The Basics of Hot Dip Galvanized Steel

First and Last Line of Defence

Galvanizers Association of Australia

galvanizers
ASSOCIATION OF AUSTRALIA

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About the Galvanizers Association of Australia

The Galvanizers Association of Australia (GAA) comprises many of the leading galvanizing companies throughout Australia, New Zealand and Asia.

The GAA is an industry Association established in 1963 to represent galvanizing companies and to provide technical consulting services on a not for profit basis.

The Association's objectives are to provide the highest standards in design and quality of galvanized products and to assist consumers achieve the economics inherent in the correct design and application of galvanized products.

We provide free technical publications and practical assistance on all aspects of design, application, process, bolting, welding and painting of galvanized steel. Further information is readily available from the GAA or any of the leading galvanizers listed in our members' directory.

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Prevention of Corrosion

When iron is extracted from its ore, a fundamental tendency of nature is abruptly reversed. Unless protected, iron and steel will corrode in most environments, slowly returning to their natural state.

Corrosion prevention is an essential factor in the economic utilisation of steel. Provision of the appropriate protective coating can bring initial savings plus substantial economies in service, due to reduction or elimination of maintenance and lost service time, and by deferring the replacement date of structures and equipment.

In suitable applications, galvanizing provides ideal corrosion protection for steel – no other coating matches galvanizing's unique combination of low first cost, ease of inspection for coating quality, durability, predictable performance, low maintenance, and resistance to abrasion and mechanical damage.

This guide is an **introduction to hot dip galvanizing in atmospheric conditions**. Further details can be obtained from "**After Fabrication Hot Dip Galvanizing**" – a practical reference guide for designers, specifiers, engineers, consultants, manufacturers and users, available from the GAA (www.gaa.com.au). Information on the performance of **hot dip galvanized reinforcement in concrete** and **painting over galvanizing** are available separately; also from the GAA.

Costs of Corrosion

Increased Taxes

In 2001, a major study on the costs of corrosion in the US was conducted by a government task force. They discovered the direct cost of corrosion to the US economy was 3% and estimated the indirect cost as adding another 2% onto the total. These figures have since been confirmed by many other studies around the world, including Australia where the annual costs are thought to be $39 - $65 billion per annum.

By extending the life and durability of steel, not only will capital investments be less, but also taxpayers will be spent more wisely. When you design and specify for corrosion protection, do not think only of initial costs, but also consider life-cycle costs.

Natural Resources

Corrosion, if unchecked, contributes to waste, with dramatic environmental implications through process and plant failure. Further, the increased energy implications in replacing corroded structures are very significant in both financial and environmental terms. Specifiers must design and specify for the longest product life possible. By doing this, your project will not need to be replaced or rehabilitated as frequently. Early project failures require unnecessary consumption of natural resources. By protecting steel against corrosion, resources such as iron ore and energy will be saved.

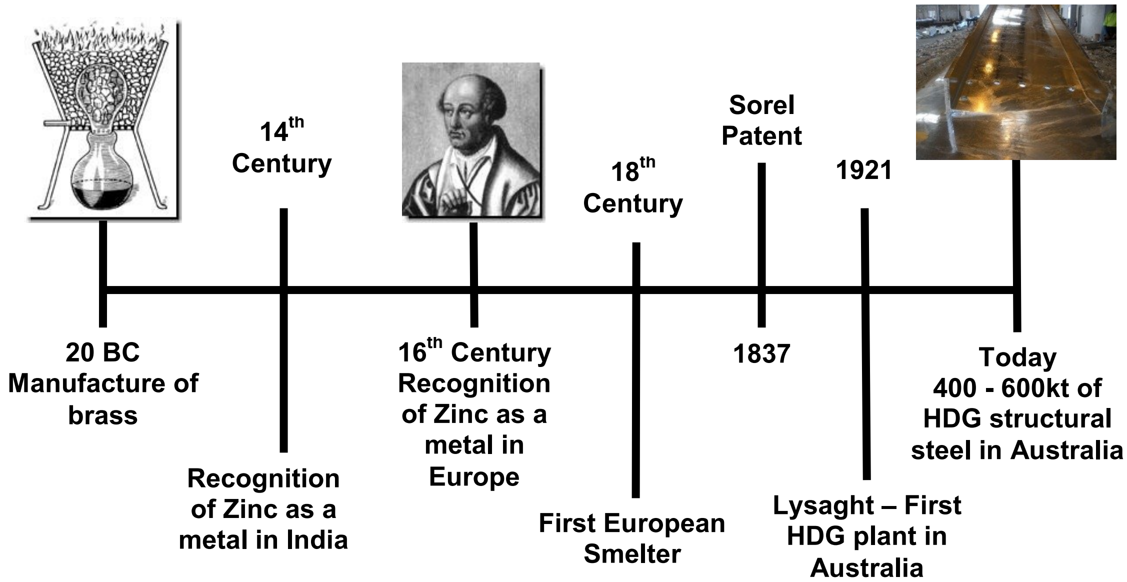
Increased Hazards

Corrosion control and public safety go hand-in-hand. For example, corrosion is one of the leading causes of pipeline accidents in the world. When a pipeline fails, the results can be devastating in terms of loss of life, property damage, and environmental contamination.

Public Outcry

The public outcry and inconvenience is the verbalization of many indirect costs. How many times have you been held up on the way to or from work because there are emergency road works due to a burst pipe or the trains are delayed due to a signal malfunction? – These are not preventative or planned maintenance works, but emergency fixes. Many of these faults are due to corrosion.

A Brief History of Galvanizing



It is known that around 20 BC – 14 AD, brass was made by the Romans from zinc and copper. By the 14th century, zinc was recognised as the 8th metal by the Indians. Zinc was recognized in Europe as a separate metal in the 16th century when Agricola (1490 – 1555) observed when a metal called "zincum", produced in Slesia and Paracelsus (1493 – 1541), stated clearly that "zincum" was a new metal.

In 1743, the first European zinc smelter was established in Bristol in the United Kingdom using a vertical retort procedure. A major technological improvement was achieved with the development of the horizontal retort process in Germany, which led to the erection of smelting works in Slesia, Liege, Belgium and Aachen, the Rhineland and the Ruhr areas in Germany.

In 1837, a French engineer Stanislaus Tranquille Modeste Sorel took out a patent for the early galvanizing process and in 1921, the first galvanizing plant opened in Australia by Lysaght.

Today, around 500,000 tonnes of steel are hot-dip galvanized in Australia every year, although many more tonnes are produced in continuous lines, such as for BlueScope Steel's Colorbond® products.

How Hot Dip Galvanizing Protects Against Corrosion of Steel

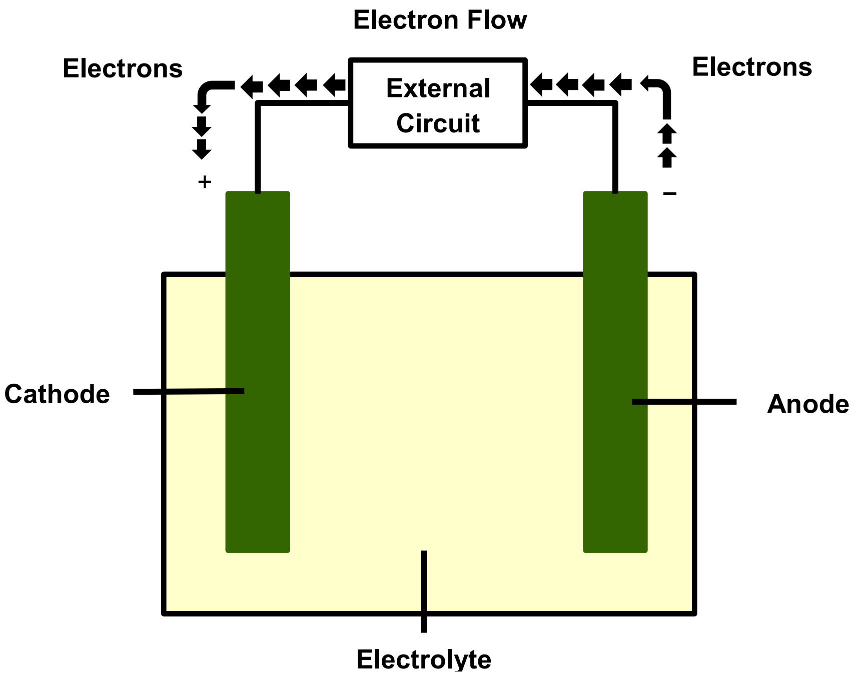
Corrosion can simplistically be viewed as the tendency for the metal, after production and shaping, to revert to its lower, more natural energy state of ore. This tendency is known as the *Law of Entropy*.

