

# Hot dip galvanizing – Process, applications, properties

---

Hot dip galvanizing protects steel from corrosion by providing a thick, tough metallic zinc envelope, which completely covers the steel surface and seals it from the corrosive action of its environment. The galvanized coating provides outstanding abrasion resistance. Where there is damage or minor discontinuity in the sealing coat of zinc, protection of the steel is maintained by the cathodic action of the surrounding galvanized coating.

Metallic zinc is strongly resistant to the corrosive action of normal environments and hot dip galvanized coatings therefore provide long-term protection for steel. By contrast, most organic paint coatings used on steel need frequent renewal and when coatings are breached corrosion begins at the exposed area of steel, spreading rapidly beneath the coating film.

## The galvanized coating

The galvanizing process produces a durable, abrasion resistant coating of metallic zinc and zinc-iron alloy layers bonded metallurgically to the steel base and completely covering the work piece. No other coating for steel matches galvanizing's unique combination of properties and advantages:

- 1 For most classes of steelwork galvanizing provides the lowest long-term cost. In many cases galvanizing also provides lowest initial cost.
- 2 The galvanized coating becomes part of the steel surface it protects. See 'Metallurgy', page 13.
- 3 The unique metallurgical structure of the galvanized coating provides outstanding toughness and resistance to mechanical damage in transport, erection and service. See 'Abrasion resistance' page 13.
- 4 The galvanized coating is subject to corrosion at a predictably slow rate, between one-seventeenth and one-eightieth that of steel, depending on the environment to which it is exposed. See 'Corrosion rates', page 19.
- 5 Galvanizing's cathodic protection for steel ensures that small areas of the base steel exposed through severe impacts or abrasion are protected from corrosion by the surrounding galvanized coating. See 'Cathodic protection', page 10.
- 6 An inherent advantage of the process is that a standard minimum coating thickness is applied. See 'Coating thickness', page 13.
- 7 During galvanizing the work is completely immersed in molten zinc and the entire surface is coated, even recesses and returns which often cannot be coated using other processes. If required, internal surfaces of vessels and containers can be coated simultaneously. See 'Design', page 33.
- 8 Galvanized coatings are virtually 'self-inspecting' because the reaction between steel and molten zinc in the galvanizing bath does not occur unless the steel surface is

chemically clean. Therefore a galvanized coating which appears sound and continuous **is** sound and continuous. See 'Metallurgy', page 13, and 'Inspection', page 42.

- 9 Galvanizing is a highly versatile process. Items ranging from small fasteners and threaded components, up to massive structural members can be coated. See 'Galvanizing', page 11 and 'Design', page 33.
- 10 The mechanical properties of commonly galvanized steels are not significantly affected by galvanizing. See 'Mechanical properties', page 15.
- 11 Galvanizing provides outstanding corrosion performance in a wide range of environments. See 'Performance', page 19.
- 12 'Duplex' coatings of galvanizing-plus-paint are often the most economic solution to the problem of protecting steel in highly corrosive environments. Such systems provide a synergistic effect in which life of the combined coatings exceeds the total life of the two coatings if they were used alone. See 'Synergistic effect', page 65.

## Cathodic protection

Metallic zinc is anodic to steel as indicated by the galvanic series of metals on page 10.

In the presence of an electrolyte, the anodic zinc coating on a galvanized article corrodes preferentially to the cathodic steel basis metal, preventing corrosion of small areas which may be exposed through accidental damage to the coating. The cathodic or sacrificial protection continues for as long as the galvanized coating remains.

A simple description of the phenomenon of corrosion of steel is given on following pages as background for the explanation of cathodic protection.

## The nature of corrosion

Corrosion is basically an electrochemical process. It occurs because of differences in electrical potential which exist between dissimilar metals in contact or between small areas on a metal surface in the presence of an electrolyte.

Differences in potential on a metal surface are caused by:

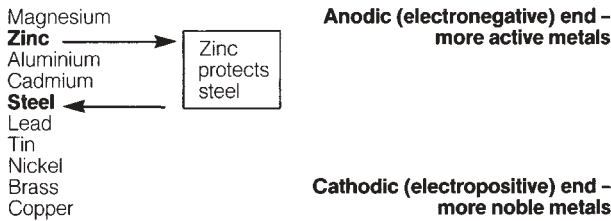
- 1 Variations in composition
- 2 Presence of impurities
- 3 Uneven internal stresses
- 4 A non-uniform environment.

The environment may be a damp atmosphere, surface moisture, or liquid in which the metal is immersed. All serve as electrolytes allowing formation of small electrolytic cells at the metal surface, with resulting corrosion.

Each cell comprises a positive electron-producing anode and a negative cathode. Negatively charged electrons flow from anode to cathode. The loss of electrons converts some atoms of the anode to positively charged ions which in turn react with negatively charged ions in the electrolyte. This reaction between anode and electrolyte causes disintegration and corrosion of the anode metal. There is no corrosion of the cathode metal.

### Galvanic series of metals in a sea water electrolyte

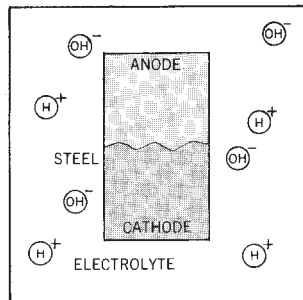
The table below shows a series of metals arranged in order of electrochemical activity in a sea water electrolyte. Metals high in the scale provide cathodic or sacrificial protection to the metals below them. Zinc therefore protects steel.



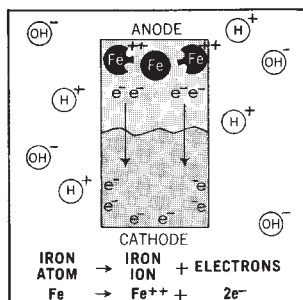
The scale indicates that magnesium, aluminium and cadmium should also protect steel. In most normal applications magnesium is highly reactive and is too rapidly consumed. Aluminium forms a resistant oxide coating and its effectiveness in providing cathodic protection is limited. Cadmium provides the same cathodic protection for steel as zinc but its applications are limited for technical and economic reasons.

### Corrosion of steel

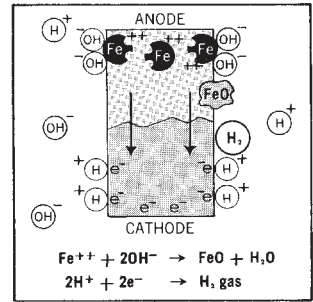
Differences in electrical potential are caused on surface areas of exposed steel by non-uniformity of surface composition, by surface moisture or by the electrolyte in which it is immersed. Small electrolytic cells are formed comprising anodes and cathodes. One such cell is shown diagrammatically.



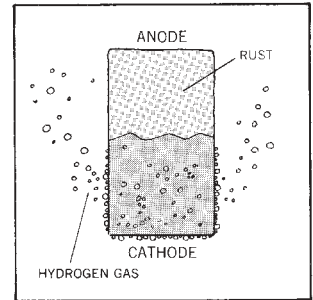
As the result of differences in electrical potential within the cell, negatively charged electrons flow from anode to cathode and iron atoms in the anode area are converted to positively charged iron ions.



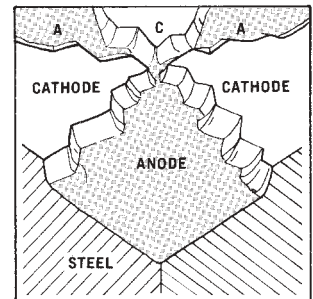
The positively charged iron ions of the anode attract and react with negatively charged hydroxyl ions in the electrolyte to form iron oxide or rust. Negatively charged electrons react at the cathode surface with positively charged hydrogen ions in the electrolyte to form hydrogen gas.



