
**Zinc coatings — Guidelines and
recommendations for the protection
against corrosion of iron and steel in
structures —**

**Part 1:
General principles of design and
corrosion resistance**

*Revêtements de zinc — Lignes directrices et recommandations
pour la protection contre la corrosion du fer et de l'acier dans les
constructions —*

Partie 1: Principes généraux de conception et résistance à la corrosion



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 107, *Metallic and other inorganic coatings*, Subcommittee SC 4, *Hot dip coatings (galvanized, etc.)*.

This second edition cancels and replaces the first edition (ISO 14713-1:2009), of which it constitutes a minor revision following the publication of ISO 17668:2016 and ISO 9223:2012, with the following changes:

- ISO 17668 has replaced EN 13811;
- revisions to [Table 1](#) to align with corresponding descriptions of typical environments in ISO 9223:2012, Table C.1 and to make clearer that the corrosion rates presented are for the first year of exposure.

A list of all parts in the ISO 14713 series can be found on the ISO website.

Zinc coatings — Guidelines and recommendations for the protection against corrosion of iron and steel in structures —

Part 1: General principles of design and corrosion resistance

1 Scope

This document provides guidelines and recommendations regarding the general principles of design which are appropriate for articles to be zinc coated for corrosion protection and the level of corrosion resistance provided by zinc coatings applied to iron or steel articles, exposed to a variety of environments. Initial protection is covered in relation to

- available standard processes,
- design considerations, and
- environments for use.

This document applies to zinc coatings applied by the following processes:

- a) hot dip galvanized coatings (applied after fabrication);
- b) hot dip galvanized coatings (applied onto continuous sheet);
- c) sherardized coatings;
- d) thermal sprayed coatings;
- e) mechanically plated coatings;
- f) electrodeposited coatings.

These guidelines and recommendations do not deal with the maintenance of corrosion protection in service for steel with zinc coatings. Guidance on this subject can be found in ISO 12944-5 and ISO 12944-8.

NOTE There are a variety of product-related standards (e.g. for nails, fasteners, ductile iron pipes, etc.) which provide specific requirements for the applied zinc coating systems which go beyond any general guidance presented in this document. These specific product-related requirements will take precedence over these general recommendations.

2 Normative references

ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles — Specifications and test methods*

ISO 2063, *Thermal spraying — Metallic and other inorganic coatings — Zinc, aluminium and their alloys*

ISO 2064, *Metallic and other inorganic coatings — Definitions and conventions concerning the measurement of thickness*

ISO 8044:2015, *Corrosion of metals and alloys — Basic terms and definitions*

ISO 12683, *Mechanically deposited coatings of zinc — Specification and test methods*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1461, ISO 2063, ISO 2064, ISO 8044, ISO 12683 and ISO 17668 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1 atmospheric corrosion

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

[SOURCE: ISO 8044:2015, 3.4]

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 life to first maintenance

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

4 Materials

4.1 Iron and steel substrates

In hot dip galvanizing, the reactivity of the steel is modified by its chemical composition, particularly by the silicon plus phosphorus contents (see ISO 14713-2). The metallurgical and chemical nature of the steel is irrelevant to protection by thermally sprayed or sherardized coatings.

The broad range of steels likely to be subject to zinc coating will commonly fall into the following categories:

- carbon steel, composed simply of iron and carbon, accounts for 90 % of steel production [e.g. EN 10025-2 and EN 10080 (steel reinforcement)];
- high-strength, low-alloy (HSLA) steels have small additions (usually <2 % by weight) of other elements, typically 1,5 % manganese, to provide additional strength for a modest price increase (e.g. EN 10025-6);
- low-alloy steel is alloyed with other elements, usually molybdenum, manganese, chromium, or nickel, in amounts of up to 10 % by weight to improve the hardenability of thick sections (e.g. EN 10083-1).

Steel can be hot rolled or cold formed. Hot rolling is used to produce angle, "I", "H" and other structural sections. Some structural sections, e.g. safety barriers, cladding rails and cladding panels, are cold formed.