The ***Galvanic Series of Metals*** is a list of metals and alloys arranged according to their relative potentials in a given environment.

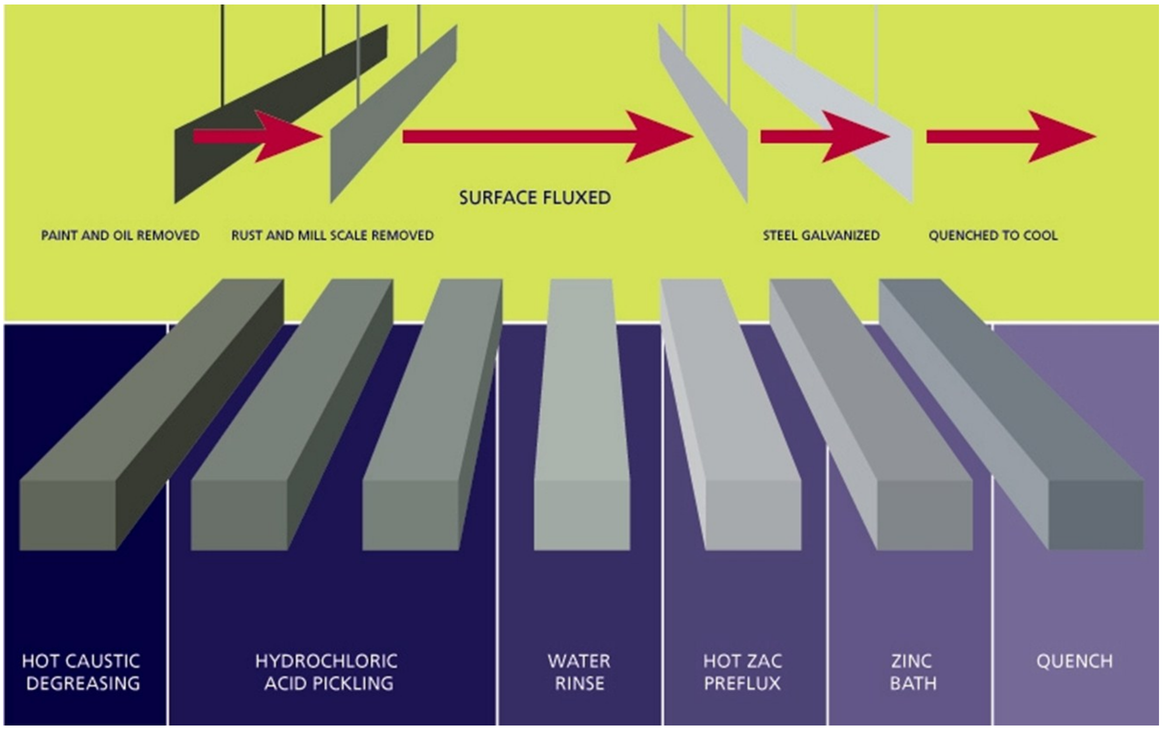
Corroded End (anodic or less noble)
Magnesium
Zinc
Cadmium
Aluminium
Steel
Lead
Tin
Nickel
Brass
Bronzes
Copper
Stainless Steel (passive)
Silver
Gold
Platinum
Protected End (cathodic or more noble)

The table (left) shows a series of metals arranged in order of electrochemical activity in seawater (the electrolyte). This arrangement of metals determines what metal will be the anode and cathode when the two are put in an electrolytic cell. Metals higher on the scale provide cathodic or sacrificial protection to the metals below them. Therefore, zinc protects steel.

The scale indicates magnesium and aluminum also should protect steel. In most normal applications, magnesium is highly reactive and is too rapidly consumed. Aluminum forms a resistant oxide coating and its effectiveness in providing cathodic protection is limited.



The Hot Dip Galvanizing Process



The hot dip galvanizing process involves dipping of suspended steel articles into a series of cleaning baths prior to dipping the cleaned steel into a bath of molten zinc, which reacts with the steel to form the galvanized coating. The individual steps are described below.

Hot Caustic Degreasing

The first cleaning step, degreasing, is usually a hot alkali solution that removes organic contaminants like dirt, water-based paint, grease and/or oil. After degreasing, the article goes through a water rinse. Note that any epoxy paints, vinyls, or asphalt coatings must be removed by mechanical means (e.g. grit blasting) before steel is taken to the galvanizer.

Pickling

Next the steel is moved to the pickle bath, an acidic solution of either ambient hydrochloric or heated sulfuric, that removes iron oxides and mill scale from the surface of the steel. After pickling, the steel is rinsed again.

Fluxing

The steel then moves into the flux tank. The flux serves two purposes; first, the lightly acidic solution cleans any remaining iron oxides, and second it provides a protective layer to prevent any iron oxide formation prior to immersion in the galvanizing kettle.

Each dipping pre-treatment process must be correctly undertaken, as if any oil or oxide remains on the surface, the metallurgical reaction of the formation of the galvanized coating will not occur.

Hot Dip galvanizing

The true “galvanizing” phase of the process consists of completely immersing the steel in a minimum 98% pure zinc bath. The bath temperature is maintained at around 450°C to 460°C). The steel is lowered at an angle by crane hoist. This allows air to escape from tubular shapes or pockets that may be within the design of a fabricated piece and of course permits the molten zinc to displace the air.

Approximately 5 – 7 minutes after complete immersion (depending on the size of the articles), the steel reaches the bath temperature and the metallurgical reaction is complete.

The coating is made up of different layers of zinc-iron alloys with a top layer of pure zinc, which is a result of its removal from the molten zinc bath.

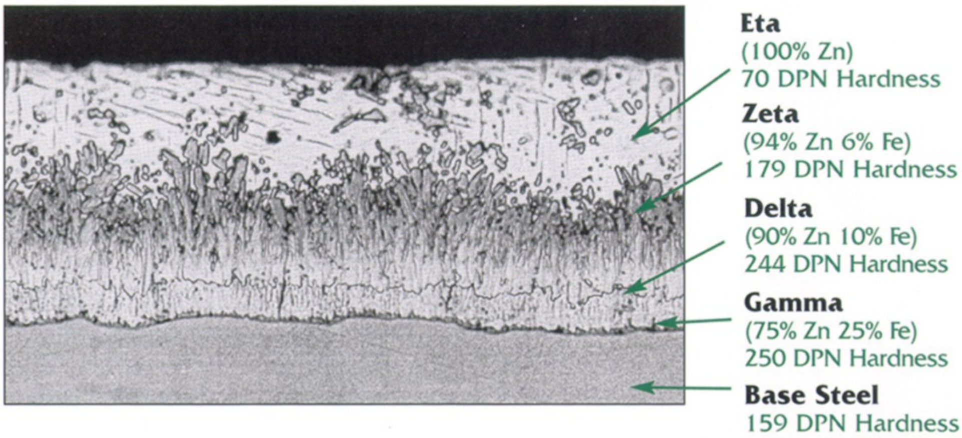
Quenching

The final step in most hot dip galvanizing processes is a quench to promote passivation of the zinc surface and to control the growth of the zinc-iron alloy layers.

A typical zinc bath, including fume hood, showing removal of a large I beam on completion of the galvanizing process

Coating Characteristics

The formation of the galvanized coating on the steel surface is a metallurgical reaction, in that the zinc and steel combine to form a series of hard intermetallic layers, prior to the outside layer being, typically, 100% zinc (see photomicrograph below).