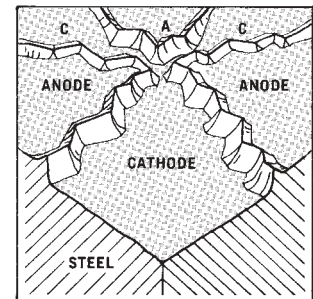
Under suitable conditions corrosion occurs at the rate of billions of complete reactions every second and soon results in a layer of rust appearing over the surface of the anode area.



The anode and cathode areas on a piece of steel are actually microscopic. When greatly magnified the surface might appear as the mosaic of anodes and cathodes visualised here, all electrically connected by the underlying steel. Corrosion occurs in the anode areas.

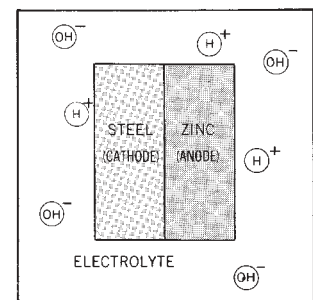


As anode areas corrode new material of different composition and structure is exposed. This results in changes in electrical potentials, causing anodes and cathodes to exchange roles, though not all at once, and areas previously uncorroded are now attacked. These processes may continue until the steel is entirely consumed.

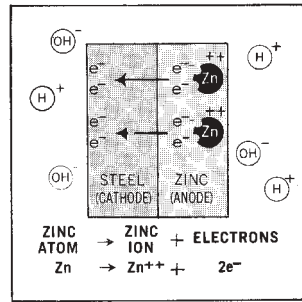


### The mechanism of cathodic protection

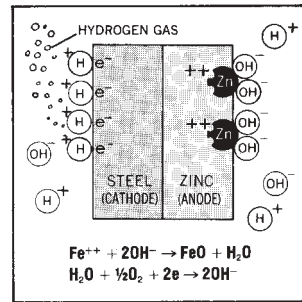
When zinc and steel are in contact in an electrolyte, differences in electrical potential develop and an electrolytic cell is formed. Zinc is more electrochemically active than steel, as shown in the galvanic series above. The zinc therefore becomes the anode for all the steel, preventing the formation of small anodic and cathodic areas on the steel surface.



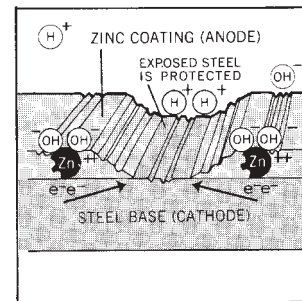
As a result of the differences in electrical potential within the cell, negatively charged electrons flow from the zinc anode to the steel cathode and zinc atoms in the anode are converted to positively charged zinc ions.



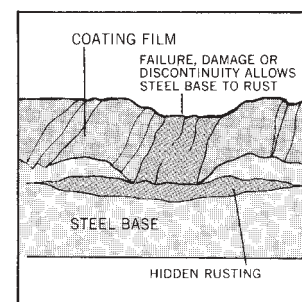
At the cathode surface, negatively charged electrons attract and react with positively charged hydrogen ions from the electrolyte, liberating hydrogen gas. There is no chemical reaction between the steel cathode and the electrolyte. This phenomenon, which prevents corrosion of the cathode, is known as cathodic protection. The positively charged zinc ions at the anode surface react with negatively charged hydroxyl ions from the electrolyte and the zinc is slowly consumed, providing sacrificial protection for the steel.



When discontinuity or damage in the zinc coating exposes the underlying steel, the cathodic protection which zinc provides for steel comes into action and ensures that the exposed steel does not corrode.



Most organic coatings and paint films depend on their sealing ability and in some cases anti-corrosive inhibitive pigments to protect steel from corrosion. They offer little or no protection to bare steel exposed by failure, damage or discontinuity in the coating film. Corrosion starts and spreads rapidly beneath the coating.



## The galvanizing process

Metallic zinc coatings are applied to prepared steel surfaces by galvanizing, electroplating, mechanical plating, sherardising, painting with zinc-rich coatings and zinc spraying or metallising. Of these the galvanizing process is by far the most widely used. Galvanizing is normally carried out to AS/NZS 4680 'Hot dip galvanized (zinc) coatings on fabricated ferrous articles'.

Prepared items are galvanized by immersion in molten zinc. The surface of the work is completely covered, producing a uniform coating of zinc and zinc-iron alloy layers whose thickness is determined principally by the mass of the steel being galvanized, as discussed on page 13. This is an important advantage of the galvanizing process – a standard minimum coating thickness is applied automatically.

The molten zinc in the galvanizing bath covers corners, seals edges, seams and rivets, and penetrates recesses to give complete protection to areas which are potential corrosion spots with other coating systems. The galvanized coating is slightly thicker at corners and narrow edges, giving greatly increased protection compared to organic coatings which thin out in these critical areas. Complex shapes and open vessels may be galvanized inside and out in one operation.

Articles ranging in size from small fasteners to structures hundreds of metres high may be protected by the use of modular design techniques. Large galvanizing baths, in conjunction with modular design techniques and double-end dipping allow almost any structure to be galvanized, with greatly reduced maintenance costs and extended service life.

Visual inspection of galvanized products shows that work is completely protected and gives an excellent guide to overall coating quality. (See page 42.)

### Preparation of work for galvanizing

Scale, rust, oil, paint and other surface contaminants are carefully removed from the steel by suitable preliminary treatment and subsequent acid cleaning or pickling in sulphuric or hydrochloric acids, followed by rinsing. Iron and steel castings are usually abrasive blast cleaned followed by a brief acid cleaning or they may be cleaned electrolytically to remove foundry sand and surface carbon.

Rolled steel surfaces covered by heavy mill scale may require abrasive blast cleaning prior to acid cleaning.

### Fluxing

The acid-cleaned steel article is immersed in a flux solution, usually 30 per cent zinc ammonium chloride with wetting agents, maintained at about 65°C. The flux solution removes the oxide film which forms on the highly reactive steel surface after acid cleaning, and prevents further oxidation before galvanizing. The work is then dried ready for galvanizing.

Alternatively the acid-cleaned article is rinsed and dried, and passed into the galvanizing bath through a layer of molten zinc ammonium chloride flux which floats on the surface of the molten zinc. The molten flux is maintained at 440°C to 460°C, ensuring final cleaning of the steel surface before it contacts the molten zinc.

### Galvanizing

On immersion in the galvanizing bath the steel surface is wetted by the molten zinc and reacts to form a series of zinc-iron alloy layers as discussed on page 13. To allow formation of the coating the work remains in the bath until its temperature reaches that of the molten zinc, in the range 445°C to 465°C. The work is then withdrawn at a controlled rate and carries with it an outer layer of molten zinc which solidifies to form the relatively pure outer zinc coating.

The period of immersion in the galvanizing bath varies from several minutes for relatively light articles, up to half an hour or longer for massive structural members.

The resulting galvanized coating is tough and durable, comprising relatively pure zinc and zinc-iron alloy layers bonded metallurgically to the underlying steel, completely covering the article and providing unmatched resistance to abrasion.

An important advantage of the galvanizing process is that visual inspection shows that work is completely protected and gives an excellent guide to coating quality. Inspection of galvanized products is detailed on page 42. Standards covering galvanized coating thickness and quality are listed on page 42.