Cast and wrought irons are of various metallurgical and chemical compositions. This is irrelevant to protection by thermally sprayed or sherardized coatings but special consideration is needed regarding the cast irons most suitable for hot dip galvanizing (see ISO 14713-2).

4.2 Zinc coatings

The application of zinc coatings provides an effective method of retarding or preventing corrosion of ferrous materials (see [Clause 1](#) for the range of zinc coatings/processes covered by this document). Zinc coatings are used in this regard because they protect iron and steel both by barrier action and by galvanic action.

5 Selection of zinc coating

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

- a) the general environment (macro-climate) in which it is to be applied;
- b) local variations in the environment (micro-climate), including anticipated future changes and any exceptional exposure;
- c) the required life to first maintenance of the zinc coating system;
- d) the need for ancillary components;
- e) the need for post-treatment for temporary protection;
- f) the need for painting, either initially (duplex system) or when the zinc coating is approaching the end of its life to first maintenance to achieve minimal maintenance cost;
- g) the availability and cost;
- h) if the life to first maintenance of the system is less than that required for the structure, its ease of maintenance.

NOTE The life for a zinc coating in any particular atmospheric exposure condition is approximately proportional to the thickness of the coating.

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

6 Design requirements

6.1 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 items in a) to j) should be considered.

- a) Safe and easy access for cleaning and maintenance should be provided.
- b) Pockets and recesses in which water and dirt can collect should be avoided; 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, e.g. drainage tubes should be used to control de-icing salts.
- c) Areas which 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 (see ISO 14713-2).
- e) Where the coated 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 paint, tapes or plastic foils should be considered.

- f) Hot dip galvanizing, sherardizing, mechanical coating, zinc flake coating or electroplating can be provided only in works; thermal spraying can be applied in works or on site. When paint is to be applied to a zinc coating, the application is more readily controlled in works 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 metal-coated steel can only be done in works.

Where the total system is applied offsite, the specification has to 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 ISO 1461), sherardizing (in accordance with ISO 17668) or thermal spraying (in accordance with ISO 2063) should take place after bending and other forms of fabrication.
- h) Methods of marking parts should not have an influence on the quality of the pre-treatment operations prior to coating.
- i) Precautions may be required to minimize the likelihood of deformation during processing or subsequently.
- j) The conditions experienced by the articles during coating application may also need to be considered.

6.2 Design for application of different zinc coating processes

The design practice for hot dip coating differs from that for other zinc coating systems. ISO 14713-2 provides guidance on the design for hot dip coatings. This supplements the general principles of good design for steel structures.

The design practice for sherardized coatings can be found in ISO 14713-3.

The design for zinc thermal spraying should be discussed with the thermal sprayer at an early stage so that adequate provision is made for access to all areas of the article (see EN 15520).

The design for electroplating with zinc follows the general design principles for electroplating and these are not given here. The design for mechanical coating 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.

6.3 Tubes and hollow sections

6.3.1 General

If they are dry and hermetically sealed, the internal surfaces of tubes and hollow sections will not need protection. 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.

6.3.2 Corrosion protection of internal and external surfaces

Hot dip galvanizing gives equal thickness internally and externally. There are some special products where the thickness of the coating is different on internal and external surfaces, e.g. tubes for water distribution systems (see EN 10240). When tubes and hollow sections are hot dip galvanized after assembly into structures, drainage/venting holes should be provided for processing purposes (see ISO 14713-2).

Sherardizing gives equal thickness internally and externally. No precautions are needed for hollow sections. When tubes are sherardized, the zinc dust and sand mixture should be loaded into the tubes before starting the thermal diffusion process (see ISO 14713-3).