The photomicrograph is a cross-section of a galvanized steel coating. The first zinc-iron alloy layer, the Gamma layer, is approximately 75% zinc and 25% iron. The next layer, the Delta layer, is approximately 90% zinc and 10% iron. The third layer, the Zeta layer, is approximately 94% zinc and 6% iron. The last layer, which forms as the material is withdrawn from the zinc bath, is identical to the zinc bath chemistry, i.e. pure zinc. As you can see, the Gamma, Delta and Zeta layers form approximately 60% of the total galvanized coating, with the Eta layer making up the balance.

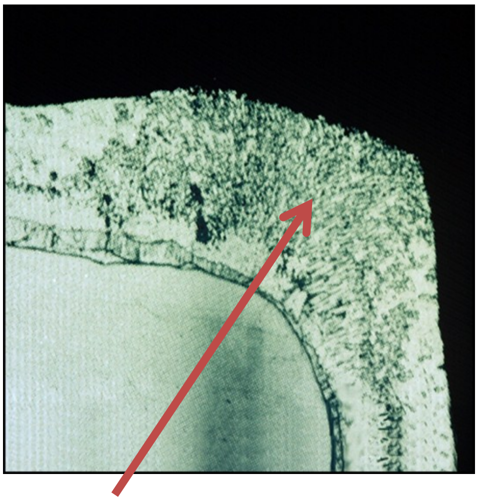
During the reaction of the steel with the molten zinc in the galvanizing bath, two factors will have a predominant effect on the growth of the coating. The galvanized coating thickness is primarily determined by both the thickness of the steel and the chemical composition of the steel being coated. This is important for two reasons: (1) in general, the thicker the zinc coating, the longer the corrosion protection provided and (2) excessively thick coatings may have less adherence and bond than coatings of normal thickness.

The steel chemistry, particularly the levels of silicon, phosphorus, manganese, and carbon, influence coating characteristics. The GAA has produced an Advisory Note to assist in understanding these issues.

The surface of the steel also influences the coating growth, although not as significant as steel chemistry. Rough coatings often produce thinner coatings because the intermetallic layers will grow into each other, stunting their growth. However, in some cases, certain chemistries and a rough coating will produce thicker coatings.

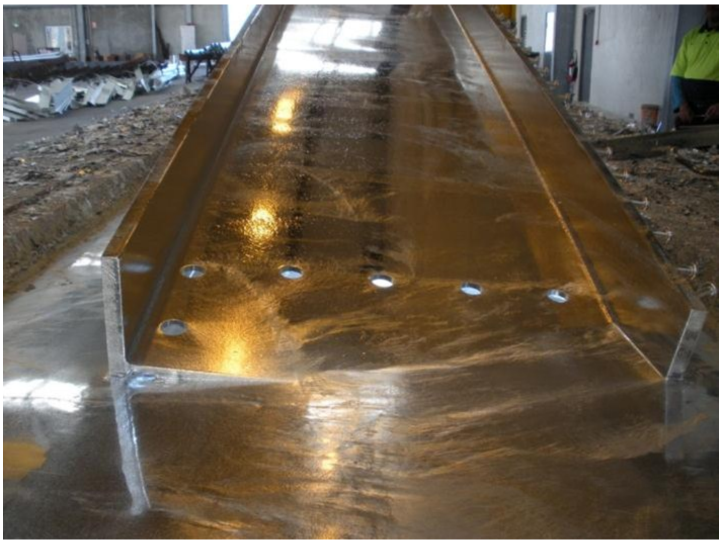
Edge Protection

As depicted in the photomicrograph of a cross-section of the edge of a galvanized part, the galvanizing process naturally produces coatings at least as thick at the corners and edges as the coating on the rest of the part. This is because the reaction between iron and zinc is a diffusion reaction and thus the crystalline structure of the coating forms perpendicular to the steel surface. As coating damage is most likely to occur at the edges, this is where added protection is needed most. Brush- or spray-applied coatings have a natural tendency to thin at corners and edges.



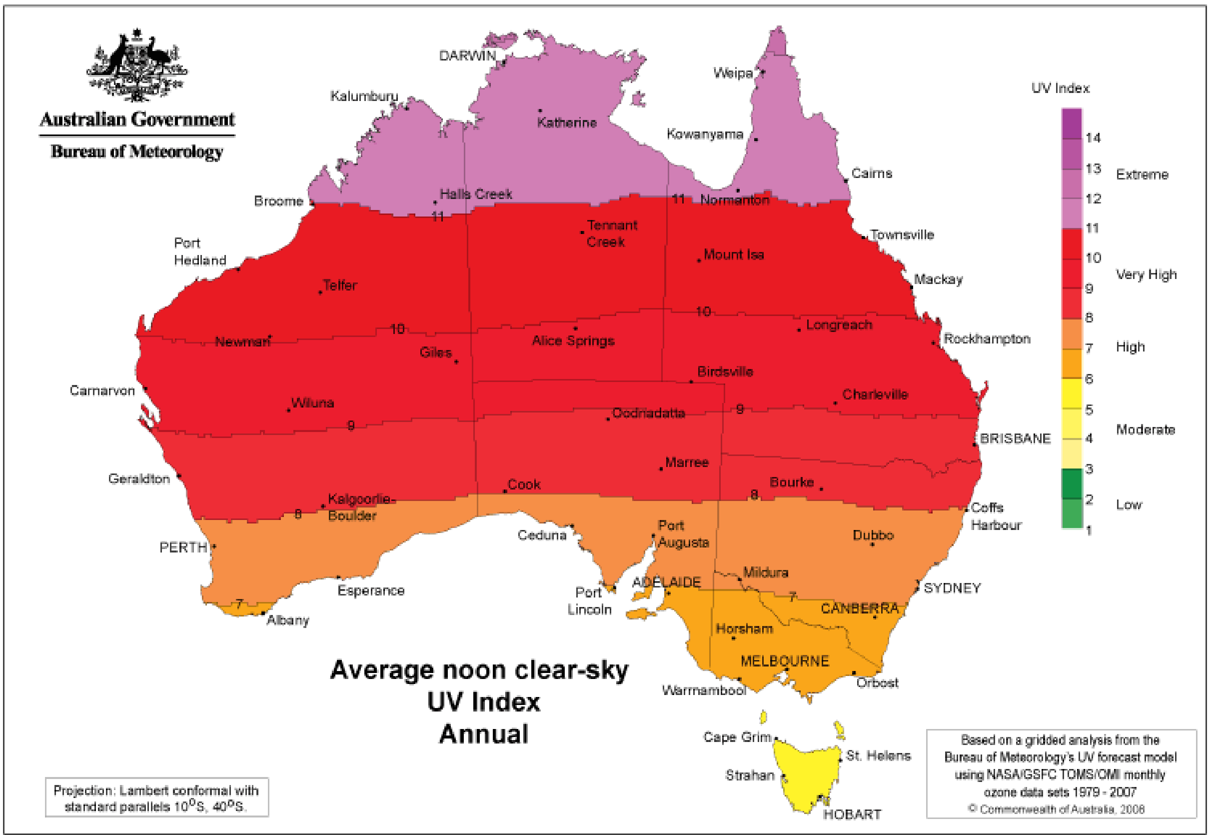
The coating is at least as thick at the edge or corner because the coating grows perpendicular to the surface

Complete Coverage



Because the galvanizing process involves total immersion of the material into cleaning solutions & molten zinc, all interior & exterior surfaces are coated. This includes the insides of hollow and tubular structures, and the threads of fasteners. Complete coverage is important because corrosion tends to occur at an increased rate on the inside of some hollow structures where the environment can be extremely humid and condensation occurs. Hollow structures that are painted have no corrosion protection on the inside. Additionally, fasteners with no protection on the threads are susceptible to corrosion, and corroded fasteners can lead to concerns about the integrity of structural connections.

