average section thickness

Galvanizing cost	$1500/tonne
Surface area per tonne:	85 m2/tonne
Cost/m2:	$18.00/m^2

A fringe benefit of hot dip galvanizing, because it is an immersion process, is that all internal surfaces of hollow sections are coated uniformly. This may be an advantage or disadvantage, as the external surface area of a hollow section is only half that of an open section of the same section thickness.

Another fringe benefit of hot dip galvanizing compared to both paint coatings and continuously

galvanized coatings is that the applied coating thickness almost always in excess of Australian Standard requirements.

This is a bonus for the customer, as additional zinc pick-up on steelwork cannot be accurately predicted by the galvanizer, as it is influenced by the surface condition, section thickness and chemistry of the steel. It can add $50-$100/tonne to the galvanizer's material costs, with the added bonus for the customer of the extra zinc adding proportionately to the service life of the coating.

THE REALITIES OF FUTURE MAINTENANCE

Where maintenance coating is required on an infrastructure or industrial project, the real cost experienced in 2008 would not have been even considered 25 year ago.

The major cost factors impacting on maintenance costs include:

1. Access
2. Containment
3. OH&S Management
4. Productivity.

It is worth looking at each of these factors in more detail.

1. ACCESS

It is now mandatory in most jurisdictions in Australia to use scaffolding systems when working at heights. Ladders and trestles are no longer acceptable for commercial coating contractors.

The cost of erecting, hiring and dismantling scaffolding is a major component of any maintenance coating operation. Since the introduction of more stringent safety requirements on residential building sites, few houses are now built that do not require scaffolding to be erected during their construction. While this is not directly connected to the life-cycle costing of industrial coatings, it is worth noting that the value of the residential scaffolding market in Australia now exceeds $250 million annually.

On industrial projects, much larger scaffolding systems may be required to provide the needed access for maintenance.

In assessing the likely maintenance costs, access factors can be applied to life cycle costing models to more accurately estimate costs on a specific structure.

It is possible to classify structures for assessing access issues. The following is an example:

Level 1 – Simple structure to 15 m. Maintenance able to continue while structure is operational. Easy access for scaffolding or lifts.

Level 2 – Simple structure 15-30 m. Greater scaffolding requirements. Maintenance able to be done while structure operational.

Level 3 – Simple structure over 30 m. Specialised external access required. Operating requirements of other plant and equipment must be considered.

Level 4 – Complex structure to 15 m. Internal and external access required. Operating requirements of other plant and equipment must be considered.

Level 5 – Complex structure 15 – 30 m. Internal and external access required. Staging at each level may be required. Operating requirements of other plant and equipment must be considered.

Level 6 – Complex structure over 30 m. Staged internal and specialised external access required. Operating requirements of other plant and equipment must be considered.

2. CONTAINMENT

Like access, containment costs will vary with the complexity of the requirements for containment. As with access, models can be developed to classify containment levels and factor in the costs of containment for a specific containment requirement.

An example of classification of containment factors is as follows:

None – No recovery of residues or paint.

Level 4 (Minimum) – For abrasive blast cleaning only – air penetrable walls, flexible framing, open entryways and natural air flow.

Level 3 (Moderate) – For abrasive blast cleaning – air penetrable walls, rigid or flexible framing, partially sealed entryways and joints, exhaust air filtration.

Level 2 (High) – For abrasive blast cleaning – air impenetrable walls rigid or flexible framing, fully sealed joints, airlock entryways, negative air flows and exhaust air filtration.

A good example of high-level containment is the maintenance painting program undertaken on under-road steelwork on the Sydney Harbour Bridge, which also incorporates very complex staging and access systems.

Where lead based paints are concerned, additional environmental management systems may be required to monitor local soil and water system during the remediation activities.

3. WH&S MANAGEMENT

Worker safety is now the first priority in any business and where heights are involved, stringent requirements for personal safety equipment are mandatory. Industrial manslaughter laws apply in many Australian States, and while managers should not need the threat of such legislation to care for the welfare of their workers, it is an indication that the most stringent risk assessments must be applied to any hazardous activity.

Certified safety equipment is mandatory when working at height, and approved safety harnessing and attachment systems have to be provided by contractors. Other Workcover regulations related to working in enclosed spaces places further onus on employers to ensure that no cost-cutting shortcuts are taken in the provision of maintenance coating services.

4. PRODUCTIVITY
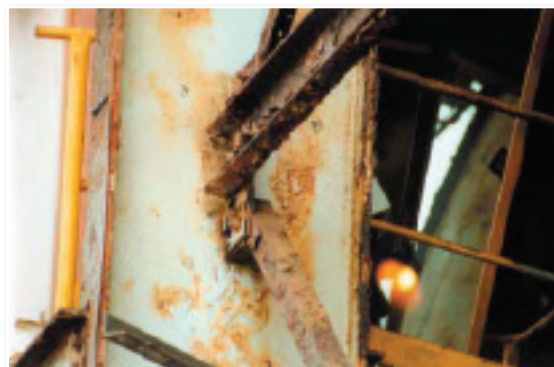
The cost of the coating materials for maintenance coating of rusting structures is insignificant compared to the cost of surface preparation, environmental management and access.

Each of the above factors will have an impact on productivity. With new steelwork, labour costs represent about 75-80% of the coating cost. For on-site maintenance, the labour cost component is far greater and for this reason material costs (paint costs) are less significant and more expensive surface tolerant paints will have little impact on the overall costs of a maintenance project, and represent better value given the expectation of higher levels of performance.

Surface preparation is the most labour-intensive part of the process. Surfaces may be contaminated with soluble salts so may require water washing/blasting prior to mechanical removal of the rusted surface or failed paint coating.

As a guide, the cost per square metre for maintenance coating a rusted steel structure may be 5-10 times the cost of applying an equivalent coating to new steelwork.

SUMMARY
Regardless of the protective coating used, there is a strong case, particularly in the present environment of low interest rates and decreasing company taxes, to use the longest life coatings available commensurate with the design life of the asset.

This may mean more stringent inspection with applied coatings, the use of QA certified applicators or the insistence in a coating performance guarantee from the supplier to better manage the risk and avoid the inevitable and more costly than expected future maintenance costs.

INTRODUCTION

Developments in paint technology, closer involvement of galvanizers in duplex coating development and application, and an increasing demand for very long life coating systems have resulted in better paint technology, better application techniques and better economies for duplex coating systems.

WHY DUPLEX COATINGS?

The application of paint to galvanized surfaces has historically largely been done for aesthetic reasons. For heavy-duty applications, it has been found that the application of appropriately durable topcoats can increase the maintenance free life of a structural item by 200-400% over that of a similar item in the same environment that uses either paint or galvanizing independently.

A good practical example of the effectiveness of duplex coatings is with BlueScope Steel's Colorbond™ coatings used on sheet and coil products for roofing, cladding and manufactured products.

The remarkable durability on Colorbond products is achieved with what are essentially quite thin coatings. The Zincalume™ substrate is typically around 20 microns in thickness and the Colorbond topcoat system is around 25 microns in thickness on the weather side of the sheeting yet maintenance free life well in excess of 20 years has been proven with this product, thanks to the use of high quality paints and very careful process control during application.

By combining heavy duty industrial paint coatings which are typically at least 100 microns in thickness, with hot dip galvanized coatings which are also around 100 microns in thickness, true zero maintenance coating systems can be produced for steel with corrosion free life expectancy in excess of 50 years.

HOW LONG IS FOREVER?

Is there a need for protective coatings to last more than 25 years? After all, hot dip galvanized coatings will generally last that long in other than marine or severe industrial environments. The fact is that 25 years is not a long time for a major building or

Galvanized stadium lighting poles are usually painted for aesthetics. Properly applied finished add substantially the maintenance free life of the structure.

infrastructure asset. On many projects, clients are calling for 25-year performance guarantees on the coatings and interest in 50-year coating life for significant infrastructures projects is increasing.

WHAT ARE THE PROBLEMS?

In one form or another, the use of paint over galvanizing goes back to the early part of last century. The technology used was not technology-based and the mechanisms of paint adhesion on metallic zinc coatings were poorly understood. It was not until the 1970's that research was carried out to better define the requirements.

Even in more recent times, basic problems such as the incompatibility of some paints with zinc coatings were not clearly identified, and the common sight of paint peeling off galvanized surfaces; guttering and railing in particular, created an attitude which still prevails, that galvanizing is difficult to paint.

The common alkyd (linseed oil based) enamel paints are incompatible with zinc coatings with some very limited exceptions. The oil in the paint resin reacts with the zinc to form zinc soaps that cause delamination of the paint film from the zinc surface.

Special zinc primers, particularly two-pack vinyl-etch primers, were developed to provide a properly conditioned surface for subsequent painting. These vinyl etch primers are no longer used as they contained zinc tetroxychromate.

The application of these priming systems and subsequent top-coating can be done satisfactorily in a controlled environment on manufactured items. The application of duplex coatings on structural projects means that galvanizing and painting operations are largely independent of each other, and often done by different sub-contractors.

The galvanizer thus may have no input into the painting operation and the painter has no insight into the techniques used by the galvanizer that may affect the quality of the duplex system.
The standard galvanizing practice of quenching hot dip galvanized products in a chromate quench immediately after galvanizing to cool the steel and passivate the zinc surface to prevent premature oxidation can in fact be detrimental to the adhesion of the paint system.

One of the major problems associated with this separation of responsibilities is in the surface preparation prior to painting. Brush blasting is required to ensure that the hot dip galvanized surface is clean and free of oxidation prior to painting, however considerable damage can be done to the galvanized coating at this stage if the incorrect blasting media and procedures are used. A recommended specification for brush blasting of hot dip galvanized surfaces in contained elsewhere in this manual, but is included here.

SPECIFICATION FOR ABRASIVE BLASTING GALVANIZING PRIOR TO PAINTING
Where brush or sweep blasting is required to prepare a galvanized surface for painting, the following specification is recommended for inclusion in the total painting specification. Unlike grit blasting for steel, this procedure is intended to remove oxide film and surface contamination and lightly profile the surface with minimal reduction in the galvanized coating thickness (no more than 10 microns).

- Blast pressure 40 psi maximum
- Abrasive Grade 0.2-0.5mm (clean Ilmenite)
- Angle of blasting to surface 45"

This navigation tower on Newcastle (NSW) Harbour was galvanized and painted to provide additional durability in a marine environment, and remains in good condition after 20 years in service

- Distance from surface 300-400mm
- Nozzle type minimum 10mm venturi type.

The challenge for all participants has been to develop systems and coating technology to allow the reliable application of high performance paint coatings to hot dip galvanized surfaces at a cost acceptable to the customer.

**DUPLEX COATING DEVELOPMENTS ...
THE STATE OF THE ART**
There are three factors determining the quality and durability of duplex coatings which are in fact common for most paint systems:

- the condition of the galvanized surface
- the type of paint system used
- the quality of the application.

If these three elements are successfully integrated, exceptionally good performance can be expected with a much higher degree of coating reliability than could be expected with paint coatings applied directly over black steel.

The Condition of the Galvanized Surface
There are two ways the condition of the galvanized surface can he changed: either through natural weathering or through chemical or mechanical pre-treatment. Natural weathering is frequently put forward as a method of conditioning the surface for painting, with a period of 6 months frequently nominated as a desirable weathering period prior to painting. This is a strategy fraught with risk because of the environmental factors that will impact on the surface with time.

The following table shows typical changes in surface condition of zinc coatings over time when exposed to normal atmospheric weathering:

Exposure period	Surface condition	Surface chemistry
0 month	Newly galvanized	No oxidation products or chromate passivation film ->5µ
1 month	Zinc oxide film formation	ZnO and $Zn(OH)_2$
2-3 months	Zinc oxides and other metal oxides (aluminium)	Zinc and aluminium hydroxides and zinc oxy-chlorides in marine areas and zinc hydrosulfates in industrial areas
9 months	Zinc patina stabilised	Complex zinc carbonate-based patina – $ZnCO.3Zn(OH)_2$
9 months +	Insoluble zinc patina	Atmospheric pollutants accumulate on surface

The times can vary significantly depending on local environmental factors. As a result, natural weathering of the surface to condition the galvanized coating for painting is unreliable and logistically impractical for most construction projects.

Paints for duplex paint systems
The selection and suitability of paints for use over hot dip galvanized surfaces depends on five main parameters:
1. The design life of the coating in its environment and its aesthetic requirements.
2. The paint systems and method of application.
3. Occupational health/environmental regulations regarding composition and application of the product.
4. Transport, handling and erection of pre-painted steelwork to and at the construction site.
5. The major factor in the performance of duplex systems is to ensure good adhesion to the galvanized steel surface because the hot dip galvanized coating in itself provides superior anti-corrosion performance to the steel substrate.

Paints consist of four major components:
1. The binder
2. Pigments and extenders
3. Volatile products (solvents)
4. Additives (UV stabilisers, drying agents, surfactants, emulsifiers, dispersants).

It is beyond the scope of this article to deal with these in detail, but all are important in the formulation of suitable paint chemistry for duplex coatings. The binder generally determines the generic type of paint. i.e. Epoxy, alkyd, acrylic, vinyl, chlorinated rubber, polyurethane etc.

Within each of these generic types there are many sub-categories and hybrid resin combinations that are tailored to particular applications.

Pigments and extenders provide the colour and enhance the mechanical and weathering properties of the coating. i.e. Micaceous iron oxide, glass flake, zinc dust, titanium dioxide etc.

Volatile products evaporate from the coating after application and are used to control the viscosity, wetability of the substrate, film thickness characteristics and drying performance of the coating. The level of volatile compounds in paints will continue to decrease to meet local and international environmental standards.

WHAT MAKES IT STICK?
Adhesion is the factor determining the success or otherwise of duplex systems. While by their nature there is little risk of premature rusting and structural deterioration should duplex topcoats fail, the major synergistic benefit of duplex systems depends on the two coatings working together in their mutual benefit for the design life of the system.

Preparation	Method	Advantages	Problems
Rubbing or scouring with abrasive media	*Hand or mechanical buffer*	*Good for small parts or areas. Complete removal of surface compounds*	*Low productivity. Risk of excessive zinc removal. Access limited to open surfaces*
Brush or sweep blasting	*Surface blasted with fine abrasives using compressed air*	*Produces good surface for painting, can treat large surfaces quickly*	*Skilled operators required to prevent damage to galvanized coating.*
Heat treatment (Galvannealing)	*Heating to 650'C converts all free zinc to alloy layer and removes organic & hydrated contaminants*	*Excellent adhesion with appropriate paint systems*	*Relatively expensive on complex fabrications Requires large capital equipment and best suited to large scale treatment of sheet products*
Cold phosphating	*Brush application of phosphate etch solution (phosphoric acid based) followed by water rinsing*	*Best suited to small items in small quantities. Simple process*	*Low productivity. Careful rinsing required to remove all treatment residues*
Hot Phosphating	*Dipping or continuous Spray process used in conjunction with chromating and rinsing pre-treatments*	Low cost per unit treated. Consistent high quality. All surfaces treated	*High capital cost. Best suited to large volumes of manufactured products*
Chromating	*Dipping process usually done immediately after galvanizing to prevent 'white rusting*	*Simple and low cost process*	*Chromate not a suitable pre-treatment for most paint systems*

Adhesion in duplex systems depends on the chemical and physical behavior of the underside of the paint film and the surface of the galvanizing. With better surface analysis tools available to the researcher, and the increased awareness of the importance of surface chemistry in the behavior of materials, a clearer understanding of what happens at the interface is assisting in the development of better duplex coatings.

There has been much fundamental research done in this area, and in summary the following forces are considered to be important in influencing adhesion of paint to galvanizing or other metal substrates.

1. The bonding forces in the very thin (sub-micron) boundary zone
2. The thermodynamic forces relating to the surface energies of the two materials.
3. Electrostatic forces which are a measure of the energy required to remove a coating from its substrate. The energy involved to do this should exceed that required to break down the molecular bonds in the polymers.
4. Mechanical adhesion forces.

Thus the mechanism of adhesion is a combination of atomic and molecular bonding, wetting angles, electrostatic and mechanical keying forces. Coating developments focus on each of these areas to improve the adhesion performance of paint over galvanizing.

CURRENT DEVELOPMENTS
A great deal of test work and duplex coating evaluation has been done, particularly by the Dutch Galvanizing Institute in severe atmospheric

exposure condition (industrial/marine) and a number of systems have provided very good performance with the following conclusions:

1. Brush blasting of the galvanized surface resulted in very good adhesion of all paints tested.
2. The epoxy and polyurethane paints did not adhere well to weathered zinc surfaces. Chlorinated rubber, polyvinyl and water borne acrylic paints had acceptable adhesion.
3. All paints adhered satisfactorily to newly galvanized surfaces.

To date, all of the spray applied duplex systems that have excellent performance in service are multi-stage processes requiring brush blasting or chemical pre-treatment, priming and top-coating. While this approach provides the performance required, the additional cost of applying what is essentially a full scale paint system over the top of hot dip galvanizing puts the costs for a duplex system to level that many end-users deem to be unacceptable.

As duplex coatings in the context of this document are applied to structural steel or steel fabrications in a contracting or jobbing environment, the logistics of timing of galvanizing and painting, pre-treatment and application are vital components in ensuring an economical and reliable coating job.

Thus, the focus of duplex coating developments in Australia has been to develop coating systems that are surface tolerant on hot dip galvanized surfaces and are easy to apply. Much test work has been done both in Australia and in Europe on defining the best conditions in which to paint hot dip galvanizing. It has been shown conclusively through work done by Industrial Galvanizers Corporation in the development of polyester powder coatings and solvent based paint systems that very good results are obtained if the hot dip galvanized coating is painted as soon as possible after galvanizing and the work is not chromate quenched after galvanizing. The elimination of any special surface preparation prior to painting saves the cost of brush blasting which is typically at least $10/m^2$.

While this application technology has been well proven and has been available commercially since the 1980's, the tight time limits between galvanizing and painting pose logistic problems in practice. These can be as follows:

- Site limitations precluding painting on the galvanizer's site
- Unsuitable weather conditions during scheduled painting periods
- Production scheduling from fabricator effecting timing of galvanizing
- Requirement to store work in batches prior to painting for efficient transport.

The development of more surface tolerant coating for use over galvanizing is aimed at eliminating any surface preparation over either chromate quenched or unquenched galvanizing and also to eliminate the need for priming systems so that a finish coat can be applied in a single coat.

The means to do this already exists and has been well proven over the past 20 years. Water based acrylic coatings have been used successfully in Australia over hot dip galvanizing. These readily available premium house paints, while having low chemical and abrasion resistance, have excellent UV resistance and good adhesion to galvanized surfaces.

Poor surface preparation (no primer used) combined with paint application on damp galvanized steel resulted in this paint failure caused by water blisters under the paint film.

Some polyurethane systems applied directly to freshly galvanized surfaces have been used in the USA but the reliability factors associated with these duplex coatings are not at a level that would recommend their use.

Development work done in the late 1980's as a joint venture by Industrial Galvanizers and Wattyl resulted Wattyl Superetch being recognized as an excellent standard priming system for zinc coatings. Accelerated weathering tests have given salt spray resistance consistently in excess of 1000 hours for a 20 micron Superetch coating over hot dip galvanizing, with most samples easily exceeding 2000 hours salt spray resistance.

The Superetch primer is a single pack epoxy etch primer with the following characteristics:

Positives
- excellent adhesion to galvanized surfaces
- easy application
- fast drying - touch dry in 1 hour
- economical - low cost per litre, high coverage rates
- long weathering performance - does not need overcoating immediately: ideal for pre-construction priming.
- suitable for overcoating with a wide range of topcoats

Negatives
- Must not be applied to thicknesses in excess of manufacturer's recommendations (20 microns)
- Must be used with compatible topcoats - sensitive to attack by some solvents.
- Not well suited for brush application.
- Not as good as epoxy primers such as Wattyl Sigma EP Universal Primer for heavy-duty (marine) applications

The development of compatible primers such as Superetch has simplified the application of duplex systems and has been used successfully for 20 years with no field failures yet recorded. The ultimate goal of single coat application over as-galvanized surfaces is achievable with some coatings and test work done by Industrial galvanizers has shown that moisture cured urethanes can be used in this role.

Single coat paint system for galvanizing is well within reach of currently available technologies. Water based acrylics (familiar to most as house paints such as Wattyl Solarguard, Taubmans Sunproof and Dulux Weathershield) give very good performance when applied directly over galvanized surfaces that are free of oil and grease. While these paints have excellent weathering characteristics (colour and gloss retention and UV resistance), they have relatively poor abrasion and chemical resistance. They do however perform well as architectural finish coats on galvanizing where they will be only exposed to standard environmental exposure.

Moisture cured urethanes have also been found to perform very well when applied directly over hot dip galvanized surfaces. They are relatively costly and the technology is US based so manufacture in Australia is subject to licensing arrangements that have led to some supply uncertainties.

SUMMARY
For a variety of reasons, there has been a significant increase in the tonnage of hot dip galvanized fabricated steelwork specified to be painted after galvanizing. Industrial Galvanizers has been actively involved in the specification and application of duplex coatings for over 20 years. This has included major infrastructure projects with the most stringent quality requirements such as steelwork on the Sydney 2000 Olympic site at Homebush Bay, NSW.

Given an understanding of the technical requirements associated with surface preparation and generic paint selection, very good results can be obtained. The resulting coating system offers long-term durability that will see out the design life of any project to which it is applied.

INTRODUCTION

Polyester powder (PE) coatings are thermosetting resins where a low molecular weight polymer melts and flows during fusion while simultaneously undergoing a chemical conversion to a thermo set or cross linked condition.

Once cured at temperature, the polymer cannot be re-melted to a plastic condition, as is the case with thermoplastic resins like PVC. The use of polyester powder coatings has been well established since the 1960's, and the process is well suited to coating large volumes of uniform products.

Polyester resins have excellent exterior durability in atmospheric environments and are well suited to architectural applications because of their gloss retention, resistance to mechanical damage and resistance to fading.

Reliable application of PE coatings to hot dip galvanized surfaces was identified as a problem by the industry, in plants designed to coat bare steel or pre-galvanized steel products.

In 1987, Industrial Galvanizers undertook a development program with Taubmans (Akzo Nobel) Powder Coating Division to resolve the problems associated with powder coating over hot dip galvanizing. In April 1988 a purpose-designed powder coating plant was commissioned to process hot dip galvanized product using special grades of polyester powder developed by Taubmans.

The facility operated satisfactorily for 16 years until it was decommissioned following a change of ownership.

PROBLEMS & PERFORMANCE
PROBLEMS WITH POWDER COATING OVER HOT DIP GALVANIZING.

There are two significant problems associated with the use of polyester powders on hot dip galvanized products. These are:

- adhesion of the coating to the galvanized surface:
- pinholing of the cured coating.

A lesser problem is related to the curing of the polyester resin that is associated with the nature of the work being processed rather than its coating system.

Adhesion

When steel is hot dip galvanized, it is degreased in a hot caustic bath, pickled in hydrochloric acid to remove oxides, fluxed in a zinc ammonium chloride solution and then galvanized by immersing the work in molten zinc at 455°C.

The zinc reacts with the steel at that temperature to form the galvanized coating, which is typically 80-100 microns in thickness and consists of a series of crystalline zinc-iron alloy layers comprising typically 80% of the coating thickness, coated with a layer of zinc, making up the balance of the coating.

Depending on the metallurgy of the steel and the galvanizing bath conditions, the galvanized coating is sometimes made up entirely of alloy layer with no free zinc layer. These coatings are typically dull gray and tend to be thicker than standard galvanized coatings.

After galvanizing, the work is generally quenched in water containing a low percentage, typically less than 0.25%, of sodium dichromate. The dichromate solution applies a passivation film to the surface of the zinc that inhibits the zinc's reaction with atmospheric moisture prior to the formation of the basic carbonate films that give zinc its outstanding corrosion resistance in atmospheric exposure conditions.

The nature of the basic carbonate films may vary in complexity depending on the environment in which they are formed, but are typically $2ZnCO_2 \cdot 3Zn(OH)_2$.

Weathering in chloride rich marine atmospheres or sulfide rich industrial atmospheres will produce other complex oxides with differing weathering characteristics.

On chromate passivated hot dip galvanized surfaces, there is an added degree of complexity as the chromate film weathers and is progressively replaced by the basic zinc carbonate oxide layer.

When considering the powder coating of hot dip galvanized surfaces, these variables must be considered and minimised to ensure reliable adhesion of the coating.

The most obvious problem experienced when powder coating hot dip galvanized products is

pinholing. This occurs when the cured coating is affected by minute bubbles in the paint film that are at unacceptably high density levels and compromise the performance of the coating in service.

While many theories abound, no clear-cut satisfactory explanation has yet been put forward to fully explain this pinholing phenomenon, although plant design and powder chemistry can minimise pinholing effects on galvanized product.

These factors will be discussed later in this paper.

POWDER COATING OVER GALVANIZING PROCESSES

Polyester powder coating over hot dip galvanized surfaces requires a series of processes. These are:

1. Hot dip galvanizing
2. Thermal pre-treatment
3. Chemical pre-treatment
4. Powder application
5. Curing.

Each of these processes is important in assuring the quality of the coating.

CHEMICAL PRE-TREATMENT
Phosphating

Zinc phosphate conversion coatings have been the preferred pre-treatment over hot dip galvanized surfaces producing a fine grained crystalline zinc phosphate at coating weights of 1-2 g/m^2. More recently, chrome phosphate has been found to provide superior performance in high-durability applications.

Zinc phosphate has poor detergent cleaning properties, and is not well suited to processing work that is contaminated with organic contaminants.

Iron phosphate is commonly used to pre-treat pre-galvanized products and this is usually applied at iron phosphate concentrations of 0.3-1.0 g/m^2. A number of pre-galvanized products, particularly hollow sections, have a clear polymer coating applied over the galvanized coating by the manufacturer, and this will influence the type of pre-treatment best suited for this type of product.
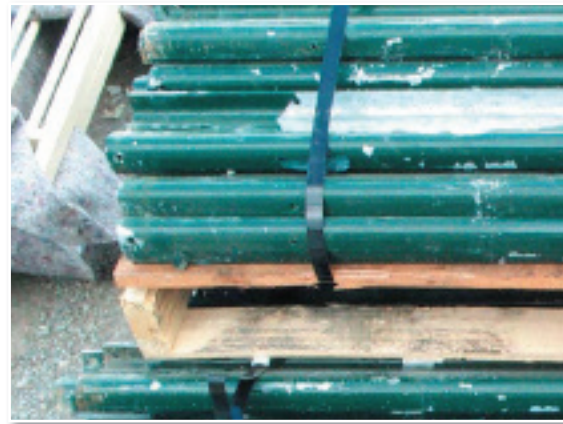
Poor pre-treatment resulted in this total failure of the polyester powder coating in these galvanized posts.

The zinc phosphate coatings offer superior weathering performance and were found in the development trials to be the only pre-treatment capable of passing 1000 hours salt spray (ASTM B117 -73) and cyclic humidity (BS 3900: Part F2: 1973) tests.

The use of alkaline degreasing operations on galvanized product prior to phosphating must be carefully controlled because of the risk of attack on the zinc by the alkali.

Control of zinc phosphate coating mass is important in achieving good adhesion. With batch pre-treatment processes, extended residence time in the zinc phosphate may result in coating weights exceeding 4g/m^2. At this coating mass, adhesion problems can arise because of the inherent weakness of the thicker phosphate film.

In continuous process operations, the residence time in the phosphate pre-treatment can be controlled by the line speed, and better control of the phosphate coating is possible. The temperature and concentration of the pre-treatment chemicals can also be modified to match line speed requirements.

With experience, the visual appearance of the galvanized surface after phosphating will give a reliable guide to the presence of a phosphate conversion film of required thickness.

Water rinsing

Following phosphating, the rinsing stages are equally important. All soluble salts must be removed from the surface prior to powder application. Mains water is not necessarily suitable for this application because of its level of soluble impurities.

The two-stage rinse process selected by Industrial Galvanizers included a primary rinse stage followed by a final de-mineralised water rinse.

An additional chromate passivation stage was initially incorporated in the process but coating performance trials revealed that elimination of this stage did not have any measurable effect on coating durability.

THERMAL PRE-TREATMENT

Following phosphating, it is normal procedure to pass the work through a dry-off facility to remove residual moisture from the work prior to powder application. Trials showed that conventional powder coating plant dry-off facilities operated at too low a temperature, and a dry off oven capable of operating at air temperatures of 250°C was found to be desirable, with an optimum operating temperature of 140°C. At surface temperatures over 140°C, the phosphate coating may break down.

Heavier sections with more mass require higher pre-heat oven temperatures to obtain optimum surface temperatures.

POWDER APPLICATION

Polyester powder is applied through electrostatic application guns that operate at voltages from 50 kV to 100 kV. The powder particles acquire an electrostatic charge as they pass through the gun transported by low pressure, dehumidified air at a discharge rate of 100-600 g/min, depending on the application.

The work being coated is earthed and the charged powder particles are attracted to the surface of the work, where they electrostatically adhere in a uniform layer typically 50-100 microns thick. The location and motion of the guns, the transport air pressure and the types of nozzles used will determine the uniformity of distribution of powder.

Complex shapes generally require localised hand spraying to ensure that powder is adequately deposited in all necessary areas on the work.

One benefit of the high temperature pre-heating technology that was developed for the powder coating of hot dip galvanized surfaces has been the improvement in powder uniformity on the surface of the work with a significant minimisation of Faraday Caging effects, which are a problem in recessed areas and that prevent deposition of the charged powder in these areas.

The powder particle size is important in controlling film thickness and ensuring that the electrostatic performance of the powder is maintained.

As up to 40% of powder is recycled, blending powder to maintain optimum size distribution is important. Most commercial powder has a particle size between 2 and 80 microns, with peak distribution in the 40-50 micron range. A mixture of particle sizes is desirable as it aids in establishing a dense, tightly packed particle layer prior to fusion during the curing process.

CURING

Polyester powders are thermosetting resins that cross link at a specific temperature. For these powders to be fully cured, this temperature must be maintained until the reaction is complete. Elevating the curing temperature above the minimum level will shorten the curing time at the risk of burning the powder.