6.4 Connections

6.4.1 Fastenings to be used with hot dip galvanized, sherardized or thermally sprayed 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. Specific requirements are given in the appropriate product International Standards (e.g. ISO 10684) 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, ISO 1461 which covers specified minimum coating thicknesses up to 55 µm), sherardized or other coatings on steel fasteners should be considered. Alternatively, stainless steel fasteners can be used; for precautions, to take in order to minimize the potential for bimetallic corrosion, see [7.9](#).

The mating surfaces of connections made with high-strength friction-grip bolts should be given special treatment. It is not necessary to remove thermally sprayed, sherardized or 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.

6.4.2 Welding considerations related to coatings

It is recommended to weld prior to hot dip galvanizing, sherardizing or thermal spraying. 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. The normal pretreatments for thermal spraying are usually sufficient for this purpose but 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. These have to be removed by blast-cleaning followed by washing with clean water before applying thermally sprayed coatings. (This does not apply to hot dip galvanizing and sherardizing where the pretreatment process removes alkaline deposits.)

It is desirable that fabrication takes place without the use of a blast primer, as this has to be removed before hot dipping, sherardizing or thermal spraying.

Where welding takes place after hot dip galvanizing, sherardizing or thermal spraying, it is preferable, before welding, to remove the coating locally in the area of the weld to ensure the highest-quality weld. After welding, protection should be appropriately restored locally by thermal spraying, "solder sticks" and/or zinc dust paints.

It is not recommended to weld sherardized articles, but spot-welding may be possible in certain applications.

After welding of coated 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 pre-treatments should be discussed with the processor.

Welding of zinc-coated parts must be done with appropriate local air ventilation in accordance with health and safety regulations.

6.4.3 Brazing or soldering

Soft-soldered assemblies cannot be hot dip galvanized or sherardized and brazing should be avoided if possible — many types of brazing are unsuitable for hot dip galvanizing or sherardizing. The galvanizer or sherardizer should be consulted if brazing is being considered.

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

6.5 Duplex systems

ISO 12944-5 and EN 13438 give information on organic coatings which are applied to hot dip galvanized or sherardized coatings. When such an organic coating has been applied, the term “duplex system” is used to describe the combination of coatings — historically, this term was most commonly used to describe organic coatings on hot dip galvanized articles.

NOTE EN 15773 deals with quality and communications requirements in the supply chain when specifying the supply of duplex systems.

The life of a zinc-coated steel structure is longer than the life of the zinc coating system that is initially applied to it, as some steel can be lost by corrosion before a structure becomes unserviceable. If it is necessary to prolong the life of the zinc coating, maintenance has to take place before any steel rusting occurs and preferably while at least 20 µm to 30 µm of zinc coating remains. This gives a maintained zinc coating plus organic coating system a longer total life than a simple organic coating.

The total life of a zinc coating plus organic coating system is usually significantly greater than the sum of the lives of the zinc coating and protective organic coating. There is a synergistic effect, i.e. the presence of zinc coatings reduces under-rusting of the paint film; the paint preserves the zinc 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.

Maintenance usually takes place when the zinc coating loses its appearance or becomes degraded. Zinc coatings usually take longer to degrade than paint. Hence, a zinc 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. It should also be noted that 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 zinc coating has been consumed and rusting has started, the iron and steel have to be maintained in the same way as rusted painted steel.

6.6 Maintenance

Zinc coatings may be left unmaintained if the corrosion rate of the coating is insufficient to affect the performance of the structure in its designed period of use. If a longer life span is required, 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.

7 Corrosion in different environments

7.1 Atmospheric exposure

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, but the corrosion rates are much slower than for steel and often decrease with time. General information on the atmospheric corrosion rate for zinc is given in ISO 9224.

[Table 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 zinc coating, e.g. inside

many buildings. Zinc 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. The temperature also influences the corrosion rate of unprotected iron and steel and temperature fluctuations have a stronger effect than the average temperature value.

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

The corrosion of steelwork inside buildings is dependent upon 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. Steelwork which is partially sheltered, e.g. farm barns and aircraft hangars, should be considered as being subject to the exterior environment.