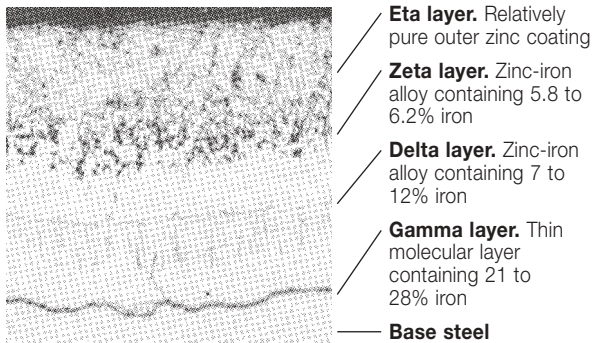
### Galvanizing fasteners and small components

Fasteners and small components are loaded into perforated cylindrical steel baskets. After acid pickling and prefluxing, baskets are lowered into the galvanizing bath. On withdrawal from the molten zinc, baskets are raised without delay into a centrifuge or 'spinner' and rotated at high speed for 15 to 20 seconds. Excess zinc is thrown off, providing a smooth, uniform coating. (See also page 47.)

## Metallurgy of galvanizing

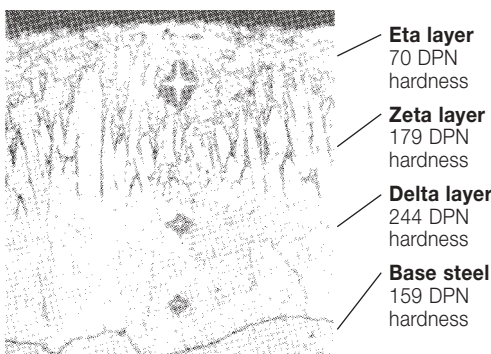
When the cleaned and fluxed steel surface contacts the molten zinc of the galvanizing bath the protective flux layer is removed leaving a clean steel surface which is immediately wetted by the zinc. This results in reaction between zinc and steel with the formation of zinc-iron alloy layers.

The photomicrograph below shows a section of a typical galvanized coating which consists of a progression of zinc-iron alloy layers bonded metallurgically to the base steel, with the relatively pure outer zinc layer.



### Abrasion resistance of galvanized coatings

The photomicrograph below shows that the delta and zeta zinc-iron alloy layers are actually harder than the base steel, resulting in galvanizing's outstanding resistance to abrasion and mechanical damage. Abrasive or heavy loading conditions in service may remove the relatively soft eta layer of zinc from a galvanized surface, but the very hard zeta alloy layer is then exposed to resist further abrasion and heavy loading.



## Coating thickness

During the first minute of immersion in the galvanizing bath zinc-iron alloy layers grow rapidly on the surface of the steels which are most commonly galvanized. The rate of alloy layer growth then diminishes and is finally very slow. When the work is withdrawn from the bath an outer layer of relatively pure zinc is also carried out. The total zinc coating mass applied depends mainly on the mass and thickness of the steel being galvanized.

AS/NZS 4680 specifies the following minimum average coating thicknesses.

**Table 1**  
**Requirements for coating thickness and mass for articles that are not centrifuged**

Steel Thickness mm	Local coating thickness minimum $\mu\text{m}$	Average coating thickness minimum $\mu\text{m}$	Average coating mass minimum $\text{g/m}^2$
A1.5	35	45	320
>1.5 A3	45	55	390
>3 A6	55	70	500
>6	70	85	600

Note: 1  $\text{g/m}^2$  coating mass = 0.14  $\mu\text{m}$  coating thickness.

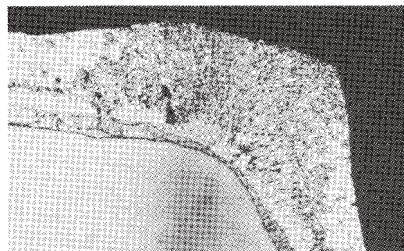
**Table 2**  
**Requirements for coating thickness and mass for articles that are centrifuged**

Thickness of articles (all components including castings) mm	Local coating thickness minimum $\mu\text{m}$	Average coating thickness minimum $\mu\text{m}$	Average coating mass minimum $\text{g/m}^2$
<8	25	35	250
B8	40	55	390

Notes:

- For requirements for threaded fasteners refer to AS 1214.
- 1  $\text{g/m}^2$  coating mass = 0.14  $\mu\text{m}$  coating thickness.

As indicated the total coating mass on heavier steel sections normally contains a minimum of 600 grams of zinc per square metre of surface area, ( $\text{g/m}^2$ ) equivalent to about 85  $\mu\text{m}$  thickness. As illustrated below, coating thickness is slightly greater at corners.



Galvanized coatings are slightly thicker at corners and edges as shown, an important advantage over most organic coatings which thin out in these critical areas.

The structure of the galvanized coating and the relative thickness of its zinc-iron alloy layers have little or no effect on the protective life of the coating. Protective life depends basically on total coating mass as discussed on page 19.

On most commonly galvanized steels, the relatively pure outer zinc layer of the galvanized coating solidifies to give the typical bright zinc crystal or 'spangle' finish. Certain steel compositions may cause the zinc-iron alloy layer to grow through to the surface of the galvanized coating producing a matt grey finish sometimes known as 'grey bar', as discussed below under 'Composition of steel' and on page 42 under 'Dull grey coating'. There is negligible difference between the protective lives provided by either coating.

## Factors influencing coating thickness

The thickness, alloy structure and finish of galvanized coatings are influenced by:

- 1 Surface condition of steel
- 2 Composition of the steel

Increasing the period of immersion in the galvanizing bath will not increase coating thickness except in the case of silicon steels, as discussed on this page.

### Surface condition of steel

Grit blasting steel before galvanizing roughens the surface and increases its surface area, resulting in higher reactivity to molten zinc. Greater zinc-iron alloy growth occurs during galvanizing, producing thicker coatings, though at the expense of a rougher surface and poorer appearance.

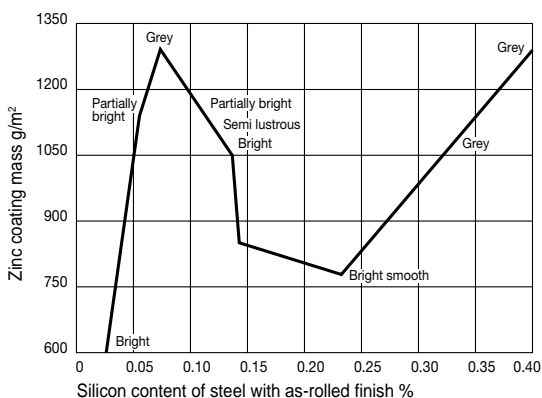
Application of this method of achieving thicker coatings is generally limited by practical and economic considerations. Where increased service life or reduced maintenance is required the use of duplex galvanizing-plus-paint systems is a preferable alternative, as discussed on page 65.

### Composition of steel

Both silicon and phosphorous contents can have major effects on the structure, appearance and properties of galvanized coatings. In extreme cases, coatings can be excessively thick, brittle and easily damaged.

**Silicon.** As shown in the graph below, certain levels of silicon content will result in excessively thick galvanized coatings. These very thick coatings result from the increased reactivity of the steel with molten zinc, and rapid growth of zinc-iron alloy layers on the steel surface. The graph shows that excessive growth in coating thickness takes place on steels with silicon contents in the range 0.04 to 0.14%. Growth rates are less for steels containing between 0.15 and 0.22% silicon, and increase with increasing silicon levels above 0.22%.

### Effect of silicon content of steels on galvanized coating mass and appearance



**Phosphorous.** The presence of phosphorous above a threshold level of approximately 0.05% produces a marked increase in reactivity of steel with molten zinc, and rapid coating growth. When present in combination with silicon, phosphorous can have a disproportionate effect, producing excessively thick galvanized coatings.

