AS/NZS 2312.2:2014

Australian/New Zealand Standard™

Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings

Part 2: Hot dip galvanizing

STANDARDS Australia

STANDARDS® NEW ZEALAND PAEREWA AOTEAROA

AS/NZS 2312.2:2014

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Australian/New Zealand Standard™

Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings

Part 2: Hot dip galvanizing

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee MT-014, Corrosion of Metals, to supersede, in part, AS/NZS 2312:2002, *Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings*. It completely replaces references to hot dip coatings in AS/NZS 2312:2002, Section 5, and elsewhere in that document.

This Standard is Part 2 of a series for the protection of steel from corrosion, as follows:

AS/NZS		
2312	Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings	
2312.1	Part 1:	Paint coatings
2312.2	Part 2:	Hot dip galvanizing (this Standard)
2312.3	Part 3:	Thermally sprayed metallic coatings (in preparation)

This Standard does not cover thermal metal spray coatings, including zinc coatings and zinc-alloy coatings, which are the subject of AS/NZS 2312.3 (in preparation).

The objective of this revision is to provide guidelines for the proper specification and design of hot dip galvanized articles in the atmosphere. In preparing this Standard, reference was made to the ISO 14713 series, *Zinc coatings—Guidelines and recommendations for the protection of iron and steel in structures*.

This Standard should be used in conjunction with the relevant manufacturing Standards.

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Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings

Part 2: Hot dip galvanizing

1 SCOPE

This Standard provides guidelines and recommendations regarding general principles of design, appropriate for articles to be hot dip galvanized for corrosion protection. The application of zinc coatings by hot dip galvanizing provides an effective method of retarding or preventing corrosion of ferrous materials. Zinc coatings are used in this regard because they protect iron and steel both by barrier action and by galvanic action.

The protection afforded by the zinc coating to the article will depend on the method of application of the coating, the design of the article (both of which directly influence the thickness of the zinc coating), and the specific environment to which the article is exposed. The zinc coated article can be further protected by application of additional coatings, such as organic coatings (paints or powder coatings). When applied to hot dip galvanized articles, this combination of coatings is often known as a 'duplex system'.

This Standard applies to hot dip galvanized coatings applied by the following processes:

(a) Hot dip galvanized coatings, applied after fabrication. (See Clause 5.1.2.)

(b) Hot dip galvanized coatings, applied onto continuous sheet. (See Clause 5.1.3.)

(c) Hot dip galvanized coatings, applied onto continuous cold-formed shapes. (See Clause 5.1.4.)

Other zinc coating processes covered in this Standard are the following:

(i) Mechanically plated coatings (see Clause 5.1.5).

(ii) Electrodeposited coatings (see Clause 5.1.6).

Specific product-related requirements (e.g. for hot dip galvanized coatings on tubes or fasteners, etc.) will take precedence over these general recommendations.

2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

NOTE: Documents that may be referred to for additional information are listed in the Bibliography.

AS

1074 Steel tubes and tubulars for ordinary service

1214 Hot-dip galvanized coatings on threaded fasteners (ISO metric coarse thread series)

1397 Continuous hot-dip metallic coated steel sheet and strip—Coatings of zinc and zinc alloyed with aluminium and magnesium

1442 Carbon steels and carbon-manganese steels—Hot rolled bars and semi-finished products

1447 Hot-rolled spring steels

AS		
1789	Electroplated zinc (electrogalvanized) coatings on ferrous articles (batch process)	
1830	Grey cast iron	
1832	Malleable cast iron	
1897	Electroplated coatings on threaded components (metric coarse series)	
2309	Durability of galvanized and electrogalvanized zinc coatings for the protection of steel in structural applications—Atmospheric	
4100	Steel structures	
4291	Mechanical properties of fasteners made of carbon steel and alloy steel	
4291.1	Part 1:	Bolts, screws and studs
4312	Atmospheric corrosivity zones in Australia	
4506	Metal finishing—Thermoset powder coatings	
4750	Electrogalvanized (zinc) coatings on ferrous hollow and open sections	
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1163	Cold-formed structural steel hollow sections	
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2312.1	Part 1:	Paint
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2699	Built-in components for masonry construction	
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3678	Structural steel—Hot-rolled plates, floorplates and slabs	
3679	Structural steel	
3679.1	Part 1:	Hot-rolled bars and sections
3679.2	Part 2:	Welded I sections
4671	Steel reinforcing materials	
4680	Hot-dip galvanized (zinc) coatings on fabricated ferrous articles	
4791	Hot-dip galvanized (zinc) coatings on ferrous open sections, applied by an in-line process	
4792	Hot-dip galvanized (zinc) coatings on ferrous hollow sections, applied by a continuous or a specialized process	
NZS		
3404	Steel Structures Standard	
3404.1	Part 1:	Materials, fabrication, and construction

* To be published.

ISO

2063	Thermal spraying—Metallic and other inorganic coatings—Zinc, aluminium and their alloys
8044	Corrosion of metals and alloys—Basic terms and definitions
9223	Corrosion of metals and alloys—Corrosivity of atmospheres—Classification, determination and estimation
9224	Corrosion of metals and alloys—Corrosivity of atmospheres—Guiding values for the corrosivity categories
12944	Paints and varnishes—Corrosion protection of steel structures by protective paint systems
12944-5	Part 5: Protective paint systems
12944-8	Part 8: Development of specifications for new work and maintenance

ASTM

B117	Standard Practice for Operating Salt Spray (Fog) Apparatus

Australian Building Codes Board
National Construction Code of Australia

3 DEFINITIONS

For the purposes of this Standard, the terms and definitions given in AS 4312, AS/NZS 4680, ISO 8044, and those below apply.

3.1 Atmospheric corrosion

Corrosion with the earth's atmosphere at ambient temperature as the corrosive environment.

3.2 Elevated temperatures

Temperatures between +60°C and +200°C.

3.3 Exceptional exposure

Special cases, such as exposure that substantially intensifies the corrosive exposure and/or places increased demands on the corrosion protection system.

3.4 Hot dip galvanized coating

Coating obtained by hot dip galvanizing.

NOTE: The term 'hot dip galvanized coating' is subsequently referred to as the 'coating'.

3.5 Hot dip galvanizing

Formation of a coating of zinc and/or zinc/iron alloys on iron and steel products by dipping prepared steel or cast iron in a zinc melt.

3.6 Life to first maintenance

The time interval that can elapse after initial coating before coating deterioration reaches the point when maintenance is necessary to restore protection of the base metal.

4 MATERIALS—IRON AND STEEL SUBTRATES

In hot dip galvanizing, the reactivity of the steel is modified by its chemical composition, particularly by the silicon plus phosphorus contents (see Clause 9.1).

Most steels, including unalloyed carbon steels and fine-grained steels (e.g. AS/NZS 1594, AS/NZS 3678, AS/NZS 3679.1, AS/NZS 3679.2, AS 1442, and AS 1447), hollow sections that are cold finished (e.g. AS/NZS 1163 and AS 1074), reinforcement steels (e.g. AS/NZS 4671), and fastener grade steels (e.g. AS 4291.1), can be galvanized. Where other ferrous metals are to be galvanized, adequate information or samples should be provided by the specifier for the galvanizer to decide whether these steels can be satisfactorily galvanized. Sulfur-containing free-cutting steels are normally unsuitable (e.g. AS 1442 S1214 grade).

Steel can be hot rolled or cold formed. Hot rolling is used to produce angle, 'I', 'H' and other structural sections and these sections are normally only batch hot dip galvanized (see Clause 5.1.2). Some structural sections (e.g. tubes, pipes and purlins) are cold formed and these can be batch hot dip galvanized or in-line galvanized (see also Clause 5.1.4).

Cast and wrought irons of various metallurgical and chemical compositions (e.g. grey cast iron [AS 1830] and malleable cast iron [AS 1832]) can be hot dip galvanized according to AS/NZS 4680. Special consideration is needed regarding the cast irons most suitable for hot dip galvanizing (see Clause 9.3).

5 ZINC COATINGS

5.1 Types of coating

5.1.1 *General*

The specifier should be aware of the available types of zinc coating and take these distinctions into account when designing articles (see Clause 7). Importantly, the corrosion protection in any particular environment is directly related to the thickness of the coating (see Table 6.2).

5.1.2 *Hot dip galvanized coatings (applied after fabrication to AS/NZS 4680 and AS 1214)*

Coating where, after suitable pretreatment, fabricated iron or steel articles are dipped in a bath containing a zinc melt. Typically, this process is used on pre-fabricated articles requiring longer term corrosion protection, including those articles that are centrifuged and non-centrifuged.

The design practice for coating to AS/NZS 4680 differs from that for other coating systems. Detailed guidance on the design practice is provided in Clauses 8 and 9.

5.1.3 *Hot dip galvanized coatings (applied onto continuous sheet to AS 1397)*

Coating where, after suitable pretreatment, sheet materials are continuously fed through a zinc melt and the hot dip galvanized sheet materials formed are used to fabricate a semi-finished structural article, such as purlins.

Post-galvanizing fabrication, such as bending, drilling and cutting may create uncoated areas, which will reduce the life of the formed article unless additional protective steps are taken.

The coating thickness of these products is measured as a total applied zinc mass, and the thickness of the coating (and hence the corrosion protection) may not be the same on each side of the sheet.

NOTES:

1 Other coating thickness and alloys are given in AS 1397, in addition to coatings with longer durability than the coatings from AS 1397 described in this Standard.

2 The design practice for continuous galvanizing to AS 1397 is available from specialist manufacturers.

5.1.4 *Hot dip galvanized coatings (applied onto continuously cold-formed shapes to AS/NZS 4791 and AS/NZS 4792)*

Coating where, after suitable pretreatment, coil materials are continuously fed through a zinc melt and the hot dip galvanized coil materials are cold formed into structural shapes within the process line of the galvanized article (commonly known as in-line galvanizing). Shapes formed include light structural sections (AS/NZS 4791) and cold formed tube (AS/NZS 4792).

Post-galvanizing fabrication such as bending, drilling, cutting and welding may create uncoated areas, which will reduce the life of the formed article unless additional post-fabrication protective steps are taken.

Some in-line galvanized tubular sections have no internal coating, while others have a different internal coating thickness from the external coating thickness. Hence, the internal corrosion protection requirement has to be taken into account by the designer (see Clause 7.2).

The design practice for continuous galvanizing to AS/NZS 4791 and AS/NZS 4792 is available from specialist manufacturers.

5.1.5 *Mechanically plated coatings (to AS 5056)*

Coating where, after suitable pretreatment, a zinc powder is mechanically applied to the surface of the steel article, usually by tumbling in a barrel. The articles coated are typically fasteners and other small items ancillary to the main structural components.

NOTE: Further information is available from the manufacturers of the finished articles.

The design for mechanical coating to AS 5056 is best discussed with specialist applicators; in general, these processes are most suitable for small parts which can be tumbled in a barrel but specialist plants may be available for other shapes.

5.1.6 *Electrodeposited coatings (to AS 1789, AS 1897 or AS 4750)*

Where, after suitable pretreatment, materials have a coating of zinc attached to the surface of the steel using the electroplating process. In some cases, electrodeposited coil material is further processed by slitting, roll forming and welding the coil into articles such as cold formed tubing (AS 4750), where the coating in the area of the heat affected zone (HAZ) of the weld is repaired as part of the tube manufacturing process.

Post-electroplating fabrication such as bending, drilling, cutting and welding may create uncoated areas, which will reduce the life of the formed article unless additional post-fabrication protective steps are taken.

NOTE: Further information is available from the manufacturers of the finished articles.

The design for electroplating with zinc to AS 1789 and AS 1897 follows the general design principles for electroplating.

The design for use of articles manufactured to AS 4750 is available from specialist manufacturers.

5.2 Selection of hot dip galvanized coating

The hot dip galvanized coating system to be used should be selected by taking the following items into account:

(a) The design life of the coated article determined from Standards (e.g. AS 4100, NZS 3404.1), the asset owner's expectations, or other available sources (e.g. the National Construction Code of Australia).

(b) The site specific corrosivity category, taking into account the general environment (macro-climate) and the effects of any local variations in the environment (microclimate), including anticipated future changes and any exceptional exposure (see Clause 6.1 and Table 6.1).

(c) The life to first maintenance available options (see Table 6.2) taking into account the general principles of design to avoid corrosion (Clause 7.1) and whether tubular sections require internal protection (Clause 7.2).

NOTE: The life to first maintenance of some or all of the options may be less than the required design life, meaning that the coated article may require maintenance during the design life to maintain the structural integrity of the article.

(d) The need for, and effect of, ancillary components such as bolted and welded connections on the overall durability of the coated article (see Clause 7.3).

(e) The ease of maintenance of the coated article (see Clause 7.4) if the life to first maintenance of the coated article or ancillary components is less than the required durability.

NOTES:

1 A hot dip galvanized article may be designed for disassembly and re-galvanizing to extend its practical life. Alternatively, the article may be painted on site to extend its practical life, in the same way as an initially painted steel article (see AS/NZS 2312.1).

2 The life for a coating in any particular atmospheric exposure condition is approximately proportional to the thickness of the coating (see Table 6.2).

(f) The need for painting the coated article, either initially (duplex system) or touch-up painting when the hot dip galvanized coating is approaching the end of its life to first maintenance (see Clause 7.5 and Table 7.1).

NOTE: A duplex coating may be specified for decorative or other reasons not related to durability of the coated article. Maintenance is often required at more frequent intervals because of paint fading, chalking, contamination, wear and tear, for aesthetic or other reasons.

(g) The cost and availability of the options, including any required maintenance.