[Table 1](#) also sets out an indication of the likely range of corrosion rates which are applicable to zinc coatings exposed to the different types of corrosivity category dealt with in ISO 9223.

Table 1 — Description of typical atmospheric environments related to the estimation of corrosivity categories

Corrosivity category C Corrosion rate for zinc (based upon first year of exposure), r_{corr} in $\mu\text{m}\cdot\text{a}^{-1}$ and corrosion level	Typical environments (examples)	
	Indoor	Outdoor
C1 $r_{\text{corr}} \leq 0,1$ 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 Arctic/Antarctica
C2 $0,1 < r_{\text{corr}} \leq 0,7$ Low	Unheated spaces with varying temperature and relative humidity. Low frequency of condensation and low pollution, e.g. storage, sport halls	Temperate zone, atmospheric environment with low pollution ($\text{SO}_2 < 5 \mu\text{g}/\text{m}^3$), e.g. rural areas, small towns. Dry or cold zone, atmospheric environment with short time of wetness, e.g. deserts, sub-arctic areas
C3 $0,7 < r_{\text{corr}} \leq 2,1$ Medium	Spaces with moderate frequency of condensation and moderate pollution from production process, e.g. food-processing plants, laundries, breweries, dairies	Temperate zone, atmospheric environment with medium pollution ($\text{SO}_2: 5 \mu\text{g}/\text{m}^3$ to $30 \mu\text{g}/\text{m}^3$) or some effect of chlorides, e.g. urban areas, coastal areas with low deposition of chlorides. Subtropical and tropical zones with atmosphere with low pollution
C4 $2,1 < r_{\text{corr}} \leq 4,2$ High	Spaces with high frequency of condensation and high pollution from production process, e.g. industrial processing plants, swimming pools	Temperate zone, atmospheric environment with high pollution ($\text{SO}_2: 30 \mu\text{g}/\text{m}^3$ to $90 \mu\text{g}/\text{m}^3$) or substantial effect of chlorides, e.g. polluted urban areas, industrial areas, coastal areas without spray of salt water, exposure to strong effect of de-icing salts. Subtropical and tropical zones with atmosphere with medium pollution

Table 1 (continued)

Corrosivity category C Corrosion rate for zinc (based upon first year of exposure), r_{corr} in $\mu\text{m}\cdot\text{a}^{-1}$ and corrosion level	Typical environments (examples)	
	Indoor	Outdoor
C5 $4,2 < r_{\text{corr}} \leq 8,4$ 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, atmospheric environment with very high pollution (SO_2 : $90 \mu\text{g}/\text{m}^3$ to $250 \mu\text{g}/\text{m}^3$) and/or important effect of chlorides, e.g. industrial areas, coastal areas, sheltered positions on coastline
CX $8,4 < r_{\text{corr}} \leq 25$ 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), atmospheric environment with very high (SO_2) pollution (higher than $250 \mu\text{g}/\text{m}^3$), including accompanying and production factors and/or strong effect of chlorides, e.g. extreme industrial areas, coastal and offshore areas, occasional contact with salt spray
NOTE 1 Deposition of chlorides in coastal areas is strongly dependent on the variables influencing the transport inland of sea salt, such as wind direction, wind velocity, local topography, wind sheltering islands beyond the coast, distance of the site from the sea, etc. NOTE 2 Corrosivity classification of specific service atmospheres, e.g. in chemical industries, is beyond the scope of ISO 9223. NOTE 3 Sheltered and not rain-washed surfaces, in a marine atmospheric environment where chlorides are deposited, can experience a higher corrosivity category due to the presence of hygroscopic salts. NOTE 4 In environments with an expected "CX category", it is recommended to determine the atmospheric corrosivity classification from one-year corrosion losses. NOTE 5 The concentration of sulfur dioxide (SO_2) should be determined during at least 1 year and is expressed as the annual average. NOTE 6 Detailed descriptions of types of indoor environments within corrosivity categories C1 and C2 is given in ISO 11844-1. Indoor corrosivity categories IC1 to IC5 are defined and classified. NOTE 7 The classification criterion is based on the methods of determination of corrosion rates of standard specimens for the evaluation of corrosivity (see ISO 9226). NOTE 8 The thickness-loss values are identical to those given in ISO 9223. NOTE 9 The zinc reference material is characterized in ISO 9226. NOTE 10 Corrosion rates exceeding the upper limits in category C5 are considered as extreme. Corrosivity category CX refers to specific marine and marine/industrial environments. NOTE 11 To a first approximation, the corrosion of all metallic zinc surfaces is at the same rate in a particular environment. Iron and steel will normally corrode 10 to 40 times faster than zinc, the higher ratios usually being in high-chloride environments. The data is related to data on flat sheet given in ISO 9223 and ISO 9224. NOTE 12 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 category for these regions. This has, in turn, led to the zinc coatings experiencing lower corrosion rates compared to historical corrosion performance data. Other regions have experienced increasing pollution and industrial activity and therefore would be expected to develop environments more accurately described by higher corrosivity categories. NOTE 13 The corrosion rate for zinc and for zinc-iron alloy layers are approximately the same.		