A typical polyester powder will cure in 10 minutes at a metal temperature of 200°C. At 190°C, curing time must be extended to 15 minutes, or may be shortened to 8 minutes at 210°C. These curing parameters will vary between manufacturers, and the process should be tailored to the specific powder requirements recommended by the manufacturer.

Almost all polyester powder coating applications have been developed for manufactured products produced from sheet, wire or other light sections.

The introduction of hot dip galvanized products, which in general are fabricated from heavier sections, requires considerable attention to the curing phase of the process to ensure that the

powder is fully cured. It is the surface temperature of the steel that determines the curing of the polyester powder, not the air temperature inside the oven.

Hot dip galvanized products that are powder coated will often contain steel members 12 mm or more in thickness and at normal line speeds of 1.2 m/min, steel surface temperatures will remain well below optimum curing temperatures and the length of the curing oven.

While the coating may appear normal on exiting the oven, it will not have achieved its design properties if the time-at-temperature requirements have not been met. Simple solvent testing procedures will quickly determine whether the coating has been fully cured.

With curing ovens using radiant heaters for curing, care must be taken to ensure that effective curing is being obtained, especially on white or pale coloured coatings which have high reflectivity and may delay heat transfer to the steel substrate.

COATING PERFORMANCE

The coating performance of polyester powder coatings over galvanizing is determined by:

1. The performance of the polymer:
2. The integrity of the application.

POLYMER PERFORMANCE

Polyester powders are available in a variety of grades and their performance is generally reflected in the cost of the powders. The highest grades of powders designed for exterior use have excellent UV resistance and as a result have very good gloss and colour retention in atmospheric exposure conditions. The higher grades of polyester powders can be expected to pass 1000 hour Salt Spray (AS3715 Appendix 2.10), 500 hour Humidity Resistance (AS3615 Section 2.7) and Distilled Water Immersion (BS3900 - F7 at 40ºC).

Changes in polyester powder technology have occurred since 1991 because of the potential environmental health problems associated with triglycidyl isocyanurate (TGIC), used as the poly-epoxide curing agent for carboxyl functional polyester powder coatings. Recent opinion as to the health issues associated with TCIG based

polyester powders have questioned the validity of the data that led to the move away from TCIG-based powders.

Powder manufacturers developed TGIC free polyester powders and these powders are widely used with acceptable results, although industry sources indicate that TCIG containing powders still provide the best long-term durability.

Polyester powders, while performing well in normal atmospheric exposure conditions, may not perform satisfactorily in chemical environments where epoxy powders may be more appropriate. As a rule, the polyester powders should be considered for high performance architectural applications rather than industrial exposures. Epoxies are unsuitable for architectural applications because of their chalking tendencies when exposed to UV radiation.

There are specialised polymers now available for powder coating applications, with a range of epoxy, acrylic and hybrid powders that are formulated for specific industrial environments.

INTEGRITY OF APPLICATION

Like most applied coatings, failures associated with polyester powder coatings that have otherwise been correctly specified are related to the integrity of application. Apart from the factors discussed above related to quality of application, coating integrity of polyester powder coated galvanized surfaces is most often affected by inadequate powder coverage or pinholing in the cured polyester film.

Problems associated with powder coverage are not unique to galvanized products, but are a function of the design of the product being coated and the techniques and equipment used to apply the powder to ensure adequate penetration of the charged powder particles onto all surfaces of the work.

Pinholing

The phenomenon of pinholing in polyester powders applied over hot dip galvanized surfaces has been identified as the most serious problem associated with coating integrity. To date, no conclusive explanation has been offered as to the specific cause of pinholing on hot dip galvanized work.

Polyester powder manufacturers, along with powder coaters, have combined to develop systems and technology that minimises or eliminates pinholing.

Pinholing can be controlled by:

- pre-heating the work prior to applying powder;
- use of `degassing' grades of polyester powder.

Additives included in the degassing grades of polyester powder delay the onset of fusion of the powder, which gives more time for entrained gas to escape from the molten polymer film.

Pinholing of the coating can severely limit its potential performance, especially in aggressive chloride environments where there is often a requirement for architectural steelwork to be used.

The presence of pinholes gives chlorides and other corrodents access to the zinc substrate with consequent production of bulky zinc corrosion products which leach out through both amide (epoxy) and polyester coatings.

While the presence of these corrosion products may not result in associated disbonding of the coating, unsightly white staining of the coating can occur that is quite extensive in relation to the size of the pinholes from which the corrosion products emanate.

Assumptions have been made that the gas causing the pinholing phenomenon arises from within the galvanized coating. Examination of micrographs of hot dip galvanized coatings make this claim difficult to substantiate.

The typical hot dip galvanized coating comprises a series of zinc-iron alloys that are formed through the reaction of the steel with the zinc at 450°C - 460°C.
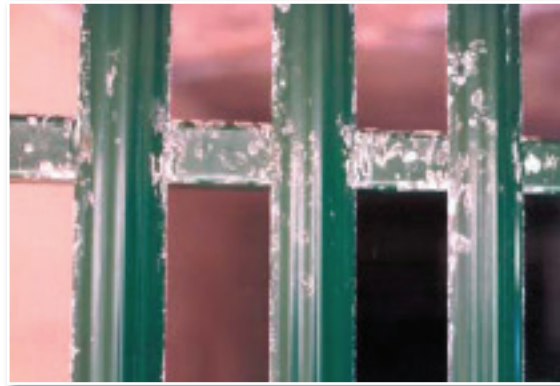
Pinholing is the most common problem associated with powder coating over galvanizing. It is caused by using incorrect powders and pre-treatment

Superior Coaters uses a batch powder coating system for coating all of INGAL EPS' Estate Poles. On-site garnet blasting facilities and large booths and ovens allow the processing of these larger galvanized poles.

These alloy layers take the form of tightly packed crystals in a matrix of free zinc typically around 80 microns in thickness, coated with a free zinc layer that is about 20 microns in thickness.

The metallurgy of the galvanized coating's formation while fully immersed in molten zinc thus makes the absorption of any gases or moisture that would be subsequently expelled from the coating during the 200°C curing of the polyester powder unlikely.

This leaves a gap in fully understanding the performance of polyester powders over hot dip galvanizing that has yet to be filled by the industry. Based on close observation of both hot dip galvanizing and polyester powder coating over galvanizing, the following are suggestions as to causes of pinholing:

a. Hot dip galvanized sections are generally heavier than those typically powder coated. The greater section mass delays uniform fusion of the coating, entrapping air in the lower level of the coating.

b. The thicker phosphate films formed may on the highly reactive hot dip galvanized zinc surface may release water of crystallisation as curing temperatures are approached that give rise to water vapour becoming entrapped in the paint film.

c. The high reflectivity and lower emissivity of the galvanized surface, coupled with the generally heavier section thickness of the steel used delays heat absorption by the steel.

Shiny metal surfaces have the capacity of reflecting as well as absorbing and re-radiating heat. These properties are important in the thermal performance of roofing materials. Uncoated galvanized roof sheeting, for example, has an emittance factor of 0.1 where a dark coloured surface typically has 0.9 emittance.

Elements of each of these factors may contribute to the pinholing phenomenon, and it should be noted that the preheating of the work to higher than normal temperatures prior to powder application would contribute beneficially to reducing the effects of each of these factors.

It is very difficult for any applied coating less than 100 microns in thickness, applied in a single coat, to be free of holidays in the coating. While galvanized substrates supply a high level of corrosion resistance in their own right, and will generate stable corrosion products that will usually seal any pinholes in the coating, the presence of chlorides will result in excessive leaching of the oxides.

For this reason, single-coat polyester coatings are not recommended in marine environments,

INGAL Civil Products is a division of Industrial Galvanizers that powder coats all its galvanized Flexfence roadside safety posts with 100% reliability

and two-coat systems are now available that offer exceptional performance where high levels of airborne chlorides are present.

These systems consist of an epoxy based 'primer' coat over the hot dip galvanized surface, followed by a polyester top-coat. In addition to providing additional total coating thickness, the additional topcoat reduces the risk of pinholing significantly, although pinholes in the primer coat may give rise to visible defects in the polyester topcoat.

AESTHETICS

In addition to the durability requirements of powder coated hot dip galvanized steel, a major issue is the aesthetic appearance of the finished product.

Hot dip galvanized coatings are inherently less smooth and uniform than continuously applied coatings. Any irregularities in the galvanized coating's surface will be reflected in the polyester topcoat's final appearance, particularly with high gloss products.

Ripple-finish powders have now been developed that provide an attractive finish while masking the irregularities that are typical of hot dip galvanized coatings.

SCHEDULING

Many products that are hot dip galvanized are not series production items. Many may be one-off products that are required to be a specific colour. No heavy-duty or architectural painting technology is as efficient as powder coating for processing large number of similar products in long runs of the same colour.

This benefit can rarely be realised with hot dip galvanized products. This can create scheduling issues for powder coaters as colour changing is a significant operation that requires complete and thorough cleaning of the powder delivery systems.

Powder coating companies have addressed this issue by taking a completely different approach to the continuous conveyor handling systems typical of most powder coating operations.

They use a facility specifically designed for garnet blasting structural and heavier fabricated components. This removes one of the major hurdles in the galvanizing process, as the surface condition (passivated, un-passivated, weathered, oxidized) becomes irrelevant. All work is whip blasted in the garnet chamber immediately prior to powder application, ensuring a clean zinc surface.

The powder is applied electrostatically in a spray-to-waste booth and the work is then transferred to large batch-curing ovens. Oven management systems that ensure that the powder is correctly cured on whatever steel section to which it has been applied; as the steel temperature, and not the oven atmosphere temperature determines the curing time.

CONCLUSION

Polyester powder coating of hot dip galvanized surfaces can be accomplished successfully with proper process and quality controls. There is an opportunity to extend the application of polyester powders to heavier steel sections and fabrications with the attendant cost and performance benefits of powder coatings.
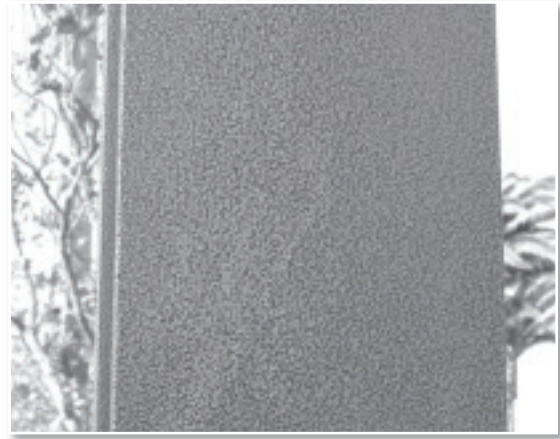
Hot dip galvanized surfaces are rarely smooth and uniform. The use of hammertone or ripple powders conceal surface irregularities and produce an attractive and durable finish

INTRODUCTION

While the care taken in the galvanizing process and design of fabrications for galvanizing are major factors in determining the quality of the finished product, there are a number of other factors unrelated to the process that can affect the final appearance of the hot-dip galvanized product, or the efficiency with which the steel can be processed.

These are:

1. Surface condition

Steel that is heavily rusted will be slow to pickle and result in costly processing delays. Badly rusted steel should be abrasive blasted prior to delivery for galvanizing. While heavily pitted steel will galvanized satisfactorily after cleaning, the galvanized coating will reflect the profile of the rough steel surface.

2. Previously coated steel.

New steel sections, specifically hollow sections, are coated with a preservative paint coating in the manufacturing process. This coating is usually easily removed in the galvanized process. Steel that has been previously painted with architectural or industrial paint systems, should be cleaned by abrasive blasting prior to delivery for galvanizing, as these types of paints are difficult to remove in the pre-treatment process.

A range of hollow and light structural sections are manufactures with a thin zinc coating already applied. These are frequently used with black steel sections in fabrications to be hot-dip galvanized. While this zinc coating is easily removed, a stripping cost may be incurred as the zinc will accelerate the deterioration of the pre-treatment chemicals.

3. Type of product.

Heritage products that are may be brazed, riveted or soldered, or manufactured from wrought or cast iron may not be able to be galvanized, or may require special handling in the galvanizing process.

Riveted or brazed connection can be galvanized provided steel rivets are used. Aluminium pop rivets will dissolve in the pre-treatment chemicals. Solder will melt well below the temperature of the galvanizing bath.

This load of fabricated steel contains a mixture of black steel, galvanized steel, painted and powder coated components welded in assemblies. This causes problems in the pre-treatment process for galvanizers
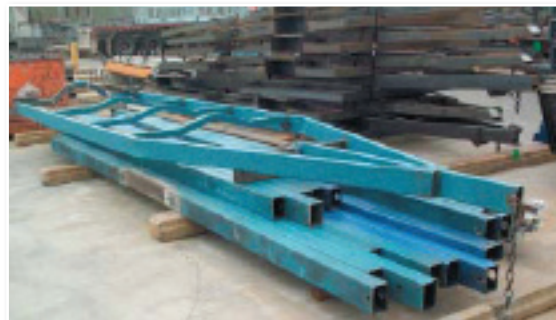
While the primer used on pipe sections is designed to easily removed in the galvanizers' pre-treatment process, uncoated sections (at the back) are much faster to process as they do not require paint stripping.

Old wrought of cast iron may contain voids or non-metallic inclusions that will trap air or pre-treatment chemicals in the surface of the item, creating a risk of blow-outs or more serious steam explosions that could damage or destroy the item. Abrasive blasting prior to galvanizing can highlight any such defects and minimise the time in the pre-treatment process.

4. Weld quality

Welding slag is inert being a ceramic material, and will not be removed during the pre-treatment process. Welding slag left on fabrications will give rise to `misses' in the galvanized coating.

Weld splatter will be galvanized along with the steel to which it is attached, creating a rough and unsightly area adjacent to the weld.

Most weld metal used for structural steel welding has a high silicon content. This will generally result in the weld areas having a thicker coating than the adjacent steel, and they may have a duller, gray appearance compared to the more shiny conventional galvanized surface. Where aesthetics are important and welds are required to be flush with the surrounding surfaces after galvanizing, low silicon welding wire should be used.

Poor quality welds with inadequate penetration will allow pre-treatment chemicals to penetrate the joint. The poor weld quality will be manifested after galvanizing as staining around the weld joint occurs as these chemicals leach out of the joint.

Submerged arc welds used on heavy sections may contain small particles of flux fused into the weld surface. After galvanizing, these appear as pinholes in the weld metal. As they are generally smaller than 1 mm in diameter, and the galvanizing coating thickness on the weld is usually very high, they do not affect durability.

Abrasive blasting the weld areas prior to galvanizing can minimise this phenomenon.

5. Very thick sections
Very thick cast steel sections (over 100 mm thick) such as counterweights or bollards can cause problems in the hot-dip galvanizing process. This occurs because their mass of the item is such that the zinc freezes around it, and remains frozen for several minutes until the heat of the steel increases to over 420°C – the melting point of zinc.

This phenomenon can result in the preflux coating on the steel surface deteriorating and not performing effectively. This will cause misses in the galvanized coating.

By abrasive blasting these types of items immediately prior to galvanizing, the cleaned steel surface will minimise the need for preflux and galvanize more readily.

This long universal beam has been double dipped, leaving an aesthetically unacceptable double-dip mark on the beam. This can be avoided by sizing sections to single-dip dimensions.
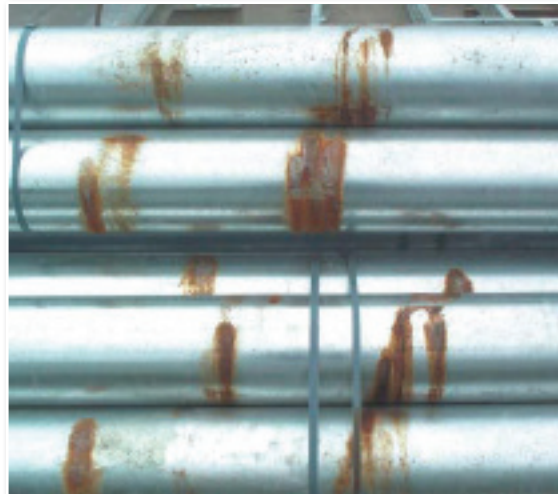
This completed load of large galvanized pipes has been stained by prolonged storage on hardwood dunnage during periods of wet weather.

6. Vent and drain hole locations
The location of vent and drain holes on hollow or partly closed sections, other than causing air locks or zinc puddling if poorly located, can cause unsightly runs or blowouts on the surface of the item if not correctly located or sized.

7. Lifting points
For larger items, the provision of lifting point for transporting the work through the galvanizing process will improve appearance and coating quality, and minimise the risk of handling damage in the process.

If chains have to be used to support the work, 'chain marks' will be unavoidable. This is particularly undesirable on larger circular sections such as poles, where there will be a large area of contact between the lifting chains and the surface of the item.

INTRODUCTION

Much of Australia's power, water and transport infrastructure was installed in the third quarter of the 20th Century. Much of this construction was hot dip galvanized steel, particularly in the power transmission area. In addition, the ownership of many of these assets has changed. Most have been 'corporatised' and some have been privatised.

Many of these facilities have now been in service for close to 50 years, and structurally, are still capable of performing their original function.

Galvanized coatings are alloyed to the steel, and the zinc in the coating acts as an anode to prevent the steel from corroding while any zinc is present. The galvanized coating closest to the steel surface has higher levels of iron in the alloy layer (about 10%). This gives some early warning of the end of the galvanized coating's life on ageing infrastructures.

The approaching end of the galvanized coating's life is manifested by brown staining on the surface but this will not give rise to the severe flaking or blistering associated with the corrosion of un-galvanized steel.

This is an advantage when galvanized coatings need to be maintained, because surface preparation is very simply and there are few, if any hazardous residues to have to contain during the maintenance schedule.

METHODS OF REMEDIATION.

1. Re-galvanizing

If it is feasible to remove the item from service, the most economical treatment is simply to have it re-galvanized. No special preparation is needed to do this, as the chemical pre-treatment in the hot dip galvanizing facility will remove any remaining coating or surface rust.

The galvanizing process will restore the item to virtually as-new condition with the expectation that its service life will be at least as long as its existing service has indicated. In most cases, this will be exceeded, as the re-galvanizing process will result in the production of a thicker galvanized coating

This 50-year old cast marine bollard has been hot dip galvanized. Although it is badly pitted, the bollard was easily re-galvanized to restore its durability.

On a typical manufactured item, the savings associated with this form of remediation compared to replacement with new product is in the order of 50-70% when labour costs for removal or replacement are considered.

Savings may be considerably higher for greater volumes of structural steelwork.

2. Painting

In non-industrial environments, where the weathering of the original galvanized coating has left a measurable amount of sound coating on the surface (10-20 microns), a very simply life extension measure is the coating of the weathered galvanized surface with a water-based acrylic topcoat typified by high quality acrylic house paints.

These types of coatings have excellent UV resistance and all have very good adhesion to clean galvanized surfaces (free of oily contaminants). While these paint coatings do not have high abrasion or chemical resistance, they perform very well in normal atmospheric environments, and have been used quite extensively as aesthetic coatings on prominent galvanized structures such as transmission towers.

Where rust blooming is starting to appear on the surface arising from the iron's oxidation in the alloy layers, a primer is recommended prior to the application of an appropriate topcoat.

For over 15 years, Industrial Galvanizers Corporation has recommended Wattyl Superetch primer for applications of this type. This recommendation has been based on comprehensive laboratory trials as well as numerous projects on which the system has been used.

Wattyl Superetch is a phosphate-based single-pack inhibitive epoxy primer that performs equally well with either uncoated or galvanized steel. It is a high solvent coating with a recommended applied dry film thickness of no more than 15 microns. It dries very quickly and can be top-coated very quickly after application while it also has a long (months) top-coating latitude.

For aggressive environments (severe marine or industrial) an epoxy primer such as Wattyl Sigma EP Universal primer can be used.

There are a number of zinc-rich paint (ZRP) products that are used for repairing new galvanized coatings, and can equally provide a solution to remediating aged galvanized coatings.

The inorganic ZRP coatings are not recommended for this application so organic (usually epoxy-based) ZRP's are specified for recoating of galvanized steel. These can be either single-pack or two-pack systems.

To emulate the performance of the original galvanized coating, organic zinc-rich paints need a high zinc loading. Most organic zinc rich paints have a zinc loading, by weight, in the dry film exceeding 90%.

WHEN TO TREAT OLD GALVANIZED STEEL.
The weathering of galvanized steel is relatively uniform. Some variations can occur in a single location. They can occur because of the design of the structure and the orientation of the components within it.

The re-galvanizing of old boat trailers will restore them to 100% original condition. Boat trailers, anchors and chains are routinely re-galvanized to restore their original corrosion prevention performance.

However, average corrosion rates can be established by simply measuring the remaining coating thickness and calculating coating loss over time, given that the date of installation and the original galvanized coating thickness can be determined with an acceptable degree of accuracy.

SURFACE PREPARATION
Weathered galvanized coatings develop a stable complex carbonate film on their surface. This provides a good substrate for the application of paints as long as the surface is clean and free of grease and oil.

High pressure water washing will often be sufficient surface preparation as it removes any soluble salts or other corrodents from the surface. Where contamination of the surface has occurred, proprietary degreaser/cleaners are available that will condition the galvanized surface.

Where rusting or more serious oxidation of the zinc (e.g. heavy white rust) has occurred, brush blasting with illmenite or garnet, or other specialised mild abrasives (foam jet, ice jet) to specification will produce a very good surface for remediation painting of galvanized steel.

Obviously, where such pre-treatment can be avoided, the environmental management issues associated with site painting become very simple.

SUMMARY

The hot dip galvanizing of steel is a proven method of providing very long-term protection against corrosion for steel in atmospheric environments. 50-year coating life is common, and while the coating is intact, the steel remains in its original condition.

By utilizing the unique characteristics of the galvanized coating, in combination with appropriate coating systems and techniques, the service life of any accessible steel structure can be extended indefinitely at a very low life cycle cost.

Re-galvanizing the steel will restore its durability to as-new condition or better, if the steel item itself is still appropriate for the application.

When hot dip galvanized coatings are damaged by cutting or welding, it is recommended that the uncoated areas are repaired. There are a number of repair methods that are available and the galvanizing industry has used and evaluated a wide range of products for over 35 years.

There are a number of factors that have to be considered when repairing hot dip galvanized coatings. These are:

• the size of the area to be repaired
• the ease of use of the repair material
• the performance of the repair method with respect to the required performance of the hot dip galvanized coating.

ZINC RICH PAINT REPAIR

Jotun Protective Coatings products are recommended by Industrial Galvanizers.

For standard duty applications, Jotun Galvanite, a one-pack, air-drying zinc-rich primer can be used. The single pack system has good adhesion to prepared surfaces and can be handled after 2 hours (at 20°C). Coating thickness per coat is typically 45 microns and two coats are required to ensure compatible coating thickness to the hot dip galvanized coatings.

Jotun's Barrier two-pack epoxy zinc rich system is recommended for heavy-duty applications and full coating reinstatement. The two-pack system is touch dry in 15 minutes and hard dry in less than 2 hours at 20°C. Two coats at 45 microns each are recommended to provide equivalent coatings thickness to hot dip galvanizing.

The recommended procedure for touch-up is as follows:

1. Power tool clean to Australian Standard 1627:2 Class 3 to remove all welding scale, slag and corrosion products.

2. Degrease and remove all surface oil, grease or soil. (This step can be omitted on new welds where no organic contamination of the exposed steel has occurred.)

3. Apply two coats of Galvanite or Barrier to a minimum dry film thickness of 85 microns.
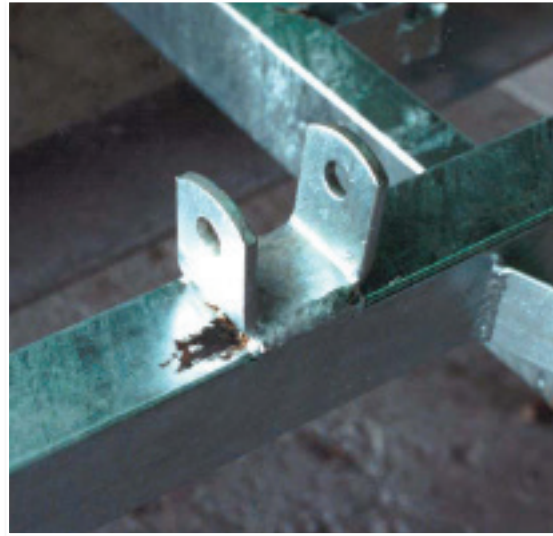
Blow-out from over lapping area on this fabrication has caused a galvanized coating defect

4. Observe good painting practice with respect to weather condition and application conditions. Ensure that the steel surface is above Dew Point prior to application. If below the Dew Point, warm area to ensure surface dryness

5. Adhere to coating manufacturers product data sheets for safety, mixing, pot life, application, overcoating and curing information.

6. If a close colour match is essential, apply a light coat of aluminium paint over repair area after drying. Rub over aluminium paint with a soft rag before drying to blend the repair into the surrounding galvanized coating appearance. NOTE: The aluminium paint is NOT an anti-corrosive coating and does not contribute to the performance of the repair.

METALLIC REPAIR COATINGS

There are various types of metallic repair materials available in the form of alloy `sticks' which are applied by heating the area to be repaired and melting the repair material onto the area. Early repair sticks had a high lead content and did not reflect the characteristics of a galvanized coating.

Cominco of Canada has developed its Galvaguard repair alloy that has a high zinc content and is easier to use than previous repair alloys.

These repair alloys are best used for repairing welds and similar small areas on horizontal surfaces, that can be easily and quickly heated . A higher level of operator skill is required to effect successful repairs using Galvaguard or similar products. Some of these products contain high levels of tin or lead. They are difficult to apply in other than down-hand positions.

Zinc metal spray is an effective repair method for larger areas, as it will apply a zinc coating of any required thickness. However, successful application requires a high quality surface preparation (Class 3) to ensure good adhesion. Specialised equipment and skilled operators are required to apply zinc metal spray coatings, but they provide a high quality repair solution where larger areas of the item have not been galvanized due to design constraints.

Surface to be repaired is cleaned by wire brushing.

Approved epoxy-based zinc-rich paint is applied to the uncoated area to at least equivalent thickness to the galvanized coating.

INTRODUCTION

Over the past 10 years, steel makers worldwide have developed new structural grades of steel with higher yield and tensile strengths. These developments have enabled manufacturers to design their steel products using lighter-section steel that in turn reduces the production, transport and erection costs of the finished product. Prior to these developments, the steel fabrications that were most commonly galvanized were manufactured from Grade 250MPa hot rolled structural steels.

Since the early 1970's, the results from research and testing centres around the world have shown that the hot dip galvanizing process does not affect the tensile and proof (yield) strengths of the Grade 250 MPa structural steels. But does the hot dip galvanizing process affect the yield and tensile strengths of the newer high-tensile grades of structural steels?

Industrial Galvanizers has been asked these questions on a number of occasions. To ensure that factual information is available, Industrial Galvanizers undertook a testing program involving galvanizing these steels to establish the effect of hot dip galvanizing on their structural performance.

OBJECTIVE

The aim of this test program was to establish whether the process of dipping steel in molten zinc adversely affected the strength properties of a typical high tensile steel using standard hot dip galvanizing practices. These practices include duplicating the immersion time of the steel in the molten zinc (this is typically 5 - 10 minutes under normal conditions) at a temperature of 455°C.

TEST 1

Product: HA70T-P Hot rolled, with black finish manufactured by BlueScope Steel.

HA70T-P hot rolled steel has guaranteed minimum yield strength of 450 MPa, and minimum hardness of 70 HRB. The typical yield strength is between 520 to 610 MPa. The typical tensile strength is between 530 to 620 MPa. This steel is normally used in shelving, automotive parts and more recently for purlins and other roll-formed light structural sections.

PROCEDURE

The test procedure involved cutting eleven pieces from a of 3.0mm thick black HA70T-P steel coil. Six of the pieces were hot dip galvanized in accordance with AS/NZS 4680:2006. The remaining pieces were left in black (as rolled) finish. All sections were then delivered to BlueScope Technical Services Laboratory at Port Kembla for testing.

Table 1.

	Finish	Thickness Nominal mm	Thickness Actual mm	Hardness (Brinnel)	Yield Strength MPa	Tensile Strength MPa
1.	Black	3.000	2.982	82	471	482
2.	Black	3.000	2.996	83	450	465
3.	Black	3.000	2.986	83	451	466
4.	Black	3.000	2.984	83	453	466
5.	Black	3.000	2.982	83	448	466
6.	HDG	3.000	2.966	83	445	482
7.	HDG	3.000	2.969	84	465	499
8.	HDG	3.000	2.977	84	473	501
9.	HDG	3.000	2.972	84	443	480
10.	HDG	3.000	2.966	83	443	481
11.	HDG	3.000	2.968	84	442	482

TEST 2
Product: GALVASPAN G450 Zinc coated, structural grade manufactured by BlueScope Steel.

GALVSPAN G450 has guaranteed minimum yield strength of 450 Mpa, and is an in-line hot dip zinc coated structural grade steel. The typical yield strength is between 470 to 550 MPa. The typical tensile strength is between 510 to 600 MPa. This steel is normally roll formed into products such as purlins, girts and light structural profiles.

PROCEDURE
The test procedure involved cutting six pieces from a single length of a roll-formed Z25024 purlin, which had been roll formed by BHP Building Products. The steel thickness is 2.4mm. Three of the pieces were acid pickled (to completely remove the Z350 mill applied zinc coating) and hot dip galvanized in accordance with the Australian Standard. The remaining pieces were left in the mill applied Z350 Zinc coating (as rolled) finish. All sections were then delivered to the BlueScope Steel Technical Services at Port Kembla for testing.

Table 2.

	Finish	Thickness Nominal	Thickness Actual	Hardness (Brinnel)	Yield Strength Mpa	Tensile Strength MPa
1.	Zinc coated	2.400	2.400	91	537	573
2.	Zinc coated	2.400	2.374	91	531	564
3.	Zinc coated	2.400	2.372	92	535	569
4.	HDG	2.400	2.372	91	532	566
5.	HDG	2.400	2.383	91	529	563
6.	HDG	2.400	2.383	92	536	569

RESULTS
Tables 1 and 2 show the results of the testing. If the results of the yield strengths of the black sections and the results for the galvanized sections of the HA70T-P are averaged, the difference is 0.4%. As this variation is less than 1% it is considered to be within the accuracy tolerance of the testing procedure.