NOTE: If there are no suitable options the specifier should consider a design change, alternative materials (e.g. stainless steel) or alternative protection methods.

The operational sequence for applying the selected system should be determined in consultation with the steel fabricator and the applicator of the coating system.

6 CORROSION IN THE ATMOSPHERE

6.1 General

The corrosion rate of a zinc coating is affected by the time for which it is exposed to wetness, air pollution and contamination of the surface. To a first approximation, the corrosion of all zinc surfaces is at the same rate in a particular environment. The corrosion rates for zinc are much slower than for steel and often decrease with time. Iron and steel will normally corrode 10 to 40 times faster than zinc, the higher ratios usually being in high-chloride environments. The corrosion rate for zinc and for zinc-iron alloy layers in a hot dip galvanized coating are approximately the same.

NOTES:

1 For general information on the atmospheric corrosion rate for zinc, see ISO 9224.

2 For information on the major factors that affect atmospheric corrosion in Australia, see AS 4312.

3 For information on the major factors that affect atmospheric corrosion in New Zealand, see NZS 3404.1.

Table 6.1 gives basic groups of environments (related to ISO 9223). Where the relative humidity is below 60%, the corrosion rate of iron and steel is negligible and they may not require coating (e.g. inside many buildings). A hot dip galvanized coating with or without painting may; however be required for appearance or for reasons of hygiene (e.g. in a food factory).

When the relative humidity is higher than 60% or where they are exposed to wet or immersed conditions or prolonged condensation then, like most metals, iron and steel are subject to more serious corrosion. Contaminants deposited on the surface, notably chlorides and sulfates, accelerate attack. Substances that deposit on the surface of the iron and steel increase corrosion if they absorb moisture or go into solution on the surface of the iron and steel. Deposition of chlorides in coastal areas is strongly dependent on the variables influencing the transport inland of sea salt (e.g. wind direction, wind velocity, local topography, wind sheltering islands beyond the coast, distance of the site from the sea, etc.). The temperature also influences the corrosion rate of unprotected iron and steel and temperature fluctuations have a stronger effect than the average temperature value.

NOTES:

1 In Australian capital cities, the level of atmospheric sulfur dioxide (SO_2) is very low (typically averaging no more than 8 μg/m^3). For the most part this means that the effects of pollution can be ignored. However, there are special cases (for example, near industrial plants) where the concentration of SO_2 should be determined during at least 1 year and is expressed as the annual average.

2 Change in atmospheric environments occurs with time. For many regions, the concentrations of pollutants (particularly SO_2) in the atmosphere have reduced with time. This has led to a lowering of the corrosivity for these regions, which, in turn, has led to the hot dip galvanized coatings experiencing lower corrosion rates compared to historical corrosion performance data. An example of this is the closure of the BHP Steel Works in Newcastle. Other regions have experienced increasing pollution and industrial activity and, therefore, would be expected to develop environments more accurately described by higher corrosivity.

3 Extreme influence of chlorides, which is typical of marine splashing or heavy salt spray, is beyond the scope of this Standard.

The micro-environment (that is, the conditions prevailing around the structure) is also important because it allows a more precise assessment of the likely conditions than the study of the basic climate alone. The micro-environment is not always known at the planning stage of a project. Every effort should be made to identify it accurately because it is an important factor in the total environment against which corrosion protection is required.

NOTE: An example of a microclimate is sheltered and not rain-washed surfaces, in a marine atmospheric environment where chlorides are deposited and where the article can experience a higher corrosivity category due to the presence of hygroscopic salts.

The corrosion of steelwork inside buildings is dependent on the internal environment but in 'normal' atmospheres (e.g. dry and heated) it is insignificant. Steelwork in the perimeter walls of buildings is influenced by the configuration within the perimeter wall (e.g. steelwork without direct contact with the outer leaf of a wall comprising two parts separated by an air space is at less risk of corrosion than steelwork in contact with or embedded in the outer leaf). Buildings containing industrial processes, chemical environments, wet or contaminated environments should be given special consideration, as these are beyond the scope of this Standard. Steelwork that is partially sheltered (e.g. farm sheds and aircraft hangars) should be considered as being subjected to the exterior environment.

Table 6.1 also sets out an indication of the likely range of corrosion rates that are applicable to zinc coatings exposed to the different types of corrosivity category dealt with in ISO 9223.

6.2 Atmospheric corrosivity in Australia and New Zealand

Examples of typical external atmospheric conditions in Australia and New Zealand are described below. These descriptions are developed from AS 4312 and NZS 3404.1. If there is any doubt as the corrosivity category, professional advice should be sought.

Category C1 (Very low The only external environments in Australia or New Zealand are some alpine regions although generally these environments will extend into Category C2.

Category C2 (Low) External environments in this category include dry, rural areas as well as other regions remote from the coast or sources of pollution. Most areas of Australia and New Zealand beyond at least 50 km from the sea are in this category, which can however extend as close as one kilometre from seas that are relatively sheltered and quiet. Typical areas occur in arid and rural inland regions, most inland cities and towns such as Canberra, Ballarat, Toowoomba, Alice Springs and Hamilton (NZ), and suburbs of cities on sheltered bays, such as Melbourne and Hobart. Proximity to the coast is an important factor.

Category C3 (Medium) This category mainly covers coastal areas with low salinity. The extent of the affected area varies significantly with factors such as winds, topography and vegetation. Around sheltered seas, such as Port Philip Bay, Category C3 extends beyond about 50 m from the shoreline to a distance of about one kilometre inland. For a less sheltered bay or gulf, such as near Adelaide, this category extends from 100 metres from the shoreline to about 3 to 6 km inland. Along ocean front areas with breaking surf and significant salt spray, it extends from about 1 km inland to between 10 to 50 km inland, depending on the strength of prevailing winds and topography. Much of the metropolitan areas of Wollongong, Sydney, Newcastle, the Gold Coast, Auckland and Wellington are in this category. In South Australia, the whole of the Yorke Peninsula falls within this or a more severe category, and in the south-east of the state, from Victor Harbour to the Victorian border, this category extends between 30 and 70 km inland. Such regions are also found in urban and industrial areas with low pollution levels and although uncommon in Australia and New Zealand, exist for several kilometres around major industries, such as smelters and steelworks, and in the geothermal areas of New Zealand. Micro-environmental effects, such as result from proximity to airports and sewage treatment works, may also place a site into this category.

Category C4 (High) This category occurs mainly on the coast. Around sheltered bays, Category C4 extends up to 50 m inland from the shoreline. In areas with rough seas and surf, it extends from about several hundred metres inland to about one kilometre inland. As with Categories C2 and C3, the extent depends on winds, wave action and topography. Industrial regions may also be in this category, but in Australia and New Zealand these are only likely to be found within 1.5 km of the plant. This category extends inside the plant where it is best considered as a micro-environment.

Category C5 (Very High) This category is common offshore and on the beachfront in regions of rough seas and surf beaches. The region can extend inland for several hundred metres. (In some areas of Newcastle, for example, it extends more than half a kilometre from the coast.) This category may also be found in aggressive industrial areas, where the environment may be acidic with a pH of less than 5.5.

Category CX (Extreme) These regions are found at some surf beach shoreline regions with very high salt deposition. Such corrosion rates would also be found in severe acidic industrial environments.

NOTE: This new category is not covered in the 2008 edition of AS 4312 or the 2009 edition of NZS 3404.1.

If a site is considered to be in more than one category, for example, an industry on the coast in a tropical region, then the hot dip galvanized coating should be capable of resisting the most severe of the environments involved.

6.3 Life to first maintenance of coatings

6.3.1 *General*

Table 6.2 indicates the life to first maintenance for a selection of hot dip galvanized and other zinc coatings exposed to the range of standard corrosivity categories. The minimum and maximum life expectancies are indicated for each chosen system and durability class indicated. Durability is classified into the following classes:

(a) Very short term (VS) .... 0 to ≤2 years.

(b) Short term (S).. 2 to <5 years.

(c) Medium term (M) .... 5 to <10 years.

(d) Long term (L)... 10 to <15 years.

(e) Very long term (VL).. 15 to <25 years.

(f) Extra long term (EL)... ≥25 years.

Table 6.2 also provides guidance for coatings applied to structural and cold-forming grades of hot dip galvanized sheet and cold-rolled sections, on electrogalvanized and hot dip galvanized tube, and for articles hot dip galvanized after manufacture. Hot dip galvanized fabricated and semi-fabricated products made from thin material and fasteners and other centrifuged work usually have intermediate thicknesses of coating (e.g. AS 1214). As the life of all hot dip galvanized coatings is approximately proportional to the thickness or mass of zinc coating present, the relative performance of such intermediate thicknesses can readily be assessed.

Table 6.2 does not take into account any micro-environment experienced by the article (Clause 6.1). If the specifier is in any doubt as to the overall corrosivity category likely to be experienced by the article, expert advice should be sought.

The figures for life in Table 6.2 have been rounded to whole numbers. The allocation of the durability designation is based on the average of the minimum and maximum of the calculated life to first maintenance. For example, 85 µm hot dip galvanized coating in corrosivity Category C4 (corrosion rate for zinc between 2.1 µm per annum and 4.2 µm per annum from Table 6.1), gives an expected maximum durability of 85/2.1 = 40.746 years (rounded to 40 years) and an expected minimum durability 85/4.2 = 20.238 years (rounded to 20 years). The average durability of (20 + 40)/2 = 30 years is therefore designated 'EL'.

NOTES:

1 Corrosivity Categories C1 and C2 are not included in the Table as the zinc coating systems listed with a coating thickness more than 36 µm will achieve at least a minimum life to first maintenance of 50 years in C1 and C2 corrosivity zones, which exceeds the typical design requirements of most Standards and Codes such as the National Construction Code of Australia.

2 The list of systems given in Table 6.2, classified by environment and typical time to first maintenance, indicates the hot dip galvanized coating options open to the specifier. The recommended treatments listed for longer lives will always protect for shorter periods and also are economical for these shorter periods.

6.3.2 *Criteria for assessing when to repair or regalvanize*

Repair or regalvanizing of hot dip galvanized coatings should be carried out when about 2% of the surface in any particular area is showing signs of rusting.

NOTES:

1 Surface staining of iron/zinc alloys of unpainted hot dip galvanized coatings should be ignored unless it is aesthetically unacceptable.

2 See AS/NZS 2312.1 for schematic representations of surface rusting.

6.4 Accelerated test methods applied to zinc coatings

Accelerated test methods should not be used to predict the life to first maintenance of zinc-coated steel unless appropriate corroborating long-term atmospheric exposures have been conducted.

NOTE: Efforts have been made in many zinc-coated steel applications to develop the correct test method to determine a proper 'accelerated' lifetime. One test for corrosion prevention systems in the United States is ASTM B117; however, the test results obtained from that Standard seldom correlate to real life performance in natural environments and cannot be used to accurately test zinc-coated steel because the test accelerates the wrong failure mechanism. Without a proper wet/dry cycle, the zinc coating cannot form patina layers. The absence of a patina layer allows constant attack of the zinc metal and gives a very low prediction of the zinc coating lifetime.

ISO 9224 provides guiding values for long-term corrosion rates of zinc-coated steels which are based on a large number of exposures in many locations throughout the world; however, the procedure used in ISO 9224 cannot possibly cover all the situations that can occur in natural environments and service conditions. In particular, situations (e.g. as described in Clause 6.1) that result in significant changes in the environment can cause major increases or decreases in corrosion rates. Users of this Standard are cautioned to consult with qualified experts in the field of outdoor atmospheric corrosion in cases where localized corrosion can be more significant than general attack.

TABLE 6.1

DESCRIPTION OF TYPICAL ATMOSPHERIC ENVIRONMENTS

Corrosivity Category C, corrosion rate for zinc (based on one year exposures), r_{corr} (µm/year), and corrosion level	Typical environments (examples from ISO 9223)	
	Indoor	**Outdoor**
C1 $r_{corr} \leq 0.1$ Very low	Heated spaces with low relative humidity and insignificant pollution (e.g. offices, schools, museums).	Dry or cold zone. Atmospheric environment with very low pollution and time of wetness (e.g. certain deserts, central Antarctica).
C2 $0.1 < r_{corr} \leq 0.7$ Low	Unheated spaces with varying temperature and relative humidity. Low frequency of condensation and low pollution (e.g. storage, sport halls).	Temperate zone with an atmospheric environment with low pollution (SO_2 < 5 µg/m^3) (e.g. rural areas, small towns). Also, dry or cold zone with an atmospheric environment with short time of wetness (e.g. deserts).
C3 $0.7 < r_{corr} \leq 2.1$ Medium	Spaces with moderate frequency of condensation and moderate pollution from production process (e.g. food-processing plants, laundries, breweries, dairies).	Temperate zone with an atmospheric environment with some effect of chlorides, or medium pollution (SO_2: 5 µg/m^3 to 30 µg/m^3) (e.g. coastal areas with low deposition of chlorides, urban areas). Also, subtropical and tropical zones with an atmosphere with low pollution.
C4 $2.1 < r_{corr} \leq 4.2$ High	Spaces with high frequency of condensation and high pollution from production process (e.g. industrial processing plants, swimming pools).	Temperate zone with substantial effect of chlorides or an atmospheric environment with high pollution (SO_2: 30 µg/m^3 to 90 µg/m^3) (e.g. coastal areas without spray of salt water, polluted urban areas, industrial areas). Also, subtropical and tropical zones with an atmosphere with medium pollution.
C5 $4.2 < r_{corr} \leq 8.4$ Very high	Spaces with very high frequency of condensation and/or with high pollution from production process (e.g. mines, caverns for industrial purposes, unventilated sheds in subtropical and tropical zones).	Temperate and subtropical zones with an important effect of chlorides and/or an atmospheric environment with very high pollution (SO_2: 90 µg/m^3 to 250 µg/m^3) (e.g. coastal areas, sheltered positions on coastline, industrial areas).
CX $8.4 < r_{corr} \leq 25$ Extreme	Spaces with almost permanent condensation or extensive periods of exposure to extreme humidity effects and/or with high pollution from production process (e.g. unventilated sheds in humid tropical zones with penetration of outdoor pollution including airborne chlorides and corrosion-stimulating particulate matter).	Subtropical and tropical zones (very high time of wetness) and an atmospheric environment with strong effect of chlorides and/or very high pollution (SO_2 higher than 250 µg/m^3), including accompanying production pollution (e.g. coastal and offshore areas with occasional contact with salt spray, extreme industrial areas).