**Suitability of silicon/phosphorous steels for galvanizing.** As a guide to the suitability of silicon and phosphorous containing steels for galvanizing, the following criteria should be applied:

- % Si < 0.04%
- and
- % Si + (2.5 x % P) < 0.09%

Galvanized coatings on silicon steels are usually dull grey or patchy grey in colour with a rough finish, and may be brittle. Coating service life is proportional to the increased thickness

and is unaffected by appearance, provided the coating is sound and continuous. In general, the thickness, adherence and appearance of galvanized coatings on silicon and phosphorous steels are outside the control of the galvanizer. (See also 'Dull grey coatings', page 42.)

**Double dipping** or galvanizing a second time will not increase the thickness of a galvanized coating for reasons discussed under "Coating thickness" page 13, and may adversely affect coating appearance.

The terms 'double dipping' and 'double-end dipping' are sometimes confused. Double-end dipping is a method of galvanizing articles too long for the available bath by immersing one end of the work at a time, as described on page 33.

## Mechanical properties of galvanized steels

The galvanizing process has no effect on the mechanical properties of the structural steels commonly galvanized.

### Strength and ductility

The mechanical properties of 19 structural steels from major industrial areas of the world were investigated before and after galvanizing in a major 4-year research project by the BNF Metals Technology Centre, UK, under the sponsorship of International Lead Zinc Research Organisation. Included were steels to Australian Standard 1511 grade A specification, and British Standard 4360 series steels.

The published BNF report 'Galvanizing of structural steels and their weldments' ILZRO, 1975, concludes that '... the galvanizing process has no effect on the tensile, bend or impact properties of any of the structural steels investigated when these are galvanized in the "as manufactured" condition. Nor do even the highest strength versions exhibit hydrogen embrittlement following a typical pretreatment in inhibited HCl or H<sub>2</sub>SO<sub>4</sub>.

'Changes in mechanical properties attributable to the galvanizing process were detected only when the steel had been cold worked prior to galvanizing, but then only certain properties were affected. Thus the tensile strength, proof strength and tensile elongation of cold rolled steel were unaffected, except that the tensile elongation of 40% cold rolled steel tended to be increased by galvanizing. 1-t bends in many of the steels were embrittled by galvanizing, but galvanized 2-t and 3-t bends in all steels could be completely straightened without cracking.'

### Embrittlement

For steel to be in an embrittled condition after galvanizing is rare. The occurrence of embrittlement depends on a combination of factors. Under certain conditions, some steels can lose their ductile properties and become embrittled. Several types of embrittlement may occur but of these only strain-age embrittlement is aggravated by galvanizing and similar processes. The following information is given as guidance in critical applications.

**Susceptibility to strain-age embrittlement.** Strain-age embrittlement is caused by cold working of certain steels, mainly low carbon, followed by ageing at temperatures less than 600°C, or by warm working steels below 600°C.

All structural steels may become embrittled to some extent. The extent of embrittlement depends on the amount of strain, time at ageing temperature, and steel composition, particularly nitrogen content. Elements that are known to tie up nitrogen in the form of nitrides are useful in limiting the effects of strain ageing. These elements include aluminium, vanadium, titanium, niobium, and boron.

**Cold working** such as punching of holes, shearing and bending before galvanizing may lead to embrittlement of susceptible steels. Steels in thicknesses less than 3 mm are unlikely to be significantly affected.

**Hydrogen embrittlement.** Hydrogen can be absorbed into steel during acid pickling but is expelled rapidly at galvanizing temperatures and is not a problem with components free from internal stresses. Certain steels which have been cold worked and/or stressed during pickling can be affected by hydrogen embrittlement to the extent that cracking may occur before galvanizing.

**The galvanizing process** involves immersion in a bath of molten zinc at about 450°C. The heat treatment effect of galvanizing can accelerate the onset of strain-age embrittlement in susceptible steels which have been cold worked. No other aspect of the galvanizing process is significant.

### Recommendations to minimise embrittlement

Where possible, use a steel with low susceptibility to strain age embrittlement. Where cold working is necessary the following limitations must be observed:

- 1 Punching.** The limitations specified in AS 4100 and AS/NZS 4680 on the full-size punching of holes in structural members must be observed. Material of any thickness may be punched at least 3 mm undersize and then reamed, or be drilled. Good shop practice in relation to ratios of punched hole diameter to plate thickness, and punch/die diametral clearance to plate thickness should be observed. For static loading, holes may be punched full size in material up to  $\frac{5600}{F_y}$  mm thick where  $F_y$  is material yield stress up to 360MPa.
- 2 Shearing.** Edges of steel sections greater than 16 mm thick subject to tensile loads should be machined or machine flame cut. Edges of sections up to 16 mm thick may be cut by shearing. Sheared edges to be bent during fabrication should have stress raising features such as burrs and flame gouges removed to a depth of at least 1.5 mm. Before bending, edges should be radiused over the full arc of the bend.
- 3 Bending.** Susceptible steels should be bent over a smooth mandrel with a minimum radius 3 times material thickness. Where possible hot work at red heat. Cold bending is unlikely to affect steels less than 3 mm thick.
- 4 Critical applications.** It is better to avoid cold work such as punching, shearing and bending of structural steels over 6 mm thick when the item will be galvanized and subsequently subjected to critical tensile stress. If cold working cannot be avoided a practical embrittlement test in accordance with ASTM A143 should be carried out. Where the consequences of failure are severe and cold work cannot be avoided, stress relieve at a minimum of 650°C before galvanizing. Ideally, in critical applications structural steel should be hot worked above 650°C in accordance with the steelmaker's recommendations.
- 5 Edge distances of holes.** In accordance with Australian Standard 4100 'Steel structures' minimum edge distances from the centre of any bolt to the edge of a plate or the flange of a rolled section should be used. See page 39.

## Fatigue strength

Research and practical experience shows that the fatigue strength of the steels most commonly galvanized is not significantly affected by galvanizing. The fatigue strength of certain steels, particularly silicon killed steels may be reduced, but any reduction is small when compared with the reductions which can occur from pitting corrosion attack on ungalvanized steels, and with the effects of welds.

For practical purposes, where design life is based on the fatigue strength of welds, the effects of galvanizing can be ignored.

Fatigue strength is reduced by the presence of notches and weld beads, regardless of the effects of processes involving a

heating cycle such as galvanizing. Rapid cooling of hot work may induce microcracking, particularly in weld zones, producing a notch effect with consequent reductions in fatigue strength.

In critical applications, specifications for the galvanizing of welded steel fabrications should call for air cooling rather than water quenching after galvanizing to avoid the possibility of microcracking and reductions in fatigue strength.

## Other metallic zinc coatings for steel

**Zinc plating** should not be confused with After-Fabrication galvanizing which applies much heavier coatings providing a correspondingly longer service life. However several grades of plating now exist, ranging up to 100g/m<sup>2</sup> where use in coating systems for automobile and white goods continuous production lines, have become known as electrogalvanizing.

There is in general an economic upper limit to the zinc coating mass which can be applied by electroplating. Zinc plating therefore is normally not recommended for outdoor exposure without supplementary coatings.

Zinc plating is an economic, versatile and effective method of applying a protective coating to small steel components. It is the most widely used method of applying metallic zinc coatings to small fasteners, as described on page 48.

However fasteners used with after-fabrication galvanizing should have comparable coating and composition.

**Sherardising** is a method of zinc coating small, complex steel parts such as fasteners, springs and chain links, as described on page 48. The dark grey sherardised coating is hard, abrasion resistant and uniform in thickness over the whole surface of the article. The sherardising process is not used in Australia.

**Mechanical plating** or peen plating is an electroless plating method used to deposit coatings of ductile metals onto metal substrates using mechanical energy. It is used to plate zinc onto steel parts, particularly threaded components and close tolerance items, as discussed on page 48.