If the results of the yield strengths of the black sections and the results for the galvanized sections of the Galvaspan G450 are averaged, the difference is 0.6%. As this variation is less than 1% it is considered to be within the accuracy tolerance of the testing procedure.

Both of these tests have verified that hot dip galvanizing of either un-coated high strength steel or the hot dip galvanizing of pre-galvanized high strength steel after acid stripping of the original coating has no effect on the structural strength of the steels involved.

NOTE
A subsequent comprehensive test program was undertaken by Industrial Galvanizers in partnership with OneSteel to evaluate the effect of hot dip galvanizing on 500N Grade reinforcing bar in 2007. The results of these tests support the findings of the testing detailed above, in that hot dip galvanizing does not affect the mechanical properties of standard grades of steel.

INTRODUCTION

Australian Standard **AS/NZS 4680:2006 – Hot dip galvanized (zinc) coatings on fabricated ferrous articles** is the defining standard for hot dip galvanized coating specifications in Australia. It is closely aligned with the **International Standard ISO 1461:2009 – Hot dip galvanized coatings on fabricated ferrous products**, in keeping with the Australian Governments policy of aligning all Australian standards with appropriate international standards.

AS/NZS 4680 defines the minimum requirements for coating mass (thickness) for various steel sections, methods of test and repairs to galvanized coatings, as well as containing informative information on design for galvanizing, surface preparation for painting and metallurgical information.

Some of the key parts of the Standard have been reproduced here in condensed form. Copies of all Australian and International standards can be downloaded from the Standards Australia web site at www.standards.com.au.

ASSOCIATED STANDARDS

The original galvanizing standard, AS 1650:1989, has been replaced by a series of standards dealing with each type of galvanized product; sheet, wire, tube and after fabrication galvanized products. This has resolved a deal of confusion as each product and process produced galvanized coatings of differing durability and metallurgical characteristics. The additional standards are:

AS
1397 Steel sheet and strip—Hot-dipped zinc-coated or aluminium/zinc coated

AS/NZS
4534 Zinc and zinc/aluminium-alloy coatings on steel wire

4791 Hot-dip galvanized (zinc) coatings on ferrous open sections, applied by an in-line process

4792 Hot-dip galvanized (zinc) coatings on ferrous hollow sections, applied by a continuous or a specialised process.

COATING THICKNESS SPECIFICATION

AS/NZS 4680:2006 specifies minimum coating thickness requirements for steel of various section thicknesses. While most galvanized coatings are classified by the mass of the galvanized coating in g/m^2, the practical requirements of testing and measuring galvanized coatings non-destructively require the coating thickness to be a measure of conformance.

Because of the variations inherent in the steel chemistry, surface condition and the nature of the hot dip galvanizing process, both local minimum coating thickness and average coating thickness levels are nominated in the Standard.

Small parts may be galvanized using a centrifuge process to remove excess zinc from the components. This produces a galvanized coating that contains less free zinc than those that are galvanized using standard hot-dipping procedures. The coating thickness characteristics produced by these processes are reflected in the following tables:

REQUIREMENTS FOR COATING THICKNESS AND MASS FOR ARTICLES THAT ARE NOT CENTRIFUGED

Article thickness mm	Local coating thickness minimum μm	Average coating thickness minimum μm	Average coating mass minimum g/m²
<1.5	35	45	320
>1.5 ≤3	45	55	390
>3 ≤6	55	70	500
>6	70	85	600

REQUIREMENTS FOR COATING THICKNESS AND MASS FOR ARTICLES THAT ARE CENTRIFUGED

Thickness of articles (all components including castings) mm	Local coating thickness minimum μm	Average coating thickness minimum pm	Average coating mass minimum g/m²
<8	25	35	250
>8	40	55	390

NOTE: 1 g/m² coating mass = 0.14 pm coating thickness.

PURCHASER OBLIGATIONS

A large variety of items are delivered to the galvanizer for processing. These items vary in design, steel chemistry, surface condition and end-use requirements. There are obligations on the purchaser of the galvanizing service to provide information to the galvanizer as to the characteristics of the item to be galvanized and any specific requirements related to its application.

To ensure that the end-result is satisfactory, the purchaser needs to supply the following information to the galvanizer. These purchaser obligations are included in the Standard. Some of the more significant purchaser obligations are:

1. Reference to AS/NZS 4680 as the basis of the galvanizing specification.
2. The nature, chemical composition and mechanical properties of the product to be galvanized, and its end use
3. Whether a passivation coating is required.
4. Whether removal of surplus zinc on threads is required.
5. Requirements for independent testing, if applicable.
6. Location of significant surfaces.
7. Any special or supplementary requirement of the coating, e.g. for a special finish such as powder coating, or requirements for pretreatment or post-treatment.
8. Any special coating thickness requirements.
9. Instructions for renovation of damaged or uncoated areas

STEEL CHEMISTRY

Most ferrous metals used for structural applications can be satisfactorily hot-dip galvanized. Where there is uncertainty about other types of ferrous metals, adequate information, or samples, should be provided by the purchaser to the galvanizer to decide whether they can be satisfactorily galvanized.

Steels containing higher than standard levels of sulfur, silicon or phosphorous can produce thick galvanized coatings that are not of uniform appearance and have lower impact resistance than galvanized coatings on standard grades of steel.

STRESSES IN THE BASIS METAL

AS/NZS 4680: 2006 contains information on stresses giving rise to distortion and embrittlement of the steel arising from the hot dip galvanizing process. These issues are covered in more detail elsewhere in this Specifiers Manual.

EXTENT OF REPAIRABLE DAMAGED OR UNCOATED AREAS

One of the contentious issues associated with hot dip galvanized coatings is the allowable extent of damaged or missing coating that can be repaired. This aspect is covered precisely in AS/NZS 4680.

The Standard nominates that the sum total of the damaged or uncoated areas shall not exceed 0.5% of the total surface area or 250 cm^2, whichever is the lesser, and no individual damaged or uncoated area shall exceed 40 cm^2. Where the design of the item or fabrication makes larger uncoated areas unavoidable, uncoated areas greater than 40 cm^2 shall be repaired.

REPAIR REQUIREMENTS

AS/NZS 4680:2006 nominates coating repair requirements for damaged or uncoated areas. While these recommendations may produce satisfactory results, this section of the Standard does not reflect industry best practice.

Single pack organic zinc rich paint, containing 90% zinc by weight in the dry film, is used throughout the industry for touch-up and repair, unless specified by the client. The Galvanizers Association of Australia endorses this procedure.

Inorganic zinc rich paints are not considered suitable as touch-up coatings for galvanized products because the surface preparation requirements specific to uncoated steel will damage the galvanized coating adjacent to any area being repaired.

SWEEP (BRUSH) BLAST CLEANING OF GALVANIZED STEEL PRIOR TO PAINTING

A frequent problem arises with inexperienced painting contractors painting over hot-dip galvanized coatings, where abrasive blasting is required as the surface preparation. This has been addressed in AS/NZS 4680 and the surface preparation procedure nominated in the standard should always be referenced when painting over galvanizing is specified. This process is covered in more detail elsewhere in the Specifiers Manual.

SUMMARY

AS/NZS 4680:2006 should be used as the reference document when specifying hot dip galvanized coatings. This Standard is subject to periodic reviews to ensure that it remains current with industry best practice. It is also aligned with the major international galvanizing standards, particularly the ISO Standard, ISO 1461.

INTRODUCTION

With the globalisation of commerce and industry, there is an imperative to ensure that performance benchmarks are set in all jurisdictions. International standards are increasingly called up in specifications, and Standards Australia has adopted a policy of aligning all Australian standards with International Standards Organisation (ISO) standards as they are published or revised.

The importance of consistent standards in an international trading environment is essential to ensure that suppliers are competing on an equal footing in terms of product specifications and quality. While the world is rapidly moving towards uniform standards, there are still many regional, national and internal standards that are called up in specifications. These may include standards from:

United Kingdom	- BSI
International	- ISO, EC, ETSI
United States	- ANSI, ASTM, ASME…
Germany	- DIN
New Zealand	- SANZ
Japan	- JIS
Canada	- CSA

There are now many Australian/New Zealand standards that have been released in recent times, related to coatings on steel in particular. Those related to zinc-based (galvanized) coatings on steel products are of particular interest, as most address identification issues that are important to specifiers.

Many zinc-based coatings look similar, but can vary significantly in durability performance as a result of the technology used in their application.

This chapter is aimed at listing the more important of these new standards, and highlighting the performance related issues addressed therein.

In addition, we have included a complete listing of current Australian standards associated with coatings for reference.

CATEGORIES OF COATING STANDARDS

There are six categories into which the current coating standards fall. These are:

1. Process applied coatings
2. Manually applied coatings
3. Product related standards that define coating performance requirements
4. Environmental classification standards
5. Methods of measurement standards.
6. Generic materials standards (e.g. zinc metal, organic and inorganic coatings etc.)

While most of these standards are designed as stand-alone documents, most reference related standards and hence form a matrix of information sources that can be quite complex.

1. Process applied coatings.

These include galvanized coatings of all types, powder coatings, electroplated coatings and any other coating that is applied to an item in a purpose designed facility. The coating's characteristics are determined by the process and are usually maintained to tight specifications in a controlled environment.

2.Manually applied coatings.

These include most types of commercial and industrial paint coatings, where the surface preparation is at the discretion of the operator, as is the application of the coating. These coatings are heavily dependent on the skill of the applicator and the ability to deal with the variables of the environmental conditions prevailing at the time of application.

3. Product related standards that define coating performance requirements.

These types of standards reflect the shift to performance-based standards rather than prescriptive standards. The recently published AS/NZS 2699.3:2002 Built-in components for masonry construction – Lintels and shelf angles (durability requirements) is a good example of this new generation of standards. A minimum performance life (50 years) is nominated, and complying coatings are listed in the standard for a range of exposure classifications.

In 2008, Standards Australia released a new standards: AS 2309 – Durability of galvanized and electrogalvanized zinc coatings for the protection of steel in structural applications that defines the performance of the various types of zinc-based coatings for steel with respect to their thickness in atmospheric exposures in Australia.

4. Environmental classification standards.

These standards are intended to provide environmental classifications based on a range of corrosivity factors, which can then be overlaid on coating standards to determine system performance. AS/NZS 2312:2002 Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings, along with ISO standards ISO 9223, 9224, 9225, and 9226 cover the classification of environments. A new standard (AS 4312: 2008 – Corrosivity zones in Australia), has been developed by Standards Australia, and is a single-source document for this application.

5. Methods of measurement standards.

There is a large number of very specific standards related to the measurements and test procedures associated with the application and performance of applied coatings of all types. These standards range from methods of measurement of coating thickness to the determination of surface cleanliness.

6. Generic materials standards.

These standards related to the quality requirements for the basic materials used in the protective coating process. Some are incorporated into the coatings standards. Examples include a standard for testing the metallic zinc content of zinc-rich paint coatings and the component requirements for two-pack epoxy paint designed for industrial applications.

The aim of all standards is to clearly define the requirements of the product or process for the purposes of specification and the assurance of the quality of the finished product. Most standards are quite product-specific, and rarely give rise to confusion in the specification process.

One exception is zinc (galvanized and electroplated) coatings, which until recently, have not been separated sufficiently the facilitate clear specification based on required performance.

For that reason, these standards will be dealt with in more detail in this summary.

THE ZINC-COATED (GALVANIZED) STEEL STANDARDS.

AS/NZS 4680:2006 – Hot dip galvanized (zinc) coatings on fabricated ferrous articles

AS/NZS 4680 – Is specific to after-fabrication galvanizing and specifies the heaviest galvanized coatings. In most cases, the hot dip coating will always exceed the specified minimum thickness because of the nature of the application process. Minimum coating thickness is specified on the basis of steel thickness. The coating is specified in grams/m^2 which is usually converted to average coating thickness in microns so non-destructive measurement of the coating can be done.

AS/NZS 4534:2006 – Zinc and zinc/aluminium coatings on steel wire

AS/NZS 4534 – Is specific to continuously galvanized wire. The coating is applied in a continuous process. A number of coating classes are available that vary with wire diameter. A WXX identification system is used, with W10 being the standard class against which the other classes are rated. e.g. W20 is double the coating mass of W10 and W05 is half the coating mass of W10 for the same wire diameter

AS/NZS 4791:2006 – Hot dip galvanized (zinc) coatings on ferrous open sections applied by a continuous or specialised process.

AS/NZS 4792:2006 – Hot dip galvanized (zinc) coatings on ferrous hollow sections applied by a continuous or specialised process.

AS/NZS 4791 – Open sections
AS/NZS 4792 – Hollow sections
These two standards were developed specifically for OneSteel's Duragal™ continuously galvanized hollow and open sections and Palmer Tube's and Orrcon's hollow sections manufactured from continuously galvanized (CG) strip. Some sections may be hot dip galvanized using a semi-continuous galvanizing process.

Where the hot dip galvanized coating is used, the coating class is designated by the classification HDGXXX, where the XXX numerals are the coating mass per square metre on each surface. e.g. HDG200 is 200 g/m^2 average.

Where CG strip is used, the coating class is designated by the classification ZBXXX/XXX. The ZB indicates `zinc both sides' and the XXX is the coating mass per side in g/m^2. e.g. ZB100/100 represents 100 g/m^2 coating mass average on both sides.

Where the coating is applied by an in-line process (Duragal ™), the coating class is designated by the classification ILGXXX, where ILG indicates in-line galvanized and the XXX is the single-side coating mass in g/m^2. e.g. ILG100 represents 100 g/m^2 on the outside of hollow sections and all surfaces of open sections.

AS 1397:2011 – Steel sheet and strip – Hot dipped zinc coated and aluminium/zinc coated coated

This standard has been virtually unchanged from previous editions and covers both galvanized (zinc), zinc/iron alloy and Zincalume™ coated steel sheet and strip. The Zincalume™ coating contains approximately 60% aluminium and 40% zinc.

The steel strength grade is designated by a GXXX classification, where the XXX represents the steel's yield strength in megapascals (MPa). e.g. G350 indicates a 350 MPa minimum yield strength.

The coating type is designated by ZXXX for galvanized (zinc) coatings, ZFXXX for zinc/iron alloy coatings and AZXXX for Zincalume™ coatings, where the XXX represents the total average coating mass on BOTH sides of the sheet. e.g. Z350 indicates a galvanized coating with a total coating mass on BOTH sides of the sheet of 350 g/m^2 or 175 g/m^2 on each side of the sheet.

AS 4750:2003 – Electro- galvanized (zinc) coatings on ferrous hollow sections.

This standard was developed to complement the other in-line galvanizing standards, where the zinc coating is applied by a continuous electroplating process, rather than using a molten zinc bath.

There are a number of hot-dip galvanizing standards related to structural fasteners. These standards are similar with respect to coating specifications, but are differentiated by the types of fasteners.

These standards include:

AS 1214:1983 Hot-dip galvanized coatings on threaded fasteners (ISO Metric coarse thread series)

AS/NZS 1559:1997 Hot-dip galvanized steel bolts with associated nuts and washers for tower construction.

AS/NZS 1252:1996 High strength steel bolts with associated nuts and washers for structural engineering.

AS/NZS 1390:1997 Cup head bolts with ISO metric coarse pitch threads.

THE ENVIRONMENTAL CLASSIFICATION STANDARDS.
The most significant document in the Standards Australia library on the classification of environments for corrosivity is **AS/NZS 2312:2002** – Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings.

The section in this standard covering classification of atmospheres is largely descriptive and makes no attempt to quantify corrosivity in given environments.

AS/NZS 2312 references a suite of ISO standards that are intended to provide the platform for classification of corrosivity or atmospheres. These standards are:

ISO 9223 - Corrosivity of atmospheres – Classification

ISO 9224 – Corrosivity of atmospheres – Guiding values for corrosivity categories

ISO 9225 – Corrosivity of atmospheres – Measurement of pollution

ISO 9226 – Corrosivity of atmospheres – Determination of corrosion rate for standard specimens for the evaluation of corrosion.

While these standards provide the metrics to determine atmospheric corrosivity, they have been developed for Northern hemisphere conditions, and fall short in some areas that are appropriate for the Asia-Pacific region. AS 4312 has been developed to overcome these issues.

Standards of this type will become increasingly important as the determination of durability of construction materials will lead to more performance based, rather than prescriptive, standards being published and also incorporated in to building codes and standard specifications.

FINDING THE STANDARD
It is no longer necessary to reference a large printed catalogue of standards, or even purchase a printed standard from an authorized distributor. Standards Australia develops the standards and they are them sold through SAI Global which is a public company with exclusive distribution rights for Standards Australia publications.

Information about individual standards is available from the SAI Global web site, and any Australian or international standard can be purchased as a hard copy or as a downloadable .pdf file from the SAI Global site.

Students can register with Standards Australia and this will allow access to any standard for downloading for reference. These files are time stamped and copyrighted and have very short use-by date after downloading, but provide students with standards access on a 24/7 basis.

The Standards Australia web address is www.standards.com.au. The SAI Global web address is www.saiglobal.com.

COATING STANDARDS SURVEY
This listing contains most of the Australian Standards that cover industrial protective coatings. There are additional standards that deal with specialised coatings (gold plating, vitreous enamel, etc) that have been excluded for practical reasons from this listing.

Standard	Title
AS 1231 –2000	Aluminium and aluminium alloys – Anodic oxidation coatings
AS 4750 – 2003	Electrogalvanized (zinc) coatings on ferrous hollow and open sections
AS 1192 -2004	Electroplated coatings – nickel and chromium
AS 4397 - 2007	Electroplated coatings of zinc on steel fasteners with imperial threads
AS 1897 – 1976	Electroplated coatings on threaded components (metric coarse series)
AS 1789 – 2003	Electroplated zinc (electro galvanized) coatings on ferrous articles (batch process)
AS/NZS 2312 –2002	Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings.
AS 1214-1983	Hot-dip coatings on threaded fasteners (ISO metric coarse thread series)
AS/NZS 4680 –2006	Hot-dip galvanized (zinc) coatings on fabricated ferrous articles
AS/NZS 4791 -2006	Hot-dip galvanized (zinc) coatings on ferrous hollow sections, applied by a continuous or specialised process.
AS/NZS 4792 -2006	Hot-dip galvanized (zinc) coatings on ferrous open sections, applied by a continuous or specialised process.
AS 4750 - 2003	Electrogalvanized (zinc) coatings on ferrous and open sections
AS/NZS 1559 -1997	Hot-dip galvanized steel bolts with associated nuts and washers for tower construction
AS 2483- 2003	Metal finishing – Recommended sampling plans for the inspection and testing of coatings (ISO 4519:1980, Mod)
AS 1247- 2004	Metallic coatings – Rating of test specimens and manufactured articles subject to corrosion tests
AS 2331.3.11 – 2004	Methods of test for metallic and related coatings - Corrosion and related property tests – Chemical residue tests – Chemical residue tests
AS 2331.3.2 – 2001	Methods of test for metallic and related coatings - Corrosion and related property tests – Chemical residue tests – Acetic acid salt spray test (ASS test)
AS 2331.3.3 – 2001	Methods of test for metallic and related coatings - Corrosion and related property tests – Chemical residue tests – Copper accelerated acetic acid salt spray test (CASS test)
AS 2331.3.4 – 2001	Methods of test for metallic and related coatings - Corrosion and related property tests – Thioacetamide anti-tarnish and porosity tests
AS 2331.3.5 – 2001	Methods of test for metallic and related coatings - Corrosion and related property tests – Sulfur dioxide/hydrogen sulfide porosity tests
AS 2331.3.6 – 2001	Methods of test for metallic and related coatings - Corrosion and related property tests – Electrographic porosity tests
AS 2331.3.7 – 2004	Methods of test for metallic and related coatings - Corrosion and related property tests – Corrodkote (Corr) test (ISO 4541:1978.Mod)
AS 2331.3.8 – 2001	Methods of test for metallic and related coatings - Corrosion and related property tests- Humidity test –24 hour cycle – Damp heat
AS 2331.3.9 – 2001	Methods of test for metallic and related coatings - Corrosion and related property tests – Metallic coatings – Porosity tests – Ferroxyl test
AS 2331.3. 18–2001	Methods of test for metallic and related coatings – Corrosion and related property tests – Neutral salt spay (NSS) tests

AS 2331.0 –2006	Methods of test for metallic and related coatings – Method Selection Guide
AS 2331.1.1 –2001	Methods of test for metallic and related coatings – Local thickness tests – Micrographic examination of cross section
AS 2331.1.2 –2001	Methods of test for metallic and related coatings – Local thickness tests – Colourmetric method
AS 2331.1.3 –2001	Methods of test for metallic and related coatings – Local thickness tests – Magnetic method
AS 2331.1.4 –2001	Methods of test for metallic and related coatings – Local thickness tests – Magnetic induction and eddy current method
AS 2331.1.5 –2001	Methods of test for metallic and related coatings – Local thickness tests – Beta backscatter method
AS 2331.4.2 – 2004	Methods of test for metallic and related coatings – Physical tests – Ductility test
AS 2331.4.1 – 2001	Methods of test for metallic and related coatings – Physical tests – Qualitative adhesion tests
AS 2331.4.4 – 2001	Methods of test for metallic and related coatings – Physical tests – Assessment of intensity of shot peening.
AS 2331.2.1 –2001	Methods of test for metallic and related coatings – Test for average coating mass per unit area or for thickness. Dissolution methods – Strip and weight analytical
AS 2331.2.3 –2001	Methods of test for metallic and related coatings – Test for average coating mass per unit area or for thickness. Hydrogen evolution method for zinc coatings
AS/NZS 1580.205.3 -1997	Paints and related materials – Methods of test – Application properties – Roller coating
AS/NZS 1580.481.0 -2003	Paints and related materials – Methods of test – Coatings – Guide to assessing paint systems exposed to weathering conditions
AS/NZS 1580.481.5 -2004	Paints and related materials – Methods of test – Durability and resistance to fouling – Marine underwater paint systems
AS/NZS 1580.481.1.10 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of flaking and peeling
AS/NZS 1580.481.1.11- 1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of chalking
AS/NZS 1580.481.1.12 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of colour change
AS/NZS 1580.481.1.13 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of fungal and algal growth
AS/NZS 1580.481.1.2 -1998	Paints and related materials – Methods of test – Exposed to weathering – Discoloration (including bronzing)
AS/NZS 1580.481.1.3 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of dirt collection
AS/NZS 1580.481.1.4 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of dirt retention (after washing)
AS/NZS 1580.481.1.5 -1999	Paints and related materials – Methods of test – Exposed to weathering – Change in gloss
AS/NZS 1580.481.1.6- 1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of erosion
AS/NZS 1580.481.1.7 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of checking

AS/NZS 1580.481.1.8 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of cracking
AS/NZS 1580.481.1.9 -1998	Paints and related materials – Methods of test – Exposed to weathering – Degree of blistering
AS 1580.481.5 - 2004	Paints and related materials – Methods of test – Coatings – Durability and resistance to fouling – Marine underwater paint systems
AS 3894.4 - 2002	Site testing of protective coatings – Assessment of degree of cure
AS 3894.1 - 2002	Site testing of protective coatings – Continuity testing – High voltage (brush) method
AS 3894.9 - 2003	Site testing of protective coatings – Determination of adhesion
AS 3894.3 - 2002	Site testing of protective coatings – Determination of dry film thickness
AS 3894.6 - 2002	Site testing of protective coatings – Determination of residual contaminants
AS 3894.5 - 2002	Site testing of protective coatings – Determination of surface profile
AS 3894.7 - 2002	Site testing of protective coatings – Determination of surface temperature
AS 3894.11 - 2002	Site testing of protective coatings – Equipment report
AS 3894.12 - 2002	Site testing of protective coatings – Inspection report - Coating
AS 3894.13- 2002	Site testing of protective coatings – Inspection report - Daily
AS 3894.14 - 2002	Site testing of protective coatings – Inspection report – Daily painting
AS 3894.10 - 2002	Site testing of protective coatings – Inspection report – Daily surface and ambient conditions
AS 3894.0 - 2002	Site testing of protective coatings – Introduction and list of test methods
AS 3894.2 - 2002	Site testing of protective coatings – non-conductive method – Continuity testing – Wet sponge method
AS 3894.8 - 2002	Site testing of protective coatings – Visual determination of gloss
AS 1397 - 2011	Steel sheet and strip – Hot-dip zinc coated or aluminium/zinc coated
AS/NZS 4506 –2005	Thermoset powder coatings
AS/NZS 4534 -2006	Zinc and zinc/aluminium alloy coatings on steel wire
AS 4848.1 - 2006	Application specifications for coating systems – Single coat inorganic (zinc) silicate – Solvent-bourne.
AS 5056 - 2006	Powder metal (and composites) applied by mechanical means at ambient temperature.

INTRODUCTION

With any applied coating, the quality of the surface preparation is the most important factor in determining whether the coating will perform for its expected design life. With paint coatings in particular, almost all failures are due to poor surface preparation. Longer maintenance free performance is being demanded of protective coatings, and environmental and heritage issues increasingly impact upon surface preparation technology. The specification and quality assurance of surface preparation thus require as much attention as the priming and topcoating systems. There are no shortcuts to good surface preparation and the costs premature failure render the savings associated with cheap surface preparation insignificant.

Difficult surfaces such as the corroded steel shell of the hydrochloric acid pickling tank require stringent surface preparation to remove both corrosion products and residual chlorides

INITIAL SURFACE CONDITION

SURFACE PREPARATION

Rust is an oxide of iron formed by the action of air and water. It is voluminous and occupies one and three-quarter times the volume of the steel from which it originated. Rust forming under a paint coating or through breaks in the coating, can burst through and may creep under the coating resulting in flaking so that repair is both difficult and costly.

Proper surface preparation is essential for the success of any protective coating scheme. The importance of removing oil, grease, old coatings and surface contaminants (such as mill scale and rust on steel, laitance on concrete and zinc salts on galvanized surfaces) cannot be over emphasised.

The performance of any paint coating is directly dependent upon the correct and thorough preparation of the surface prior to coating.

The most expensive and technologically advanced coating system WILL fail if the surface pre-treatment is incorrect or incomplete.

DEGREASING & PRELIMINARY SURFACE PREPARATION

Organic Solvents

Aliphatic and aromatic solvents will remove most process oil and grease. It is not always appropriate to use these solvents because of fire, pollution or occupational health hazards.

Statutory environmental requirements will generally require recovery of used solvents and solvent degreasing is best suited to controlled static manufacturing operations.

Detergent Degreasers

Spray or dip application is the best method for using detergent degreasers. There are many types of detergent degreasers. Many are alkaline and most require rinsing with clean water after application. Galvanizing plants use hot (70°C) caustic degreasing tanks for paint removal as well as degreasing. Containment of the detergent cleaning residues is a mandatory requirement as strict controls on such industrial waste products are now almost universal.

Steam Cleaning

Steam cleaning is well suited to small parts or machinery. Steam alone is unlikely to dislodge the lubricants used to grease working machinery. For more highly efficient steam cleaning of oil and grease from working machinery, a detergent is typically added. Operating conditions may be between 690-1,034 KPa and 60-71° C

Newer Methods

Among the newer methods available for grease and oil removal from working machinery are ice blasting, carbon dioxide pellet blasting, abrasive blasting with rubberized pellets, and blasting with a sodium bicarbonate slurry.

• Ice Blasting – Ice crystals generated within the blasting equipment are used as the abrasive nmedie. Ice blasting is well suited to the removal of contaminants from softer substrates such as aluminium or brickwork that would be damaged by conventional abrasives.

• Carbon Dioxide Blasting - The principle of operation of this method involves solidification and erosion/abrasion of oil or grease from the structure. The operating conditions are typical of abrasive blasting with nozzle pressures at or near 550 KPa. Feed rates for the CO_2 are measured as a few kg per minute. The primary benefit claimed for this method is that the clean up required is very limited because the CO_2 sublimes to a gas after hitting the substrate, leaving only the removed oil and grease behind.

• Rubber Pellet Blasting - Blasting with pellets of rubbery polyurethane foam has been identified as a versatile method for a number of cleaning operations. Like CO_2 blasting, this method is said to dramatically reduce the need for clean-up of fractured abrasive. The principle involves the sponging of the oil or grease from the surface into pores on the foam pellets. The pellets change shape when they hit the metal surface, and grease or oil is squeezed into the pores of the rubbery foam. Operating conditions are quite mild, with nozzle pressures around 30-60 psi (200-400 kPa) being common.

Paint failure on galvanized balustrade resulted from paint being applied to a contaminated surface.

Complete failure of this paint system on this galvanized stairway occurred because the piant was applied directly to the chromate quenched galvanized surface. This passivation treatment interferes with paint adhesion

• Sodium Bicarbonate Slurry Blasting - Several types of this method exist. A super-saturated slurry of baking soda in water is projected at the work piece with nozzle pressures of 85-100 psi (586-690 kPa).

Rust and Scale Removal

The various methods of preparing steel for subsequent painting are given in Australian Standard 1627 Parts 0 to 10, issued by the Standards Association of Australia, with reference to pictorial standards depicted in Aust. Standard 1627.9 . It is strongly recommended that the appropriate Standard be stated to define clearly the degree of surface preparation required. **Australian Standard 2312:2002, Guide to the protection of iron and steel against exterior atmospheric corrosion** also provides a comprehensive guide to surface treatment in Section 5 of that Standard.

It is essential to remove all oil, grease, drilling and cutting compounds and other surface contaminants prior to further surface preparation or painting of the steel. The most common method is by solvent washing, followed by wiping dry with clean rags. The wiping clean is critical, because if this is not carried out thoroughly the result of solvent washing will simply spread the contamination over a wider area. Proprietary emulsions, degreasing compounds and steam cleaning are also commonly used. Recommended procedures are described in Australian Standard 1627, Part 1 and in the above section of this article.