NOTE: Corrosion rates exceeding the upper limits in Category C5 are considered extreme. Corrosivity Category CX refers to specific marine and marine/industrial environments. In environments with an expected 'CX category', it is recommended to determine the atmospheric corrosivity classification from one year corrosion losses.

TABLE 6.2

LIFE TO FIRST MAINTENANCE FOR A SELECTION OF HOT DIP GALVANIZED COATING SYSTEMS IN A RANGE OF CORROSIVITY CATEGORIES

System	Reference Standard		Minimum thickness (Note 1)		Selected corrosivity category (ISO 9223) calculated min.–max. life (years) and durability class (VS, S, M, L, VL, EL)							
			g/m²	µm	C3		C4		C5		CX	
Hot dip galvanizing	AS/NZS 4680 (Note 2)	HDG390	390	55	26–78	EL	13–26	VL	6–13	M	2–6	S
		HDG500	500	70	33–100	EL	16–33	VL	8–16	L	2–8	M
		HDG600	600	85	40 > 100	EL	20–40	EL	10–20	VL	3–10	M
		HDG900	900	125	60 > 100	EL	30–60	EL	15–30	VL	5–15	H
Hot dip galvanized sheet	AS 1397 (Note 3,4)	Z350	140	20	10–29	VL	5–10	M	2–5	S	1–2	VS
		Z450	180	25	12–36	VL	6–12	M	3–6	S	1–3	VS
Electro galvanized tube	AS 4750	ZE100	100	14	6–20	L	3–6	S	1–3	VS	0–1	VS
		ZE300	300	42	20–60	EL	10–20	VL	5–10	M	1–5	S
Hot dip galvanized tube	AS/NZS 4792 (Note 5)	ILG100/ ZB100/100	100	14	6–20	L	3–6	S	1–3	VS	0–1	VS
		ILG140/ ZB140/140	140	20	10–29	VL	5–10	M	2–5	S	1–2	VS
		ILG300/ ZB300/300	300	42	20–60	EL	10–20	VL	5–10	M	1–5	S
Mechanical plating	AS 5056 (Note 6)		55	8	4–11	M	2–4	S	1–2	VS	0–1	VS
			175	25	12–36	VL	6–12	M	3–6	S	1–3	VS
Electroplated coatings	AS 1897	Fe/Zn 8c	55	8	4–11	M	2–4	S	1–2	VS	0–1	VS
		Fe/Zn 25c	175	25	12–36	VL	6–12	M	3–6	S	1–3	VS

NOTES TO TABLE 6.2:

1 It is impossible to achieve an exactly uniform thickness of any type of coating. The minimum thickness columns of this Table indicate the minimum average coating thickness for each system. In practice, the overall mean is likely to be substantially in excess of this minimum, which is important as zinc coatings are able to provide protection to adjacent areas that can lose their coating prematurely.

2 AS/NZS 4680 specifies the standard hot dip galvanized coating at the equivalent of 85 µm minimum for steel >6 mm thick. 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.

3 Unlike other hot dip galvanizing standards referenced in Table 6.2, the thickness requirements in AS 1397 are recorded as the total of both sides, but are shown in the Table as approximate local thickness requirements on one side only for consistency.

4 Zinc/aluminium alloy coatings (with 5% to 55% aluminium) usually last longer than pure zinc of the same thickness; pending wider use, they are not included in this Table. There is widespread technical literature available on these classes of materials.

5 Hot dip galvanized tube manufactured to AS/NZS 4792 may be supplied with the internal surface uncoated. In this case the durability only applies to the coated external surface and the specifier may need to consider alternative corrosion protection methods for the internal surface, such as end caps.

6 Mechanical plated coatings in AS 5056 are specified on the basis of coating thickness and porosity rather than coating mass. Table 6.2 assumes that these coatings are 100% dense. This is only true in a limited number of cases, as Clause 7.4 and Appendix F in AS 5056 specifies a range of coating porosities from 40% to 0% (i.e. 60% to 100% dense). In practice, the lifetimes of these coatings are likely to be up to 40% less than the figures in Table 6.2.

7 GENERAL DESIGN REQUIREMENTS

7.1 General principles of design to avoid corrosion

Design of structures and products should influence the choice of protective system. It may be appropriate and economic to modify the design to suit the preferred protective system.

The following should be taken into consideration:

(a) Provision of safe and easy access for cleaning and maintenance.

(b) Avoid pockets and recesses in which water and dirt can collect; a design with smooth contours facilitates application of a protective coating and helps to improve corrosion resistance. Corrosive chemicals should be directed away from structural components.

(c) Areas that are inaccessible after erection should be given a coating system designed to last the required life of the structure.

(d) If bimetallic corrosion (corrosion due to contact between dissimilar materials: metals and/or alloys) is possible, additional protective measures should be considered.

NOTE: For information on bimetallic contact, see Paragraph B8, Appendix B.

(e) Where the hot dip galvanized iron and steel are likely to be in contact with other building materials, special consideration should be given to the contact area (e.g. the use of insulating paint, tapes or plastic foils should be considered).

(f) Hot dip galvanizing can be provided only in a specialized plant. When paint is to be applied to a hot dip galvanized coating, the application is more readily controlled under factory conditions but where there is a likelihood of substantial damage occurring during transportation and erection, specifiers may prefer to apply the final paint coat on site. The application of a powder coating on hot dip galvanized coated steel can only be done in a specialized powder coating plant.

Where the total system is applied offsite, the specification should cover the need for care at all stages to prevent damage to the finished iron and steel and set out repair procedures to the coating once the steelwork is erected.

(g) Hot dip galvanizing in accordance with AS/NZS 4680 is often appropriate after bending and other forms of fabrication.

NOTE: Other hot dip galvanizing methods are always carried out prior to bending and other forms of fabrication, meaning that the specifier has to consider suitable methods to repair any damage to the pre-applied coating.

(h) Methods of marking parts should not have an influence on the quality of the pre-treatment operations prior to hot dip galvanizing.

(i) Precautions may be required to minimize the likelihood of deformation during processing or subsequently.

(j) The conditions experienced by the articles during hot dip galvanizing application may also need to be considered.

7.2 Tubes and hollow sections

7.2.1 *General*

If they are dry and hermetically sealed, the internal surfaces of tubes and hollow sections will not need protection (see Clause 7.2.2). Where hollow sections are fully exposed to the weather, or interior environments that might give rise to condensation, and are not hermetically sealed, consideration should be given to the need for both internal and external protection.

7.2.2 *Corrosion protection of internal and external surfaces*

There are some specialized products where the thickness of the coating is different on internal and external surfaces (see AS/NZS 4792 and AS 1397).

Hot dip galvanizing to AS/NZS 4680 gives equal thickness internally and externally. When tubes and hollow sections are hot dip galvanized after assembly into structures to AS/NZS 4680, drainage/venting holes should be provided for processing purposes (see Clause 8 and Appendix A).

7.3 Connections

7.3.1 *Fastenings to be used with coatings*

The protective treatment of bolts, nuts and other parts of the structural connections should be given careful consideration. Ideally, their protective treatment should provide a similar performance to that specified for the general surfaces.

NOTE: Specific requirements are given in the appropriate product Standards (e.g. AS 1214) and in a series of International Standards for coatings on fasteners which are in the course of preparation/publication.

Hot dip galvanized (see, for example, AS 1214, which covers specified minimum coating thicknesses up to 52.5 µm), or other coatings on steel fasteners should be considered. Alternatively, stainless steel fasteners may be used.

NOTE: For precautions to take in order to minimize the potential for bimetallic corrosion, see Appendix B.

The mating surfaces of connections made with high-strength friction-grip bolts should be given special treatment. It is not necessary to remove hot dip coatings from such areas to obtain an adequate coefficient of friction; however, consideration has to be given to any long-term slip or creep-avoidance requirements and to any necessary adjustments to the assembly dimensions as per the requirements of AS 4100 and NZS 3404.1.

NOTE: Further information is available from the Galvanizers Association of Australia or the Galvanizing Association of New Zealand.

7.3.2 *Welding considerations related to coatings*

7.3.2.1 *General*

It is recommended to weld prior to hot dip galvanizing to AS/NZS 4680. The use of welding anti-spatter sprays that cannot be removed in the pretreatment process at the galvanizers' works should be avoided. For this reason, where welding sprays are used, low silicone, water-soluble sprays are recommended. After welding, the surface should be prepared to the standard specified for preparing the steelwork overall before applying the protective coating process. Welding should be balanced (i.e. equal amounts on each side of the main axis) to avoid introducing unbalanced stresses in a structure. Welding residues have to be removed before coating. Extra pretreatment may be needed for hot dip galvanizing; in particular, weld slag should be removed separately. Some forms of welding leave alkaline deposits behind. The hot dip galvanizing pretreatment process removes alkaline deposits for articles that are to be galvanized after fabrication.

It is desirable that fabrication takes place without the use of paint or weld primer, as this has to be removed before hot dipping.

Where welding takes place after hot dip galvanizing, it is preferable, before welding, to remove the coating locally in the area of the weld to ensure the highest quality weld.

Welding of hot dip galvanized parts has to be done with appropriate local air ventilation in accordance with health and safety regulations.

7.3.2.2 *Repair requirements after welding*

After welding of hot dip galvanized coatings, protection should be appropriately restored locally by one of the following methods.

(a) Organic zinc rich epoxy paint complying with AS/NZS 3750.9 applied to the repair areas in two coats. Each coat should have a minimum dry film thickness of 50 µm.

(b) Inorganic zinc silicate paint complying to AS/NZS 3750.15 with a minimum dry film thickness of 100 µm.

NOTES:

1 For subsequent powder coating, these two coating repair systems should be capable of passing 1000 hour neutral salt spray performance when tested in accordance with AS 2331.3.1 and should be stable under powder coating curing conditions.

2 Zinc rich paint applied using the aerosol spray can method is unlikely to give the required thickness or quality of repair material and should not be used.

(c) Zinc metal spray to ISO 2063 or AS/NZS 2312.3 (in preparation).

(d) Zinc alloy solder stick.

All of the above treatments are be applied as per manufacturers' requirements and include any necessary pre-treatment to ensure good adhesion to the substrate.

The coating thickness on the renovated area should be a minimum of 30 µm more than the local coating thickness requirements for the relevant hot dip galvanized coating unless the purchaser advises the galvanizer otherwise (e.g. when the hot dip galvanized surface is to be over coated and the thickness for renovated areas is to be the same as for the hot dip galvanized coating).

After welding of hot dip galvanized steels, the surface should be prepared to the standard specified for preparing the steelwork overall before applying paint or fusion-bonded powder coatings.

Assemblies comprising different metals needing different pretreatments should be discussed with the processor.

7.3.3 *Brazing or soldering*

Soft soldered assemblies cannot be hot dip galvanized to AS/NZS 4680 and brazing should be avoided if possible, as many types of brazing are unsuitable for hot dip galvanizing. The galvanizer should be consulted if brazing is being considered.

Since corrosive fluxes may be used in these processes, removal of flux residues after the process is essential to avoid corrosion of the coated parts; the design of these parts should facilitate this.

7.4 Maintenance of coatings

A hot dip galvanized coating may be left unmaintained for the service life of the structure if the coating life is longer than the service life of the structure (see Clause 6.3).

If the required service life of the structure is longer than the coating life, maintenance of the coating should be carried out by stripping and re-galvanizing (part of) the structure or by painting while some original coating remains (see AS/NZS 2312.1).

7.5 Duplex systems

7.5.1 *General*

Table 7.1 gives information on organic coatings that are applied to hot dip galvanized coatings manufactured to AS/NZS 4680. When such an organic coating has been applied, the term 'duplex system' is used to describe the combination of coatings.

NOTES:

1 AS 4506 provides information on powder coatings that are applied to hot dip galvanized coatings.

2 Detailed information on painting steel is contained in AS/NZS 2312.1. Users should be familiar with this Standard prior to preparing a specification based on the paint systems detailed in Table 7.1.

7.5.2 *Painting for decorative, identifying colour or enhanced service life*

Hot dip galvanized coatings are sometimes required to be painted for decorative reasons, to provide an identifying colour, or to enhance service life (see Clause 7.5.4, 7.5.5, 7.5.6 and 7.5.7).

In contrast with organic paints, which are degraded by solar radiation (UV), hot dip galvanized coatings are unaffected by sunlight, so over-painting is not usually required to extend service life in this circumstance.

The systems shown in Table 7.1, when applied and maintained correctly, will increase the service life of the hot dip galvanized article beyond that of the unpainted article. Where an appropriate system exists, as shown in Table 7.1, and aesthetic requirements are not the overriding factor, the duplex coating life to first maintenance (corrosion) is estimated to be more than 25 years (durability class 'EL') in all corrosivity categories below C5.