**Zinc spraying** or zinc metallising allows coating of fabricated items which cannot be galvanized because of their size or because coating must be performed on site. Zinc spraying has the advantage that zinc coatings up to 250 µm thick, equivalent to 1500 g/m<sup>2</sup> can be applied, by either manual or mechanised methods. The steel surface must be prepared by grit blasting. The resulting zinc coating provides cathodic protection for the underlying steel in the same way as a galvanized coating.

**Zinc rich coatings** consist of zinc dust in organic or inorganic vehicle/binders. Surface preparation by abrasive blast cleaning is necessary, and coatings may be applied by brush or spray. Zinc rich coatings are barrier coatings which also provide cathodic protection to small exposed areas of steel, provided the steel surface is properly prepared, and the paint conforms to relevant Australian/New Zealand Standards AS/NZS 3750.15.1998 and AS/NZS 3750.9.1994. Suitable zinc rich paint coatings provide a useful repair coating for damaged galvanized coatings as discussed on page 45.

**Preconstruction primers** are relatively thin weldable zinc rich coatings used widely for ship building, storage tanks, and similar steel plate constructions, intended for subsequent top coating.

**Continuous galvanizing processes.** Steel sheet, pipe and wire are continuously galvanized in specially developed galvanizing processes which allow accurate control of coating thickness, ductility and other characteristics of the zinc coating, producing a wide range of products to suit the varying requirements of subsequent manufacturing operations and end usage. Because of the differing process and wide variety of coatings offered, these products should not be confused with after-fabrication galvanizing. In-line products with thinner coatings often require supplementary coatings for outdoor exposure.

# Zinc coating mass comparisons

The range of zinc coating mass which can be applied efficiently and economically by various zinc coating processes is given below. As the protective life of any zinc coating is proportional to thickness, the figures show that galvanizing has an advantage for many applications in that 600 g/m<sup>2</sup> is the normal coating mass on fabricated articles, as detailed on page 13. Heavier coatings can be applied by zinc spraying at greater cost but the coating lacks many of the characteristics of a galvanized coating which is alloyed to the base steel.

## Zinc coating mass applied by commercial processes, g/m<sup>2</sup>

Zinc plating	Up to 100 g/m <sup>2</sup>			
Sheet galvanizing*	40 to 240 g/m <sup>2</sup>			
Hot dip galvanizing			300 to 900 g/m <sup>2</sup>	
Zinc spraying	600 to 1500 g/m <sup>2</sup>			

300      600      900      1200      1500

\* Manufacturers of continuous sheet galvanized products quote coating mass as the total coating mass on both sides of the sheet. To provide a valid comparison figures given here are for coating mass on one side only.

# Corrosion rates of steel and zinc

Exposure tests by The American Society for Testing and Materials show that panel weight loss – a measure of the rate of corrosion – is much lower for zinc than for steel in a wide range of exposures. Galvanized coatings are consumed at rates between one seventeenth and one eightieth that of steel, so that even in aggressive environments, hot dip galvanizing provides long life.

## Corrosion rates, Steel:Zinc

Test panel weight loss in various exposures

Arid	Phoenix, Arizona	17:1
Rural	State College, Pa	22:1
Light Industrial	Monroeville, Pa	28:1
Industrial	East Chicago, Ill	52:1
Marine	Kure Beach, NC	80:1

# Protective life of galvanized coatings

The protective life of a metallic zinc coating on steel is roughly proportional to the mass of zinc per unit of surface area regardless of the method of application. The graph at right below demonstrates this by the results of tests conducted by British Iron and Steel Research Association at Sheffield Corrosion Testing Station, UK, on different masses of zinc coatings applied by sherardizing, zinc plating, galvanizing and zinc spraying.

The graph shows that the period of corrosion protection provided in a given environment is proportional to the mass of zinc in the coating, and that the protective life of a coating is therefore directly determined by the environment to which it is exposed.

The following notes are offered for general guidance. An indication of the life of a galvanized coating in a particular environment may be given by the performance of existing galvanized structures; more detailed information on coating life for specific applications is available from your galvanizer, or from Galvanizers Association of Australia.

# Performance in various environments

The excellent corrosion resistance of galvanized coatings in the atmosphere and in most natural waters is due to the formation of a protective layer or patina which consists of insoluble zinc oxides, hydroxides, carbonates and basic zinc salts, depending on the environment. When the protective patina has stabilised, reaction between the coating and its environment proceeds at a greatly reduced rate resulting in long coating life.

## In the atmosphere

The appraisalment of the protective life of a galvanized coating in a particular location must take into account factors such as climatic conditions, the presence in the atmosphere of contaminants introduced by urban or industrial activity, and chlorides in the air due to proximity to the sea. Environments which appear to be generally similar often produce considerable differences in corrosive conditions due to relatively minor variations such as the effects of prevailing winds, proximity to corrosive effluents and general atmospheric conditions.

**In warm dry atmospheres** the stability of zinc is remarkable. The zinc oxide film formed during initial exposure remains intact and prevents further reaction between the galvanized coating and the air, and protection continues indefinitely

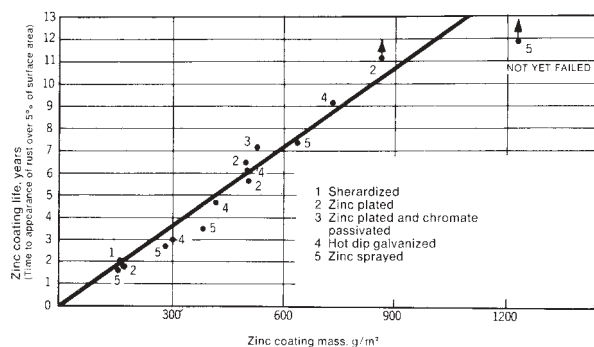
**In the presence of atmospheric moisture** the zinc oxide film is quickly converted to zinc hydroxide, and carbon dioxide normally present in the air reacts to form basic zinc carbonates. These stable inert compounds resist further action and ensure long life for the protective galvanized coating.

**In rural areas** the life of galvanized coatings may be reduced due to the effects of aerial spraying of fertilizers or insecticides. In dry form most fertilizers and insecticides are harmless to zinc coatings but when wetted by rainwater or irrigation spray water, aggressive solutions can be formed which will attack galvanized coatings until washed off by further wetting.

**Near the sea coast** the rate of corrosion is increased by the presence of soluble chlorides in the atmosphere. The performance of galvanized coatings relative to other protective systems is outstanding however, particularly when used as part of a duplex galvanizing-plus-paint system.

**In industrial areas** the presence of atmospheric impurities such as sulphurous gases and chemicals results in the formation of soluble zinc salts. These are removed by moisture, exposing more zinc to attack. In light industrial areas galvanized coatings give adequate protection, but in

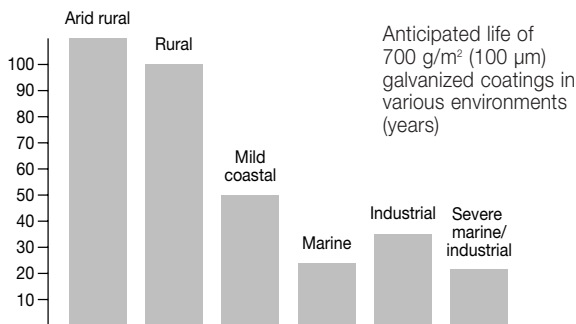
## Service life test results, various zinc coatings



Note. These test results were obtained in an extremely corrosive environment, and should not be taken as a guide to coating life for applications under normal conditions.

the extremely corrosive conditions of heavy industrial areas it is desirable to reinforce galvanized coatings with a paint system resistant to prevailing conditions.