[Table 2](#) indicates the life to first maintenance for a selection of zinc coatings exposed to the range of these 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 low (VL): 0 to < 2 years
- b) Low (L): 2 to < 5 years
- c) Medium (M): 5 to < 10 years
- d) High (H): 10 to < 20 years
- e) Very high (VH): ≥ 20 years

7.2 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 ohms to approximately 100 kΩ) and the gross inhomogeneity of soils means that corrosion of zinc 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 EN 12501-1.

Lime-containing soils and sandy soils (provided that they are chloride-free) are, in general, the 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 zinc coating.

Corrosion cells can also form at the soil/air and soil/ground-water-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 zinc 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.

Table 2 — Life to first maintenance for a selection of zinc coating systems in a range of corrosivity categories

System	Reference standard	Minimum thickness μm	Selected corrosivity category (ISO 9223) life minimum/maximum (years) and durability class (VL, L, M, H, VH)							
			C3		C4		C5		CX	
Hot dip galvanizing	ISO 1461	85	40/>100	VH	20/40	VH	10/20	H	3/10	M
		140	67/>100	VH	33/67	VH	17/33	VH	6/17	H
		200	95/>100	VH	48/95	VH	24/48	VH	8/24	H
Hot dip galvanized sheet	EN 10346	20	10/29	H	5/10	M	2/5	L	1/2	VL
		42	20/60	VH	10/20	H	5/10	M	2/5	L
Hot dip galvanized tube	EN 10240	55	26/79	VH	13/26	H	7/13	H	2/7	L
Sherardizing	ISO 17668	10	5/14	M	2/5	L	1/2	VL	0/1	VL
		15	7/21	H	4/7	M	2/4	L	1/2	VL
		30	14/43	VH	7/14	H	4/7	M	2/4	VL
		45	21/65	VH	11/25	H	5/11	M	3/6	L
		60	29/86	VH	14/29	VH	7/14	H	2/7	L
		75	36/>100	VH	18/36	VH	9/18	H	3/9	M
Electrodeposited sheet	ISO 2081	5	2/7	L	1/2	VL	1/1	VL	0/1	VL
		25	12/36	H	6/12	M	3/6	M	1/3	VL

Table 2 (continued)

System	Reference standard	Minimum thickness μm	Selected corrosivity category (ISO 9223) life minimum/maximum (years) and durability class (VL, L, M, H, VH)							
			C3		C4		C5		CX	
Mechanical plating	ISO 12683	8	4/11	M	2/4	L	1/2	VL	0/1	VL
		25	12/36	H	6/12	M	3/6	L	1/3	VL

NOTE 1 The figures for life have been rounded to whole numbers. The allocation of the durability designation is based upon the average of the minimum and maximum of the calculated life to first maintenance, e.g. 85 μm zinc coating in corrosivity category C4 (corrosion rate for zinc between 2,1 μm per annum and 4,2 μm per annum), gives expected durability of $85/2,1 = 40,476$ years (rounded to 40 years) and $85/4,2 = 20,238$ years (rounded to 20 years). Average durability of $(20 + 40)/2 = 30$ years (designated "VH").