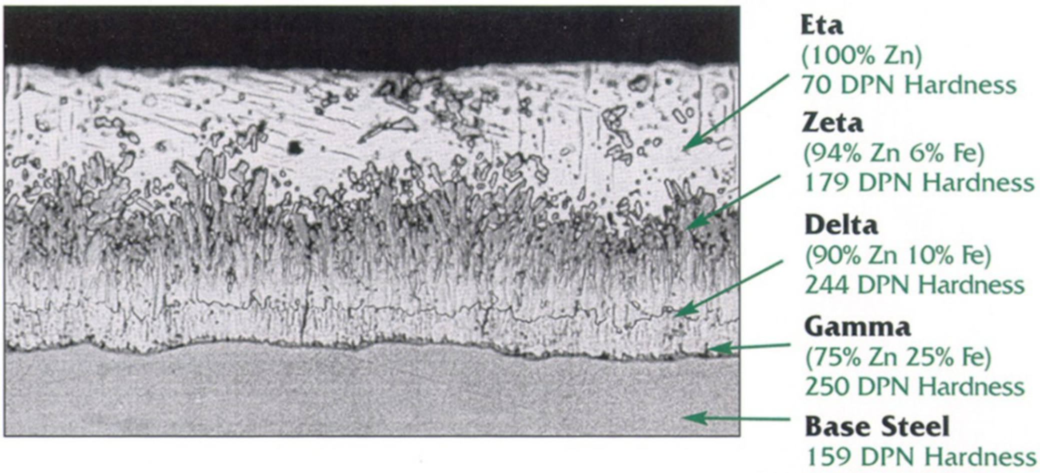
Galvanized Coatings are Not Affected by Ultra-Violet (UV) Light



Australia's climate is recognized as very high to extreme for UV throughout much of the year. The figure above shows the average UV experienced across the continent.

Hot dip galvanized coatings are not affected by UV, unlike most paints, and therefore no special precautions need to be taken.

Abrasion Resistance



This photomicrograph lists the hardness of the intermetallic layers, as a Diamond Pyramid Number (DPN). As you can see, the Gamma, Delta, and Zeta layer are all harder than the base steel, which gives hot-dip galvanizing its great abrasion-resistance.

Inspecting Galvanized Steel

Inspecting galvanized steel is a simple process. Zinc will not adhere to unclean steel; therefore, a visual inspection of the product will provide a good assessment of the quality of the coating. There are additional tests for coating thickness and adherence that can also be performed.

Coating Thickness Measurement

The coating thickness is usually tested by using a magnetic thickness gauge. The minimum coating thicknesses and sampling requirements are contained in the appropriate specification for the product (AS/NZS 4680 and AS1214) – see also pages 24-25 for the sample specification.

AS/NZS 4680 provide guidelines for the number of specimens that must be measured based on the total lot size of the job.

The most accurate and arguably the most easy thickness gauge to operate is an electronic magnetic thickness gauge. No individual reading of a specimen can be less than one coating grade lower than the required coating grade and the average must be equal to or more than the required coating grade.

Multi-specimen articles of differing steel thicknesses shall be measured separately and are required to meet their respective minimum coating thickness values as specified by AS/NZS 4680, i.e. values should be in accordance with the appropriate material category and measured steel thickness.

Adherence Test

An adherence test is not part of the Standard but can be performed using a stout knife. If the galvanized coating cannot be removed by pressing firmly with a stout knife it is sound.

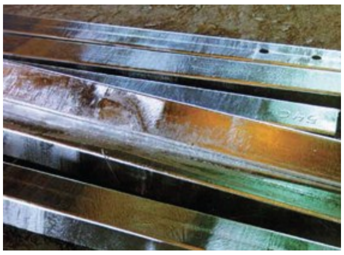
Test Certificates

Members of the Galvanizers Association of Australia are ordinarily only able to supply test certificates if they have been requested prior to production of the galvanized articles. However, they would ordinarily supply a certificate of compliance stating that production was carried out to the requirements of AS/NZS 4680.

The key difference between a test certificate and a certificate of compliance is that test certificates will state the actual galvanized thickness for all parts as per the detailed requirements of the standard, while a compliance certificate will not record actual measurements, as compliance would normally be ascertained from a sampling program.

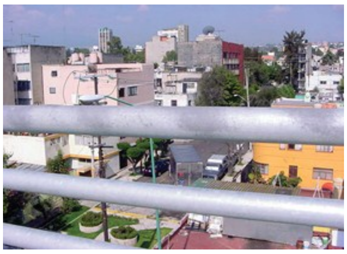
Appearance of New Galvanized Coatings

Shiny



Matte Grey

Spangled



Shiny & Dull

Galvanized coatings can take on a number of different appearances. Commonly, steel chemistries with atypical levels of silicon, phosphorus, manganese & carbon tend to produce galvanized coatings made up primarily of zinc-iron intermetallic layers, with little or no free zinc layer. When no free zinc layer is present, a darker, matte gray appearance is common. Above are some examples of different coating appearances, each of these appearances were present right after galvanizing.

Visual: The coating can be bright and shiny, spangled, matte gray, or combination of all of these (see photos below). The matte gray appearance may be due to the absence of the free zinc layer or could be a difference in cooling time.

Adherence: Atypical coatings (dark gray) tend to be thicker than typical galvanized coatings. While it is true, the thicker the coating, the longer the service life, excessively thick coatings that may result from atypical steel chemistries can be prone to adhesion problems.

Corrosion Resistance: Galvanizing is specified for corrosion prevention. While a matte appearance may occur, differences in appearance do not affect the corrosion protection provided. The dark gray coatings' corrosion resistance is equal to the corrosion resistance of bright and shiny coatings.

When possible, galvanizers should be advised of the grade of steel selected in order to determine whether to utilize special galvanizing techniques that ***may*** mitigate the effect of atypical chemistries.

Weathering of Galvanized Steel in the Atmosphere

Photo taken 18 December 2002

Photo taken 28 March 2003

(photographs courtesy American Galvanizers Association)

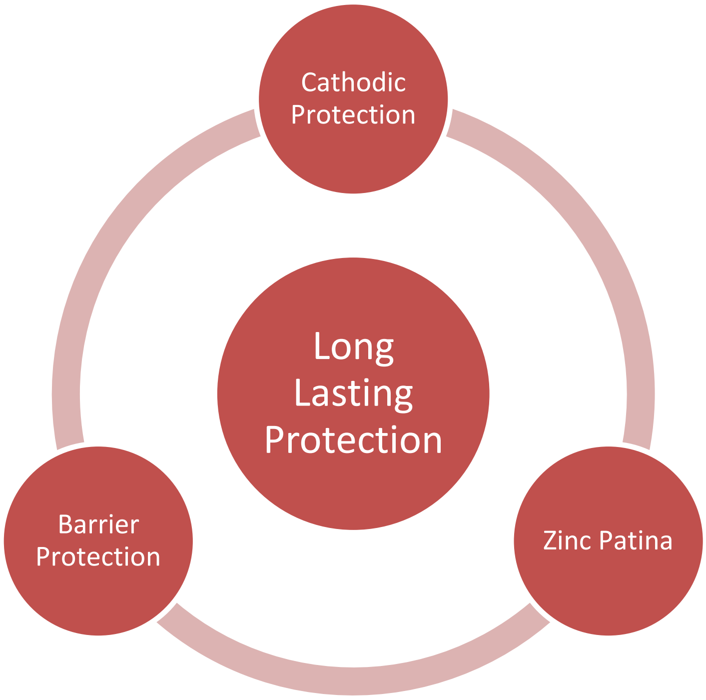
Regardless of the coating appearance immediately after galvanizing, over time all galvanized coatings take on a uniform matte gray appearance. The photos above illustrate how galvanized pieces with different appearances will weather and blend in with surrounding galvanized steel upon installation.

The dull-gray section of guardrail on the left side of the top picture was taken from the interior of a stack of hot-dip galvanized guardrail exposed to moisture (humidity or rain) but not exposed to freely flowing air. As a result, these sections of guardrail formed a zinc corrosion film (wet storage stain) over a period of one week. The shiny section of guardrail on the right side of the top picture was galvanized and stored under cover while exposed to freely flowing air. Both were galvanized in the same batch.

The lower photo depicts the same guardrail sections 3½ months after they were first attached to the concrete barrier. The left section of the guardrail now matches the right piece of guardrail that was originally bright and shiny.

When hot-dip galvanized steel with light to moderate wet storage stain is ultimately exposed to freely flowing air, the zinc corrosion products react with carbon dioxide to form the matte gray zinc carbonate film that we recognize as the stable patina that gives hot-dip galvanized steel its incredible resistance to corrosion. The section on the right progressed in a normal fashion to the zinc carbonate stage, and the corrosion protection provided by each section is identical.