In these severely corrosive conditions galvanized coatings in combination with suitable paint systems provide longer, more economic life than the best alternative systems. Suitable paint systems and application techniques are described in the section 'Painting galvanized steel'.



## Effect of temperature

Hot dip galvanized coatings should not be used in applications where temperatures continuously exceed 200°C, as prolonged exposure to these temperatures will lead eventually to detachment of the coating from the base steel.

## Under water

**General.** The corrosion rate of zinc under immersed conditions can be high in acidic solutions below pH 6 and alkaline solutions above pH 12.5. Between these limits the rate of corrosion is much lower.

**In mains supply water** of pH 6 to pH 8, calcium carbonate is normally present and this is precipitated onto the galvanized coating as an adherent calcium carbonate scale, together with zinc corrosion products, forming an impervious layer. When sufficiently dense, this layer virtually stops corrosion of the coating, resulting in very long life in many domestic water systems.

Other factors may interfere with this scale deposition. If the water has a high concentration of uncombined carbon dioxide, the protective scale is not formed and full protection never develops. The characteristics of the water supply should be taken into account in the design of domestic water systems. The presence of even small quantities of dissolved copper of the order of 0.1 parts per million in the water may cause corrosion by rapid pitting as discussed under galvanic corrosion page 22.

In unfavourable waters galvanized steel may require the added protection of galvanic anodes or suitable paint coatings.

**Pure water.** When newly galvanized articles are immersed in pure water such as rainwater there are no dissolved salts present to form the film of insoluble compounds which normally protects the coating from further action. Where practical this condition can be corrected by the addition to the water of controlled amounts of salts during initial immersion.

Most natural waters contain sufficient dissolved salts to prevent initial attack and galvanized tanks and equipment give excellent service.

**Effect of water temperature.** In cold water of normal composition galvanized coatings are most effective and the rate of consumption of the coating is very low. This has resulted in almost universal use of galvanized steel for tanks for water storage and transport.

At about 60°C to 65°C the rate of corrosion of galvanized coatings increases and continued corrosion resistance depends on early formation of adequate non-flaking scale. Hard water in hot water systems will deposit a scale of calcium and magnesium carbonates on the galvanized surface, nullifying the temperature effect. Soft water may not deposit a protective scale. In such cases galvanized coatings are unsuitable for hot water systems.

**Sea water.** Galvanized coatings perform relatively well in submerged sea water conditions which are severely corrosive to most protective systems. Dissolved salts present in sea water react with zinc to form a protective layer minimising corrosive action.

The addition to the galvanized coating of a suitable paint system is recommended in areas of severe sea water exposure, particularly in the splash zone. Such duplex systems provide the best available protective coating for steel in sea water. Suitable paint coating systems are listed in table 3, page 69.

## Underground

The corrosion behaviour of buried galvanized steel varies greatly with the type of soil. Knowledge of local conditions is therefore essential in estimating the life of galvanized steel pipes. Generally galvanized steel lasts considerably longer than uncoated or painted steels but performance is best in alkaline and oxidising soils, where a 600 g/m<sup>2</sup> galvanized coating will give an additional life of about 10 years to steel pipes. Highly reducing soil is most aggressive and may consume zinc coatings at more than 13 µm per year.

The life of galvanized steel underground is extended by the use of paint coatings, bituminous compounds, tape wraps or concrete encasement.

## In contact with chemicals

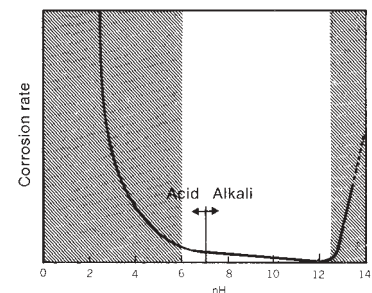
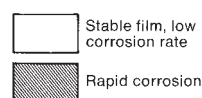
Galvanized coatings are highly resistant to attack over a wide pH range, particularly in moderately alkaline solutions as shown in the diagram below. Unprotected galvanized coatings should not be used with acid solutions below pH 6 or alkaline solutions above pH 12.5.

At intermediate values between these limits a protective film is formed on the zinc surface and the coating corrodes very slowly. Since this range covers most types of water and all but the strongest alkalis, galvanized coatings have wide application for storing and conveying liquids.

Most organic liquids, other than those acid, attack zinc only slightly and galvanized coatings are suitable for storage tanks and equipment for handling a wide range of organic chemicals, including motor fuels, creosotes, phenols and esters.

Galvanized coatings are used in refrigeration equipment circulating brine solutions treated with sodium dichromate inhibitor.

Effect of pH on corrosion rate of zinc. In the range pH 6 to pH 12.5 the zinc coating forms a stable protective film and corrosion rate is low.



## Compatibility of galvanized coatings with various media

Compatibility of galvanized coatings with various media is summarised in the table below. Further specific information is available from Galvanizers Association of Australia.

Aerosol propellants		excellent
Acid solutions	weak, cold quiescent strong	fair not recommended
Alcohols	anhydrous water mixtures beverages	good not recommended not recommended
Alkaline solutions	up to pH 12.5 strong	fair not recommended
Carbon tetrachloride		excellent
Cleaning solvents	chlorofluorocarbon	excellent
Detergents	inhibited	good
Diesel oil	sulphur free	excellent
Fuel oil	sulphur free	excellent
Gas*	towns, natural, propane, butane	excellent
Glycerine		excellent
Inks	printing aqueous writing	excellent not recommended
Insecticides	dry in solution	excellent not recommended
Lubricants	mineral, acid free organic	excellent not recommended
Paraffin		excellent
Perchloroethylene		excellent
Refrigerants	chlorofluorocarbon	excellent
Sewage		excellent
Soaps		good
Timber preservatives:		
Copper-chromium-arsenic, freshly treated		poor
After drying is completed		excellent
Boron		excellent
Trichloroethylene		excellent

\*Chromate passivation is recommended because moisture may be present.

## Sewage treatment

Galvanized coatings perform extremely well by comparison with other protective coatings for steel in the severely corrosive conditions prevailing in most sewage treatment operations. As a result galvanized steel is used extensively in sewage treatment plants throughout the world.

## In contact with building materials

Galvanized coatings give invaluable protection to steel used in all sections of the building industry. The slight etching action upon galvanizing by mortar, concrete and plaster ceases after setting.

When galvanized steel products and fasteners are installed in direct contact with unseasoned timber it may be necessary to protect them by the application of a suitable paint.

Care should be taken that galvanized products are stored and transported under dry ventilated conditions as discussed above right.

## In contact with timber preservatives

Timbers freshly treated with acidic preservatives of copper-chromium-arsenic type, such as Celcure, Copas and Tanalith,

can be severely corrosive to metallic building materials, including galvanized coatings. Once the timber has dried out the preservatives become fixed, and the performance of galvanized coatings in contact is excellent, even when the timber is again wetted. Galvanized coatings also perform well in contact with boron-treated timbers.

## Transport and storage

New galvanized products should be handled, transported and stored with the normal care given to any other surface-finished building material. New galvanized steel surfaces which have not yet developed the patina of protective insoluble basic zinc carbonates which normally contributes to the long life of aged coatings are highly reactive and susceptible to premature corrosion under poor conditions of exposure.

Transport should be under dry, well ventilated conditions. When stored on site, material should be covered where possible and raised clear of the ground on dunnage or spacers. When shelter is not possible material should be stacked to allow drainage of rainwater. Storage in contact with cinders, clinkers, unseasoned timber, mud or clay will lead to surface staining and in severe cases, premature corrosion.