Processes like hot dip galvanizing and use in-line pretreatment systems that remove all organic contaminants from the steel surface by immersion in hot caustic soda solution prior to pickling off of the mill scale and rust

Hand Tool Cleaning

Hand tool cleaning is defined as a method of preparing new, corroded or previously painted steel surfaces prior to painting by removing loose mill scale, loose rust and loose paint by using hand wire brushing, hand sanding, hand scraping hand chipping or a combination of these methods. Preliminary cleaning of large deposits of oil or grease, soluble fluxes and fume deposits from areas adjacent to weld runs should be carried out by solvent or detergent cleaning, detailed in Australian Standard 1627 Part 1 or by fresh water washing as appropriate.

Three standards of surface preparation are defined:

Class 1: is produced by "light wire brushing" to at least as good as Standard St 1 of AS1627.9.

Polyester powder coating facilities have carefully controlled on-line pretreatment systems that ensure consistent surface preparation standards .

Large galvanized fabrications such as these lighting poles are garnet blasted prior to powder coating. This improves the powder coating adhesion and ensured that the zinc surface is free of oxidation products.

Class 2: is produced by "thorough scraping and wire brushing", and heavy rust scale first removed by hand hammering, The prepared surface to he at least as good as Standard St 2 of AS 1627.9.

Class 3: is produced by "very thorough scraping and wire brushing", any heavy rust scale being first removed by hand hammering. The prepared surface to be at least as good as Standard St 3 of AS1627.9.

Hand tool cleaning should only be specified for normal atmospheric exposures and interiors when the painting system includes a primer of good wetting ability. Hand cleaning will not remove all residues of rust, nor will it remove firmly adherent mill scale, and particularly corrosive salts such as chlorides and sulfates.

Power Tool Cleaning

When removal of rust and mill scale is required, other Australian Standards; Power Tool Cleaning 1627.2; Blast Cleaning 1627.4; or Pickling 1627.5 should be considered.

(a) Power Tool Cleaning is defined as a method of preparing new, corroded or previously painted steel surface prior to painting by removing loose mill scale, loose rust, loose paint and all welding scale with power impact tools, power grinders, power sanders, power wire brushes or a combination of these tools. Tightly adhering mill scale and rust In deep pits will not normally be removed by this method of cleaning. Care should be taken not to polish the metal surface as this may reduce the key for subsequent coating.

(b) All surfaces to be coated shall be cleaned by the use of power-driven tools according to Australian Standard 1627 Part 2. Reference is made to Pictorial Standards of original unpainted surfaces of Australian Standard 1627.9 and to painted surfaces with varying amounts of visible rust, the amount rated typified by the Reference Standards of Australian Standard 1580 Method 481,3.

(c) Three standards of preparation are defined -

Class 1: is produced by power wire brushes only

Class 2: is produced by power impact tools followed by a light wire brushing

Class 3: is produced by power impact tools or power sanders, followed by light wire brushing.

Flame Cleaning

Flame cleaning is affected by the use of high velocity, high temperature oxy-fuel gas flames over the surface to be treated. It is slightly more effective than power rod cleaning and covered by Australian Standard AS1627, Part 3. It is expensive and has inherent risks of fire and explosion, and of possible distortion to light gauge steel. It is generally used for cleaning corroded and previously painted steel.

Pickling

Pickling may be carried out by any of the methods using either acid, alkaline or electrolytic baths, or in combination, provided adequate precautions are observed to:

(a) Ensure sufficient inhibitor has been added to minimise attack on the base metal when pickling

Ultra-high pressure (35,000 psi+) water blasting is an effective way of preparing contaminated surfaces for maintenance painting, particularly where chlorides are present.

Special abrasives such as Sponge Jet media can be used for delicate removal operations

in acid solutions. NOTE: Hydrochloric acid is much less aggressive on the base steel than sulfuric and generally does not require an inhibitor if used at concentrations under 15%.

(b) Acid pickling or cathodic treatment methods should not be used on steel having a tensile strength greater then 800 MPA. This precaution is necessary to prevent hydrogen absorption and subsequent embrittlement that may result in fracture due to hydrogen cracking.

The pickled steel must be thoroughly rinsed of residual acid and will require passivation treatment with phosphate or other appropriate medium to prevent re-rusting. This is not required for hot dip galvanizing as the steel is normally fluxed and galvanized immediately after pickling.

Blast cleaning

By far the most effective method for removal of mill scale, rust, and old coatings is through the use of abrasives such as slag, grit or shot transported by high pressure air. There are four commonly used grades of blast cleaning, and the approximate equivalents between the various International Standards are as follows:

Aust. Std 1627.4	US Spec SSPC NACE	British Std BS4232	Swedish Std SIS 05-5900
White metal	Class 3	SP-11 NACE-1	1st Quality Sa 3
Near white metal	Class 2½	SP-3 NACE-2	2nd Quality Sa 2½
Commercial blast	Class 2	SP-2 NACE-3	3rd Quality Sa 2
Brush blast	Class 1	NACE-4	Sa 1

Australian Standard 1627.4 describes the correct practice to be followed in abrasive blast cleaning and details the various qualities of blast. All surfaces should be cleaned free of oil and grease before blasting. Australian Standard 1627 Part 9 provides pictorial representations of four different rust grades on steel that has been previously rusted as well as new steel. Pictorial representations are then given showing the appearance of each when blasted to any of the four classes of preparation.

The grade of blasting suitable for a particular coating specification depends on a number of factors, the most important of which is the type of coating system selected.

Prior to blasting, steelwork should be degreased and all weld spatter removed. If grease or oil is present on the surface it will appear to be removed by the blasting process, but this is not the case. Although not visible, the contamination will still be present as a thin layer, and will affect the adhesion of subsequent coatings.

The presence of residual chlorides on the surface of rusted steel will create a problem with subsequent coating operations, as the blasting will not remove these chlorides from the surface. Test procedures for chloride detection have been established and high-pressure water blasting after dry blasting may be required to reduce chlorides to acceptable levels.

Chemical pre-treatment usually involved multiple processes. This hot caustic degreasing operation in the hot dip galvanizing process is necessary to ensure the acid pickling stage is effectice.

Weld seams and sharp edges should be ground down. This is because paint coatings tend to run away from sharp edges, resulting in thin coatings and reduced protection. Weld spatter is almost impossible to coat evenly, in addition to often being loosely adherent, and it not removed is a common cause of premature coating failure.

The profile or roughness obtained during blasting is important, and will depend on the abrasive used, the air pressure and the technique of blasting. Too low a profile may not provide a sufficient key for a coating, while too high a profile may result in uneven coverage of high, sharp peaks which will protrude through the applied paint film, possibly leading to premature coating failure, particularly for thin coatings such as blast primers. The following table gives a brief guide to typical roughness profiles obtained using various types of abrasive.

Type or Abrasive	Mesh Size	Max Height of Profile
Very fine sand	80	37 micrometers
Coarse sand	12	70 micrometers
Iron shot	14	90 micrometers
Typical non-metallic "copper slag"	75	100 micrometers
Iron grit No. G16	12	200 micrometers

Wet abrasive blasting

Wet abrasive blasting uses a slurry of water and abrasive rather than dry abrasive alone. This has the advantage that the hazards of dust and associated health problems are largely overcome. A further important advantage is that when wet blasting old, well rusted surfaces, many of the soluble corrosion products in the pits of the steel will be washed out, which will greatly improve the performance of the following paint system. However, a disadvantage of this technique is that the cleaned steel begins to rust rapidly after blasting.

It is therefore common practice to include proprietary inhibitors in the blast water that will prevent this rusting for a sufficient time to allow painting to be carried out. In general, the use of very low levels of such inhibitors does not affect the performance of subsequent paint coatings for non-immersed steel work. The use of a moisture tolerant primer, which can be applied to wet blasted steel while it is still damp, can make the use of inhibitors unnecessary.

Where wet blasted surfaces have been allowed to corrode, they should be mechanically cleaned or preferably sweep blasted, to remove the corrosion prior to painting unless a surface tolerant paint has been specified.

High Pressure Fresh Water Cleaning

A number of factors influence the results obtained by high-pressure water washing. There are no recognised standards of surface cleaning - as exist for grit blasting - and it is difficult to predict the outcome of a cleaning procedure.

Pressures used range from 70kg/cm^2 to 2800kg/cm^2 (1000 psi to 40000 psi) and volumes of throughput also vary considerably.

High-pressure washing can also he used to clean corroded areas and has been used as an alternative to grit blasting. The result depends to a very large extent on the condition of the surface. Compact corrosion scale cannot be completely removed at a reasonable rate until pressures exceed 2100 kg/cm^2 (30000 psi).

Vacuum Blasting

Vacuum blasting, which eliminates the dust hazard, has a relatively slow rate of cleaning, but is ideal for cleaning limited areas, such as welds and burn damage when open blasting may seriously damage the intact surrounding coating. The abrasive is driven by compressed air into a specially designed head held on the steel surface, where, as soon as it strikes the surface it is sucked back into the machine for separation of the dust and re-use of the abrasive.

Wet Blasting (Hydro blasting)

Water and abrasive are now more commonly used to clean surfaces. There are two main methods available:

(1) High pressure water + grit - this system is essentially a fan-jet washing type of equipment (approx.140kg/cm^2 with small amounts of abrasive present in the fan). It is useful for the controlled removal of particular coats of paint but a very slow method for total removal of paint to bare steel as the quantity of abrasive used is normally only 25% of that consumed by dry blasting.

(2) Abrasive blasting + water injection - the abrasive stream is shrouded in water by the injection of a small amount of water at the blasting nozzle. Production rates are similar to dry blasting.

The main advantages of these systems are that they cut down air pollution, compared to dry blasting and eliminate contamination of nearby areas by abrasive dust. Wet blasting has also proved an excellent tool when preparing old steel that is heavily contaminated with soluble salts, particularly chlorides.

The main draw back of wet blasting is that the steel exposed flash rusts on drying. This can be prevented by the introduction of a rust inhibitor in the water; these inhibitors are usually water soluble inorganic materials.

ABRASIVE CHARACTERISTICS

The highest quality applied paint coatings require the highest quality surface preparation, and a Class 2½ blast is a minimum requirement for maximum coating performance. The characteristics of the abrasive will influence the nature of the blasted surface and thus the ultimate performance of the coating.

The abrasive blast cleaning industry borrows heavily from the terminology of the geological sciences. The concept of relative hardness adopted by the abrasive industry is taken from a term from mineralogy called the "Mohs number" developed by Friedreich Mohs, a nineteenth century German mineralogist . His scale of hardness for 10 common minerals (talc is the softest rated at 1 and diamond is the hardest rated at 10) is widely used to grade mineral hardness.

Abrasives for blasting generally have a hardness greater than 6.0 on the Mohs scale. Silica sand has a hardness of 7.0 and garnet has a Mohs number of 7.5. Diamond is arbitrarily set at 10.

Grain shape will influence the performance of the abrasive on the steel surface. Rounded or smooth grains have a peening effect on the steel. Angular or sharp edges grains will produce a sharper profile.

The shape of the abrasive grain affects the performance of the media. Very angular grains may tend to break down more readily than rounded grains, forming greater amounts of dust. More rounded grains may present a larger surface area for contact with the steel, resulting in surface profiles that are deeper than expected. Like the

size and hardness of an abrasive, grain shape can influence materials consumption, waste minimization, dust generation, environmental compliance, and surface profile. All of these items significantly affect total project cost.

Metal abrasive media is widely used in for surface preparation. Chilled iron shot or grit is used almost universally for high efficiency blasting of steel. Cut wire shot is also used as an aggressive blasting media. Because it does not shatter on impact like most mineral media, metal shot is well suited to blasting systems that recycle their abrasive media.

ABRASIVE BLASTING & OCCUPATIONAL HEALTH

The occupational health and safety risks associated with abrasive blasting are well established, although requirement may vary from state to state. Silica sand in not a permissible abrasive in many areas unless it is used under strict environmental control standards. The ethics of awarding contracts to low cost tenders who use cheap (silica sand) abrasives and do not comply with accepted OH&S industry standards are questionable.

Blast cleaning involves propelling abrasive media at speeds in excess of 175 km per hour and turning paint, rust, and substrate surfaces into a dust cloud consisting of many air-borne particles. In fact, if a particle size analysis of the air-borne particles generated from blast cleaning process is done, dust particles ranging in size from less than 1 micron to 1,000 microns could be found. One micron is 1/1000th of a millimetre.

The smallest size particle that the unaided eye can see is generally accepted to be around 50 microns.

However, dust particles 10 microns and smaller are the only dust particles small enough to reach the deep inner regions of the lung. As particle size increases above 10 microns, particles are more likely to be arrested in the upper respiratory system and be either swallowed or expelled. (In the case of lead dust particles). This is one way for lead to be inadvertently ingested and be absorbed in the gastrointestinal system). Thus the dust particles that cannot be seen maybe the most dangerous, not the big particles that are visible in most dust clouds.

Whether or not any of the air-borne dust particles are a potential health hazard depends not only on the size of the dust particles but also on the toxicity of the materials in the dust cloud and the amount of dust breathed into the respiratory system. This depends on the size of the dust particles in the work area and the concentration (total amount) of dust present. The toxicity of the particles in the dust cloud depends upon several other factors.

Air-borne dust generated from a blasting process may consist of broken down abrasive, pulverized surface coating, and abraded material from the object being blasted. The potential toxicity of each component in the dust cloud can be determined by reviewing material safety data sheets (MSDS) for the abrasive in use, and reviewing specific information on the chemical content of any old coatings being removed, as well as identifying the chemical make-up of the substrate or object being cleaned.

Some dusts are termed "nuisance" dusts. They produce little adverse effect to the body unless the airborne concentration is so high that it defeats the normal clearance mechanisms of the lungs. Other dusts are highly toxic to the body, such as dust from silica sand.

CONCLUSION

Almost all steel that is coated required some type of surface preparation and the quality of surface preparation is the single most important factor in determining coating reliability. 95% of all paint failures are caused by inadequate or poor quality surface preparation. The environmental responsibilities associated with maintenance painting and the impact of environmental legislation on paint technology will make adequate surface preparation even more important in the understanding of coating performance and the management of corrosion.

INTRODUCTION

There are many instances where hot dip galvanized coatings need to be painted. There are well established quality assurance procedures for the painting of hot dip galvanized components in a controlled environment, but it a common requirement to apply paint coatings to hot dip galvanizing under separate contract arrangements or on site.

When a steel item is first hot dip galvanized, its surface is free from oxidation and contamination and is in the best condition for coating. It is also highly susceptible to oxidation, particularly reaction with atmospheric moisture. Most galvanizers quench the work in a weak sodium dichromate solution to passivate the surface. This chromate passivation film weathers away with time and is replaced by a stable complex carbonate oxide film. This dynamic set of surface conditions needs to be considered when painting galvanized steel.

In addition, surface contamination can occur that will interfere with paint adhesion. Diesel fumes are a common source of surface contamination that is very difficult to detect, as the galvanized coating may still appear clean and bright.

Handling the galvanized items with dirty or oil-contaminated gloves can leave residues on the surface of the galvanizing that will interfere with the adhesion of the paint coating.

Where close control of surface condition is not possible, the best alternative to ensure a high quality paint application is to brush or sweep blast the galvanized surface immediately prior to painting. This is a poorly understood technique with many paint contractors. Incorrect technique will cause serious damage to the hot dip galvanized coating.

The following specification is recommended for abrasive blasting of hot dip galvanized surfaces prior to painting.

Specific abrasive blasting parameters are required when preparing galvanized surfaces for painting. The same techniques used for preparing 'black; steel will damage the galvanized coating.

Compliance with this specification will ensure that not more than 10 microns of zinc will be removed from the galvanized coating during the blasting process, and that the coating will not be damaged by fracturing of the alloy layers through excessive impact energy of the blast media on the galvanized coating.

BRUSH OR SWEEP BLASTING PROCEDURES FOR PREPARING HOT DIP GALVANIZING FOR PAINTING

1. Blast nozzle pressure 40 psi (280 kpa) maximum
2. Abrasive grade 0-2 - 0.5 mm
3. Abrasive type - clean limonite or garnet
4. Distance of nozzle from surface 400 - 500mm
5. Nozzle type - 10mm minimum diameter venturi type
6. Blasting angle to surface - 45 degrees

The aim of this blasting procedure is to remove any oxide films and surface contaminants from the surface. It is NOT to produce a profile similar to that required on bare steel. The brush blasting of the relatively soft zinc will automatically produce a fine profile, giving the clean surface a satin

appearance.
With inexperienced operators, a test section should be evaluated by measuring coating thickness before and after blasting with an approved magnetic thickness gauge.

A maximum 5-10 micron reduction in galvanized coating thickness indicates an acceptable technique. Over 10 microns of coating removed indicates an unacceptable technique.

On reactive steel, the coating may already have a matte gray or satin appearance. This indicates the presence of the zinc-iron alloy layers at the surface, which also indicates a thicker than standard galvanized coating. Grey galvanized coatings are more susceptible to mechanical damage than shiny coatings and should be treated accordingly.

The micro-roughness of the alloy layers already provides a good mechanical key for appropriate paint, and only very light brush blasting is required on galvanized coatings of this type.

Weathering of the galvanized surface will generally result in any residual chromate passivation films being removed. However, the galvanized surface can also accumulate corrodents during the weathering period and should be evaluated for cleanliness prior to any coating application.

With weathered galvanizing, free of organic contamination, high pressure water blasting of the surface will often be sufficient to ensure adequate coating adhesion to the galvanizing, given that appropriate primers are used.

INTRODUCTION

With almost all applied coatings, regardless of their technology, the factor that determines their reliability in service, given proper application, is coating thickness. With organic coatings, the coating thickness provides the barrier between the environment and the substrate. The thicker the coating, the more impermeable it is to moisture and corrodents. With galvanized coatings, coating life is determined by the corrosion rate of zinc and the thickness of the galvanized coating, so thicker galvanized coatings will always give proportionately longer lives than those that are thinner.

With both paint and galvanized coatings, the process determines the thickness of the coating. The application and specifications related to coating thickness are defined by Australian or international standards for generic coatings, by manufacturers' data sheets, or by particular product or application specific specifications written for a particular project.

Almost without exception, coating thickness is an essential part of these specifications.

COATING THICKNESS - HOW IS IT MEASURED?

While coatings are applied to a variety of materials, the majority of coating thickness testing is done over ferrous (iron and steel) surfaces, although many digital electronic thickness gauges have the capability to measure coatings on nonferrous metal surfaces using circuitry that measures eddy currents rather than magnetic flux used on steel substrates.

Most protective coatings over steel are applied in a thickness range from zero to 1000 microns, although most coatings, both paint and galvanizing, would commonly be in the 10-300 micron range. The accuracy of these gauges is in the order of ± 3% although some high performance instruments are rated at ± 1%. The older style mechanical banana and pull-off gauges operate with an order of accuracy of ± 10%.

Few applied coatings are uniform in thickness and acceptable variations are accommodated in specification standards. Most galvanized coatings are actually specified in terms of

The durability of metallic coatings like hot dip galvanizing are dependent on their coating thickness. Measuring coating loss over time can accurately determine coating life.

coating mass rather than coating thickness. The mass/m^2 is converted to theoretical thickness as a practical non-destructive method of measuring the galvanized coating. Some electronic thickness gauges have the capacity to store readings and provide statistical analysis of coating thickness data.

Calibration of coating thickness gauges is an essential element in their performance. Ferrous and nonferrous coating thickness standards are calibrated to comply with all Australian (AS 3894.3 - 2002) and international standards. Coating thickness standard sets comprise five standard plates including one zero plate and four epoxy coated reference plates. Various coating thickness standard sets are available for particular coating classes. For example, coating thickness standards for heavy duty coatings comprise 0, 75, 150, 250 and 500 micron standards while coating thickness standards for plating and anodizing include 0, 10, 15, 20 and 40 micron standards. Other standard sets are available for powder coatings, galvanized coatings and ultra high-build coatings.

COATING THICKNESS IN THE REAL WORLD

All the instrumentation used to measure coating thickness is calibrated using standards that are smooth and flat. In practice, particularly on steel surfaces, a variety of conditions may be encountered that will affect the way the instruments read coating thickness. The factor that determines coating performance, if coating thickness counts, is the distance between the highest points on the substrate and the surface of the coating, as this is where failure is most likely to occur.

Industrial coatings are applied to steel surfaces that may be very smooth, hot rolled, abrasive blasted to various standards, previously rusted and pitted, oxy-cut or curved. Paint coatings, because of their surface tension effects are usually level across their surface. Hot dip galvanized coatings, because they are formed through reaction with the steel's surface, tend to follow the contour of the surface.

It is common practice to measure coating thickness after application - a logical thing to do. The condition of the steel's surface prior to coating will determine the actual thickness of the coating that needs to be adjusted to take the effects of surface condition into consideration. Thus some knowledge of the surface prior to coating would be useful in the evaluation of the coating thickness measurements.

With abrasive blasted steel, the profile produced by the blasting will be determined by the type of blasting media used, and the techniques used in the blasting. Chilled iron shot produces a different type of surface profile to grit. Some coarse blasting media can produce blast profiles exceeding 100 microns.

Unless the peaks of these coarse profiles are adequately coated, the performance of the coating will be compromised.

There are surface profile gauges that use comparative or direct measurement of surface profile prior to coating, such as the Keane-Tator Profile discs and magnifier, the PCWI Surface Profile Gauge or the Mitutoyo Dial Gauge/Testex Tape system for permanent recording of profiles, but the thickness gauges themselves can be used to give an indication of surface profile height.

Electronic thickness gauges such as this Positector 6000 can measure any non-magnetic coating over a steel substrate. All coating specifications are based in applied coating thickness.

By taking the average of 10 thickness readings on the uncoated steel surface, the electronic gauge that has been zero calibrated on a smooth surface will give a reading. For profile heights up to 30 microns, the gauge will generally read about 25% of the profile height. For profiles up to 50 microns, this proportion is approximately 33% and for coarse profiles around 100 microns, the gauge will read about 50% of the profile height. Thus, if a reading of 13 microns is obtained on the prepared surface, the profile height can be expected to be in the order of 40 microns.

Once the coating is applied, the reading of 100 microns would indicate that the coating thickness over the highest points in the profile is around 50 microns. The profile height is 40 microns and the actual applied coating thickness is 87 microns because the instrument registers 13 microns on the uncoated steel due to the profile effect.

While high build coatings have plenty of latitude to accommodate these factors, the new generation of low permeability polymers that depend on lower applied coating thicknesses for their cost effectiveness have to take the above factors into account. Zeroing the thickness gauge on the surface to be coated, or zeroing the instrument from the top of the profile height by using a standard coating thickness film will allow coating thickness readings to reflect the actual coverage over the highest points on the surface being measured. This will not take into account what are known as surface hackles or stray rogue peaks.

This can be very costly, as the voids in the profile must be filled. The question is, 'At who's cost?' A 40 micron profile may well take up to 26 microns of the coating to fill which will be at the applicators cost. If the substrate is measured first, this would build in an allowance of 13 microns.

Other factors such as steel composition, edge and corner affects and surface flatness can affect the precision with which the instruments can determine coating thickness. For most industrial coating applications, very high levels of precision are not necessary. However, the potential for variations versus actual coating thickness needs to be taken into consideration. If too many anomalies are allowed to accumulate, the performance of the coating will be compromised because it will not meet its own application criteria for adequate performance.

Welding techniques for galvanized steel include GMA (gas metal arc), carbon arc, GTA (gas tungsten arc), manual metal arc, and torch welding. Galvanized steels are welded easily and satisfactorily by all commonly practiced welding techniques. Closer control of welding conditions than for uncoated steel is usually necessary but procedures are simple and well established.

GMA (gas metal arc) welding, also known as CO_2 or MIG welding, is a versatile semi-automatic welding process which is convenient and easy to use. It is particularly suited to the welding of thinner materials. In the GMA welding of galvanized steel the presence of the zinc coating has no effect on weld properties although some weld spatter is produced. Arc stability is excellent and is not affected by the galvanized coating. Some reduction in welding speed is required.

The GMA welding process

The weld takes place in a protective gas shield. A small diameter consumable wire electrode of 0.8 mm to 1.6 mm is fed automatically to the weld torch. The high current density resulting from the small diameter of the wire is in the region of 200 amperes per square millimetre.

Shielding gas for GMA welding galvanized steel

Galvanized steel is welded satisfactorily using the GMA process and pure carbon dioxide shielding gas that provides excellent weld penetration, but considerable weld spatter. The use of a spatter release compound should be considered for this application.

Alternatively, the more expensive argon/CO_2 or argon/CO_2/ O_2 mixtures provide adequate weld penetration, a superior weld bead, and far less spatter. A 92% Ar/5% CO_2/3% O_2 mixture has been found to provide excellent results on galvanized sheet up to 3.0 mm thickness.

Welding conditions

GMA welding speeds should be lower than on uncoated steel as specified in the weld conditions tables, to allow the galvanized coating to burn off at the front of the weld pool. The reduction in speed is related to the thickness of the coating, the joint type and the welding position, and is generally of the order of 10 to 20 per cent. Fillet welds in steel with thicker galvanized coatings may be welded more readily if the current is increased by 10 amps.

The increased heat input helps to burn away the extra zinc at the front of the weld pool. Penetration of the weld in galvanized steel is less than for uncoated steel so that slightly wider gaps must be provided for butt welds. A slight side-to-side movement of the welding torch helps to achieve consistent penetration when making butt welds in the flat position.

Effect of welding position in GMA welding galvanized steel

To achieve complete penetration in the overhead position on galvanized steel with 600 g/m² coatings, weld current should be increased by 10 amps, and voltage by 1 volt. Welds in the vertical downwards and overhead positions may require a speed reduction of 25 to 30 per cent by comparison with uncoated steel, depending on joint type and coating thickness, to prevent rising zinc vapor from interfering with arc stability. Butt welds in the horizontal-vertical positions require less reduction in speed because the zinc vaporises away from the weld area.

Appearance of GMA welds in galvanized steel

Surface appearance of GMA welds in galvanized steel is satisfactory although a certain amount of weld spatter is generated, regardless of whether CO_2 shielding gas or an argon/CO_2 mixture is used.

Adhesion of weld spatter to the gun nozzle, and to the workpiece with resulting marring can be prevented by application before welding of an aerosol spray petroleum base or silicone base spatter release compound available from welding consumables suppliers. Any adhering spatter particles can then easily be brushed off. Silicone-based compounds may interfere with the application of subsequent coatings.

GMA braze welding

An extension of the GMA process, GMA braze welding utilises a filler metal with a lower melting point than the parent metal. The joint relies neither on capillary action nor on intentional melting of the parent metal. Shielding gases of the argon/oxygen type are the most suitable, the low oxygen

level being sufficient to permit excellent edge wash and a flat weld without causing surface oxidation.

The low heat input minimises damage to the coating on the underside of the parent plate, enables the corrosion resistant bronze filler to cover any of the coating damaged by the arc, and minimises the level of distortion when welding sheet metal components.

Finishing costs of thin tubular or sheet metal components such as automotive panels can therefore be reduced substantially.

Manual metal arc welding galvanized steel
Manual metal arc welding is recommended only for galvanized steel of 1.6 mm thickness or thicker, as difficulies may occur with burning through on light gauges. GMA, GTA, or carbon arc welding are recommended for sheet lighter than 1.6 mm. In general, manual metal arc welding procedure for galvanized steel sheet is the same as for uncoated steel although the following points should be noted:

1 The welding electrode should be applied a little more slowly than usual with a whipping action which moves the electrode forward along the seam in the direction of progression and then back into the molten pool. All volatilisation of the galvanized coating should be complete before bead progress, after which welding is the same as for uncoated steel.

2 A short arc length is recommended for welding in all positions to give better control of the weld pool and to prevent either intermittent excess penetration or undercutting.

3 Slightly wider gaps up to 2.5 mm are required in butt joints in order to give complete penetration.

4 For operator comfort adequate ventilation should be provided and the use of a respirator is recommended in confined space.

5 Grinding of edges prior to welding will reduce fuming from the galvanized coating. Welding schedules will then be the same as for uncoated steel.

6 Repairs to the coating should be carried out.

Electrodes for manual metal arc welding galvanized steel
Electrodes to Australian Standard 1553.1 classifications E4112 and E4113 are recommended as suitable for all positions. In butt and tee-joint welds in the flat and horizontal-vertical positions the E4818 basic coated electrode is highly suitable, giving fast, easy welding, improved bead shape, and easier slag removal.

Both rutile and basic coated iron powder electrodes perform satisfactorily on galvanized steel, giving a good weld profile with freedom from undercutting, and easy slag removal. In butt joints in plate with vee edge preparation, an electrode should be chosen which limits the tendency to produce a peaky or convex deposit run since this can cause slag entrapment which will not be removed by subsequent weld runs.

Physical properties of arc welds in galvanized steel
Extensive tensile, bend, radiographic and fatigue testing at the Welding Institute Cambridge, UK, for International Lead Zinc Research Organisation has shown the properties of sound GMA welds and manual metal arc welds in galvanized steel to be equivalent to those of sound welds in uncoated steel. Test welds were made without removing the galvanized coating from edges to be welded. The presence of any weld porosity due to volatilisation of the galvanized coating during welding has no effect on joint properties except in loss of fatigue strength.

PROPERTIES OF SOUND WELDS IN GALVANIZED STEEL

General properties
When welding conditions are chosen to give sound welds in galvanized steel, the tensile, bend and charpy impact properties are equivalent to those of welds in uncoated steel. Tests showed that the presence of zinc at the levels occurring in the weld metal does not affect tensile, bend or impact properties.

Fracture toughness
Crack opening displacement (COD) measurements and drop weight tests established that fracture toughness properties of welds are unaffected by the presence of galvanized coatings.

Fatigue strength

The fatigue strength of arc welds in galvanized steel is equivalent to welds in uncoated steel. Fatigue tests were carried out on fillet welded cruciform joints made by CO_2 GMA welding with low silicon filler metal of the AWS Classification E60S-3.

PROPERTIES OF WELDS CONTAINING POROSITY

General effects

Porosity will occur in certain weld joint designs in galvanized steel, depending on coating thickness, due to volatilisation of the zinc coating and entrapment of gas in the weld.