The Three Ways Galvanizing Protects Steel from Corrosion



The three elements shown above (barrier protection, cathodic protection, and the zinc patina) are what provide galvanizing its long-lasting protection because:

- The zinc coating acts as a barrier against the penetration of water, oxygen, and atmospheric pollutants.
- The zinc coating cathodically protects the steel from coating imperfections caused by accidental abrasion, cutting, drilling, or bending.
- The zinc patina is impervious, and passive, which slows the corrosion rate of the zinc.

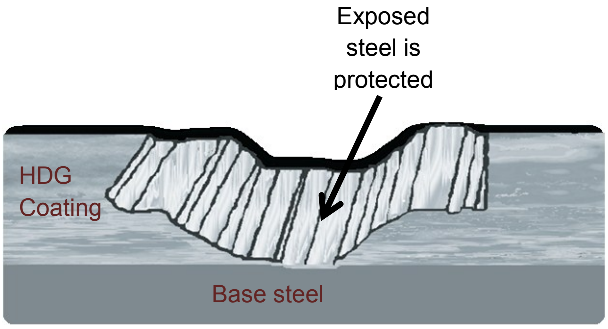
The zinc patina, which is a critical part of the galvanized coating's longevity, requires natural wet and dry cycles to form. Accelerated testing (commonly known as salt spray tests) do not accurately predict the life of a galvanized coating because they are conducted under a constant salt fog, inhibiting the formation of the passive zinc patina.

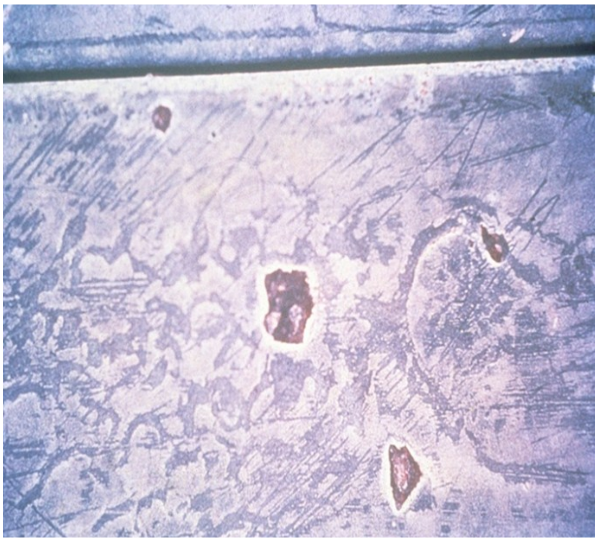
Barrier Protection

Like paints, the hot-dip galvanized coating provides barrier protection from corrosion. Barrier protection, as it name implies, protects against corrosion by isolating the steel from the electrolytes in the environment. As long as the barrier is intact, the steel will be protected and corrosion will not occur. However, if the barrier is breached, corrosion will begin. The impervious nature of zinc makes it a very good barrier coating. Furthermore, zinc corrodes approximately 1/10 to 1/40 the rate of steel depending on the environment, making the corrosion rate of a thin zinc coating equivalent to a much thicker steel piece.

Cathodic Protection – Sacrificial Zinc

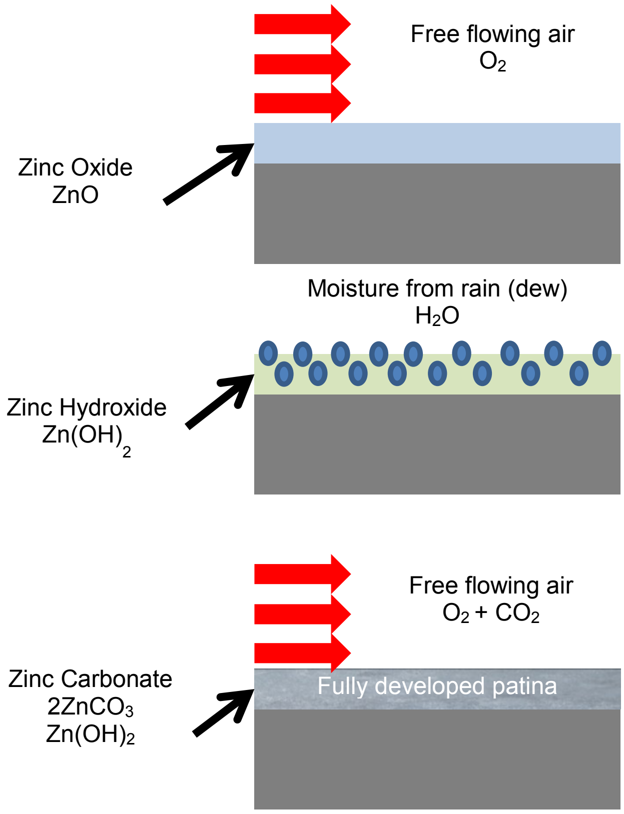
Zinc is anodic to steel; therefore, the galvanized coating will provide cathodic protection to exposed steel. When zinc and steel are connected in the presence of the electrolyte, the zinc is slowly consumed while the steel is protected. The zinc's sacrificial action also offers protection where small areas of steel may be exposed due to cut edges, drill holes, scratches, or as the result of severe surface abrasion during rough handling or job site erection. Cathodic protection of the steel from corrosion continues until all the zinc is consumed.





On the left is an example of cathodic protection of a transmission tower that was damaged by bullets in World War II. The photo, taken 40 years after the damage occurred, shows only minor localized corrosion and no structural damage.

The Growth of the Zinc Patina



The third factor that affords zinc its long-lasting corrosion protection is the zinc patina. The zinc patina is the formation of zinc corrosion byproducts on the surface of the steel. Zinc, like all metals, begins to corrode when exposed to the atmosphere. As galvanized coatings are exposed to both moisture and free flowing air, the corrosion byproducts will naturally form on the coating surface. The formation of the zinc patina is critical in terms of delivering long-term corrosion protection.

The silvery metallic appearance of galvanized material evolves to a matte, light gray as the zinc oxidizes. A corrosion-resistant film of zinc oxide forms usually within 24 hours of galvanizing. Zinc oxide is a thin, hard, tenacious layer and is the first step in the progressive development of the protective zinc patina.

When the whitish layer of zinc oxide is exposed to freely moving air, the surface reacts with moisture in the atmosphere to form a porous, gelatin-type, grayish-white zinc hydroxide. Depending on the type of exposure, the zinc hydroxide can form anywhere from 24 hours to three months after galvanizing.

During dry cycles of exposure, the zinc hydroxide reacts with carbon dioxide in the atmosphere and progresses into a thin, compact, tightly adherent layer of basic zinc carbonate. This grayish-white powdery film can take anywhere from three to 12 months to form. This progression to zinc carbonate enhances the excellent barrier protection afforded by the galvanized coating. Because the zinc patina is relatively insoluble, it prevents rapid atmospheric corrosion of the zinc on the surface of galvanized steel underneath the patina.

The rate of formation of the zinc patina depends not only on the amount of moisture in the atmosphere, but also on the period during which the zinc surface remains wet. The rate at which the carbon dioxide reacts with the zinc hydroxide to form zinc carbonate also determines the rate of formation of the zinc patina. The patina formation is progressive: There will not be a layer of zinc oxides and then a layer of zinc hydroxides.

Performance of Hot Dip Galvanized Steel in Atmospheric Conditions

Factors Influencing the Corrosion of Metals

There are two key factors that influence the corrosion of metals; being the macro-environment or general atmospheric conditions experienced in a local area and the micro-environment or the very specific conditions experienced by a piece of steel in its operating environment.

Macro Environment	Micro Environment
Industrial pollutants and chemical attacks (e.g. Sulfur Dioxide (SO_2))	Shelter from rain and regular washing
Temperature and humidity (time of wetness)	Prolonged surface wetness
Proximity to the sea and prevailing winds (chloride availability)	Abrasion and erosion

Macro Environment

Industrial Pollution

Industrial pollution is not a major cause of corrosion of metals, including zinc, in Australia. Our air, as reported by sulfur dioxide levels by the Federal Government in 2011, is typically quite clean. However, very close to chemical plants and other polluting industries it would be wise to obtain local readings if it is known that these facilities emit higher levels of airborne pollutants.