Clearance for ventilation between stacked galvanized products is necessary under damp or humid conditions to avoid the possibility of wet storage stain and the development of bulky white corrosion product. Attack on the galvanized coating producing white corrosion is caused by the retention of condensation or run-off water between contacting surfaces under conditions of restricted air circulation. The attack is frequently superficial despite the relative bulkiness of the corrosion product but may be objectionable because of appearance. In severe cases corrosion product should be removed as described on page 44 to allow the natural formation of protective basic zinc carbonate film.

Where galvanized products are likely to be stored or transported under poor conditions the galvanizer can, on request, apply a simple chromate treatment which will minimise wet storage stain. Under severe conditions chromating should not be relied on and new galvanized products should be packed carefully and protected for shipment and storage.

Continuously galvanized sheet steel products designed for outdoor exposure are normally given a carefully controlled chromate treatment during manufacture. This treatment provides excellent resistance to wet storage staining and against early dulling during initial outdoor exposure. Care should nevertheless be taken to see that sheet and coil is kept dry while awaiting fabrication or erection.

## Galvanic corrosion

Galvanic or electrolytic corrosion with resulting rapid consumption of the zinc coating is likely if a galvanized article is installed in contact with brass or copper, particularly in a moist environment. Contact between aluminium or cadmium and galvanized surfaces is normally satisfactory.

Galvanic corrosion occurs for the same electrochemical reasons as those by which zinc provides cathodic protection for steel as explained on page 10, but the rate of consumption of zinc coatings by galvanic corrosion may be extremely high.

A guide to compatibility of metals and alloys in contact is given opposite.

## Galvanized surfaces in contact

For maximum corrosion resistance under conditions of extreme humidity, overlapping galvanized surfaces should be isolated from each other by the application of an inhibitive jointing compound such as Dulux Foster C1 Mastic or equivalent. Alternatively a suitable paint may be used. Galvanized surfaces in contact with other materials may also require isolation.

Galvanized members in contact with aluminium conductors may require the use of an electrical conducting compound such as Denso Densal Electrical Jointing Compound or equivalent at joint faces to repel moisture and inhibit corrosion. Galvanizers Association of Australia can make recommendations.

## Copper and copper alloys

Galvanic corrosion requires electrical contact in the presence of an electrolyte and cannot occur in the absence of these factors. However run-off water from copper surfaces frequently contains small quantities of dissolved copper, sufficient to cause attack and rapid deterioration of zinc coatings through chemical deposition of copper.

Where use of copper or brass together with galvanized steel in the presence of an electrolyte cannot be avoided, precautions should be taken to prevent electrical contact between the dissimilar metals. Joint faces should be insulated using non-conducting gaskets or mastics and connections should be made with insulating grommet-type

## Galvanic corrosion of galvanized coatings in contact with other metals

Contacting metal	Environment				
	Atmospheric exposure			Immersed	
	Rural	Industrial/urban	Marine	Fresh water	Sea-water
Aluminum and aluminum alloys	0	0 to 1	0 to 1	1	1 to 2
Aluminum bronzes and silicon bronzes	0 to 1	1	1 to 2	1 to 2	2 to 3
Brasses including high tensile (HT) brass (manganese bronze)	0 to 1	1	0 to 2	1 to 2	2 to 3
Cadmium	0	0	0	0	0
Cast irons	0 to 1	1	1 to 2	1 to 2	2 to 3
Cast iron (austenitic)	0 to 1	1	1 to 2	1 to 2	1 to 3
Chromium	0 to 1	1 to 2	1 to 2	1 to 2	2 to 3
Copper	0 to 1	1 to 2	1 to 2	1 to 2	2 to 3
Cupro-nickels	0 to 1	0 to 1	1 to 2	1 to 2	2 to 3
Gold	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
Gunmetals, phosphor bronzes and tin bronzes	0 to 1	1	1 to 2	1 to 2	2 to 3
Lead	0	0 to 1	0 to 1	0 to 2	(0 to 2)
Magnesium and magnesium alloys	0	0	0	0	0
Nickel	0 to 1	1	1 to 2	1 to 2	2 to 3
Nickel copper alloys	0 to 1	1	1 to 2	1 to 2	2 to 3
Nickel-chromium-iron alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	(1 to 3)
Nickel-chromium-molybdenum alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	(1 to 3)
Nickel silvers	0 to 1	1	1 to 2	1 to 2	1 to 3
Platinum	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
Rhodium	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
Silver	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
Solders hard	0 to 1	1	1 to 2	1 to 2	2 to 3
Solders soft	0	0	0	0	0
Stainless steel (austenitic and other grades containing approximately 18% chromium)	0 to 1	0 to 1	0 to 1	0 to 2	1 to 2
Stainless steel (martensitic grades containing approximately 13% chromium)	0 to 1	0 to 1	0 to 1	0 to 2	1 to 2
Steels (carbon and low alloy)	0 to 1	1	1 to 2	1 to 2	1 to 2
Tin	0	0 to 1	1	1	1 to 2
Titanium and titanium alloys	(0 to 1)	(1)	(1 to 2)	(0 to 2)	(1 to 3)

**Key** 0 Zinc and galvanized steel will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.  
 1 Zinc and galvanized steel will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.  
 2 Zinc and galvanized steel may suffer fairly severe additional corrosion and protective measures will usually be necessary  
 3 Zinc and galvanized steel may suffer severe additional corrosion and the contact should be avoided.

General notes: Ratings in brackets are based on very limited evidence and hence are less certain than other values shown. The table is in terms of additional corrosion and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure. Source: British Standards Institution.

fasteners. The design should be arranged so that water flows from the galvanized surface onto the brass or copper surface and not the reverse.

### Cathodic protection of damaged areas

Where continuity of a galvanized coating is broken by cut edges, drilled holes or surface damage, small areas of exposed steel are protected from corrosion cathodically by the surrounding coating as discussed on page 10. No touch up is necessary, and cathodic or sacrificial protection continues for many years. In service, zinc corrosion product tends to build up in coating discontinuities, slowing the rate at which the surrounding coating is consumed in protecting a damaged area.

Practical examples of this cathodic protection phenomenon include exposed cut edges in galvanized steel roofing and cladding, and the uncoated internal threads of certain fasteners.

In standard building practice cut edges in galvanized sheet are not treated in any way and when failure of the coating finally occurs after long exposure, corrosion normally is relatively uniform across the sheet surface without concentration at edges or fastener holes. Similarly, the uncoated internal threads of large galvanized nuts are protected from corrosion by the zinc coating on mating bolts and studs.

When substantial coating damage has occurred to a galvanized coating during handling, fabrication or erection, coating repairs are necessary as detailed page 45.

### Comparative properties of coatings\*

The following tables provide a useful assessment of the properties and characteristics of various coatings for steel in a range of applications and environments.

	Key	Galvanizing	Paint	Bitumen	Vitreous enamel
Corrosion protection	(1)	A	B	B	B
Electrochemical protection	(1)	A	D	D	D
Durability in atmosphere	(1)	A	B	C	A
Durability in water	(1)	B	B	A	A
Adhesion	(1)	A	B	B	A
Resistance to damage	(1)	A	C	C	D
Resistance to abrasion	(1)	A	C	C	A
Size limitations	(2)	B	A	A	C
Risk of deformation	(2)	B	A	A	B
Inspection possibilities	(1)	A	B	B	C
Initial costs	(3)	B	B	B	C
Maintenance costs	(3)	A	C	B	A

	Key	Galvanizing	Zinc spraying	Zinc plating	Zinc rich paints	Mechanical plating
Alloying with base steel	(1)	A	D	D	D	D
Durability of coating	(1)	A	A	C	C	B
Cathodic protection	(1)	A	A	A	C	B
Resistance to mechanical damage	(1)	A	B	C	C	C
Resistance to abrasion	(1)	A	B	C	C	C
Piece size limitations	(2)	B	A	C	A	C
Risk of deformation	(2)	B	A	A	A	B
Ease of inspection	(1)	A	C	C	C	C
Initial costs	(3)	A	B	C	B	B
Maintenance costs	(3)	A	A	D	B	C
Suitability for painting	(1)	B	B	B	B	B
<b>Key</b>	<b>(1)</b>	<b>(2)</b>	<b>(3)</b>			
	A Very good	A None	A Very low			
	B Good	B Little	B Low			
	C Poor	C High	C High			
	D Very poor	D Very high	D Very high			

\*R. Thomas, 1980 (modified).