The type of joint affects pore formation since gases cannot readily escape from tee joints and lap joints or from butt joints in thick materials. In the case of butt joints, a vee edge preparation or provision of a gap between square edges facilitates the escape of gases, minimising porosity. Pore formation is also influenced by the thickness of the galvanized coating relative to the steel base. Close attention to welding conditions will reduce the extent of porosity but complete elimination is not always possible and it is important to consider the effect of porosity on static strength, fatigue strength and cracking of the weld joint.

Effect of porosity on fatigue strength

The extent of weld porosity is a function of heat input and the solidification rate of the weld metal. Not always possible to eliminate, porosity affects the fatigue strength and cracking tendencies of welds. When welds are subject to fatigue loading, welds on galvanized steel should be made oversized to reduce the influence of any weld metal porosity. When evaluating the effect of porosity on the fatigue strength of a fillet weld, it is necessary to consider both the function of the joint and the weld size. When a fillet weld on galvanized steel is large enough relative to plate thickness to fail by fatigue from the toe of the weld in the same manner as in uncoated steel, the presence of porosity in the weld does not reduce the fatigue strength of the joint. Where the dimensions of the weld are just large enough to cause fatigue failure from the toe in a sound weld, a weld containing porosity at the root may fail preferentially through the throat of the weld.

Cracking

Intergranular cracking of fillet welds containing porosity, sometimes referred to as zinc penetrator cracking, does not significantly affect the strength of non-critical joints. For more critical stressed applications however, it is advisable to carry out procedural tests on material and samples.

GTA brazing galvanized steel

GTA (gas tungsten arc) process, also known as argon arc, provides an excellent heat source for braze welding. In GTA brazing, the weld area is shielded from the atmosphere by a protective flow of inert argon gas. A non-consumable tungsten electrode is employed with a separate 'Cusilman' (96%Cu, 3% Si, 1% Mn) filler wire, as used for carbon arc welding. The argon barrier prevents oxidation of the electrode or the weld pool and welds of excellent appearance result. The process allows continuous welding at very high speeds, particularly with mechanised arrangements.

In the GTA brazing of galvanized steel the arc should be played on the filler wire rather than on the weld area to prevent undue coating damage. The following variations in welding technique are also recommended to minimise contamination of the tungsten electrode by traces of zinc oxide fume:

1 Hold the weld torch at a 70° angle rather than the 80° angle normally used for uncoated steel

2 Increase shielding gas flow from 6 to 12 p/min to flush zinc oxide fume from the electrode area.

Corrosion resistance of GTA brazed joints made in galvanized steel is excellent. During the welding operation the corrosion resistant brazed metal tends to wet and flow out over the small area from which the galvanized coating has been volatilized. GTA welding is recommended only as a heat source for brazing galvanized steel, not as a fusion welding technique. When used for fusion welding the tungsten electrode is fouled rapidly by zinc oxide fume.

Torch welding galvanized steel

Torch welding of galvanized sheet steel either with or without a filler rod is generally carried out on the lighter gauges. Because zinc volatilises at about 900°C while steel melts at about 1500°C, the necessary welding temperature usually results in coating damage and the need for subsequent treatment of damaged areas.

Brazing

Coating damage may be overcome by brazing. Brazing employs much lower temperatures (900°C), producing very little coating damage in the area adjacent to the weld. The weld metal itself is corrosion resistant and tends to wet and cover all bare steel in the weld area so that joints are normally acceptable without further treatment. The suggested filler rod is a copper-zinc-silicon alloy, such as Austral Tobin Bronze (63% Cu, 37% Zn, 0.3% Si, 0.15%Sn). Prior to brazing, the edges of components should be painted for about 6 mm back with a flux such as Comweld Copper and Brass Flux or Liquid Air 130 Flux. The lowest practical heat input is desirable and flame adjustment must be oxidising, as this helps to reduce local loss of zinc in the weld zone.

Butt welds are preferred to lap joints and the gap in such welds should be equal to half the thickness of the sheet.

Cutting galvanized steel

Cutting of galvanized steel is commonly done with oxy-acetylene cutting torches. Thinned galvanized sections may also be cut using abrasive cut-off saws. Each of these processes generates sufficient heat to volatilise the galvanized coating.

Some coating burn-back will occur when oxy-cutting galvanized steel, although this is usually less than 10 mm from the affected area, and dependent on steel thickness.

In both these processes, fume management should be implemented as for welding galvanized steel, and remediation of the cut edges and areas affected by burn-back should also be done. The heat affected area of thinner galvanized sections (under 3 mm thick) cut by abrasive saw is very small, and the cut edges of such thin sections may not require repair because of the cathodic protection of the exposed steel provided by the galvanized coating on the adjacent surfaces.

RECONDITIONING WELD-DAMAGED SURFACES

Weld damage

When damage to the galvanized coating has occurred during welding or when the weld area will be exposed to corrosive service conditions, the damaged area should be repaired. Width of the weld-damaged zone will depend on heat input during welding, being greater with a slow process such as torch welding than with high speed arc welding. In the manual metal arc welding and torch welding of galvanized steel, the weld metal itself will corrode in most atmospheres and the application of a protective coating is essential. Suitable materials for coating the weld metal and adjacent damaged areas of the coating are zinc rich paints, and in some circumstances, zinc metal spraying.

Repair methods

The methods described are in accordance with **Australian/New Zealand Standard 4860:2006 Appendix E 'Renovation of damaged or uncoated areas'**. In the case of weld repairs, surface preparation consists of removal of any welding slag with a chipping hammer followed by vigorous wire brushing.

Welding fumes

All welding processes generate fumes. Hazardous Substances regulations have been introduced in all Australian states and territories. The National Occupational Health and Safety Commission (NOHSC) has set standards for allowable exposure for atmospheric contaminants in the occupational environment (NOHSC: 1003 – 1995).

The Welding technology Institute of Australia (WTIA) has published guidelines for fume minimisation and control.

Zinc volatilizes at welding temperatures to form white zinc oxide, so its presence is easily detected. Various fume extraction options are listed in the WTIA Fume Minimisation Guidelines – Guideline 2.

All materials of construction may contain potentially hazardous components that can be released in the welding process. In addition to zinc coatings such as galvanizing, other coatings in steel including paints, plastics and other metallic coatings can give rise to a wide range of prescribed hazardous compounds.

Good welding practice in keeping with these WH&S industry guidelines will define the operational requirements for welding galvanized steel.

INTRODUCTION

The hot dip galvanizing process was developed in the 18th Century, with the first hot dip galvanized products (galvanized iron sheeting) being imported to Australia in the 1850's.

It was found that molten zinc would react with steel to form a metallurgically bonded protective coating that had superior durability to any other coatings for atmospheric exposure.

While all early hot dip galvanized items were manufactured by dipping them in batches in a molten zinc bath, different technologies have been developed to more efficiently apply zinc-based coatings to continuously manufactured products such as wire, sheet and tube.

The characteristics of the coatings applied by these continuous galvanizing technologies are quite different to those of coatings applied by the traditional batch galvanizing process.

The main difference in the nature of these galvanized coatings is the time that the steel is immersed in the molten zinc alloy. This time is very short (a few seconds) in continuous galvanizing processes – and much longer (typically 4-8 minutes) in the hot dip galvanizing process. The resulting zinc-based coatings produced by these processes are metallurgically quite different in their characteristics and performance.

THE HOT DIP GALVANIZING PROCESS

Steel fabrications or sections are delivered to the galvanizing plant. These items may contain steels of differing chemistry and surface condition and may be coated with preconstruction primers or other applied protective coatings, including continuously applied zinc coatings.

The hot dip galvanized coating is the result of a metallurgical reaction between the steel and the molten zinc, and this reaction will not occur if the steel's surface is contaminated with paint, grease, oil or rust. If any of these surface contaminants are present, the coating will not form and 'misses' will result in the galvanized coating.

For this reason, the pre-treatment of the steel sections or fabrications to remove grease, oil, paint

The hot dip galvanizing process involved immersion of steel fabrications in molten zinc at 455°C until the steel reaches the molten zinc temperature. Oxide residues are formed from the combined reaction between the flux, the steel and the zinc, which are here being skimmed off the surface as the work emerges from the zinc bath.

and rust is critical to the successful application of the galvanized coating.

DEGREASING AND PAINT REMOVAL

The grease, oil and paint is removed by immersing the fabrication in a hot sodium hydroxide (caustic soda) bath. Where steel fabrications have been recycled and have been previously painted with industrial paint coating, abrasive blasting may be required to remove these types of coatings that are resistant to the caustic degreasing process.

ACID PICKLING AND RUST REMOVAL

The steel is then rinsed and pickled in 10% hydrochloric acid to remove mill scale, rust and other surface oxides.

Heavily corroded steel will generally require abrasive blasting to remove heavy rust to prevent processing delays in the pickling process and to avoid over-pickling of the steel sections that may not be heavily corroded in the same fabrication.

PREFLUXING

After pickling, the item is again rinsed and then immersed in a hot zinc ammonium chloride preflux solution. This preflux solution conditions the steel surface to facilitate the reaction between the steel and the molten zinc.

GALVANIZING

The preflux is allowed to dry on the steel's surface and then the fabrication is immersed in the molten zinc (Temperature 455°C). The steel must be heated to about this temperature for the zinc-steel reaction to occur. Heavy sections take longer to heat up, hence their longer residence time in the molten zinc bath.

This zinc-steel reaction produces a crystalline layer of zinc-iron alloy, with the iron content varying from around 10% at the steel surface to 4% at the zinc surface. When the steel is withdrawn from the molten zinc, a thin layer of zinc remains on the surface of the coating, giving hot dip galvanized coatings their shiny appearance. The melting point of zinc is only 35° below the bath temperature and any free zinc on the surface of the work quickly solidifies. An exception can occur with reactive steel. The zinc-steel reaction can continue after the steel fabrication is withdrawn from the molten zinc, and all the 'free' zinc on the surface will be converted to zinc-iron alloy. This is grey in colour and the galvanized coating will thus have a matte silver-grey appearance.

QUENCHING AND PASSIVATION

After the fabrication is withdrawn from the galvanizing bath, it is quenched in a weak sodium dichromate solution. This process quickly cools the item so that it can be handled for unloading from dipping equipment and also applies a low level of chromate passivation to the galvanized coating's surface.

Freshly applied galvanized coatings are susceptible to rapid oxidation (white rusting) if exposed to rain water or condensation, as the zinc takes time (usually 2-3 weeks) to develop its patina of stable oxides that give it its exceptional anti-corrosion performance. The chromate passivation provides temporary protection to the new zinc surface to allow the patina to develop.

Large fabrications such as this spiral staircase can be hot dip galvanized by double-dipping. The first stage of the process is shown here.
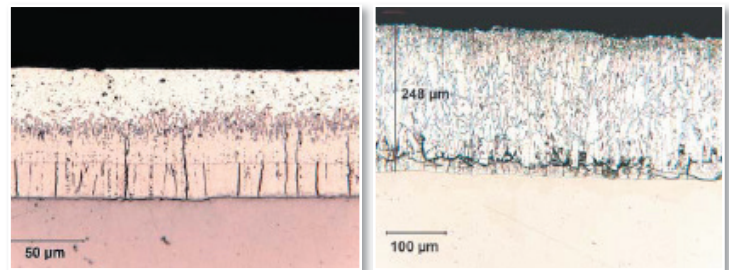
These two micrographs illustrate the effect of steel chemistry on the characteristics of the hot dip galvanized coating. The micrograph on the left shows the appearance of a coating on normal steel, with the alloy layers (the crystalline, darker section of the coating) being coated with a layer of zinc (the lighter area). The micrograph on the right shows the appearance of a coating on reactive steel. This coating is 100% alloy layers and much thicker than the standard coating

Quenching of the items may be deferred or not done at all, if the fabrication is of a design that is likely to distort if cooled quickly.

INSPECTION AND DRESSING

Depending on the design (size, shape, configuration) of the steel section or fabrication, it will be subject to inspection and dressing as the final stage of the galvanizing process. The dressing process may involve removal of drainage spikes and touch-up of areas of coating affected by contact with jigs or lifting chains essential to the handling of the item through the process.

NOTE: This chapter is intended to explain the hot dip galvanizing process. Other important issues in ensuring quality, such as design for galvanizing, are covered in detail in other chapters of this Manual.

Zinc-based coatings are the world's most widely used coatings for the protection of steel from corrosion.

These coatings are applied using differing technologies, giving rise to zinc coatings with differing mechanical and durability characteristics.

As the obvious reason for applying protective coatings to steel is to prevent it from corroding for as long as possible in its service environment, it is important that the characteristics of the coatings produced by these diverse processed be understood with respect to their relative durability.

There are 5 basic application processes, each of which is associated with alternative technologies. Each of these processes are best suited to particular classes of steel product and no one process is suitable for all types of steel coating. They are:

Hot dip processes:
These involve the immersion of pre-treated steel in molten zinc or zinc alloys.

Chemical processes:
These involve the electro-deposition of zinc or zinc alloys from a chemical solution in combination with the application of an electric current.

Applied processes:
These involve the application of zinc in the form of zinc dust as a pigment in a paint coating, or as a momentarily molten metal spray using a hot metal spray gun.

Diffusion processes:
These involve the heating of the steel to below the melting point of zinc while in close contact with zinc dust.

Mechanical processes:
These involve the application of a zinc or zinc alloy coating to the surface of small steel parts by rumbling them in a rotating vessel causing the part-to-part impacts to apply an adherent zinc-based coating to the parts.

Hot dip processes
The greatest percentage of steel that is zinc coated is processed immersing the steel in molten zinc or zinc alloy. There are two fundamental types of hot dipping processes; continuous and batch galvanizing.

Continuous galvanizing processes
Products such as sheet, wire and tube are commonly continuously galvanized by passing the steel sections through the molten metal during the manufacturing process at relatively high speed – up to 180 metres/minute with some products.

Sheet and wire are fed into the galvanizing process from coils and re-coiled after galvanizing. Tube sections are coated externally after forming in straight lengths, or manufactured from steel coil that has previously been galvanized.

This process produces a galvanized coating that has specific characteristics. These are:

a. The coating is relatively thin and usually around 25 microns in thickness.
b. The coating is almost 100% zinc.
c. The alloying of the zinc to the steel is limited by the high speed of the continuous process. This creates a malleable coating that allows the pre-galvanized sections to be roll formed, bent or pressed in subsequent manufacturing operations.
d. The cutting and punching of the sections in manufacture results in all edges being uncoated. The cathodic protection provided by the zinc coating on adjacent surfaces prevents corrosion of these exposed steel areas.

Continuous galvanizing and coating are efficient but have high capital costs. The zinc coating thickness is limited by the high speed of the process

BATCH GALVANIZING PROCESSES

Batch galvanizing involves processing the steel after fabrication. For larger fabricated items, these are suspended from chains, jigs or head frames to transport the fabricated steel items through the hot dip galvanizing process.

For small parts such as nails, screws and bolts, perforated baskets are used to transport the work through the process and centrifuge the excess zinc from the items as they exit the molten zinc.

The items being processes are immersed in the molten zinc for several minutes. This creates a galvanized coating with its own set of unique metallurgical characteristics. These are:

a. The coating largely comprised zinc-iron alloys arising from the longer immersion time in the molten zinc. The presence of this alloy layer results in a thicker coating usually no thinner than 50 microns on thin sections to more than 200 microns on heavy structural sections.
b. Because the steel items are immersed in molten zinc after fabrication, all surfaces and edges are coated.
c. The appearance of a batch galvanized coating is less smooth and uniform than that on a continuous galvanized product.
d. The alloy layers much are harder than pure zinc (approx. 4X). This gives the batch galvanized coating excellent abrasion resistance but lower flexibility that continuously galvanized coatings, making it unsuitable for forming after galvanizing.

CHEMICAL PROCESSES

Zinc electroplating is widely used to coat small parts, appliance components and builders hardware. The process involves passing the cleaned steel parts through a zinc-bearing solution containing other chemicals to assist in leveling or brightening the coating.

While some proprietary processes can apply relatively heavy zinc plated coatings to steel components, the majority of zinc-electroplated products have coating thicknesses less that 10 microns, making them unsuitable for exterior use.

Zinc electroplated coatings are used on a wide range of builders hardware. The relatively thin, pure zinc coating is unsuitable for external applications.

The characteristics of an electroplated zinc coating are:

a. The coating is bright and uniform. Some products such as screws may have a heavy chromate coating, giving them a brown/yellow appearance, to improve their corrosion resistance.
b. The coating is pure zinc and is quite soft.
c. The coating is relatively thin – usually less than 10 microns, and conforms closely to the surface profile of the steel item, making it suitable for use on small threaded components.

APPLIED PROCESSES
Zinc-rich paints

Zinc can be applied to steel surfaces as zinc-rich paint, where either organic or inorganic binders are heavily loaded with zinc dust as a pigment. Silicate binders are commonly used for inorganic zinc-rich paints and epoxies are the most common of the organic binders used in these paints.

A high level of steel surface cleanliness is required for best results with such paints, with those having organic binders more tolerant of lower levels of surface condition that the inorganic systems.

Zinc rich paints are well suited to the coating of large structures and for on-site application to structural steelwork of all types.

Zinc metal spraying

Metal sprayed coating are applied by passing zinc dust or wire through an electric arc or gas flame. This melts the metal and deposits the molten metal on the steel's surface. A very high level (Class 3) of steel surface cleanliness is recommended for metal spray applications. Metal sprayed coating have the following characteristics:

a. The coating consists of flattened droplets of zinc mechanically bonded to the steel surface. Some of the zinc (up to 30%) is converted to zinc oxide during the high temperature application process.

b. Very thick (up to 500 micron) coatings can be applied.

c. The newly applied coating is rough and porous. Sealing of the metal-sprayed coating with a polymer coating is recommended for aggressive environments.

d. Only the external surfaces of fabrications can be readily coated.

e. The zinc dust/wire can be alloyed with other metals such as aluminium to improve corrosion resistance.

f. A metal spray gun can deposit approximately 30 kg of zinc per hour with overspray losses up to 30%, depending on the shape of the fabrication. Typical application rate is around 1 kg/m^2. This is a higher cost process than other zinc coating processes.

g. Low heat transfer to the steel minimises distortion risks on thin steel sections.

DIFFUSION PROCESSES

The process of Sherardizing is a diffusion process, where small parts are tumbled in a zinc/sand mixture at a temperature of around 380°C. It is rarely used today because of its low productivity as processing a batch of parts weighing a few hundred kg may take up to 3 hours, with zinc recovery of around 50%.

Steel roofing is now almost 100% Zincalume (zinc-aluminium alloy) coated, and combined with a proprietary paint coating for added appearance and durability. The zinc-aluminium alloy has excellent corrosion resistance for this application.

It is well suited to small parts and threaded fasteners, as the coating conforms closely to the surface profile. The items are best cleaned by grit blasting prior to coating. The characteristics of a Sherardized coating are:

a. Coatings applied are typically between 15 and 30 microns in thickness.

b. The coating is 100% alloy layer containing no free zinc. It has a matt gray appearance.

c. The coating is metallurgically bonded to the surface.

d. The coating has good abrasion resistance

MECHANICAL PROCESSES

Mechanical plating of zinc and zinc alloys is now widely used for the protective coating of high strength fasteners such as self-drilling TEC screws. Batches of components are cleaned of oxide deposits and organic contamination and loaded into a rotating barrel with a carefully controlled mixture of metal dust and reaction chemicals. The batch is processed for about 20 minutes.

Glass beads are also used to assist in peening the metal particles on to the surface. Because of the autogenous nature of the process, the steel items being mechanically plated need to be manufactured from higher strength steel grades to prevent mechanical deformation during the plating process. Zinc-tin alloys mixtures are commonly used in Australia on roofing fasteners to improve their corrosion resistance.

The process is well suited to automation and large numbers of parts can be mechanically plated efficiently in an automated facility.

The characteristics of a mechanically plated coating are:

a. Applied at room temperature
b. Zinc alloy coatings can be used that are difficult to apply by other methods.
c. The coating conforms closely to the profile of the part.
d. The mechanically plated coatings are relatively thin – usually less than 20 microns.
e. The coating may be thinner on edges and corners due to the mechanical impacts intrinsic to the process.

The characteristic that determined durability of zinc coatings in any given environment is the thickness of the coating. This will be dealt with in detail elsewhere in this manual.

SUMMARY

Australian and international standards have been developed for each of the commonly used zinc-coating processes. These standards define coating thickness with respect to the various product classifications. This can, in turn, be used to determine the appropriate coating for a particular durability or manufacturing requirement.

Mechanical plating peens zinc or zinc alloy particles into the steel surface. It is effective on small fasteners where, particularly self-drilling screw where cutting edges must be maintained.

Hot dip galvanizing after fabrication applies a heavy zinc-based coating to a wide range of manufactured products. The zinc-iron alloy layers in the coating provide it with additional abrasion resistance.

Continuous galvanizing processes have been developed for a large range of smaller hollow sections. Some are galvanized externally only and typical coating thickness is approximately 20 microns.

Unlike most other applied organic coatings used to protect steel, galvanized coatings are zinc-based metallic coatings applied to steel using a variety of technologies.

The performance of these zinc-based coatings when subjected to bushfire depends on a number of factors, not the least of which is the characteristics of the galvanized coating arising from the technology with which it is applied.

Pure zinc has a melting point of about 420°C, this a coating consisting mainly of pure zinc can be expected to start melting once this temperature is reached on the metal surface.

Many galvanized products produced by a continuous galvanizing process (sheet, coil and some tube) have a coating that is largely pure zinc and is typically 15-25 microns in thickness.

Hot dip galvanized coatings, applied by immersing batches of fabricated steel in a bath of molten zinc, are made up of zinc-iron alloy crystals with a thin coating of zinc on the surface. These zinc-iron alloys constitute 80-100% of the coating, depending on steel chemistry and some processing techniques.

These zinc-iron alloys are not only much harder than pure zinc (about 4-5X) but have a much higher melting point of around 650°C.

Typical bushfire conditions may expose steel structures to air temperature of 800°C for periods of up to 120 seconds. Depending on section thickness of the steel, the actual steel surface temperatures do not exceed 350°C for a Level II bushfire event, according to recent tests done on behalf of BlueScope Steel by the CSIRO Manufacturing and Infrastructure Technology Bushfire CRC.

At the temperature of molten zinc (420°C), proof stress of the steel is reduced to 70% of its original value. At a temperature of 650°C, the steel will suffer a significant reduction in proof stress. Unlike most other metals, zinc-based coatings will vaporize at relatively low (about 950°C) temperatures and re-condense as zinc oxide fume below that temperature. This phenomenon is commonly seen when galvanized coatings are flame-cut or welded.

CSIRO Bushfire CRC – Mogo NSW. Sureline galvanized steel poles undergoing Level 2 bushfire testing. This test simulates actual bushfire conditions and flame duration. Galvanized coating unaffected.

CSIRO Bushfire CRC – Mogo NSW. Sureline galvanized steel poles undergoing Level 3 bushfire testing. This test substantially exceeds actual bushfire conditions. Galvanized coating unaffected

In addition, zinc coatings are generally reflective and being metallic, have high emissivity characteristics. For this reason, a galvanized surface will not absorb heat at the same rate as an organically coated or uncoated steel surface.

Another interesting metallurgical phenomenon takes place with galvanized coatings in that if there is any free zinc in the galvanized coating and the steel temperature approaches but does not exceed the melting point of zinc, a `solid state' reaction takes place and the free zinc will be converted into zinc-iron alloy.

In summary, the bushfire flame duration and intensity are not high enough to compromise the structural strength of the steel. The hot dip galvanized coating will thus remain largely unaffected through a bushfire event. This has been verified in the testing of the hot dip galvanized BlueScope Sureline™ hot dip galvanized steel power poles in the CSIRO Bushfire CRC testing done in the Spring of 2005.

Timber poles following grass fire in ACT in 2003 – burnt off at base

Burning timber pole – Canberra fires – 2003.

38. LIQUID METAL ASSISTED CRACKING OF GALVANIZED STRUCTURAL STEEL SECTIONS

INTRODUCTION

In excess of 300,000 tonnes of fabricated steel is hot dip galvanized in Australia annually and approximately 20 million tonnes is galvanized world-wide each year.(Note: This tonnage does not include continuously galvanized sheet, wire and tube). A significant proportion of this tonnage is structural sections.

In a very small number of instances in Europe, Asia and the USA, a phenomenon called liquid metal assisted cracking (LMAC) has occurred in the webs of larger structural beams. This phenomenon is also called cope cracking, as it arises in the coped sections of the beam webs.

There have been no recorded instances of LMAC occurring in universal structural sections in Australia. However, the potential for the development of cracks on what is a critical zone of these structural sections is an issue that needs to de defined in the interests of designers intending to use hot dip galvanized coatings for long-term protection of the structural sections used in their construction projects.

INDUSTRY RESEARCH

The infrequency of LMAC events and the somewhat unpredictable nature of the phenomenon have prevented conclusive research to be undertaken by interested industry oranisations. However, a significant amount of research has been done or is underway. The Galvanisers Association (GA) and the British Construction Steelwork Association (BCSA) in the UK, as well as the International Lead Zinc Organization (ILZRO) and the American Galvanizers Association (AGA) and other international industry groups in Germany and Japan are involved in ongoing research and investigation into LMAC phenomena.

WHAT IS A COPE?

The illustration below shows a cope detail on a universal beam. Copes are oxy cut, usually in two operations. The first cut removed the top flange and a section of the web. The second operation cuts the cope radius and removes the remaining section of the web.

While LMAC in structural sections has generally been identified with copes, cracking may also arise where excessive stress has been induced in the steel through welding, oxy cutting or the punching of holes.

cope

Coped universal beam

STEEL SUSCEPTABILITY

From research and case studies done to date, it has been recognised that there is a range of factors that can influence the initiation of LMAC, and there is a degree of synergy between some of the factors that may contribute to the phenomenon jointly, rather than individually.

Factors that have been identified as important as prerequisite for LMAC to occur are:
- the initial stress level of the steel
- steel chemistry
- steel section factors

The factors causing embrittlement of steel in the hot dip galvanizing process are well defined and understood. The most commonly encountered embrittlement problems associated with galvanizing are hydrogen embrittlement and strain-age embrittlement. The former arises with high strength steels (over 800 MPa) where they are acid pickled, allowing hydrogen to penetrate into the grain boundaries. This is independent of the galvanizing process itself, and will occur with any high strength steels that are pickled in acid in electroplating and other coating processes.

38. LIQUID METAL ASSISTED CRACKING OF GALVANIZED STRUCTURAL STEEL SECTIONS

Strain-ageing embrittlement arises where steel of lower strength are severely cold-worked by bending or punching. The severely cold-worked steel 'ages' to a brittle state over time. The heat of the galvanizing process, or any other processes that heat the strained area such as welding, will accelerate the onset of embrittlement.

Liquid metal embrittlement is a less common cause of embrittlement that does not affect structural steels, and it should not be confused with LMAC. Stainless steels are particularly susceptible to liquid metal embrittlement in molten zinc, and the use of stainless steel elements in mild steel assemblies that are to be hot dip galvanized is not recommended.

FACTORS IN LMAC

In an ILZRO funded project (MTL 97-18) undertaken by the CANMET Materials technology laboratory found that steels below 415 MPa have a very low susceptibility to LMC. Where steels are oxy cut in the cope areas, usually requiring two operations as described above, considerable thermal stress can be induced in the heat affected zone (HAZ).

A significant level of micro-cracking can occur on the HAZ of higher strength steels and these micro-cracks are the precursors of more significant cracking when further thermal stresses are induced in the hot dip galvanizing process, where the steel is raised from ambient temperate to 455°C in a very short time.

The form of the section is a factor here. The flange/web connection is a relatively heavy cross section and in many cases, the web/flange thickness ratio is less that 1:1. This results in differential heating at each end of the cope that may further increase the stress in this critical area while the section is immersed in the molten zinc.

Steel chemistry factors have also been identified as a contributor to LMAC susceptibility. Residual elements such as copper and tin and to a lesser extent, nickel and chrome, are known contributors to hot shortness in steel as they can come out of solution in the iron and migrate to the grain boundaries when the steel is heated to elevated temperatures of over 1000°C. The presence of these residual elements in steel are known to

Crack propagated from the corner of this angle frame after galvanizing is suspected of arising from liquid metal assisted cracking.

These large galvanized beams, galvanized in Malaysia, have all been affected by 'cope cracking' in the circular (coped) area of the beam webs. Steel sourced from electric furnace sources is more prone to this form of liquid metal assisted cracking that steel sourced from blast furnaces. This phenomenon has never been reported in Australia as all the locally produced structural sections are manufactured from blast furnace sources.

contribute to micro-cracking when the steel is heated to temperatures typically encountered when oxy-cutting.

Anecdotal evidence supports this. These residual elements commonly report in steel that is manufactures from scrap via the electric furnace process. Steel produced via the blast furnace route, using largely natural raw materials, have lower levels of these residual elements.

All steel structural sections (universal columns and beams) manufactured in Australia are produced via the blast furnace steelmaking process and there have been no reported incidents of LMAC with any

of this material. Australia is unique in this respect as many other steel producing countries do not have the manufacturing processes for their steel sections so clearly delineated.

One known incident has been reported to Industrial Galvanizers of what appears to be an LMAC event on a light (100x100x10 mm) angle frame that had cracks propagating from the HAZ adjacent to the welds. All of these smaller merchant sections are produced from scrap-fed electric furnaces.

AVOIDING LMAC IN STRUCTURAL FABRICATIONS

The British Construction Steelwork Association has published a technical note, authored by its Technical Manager, David Moore, containing recommendations to minimise the risk of LMAC in galvanized structural sections.

These include:

- attention to design and detailing
- type and quality of steel specified
- fabrication techniques
- the galvanizing process and post-treatment and inspection.

If LMAC is identified in a structural section after galvanizing, procedures are available to remediate the affected area by gouging out the cracked area, re-welding and repairing the coating in the weld zone.