Table 7.2 provides an estimate of the life to first maintenance of selected properly applied and maintained duplex systems in a C5 environment where protection against corrosion of the steel base is the overriding factor. Examples of where this might be important include industrial facilities, or where access for major repairs is difficult or costly and where maintenance of an aesthetic finish is not critical.

NOTE: In higher corrosivity areas (C3–C5) a paint system may accelerate corrosion of the hot dip galvanized substrate and reduce the overall service life of the article from the expected hot dip galvanized-only life unless a properly selected, high build paint system is applied and the integrity of that paint system is maintained throughout its service life as per the manufacturer's instructions.

7.5.3 *Preparation for painting*

7.5.3.1 *General*

When painting hot dip galvanized coatings, as when painting any other surface, the cleanliness and condition of the surface are of critical importance and a high proportion of paint failures on hot dip galvanized coatings can be attributed to inappropriate or inadequate surface preparation.

In preparing hot dip galvanized coatings for painting, the basic requirements are largely the same as for other surfaces. Namely, anything that prevents the paint wetting out or adhering to the surface needs to be removed. Therefore, oils, dirt, dust, salts, corrosion products and other friable material and soluble salts have to be removed prior to painting.

Abrasive sweep (brush) blast cleaning is a common method used for the preparation of a galvanized coating prior to the application of a paint coating. The purpose of this procedure is to remove the oxide film from the zinc surface.

Paint coatings should be applied as soon as possible after galvanizing or abrasive blasting.

7.5.3.2 *Procedure for sweep blast cleaning*

The following procedure should be observed when sweep blast cleaning is carried out to ensure that a good surface is produced for painting, without severely damaging the existing galvanized coating:

(a) Use fine non-metallic abrasives of a size which will pass through a test sieve of nominal aperture size 150 µm to 180 µm (e.g. ilmenite or garnet).

(b) Use a venturi nozzle which has an orifice diameter of 10 mm to 13 mm.

(c) Set the blast pressure at 275 kPa maximum.

(d) Keep the venturi nozzle at a distance of 350 mm to 400 mm from the surface of the workpiece and at an angle no greater than 45° to the surface.

NOTE: It is important that this procedure be performed carefully to ensure that no more than 10 µm of zinc is removed.

7.5.4 *Painting for unwashed surfaces*

In coastal service and industrial atmospheres where the steel article is not subject to the cleansing influence of rain, such as on the underside of horizontal surfaces, the proper over-painting of hot dip galvanized coatings will significantly extend service life. In this case, the paint insulates the hot dip galvanized surface somewhat from the corrosive contaminants (e.g. hygroscopic salts in a marine environment).

7.5.5 *Painting for exposure to soil and/or prolonged dampness*

While the majority of a hot dip galvanized structure might be exposed to the atmosphere, it may also be partially embedded in the soil or exposed to prolonged dampness, such as from the ponding of rainwater. In such situations, localized painting of the coating with a high build epoxy primer or the use of a tape or wrap may be needed to avoid premature corrosion in the exposed areas.

NOTE: See also AS/NZS 4680 and manufacturer's recommendations.

7.5.6 *Painting for specific industrial chemical or solvent exposure*

Hot dip galvanized coatings are recommended to be used within the pH range of 6 to 12. Outside this range, the service life is likely to be unacceptable. This includes exposure to strong acids and alkalis as well as salts of strong acids and weak bases and vice versa.

To develop an appropriate paint system for protection from specific chemical exposure, the recommendations of an expert or an established successful case history should always be sought.

7.5.7 *Painting for lintels and shelf angles in masonry construction*

This is a special case, for which the requirements are outlined in the relevant Standard (AS/NZS 2699.3). The user should be familiar with the requirements of that Standard prior to preparing a paint specification as there are specific details relating to handling, marking, colour coding, repair, testing, and certification for lintels and shelf angles.

7.5.8 *Maintenance of duplex coatings*

The total life of a properly specified, applied and maintained duplex coating system is usually significantly greater than the sum of the lives of the hot dip galvanized coating and protective organic coating alone. There is a synergistic effect, that is, the presence of the hot dip galvanized coating reduces under-rusting of the paint film; the paint preserves the hot dip galvanized coating from early corrosion. Where it is desired to retain a reasonably intact layer of paint as a basis for maintenance, the initially applied paint system should have extra thickness. Systems with thinner coatings (e.g. System 1D), are more likely be damaged by impact or wear and tear.

Maintenance usually takes place when the duplex coating loses its appearance or becomes degraded. Hot dip galvanized coatings usually take longer to degrade than paint. Hence, a hot dip galvanized coating may be recommended for 20 years or more up to first maintenance, whereas the same coating when covered by paint is, for reasons of appearance of the paint, recommended for only 10 years up to first maintenance. As noted in Clause 7.5.2, an area of degraded paint can retain moisture and hence hasten the corrosion of metal, particularly on a surface not washed by rain.

If maintenance is delayed until the hot dip galvanized coating has been consumed and rusting has started the iron and steel have to be maintained in the same way as rusted painted steel.

NOTE: See AS/NZS 2312.1 for advice on identifying and preparing a rusty steel surface for painting.

7.6 Design for storage and transport

Hot dip galvanized work should be stacked securely so that the work can be handled, stored and transported safely. Normally, articles should not be stacked together while hot or wet. Small articles dipped in bulk in baskets or on jigs should be centrifuged immediately after withdrawal from the zinc to remove any surplus metal.

Where there is a specific need to minimize the development of wet-storage staining (primarily basic zinc oxide and zinc hydroxide, formed on the surface of the galvanized coating during storage of work in humid conditions), this should be communicated by the specifier to the galvanizer at the time of ordering and any relevant control measures should be agreed upon. Such measures might include, for example, storage of work such that free movement of air across the surfaces of the work is allowed, the use of spacers to minimize contact areas on the work, or avoidance of close nesting of work (where the design allows this).

To retard the possible formation of wet-storage stain on the surface, articles may be given a suitable surface treatment after hot dip galvanizing. Wet storage stain which occurs after the product leaves the galvanizer's factory is not a cause for rejection.

If the articles are to be painted or powder coated after galvanizing, the specifier should inform the galvanizer before the article is galvanized. For the application of duplex systems involving the use of paints, the requirements for surface treatment, painting system, coating thickness, application technologies, etc., have to be defined by agreement between the specifier and galvanizer.

NOTE: For the application of duplex systems involving the use of powder coatings, recommendations for powders, pretreatments, applications and system performance can be found in AS 4506 or obtained from the Australian Institute of Surface Finishing (AISF).

TABLE 7.1

PAINTING SYSTEMS FOR HOT DIP GALVANIZED STEEL TO AS/NZS 4680

Coating system details													Durability—Years to first maintenance of paint component of duplex sytem			
System No.	Service qualities	Surface preparation	First coat			Second coat			Third coat			Total NDFT µm	Atmospheric corrosivity category			
			Type	PRN	NDFT µm	Type	PRN	NDFT µm	Type	PRN	NDFT µm		C2 Low	C3 Med	C4 High	C5 Very high
1D	Decorative	Degrease, wash and dry	Acrylic latex primer	C11	25	Acrylic latex paint	C21	50				75	5–10	5–10	NR	NR
2D	Decorative	Degrease, wash and dry, followed by sweep blast cleaning	Epoxy primer (2-pack) Inhibitive	C06	75	Polyurethane or acrylic gloss (2-pack)	C26 or C33	100				175	10–15	10–15	5–10	NR
3I	Wear and Tear Industrial	Degrease, wash and dry, followed by sweep blast cleaning	Epoxy primer (2-pack) Inhibitive	C06	75	High-build epoxy (2-pack)	C13	150				225	>15	10–15	10–15	5–10
4D	Protective Long Term Decorative	Degrease, wash and dry, followed by sweep blast cleaning	High-build epoxy (2-pack)	C13	250	Polyurethane or acrylic gloss (2-pack)	C26 or C33	100				350	>15	>15	10–15	5–10
4I	Protective Long Term Industrial	Degrease, wash and dry, followed by sweep blast cleaning	High-build MIO epoxy (2-pack)	C13	350							350	>15	>15	10–15	5–10
5D	Protective Long Term Decorative	Degrease, wash and dry followed by sweep blast cleaning	Epoxy primer (2-pack) Inhibitive	C06	75	High-build epoxy (2-pack)	C13	225	Polyurethane or acrylic gloss (2-pack)	C26 or C33	100	400	>15	>15	>15	10–15
5I	Protective Long Term Industrial	Degrease, wash and dry followed by sweep blast cleaning	Epoxy primer (2-pack) Inhibitive	C06	75	High-build MIO epoxy (2-pack)	C13	325				400	>15	>15	>15	10–15

NOTES TO TABLE 7.1:

1 The systems shown in this Table are generic systems only and are only applicable for hot dip galvanized substrates to AS/NZS 4680, and other systems may be available. Other hot dip galvanized coatings have typically thinner hot dip galvanized substrates, which often require proprietary systems for effective duplex protection. Refer to manufacturer's information for other coating systems.

2 The sweep blast cleaning process is detailed in Clause 7.5.3.1.

3 PRN denotes the generic Paint Reference Number (see AS/NZS 2312.1).

4 NDFT denotes nominal dry film thickness (see AS/NZS 2312.1).

5 The durability range is in this case related to the adhesion of the paint system to the hot-dip-galvanized substrate. Maintenance is often required at more frequent intervals because of paint fading, chalking, contamination, wear and tear, for aesthetic or other reasons (see AS/NZS 2312.1).

6 The coating build (thickness) for each paint type has to comply with the paint manufacturer's recommendations. In some cases, this will mean the applicator will need to apply multiple coats to reach the designated NDFT for each paint type.

7 To properly assess the applied paint coating thickness, the actual thickness of the hot dip galvanized coating should be measured prior to painting commencing.

8 The specifier has to be aware that micro-environments can affect the life of coatings and a thorough investigation of micro-environments should be completed. The recommendations are for freely draining exposed structures. For structures not exposed to the cleansing influence of rain and microclimates, such as water, ponding or soil contact, may require additional protection. For more information, see Appendix B.

9 The durability range is not guaranteed. Durability is a technical consideration that can help the owner set up a maintenance program, there are no rules that link the durability of a system and guarantee. The guarantee time is usually shorter than the durability range (see AS/NZS 2312.1).

10 Category C5 covers atmospheres that could be generally encountered at various industrial locations. Special care should be taken when writing coating specifications for items of equipment or steelwork that could suffer from specific chemical spillages, leaking pipes or heavy air-borne contamination (see Paragraph B4, Appendix B and AS/NZS 2312.1).

TABLE 7.2

ESTIMATED LIFE TO FIRST MAINTENANCE (CORROSION) OF SELECTED DUPLEX SYSTEMS IN C5 CORROSIVITY CATEGORY

System No. (Table 7.1)	Estimated life to first maintenance (min. to max., years)		
	HDG390	HDG500	HDG600
3I	16 to >25	19 to >25	22 to >25
4I	16 to >25	19 to >25	22 to >25
5I	>25	>25	>25

NOTES:

1 The synergistic effect (Clause 7.5.8) has a factor for the C5 corrosivity category estimated at 1.5; that is, the life of the paint plus hot dip galvanized coating is estimated to be 1.5 times more than the arithmetical sum of the individual component lives as shown in Tables 6.1 and 7.1. While the life to first maintenance may well be considerably longer than 25 years for some of the systems, it is recognized that estimates for a duplex life longer than this period will increase the risk of failure.

2 Where an aesthetic requirement exists, maintenance planning should take into account the need for touch up and repair of the paint system to maintain the desired aesthetic condition (Clause 7.5.8).

3 Proper maintenance of the duplex coating at appropriately planned intervals will extend the life of the base steel for a considerable period. This includes the decorative systems (4D and 5D from Table 7.1) when used in a C5 environment.

8 DESIGN FOR HOT DIP GALVANIZING TO AS/NZS 4680

8.1 General

The design of any article required to be finished should take into account not only the function of the article and its method of manufacture but also the limitations imposed by the finish. Some of the important design features, which are specific to hot dip galvanized coatings manufactured to AS/NZS 4680, are illustrated in Appendix A.

Some internal stresses in the articles to be galvanized will be relieved during the hot dip galvanizing process and this may cause deformation or damage of the coated article. These internal stresses arise from the finishing operations at the fabrication stage, such as cold forming, welding, oxy-cutting or drilling, and from the residual stresses inherited from the rolling mill. The specifier should seek the advice of the hot dip galvanizer before designing or making a product that is subsequently to be hot dip galvanized, as it may be necessary to adapt the construction of the article for the hot dip galvanizing process.

8.2 Surface preparation

The design and the materials used should permit good surface preparation. This is essential for the production of a high-quality coating (see Clause 5.2). Surfaces should be free from defects to ensure a coating of good appearance and serviceability.

Graphite exposed at the surface of iron castings interferes with wetting by molten metal and those castings that have been annealed may have silica particles in the surface layers, which have to be removed in order to obtain a good-quality hot dip galvanized coating. Grit blasting is recommended both before and after annealing.

8.3 Procedures related to design considerations

The hot dip galvanizing bath and associated plant should be of adequate capacity to process the articles to be hot dip coated with zinc. Preferably, articles should be designed to enable coating in a single dipping operation. Articles to be coated that are too large for the available baths may be partially immersed and then reversed for length or depth, so that a complete coating is obtained. Partial immersion (and then dipping for a second time to complete the coating) is less common than the single, complete immersion operation.