## Galvanized coatings for buildings and structural steel

A vital factor to be taken into account in the assessment of coating systems for buildings and structural steel is the relative effectiveness of coatings. No protective coating applied to a structure after completion can provide the same protection as a galvanized coating which covers the entire surface of all components, automatically protecting areas to which later access may be difficult or impossible.

When steel members, fascias and other components which are to receive a final decorative or protective coating are galvanized, no surface deterioration will occur during storage, handling, erection or waiting time until completion of the project. Galvanized coatings can save considerable time and cost which might otherwise be necessary for rectification of damaged or corroded surfaces.

**Exposed frame structures.** Open frame industrial steel structures which are not protected by roofing or cladding are particularly vulnerable to corrosion. Normally they are sited in industrial areas and frequently, maintenance access is difficult.

In these circumstances no other coating system matches the economy/performance of galvanized coatings. Even in the most severe atmospheres a duplex system of galvanizing-plus-paint will usually provide the best practical balance between cost and the longest possible maintenance-free operating period. The galvanized coating provides a stable base for the paint film, ensuring far longer coating life, and the metallic zinc protects the steel in areas where the paint film may be damaged through impacts or abrasion in service. The synergistic effect gained from the galvanizing-plus-paint combination is discussed on page 65.

**Internal steelwork in industrial buildings.** Galvanized coatings are ideal for many structures which house industrial processes; in structures where the humidity of contained air is high, as in breweries, paper manufacture and sewage treatment; and in food processing and other areas where cleanliness is essential. Whether used alone or in combination with paint coatings as discussed above, galvanized steel will provide very low total long term cost, with longer maintenance-free service periods.

### Galvanized lintels or arch bars

Once rusting begins in a lintel or arch bar, it cannot be stopped. The exposed surface may be repainted but there is no treatment for concealed areas.

The advance of corrosion may continue until the expansion of steel corrosion products causes cracking of brickwork and ultimately, serious structural damage. In the paper 'Arch bars and angle lintels for brick walls' Australia's Department of Housing and Construction Experimental Building Station points out that:

'Arch bars and angle lintels are vulnerable to corrosion. Cracking of brickwork because of the build-up of rust is very common and is a more serious consequence of corrosion than is the deterioration of the lintel itself. However, hot-dip galvanizing (zinc coating) is so readily available that it could well be adopted as standard practice for all arch bars...'

Australia's Model Uniform Building Code Section 47-7 discusses suitable corrosion protection for lintels as being '... not less effective than galvanizing'. Galvanizing provides practical, economic protection for lintels in all external applications and is particularly valuable near the sea coast.

Galvanized lintels are widely available in stock lengths and sections coded to user needs.

# Reliability of coatings for steel

Protective coatings for steel are normally compared on the basis of coating life, first cost, and total long term cost. The 'reliability factor' of a coating should also be taken into account since it is crucial in determining the extent to which the apparent properties of a coating will be realised in practice, and hence the relative economics of the coating.

The reliability factor of a coating may be defined as the extent to which its optimum complex of physical-chemical and mechanical characteristics can be consistently realised during and after application.

There are numerous paint systems for steel and a wide range of possible specification and application variables. Together

these variables can substantially reduce the performance of a given system and therefore its economics. By contrast, the galvanizing process is simple, standardised and virtually self-controlling, governed mainly by the laws of metallurgy. As a result it is inherently reliable and predictable.

The table below summarises factors determining the reliability of typical paint systems for steel, and for galvanizing. The reliability factor for galvanizing is shown to be superior, mainly because it is not influenced by most of the variables which can reduce the ultimate performance of typical paint systems.

A more detailed evaluation of these factors is contained in the paper 'Reliability of hot dip galvanizing, compared with two paint systems and a duplex system' by Ing JFH van Eijnsbergen, available from Galvanizers Association of Australia.

## Factors determining protective coating system reliability

An analysis of variables which determine the extent to which apparent properties of a coating system will be realised in practice. Draws on data from Australian Standard 2312 'Guide to the protection of iron and steel against exterior atmospheric corrosion'.

Variable	Paint systems – inorganic zinc, organic zinc, chlorinated rubber etc.	Galvanizing
Nature of steel	No effect	High silicon steels may increase coating thickness by 2 to 3 times, give rough surface finish, may result in brittle coatings.
Surface preparation	AS 2312 recommends abrasive blast cleaning or acid cleaning, rather than flame cleaning or wire brushing. Inadequate grit blasting can reduce paint durability 60 to 80%. Inadequate degreasing and rinsing can reduce life by a factor of 4. Inspection procedures are critical.	Degreasing, acid cleaning and rinsing are part of the galvanizing process. The steel surface must be properly prepared, otherwise no coating will form.
Process variables	Accurate formulation, careful mixing, continued agitation, correct thinning can be critical.	The minor variations possible in the galvanizing process have minimal effect on coating integrity.
Application	Coating build and uniformity variable with method of application, eg. spray, airless spray, brush or roller. Inspection at each stage is critical. Highly reactive blast-cleaned surfaces must be painted within hours.	Formation of coating during immersion is automatic, governed by laws of metallurgy.
Application conditions:		
1. Temperature	Satisfactory results may be difficult to achieve below air temperatures of 15°C or above 30°C.	Process not affected
2. Humidity	Dew and surface condensation prevent painting. Painting should not proceed when relative humidity exceeds 85%.	Process not affected.
3. Air quality	The presence of steam, fumes, exhaust gases, dust and grit are detrimental to good painting.	Process not affected.
4. Hot surfaces	High steel surface temperatures (eg painting in the sun) may interfere with paint application and curing.	Not applicable.
5. Uniformity of application	Paint film thins out at sharp corners and edges. Bolt holes generally not protected. Paint may not penetrate narrow gaps. Shadowed areas may receive less paint build.	Total coverage obtained by submersion of article in molten zinc. Coating is usually 50% thicker on sharp corners and edges.
Coating thickness	Critical to coating performance. Variable with number of coats and application method. Inspection and checking necessary at each stage.	Reaction between molten zinc and steel surface guarantees a standard minimum coating thickness. Mass and thickness of steel influences coating thickness (thicker steel = thicker zinc).
Coating adhesion	Depends on surface preparation, paint system type, time from surface preparation to first coat, curing time between coats.	Law of metallurgy; coating is bonded metallurgically to base steel.
Inspection	Imperative after surface preparation and at every coating stage to ensure quality. Thickness testing required.	Normally visual inspection and magnetic thickness testing after completion.
Curing time	Ranges from hours to days for safe handling, depending on paint system and application conditions, and up to several weeks to full coating hardness.	Coating is completely solidified within seconds of withdrawal from galvanizing bath.
Dimensional stability	Not affected.	Process may relieve locked-in stresses if incorrect design, fabrication and welding techniques are used.
Transport and erection damage	Possible damage in handling and transport.	Unlikely. Coating is tough and abrasion resistant. Delta alloy layer of coating is harder than base steel.
Welding damage	Extent of damage dependant on coating system. May require full surface preparation.	Localised damage may need repair. Restoration with organic zinc rich paint is general practice.