SUMMARY

The rarity of LMAC occurring with Australian steels is an indication that the hot dip galvanizing of structural sections can be confidently undertaken. However, 35% of steel used by Australian fabricators and manufacturers is now imported, and the factors likely to initiate LMAC should be kept in mind when designing structures that are likely to be fabricated from steel structural section from sources other than Australian steelmakers.

39. GALVANIZING 500N GRADE REINFORCING BAR - TECHNICAL CONSIDERATIONS FOR DESIGNERS

INTRODUCTION

In the 1980's in Australia, new technology for manufacturing high strength steel reinforcing bar (rebar) was introduced that enabled the production of 410 MPa strength bar using a quenching and tempering process or alternatively micro-alloying of the steel. This grade of rebar was identified as 410Y Grade.

This technology replaced the cold-work processes that were previously used by the industry to obtain higher tensile levels for rebar. This cold-worked bar presented a barrier to hot dip galvanizing because of the high stresses involved in the cold working and subsequent bending to schedule.

This type of bar, identified as 410C Grade, was susceptible to embrittlement and required costly heat treatment after hot dip galvanizing to avoid the risk of brittle fracture in service.

On its introduction, 410Y Grade rebar was subjected to extensive testing to validate its suitability for hot dip galvanizing without requiring any special post-treatment. The satisfactory results from this test program resulted in the galvanized rebar option being incorporated into the standards, codes and practice notes that have been used as reference documents for the reinforced concrete industry since the mid-1980's.

In the early 2000's, Australian rebar manufactures modified their processes to increase the tensile rating of standard grades of high-tensile rebar to nominally 500 MPa, with the grade designation of 500N. Some of the processing recommendations for hot dip galvanizing 500N Grade rebar appear to have been transposed from the 410Y Grade data.

In 2006, a number of inquiries were received from consultants requesting technical support information related to the hot dip galvanizing of 500N Grade rebar.

A literature search indicated that there had been no specific comprehensive test information published by the industry. It should be noted that no problems had been encountered with the galvanizing of 500N Grade rebar, where the processing procedures in accordance to AS/NZS 3600 standards had been implemented.
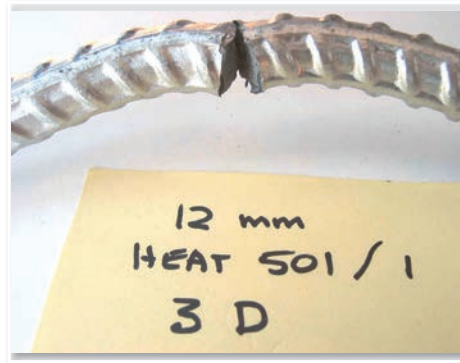
Micro-alloyed 12 mm 500n Grade reinforcing bar failed rebend testing around 3D radius

All 500N Grade 32mm reinforcing bar passed the bend test if bent after galvanizing and AS 3600 specifications for bend radii were adhered to.

500N Grade reinforcing bar presents no problems if galvanized after bending if AS3600 standards are complied with in the processing

However, to validate the performance criteria for the galvanizing of 500N Grade rebar, a research project proposal was put to the International Zinc Association (IZA), through Nyrstar, one of its member companies, to fund this project.

39. GALVANIZING 500N GRADE REINFORCING BAR - TECHNICAL CONSIDERATIONS FOR DESIGNERS

PROJECT PARTICIPANTS

The project participants included OneSteel Pty Ltd, major manufacturer of 500N Grade rebar, Nyrstar Pty Ltd, Australian zinc producer and IZA member, Industrial Galvanizers Corporation (hot dip galvanizer) and Mount Townsend Solutions Pty Ltd, metallurgical consultancy.

PROJECT DEVELOPMENT

Initial tests were done on standard uncoated lengths of 500N Grade rebar to determine the typical actual yield strength compared to the nominal 500 MPa specified for the grade. These tests were undertaken by Amdel Laboratories. Two sets of three samples each of 24 mm bar, from two separate heats were supplied by OneSteel. One set of samples from each heat was galvanized by Industrial Galvanizers (Newcastle) to evaluate the effect of hot dip galvanizing on the mechanical properties of the 500N Grade rebar, before and after galvanizing.

This series of tests showed that the actual yield stress was approximately 600 MPa, with that of the galvanized samples being slightly higher than that of the as-rolled samples (average 605 MPa versus 592 MPa or 2.2%). The galvanized samples had higher elongation than the as-rolled samples (10.8% versus 10.15%).

For practical purposes, these preliminary tests indicated that the hot dip galvanizing process had no significant effect on the mechanical properties of the 500N Grade rebar.

TYPICAL STEEL CHEMISTRY

The specification for cast analysis given in AS/NZS 4671 for this product is as follows (% max);

C - 0.22
P - 0.050
Si - 0.050
Ceq* - 0.44

* Carbon equivalent

Note: Carbon Equivalent $Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$

The typical chemical composition (in % by mass) of the OneSteel TEMPCORE product is as follows;

C - 0.20
P - 0.013
Mn - 0.80
Si - 0.20
S - 0.020
Ni - 0.06
Cr - 0.10
Mo - 0.02
Cu - 0.20

For OneSteel micro-alloyed bar, the typical composition is;

C - 0.15
P - 0.013
Mn - 1.16
Si - 0.27
S - 0.020
Ni - 0.06
Cr - 0.10
Mo - 0.03
Cu - 0.21
V - 0.073

TESTING STRATEGY

A test program was developed to evaluate the performance of hot dip galvanized rebar that was galvanized before and after bending, and to test sections that were bent in contravention of the existing recommended minimum bend radii recommendations, in addition to sections bent in accordance to the AS 3600 requirements.

The decision to test rebar bent to tighter than recommended radii was made to better define likely failure end-points and to recognise that some manufacturers providing fabricated elements containing 500N Grade rebar frequently exceeded the bend radii limitations in contravention of rebar manufacturers recommendations. (e.g. rebar welded to protection angles and other fabricated structures embedded in concrete)

The technical information published by OneSteel for its Grade 500PLUS rebar with respect to AS 4671 and AS 3600 bending limits is as follows:

Table 1 – Bending Properties

Diameter	AS4671 requirements	AS3600 Limits	TEMPCORE 500PLUS Capability	Micro-alloyed 500PLUS capability	Galvanized Bars*
≤ 16 mm	Not stated	5d generally but 4d for fitments	2d x 180 deg.	3d x 180 deg.	5d x 180 deg.
≥ 20 mm	4d x 180 deg.	5d generally but 4d for fitments	3d x 180 deg.	Not produced	8d x 180 deg

* Bending limits shown in this table have been specified in AS3600 to minimise spalling of the galvanized coating.

Table 2 – Re-bending properties.

Diameter	AS4671 requirements	TEMPCORE 500Plus Capability	Micro-alloyed 500Plus capability	AS3600 Limits
≤ 16 mm	4d	4d	4d	4d
20 ≥ d ≤ 24 mm	Not specified	5d		5d
28 ≥ d ≤ 36 mm	Not specified	6d		6d

The manufacturer's literature also states:

Rebending bars that have been bent prior to galvanizing.

This operation is currently not recommended, as cracking on the inside of the original bend may result. If it must be performed, careful checking for cracking should be carried out, and the largest diameter possible used for the initial bend but, in any case, not less than 5d for bars up to 20 mm diameter and 8d for larger diameter bars.

TEST RESULTS

A test program involving 176 samples from various steel heat numbers selected at random in 12 mm, 24 mm and 36 mm diameters was developed to include bend diameters from 1d to 8 d, bent both before and after galvanizing.

Each sample was individually ID tagged to ensure its identity was retained throughout the test program.

The test program included hardness testing samples of each section across the bend zone after bending to determine the degree of work hardening arising due to the cold working of the steel.

The samples were galvanized at Industrial Galvanizers (Newcastle) plant in accordance with AS/NZS 4680 hot dip galvanizing procedures.

Amdel Laboratories undertook the bending and hardness testing of the samples in accordance with the test schedule.

Any visible cracking of the rebar was deemed to be a failure and is reported as such in the test tables.

One bar was taken from each heat number/size and hardness tested across the bend by sectioning the bar and measuring the Rockwell B harness at the centre and the edge of the bar to determine the degree of hardening to which the sections are subjected during cold bending.

An approximate conversion relating hardness to tensile strength has been applied to the test results, based on hardness conversion tables provided by OneSteel. Unless otherwise marked, all bends were 90o. Samples bent through 1800 are identified in the tables.

A series of samples from two heats of 12 mm micro alloyed rebar failed the 3D rebend tests after being pre-galvanized (Test sheets N5033/6A and N5033/8A). A similar set of samples galvanized after the initial bend passed the 3D rebend tests (Test sheets N5033/5A and N5033/7A).Given that these results were contrary to expectations, a set of re-tests on micro alloyed rebar was undertaken, using 16 mm material. (12 mm micro alloyed bar samples were not available in a timely manner to complete the test program)

The pre-galvanized samples passed both the 3D and 5D rebend tests. However, the samples galvanized after the initial bend all failed the 3D and 5D rebend tests. This reflects the recommendations made in the OneSteel 500 Plus Rebar bending properties documentation.

SUMMARY

These tests to evaluate the limitations related to the hot dip galvanizing of 500N Grade steel reinforcing bar have supported the manufacturers' recommendations related to the processing of 500N Grade steel reinforcing bar, both prior to and after hot dip galvanizing.

These results also support the recommendations of the relevant concrete codes; specifically **AS 3600 -2009 Concrete Structures and Concrete Institute of Australia's Current Practice Note Number 17 - 2002: The Use of Galvanized Reinforcement in Concrete.**

It should be noted that bending reinforcing bar outside these guidelines either before or after galvanizing is not recommended.

It should also be noted that cold bending of 500N Grade reinforcing bar results in a significant increase in hardness in the cold-worked area. Re-bending practices should comply with manufacturers' recommendations to prevent the risk of strain age embrittlement of excessively cold-worked 500N Grade rebar.

INTRODUCTION
The major component in hot dip galvanized coatings is zinc. Zinc-based coatings in one form or another, have been used to protect steel from corrosion for more than 150 years. As a result, a great deal of performance data has been accumulated on the performance of zinc-based coatings in a wised range of environments.

The vast majority of galvanized products are used in atmospheric exposures, and in this environment, it is possible to accurately predict the life of a galvanized coating, given that its original coating thickness is know and the environment in which it is exposed is correctly classified.

Unlike most other protective coating systems that fail by other mechanisms, galvanized coatings always fail from the outside, in. This occurs through weathering of the zinc's surface through a range of oxidation reactions that are determined by the variables of the local environment.

ZINC CORROSION MECHANISMS
In the hierarchy of metals, zinc is relatively reactive, but like aluminium, relies on oxide films that develop on its surface to provide its superior corrosion resistance in atmospheric environments. Zinc is also an amphoteric metal, in that it reacts with both acids and alkalis.

This means that zinc works best as a protective coating in pH conditions that are in and around the neutral range of pH 7.
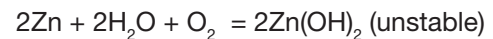
When steel is freshly galvanized, the zinc coating has not developed any protective oxidation films. Many manufacturing processes, such as hot dip galvanizing, apply a passivation film (usually sodium dichromate based) to the zinc's surface to provide protection from accelerated corrosion in the youth period of the coating.

The type of oxide film formed on the surface will depend on the exposure location and condition. In normal atmospheric exposures, the main reactions are as follows:
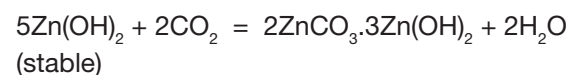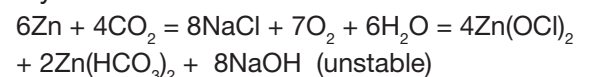
1. Initial oxidation
$$2Zn + O_2 = 2ZnO \text{ (unstable)}$$
2. Hydration
$$2Zn + 2H_2O + O_2 = 2Zn(OH)_2 \text{ (unstable)}$$
3. Carbonation
$$5Zn(OH)_2 + 2CO_2 = 2ZnCO_3.3Zn(OH)_2 + 2H_2O \text{ (stable)}$$
4. In salty air
$$6Zn + 4CO_2 = 8NaCl + 7O_2 + 6H_2O = 4Zn(OCl)_2 + 2Zn(HCO_3)_2 + 8NaOH \text{ (unstable)}$$
5. Industrial atmospheres
$$Zn + O_2 + SO_2 = ZnSO_4 \text{ (unstable)}$$
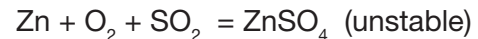
For these reactions to proceed, moisture must be present. If the surface remains dry, very little oxidation will occur. Thus, the time of wetness of the surface is an important factor in the determination of zinc coating life.

White rust on newly galvanized guard rail section caused by nesting items in wet conditions.

These old (l) and new (r) fence panels show the life cycle of a galvanized coating. Galvanized coatings are slowly eroded by oxidation of the surface. The oxidised lower layers of the zinc-iron alloy layer of the galvanized coating indicate that the coating is nearing the end of its life.

For the carbonation phase of the oxidation to occur, good air circulation is necessary to provide a source of carbon dioxide.

Very rapid corrosion of zinc coatings can occur in their 'youth' period if they are stored in poorly ventilated, damp conditions. The oxidation reaction proceeds to the hydration stage (Point 2 above), and will continue while moisture is present. Nested galvanized products are particularly prone to this form of accelerated corrosion, which is commonly called white rust or white storage stain.
The stable carbonate film, formed on the zinc's surface are relatively thin – usually only a few microns in thickness. Any action that removes these oxide films by abrasion or erosion will accelerate the consumption of the underlying zinc, as more zinc is consumed in the re-formation of the oxide films.

While sulfates arising from industrial activities can significantly increase the corrosion rate of zinc coatings, the stringent controls on sulfur-based emissions from industry has reduced the levels of sulfur oxides in the atmosphere by more than 90% since the 1970's.

The main drivers of corrosion of zinc coatings are the time the coating is wet and the presence of chlorides. Much of Australia's urban areas are in maritime environments, influenced to a greater of lesser degree by airborne chlorides generated from ocean surf.

There is a large body of data on the performance of zinc in contact with chemicals of all types. The large number of chemicals contained in this data makes it impractical to reproduce the information in the INGAL Specifiers Manual.

Should you require information about the performance of zinc (galvanized) coatings in contact with any specific chemical, contact the local IG branch.

Severe marine environments such as this ocean front site may have zinc corrosion rates of around 20 microns or more per year. In this environment, the galvanized coating on the guardrail has a predicted life of 3-5 years.

CORROSION RATES OF ZINC COATINGS

While galvanized coatings are frequently specified in terms of coating mass (grams per square metre), in practice, coating thickness is used as a measure of the coating's compliance with standards, as it can be readily measures non-destructively.

If galvanized coatings are exposed to a particular environment, they will corrode at an approximately linear rate over time. One this corrosion rate is established, the expected life of the coating can be calculated with a high degree of confidence.

For example, a typical hot dip galvanized coating on a structural steel section is in the order of 100 microns in thickness. The corrosion rate zinc in the Western Suburbs of Sydney is typically 1-2 microns per year. On that basis, the 100 micron coating in that area should have a maintenance-free life of 50-75 years.

There are a number of Australian Standards either published or in draft form that contain information on the classification of the corrosivity of atmospheres. These include AS/NZS 2312 and AS/NZS 2699.

Unfortunately, the corrosivity classification system in the existing Australian Standards is inconsistent. For example, AS/NZS 2312 uses an A,B,C,D, E & F category classification which is largely narrative and somewhat subjective.

Corrosions rates of zinc coatings
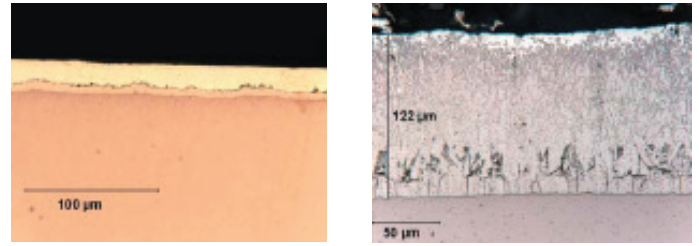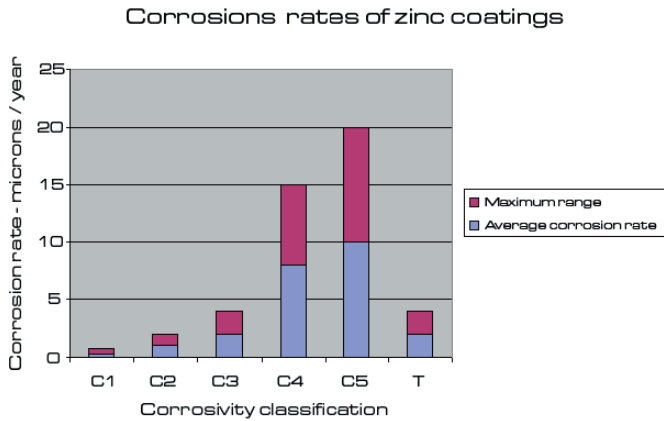
These two micrographs illustrate the difference between a continuously galvanized coating (l) and a hot dip galvanized coating (r) The continuously galvanized coating is almost 100% zinc while the hot dip galvanized coating, as well as being significantly thicker (122 microns versus 20 microns) is almost 100% zinc-iron alloy.

AS/NZS 2699, on the other hand, uses an R0, R1, R2, R3, R4 and R5 rating criteria that is based on airborne salt (chloride) deposition.

The draft standard – AS 4312 Corrosivity zones in Australia, uses a C1,C2, C3, C4 and C5 rating system that is consistent with the system used in International (ISO) standards, specifically ISO 9223.

The corrosivity classifications in each of these standards are essentially guidelines. Industrial Galvanizers INGAL Corrosion Mapping System has been developed in partnership with CSIRO to better estimate the corrosivity of atmospheres throughout Australia. Details of this service are provided elsewhere in the INGAL Specifiers Manual.

The corrosivity classifications in the above charts are detailed below in condensed form.

C1   Very low – internal and sheltered locations remote from marine influence
C2   Low – Rural areas, inland towns and cities
C3   Medium – Most coastal urban areas more than one kilometer from the ocean surf
C4   High - Within one kilometer of ocean surf, depending on prevailing wind direction and topography
C5   Very high – Ocean front locations subject to ocean surf aerosols
CX   Tropical – Northern Australian regions subject to monsoon seasonal conditions

For any corrosivity categories of C3 or below, galvanized coatings will provide whole-of-life protection for steel against corrosion.

OTHER FACTORS AFFECTING COATING LIFE

Hot dip galvanized coatings versus zinc.
Hot dip galvanized coatings are not technically zinc coatings, but are largely made up of zinc-iron alloys that usually comprise between 50% to 100% of the coating. The thicker the galvanized coating, the closer the percentage of zinc-iron alloys approached 100%.

The corrosion characteristics of the zinc-iron alloy layer has not been investigated to the extent of pure zinc coatings. However, research undertaken by CSIRO and observations of hot dip galvanized items in service indicate that the corrosions rate of the alloy layers is significantly lower that that of pure zinc. At a marine test site at Point Fairy, Victoria, hot dip galvanized coatings have been found to corrode at less than half the rate of zinc coatings exposed at the same site.

The shape of the steel structure
The shape and orientation of a structure can have a significant influence on the durability of the galvanized coating. The time the structure remains wet, and its ability to collect corrodents on its surface will affect the durability of the galvanized coating.

For example, standard high voltage lattice towers constructed from steel angles bolted together are always hot dip galvanized. The galvanized coating on these structures has a much shorter service life that an identical thickness coating used on steel monopole structures in the same environments.

This is because the monopoles have smooth vertical surfaces with no overlapping joints or flat surfaces. They dry quickly and do not accumulate contaminants.

SUMMARY
The thickness of a galvanized coating is the factor that determines its durability. Once the environmental conditions have been identified, it is a simple task to calculate the expected life of a galvanized coating of known thickness with a high degree of confidence.
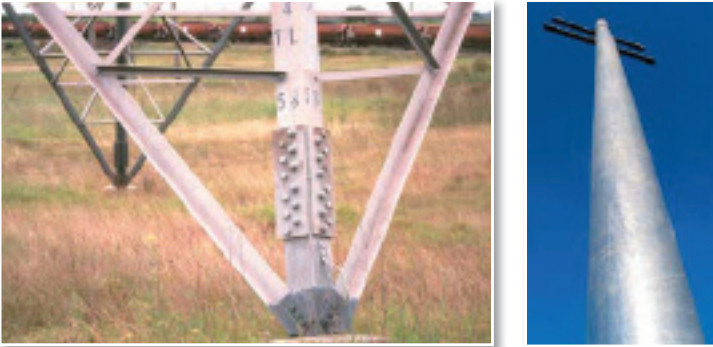
The shape of a structure will have a significant impact on durability of the galvanized coating. The lattice tower has many overlap[ping joints and horizontal or upward facing surfaces. The galvanized monopole's surface is smooth and vertical. The galvanized coating on the pole will have at least 2X the life of that on the lattice tower.
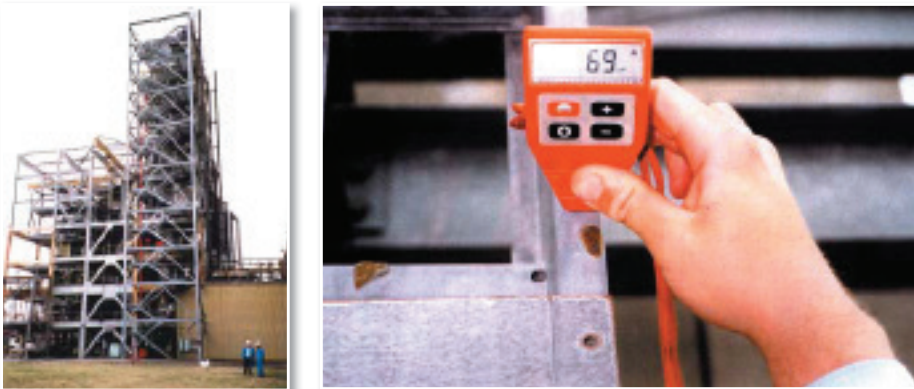
The Orica petrochemical plant at Port Botany, Sydney was galvanized in 1977. Thickness testing of the galvanized coating after 25 years indicated that the coating has a remaining service life exceeding 30years, with nearly 70 microns of coating remaining of the original 100 microns.

INTRODUCTION

While the vast majority of hot dip galvanizing is used to protect steel from atmospheric corrosion, there are always particular applications where hot dip galvanized coatings will come in contact with chemicals, food products or minerals in the course of their transport and storage. While there is an enormous number of possibilities, this chapter of the Specifiers Manual reviews the effects of contact with the more commonly encountered bulk materials on zinc (galvanized) coating.

Table 1 is a corrosivity classification based on annual rate of coating loss that is used in Table 2 as the material's corrosion rating. Table 2 lists the type of chemical, its form (solid, liquid, vapour) and its concentration and its corrosion rating on zinc based on annual estimated coating loss. It should be noted that this corrosivity classification has been arbitrarily allocated to chemicals and materials in contact with galvanized steel, as a method of classifying their corrosivity with respect to each other, and is not related to the corrosivity classifications of atmospheres, that is covered in detail in Australian Standards AS/NZS 2312 and AS 4312.

Table 1

Annual rate of coating loss - Microns	Corrosivity classification
<2	Very low
<2-5	Low
5-10	Moderate
10-25	High
>25 -100	Severe
>100	Extreme

Most commercial minerals are not particularly corrosive to zinc coatings. However, some like manganese dioxide produced in this plant will permanently stain zinc coatings.

CHEMICALS – INORGANIC AND ORGANIC
Table 2

Material	Concentration	Phase	Corrosivity classification
Acetic acid	6%	Solution	Severe
	0.1 g/l in air	Vapour	Severe
Acetone	100%	Liquid	Very low
Ammonium sulfate (fertilizer)	100%	Solid	Severe
Superphosphate (fertiliser)	100%	Solid	Very low
Agricultural lime	100%	Solid	Very low
Nitrate-based fertilisers	95% (5% moisture)	Granulated solid	Severe
Urea	100%	Damp solid	Moderate
Aluminium chloride	25%	Solution	Extreme
Anhydrous ammonia	100%	Liquid	Low
Ammonium chloride	10%	Solution	Severe
Ammonium sulfate	10%	Solution	Severe
Gypsum plaster	100%	Dry	Moderate
Plaster of Paris	100%	Damp	Low
Cement	100%	Damp	Very low
Clay	100%	Solid	Very low
Quartz sand	100%	Solid	Zero
Red brick	100%	Solid	Zero
Portland Cement sand mortar	100%	Solid	Moderate

Calcium chloride (Detergent)	20%	Solution	High
Citric acid	2%	Solution	Extreme
Sodium carbonate (Detergent)	2%	Solution	Severe
Sodium-based detergents	0.5%	Solution	Severe
Commercial soaps and syndets (no phosphates)	0.2-0.5%	Solution	High
Commercial soaps and syndets (no phosphates)	0.2-0.5%	Solution	Extreme
Ethanol	100%	Solution	Low
Ethylene glycol	50%	Solution	Moderate
Formaldehyde	0.1g/l in air	Vapour	Moderate
Gasoline	100%	Liquid	Low
Glycerin	100%	Liquid	Very low
Magnesium chloride	1.2%	Solution	Severe
Methanol	100%	Liquid	Very low
Methyl ethyl ketone	100%	Liquid	Very low
Naphtha	100%	Liquid	Severe
Fuel oil/crude oil	100%	Liquid	Very low
Phenol	100%	Solid	Low
Potassium chloride	Any concentration	Solution	Extreme
Potassium dichromate	15%	Solution	Low
Potassium fluoride	5%	Solution	Very low
Potassium nitrate	0.5-10%	Solution	Moderate
Sodium carbonate	0.5%	Solution	Severe
Sodium chloride	3%	Solution	Extreme
Sodium hydroxide	0.5%	Solution	Severe
Trichloroethylene	100%	Liquid	Extreme
Non-acidic organic chemicals – Alcohols, aldehydes, Aryls, polyethylene glycols, esters, Ethers, Plasticisers, glycol ethers, ketones, monomers, acrylics, vinyl esters, alkyl amines, nitriles etc.	100%	Liquids	Very low

OTHER MATERIALS

Galvanized steel comes in contact with a wide range of bulk materials, including grains, fruit and other farm produce, as well as minerals such as coal, iron ore and many commercial minerals.

Galvanized coatings have been widely used in the coal industry for both coal handling and treatment. The corrosivity of coal with respect to galvanized coatings is generally very low, although there is an exception where ex-mine high sulfur coal is stored in bulk and is subject to rainwater leaching through the coal stacks. This can give rise to low pH run-off ground water that can be aggressively corrosive to both zinc and steel.

Because all grains need to be dry for transport and storage, hot dip galvanized coatings perform well for this purpose. The relatively hard and abrasion resistant hot dip galvanized coating also provided an additional performance benefit in for grain handling.

These galvanized conveyor stringers have been largely unaffected after being covered in coal spillage for over 10nyears at North Goonyella.

The use of galvanized steel for the bulk handling of some fruit and products such as sugar cane has some limitations, as because of the acidic nature of the juices associated with the fruit. This may reduce the service life of the galvanized coating where liquid fruit residues can accumulate on the galvanized surfaces.

Iron ore itself is relatively benign in contact with galvanized steel. Studies of structures used in WA's Pilbara iron ore operations indicate that corrosion rates of galvanized steel in contact with iron or are very low.

The performance of galvanized coatings with other ores and commercial minerals will depend on the specific nature of the material in general, and its moisture content in particular. Many sulfide ores that are produced by floatation processes (copper, lead, zinc…) may also contain chemical residues from the floatation process that can impact on the durability of the galvanized coatings with which they come in contact

SUMMARY

In general, galvanized coatings will perform well in contact with most petroleum-based products and minerals such as coal and iron ore. Most organic chemicals, with the exception of organic acids and a few specialised products, are benign to galvanized coatings, while the majority of inorganic chemicals are corrosive to zinc and galvanized coatings.

Fertilisers and detergents tend to be corrosive to zinc, although there are some exceptions as shown in Table 2. Building materials such as cement and mortar, and plaster, particularly gypsum plaster, can be corrosive to zinc while damp (during curing) but are benign once dry or cured.

The majority of information in the chapter has been derived from "Zinc: Its corrosion resistance", by C.J.Sundler and W.K Boyd, published by the International Lead Zinc Research Organization Inc, New York, 1986.

A further useful reference is "Corrosion Resistance of Zinc and Zinc Alloys" by Frank C Porter published by Marcel Decker Inc, New York, for the International Lead Zinc Research Organization Inc, North Carolina, 1996.

Galvanized coatings perform well in contact with petroleum products such as diesel fuel.

File name; Fertiliser Blockline: Most fertilisers are aggressive to zinc coatings and with few exceptions, may cause rapid corrosion of galvanized coatings, particularly when damp.
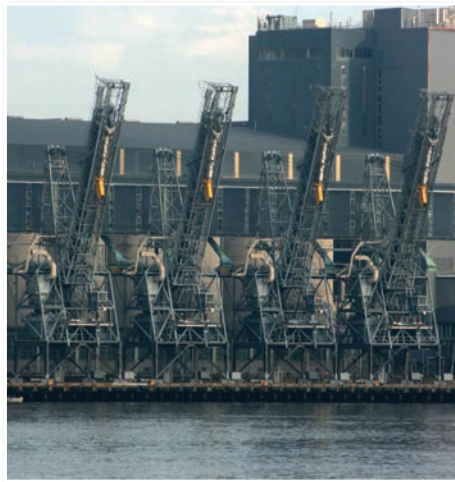
Galvanized coatings work well in storage and handling of dry grains, but not with other horticultural products such as fruit with acidic juice.

Galvanized coatings work well in storage and handling of dry grains, but not with other horticultural products such as fruit with acidic juice.

INTRODUCTION

The durability of all materials is governed by the environment to which they are exposed. The effect of atmospheric exposure is by far the dominant factor affecting the durability of materials of construction, including steel itself and the coatings used to protect it from corrosion.

There has been a long-standing interest in the performance of materials in general and in steel in particular in atmospheric exposures and there have been a number of methods developed to classify atmospheric corrosivity throughout the industrial world.