NOTE 2 Life to first maintenance of protective coating systems: The list of systems given in this table, classified by environment and typical time to first maintenance, indicates the options open to the specifier. The recommended treatments listed for longer lives will always protect for shorter periods and are often also economical for these shorter periods.

NOTE 3 This table can be applied to any zinc coating to determine the life to first maintenance. The corrosion rate for any given environment is indicated by the corrosivity classification category, C3 to CX. The minimum and maximum life to first maintenance for the selected system is set out in the body of this table.

NOTE 4 It is impossible to achieve an exactly uniform thickness of any type of coating. The third column of this table indicates 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 the zinc coatings are able to provide protection to adjacent areas which can lose their coating prematurely.

NOTE 5 Thickness requirements in EN 10240 are minimum local thickness requirements. Furthermore, the thickness quoted for coatings in these tables may not match specified coating thicknesses in some standards.

NOTE 6 In this table, guidance is given for coatings applied to structural and cold-forming grades of hot dip galvanized sheet and cold-rolled sections, on zinc electroplated sheet, on coatings thermally sprayed with zinc, on mechanically plated coatings, on sherardized coatings 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 (see also relevant product standards). As the life of all zinc coatings is approximately proportional to the thickness or mass of zinc coating present, the relative performance of such intermediate thicknesses can readily be assessed.

NOTE 7 Zinc/aluminium alloy coatings (with 5 % to 55 % aluminium) usually last longer than pure zinc; pending wider use, they are not included in this table. There is widespread technical literature available on these classes of materials.

NOTE 8 Thickness of hot dip galvanizing on products: ISO 1461 specifies the standard hot dip galvanized coating at the equivalent of 85 μm minimum for steel >6 mm thick. Thinner steel, automatically hot dip galvanized tubes and centrifugal work (usually threaded work and fittings) have thinner coatings, but these are usually greater than 45 μm. Where it is desired to use coatings of different thicknesses to those stated, their lives can be ascertained by calculation; the life of a zinc coating is (to a first approximation) proportional to its thickness. For tubes, EN 10240 includes an option for the purchaser to specify a thicker coating requirement which will give an extended service life. Hot dip galvanized coatings thicker than 85 μm are not specified in ISO 1461 but the general provisions of that International Standard apply and, together with specific thickness figures, may form a specification capable of verification. It is essential to know the composition of the steel to be used and the galvanizer should be consulted before specifying, as these thicker coatings may not be available for all types of steel. Where the steel is suitable, thick coatings may be specified.

NOTE 9 Thickness of sherardizing on products: ISO 17668 specifies coating thickness of 6 classes up to 75 μm. The sherardizer should be consulted where thicker coatings are required, as a thicker coating may not be available for all types of steel.

NOTE 10 Thermal spray coatings. These coatings are normally used as part of a corrosion protection system after receiving a sealing coat. The performance of the coating system is highly dependent upon this being carried out effectively. No data is provided for performance in this document. Further guidance can be found in EN 15520.

7.3 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 zinc coatings. With zinc 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 duration of life 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 (see also for example EN 12502-3). 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 bitumen 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 — e.g. 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 sea water, the average zinc corrosion rate will usually lie between 10 µm per annum and 20 µm per annum. Hot dip galvanized tube, hot dip galvanized/Zn electrodeposited sheet and fittings with galvanized, sherardized, electrodeposited or mechanically plated coatings normally have additional protection when used in sea water (see ISO 12944-5 and ISO 12944-8 and EN 13438). Brackish water may be more or less corrosive than sea water 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 EN 12502-3.