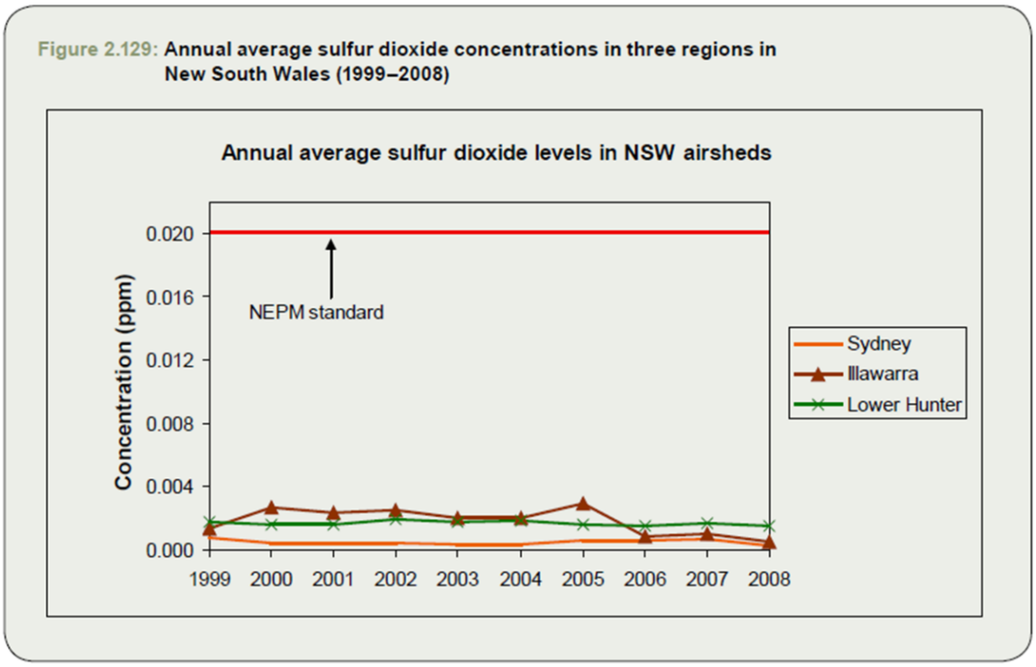
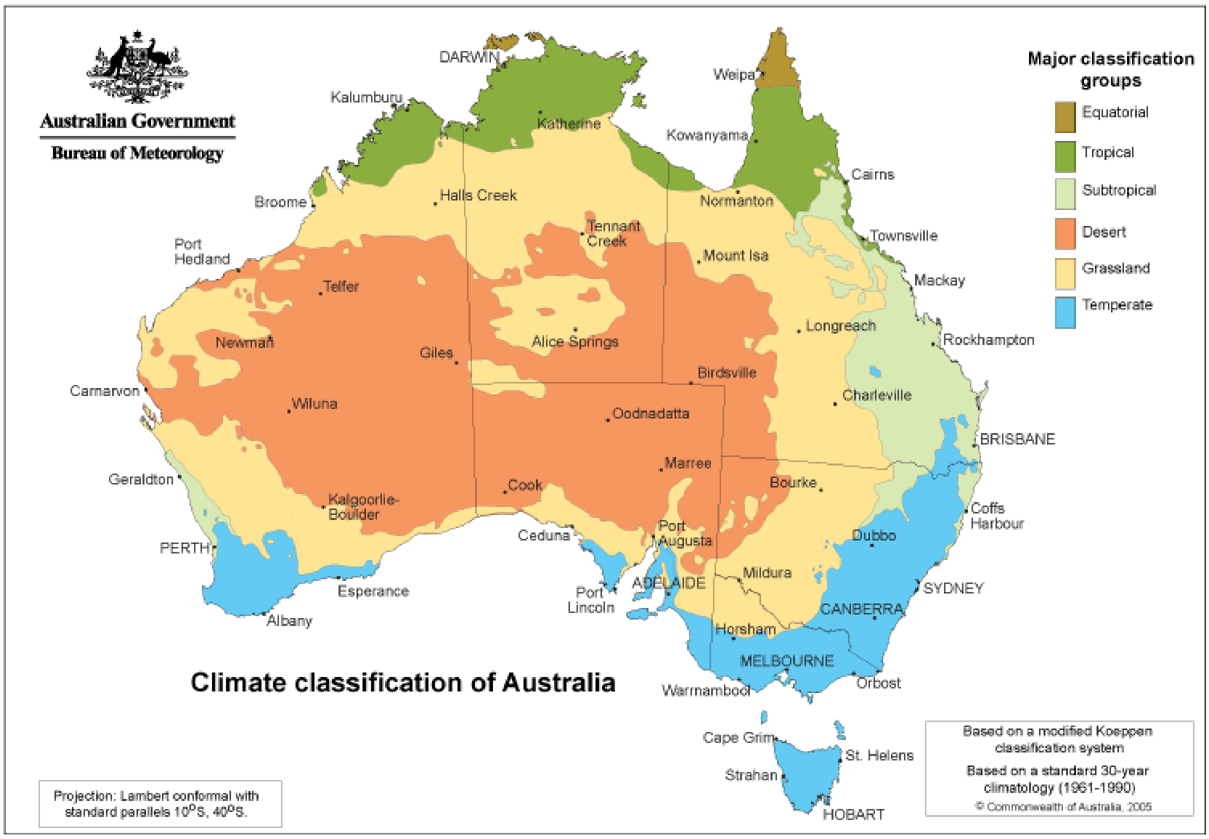
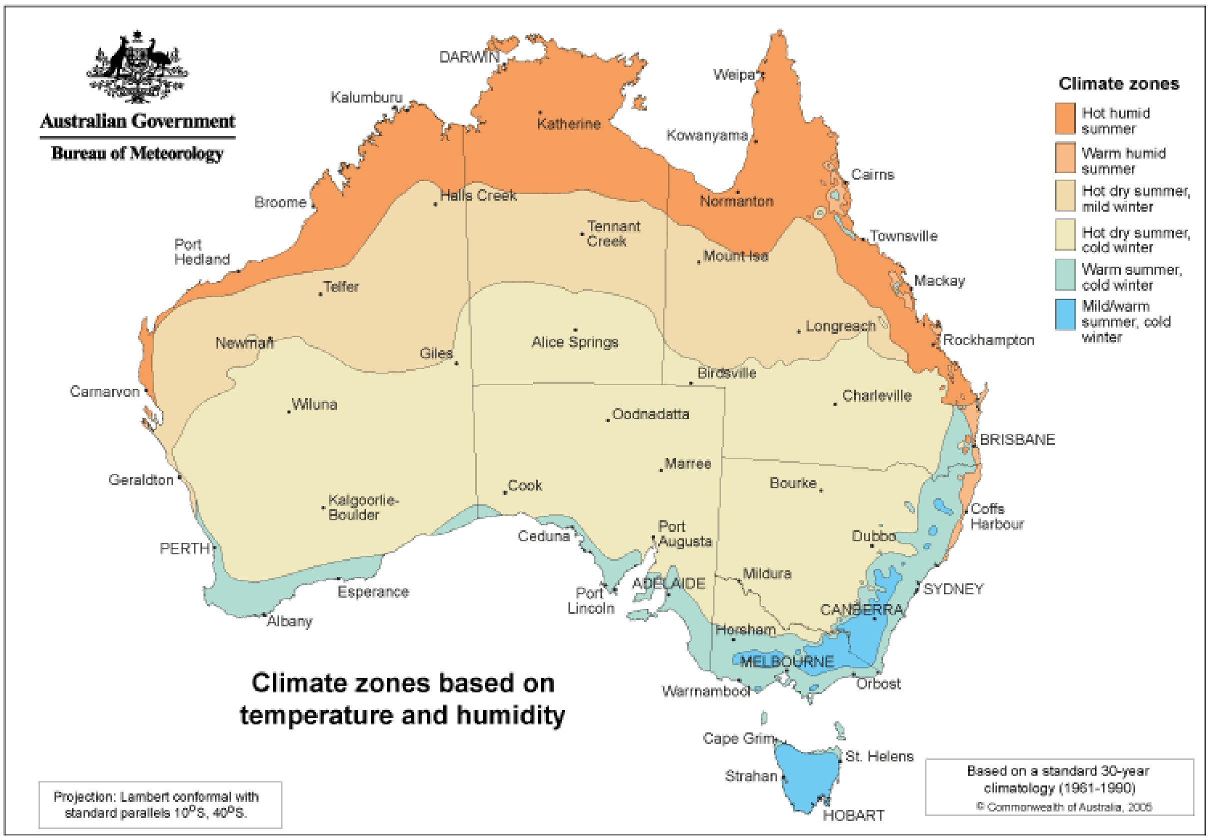