All work has to be secured during immersion in the baths. Bolt holes are often available. Lifting lugs are often incorporated to assist general handling. Articles may be held in racks or jigs; some contact marks may be visible after hot dip galvanizing in such cases. The dipping operation involves vertical movement out of the bath, but the parts being withdrawn may be inclined at an angle. The processing sequence requires circulation of air, pretreatment liquids and zinc to all surfaces of the work piece. Air pockets prevent local surface preparation and give uncoated surfaces; liquids in enclosed air vaporize at the hot dip galvanizing temperature of about 450°C and the force generated can cause buckling or explosions; excess zinc may adhere poorly, may look unattractive and is wasteful.

Suitable articles (e.g. heat exchangers and gas cylinders), may be hot dip galvanized on the outside only. This involves special techniques and equipment (e.g. to push the article into the bath against the buoyancy of the molten zinc) and a specialist galvanizer should be consulted in advance.

8.4 Design features

Preferred design features for articles to be hot dip galvanized are shown in Appendix A.

> **WARNING: IT IS ESSENTIAL THAT SEALED COMPARTMENTS BE AVOIDED OR BE VENTED, OTHERWISE THERE IS A SERIOUS RISK OF EXPLOSION THAT MAY CAUSE SERIOUS INJURY TO OPERATORS. THIS ASPECT OF DESIGN SHOULD BE GIVEN CAREFUL CONSIDERATION AND IS ESSENTIAL IN ORDER TO MAINTAIN SATISFACTORY STANDARDS OF HEALTH AND SAFETY FOR OPERATORS.**

The provision of holes for venting and draining tubular fabrications also allows a coating to be formed on the inside surfaces and, therefore, ensures better protection for the article. Occasionally, at sufficiently high levels of residual stress in the component, stress relief may occur at the hot dip galvanizing temperature. This is one of the main causes of unexpected distortion or cracking of the steel component. Symmetrical sections are preferred and, as far as possible, large variations in thickness or cross-section (e.g. thin sheet welded to thick angles) should be avoided. Welding and fabrication techniques should be chosen to minimize the introduction of unbalanced stresses and differential thermal expansion should be minimized during welding and processing. Heat treatment may be desirable before hot dip galvanizing. The specifier should discuss with the galvanizer the requirements for coating and assembly of fabricated components. Compact sub-assemblies, which occupy minimum bath space, are most economical to galvanize. Welding is preferable before hot dip galvanizing, to ensure a continuous hot dip galvanized coating over the weld.

Articles should be designed so as to assist the access and drainage of molten metal and so that air locks are avoided. A smooth profile, avoiding unnecessary edges and corners, assists hot dip galvanizing; this, and bolting after galvanizing, improves long-term corrosion resistance.

Holes, which are necessary in structures for the hot dip galvanizing process, are preferably made before assembly and by cutting or grinding off corners of sections; this facilitates the absence of 'pockets' in which excess molten zinc can solidify. When already assembled, burning may be the optimum method of producing holes, as the space available for drilling may not allow the hole to be close enough to the edge or corners.

8.5 Tolerances

8.5.1 *General*

The thickness of the hot dip coating is determined mainly by the nature and thickness of the steel. On mating surfaces and at holes, extra tolerance should be provided to allow for the thickness of the coating metal. For hot dip galvanized coatings on flat surfaces, an allowance of at least 1 mm has been found satisfactory.

NOTE: For definitions of significant surfaces and acceptance criteria for the coating, see AS/NZS 4680.

8.5.2 *Dimensional tolerances on mating threads*

There are two different ways to make allowances: either by under-cutting the male thread or by over-cutting the female thread.

NOTE: For ISO metric coarse thread fasteners in the nominal size range of M8 to M36 inclusive, see AS 1214.

Allowances should be made on mating threads to accommodate the thickness of the coating. There are no coating requirements for internal threads that are threaded or re-threaded after hot dip galvanizing.

The coating thickness given for threaded components relates to components that require centrifuging immediately after galvanizing to ensure clean threads.

NOTE: The coating on external screw threads galvanically protects the internal threads on assembly. Therefore, no hot dip galvanized coating is required on internal threads.

The coated threads should have adequate strength to meet the design requirement.

9 EFFECT OF ARTICLE CONDITION ON QUALITY OF HOT DIP GALVANIZING TO AS/NZS 4680

9.1 Material composition

Table 9.1 gives simplified guidance on steel compositions that are associated with certain typical coating characteristics when galvanizing is carried out at temperatures of 445°C to 460°C.

Certain elements, in particular silicon (Si) and phosphorus (P), in the steel surface can affect hot dip galvanizing by prolonging the reaction between iron and molten zinc. Therefore, certain steel compositions can achieve more consistent coatings with regard to appearance, thickness and smoothness (such as those from Categories A and B). The prior history of the steel (e.g. whether hot rolled or cold rolled) can also affect its reaction with molten zinc.

Where aesthetics are important or where particular coating thickness, surface smoothness or resistance to handling damage criteria exist, specialist advice on steel selection should be sought prior to fabrication of the article or hot dip galvanizing.

9.2 Mechanical properties of processed steel

In general, the mechanical properties of steel are not affected by the hot dip galvanizing process. Heat-treated or cold-worked steels may be tempered by the heat in the hot dip galvanizing bath and lose some of any increased strength obtained by heat treatment or cold working.

Materials that will be adversely affected by the heat of the hot dip galvanizing bath should not be hot dip galvanized.

9.3 Castings

Castings should be as free as possible from surface porosity and shrinkage holes and should be cleaned by grit blasting, electrolytic pickling or by other methods especially suitable for castings. Conventional hydrochloric acid pickling does not remove mould-sand deposits, graphite or temper carbon from the surface of cast iron. Grit blasting is necessary to remove these contaminants. Surface cleaning of complex shapes can be undertaken by specialist companies using hydrofluoric acid. Care needs to be exercised in the design of cast-iron sections. Small castings of simple shape and solid cross-section do not present problems for galvanizing, provided the material and surface condition are suitable. Larger castings should have a balanced design with uniform section thicknesses to avoid distortion and cracking due to thermal stress. Large fillet radii and pattern numbers should be used and sharp corners and deep recesses avoided.

The rough surface finish, which castings tend to possess, may result in thicker galvanized coatings than on rolled components.

Castings can take several forms:

(a) Grey iron castings: grey iron has a carbon content of greater than 2%, the majority of which is graphite in flake form.

(b) Spheroidal graphite (SG) castings: similar to grey iron in many aspects of composition but with carbon present primarily as graphite in spheroidal form, initiated by additions of magnesium or cerium.

(c) Malleable iron castings: black-heart, white-heart and pearlitic. The toughness and workability are derived from annealing processes and no primary graphite is permissible.

TABLE 9.1

COATING CHARACTERISTICS RELATED TO STEEL COMPOSITION

Category	Typical levels of reactive elements	Additional information	Typical coating characteristics
A	$Si \le 0.04\%$ and $P < 0.02\%$	See Notes 1 and 2	Coating has a shiny appearance with a finer texture. Coating structure includes outer zinc layer.
B	$Si > 0.14\%$ to $Si \le 0.25\%$	Fe/Zn alloy may extend through to the coating surface. Coating thickness increases with increasing silicon content. Other elements may also affect steel reactivity. In particular, phosphorus levels greater than 0.035% will give increased reactivity.	Coating has a generally shiny appearance. Can tend to an initial patchy or fully dull appearance with increasing steel thickness or silicon content.
C	$Si > 0.04\%$ to $Si \le 0.14\%$	Excessively thick coatings may be formed.	Coating has a darker appearance with a coarser texture. Iron/zinc alloys dominate coating structure and often extend to the coating surface, with reduced resistance to handling damage.
D	$Si > 0.25\%$	Coating thickness increases with increasing silicon content.	

NOTES:

1 Steels with compositions satisfying the formula $Si + 2.5P \le 0.09\%$ are also expected to exhibit these characteristics. For cold rolled steels, these characteristics are expected to be observed when the steel composition satisfies the formula $Si + 2.5P \le 0.04\%$.

2 Aluminium killed steels are sometimes produced with very low levels of silicon (≤0.01%). Depending on the steel thickness and other steel properties, including surface condition, these steels can sometimes produce coatings under the specified thickness.

3 The presence of alloying elements (e.g. nickel) in the zinc melt can have a significant effect on the coating characteristics indicated in this Table.

4 The steel compositions indicated in this Table will vary under the influence of other factors and the boundaries of each range will vary accordingly.

9.4 Surface condition

The surface of the base metal should be clean before dipping into the molten zinc. Degreasing and pickling in acid are the recommended methods of cleaning the surface. Excessive pickling should be avoided. Surface contamination that cannot be removed by pickling (e.g. carbon films (such as rolling oil residues), oil, grease, paint, welding slag, labels, glues, marking materials, fabrication oils and similar impurities) should be removed prior to pickling; this allows for more effective and efficient use of pretreatment materials.

NOTE: It is the responsibility of the fabricator to remove such contamination, unless alternative arrangements have been agreed between the galvanizer and the fabricator.

9.5 Influence of steel surface roughness on the coating thickness

The roughness of the steel surface has an influence on the thickness and structure of the coating. The effect of surface unevenness of the base metal generally remains visible after galvanizing. A rough steel surface, as obtained by grit blasting, coarse grinding, etc., prior to pickling, gives a thicker coating than a surface that is obtained by pickling alone.

9.6 Influence of thermal cutting processes

Flame-cutting, laser-cutting and plasma-cutting changes the steel composition and structure in the zone on and around the cut surface, hence the minimum coating thickness may be more difficult to obtain and the coating so formed may exhibit a decreased cohesion/adhesion to the steel substrate. In order to obtain these coating thicknesses more reliably and to ensure adequate cohesion/adhesion of the coating, flame-cut, laser cut and plasma-cut surfaces should be ground off by the fabricator and sharp edges should be removed.

9.7 Effect of internal stresses in the base steel

9.7.1 *General*

The hot dip galvanizing process involves dipping clean, pretreated, fabricated steel articles in the bath of molten zinc/zinc alloy at a temperature of about 450°C and withdrawing them when the metallurgical reaction developing the coating is complete. Relief of large or imbalanced stresses in the article during the dipping process may occur.

NOTE: The deformation of the steelwork during galvanizing is not the responsibility of the galvanizer (as the specific state of stress in the article at the time of dipping is not in the galvanizer's control) unless the distortion has occurred through inappropriate handling (e.g. mechanical damage or incorrect suspension of the article).

9.7.2 *Distortion cracking*

In rare occurrences, when the internal residual stress in a fabrication overcomes the tensile strength of the steel used to form the article, distortion cracking may occur. Good design for galvanizing will normally avoid these problems.

During the heating and cooling cycle, the work experiences stresses, caused by the differential thermal expansion of elements within the work, that interact with the pre-existing stresses in the fabrication. The magnitude of the resultant stress field in the work item cannot be predicted readily. During the heating and cooling cycle, imbalanced stresses may contribute to a degree of distortion. Good design for galvanizing and good fabrication practice will minimize any potential for distortion to occur. Where experience shows that specific steels, pretreatments, thermal and mechanical treatments, pickling and hot dip galvanizing procedures have been satisfactory, the information serves as an indication that an embrittlement problem is not to be expected for the same combination of steels, pretreatments, thermal and mechanical treatments and galvanizing procedures.

Hardened and/or high-tensile steels (steels with yield strengths above 650 MPa) may contain internal stresses of such a magnitude that pickling and hot dip galvanizing may increase the risk of cracking of the steel in the hot dip galvanizing bath. Despite the normally low potential for problems of this nature, there might be some critical geometrical configuration of heavy structures for which these effects might be reduced by stress relieving before pickling and hot dip galvanizing. Specialist advice should be sought when hot dip galvanizing such steels.

9.7.3 *Hydrogen embrittlement*

Structural steels are not normally embrittled by the absorption of hydrogen during pickling, and hydrogen remaining (if any) does not, in general, affect structural steels. With structural steels, absorbed hydrogen is discharged during hot dip galvanizing. If steels are harder than approximately 34 HRC, 340 HV or 325 HB (see AS 5016), care is necessary to minimize hydrogen absorption during surface preparation. The welds and the heat affected zone (HAZ) of structural steels do not normally exceed a hardness value of 340 HV. Consequently, these zones are not normally embrittled by the absorption of hydrogen during pickling.

NOTE: The hardness values shown above are approximately equivalent to a steel tensile strength of 1100 MPa.

9.7.4 *Cold-work (strain-age) embrittlement*

Cold-work embrittlement is a basic metallurgical phenomenon affecting any steel grade. According to the extent of cold-work deformation, the strength of steel is increased whereas the toughness and ductility are simultaneously decreased. The risks inherent to cold-work embrittlement can be reduced by selecting a steel grade with higher toughness properties; considering the original impact energy and transition temperature of the non-deformed steel material, each percent of cold-work deformation should be balanced by a 3°C decrease of the transition temperature.

To reduce the risk of embrittlement, the local cold deformation should be kept as low as possible at the design stage and at the fabrication stage. Where this latter condition cannot be fulfilled, a heat treatment for stress relieving may be applied to the deformed area before pickling and hot dip galvanizing or selecting a steel that is not susceptible to strain-age hardening.

NOTES:

1 Susceptibility to strain-age hardening and the consequent risk of embrittlement is principally caused by the nitrogen content of the steel, which, in turn, is largely dependent on the steel making process. As a general guide, the problem does not occur in modern steel making practice. Aluminium-killed steels, or steels containing sufficient alternative nitrogen-binding elements (such as V, Nb and Ti), are the least susceptible to strain-age hardening.