7.4 Abrasion

Natural mechanical exposure can occur in waters by shifting of boulders, abrasion by sand, wave splashing, etc. Particles entrained by the wind (for example, sand) can also cause increased attack. Zinc 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. The good bond between zinc coatings and steel (particularly in hot dip galvanizing and sherardizing where there is an alloying reaction) helps to limit such effects.

7.5 Exposure to chemicals

A primary factor governing corrosion behaviour of zinc coatings in liquid chemical environments is the pH of the chemical solution. Zinc coatings, such as galvanizing, 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 upon 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.

7.6 Elevated temperatures

All the zinc coatings described 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 document.

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.

Sherardized coatings have a temperature resistance up to 600 °C.

7.7 Contact with concrete

Unprotected steel articles in contact with 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). Zinc coatings (usually applied in the form of a hot dip galvanized coating to reinforcement — see ISO 14657), can be used to prevent this type of deterioration for long periods of time, dependent upon the specific exposure environment.

The corrosion protection afforded by 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, zinc has a much greater pH passivation range than steel, making 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 galvanized rebar far less susceptible to corrosion due to carbonation of the concrete.

Zinc reacts with wet concrete to form calcium hydroxyzincate accompanied by the evolution of hydrogen. This corrosion product is insoluble and protects the underlying zinc (provided that 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 hydroxyzincate coating has formed. Studies of 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 zinc 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 pullout strength of the bar. For normal concrete conditions, research has shown no statistical difference in bond strength between galvanized rebar that was passivated or not passivated.

Sherardized coatings in accordance with ISO 17668 are passivated and therefore will be prepared for either low or high levels of chloride added to concrete. In all other respects, sherardizing will act in the same way as hot dip galvanizing in contact with concrete.

7.8 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, however, to avoid direct contact between zinc coatings and timbers which 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, such as oak, sweet chestnut, western red cedar and Douglas fir 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 over the area of contact.

Sherardizing coatings consist of zinc-iron alloys, which, because of the thermal diffusion technique, produce a surface which has a high coefficient of friction similar to all-alloy layer coatings developed on many hot dip galvanized articles. These coatings would tend to require high withdrawal loads to break the bond with the wood where used on nails, for instance.

7.9 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 3](#)).

Table 3 — Galvanic series (based upon electrode potentials in sea water) showing relative position of zinc to other metals

Anodic — more prone to corrosion
Magnesium
Zinc
Aluminium
Carbon and low-alloy steels
Cast iron
Lead
Tin
Copper, brass, bronze
Nickel (passive)
Titanium
Stainless steel
Cathodic — less prone to corrosion

The bimetallic effect is the basis for the sacrificial protection that a zinc coating (e.g. hot dip galvanizing) offers to small areas of exposed steel if the coating becomes damaged. Zinc coatings will corrode preferentially to protect any metal below it in the electro-chemical series.

The level of bimetallic corrosion that will take place will depend upon 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. However, 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 which 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, however, 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 insulating the two metals from one another. For bolted connections, this might be done by using polychloroprene 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 illustrated in Table 4, provided that 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 4 — 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	Sea water
Aluminium	a	a to b	a to b	b	b to c
Brass	b	b	a to c	b to c	c to d
Bronze	b	b	b to c	b to c	c to d
Cast iron	b	b	b to c	b to c	c to d
Copper	b	b to c	b to c	b to c	c to d
Lead	a	a to b	a to b	a to c	a to c
Stainless steel	a to b	a to b	a to b	b	b to c
a The zinc coating will suffer either no additional corrosion or, at worst, only very slight additional corrosion which is usually tolerable in service. b The zinc coating will suffer slight or moderate additional corrosion which may be tolerable in some circumstances. c The zinc coating may suffer fairly severe additional corrosion and protective measures will usually be necessary. d The 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.

- 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 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.
- 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.
- 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 or zinc-coated products and the use of lead in fixing galvanized posts.
- 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.