Figure 2.129 from "State of the Air in Australia 1999–2008", Department of Sustainability, Environment, Water, Population and Communities, January 2011. This result is typical for all measured major cities in Australia

The Influence of Temperature and Humidity





In Australia the major population centres are located in the temperate (Sydney, Melbourne, Adelaide) or sub-tropical (Brisbane, Perth) zones, as shown on the maps above. It is known that, in general, the influence of climate is not pronounced in Australia.

The length of time for which the relative humidity (RH) exceeds 80% at a temperature greater than 0°C has been used to estimate time of wetness by the international standards for corrosion. In most cases in Australia, time of wetness is not the major influence on corrosion rates.

Airborne Chlorides (Salt)
The deposition of chlorides in coastal areas is strongly dependent on the variables influencing the transport inland of sea salt, such as wind direction, wind velocity, local topography, wind sheltering islands outside the coast, distance of the site from the sea, etc.

Micro-Environment

The micro-environment around a structure has consistently been shown to be an important element in the corrosion of metals. In many cases, the micro-environment can be influenced by design factors, while in other cases it can be influenced by external factors such as industrial processes.

Shelter from Rain and Regular Washing
Surfaces that are not sheltered or rain-washed in marine atmospheric environments where chlorides are deposited can experience a higher corrosivity category due to the presence of hygroscopic salts.

Research shows that this can increase corrosion rates in the sheltered areas by three to five times over those experienced in the washed areas of the same structure. This issue is not confined to galvanized coatings and designers should consider this aspect early on in the design phase, especially in relation to crevice corrosion.

Prolonged Surface Wetness (Ponding)
Galvanized steel should not be allowed to sit in ponding water – generally, this will result in accelerated corrosion.

Design of structures using concrete pads for columns or epoxy paints or wraps as additional protection over the top of the galvanized coating for embedded structures is well understood and can result in a practical life equal to the design life.

Abrasion and Erosion
Hot dip galvanized steel provides considerable increased abrasion protection over bare steel and painted structures. Even so, the designer should consider the particular micro-environment to understand what affect, if any, it will have on the life of the galvanized structure.

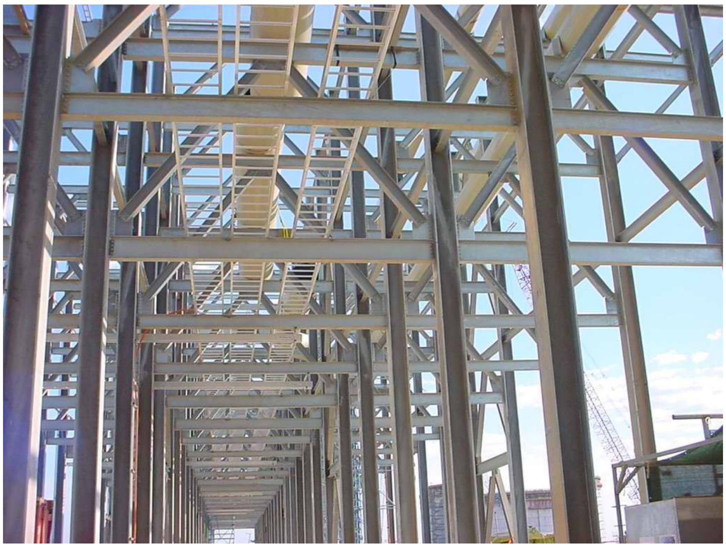
Standard Corrosion Rates for Metals in Atmospheric Conditions

ISO 9223		Typical environment	Corrosion rate for the first year of exposure (µm/annum)	
Category	Description		Mild steel	Zinc
C1	Very low	Dry indoors	≤1.3	≤0.1
C2	Low	Arid/Urban inland	>1.3 to ≤25	>0.1 to ≤0.7
C3	Medium	Coastal or industrial	>25 to ≤50	>0.7 to ≤2.1
C4	High	Calm sea-shore	>50 to ≤80	>2.1 to ≤4.2
C5	Very High	Surf sea-shore	>80 to ≤200	>4.2 to ≤8.4
CX	Extreme	Ocean/Off-shore	>200 to ≤700	>8.4 to ≤25

The table above uses the internationally recognised standard corrosion rates for mild steel and zinc metal (ISO 9223:2012). Note that the corrosion rate for the first year is slightly higher than the measured long-term averages.

In addition, it is known that the environment experienced by the metal in the first few weeks of exposure heavily affects the rate of corrosion in the first 12 months. This normally 'settles down' and long-term rates are usually unaffected by the first exposure rate.

The Categories are somewhat arbitrary to provide guidance to designers on expected corrosion zones, hence the significant variation of corrosion rates within each zone. If a designer needs information that is more accurate then he or she should seek out specific testing data for the location concerned. It is important that the testing data for a location be taken over at least 12 months. Salt spray tests must not be used to determine long-term outcomes, as they do not allow zinc to develop the patina required for long-term protection.



Durability of Hot Dip Galvanizing in Atmospheric Conditions

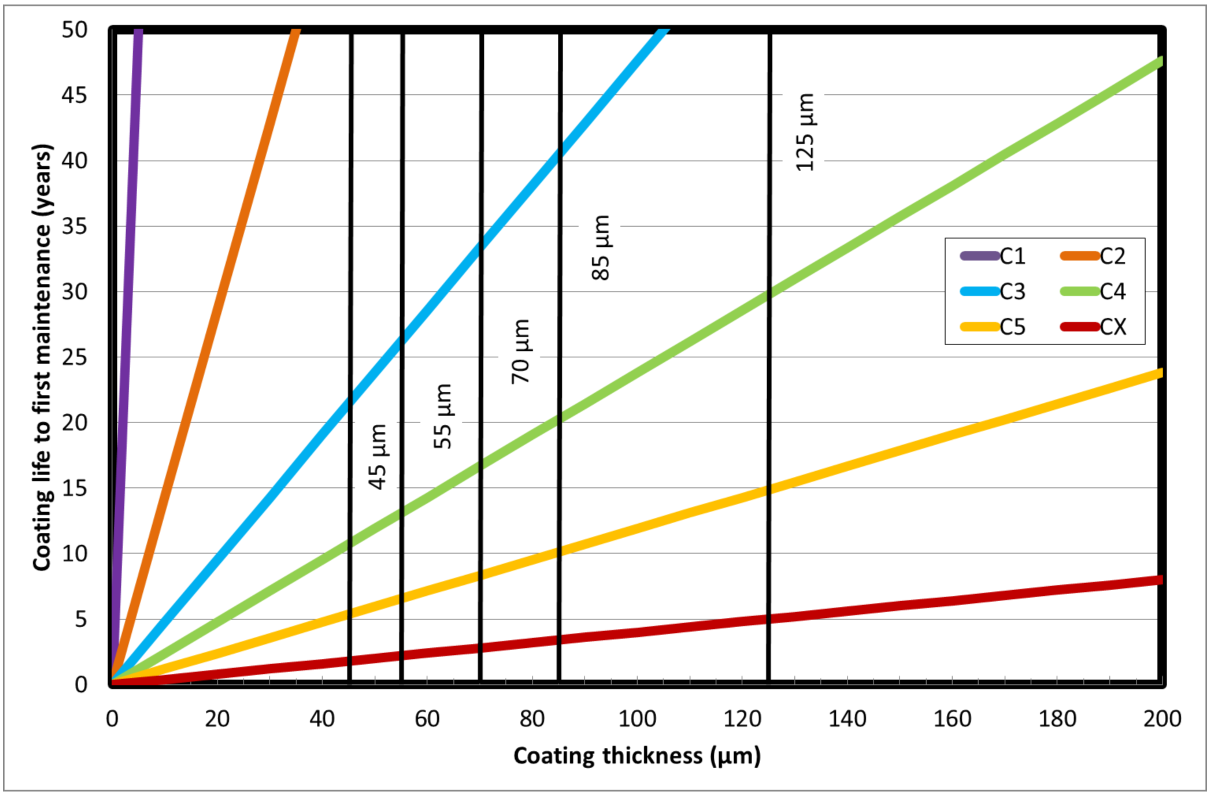
Steel Thickness mm	Coating thickness		Corrosivity Zone and Range of Life to First Maintenance (years)			
	µm	g/m²	C3	C4	C5	CX
> 1.5, ≤ 3.0	55	390	26/79	13/26	7/13	2/7
> 3.0, ≤ 6.0	70	500	33/100	17/33	8/17	3/8
> 6.0	85	600	40/100+	20/40	10/20	3/10
>> 6.0	125	900	60/100+	30/60	15/30	5/15