Through the various national and international standards organisations or their affiliates, standards have been developed that provide a structure to allow atmospheric corrosivity to be assessed. While these standards contain methods or recommendations for classification of the corrosivity of atmospheres, there is little consistency in the methodology.

Some Standards such as AS/NZS 2312 Guide to the protection of iron and steel from atmospheric corrosion have narrative descriptions of atmosphere corrosivity classification, other use more scientific classification parameters such as chloride deposition rates or quantified measurement of other pollutants that are factors on the corrosion of metals.

In addition, the terminology used to classify atmospheric corrosivity varies between standards. AS/NZS 2312 uses an A,B…E rating for classification, while AS/NZS 2699 Built-in components or masonry construction, uses an R0..R5 rating system. The ISO (International) Standards use a C1-C5 rating system.

It is Standards Australia policy to harmonise all its standards to ISO, and for that reason, new standards that have been recently publish will adopt the ISO system of atmospheric corrosivity classifications with some modification to accommodate environments (e.g. tropical) that are not included the ISO classifications.

AS 4312:2008 ATMOSPHERIC CORROSIVITY ZONES IN AUSTRALIA

The deficiencies of the existing documents were recognised by Standards Australia, and this has resulted in the development of a new standard that has been published in 2008. It is AS 4312:2008 Atmospheric corrosivity zones in Australia.

This new standard should override any previously published standards with respect to atmospheric corrosivity classification.

AS 4312 deals with macro-climatic factors affecting corrosivity and also deals in with micro-climatic factors and the influence of design on durability in the context of atmospheric exposure.

The corrosivity categories are based on those used in ISO 9223 and are classified as follows:

ISO 9223 category	Corrosivity rating	Steel corrosion rate – Microns/year	Typical environment
C1	Very low	<1.3	Dry indoors
C2	Low	1.3 - 25	Arid/urban inland
C3	Medium	25 - 50	Coastal/industrial
C4	High	50 - 80	Marine (calm water)
C5	Very high	80 - 200	Marine (Ocean surf)

An additional 'CX' classification has been included for AS 4312 to cover the tropical zones of Australia. Because of the monsoonal nature of the weather and the lack of ocean surf on tropical areas. The corrosivity classification would be generally equivalent to C2 for metals but would be higher for applied paint coatings because of the high levels of UV and its duration in tropical areas.

3. AS 2309:2008 Durability of galvanized and electro-galvanized zinc coatings for the protection of steel in structural applications - Atmospheric

Because zinc-based coatings are among the most widely used anti-corrosion coatings for steel, and there is a wide variation in the performance of the different types of zinc-based coatings that directly relate to their durability, Standards Australia implemented the development of a new standard, AS 2309:2008 Durability of galvanized and electro-galvanized zinc coatings for the protection of steel in structural applications that was closely connected with AS 4312:2008 Atmospheric corrosivity zones in Australia.

This Standard classifies the various types of zinc-based coatings (electro-galvanized, continuously galvanized and hot-dip galvanized) in terms of their durability in given atmospheric corrosion environments.

AS 2309 references AS 2312 and AS 4312 with respect to environmental classifications. It also classifies the various types of zinc-based coatings in terms of their coating thickness. It has been long established that the durability of a galvanized (zinc) coating in any given environment is proportional to its thickness.

The nominal coating thickness of each type of galvanized coating is listed against its estimated service life in years in a given atmospheric corrosivity classifications. Thus the coating on a continuously galvanized sheet product such as a roll-formed purlin that is typically 25 microns in thickness, has an expected service life of 5-8 years in an industrial environment while an HDG 600 hot dip galvanized coating has an expected life of 17-20 years in the same application.

The Standard had developed a 'Star Rating' system for classifying zinc-based coatings with respect to their durability, to make it easier for specifiers and end users to differentiate the performance of zinc-coated steel products (which may all appear similar while the on them may differ).

This durability rating is as follows:

Coating mass g/m²	Class	Star rating
<100	D1	1 star
100-199	D2	2 star
200-399	D3	3 star
400-599	D4	4 star
>600	D5	5 star

4. CORROSION MAPPING

Corrosion Mapping is covered in detail in another chapter of this Specifiers Manual, as are the factors that affect the deterioration of zinc (galvanized) coatings. However, the principles to which its use is applied can be applied logically in any known environment.

In Australia, the major driver of metal corrosion is chloride generated from ocean surf. The extent to which chlorides influence metal corrosion depends on whitecap activity in the ocean adjacent to the shoreline, the prevailing winds and their average velocity and the topography of the coastline.
It is generally accepted, and also listed in AS 4312, that the influence of chlorides does not normally extend more than a kilometer from the coastline, although there are exceptions in flat terrain with prevailing strong on-shore winds.
The time that the metal is wet is also a major influence on its rate of corrosion. For this reason, galvanized steel products used in temperate areas with moderate rainfall (<750mm/year) may suffer more corrosion stress than similar materials used in tropical environments with much higher rainfall.
This occurs because the higher ambient temperatures in the tropics maintain the steel's surface temperature well above the Dew Point, allowing it to dry quickly after rain. In colder climates, the steel surface may be below the Dew Point (and thus wet) for 24 hours/day in the winter months.

For the same reason, the shaded or sheltered sides of structures can suffer higher rates of corrosion that open and exposed areas of the same structure.

5. APPLYING THE STANDARDS

The development of these Standards, in conjunction with use of the IG Corrosion Mapping System and other information sources, allows atmospheric corrosivity to be assesses with a high degree of confidence. This then allows life cycle estimates of the performance of steel structures to be made, which will then determine the most cost-effective methods of managing these steel assets with respect o their durability.

For important infrastructure assets such as power distribution systems, durability criteria can be etablished for individual structures in their specific environments, and inspection and management plans can be developed that ensure that the safe condition of the structure can be monitored without unjustified additional inspection.

INTRODUCTION

As the climate change debate evolves, all industries need to look at their carbon footprint and develop strategies to ensure this is minimised and that their products will have the 'green' credentials to meet future environmental responsibilities.

Steel is obviously one product that is essential for the construction and manufacturing industries, while also requiring significant amounts of energy for its extraction and refining. It not only requires energy to smelt it and refine it, but is also a large carbon consumer in the use of coal (transformed into coke) to reduce the iron ore to metal.

Zinc is the other metal that has a vital role to play in ensuring the durability of steel structures and products, and it too requires energy for its extraction and refining. While some pyro-metallurgical technologies are use for zinc refining, it is predominantly an electrolytic process, requiring significant amount of power for this process. The source of the power may be from coal fired power stations on mainland Australia, to hydro-electric power in Tasmania.

Zinc used by Industrial Galvanizers is either sourced as prime metal from Australian smelters, or as recycled zinc generated by residue reprocessing in Industrial Galvanizers' Auszinc Alloys facility in Port Kembla, NSW.

In addition, the energy component of the hot dip galvanizing process itself is very low. Although all of Industrial galvanizers plants around Australia heat their galvanizing baths with gas, the relatively low temperatures (455°C) required to keep the zinc molten mean that energy costs represent only about 5% of the cost of production.

Industrial Galvanizers Australian Galvanizing Division has had an ongoing energy management program operating for over 10 years that has reduced the energy usage across the Galvanizing Division by almost 50% using waste heat recovery, improved insulation and improved burner management systems. For these reasons, the zinc component in the galvanizing of steel has a small carbon footprint, almost all of which is in the form of natural gas, which makes a significantly lower CO_2 contribution than that of coal fired electricity.

Galvanized steel structures such as these transmission towers have a long service life exceeding 50 years and are 100% recyclable. In addition, the steel could be re-galvanized for a minimal energy cost to preserve the steel indefinitely.

The galvanizing process has a relatively small carbon footprint because of the low temperature (425 degrees C) required to melt the zinc.

THE GALVANIZED STEEL EQUATION

It is obvious that any manufacturing operation involving the extraction, smelting, refining and processing of metals requires significant amounts of energy. Galvanized steel is no exception and the sustainability of the end product will be measured by the amount of energy required to produce it in the first place against its durability and ability to be recycled hot dip galvanized steel is among the world's most durable materials of construction.

In other than very aggressive corrosion environments, most hot dip galvanized structures will provide a service life of 50 years or more, with ongoing case-history studies indicating that 100 years + is achievable in many structural applications.

The amount of zinc applied to structural sections when they are hot dip galvanized is relatively small – typically 3-5% of the tonnage of steel protected. At the end of the steel's service life, this zinc coating has been largely removed by the corrosion mechanisms that determine the service life of the galvanized coating, leaving the steel to be recycled.

GALVANIZED STEEL – THE ENERGY EQUATION

The amount of energy use in producing a tonne of galvanized steel will also determine its greenhouse (CO_2) contribution. The following figures one energy usage for steel manufacture have been obtained from OneSteel and BlueScope steel who make all Australian steel between them. The zinc energy cons information comes from Nyrstar, who has zinc refineries in Hobart, Tas. and Port Pirie, SA and is the world's largest zinc producer, while the energy usage of the hot dip galvanizing process is derived from galvanizing industry average operating statistics.

Nyrstar has adopted a standardised fossil fuel protocol for its energy use statistics from its Hobart operations to bring them in line with its other Australian and International refining operations. This effectively doubles its theoretical CO_2 contribution compared to its actual contribution, as the Nyrstar Hobart refinery was large a user of hydro-electric power. Since Tasmania has connected to the Victorian coal-fired power grid through the Bass Link project, the method of calculation for CO_2 emissions has been changed to reflect that.

Table 1 lists the typical energy consumption for each component of the hot dip galvanizing process.

It should be noted that the zinc smelters/refiners in particular produce significant volumes of commercially valuable by-products from the refining

Steel must have an anti-corrosion coating for most external applications and ensuring long service life for steel enhances its environmental credentials.

operations, including sulfuric acid, silver, copper and gold whose energy consumption is included in the figures used above.

It can be seen that the relatively small energy contribution made by the galvanizing process (3.1 gigajoules – 50 kg/t of CO_2) has a significant effect in preserving the energy already embodied in the manufacture of 1 tonne of steel for the practical service life of most steel structures.

In addition, the recycling of steel uses approximately 25% of the energy required to make steel from raw materials so the overall equation for steel sections made from scrap steel would reflect a total energy usage of well under 10 gigajoules per tonne with a corresponding reduction in greenhouse emissions.

TABLE 1

Material/Process	Gigajoules/tonne	CO_2 Contribution – kg CO_2/tonne
Steel	20	1800
Zinc*	15	250
Hot dip galvanizing	2.5	40

* The energy use figures for Nyrstar have been taken from the Hobart (Risdon) plant data whose primary product is zinc. The CO_2 emissions from the Port Pirie arise from more complex operations, with the primary product being lead, with only 15% of the site's production being zinc. Using this data, an accurate estimate can be made for the total energy use/CO_2 contribution embodied in one tonne of hot dip galvanized structural steel with an average zinc pick-up of 4%. This is shown in Table 2.

TABLE 2

Material	Weight	Gigajoules	CO_2 contribution - kg
Steel	1000 kg	20	1800 kg
Zinc	40 kg	0.6	10
Hot dip galvanizing	N/A	2.5	40
TOTAL			**1850 kg/t**

1. INTRODUCTION

Because steel is relatively easy to convert from its ores (oxides) to metal, it is just as keen to return from whence it came and go back to being iron oxide in one form or another. It is for this reason that for most applications, steel needs a protective coating to ensure its durability and aesthetic appearance.

While the corrosivity of locations if often measured in terms of the corrosion rate of steel test panels, not all that much attention is given to the various types of steel and the stand-alone performance of steel in manufacturing and construction applications.

This review looks at the stand-alone performance of steel as there may be applications that do not require the use of costly protective coatings systems for many applications with short-to-medium term durability requirements.

2. STEELS AND STEELS

While any iron based product may be generically referred to as steel, there are an infinite variety of iron and steel products that have differing corrosion characteristics. For the purpose of this review, only those steel that are likely to be used in manufacturing or construction are considered. Special high strength steel, stainless steels and high-alloy steels are in categories of their own and are used for specialist applications.

The most common types of steel used in construction and manufacturing are:

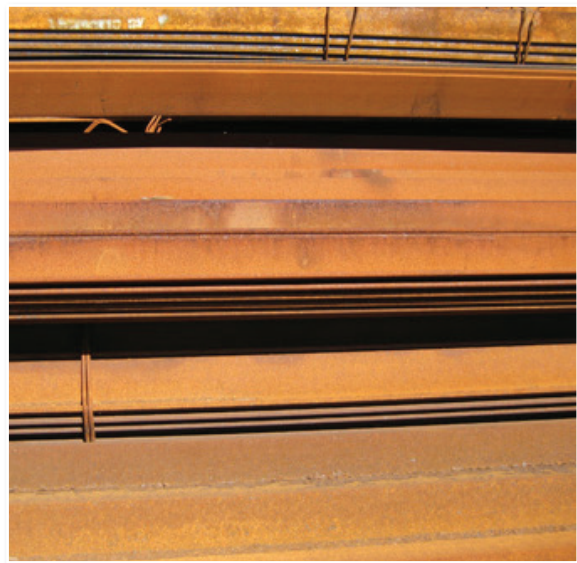1. Cast iron
2. Mild steel
3. Low alloy steel.

The chemistry of these different types of iron and steel influences their corrosion characteristics, so the following brief description of each type is included below.

2.1 CAST IRON

Cast irons include many metals having a wide variety of properties. Although cast iron is often considered a simple metal to produce and to specify, the metallurgy of cast iron is more complex than that of steel and most other metals.

Poor quality paint systems can accelerate steel corrosion by concentrating pollutants and corrosion cells around andv8nder the paint film.

Mill scale initially prevents steel from corroding but quickly breaks down into other iron oxides that accelerate the rusting process with unprotected steel.

Steels and cast irons are both primarily iron with carbon as the main alloying element. Steels contain less than 2 and usually less than 1% carbon; all cast irons contain more than 2% carbon. In addition to carbon, cast irons must also contain silicon, usually from 1 to 3%; thus, they are iron-carbon-silicon alloys.

For each basic type of cast iron, there are a number of grades with widely differing mechanical properties. These variations are caused by differences in the microstructure of the metal that surrounds the graphite (or iron carbides). Two different structures can exist in the same casting. The microstructure of cast iron can be controlled by heat treatment, but once graphite is formed, it remains.

2.1.1 Gray iron: This is a supersaturated solution of carbon in an iron matrix. The excess carbon precipitates out in the form of graphite flakes. Impact strength of gray iron is lower than that of most other cast ferrous metals. In addition, gray iron does not have a distinct yield point (as defined by classical formulas).

2.1.2 Ductile iron: Ductile, or nodular, iron contains trace amounts of magnesium which, by reacting with the sulfur and oxygen in the molten iron, precipitates out carbon in the form of small spheres. These spheres improve the stiffness, strength, and shock resistance of ductile iron over gray iron.

2.1.3 White iron: White iron is produced by "chilling" selected areas of a casting in the mold, which prevents graphitic carbon from precipitating out. Both gray and ductile iron can be chilled to produce a surface of white iron, consisting of iron carbide, or cementite, which is hard and brittle and is used for abrasion resistant applications.

2.1.4 Malleable iron: Malleable iron is white iron that has been converted by a two-stage heat treatment to a condition having most of its carbon content in the form of irregularly shaped nodules of graphite making it malleable and easily machined.

2.1.5 High-alloy irons: High-alloy irons are ductile, gray, or white irons that contain 3% to more than 30% alloy content. These irons are usually specified by chemical composition as well as by various mechanical properties. High-chromium irons (typically, about 16%), combine wear and oxidation resistance with toughness. Irons containing from 14 to 24% nickel are austenitic and they provide excellent corrosion resistance for no-nmagnetic applications. The 35%-nickel irons have an extremely low coefficient of thermal expansion and are also nonmagnetic and corrosion resistant.

2.2 Mild steel
In Australia, the chemistry of most standard grades of structural steel is covered in AS/NZS standards for the various types of steel products. AS/NZS 3697 deals with hot rolled bars and sections. AS/NZS 1594 covers hot rolled coil and flats, AS 1442 covers carbon and carbon manganese (forging and heat

There are many instances where steel is used without a protective coating. Rail lines are a good example and have excellent durability in most Australian environments.

While not widely used in Australia, weathering steel has been used extensively in structural applications in the USA, with several thousand tonnes used on the New River Gorge Bridge in west Virginia.

treatable) grades. Steels in this last classification are rarely used in structural applications. These types of steels have carbon contents typically up to 0.25%, manganese levels around 1.5% and silicon levels that can vary quite widely depending on the steelmaking process and mechanical property requirements. Some micro-alloying elements such as copper, nickel, chromium and molybdenum may also be present in these steels.

Depending on the manufacturing process, the ex-mill steel sections may have greater or lesser degrees of mill scale adherent to their surfaces. Hot rolled angles, bars, channels and universal sections may have relatively heavy adherent mill scale, while hot rolled coil may have very little, or thin adherent mill scale.

2.3 Low alloy steels.
These steels typically contain 2-3% of alloying elements such as copper, nickel. chromium and

phosphorous. These types of steels have better mechanical properties than the mild steel grades, but most importantly, they have better corrosion resistant properties because of the nature of the oxide film that form on their surfaces. Tightly adherent oxide films are formed on these steels that form a barrier to atmospheric corrodents

These types of steels are referred to as weathering steels and are have been used without any anti-corrosion coatings for many years in structural application. There are certain conditions that can affect their performance, one of the most important being that they need have good open air exposure. These steels have corrosion rates typically around 1/3 or less than those of mild steels.

In Australia, weathering steel has not been widely used for structural applications. It main use has been in transport applications such as truck bodies and rail wagons where abrasion makes the used of protective coatings impractical, or in architectural applications where the 'rust' colour of the steel is incorporated into the aesthetics of the building or structure.

BlueScope Steel is a local producer of weathering steels and it has produced technical data sheets on its weathering steel grades that highlight the special requirements associated with the use and fabrication of these types of steels.

3. IRON AND STEEL CORROSION SYSTEMS

The fact that steel rusts through its reaction with oxygen in the presence of moisture is well established. Iron and steel are not homogeneous materials. As the micrographs accompanying this chapter illustrate, there is a matrix of pure iron (ferrite), iron carbides, other intermetallic compounds and, in cast iron, graphite.

On the metal's surface, these components create a multitude of adjacent anodes and cathodes and the electrochemistry of corrosion will prosper on such a surface and the presence of moisture. Most steel used for structural application is already substantially 'rusted' when it gets to the warehouse as it is coated with mill scale. The mill scale present on steel, arising from the hot rolling process, is typically about 50 microns thick and contains the

These architectural elements on a harbour-side building in Newcastle, NSW are fabricated from uncoated weathering steel.

three common oxidation states of iron; FeO (ferrous oxide) closest to the surface, Fe_3O_4 (magnetite) in the middle and Fe_2O_3 (ferric oxide) on the top. Mill scale initially acts as a protective barrier to the steel, but soon its frangible and permeable nature allows corrodents to contact the steel surface and rapid localised corrosion can occur at the exposed sites.

The critical factors determining the atmospheric exposure rate of steel are; moisture (humidity or precipitation) and the presence of SO_2 (sulfur dioxide). Unlike on zinc coatings, sulfur dioxide is a far more important corrodent on steel than are chlorides, in that much lower levels of SO_2 will precipitate higher rates of steel corrosion.

The presence of moisture (water) on the steels surface and not its volume is the critical factor. Estimates of the amount of water on a metal surface have been made and are approximately as follows:

Critical relative humidity	0.01 g/m²
100% Relative Humidity	1 g/m²
At the Dew Point	10 g/m²
Wet with rain	100 g/m²

Low levels of surface moisture may, in fact, produce a more aggressive environment because any corrodents on the steel's surface will form more highly concentrated electrolytes, while rain may dilute and remove any soluble surface contaminants.

The major driver of metal corrosion in Australia is chloride, and while chlorides are not critical in corrosion of steel at anything like the levels at which SO_2 has an impact, the sheer volume of chlorides generated in much of Australia's coastal regions make them a force to be reckoned with when steel corrosion has to be managed. Where high levels of airborne chlorides are present (oceanfront sites), steel corrosion rates can be extremely high, but this effect drops off rapidly with distance from ocean surf.

Estimated rates of steel corrosion related to the distance from ocean surf and in other environments are tabulated below:

Location	Steel Corrosion Rate – mm/year
50 m from ocean surf	0.20 – 0.50
200 m from ocean surf	0.10- 0.20
500 m from ocean surf	0.05
1 km from ocean surf	0.025
Coastal urban/metropolitan	0.025
Inland – East of Great Dividing Range	0.010 – 0.025
Inland – West of Great Dividing Range	<0.010

NOTE: The corrosion rates shown are influenced by factors such as orientation, height above ground level, local topography, regional climatic condition (ambient temperatures) and rainfall patterns.

4. BETTER BARE THAN BADLY COATED

When steel is painted, the paint acts as a barrier coating to prevent moisture and corrodents from contacting the steel's surface. Poorly applied paint coatings can be more damaging to steel than no coating at all. When the coating is breached, highly anodic areas are created around the edges of the failed coating. These areas produce high corrosion currents and resulting concentrated corrosion cells. These areas of high corrosion energy will progress along the edge of the paint film, undercutting it. Deep localised corrosion areas causing pitting, and in some cases, perforation, of the steel section can occur under these circumstances.

5. STAND ALONE STEEL

There are many instances where uncoated steel has demonstrated excellent durability without any coating applied to it, just as there are cases where corrosion can consume a substantial steel section in a relatively short time.

In the drier rural and desert areas of Australia, uncoated steel has a negligible corrosion rate. A good example is the humble star post, along with the uncoated wire, that was used in the 19th and early 20th Centuries to fence the entire continent.

Many of these installations are 100 years old and remain serviceable.

INTRODUCTION

Metal fasteners have been used in timber structures for thousands of years, and while other methods and materials of construction have been developed, timber remains an important light structural building material.

With the declining availability of native hardwoods in Australia, much of the timber construction now takes place using graded plantation softwoods or engineered timber products based on softwood forest products.

In addition to changes in timber availability, there has also been a major shift in pre-fabricated construction, where frames and trusses are assembled off-site, leaving traditional 'stick' construction becoming a relative rarity.

Nail guns have largely replaced the carpenter's hammer and self-drilling fasteners have replaced conventional nails in many applications.

The basic reality remains with all this engineered timber construction of the need to ensure that the fasteners used are durable enough to match the design life of the structure.

WHAT FASTENERS FOR WHAT PURPOSE?
Nails.

There are three basic types of nailing systems commonly used. These are conventional nails, collated nails and gang nails. While all have specific design functions, the nature of each type of nailing systems has a significant impact on its durability.

Conventional nails.

There are many types of nails designed for general and specific purposes. Head shape and shank design determine the performance while the nail gauge (diameter) and metallurgy will determine the strength of the nail. Nails are designed to connect timber to timber (softwood and hardwood), sheeting (plasterboard, hardboard, wallboard, particle board, underlay and roofing) to timber and for other special fastening operations such as fastening timber to aerated concrete blocks. The head size is determined by the material which is being fastened so that the nail head will not pull through the material.

Uncoated steel nails used in hardwood not only corrode themselves by the corrosion products attach the surrounding timber

The nail shanks

The nail shanks may be plain, ring shanked (radially grooved) or twisted shank with the shank design determined by the nature of the material to which the attachment is being made. Assemblies subject to vibration or movement are best served by twisted shank or ring shank nails, especially in softwood. Roofing nails have an integral cap and washer and have long been the standard fastener for cor-rugated roofing. These are also available in various shank designs including those for cyclone rated areas and for use in softwood. This type of fastener has been most affected by the introduction of self-drilling Type 17 fasteners yet is a superior performer in terms of durability, which is discussed later in this article.

Collated nails

Collated nails are used in nail guns and are connected in strips or coils for use through nail gun magazines. Collated nails often have notched heads to allow the nails to nest with parallel shanks. Some collated nails are connected with paper strips while others are spot welded to a set of thin connecting wires.

Gang nails

Gang nails are manufactured from pre-galvanized or black steel sheet and are better described as nail plates. The strip has a series of points punched out at right angles to the plate. Gang nails are widely used for butt jointing timber, particularly trusses and wall framing. Special gang nail fasteners such as the National Dek Lok, designed for invisible attachment of timber decking operate on the same principle.

Self-drilling fasteners

Self-drilling fasteners are now used almost universally in many facets of timber construction. While much of this activity is inside the structure (e.g. plasterboard fixing), the most critical applications involve the fixing of external cladding.

While much of the attention has been focused on the performance of these fasteners in attaching metal cladding, and having compatible life with the cladding, they are also largely used to fasten the cladding to timber frames and trusses, hence their mention in this context.

Most metal roof and wall cladding used in Australia today is fixed to either steel or timber framework with self-drilling, self-drilling screws. The concept of this type of fastening is relatively new and was introduced by I.T.W. in the USA in the 1960's as a labour saving device in the automotive industry.

The use of fasteners rapidly expanded into the building industry for fixing plasterboard lining and metal cladding. ITW Buildex commenced manufacture of TEKS and Type 17 fasteners in Australia in the late 1960's and now produces approximately 2 million fasteners per day in plants in Melbourne and Sydney.
The early self-drilling screws were electroplated with zinc or cadmium to a minimum thickness of 8 microns and passivated. At this time, it was more common to clad building in more severe corrosive environments with asbestos cement, aluminium or protected metal claddings, most of which were fastened with stainless steel self tapping screws or wood screws.

The situation began to change dramatically in the late 1970's due to:

1. The introduction of BlueScope Steel ZINCALUME™ and COLORBOND™ cladding with increased corrosion resistance.
2. The health risks associated with asbestos cement sheeting
3. The flood of cheap, low-quality imported fasteners from Asia following the expiration of the TEKS patent.

Many of these had only 2-3 microns of electroplated zinc with a corrosion resistance 25% that of the original ITW Buildex product. The result was that ZINCALUME™ and

Poor performance of the single electroplated fastener in this external hanger bracket, compared to the galvanized nails after 5 years in trated pine.

COLORBOND™ were being used in more widely and being fixed with fasteners with inferior corrosion resistance. As a result, BlueScope steel approached fastener manufacturers in 1981, requesting that self-drilling screws have minimum of 1000 hours salt spray resistance.

The Fastener Institute of Australia formed a technical committee to produce a draft standard that eventually became **AS 3566 - Self Drilling Screws in the Building and Construction Industry** which was released in 1988 and revised in 1990 and again in 2002. It is unusual in being a performance based standard rather than a materials based standard and its aim is to ensure that fasteners have a similar life to the materials they are required to fix.

Class 3 - Screws for External Use

The Standard AS 3566 requires minimum corrosion resistance levels under accelerated testing to the following levels:

1. 1000 hours salt spray testing
2. 15 cycles Kesternich (acid rain) testing
3. 2000 hours QUV testing (for organic coatings)
4. 1000 hours humidity testing.

Screws with an average zinc coating thickness of 40 microns applied either by hot dip galvanizing or mechanical plating are exempt from these tests provided they have a minimum spot thickness of 35 microns.

The testing of new types of coatings and fasteners which have appeared since the introduction of AS 3566 in conjunction with ZINCALUME™ and COLORBOND™ have taught the industry many valuable lessons.

1. Bi-Metallic Corrosion

Stainless steel fasteners were long believed to be the answer to all fixing problems in severe environments. Stainless steel has now been shown to be incompatible with COLORBOND™ and can cause premature corrosion of the roofing sheet.

2. Shank Corrosion

Corrosion of the shank of a roofing screw can occur under the roof to an advanced stage before any sighs of external corrosion appear. This is believed to be the result of pure water corrosion arising from condensation on the underside of the cladding. In studying the possible causes of this type of corrosion, Buildex realised that a self drilling screw cut a neat sized hole in the roof sheet, causing a sharp edge of the hole to rub off a significant amount of the coating or plating that had been applied to the shank. A special feature called `Shankguard' was added to all crest fixing screws that causes a slightly oversized hole to be created in the sheet before the shank passes through, preventing damage to the corrosion resistant coating. This feature increases the corrosion resistance of the shank by 60%.

3. Sheet Movement after Fixing

Hi Grip is another feature that has been added to Buildex roofing screws since the introduction of AS 3566. This system incorporates differently pitched threads under the fastener head that grips the roof sheet against the head of the fastener which eliminates vertical vibration of the sheet against the shank of the fastener and further enhances the durability of the shank.

4. Sealing Washers

The fastener industry has worked closely with BlueScope Steel in testing many facets of corrosion resistance of fastening systems and their compatibility with cladding materials. It has been found that corrosion of the cladding in severe marine environments can he accelerated using sealing washers containing carbon black, causing galvanic corrosion of the roof sheeting.
As a result, Buildex have altered the formulation of sealing washers from black EDPM to a gray formulation containing virtually no carbon black.

Hot dip galvanized twisted shank nails are recommended by the treated pine industry for use in their structural sections.

5.Severe Marine Environments

With cladding products being used in severe marine environments, and stainless steel screws being considered incompatible, the latest revision of AS 3566 has included a Class 4 durability level for heavy duty (marine and industrial) applications.

The need continues for architects and roofing manufacturers to actively specify that fasteners must at least meet AS 3566 Class 3 if the basic objective of having fasteners and cladding of compatible life spans is to be met.

The majority of metal cladding and roofing in Australia is installed in 'moderate' environments and by simply ensuring that the minimum standards of AS 3566 Class 3 are specified and met, the benefits to be obtained both commercially and aesthetically from products such as ZINCALUME and COLORBOND will be enjoyed by the whole community.

MATERIALS OF MANUFACTURE

The vast majority of nails are made from low carbon steel. The drawing, cold heading and pointing operations increase the tensile strength of the wire and this is also a factor in the design and performance of the wire. Nails that are too soft are difficult to drive without bending and nails that are required to be driven into resistant materials such as masonry also require an additional degree of stiffness.

Nails for marine applications (boat nails) are manufactured from silicon bronze or similar alloy. Stainless steel nails are also available from specialised manufacturers but in the final analysis, most fastening applications depend on steel fasteners with varying degrees of protective coating from none, in the case of 'bright' nails to heavy hot dip galvanized coatings.