2 Heat-treated or cold-worked steels can be tempered by the heat in the hot dip galvanizing bath and lose some of any increased strength obtained by heat treatment or cold working.

9.7.5 *Liquid metal assisted cracking (LMAC) or liquid metal embrittlement (LME)*

Liquid metal assisted cracking (LMAC) or liquid metal embrittlement (LME) occurs when a combination of steel characteristics, fabrication detailing and galvanizing processing variables create conditions for brittle cracking of a steel article during galvanizing. Such a combination of factors rarely occurs in practice.

NOTES:

1 The susceptibility of fabrications to LMAC can be reduced by the specifier through control of the design (e.g. location of stress concentrations) and detailing of the component (e.g. steel quality, levels of residual stress, quality of welding, and position and finishing of drilled or punched holes and flame-cut surfaces), and the galvanizing conditions (e.g. pretreatment conditions, dipping speed and zinc melt constitution).

2 Further information is available from the Galvanizers Association of Australia or the Galvanizing Association of New Zealand.

9.8 Large objects or thick steels

Longer handling times are needed in the galvanizing bath for large articles and this, as well as the metallurgical properties of thick steels due to normal manufacturing methods, may cause thick coatings to form.

9.9 Hot dip galvanizing practice

Very small amounts of alloying elements may be added to the galvanizing bath as part of the processing technique of galvanizers, notably to reduce the adverse effects of silicon and phosphorus or to modify the surface appearance of the galvanized coating. Such possible additions, while conforming to the requirements of AS/NZS 4680, do not affect the long-term corrosion resistance of the galvanized coating.

For cases related to a critical material and/or to critical conditions of design and fabrication and identified by the specifier prior to galvanizing, the galvanizing parameters should be optimized to reduce the risk of distortion or damage. The galvanizer should record the process parameters at all stages of the galvanizing process. Tests may be performed on a small initial lot to assess the suitability of the galvanizing procedure.

APPENDIX A

PREFERRED DESIGNS OF ARTICLES FOR HOT DIP GALVANIZING TO AS/NZS 4680

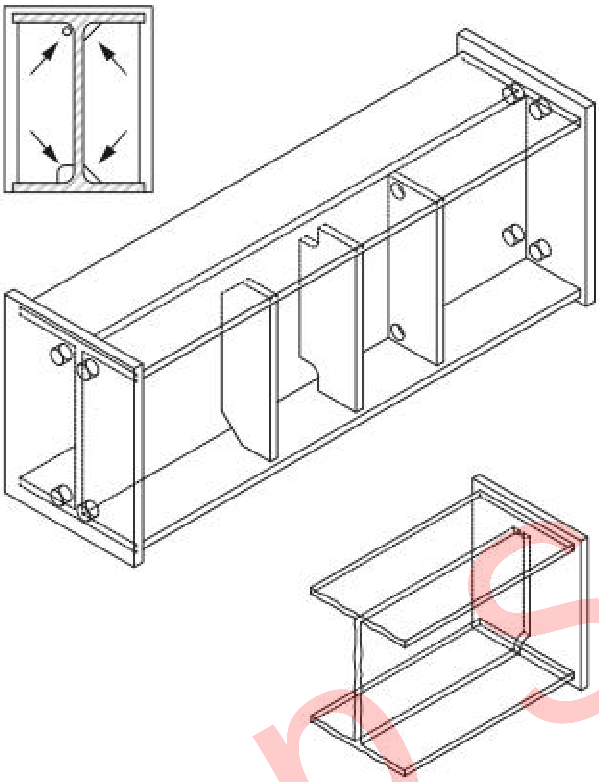
(Informative)

External stiffeners, welded gussets and webs on columns and beams and gussets in channel sections should have their corners cropped as shown in Figure A1. The gaps created should be as large as possible without compromising structural strength. If welding is required around the edge created, a radiused cut is desirable to facilitate continuity of the weld around the cut end to the other side. Circular holes are less effective; if used, they should be as close to the corners and edges as practicable. Where it is more convenient, the cropped corners or holes may be in the main beam. In large box sections (see Figure A8), internal stiffeners should have the centre cut away in addition to cropping the corners; cropping alone is sufficient with small box sections. Where practicable, angle bracings should be stopped short of the main beam flange. Where base plates are present, extra venting is needed. These features—

(a) prevent entrapment of air during processing and hence allow access of pickle acids and molten zinc to all surfaces of the work; and

(b) facilitate drainage during withdrawal from acid and rinsing tanks and from the galvanizing bath.

The precise position of holes and gaps may vary with the dipping technique and a galvanizer should be consulted at the design stage.



NOTE: Section through the main beam showing examples of cut-outs needed to facilitate metal flow during hot dip galvanizing. The figure also includes isometric views of fabricated beams showing varieties of venting arrangements.

FIGURE A1 BEAMS, GUSSETS AND WEBS

Where optimum venting for galvanizing cannot be incorporated into the design (e.g. where introduction of holes into base plates already welded to beams are prohibited), satisfactory, safe and efficient alternative venting arrangements should be agreed between the specifier and the galvanizer. The potential effects of alternative venting arrangements on the quality of the coated article should be taken into account (e.g. surface finish, potential for distortion or potential for steel cracking).

For surfaces in contact, a hole should be drilled as shown in Figure A2, especially with thin steel. Hole sizes take into account the area of overlap. More than one hole may be needed, depending on the shape of the overlap; entrapment of liquid should be avoided (see Figure A3). This precaution is necessary in order to avoid explosions in the hot dip galvanizing operation and to protect operators. It is not necessary to drill through both pieces in contact, but to do so assists the free flow of liquid.

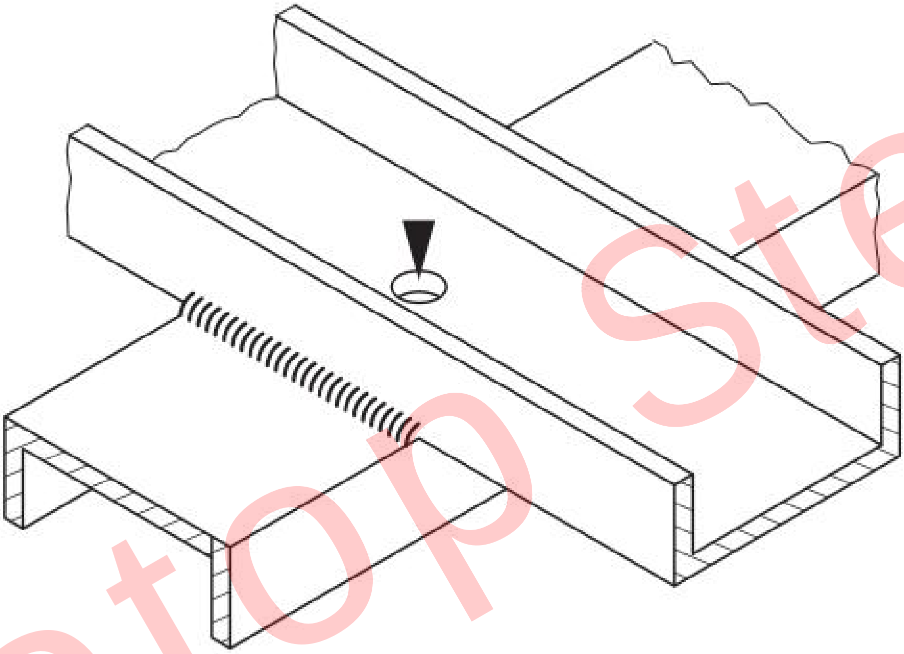
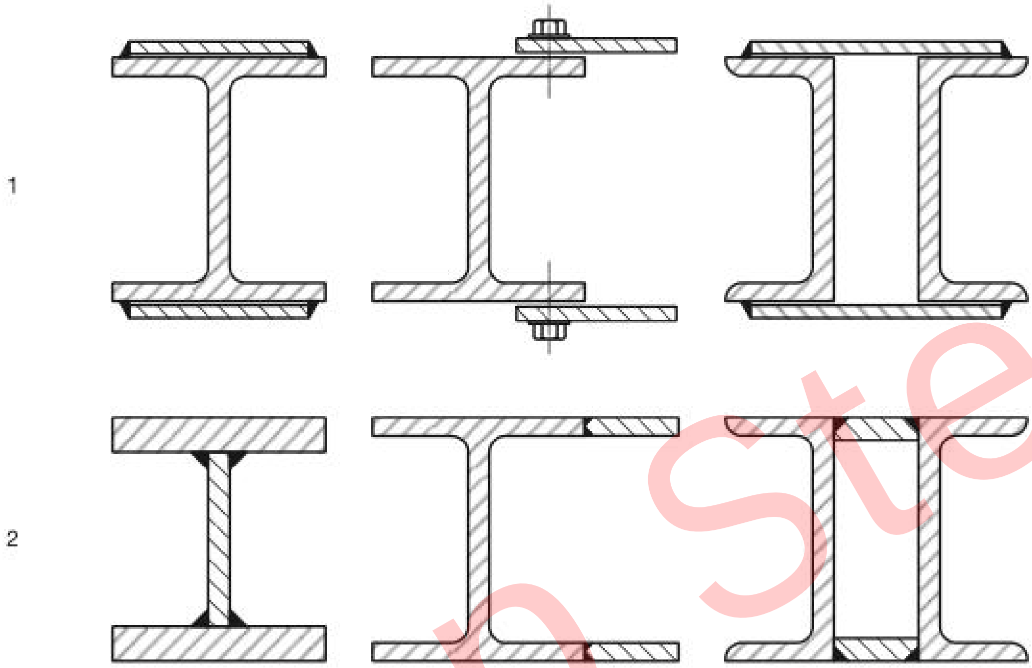


FIGURE A2 WELDING FLAT SURFACES TOGETHER

Narrow gaps between parts, and especially surfaces in flat contact with each other, will allow liquid to penetrate but will not allow a hot dip galvanized coating to form between them. Welded joints should be continuous if they do not enclose an otherwise unvented surface as shown in Figure A3. Bolted joints are preferably made after hot dip galvanizing. All components may be hot dip galvanized. Hot dip galvanizing of suitable standard rolled products before assembly by bolting facilitates both processing and construction and allows for easy disassembly later; it is also the most practical method and the least costly.



LEGEND:
1 avoid
2 prefer

FIGURE A3 NARROW GAPS

Provision should be made for venting and draining (preferably visible externally for reasons of inspection and safety) as shown in Figure A4. Cross-sections or chord members with ends sealed (e.g. by plates) should be provided with drilled holes or V-notches diagonally opposite each other at the top and bottom, as close as possible to the sealed end. The holes should be as large as possible. A typical minimum for small fabrications is 10 mm diameter; holes in larger fabrications should be about 25% of the diameter of the member (see also Figure A5).

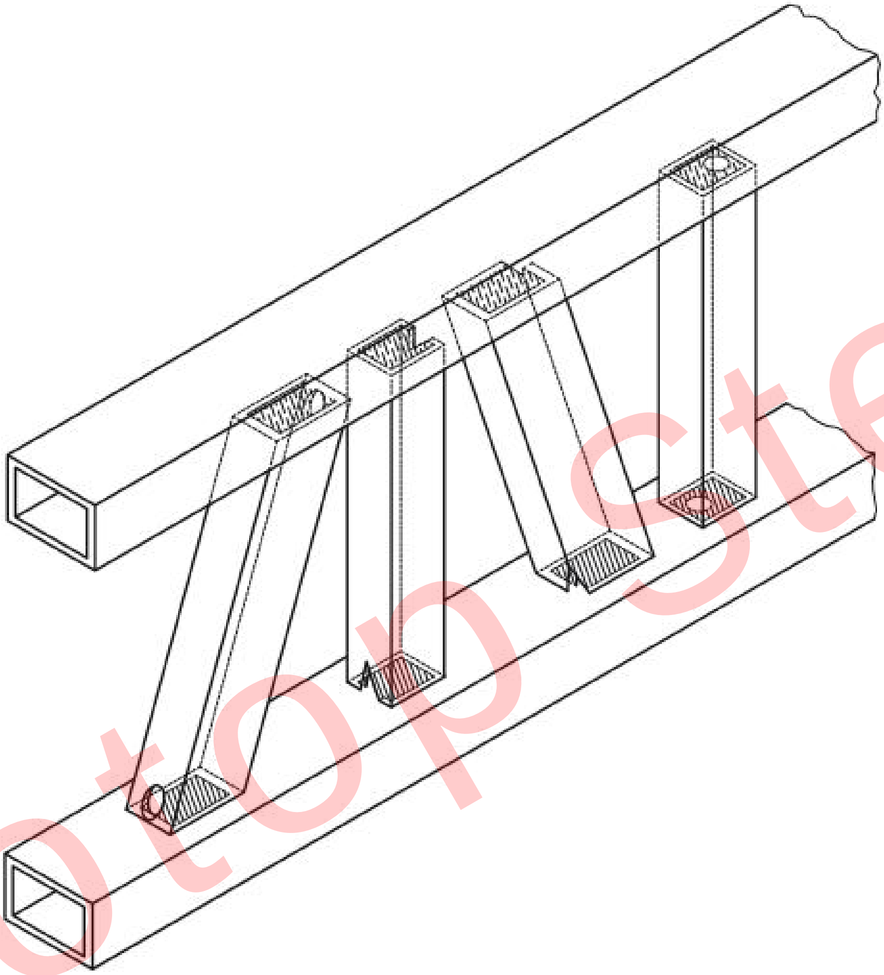
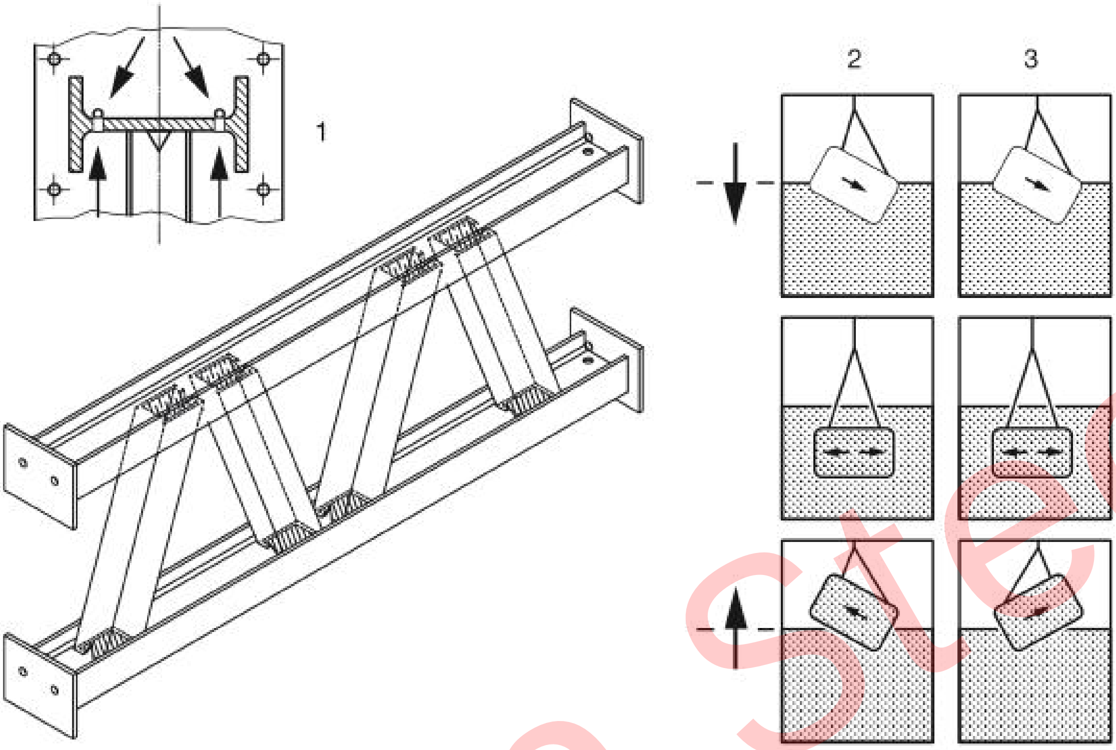