AS/NZS 4680 specifies the standard hot dip galvanized coating at the equivalent of 85 µm minimum for steel > 6 mm thick. Thinner steel, automatically hot dip galvanized tubes and centrifugal work (usually threaded work and fittings) have thinner coatings, but these are usually greater than 45 µm. Where it is desired to use coatings of different thicknesses to those stated, their lives can be ascertained by calculation; the life of a zinc coating is (to a first approximation) proportional to its thickness.

Hot dip galvanized coatings thicker than 85 µm are not specified in AS/NZS 4680 but the general provisions of that Standard apply and, together with specific thickness figures, may form a specification capable of third-party verification. It is essential to know the composition of the steel to be used and the galvanizer should be consulted before specifying, as these thicker coatings may not be available for all types of steel. Where the steel is suitable, thick coatings may be specified.

Note that standard in-line galvanized tubes and profiles have a nominal coating thickness of 100 g/m³ (14 µm) and therefore have an expected life of about 1/6th of a heavy-duty galvanized coating on a 6 mm structural section.

Coating Life versus Coating Thickness in the Macro-Environment



From the ISO9223 data and the various nominal coating thicknesses available from the hot dip galvanizing specifications, the above graph has been developed by the GAA to determine the coating life to first maintenance.

To use the chart, simply determine the corrosivity zone that applies and the galvanizing coating thickness from the nominal steel thickness and the coating life range can be read from the chart. For example, in a C4 Category, with an 85 µm coating thickness on 6 mm steel, the coating will have an expected life of 20 – 40 years.

The detailed chart and instructions for use, including how to estimate the Corrosivity Category is available separately from the GAA.

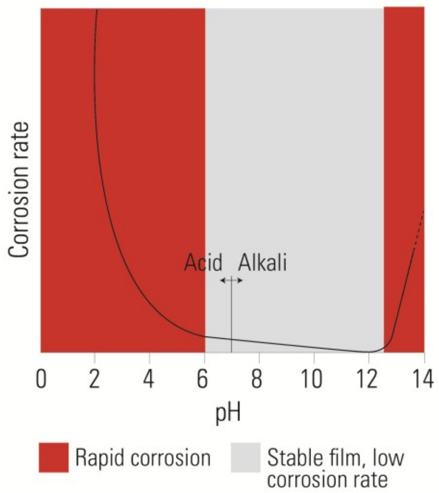
The Life of Galvanizing In Water

Except for some very hard waters, the corrosion of galvanizing in water is considerably greater than most conditions of atmospheric service; however galvanizing can be appropriate in many water immersion situations. Typical corrosion rates for zinc in water are shown in the table below

Typical Corrosion Rate for Zinc in Waters	
Water Type	Corrosion Rate (µm per annum)
Sea Water	15 - 25
Hard Fresh Water	2.5 - 5
Soft Fresh Water	5 - 10
Distilled Water	50 - 200

In freshwater, the corrosion rate depends on the ability of the coating to develop a protective layer. The formation of this layer is dictated by the pH, hardness, alkalinity and total dissolved solids of the water. The pH has a profound effect, with zinc being vulnerable outside the pH range 6 - 12.

Corrosion of Zinc with Variations in pH



Salt water at depth, with lower oxygen levels will tend to be less corrosive, whereas at the splash zone where the water is oxygen rich and more turbulent the corrosion rate is much higher and therefore galvanizing alone is not recommended.

Water temperature is also important, increasing markedly in corrosivity with increasing temperature up to 70°C when it falls away. For this reason it is not satisfactory for hot soft or condensate water applications.

The Life of Galvanizing In Soil

The corrosion of zinc in soil is on average considerably greater than in the atmosphere, but can vary greatly, even over short distances. This is essentially because of the varying moisture content and its heterogeneity, particularly along a vertical profile. In general terms, course open textures are less corrosive than fine ones, such as clays, which tend to hold water. Soil mineral content pH and oxygen content are also important indicators. Mineral content is easily appraised by measurement of soil resistivity, the lower the resistivity the greater the corrosion rate. For example, the service life of galvanized culverts can be effectively predicted from soil resistivity and pH, while galvanizing is used extensively by the rammed earth industry and, for many years, Australian domestic water supply.

Where long term service is required and the soil conditions are uncertain it is often prudent to consider additional surface protection.

Standard Specification to meet AS/NZS 4680:2006

This standard specification for hot dip galvanized coatings should be used in conjunction with AS/NZS4680 for use with materials specifications.

Scope

This specification covers the After-Fabrication Galvanized coating applied to general steel articles, structural sections, angles, channels, beams, columns, fabricated steel assemblies, castings, threaded fasteners, steel reinforcement and other steel components.

This specification does not apply to the galvanized coating on semi-finished products such as wire, tube, or sheet galvanized in continuous, semi-continuous, or specialised plants.

Galvanizing

All articles to be galvanized shall be handled in such a manner as to avoid any mechanical damage and to minimise distortion.

Design features that may lead to difficulties during galvanizing should be pointed out prior to dipping.

Galvanizing parameters such as galvanizing temperature, time of immersion and withdrawal speed shall be employed to suit the requirements of the article.

The composition of the zinc in the galvanizing bath shall not be less that 98.0% zinc.

Coating Requirements

1. Thickness

The thickness of the galvanized coating shall conform to Table 1 and Table 2 in AS/NZS 4680:

Table 1

Requirements for coating thickness and mass for articles that are *not* centrifuged.

Article thickness (mm)	Local coating thickness (µm)	Average coating thickness (µm)	Average coating mass (g/m^2)
1.5 mm or less	35	45	320
Over 1.5 to 3 mm	45	55	390
Over 3 to 6 mm	55	70	500
Over 6 mm	70	85	600

Table 2			
Requirements for coating thickness and mass for articles that are centrifuged.			
Article thickness (mm)	Local coating thickness (μm)	Average coating thickness (μm)	Average coating mass (g/m^2)
Less than 8 mm	25	35	250
8 mm and over	40	55	390

The thickness of the galvanized coating shall first be tested by the purchaser or designer at the galvanizer's works, using an approved magnetic measuring device. In the event of any dispute, an independent test shall be carried out in accordance with Appendix G of AS/NZS 4680.

2. Surface Finish

The galvanized coating shall be continuous, adherent, as smooth and evenly distributed as possible, and free from any defect that is detrimental to the stated end use of the coated article. On silicon-killed steels, the coating may be dull grey, provided the coating is sound and continuous.

The integrity of the coating shall be determined by visual inspection and coating thickness measurements.

Where slip factors are required to enable high strength friction grip bolting, where shown, these shall be obtained after galvanizing by suitable mechanical treatment of the faying surfaces.

Where a paint finish is to be applied to the galvanized coating, this should be advised at the time of order. Galvanized coatings shall have all spikes removed and all edges free from lumps and runs.

3. Adhesion

The galvanized coating shall be sufficiently adherent to withstand normal handling during transport and erection.