Gang nails or nail plates are almost always manufactured from pre-galvanized sheet. The durability requirements in more aggressive environments have required hot dip galvanized nail plates to be specified.

STEEL AND TIMBER

Non-threaded fasteners are inevitably subject to very severe treatment during their installation, and few assembly operations are more severe than being hammered, with the resultant very high impact energy of the hammer-head being transferred to the very small surface area of the nail head. There is also a degree of abrasion on the nail shank as it is driven into the timber.

For the first 150 years of Australian colonisation, the country's abundant hardwood supplies were used universally for building and construction in the absence of significant native softwoods. Also, the availability of the so-called royal grades of Australian hardwood such as mahogany, tallowood and turpentine, with their superior durability did not require the use or timber preservatives. With the increasing dependence of plantation timber and the need to use less durable hardwood timber, the use of preservative treatments has become almost universal.

The permeability of pine means it can be treated with a wide range of preservative treatments when being used in exposed situations, in contact with the ground or in any area it may be subjected to moisture such as indoor swimming pools and greenhouses. Once treated, it can withstand conditions in which insects and/or fungal decay would quickly destroy untreated timber.

CCA treated pine is very aggressive on both zinc and steel when its moisture content exceeds 20%. These electroplated bolts have almost totally corroded in pergola structure after 10 years.

Treated pine is used both for structural and non-structural purposes in a range of dressed and sawn products. Indeed, it has extensive applications both above and below ground. Preservative treatments are usually either:

• Water-borne
  – Copper Chrome Arsenic (CCA)
  – Alkaline Copper Quaternary (ACQ)
  – Copper Azole (CuAz)
• Solvent-borne
  – Light Organic Solvent Preservative (LOSP), or
• Oil-borne
  – Creosote
  – Pigmented Emulsified Creosote (PEC)

Treatments may not always be absorbed into every part of the timber, so when treated timber has been cut, an appropriate re-sealing treatment should be applied to the cut surface.

When finishing treated timber with paint, stains or clear coatings consult with the producer/supplier as to the best method of application, as the treatments may have an adverse affect if a compatible coating is not applied.

The Australian Standards requires that each piece of treated timber, claimed to conform with the standard, must be labeled on one end with the treatment plant number, the preservative code number and the hazard class.

HAZARD CLASS

The hazard class according to AS1604 is determined by a number of factors including insect attack, temperature, moisture and the geographical location of the exposure environment. There are six hazard classes:

• H1 – is used in dry, inside above ground exposure situations for furniture, flooring and interior joinery subject to attack from insects other than termites.

• H2 – is used in dry, inside above ground exposure situations for framing, trusses and flooring subject to attack from termites and borers.

• H3 – is used in outside, above ground exposure situations for pergolas (above ground), decking, fencing, cladding, fascias, joinery and any structural timber subject to moderate fungal decay, borers and termites.

• H4 – is used in outside in the ground exposure situations for fence posts, greenhouses, landscaping and pergolas (in ground) subject to severe fungal decay, borers and termites.

• H5 – is used in outside in the ground or in fresh water exposure situations for retaining walls, house stumps, building poles, pilings, cooling tower fill and any critical structural applications subject to
very severe fungal decay, borers and termites.

• H6 or H6SW– is used in marine water exposure situations for piles, jetty cross bracing, landings, steps, sea walls and boat hulls subject to marine borers and decay.

Fasteners In all exposed situations, hot-dipped galvanised or other corrosive-resistant fastenings should be used to secure preservative treated timber. Stainless steel fasteners
may be required in severe environments
in close proximity to coastal areas.

Further, all nails used with treated pine should be twist-shank or ribbed, to avoid their withdrawal as moisture conditions in the wood change

Copper chrome arsenic (CCA) treatment is the most widely used timber treatment and the presence of treatment chemicals in the timber can have a significant and sometimes dramatic effect on the durability of the fasteners used.

Another factor in fastener performance in timber is the nature of the timber itself. Although timber degradation is not electrochemical in nature, it can be treated as a special form of corrosion. Timber is a classic biodegradable material subject to 'corrosion' by numerous agents ranging from insect and fungus to ultraviolet degradation and chemical attack.

The durability of the connection between timber and metals determines the durability of the composite material formed by the attachment of the timber to steel or other medium. The designer must determine the critical factors in a wood-metal system. Is it the corrosion of the fastener that will cause the system to fail or is it decay of the timber around the fastener that will cause failure of the joint?

Anyone who has had to maintain timber fence palings will have asked these questions. Has the paling fallen off because the nail has rusted off or because the wood around the nail has degraded and the hole is bigger than the nail?

WHY DO FASTENERS CORRODE IN TIMBER?

Corrosion of fasteners in timber is due to the formation of an electrochemical cell. Metal fasteners are not usually electrically connected although with metal roof cladding it is a possibility. The electrochemical cell formed with metal fasteners in timber can thus be likened to a crevice corrosion or waterline corrosion situation. The head of the fasteners (bolt, nail, screw or gangnail plate) becomes the cathode and the embedded part of the fastener becomes the anode because of its oxygen deficient environment. In the presence of an electrolyte, corrosion will proceed because of the current flow that occurs between the anodic and cathodic sites.

The likelihood of corrosion of metal fasteners in timber is influenced by the following factors:
- moisture content
- wood species
- preservative treatment
- presence of decay (micro-organisms)

Moisture in timber

The naturally occurring inorganic salts, wood acids, atmospheric contaminants and timber preservatives will contribute to the ionisation of any moisture that comes in contact with the timber. Fortunately. there is a critical moisture level in timber below which the corrosion reaction is significantly reduced. This moisture content is about 16-18%. Moisture content alone is the main factor controlling corrosion of metal fasteners in timber.

While seasoned timber will have moisture levels below the critical levels, it should be remembered that rain and condensation on the surface is sufficient to stimulate corrosion at the interface. Short cycles of wetting and drying and the resulting expansion and contraction of the timber will result in cracking and splitting of the wood, especially around fasteners which allow end grain ingress of moisture into the timber. It is for this reason that paint systems for timber are designed to fill the pores in the timber and seal and preserve the surface.

The ubiquitous pink primer applied to exterior woodwork prior to priming and painting contains various extenders, UV and fungicide additives such as zinc oxide to assist in maintaining a stable environment for the timber in service.

Fungal decay

Fungal activity. and moisture levels around 20% are deemed to be sufficient to promote fungal decay. Corrosion products from fasteners may directly stimulate the development of wood-destroying fungi through the release of nutrients or by altering the pH of the micro-environment. Alkali hydrolysis and oxidation of the wood can also occur causing the wood around the corroding fastener to become soft and absorbent, which in turn retains moisture longer and absorbs it easier, thus propagating the corrosion of the fastener.

Wood species

The acidity of timber varies depending on species and the location of the wood within the tree, as pH can vary from heartwood to sapwood. A number of studies have been done worldwide that have fitted various species of timber into an approximate corrosivity series. While pH is an obvious factor, the presence of other components such as aromatic phenols in the timber and its permeability to

moisture are also important in deter-mining the corrosive effects of wood on metal fasteners.

The following table lists some common Australian timbers with their typical pH and polyphenol contents.

Timber Species Common Name	pH (heartwood)	Polyphenols (tannic acid equivalent) %
Blackbutt	3.12 - 3.25	6 - 13.5
Peppermint	3.15	11.0
Turpentine	32 1	152
White Mahogany	3.24	8.72
Coastal Grey Box	3.42	15.8
Tallowood	3.55 - 3.56	17.0 - 17.3
Banealay	3.56	4.37
Mountain Grey Gum	3.57	12.1
Yellow Stringybark	3.62	1 1.6
Sydney Blue Gum	3.65 - 3.80	5.78 - 10.3
Red Ironbark	3.66	10.4 - 11.0
Flooded Gum	3.84	5.24
Spotted Gum	4.25 - 4.68	4.46 - 6.05
Brush Box	4.55	1.23
Grey Ironbark	4.88	6.92

Table: Acidity and polyphenol content in a range of commercial hardwoods. From Krilov and Gref (1986).

While the effect of timber species is important in the durability of fasteners, the Australian saw milling industry is acutely aware of the corrosive effects of green Australian hardwoods through the corrosive effects steel saw blades. Corrosion losses in the order of 3-8 g/m2/hour have been recorded with the stringybark species exhibiting much higher levels of corrosion damage.

PRESERVATIVE TREATMENTS AND FASTENER CORROSION

Copper chrome arsenic (CCA) preservatives are the most widely used timber preservatives. Timber which has been freshly treated with CCA has a high moisture content, a high acidity and a high electrical conductivity. All of these conditions are ideal for the electrochemical corrosion of metal. Much test work has been done, particularly by the Queensland Department of Primary Industries Forest Service, to determine the corrosive effects of timber treatment on various metals and coatings used in fasteners.

There is a dramatic increase in corrosion in both steel and galvanized coatings, and with silicon bronze and copper fasteners with freshly treated timber with high moisture content. Bare steel nails corrode almost 10 times faster in newly treated timber at 80% moisture content compared with seasoned timber at moisture levels typically under 15%. The Queensland DPI Forest Service recommends that treated timber be withheld from sale for a 'cure' period to avoid the environmental consequences of unfixed CCA salts leaching from the timber and to minimise fastener corrosion.

Other preservative treatments such as ammoniacal preservatives, boron preservatives, light organic solvent preservatives (LOSP) and oil type preservatives are now more widely used in Australia, but like CCA treatments, are not considered to present significant corrosion problems for fasteners in cured condition.

Other factors
I. Effect of rusting iron on wood: Iron acts as a catalyst in the deterioration of wood tissue and rusting iron in contact with wood causes a decrease in tensile strength of the timber due to the decomposition of hemicellullose by alkaline corrosion products.

2. Chloride ions: Wood usually contains natural chloride and as in most corrosive environments, the presence of chloride is particularly relevant. Chloride levels in eucalypts generally range between 10-100 ppm in heartwood and 100-2000 ppm in sapwood, with bark having higher levels. Pinus radiata typically contains 10-200 ppm in its sapwood.

Fastener materials and coatings
The vast majority of fasteners are manufactured from mild steel. Stainless steel, copper, monel and brass are also used for specialised fastener applications such as boat building and other heavy duty applications where steel is inappropriate.

While a large number of nails are used in `bright' (uncoated) condition, most exterior exposure applications require some type of protective coating to be used on the nails if long term performance is required.

This can be zinc plating, hot dip galvanizing or polymer coating with varnish or other paint coating for specific purposes.

Hot dip galvanizing is the most commonly used economical method of improving the durability of nails in timber, as the hot dip galvanizing process applies a very heavy coating to the fastener compared to zinc plating . In addition, the alloying of the zinc to the steel in the hot dip galvanizing process provides an extremely hard and durable coating that is able to withstand the rigors of being hammered. The thickness of the hot dip galvanized coating is generally in excess of 40 microns and is typically 6-8 times the thickness of zinc plating used on fasteners.

Hot dip galvanized nails are recommended without exception for use with CCA treated pine, and most treated pine suppliers carry only hot dip galvanized steel accessories. Durability problems can occur with gang nails used for exterior applications if they are manufactured from pre-coated steel sheet, as the zinc coating is relatively thin (around 20 microns) but more significantly, there is a large area of exposed steel on the cut edges of the nail plates that places additional demands on the zinc to cathodically protect the cut edges and accelerates failure of the coating in these areas. Some manufacturers have gone to hot dip galvanizing nail plates to improve their durability.

DESIGNING TO MINIMISE WOOD/METAL CORROSION
Like all corrosion problems, one of the best ways to minimise corrosion risk is through good anti-corrosion design. The metal/wood connection is no exception.

There is a hazard level classification under the Timber Utilisation and Marketing Act (1987) where environments for timber use are classified from HI (off the ground, well ventilated and completely protected from the weather) to H6 (fully exposed, high decay hazard, ground contact) and this is a useful guide to fastener selection and treatment.

Timber structures need to be assessed for durability in the same way as steel structures, using appropriate parameters and be designed with an awareness of the particular characteristics of timber in mind. Important considerations include:

- Exposure condition of site
- Moisture content of timber in service should be below 20%
- Selection of type of timber
- Protective coating systems to seal timber (primers, paint, varnish)
- Keep timber off the ground
- Recess fasteners and seal or plug holes
- Avoid coupling timbers of dissimilar porosity
- Avoid wood/metal interfaces near water line - full immersion may be better than intermittent immersion.
- Avoid puddling of rain and condensation at connections.
- Ensure adequate ventilation
- Use fasteners with equivalent durability to the design life of the structure.

CONCLUSION

The management of corrosion in fasteners used in conjunction with timber is an important issue and one which has a direct impact right down to the home owner. The selection of inferior fasteners in domestic construction: paling fences, decks, pergolas and other home hardware can dramatically reduce their maintenance free lives and the small premium associated with using the best available fasteners is a good example of short term savings adding up to long term problems.

REFERENCES

R.I. Davis and P.J. Allen (1993). Corrosive effect of CCA timber treatment on various metal fasteners. Research Note No 45, Queensland Dept of Primary Industries Forest Service.

R. Davis (1994). Timber and Metal - The Connection. Paper: Pacific Timber Engineering Conference July 11-15, 1994

INTRODUCTION

One of the commonly encountered problems with galvanized coatings of all kinds is 'white rust' or 'white storage stain'. It is manifested as a bulky, white, powdery deposit that forms rapidly on the surface of the galvanized coating under certain specific conditions.

White rust can cause considerable damage to the coating and is always detrimental to the galvanized coating's appearance.

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.

WHITE RUST FORMATION

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.

AVOIDING WHITE RUST FORMATION

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

These are:

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

TREATING GALVANIZED SURFACES AFFECTED BY WHITE RUST

Once the galvanized surface has been attacked and the zinc hydroxide compounds have formed, it is desirable to remove the oxide products from the surface because:

a. their presence inhibits the formation of stable carbonate based oxides
b. they are unsightly

The effect on the galvanized coating can range from very minor to extremely severe and various levels of remedial treatment are available to deal with white rust problems at the levels at which they are likely to occur.

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

1. Light white rusting

This is characterised by the formation of a light film of white powdery residue and 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.

2. 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:

a. Wire brush the affected area to remove all white corrosion products
b. 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.

3. 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:

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

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. Because the tests were 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. It 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 products.

RE-PASSIVATING THE GALVANIZED SURFACE

Where white rusting has occurred and the item may be subject to continuing exposure that may propagate similar corrosion, re-passivating of the surface can be done by treating the surface with a solution of 5% sodium dichromate, 0.1% sulfuric acid, brushing with a stiff wire brush for 30 seconds before thorough rinsing of the surface.

CONCLUSION

White rust is a post-galvanizing phenomenon. Responsibility for its prevention lies in the manner it is packed, handled and stored prior to the galvanized product's installation and use. The presence of white rust is not a reflection on the galvanized coating's performance, but rather the responsibility of all those involved in the supply chain to ensure that the causes of white rust are recognised and the risks of its occurrence minimised on newly galvanized steel.
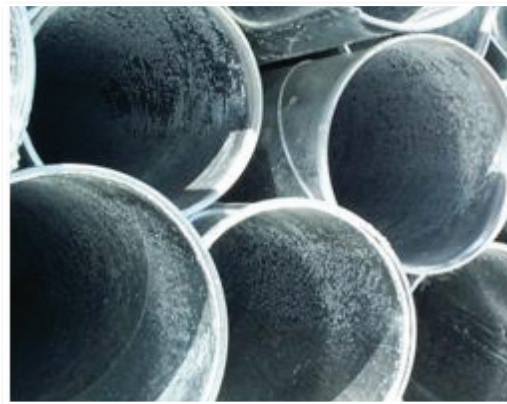
Light white rust formed inside large diameter galvanized pipes caused by prolonged period of wetness after galvanizing and slow drying of the shaded sections of the pipes.

Severe white rust on a galvanized section of guard rail as a result of rails being tightly nested and stored in wet conditions

47. ARCHITECTURALLY EXPOSED STRUCTURAL STEEL AND GALVANIZING

INTRODUCTION

Architecturally Exposed Structural Steel (AESS) not only fulfils its structural function, but is left purposely exposed as part of the architectural aesthetic. Therefore, more attention is needed regarding detail, finish and handling than is normal with standard structural steel – and cost is generally higher.

Iron Bridge, completed in 1779, was built using concepts found in carpentry – including mortice & tenon and blind dovetail joints.

The idea of AESS is not new; it could be said that early cast iron structures such as Iron Bridge (above), and Crystal Palace exhibited the aspects that define AESS:-

• Predominantly bolted or welded connections;
• Tolerances required at fabrication and erection;
• Access to detail to perform the required finish.

The introduction of steel hollow sections in the 1970's allowed architects and engineers increased scope in design and construction. Architects are increasingly using transparency in their design, as popularised by Helmut Jahn's United Airlines Terminal at O'Hare Airport in Chicago. Once considered just for high profile projects, use of AESS is now widespread in structures including small retail stores, shopping centres, entertainment arenas, casinos and office lobbies.

However, it is possible to add considerable expense to a project by specifying requirements that are not needed. Not all AESS has to be created equal, most projects can neither afford – nor need – the same level of detailing.

AESS SPECIFICATION

AESS design detailing can approach industrial design standards when creating joints between steel sections: structural requirements must be accommodated, along with tighter dimensional tolerances, form, symmetry and economy. The method of preparing and finishing connections using specialized welds and ground or filled finishes can become prohibitively expensive. Exacting (and expensive) detailing is only warranted in areas where the steelwork is close enough to be seen or even touched.

Increased use of AESS means that architects are becoming more involved in the connection issues and detailed structural specification that was once the domain of the engineer or fabricator. Similarly, the coating finish requires significant forethought regarding access for application, surface condition and preparation, and even – in the case of galvanising – the grade of steel required to consistently achieve the desired lustre on the finished product.

There is a need for increased communication between the architect, engineer, fabricator and coating specialist; and a shared meaning is required that helps standardise terms like 'smooth finish' and define where they are necessary when using AESS.

Federation Square, Melboune: galvanised interior AESS. Given the height of the building, most of the sections and joints are more than 6m away from the viewer. A different AESS standard can be applied compared to steelwork at ground level, which is highly visible.

The result is the development of a Guide to Specifying Architecturally Exposed Structural Steel, summarised in the table below:-

Characteristics	AESS C Custom Elements	AESS 4 Showcase Elements	AESS 3 Feature Elements (Viewed at distance ≤ 6m)	AESS 2 Feature Elements (Viewed at distance > 6m)	AESS 1 Basic Elements	SSS Standard Structural Steel AS 4100
1.1 Surface preparation to AS 1627 Sa2/Class 2		●	●	●	●	
1.2 Sharp edges ground smooth		●	●	●	●	
1.3 Continuous weld appearance		●	●	●	●	
1.4 Standard structural bolts		●	●	●	●	
1.5 Weld spatter removed		●	●	●	●	
2.1 Visual samples produced		○	○	○		
2.2 One-half standard fabrication tolerances		●	●	●		
2.3 Fabrication marks not apparent		●	●	●		
2.4 Welds uniform and smooth		●	●	●		
3.1 Mill marks removed		●	●			
3.2 Butt and plug welds ground smooth and filled		●	●			
3.3 RHS/CHS weld seam oriented for reduced visibility		●	●			
3.4 Cross sectional abutting surface aligned		●	●			
3.5 Joint gap tolerances minimized		●	●			
3.6 All welded connections		○	○			
4.1 RHS/CHS seam not apparent		●				
4.2 Welds contoured and blended		●				
4.3 Surfaces filled and sanded		●				
4.4 Weld show-through minimized		●				
C.1 _____						
C.2 _____						
C.3 _____						
C.4 _____						
C.5 _____						
Sample Use	Elements with special requirements	Showcase or dominant elements	Airports, shopping centres, hospitals, lobbies	Retail & architectural buildings viewed at a distance	Roof trusses for arenas, retail warehouses, canopies	
Estimated Cost Premium	Low – High (20 – 250%)	High (100 – 250%)	Moderate (60 - 150%)	Low – Mod (40 – 100%)	Low (20 – 60%)	None 0%

Required ●
Optional ○

Category Matrix for Specifying AESS: *Each category has a set of characteristics that clarify what work is required on the steel, required tolerances and any need for visual samples. Categories appear on architecture, engineering, detailing and erection documents to ensure common undersatnding of requirements.*

(**Source:** *Australia/New Zealand guide for specifying architecturally exposed structural steelwork, Terri Meyer Boake, School of Architecture, University of Waterloo, Ontario)*

The AESS specification adopts a categories approach, with each of the five categories specifying a unique level of finish. They reflect the key attributes of form, fit and finish but focus on three areas of concern:-

• **The viewing distance.**
The ability to see the steel at close range defines the level of workmanship and finish. A distance of 6 metres was selected as a basic determinant; it is the distance at which a viewer can closely scrutinise or even touch the steel surface.

This distance should be considered as a 360o measurement. For example, in a multi-storey building the steel of the walls may be 40m in the air when viewed from the ground, but only 5m away when viewed (horizontally) from a higher floor or mezzanine.

Care must be taken to eliminate build-up of dust, dirt or rubbish on exposed steel members that can be viewed from above.

Some of the blemishes left on steel from manufacturing, fabrication or coating will not be visible at a distance, and can be accepted without the need for expensive and remediation.

• **Type or function of the building**
This will have an impact on the aesthetic and finish requirements. The requirements for a hospital and an arena will differ and distinct AESS categories may be specified for spaces within the project. For example, roof trusses may be AESS 1, but the bases of supporting columns AESS 3. Such differentiation can produce substantial savings on a project.

• **Potential cost increase above standard structural steel**
Using standard structural steel as a base, the matrix indicates a range of cost increases for fabrication and erection, depending on the AESS category.

Higher AESS categories call for better fabrication techniques, more attention to weld quality and surface finish. Erection costs increase depending on whether complex shapes can be fabricated in a shop or on site. The surface finish chosen will also impact on the cost.

Paint finishes will almost always require some degree of touch-up to repair scratches from transport or erection damage. This is less a problem with galvanized sections; cosmetically due to the tough nature of the galvanized coating; and from a corrosion prevention perspective because of its 'self-healing' galvanic protection.

The categories of AESS
Standard Structural Steel (SSS) is the baseline for technical reference. Its use is well understood and specified under Australian Standards such as <u>AS 4100-1998, Steel structures and AS/NZS 4600:2005, Cold-formed steels used for light engineering purposes.</u> Generally, the strength considerations of SSS take priority over its appearance, though in many cases it will be galvanized or painted for corrosion protection of aesthetics.

AESS 1 (Basic Elements) is the first level above SSS. Enhanced workmanship is required, along with a superior finish. Examples of use include roof trusses in arenas; warehouses and canopies. Typically viewed at a distance >6 m, or out of normal eye-line, the price premium is relatively low at 20 – 60%.
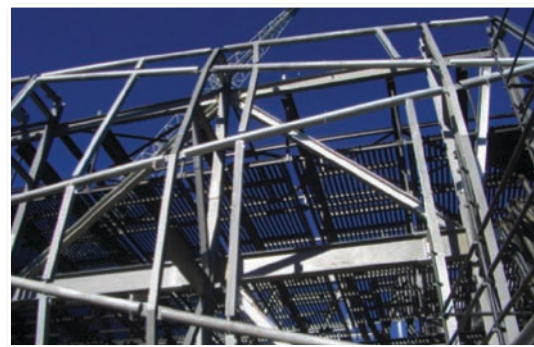
Star City Casino, Sydney: AESS 2 standard preparation required as galvanized steel to be sandwiched between interior and exterior glass. Provides a visible framework for the building but will not be subject to close inspection by patrons.

AESS 2 (Feature Elements – viewed at distance >6 m). Suitable for feature elements and requires good fabrication technique, enhanced weld treatment, connection and fabrication details, tolerances for gaps and copes. Applications include high-level roofs or ceilings, retail and architectural applications that can command the 40-100% cost premium.

AESS 3 (Feature Elements – viewed at distance ≤6 m). In this category the architect begins to showcase the art of metalworking. Welds are generally smooth but visible and minor blemishes are acceptable. Tolerances are tighter than normal standards and – as the structure is likely to be touched by the public – it requires a smooth, uniform finish and appearance. AESS 3 may be found in airports, shopping centres, hospitals and lobbies where it attracts a cost premium ranging from 60-150% above SSS.

Tempus Two Vinyard, Hunter Valley: Galvanized steel at AESS 3 standard was used in this outdoor undercover seating area. Highly visible and accessible to the public, surfaces needed to be smooth with a consistent and visually appealing finish.

AESS 4 (Showcase Elements). Used where the form will be the only feature showing in an element. Welds are ground and filled, with edges ground square and true. All surfaces are sanded and filled. Tolerances are more stringent at half those allowed for SSS. Welding is used extensively for joints, which are shop-prepared to maintain high quality. The coating finish is usually shop-applied to achieve the best quality outcome. Protection of the structure during transport and erection becomes a major issue and it is no surprise the cost premium is high at 100-250%.

AESS C (Custom Elements). This category allows flexibility in the selection of characteristics, which can be drawn from any of the other categories. For example, custom elements may include 1.1 Surface Preparation; 2.2 Half standard fabrication tolerances; 3.1 Mill marks removed; and 4.2 Welds Contoured and Blended. The final surface finish may be specified as hot dip galvanized 'Special Surface Quality'. In that case an additional Custom Element may be required to specify the grade of

steel needed to achieve a consistent coating. The range of premium from a low 20 % to a high 250% is consistent with the range of Custom Elements that may be selected.

<u>Galvanizing of AESS structures.</u>
Galvanizing is increasing popular as a finish for AESS structures. Whilst the patina and texture can provide a striking finish, the primary role of a hot dip galvanized coating is to provide corrosion protection. Galvanized coatings will vary in colour depending on the grade of steel, its shape and thickness, the application technique and the skill of the operator.

Industrial Galvanizers has been involved in many architectural projects where consistency of surface finish is of paramount importance. It is vitally important that there is communication between architect, engineer, fabricator and galvanizer for a successful and cost-effective outcome. The earlier such communication begins the better will be the result. The galvanizer can provide advice on the size of sections that can be effectively dipped as a 'single dip' as well as recommending suitable schedules for the venting and draining of hollow sections. Similarly, thinner steel sections are susceptible to distortion when immersed in molten zinc, but Industrial Galvanizers representatives can provide advice on how this can be avoided or minimised.

Olympic Tennis Centre, Homebush: Galvanized steel at AESS 3 standard was used in this outdoor arena. High volume public pedestrian use called for smooth steel surfaces. Industrial Galvanizers provided a Special Surface Quality finish for this high profile venue.

All of these requirements can be more easily accommodated at the design and detailing stage than when the work has been fabricated and delivered to the galvanizer.

47. ARCHITECTURALLY EXPOSED STRUCTURAL STEEL AND GALVANIZING

Hot dip galvanizing can be applied to complex shapes of many sizes, with a zinc coating applied in hours to all internal and external surfaces.

A premium galvanized coating depends on surface preparation. For a Special Surface Quality finish, removal of weld spatter and proper attention to welds is required, prior to grit blasting of the steel. On delivery to the galvanizer, the steel must be 'jigged' (hung on moveable frames) in such a way to allow for proper drainage and – if hollow – venting of the work. Failure to do this with skill and attention to detail will result in uneven coating, inconsistent colour, damage to the product and increased cost.

The hot dip galvanising process ensures the removal of grease, dirt and scale by processing through a series of tanks containing caustic or acid solutions and rinse water.

The clean steel components are immersed in a pre-flux solution and then in a bath of molten zinc at 465oC. At this time there is a metallurgical reaction between the steel and the zinc, with a series of zinc-iron alloy layers being formed. This tough alloy coating is highly durable and provides three-way protection to the underlying steel:-

1. An external zinc patina is formed that prevents corrosion;
2. The zinc coating provides galvanic protection and is preferentially sacrificed to protect the underlying steel;
3. The alloy coating is tough and resists scratches that would render a thin paint coating vulnerable to attack by corrosion elements.

It is not necessary to further treat hot dip galvanized steel, though it can be successfully painted or powder coated to enhance aesthetics or increase longevity in specific environments.

It should be recognized that galvanised steel changes colour over time as the zinc patina develops. What comes out of the galvanizing bath as a bright, shiny finish will change to a dull grey surface over a period of time under normal atmospheric conditions. This is a natural and desirable outcome of galvanizing, but often a surprise to those unfamiliar with the process.

Care should be taken when specifying hot dip galvanizing for AESS. If cosmetic (aesthetic) appearance is of concern, the architect or specifier should select an experienced galvanizer – such as Industrial Galvanizers - and discuss any concerns about aesthetics (surface appearance) prior to any galvanizing. In most cases, Industrial Galvanizers can provide Visual Samples of the dipped components, as per the AESS Category Matrix.

Summary

Use of AESS is increasing and it is no longer just used for high profile projects. AESS is appearing in shopping centres, hospitals and super-store warehouses.

There has been a growing need to categorise and standardise the requirements and terminology around the use of AESS. The recently developed Guide for Specifying Architecturally Exposed Structural Steelwork (Boake) provides a consistent framework for architects, engineers, fabricators and coating specialists. It provides a categorised framework for communication between the parties before and during construction.

Further, it shows that AESS standards do not need to be equally applied across a project: AESS 2 may be applicable in some spaces, and AESS 4 prescribed in more visible areas. One outcome of this is in controlling the cost of the project, which could be prohibitive if the same high standard was maintained in areas where it is not required.

The finish coating of AESS is a key element. Where galvanizing is specified it is important that the architect, engineer and fabricator begin a dialogue with the galvanizer as early as possible. This will ensure that the correct steel chemistry is specified and that design considerations are included for the proper handling and processing of galvanized AESS.

In this way, the superior finish required of an AESS structure can be delivered, resulting in long-lasting and iconic infrastructure.

References

Australia/New Zealand guide for specifying architecturally exposed structural steelwork, Boake, T.M., Published by ASI / SCNZ, October 2012

Architecturally Exposed Structural Steel, Modern Steel Construction, May 2003

Architecturally Exposed Structural Steel (AESS): Sample Specification (for Engineers), Australian Steel Institute, 2012

Architecturally Exposed Structural Steelwork (AESS): Code of Practice (for Fabricators), Australian Steel Institute, 2012