FIGURE A4 STRUCTURAL HOLLOW SECTIONS

The zinc should drain freely. The preferred practice is to immerse at an angle and, after immersion, to withdraw at the opposite angle as shown in Figure A5. The position of the vents should be related to the alignment during withdrawal.



LEGEND:
1 indicative venting
2 example of orientation during immersion (most commonly used)
3 example of orientation during immersion (alternative)

FIGURE A5 ORIENTATION DURING HOT DIP GALVANIZING

Vent holes at each end of the fabrication should be diagonally opposed as shown in Figure A6. The preferred option should be determined in conjunction with the hot dip galvanizer.

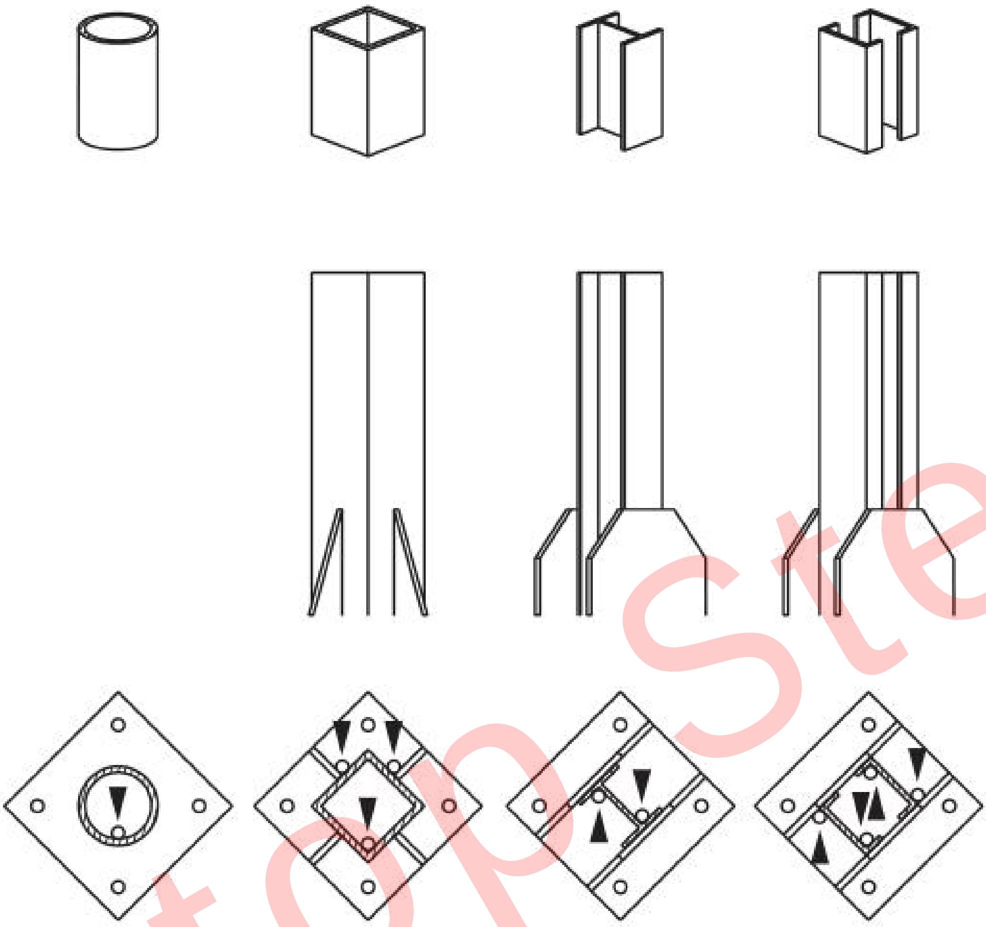


FIGURE A6 ALTERNATIVE DESIGNS FOR VENTING SECTIONS FIXED TO BASE PLATES

Large open tanks should be braced to minimize distortion. Where angles are used around the rim of the tank, openings should be provided in the corners. Flat panels are liable to distort. Where possible, braces (e.g. dished or ribbed panels) should be used as shown in Figure A7.

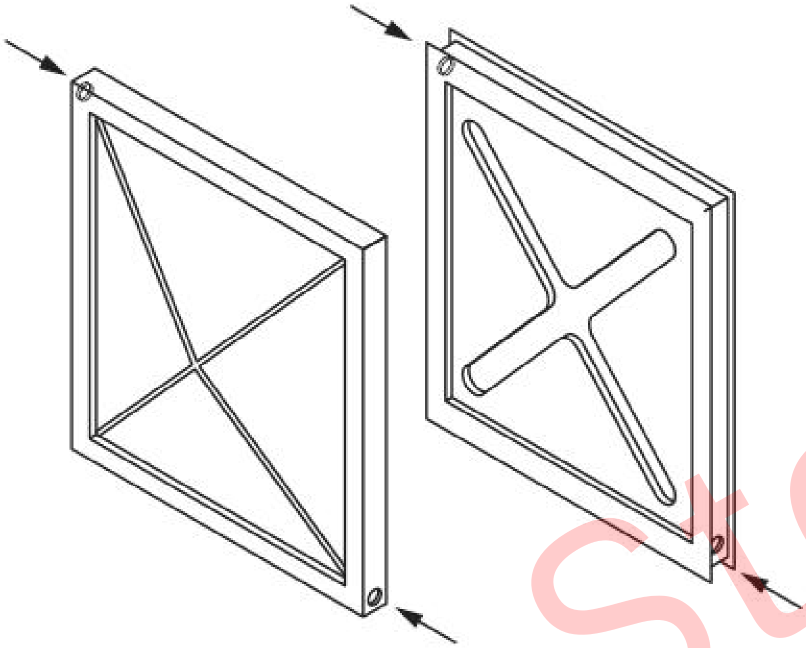


FIGURE A7 GALVANIZING OF FLAT PLATES

Vents should be diametrically opposite and at least 50 mm in diameter. Internal baffles should be cropped top and bottom and the cropped areas should be visible through an inspection hole. Large vessels require a manway of appropriate size in addition to the vents shown in Figure A8 (a galvanizer can advise on the size.) Lifting lugs should be incorporated and should be adequate for the excess mass of molten zinc within the cylinder on withdrawal.

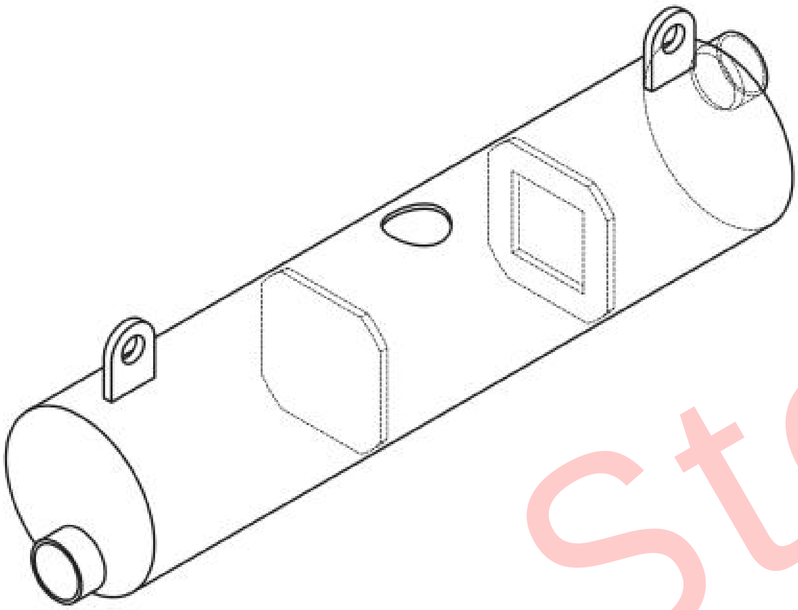
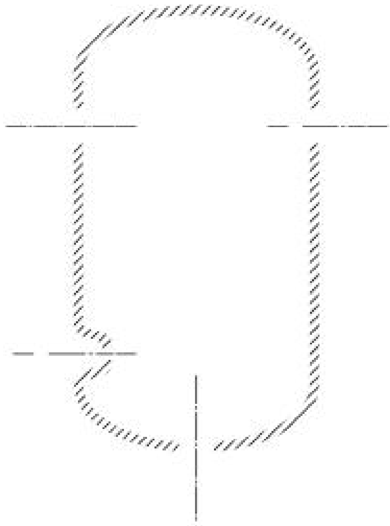
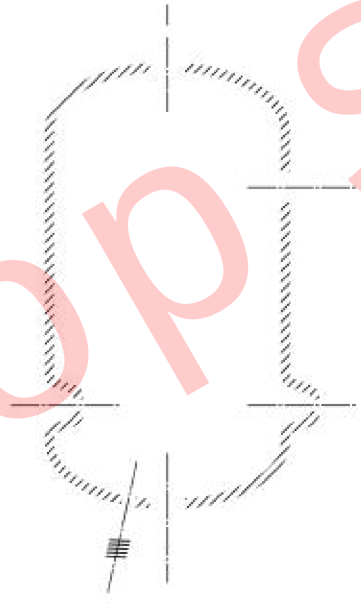


FIGURE A8 CYLINDERS

When internal bosses are used, a drain-hole should be included in the fabrication as shown in Figure A9. This may be plugged after hot dip galvanizing if required.



(a) To be avoided



(b) Prefered

FIGURE A9 ENCLOSED CAVITIES

APPENDIX B

CORROSION IN DIFFERENT ENVIRONMENTS

(Informative)

B1 EXPOSURE TO SOILS

The wide range in physical and chemical properties of soils (e.g. the pH variation from 2.6 to 12 and resistivity from tens of ohm centimetres to approximately 100 kΩ.cm) and the gross inhomogeneity of soils means that corrosion of hot dip galvanized coatings in soils is rarely uniform in nature. Corrosion in soil is dependent on the mineral content, on the nature of these minerals and on the organic components, water content and oxygen content (aerobic and anaerobic corrosion). Corrosion rates in disturbed soil conditions are usually higher than in undisturbed soil. General guidance on the corrosion likelihood in soil can also be found in AS/NZS 2041 and AS 2309.

Lime-containing soils and sandy soils (provided that they are chloride-free) are, in general, least corrosive, whilst clay soils and clay marl soils are corrosive to a limited extent. In bog and peat soils, the corrosiveness depends on the total acid content.

Where major iron and steel structures such as pipelines, tunnels, and tank installations, pass through different types of soil, increased corrosion (localized) can occur at isolated points (anodic areas) by the formation of differential aeration cells. For some uses (e.g. earth reinforcement), a controlled backfill is used in conjunction with a hot dip galvanized coating.

Corrosion cells can also form at the soil/air and soil/groundwater level interfaces, leading possibly to increased corrosion, and these areas should be given special consideration. Conversely, the application of cathodic protection for structures in soil (or in water) can both modify the protective coating requirements and lengthen their life. Specialist advice should be sought for full guidance on all conditions involved.

While the average annual corrosion rates for hot dip galvanized coatings in most soils are less than 10 µm per annum, the factors influencing corrosion in specific soil environments are complex and detailed expert advice should be sought regarding individual exposure conditions.

B2 EXPOSURE TO WATER

The type of water, soft or hard fresh water/brackish water/salt water, has a major influence on the corrosion of iron and steel in water and the selection of protective hot dip galvanized coatings. With hot dip galvanized coatings, corrosion is affected primarily by the chemical composition of the water but temperature, pressure, flow rate, agitation and oxygen availability are all important. For example, zinc should not be used in hot non-scale-forming waters; heavy corrosion of zinc can also occur in condensate, especially between about 55°C and 80°C (e.g. in saunas). Otherwise, barrier protection can occur at all temperatures; below about 60°C, zinc can also provide cathodic protection. The durability of zinc surfaces in cold scale-forming waters is usually higher than in non-scale-forming waters (Ryznar's or Langelier's index should be used to calculate whether the water is scale-forming). Since the composition of non-saline waters can vary greatly, previous experience or expert advice should be sought.

For hot water, specialist advice should always be sought. Coatings used for all structures (including pipes, fittings, tanks and tank covers) in contact with potable water should be non-toxic and should not impart any taste or odour, colour or turbidity to the water, nor foster microbial attack. With tanks, if additional protection to hot dip galvanizing is necessary, sufficient coats of high-build epoxy paint should be applied.

Zones of fluctuating water level (i.e. the area in which the water level changes as a result of natural fluctuations such as tidal movements, or artificial alteration of the water level in lock chambers or reservoirs) or splash zones should be given special consideration as, in addition to water attack, there can also be atmospheric attack and abrasion.

The many factors affecting corrosion in fresh water make it impracticable to present simple guidance. Some guidelines for seawater are set out below but it is emphasized that, for all water exposures, specialist advice should be sought for full guidance on all conditions involved.

In temperate seawater, the average zinc corrosion rate will usually lie between 15 µm per annum and 25 µm per annum (see AS 2309). Hot dip galvanized tube, hot dip galvanized and zinc electrodeposited sheet and fittings with galvanized, electrodeposited or mechanically plated coatings normally have additional protection when used in seawater (see AS 2309, ISO 12944-5 and ISO 12944-8). Brackish water may be more or less corrosive than seawater and no general estimates of durability can be given.

Guidance on the corrosion likelihood for hot dip galvanized coatings used in water storage and distribution systems can be found in AS 2309.

B3 ABRASION

Natural mechanical exposure can occur in waters by shifting of boulders, abrasion by sand, wave splashing, etc. Particles entrained by the wind (e.g. sand) can also cause increased attack. Hot dip galvanized coatings have much higher abrasion resistance (a factor of 10 or more) than most conventional paint coatings. The zinc-iron alloys are particularly hard. Areas walked on or driven on, or which rub together, can be subject to severe abrasion. Areas under coarse gravel are subjected to severe erosion by impact and abrasion. A good bond between hot dip galvanized coatings and steel helps to limit such effects.

B4 EXPOSURE TO CHEMICALS

A primary factor governing corrosion behaviour of hot dip galvanized coatings in liquid chemical environments is the pH of the chemical solution. Zinc coatings perform well in solutions of pH above 5.5 and below 12.5. Factors such as agitation, aeration, temperature, polarization, and the presence of inhibitors may affect the specific rate of corrosion experienced by the coating.

Within the pH range of 5.5 to 12.5, a protective film forms on the zinc surface and the corrosion rate is very slow. The precise chemical composition of the protective film is somewhat dependent on the specific chemical environment. Since many liquids fall within the pH range of 5.5 to 12.5, galvanized steel containers are widely used in storing and transporting many chemical solutions. Prolonged or frequent direct contact with acids or strong alkalis is not recommended.

Many organic solvents have little effect on non-ferrous metals but specific advice should be sought for each chemical.

B5 ELEVATED TEMPERATURES

All the zinc coatings described in this Standard are usually suitable for elevated temperatures. Separate advice has to be sought regarding any organic materials/coatings.

Temperatures above 200°C are not considered in this Standard.

Temperatures between +200°C and +500°C occur only under special conditions of construction and operation (e.g. in steel chimneys, flue gas ducts and gas take-off mains in coking plants). Specialist advice should be sought for the coating of surfaces so exposed.

B6 EMBEDDED IN CONCRETE

Unprotected steel articles embedded in concrete can corrode as moisture penetrates into the concrete through cracks and pores. The oxidation products from the reaction between the steel and the oxygen/moisture present can create sufficient pressure to cause damage to the concrete (spalling). Hot dip galvanized coatings applied to reinforcement may be used to prevent this type of deterioration for long periods of time, dependent on the specific exposure environment.

The corrosion protection afforded by hot dip galvanized rebar in concrete is due to a combination of beneficial effects. Of primary importance is the substantially higher chloride threshold (2 to 4 times) for zinc coatings to start corroding compared to uncoated steel. In addition, a zinc coating has a much greater pH passivation range than steel, making hot dip galvanized rebar resistant to the pH lowering effects of carbonation as the concrete ages. Even when the zinc coating does start to corrode, its corrosion rate is considerably less than that of uncoated steel.

Zinc remains passive at significantly lower pH levels than for black steel (9.5 versus 11.5) making hot dip galvanized rebar far less susceptible to corrosion due to carbonation of the concrete.

Zinc reacts with wet concrete to form calcium hydroxyl-zincate accompanied by the evolution of hydrogen. This corrosion product is insoluble and protects the underlying zinc, provided the surrounding concrete mixture is below a pH of about 13.3.

Research has shown that during this initial reaction period, until coating passivation and concrete hardening occurs, some of the pure zinc layer of the coating is dissolved; however, this initial reaction ceases once the concrete hardens and the hydroxyl-zincate coating has formed. Studies of hot dip galvanized rebar recovered from field structures indicate that the coating remains in this passive state for extended periods of time, even when exposed to high chloride levels in the surrounding concrete.

For concretes of high pH, or where some background chlorides are expected, the hot dip galvanized surface can be passivated using a range of proprietary post-treatments, as a safeguard against excessive hydrogen evolution that may, in serious cases, reduce the pull-out strength of the bar. For normal concrete conditions, research has shown no statistical difference in bond strength between hot dip galvanized rebar that was passivated or not passivated.

Further information is available from the Galvanizers Association of Australia, the Galvanizing Association of New Zealand or the Concrete Institute of Australia.

B7 CONTACT WITH WOOD

Zinc coated products are used very successfully in many applications, which bring them into contact with a variety of woods. Care should be taken to avoid direct contact between zinc coatings and timbers that have been freshly treated with acidic preservatives. Once the wood has dried and the preservatives have been fixed, contact is acceptable, even when the wood once more becomes wet. Very acidic woods can be used in conjunction with zinc coated articles, although some initial corrosion would be expected. In these cases, isolation techniques may be considered (e.g. application of an organic coating or a tape over the area of contact.)

B8 BIMETALLIC CONTACT

When two dissimilar metals come into direct contact and an electrolyte, such as moisture, is present there is a potential for bimetallic corrosion to take place with the more electronegative or anodic metal, as determined from the electro-chemical series, corroding preferentially to prevent corrosion of the other metal (see Table B1).

TABLE B1

PARTIAL GALVANIC SERIES SHOWING RELATIVE POSITION OF ZINC TO OTHER METALS

Cathodic (less prone to corrosion)
Austenitic stainless steel
Nickel-chromium-iron alloys
Nickel
Gunmetal
Monel
Copper
Phosphor bronze
Ferritic stainless steel
Brass 60/40
Aluminium bronze
Lead
Chromium
Tin
Mild steel, cast iron
Aluminium alloys
Zinc
Magnesium
Anodic (more prone to corrosion)

The bimetallic effect is the basis for the sacrificial protection that a zinc coating offers to small areas of exposed steel if the coating becomes damaged. Hot dip galvanized coatings will corrode preferentially to protect any metal more cathodic than zinc.

The level of bimetallic corrosion that will take place will depend on a number of factors, including the specific metals in contact, the ratio of the surface area of the two metals and the exposure conditions.

Generally, the level of bimetallic corrosion will increase with a greater difference in electrode potential between the two metals (e.g. the further apart the two metals are in the electro-chemical series). The electrode potential may vary due to oxide layer formation and cannot be used alone to determine if and at what level of severity bimetallic corrosion will take place, as other factors such as those described below are also important.

The ratio of the surface area of the two metals is essential and ideally the ratio of anodic-to-cathodic metals should be high. Where the ratio is reduced, problems may occur due to the greater level of oxygen reduction that may take place, leading to increased corrosion of the anodic metal.

The exposure conditions are critical, as for bimetallic corrosion to take place an electrolyte must bridge the two metals present. As a result, in dry internal environments the potential for bimetallic corrosion is very low, while in external atmospheric environments the potential increases due to the presence of water in the form of rain and condensation. The worst exposure conditions are those of immersion in a solution where an electrolyte is permanently bridging the two metals.

Normally, any potential for bimetallic corrosion may be alleviated by electrically isolating the two metals from one another. For bolted connections, this might be done by using neoprene or plastic washers, while for overlapping surfaces, it might be achieved by using plastic spacers or painting one of the surfaces with a suitable paint system.

Generally, hot dip galvanized steel performs well in contact with most common engineering metals when in an atmospheric environment as given in Table B2, provided the ratio of hot dip galvanized steel to other metal is high. Conversely, in immersed conditions, the effect of bimetallic corrosion is significantly increased and some form of isolation will normally be required.

TABLE B2

INDICATION OF ADDITIONAL CORROSION EXPECTED DUE TO DIRECT CONTACT BETWEEN ZINC AND OTHER METALLIC MATERIALS

Metal	Atmospheric exposure			Immersed	
	Rural	Industrial/urban	Marine	Fresh water	Seawater
Aluminium	a	a–b	a–b	b	b–c
Brass	b	b	a–c	b–c	c–d
Bronze	b	b	b–c	b–c	c–d
Cast iron	b	b	b–c	b–c	c–d
Copper	b	b–c	b–c	b–c	c–d
Lead	a	a–b	a–b	a–c	a–c
Stainless steel	a–b	a–b	a–b	b	b–c

LEGEND:

a = Zinc coating will suffer either no additional corrosion or, at worst, only very slight additional corrosion which is usually tolerable in service

b = Zinc coating will suffer slight or moderate additional corrosion which may be tolerable in some circumstances

c = Zinc coating may suffer fairly severe additional corrosion and protective measures will usually be necessary

d = Zinc coating may suffer severe additional corrosion and contact should be avoided

The following guidance relates to specific applications concerning zinc-coated steelwork in contact with the designated metal or alloy:

(a) *Aluminium* The severity of increase in bimetallic corrosion due to atmospheric contact with aluminium is relatively low. However, it should be remembered that one application where hot dip galvanized steel and aluminium are used in conjunction with one another is aluminium cladding. In this instance, isolation is advised due to the large surface area of the aluminium panels.

(b) *Copper* Due to the large potential set up by contact between zinc-coated steel and copper and copper containing alloys, electrical isolation is always advised, even in an atmospheric environment. Where possible, design should also avoid run-off of water from copper onto zinc coated articles, as small amounts of copper dissolved in the water may be deposited, leading to bimetallic corrosion.

(c) *Lead* Potential for bimetallic corrosion with lead is low in an atmospheric environment and no problems have been reported concerning, for example, the use of lead flashing with zinc and zinc coated products and the use of lead in fixing hot dip galvanized posts.

(d) *Stainless steel* The most common use of stainless steel with zinc-coated steel is in the form of nuts and bolts in an atmospheric environment. Given the low potential for bimetallic corrosion and the small surface area of stainless steel fasteners, bimetallic corrosion would not normally be an issue although, as always, best practice remains isolation using insulating washers.

Practical experience suggests that, where the surface area ratio of zinc to other metal is high and a rating of 'a' or 'a–b' is indicated, little or no additional corrosion will take place as a result of the contact. However, where the ratio of surface areas is reduced or the rating is higher, some form of insulation may be required.

APPENDIX C

INSPECTION OF HOT DIP GALVANIZED COATINGS

(Informative)

The inspection of hot dip galvanized coatings is detailed in the relevant Standard for each coating type.

Hot dip galvanized coatings to AS/NZS 4680 may have some special inspection requirements that will need to be developed between the galvanizer and specifier. The primary purpose of the coating in this case is to protect the underlying iron or steelwork against corrosion. Considerations related to aesthetics or decorative features should be secondary. Where these secondary features are also of importance, it is highly recommended that the galvanizer and specifier agree on the standard of finish that is achievable on the iron or steelwork (in total or in part), given the range of materials used to form the article. This is of particular importance where the required standard of finish is beyond that set out in the Standard.

It should be noted that 'roughness' and 'smoothness' are relative terms and the roughness of coatings on articles galvanized after fabrication (AS/NZS 4680) differs from that of mechanically wiped products, such as galvanized sheet (for example, AS 1397), tube and wire. In practice, it is not possible to establish a definition of appearance and finish covering all requirements.

The specifier should consider the following issues:

(a) Coating properties, including appearance of the surface.

(b) Acceptance inspection, sampling requirements, and acceptance criteria, including:

   (i) Measurement of the thickness of the coating.

   (ii) Repair to damaged or uncoated areas.

   (iii) Adhesion of the coating.

(c) Whether a certificate of compliance or test certificate is required.

Further details on inspection of hot dip galvanized coatings to AS/NZS 4680 can be obtained from the Galvanizers Association of Australia or the Galvanizing Association of New Zealand. Inspection procedures of other hot dip galvanized coatings are available from the manufacturers.

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NOTES

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